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

Week 3: Wednesday February 6th, 2019
Paul Belanger

Concerns: Rates of change, Ocean acidification, modeling

EXTRAS – slides from last week

1. Recap of climate variables and past records
2. Recap - Proxies that tell us of climate records and how it's happened before

NEW: Rates of change, models, IPCC, Laudato Si and more:

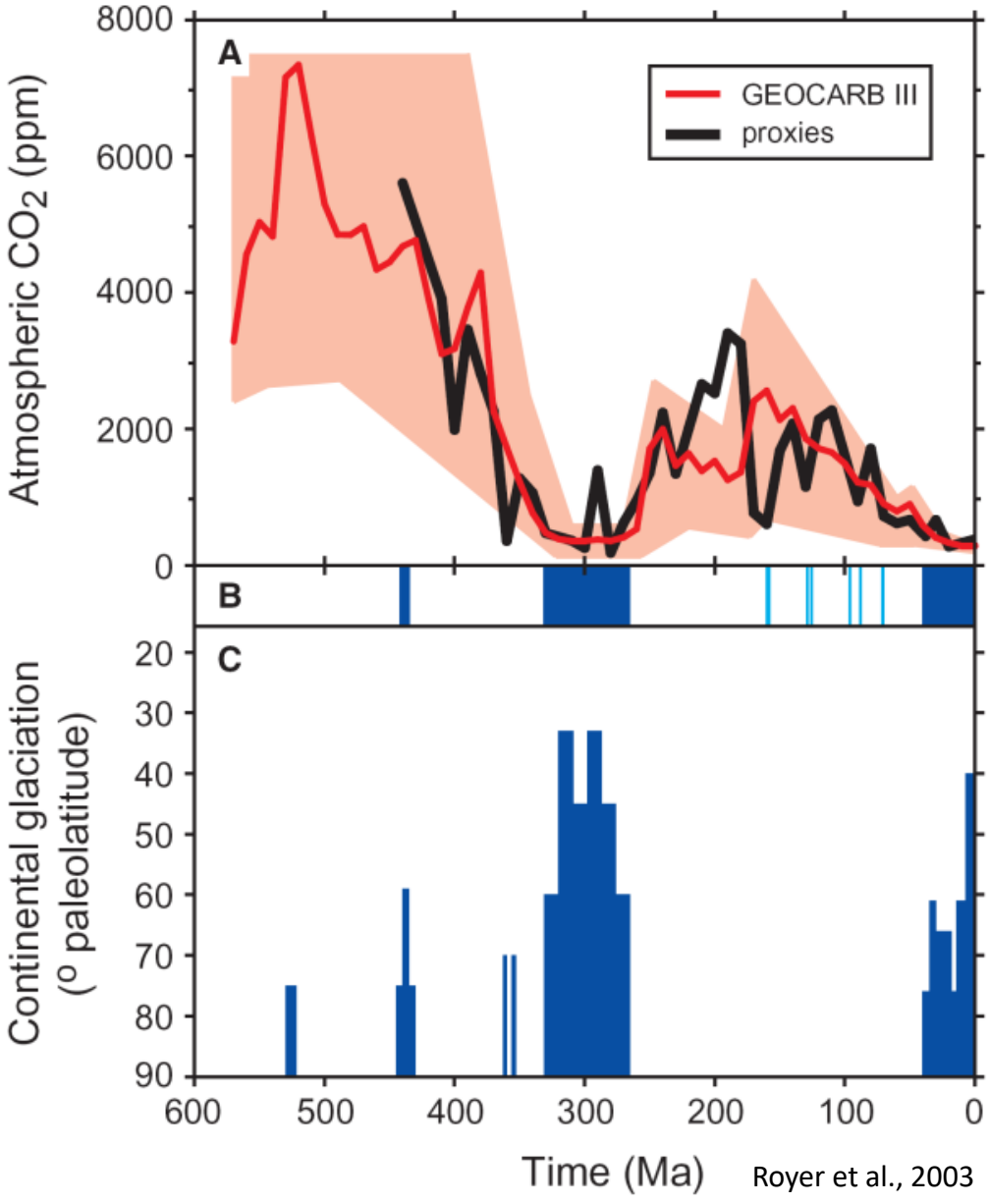
3. Rates of change
4. Ocean Acidification
5. IPCC and AR5
6. Pope's Encyclical: Laudato Si
7. Other links
8. Climate Modeling

3. **Wednesday 1-3, February 6th:**
   Earths present and future - ocean acidification, rates of change & modeling
   - Future projections and feedbacks:
   - Models
   - Rates of change: analogs and various comparisons to the past
   - IPCC Fifth Assessment report (AR5): http://www.ipcc.ch/report/ar5/
   - The Pope's encyclical: google it or go here http://denverclimatestudygroup.com/wp-content/uploads/2014/10/2015.05.24-papa-francesco_20150524_enciclica-laudato-si.pdf

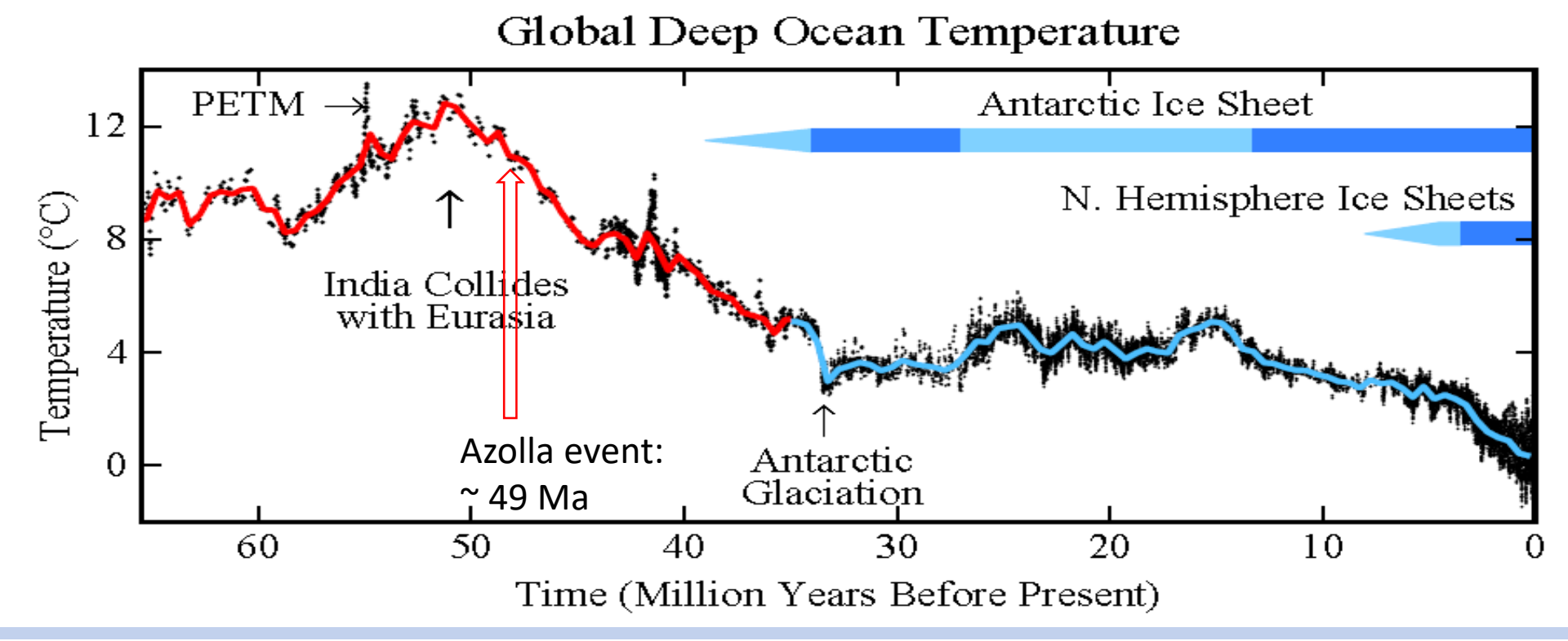
1. Recap of climate variables and past records

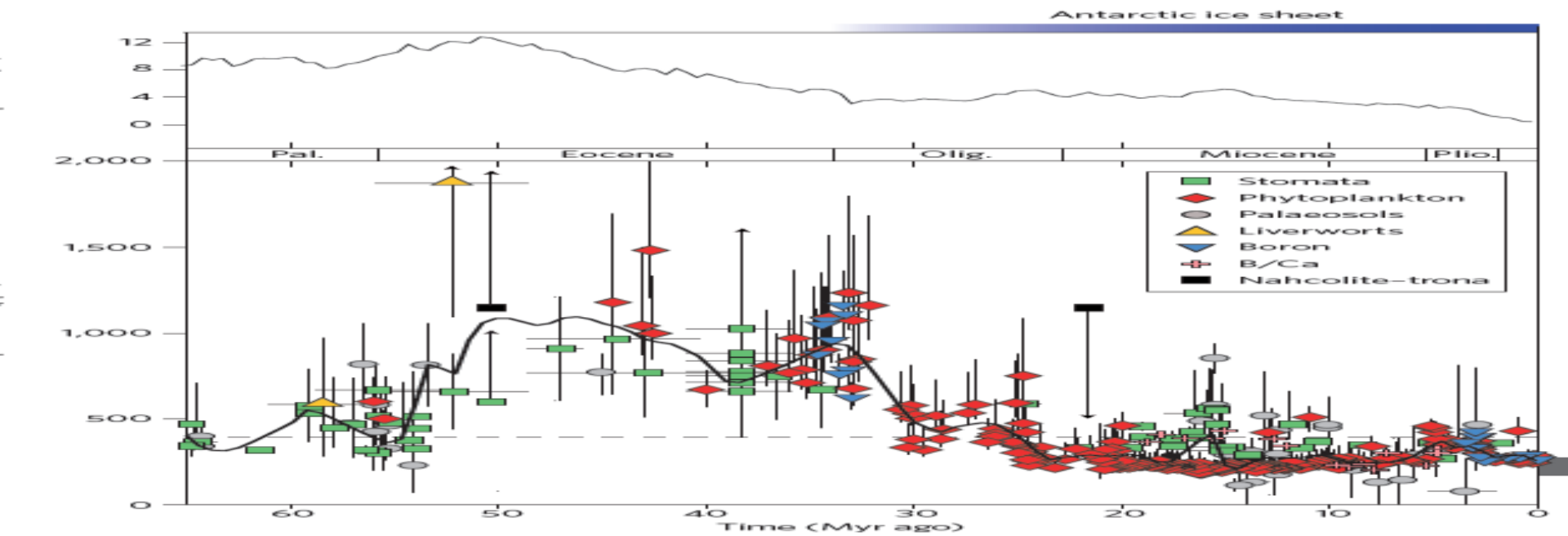
Alternating a MOSTLY Greenhouse Earth vs. occasional Ice-house Earth

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



Royer et al., 2003

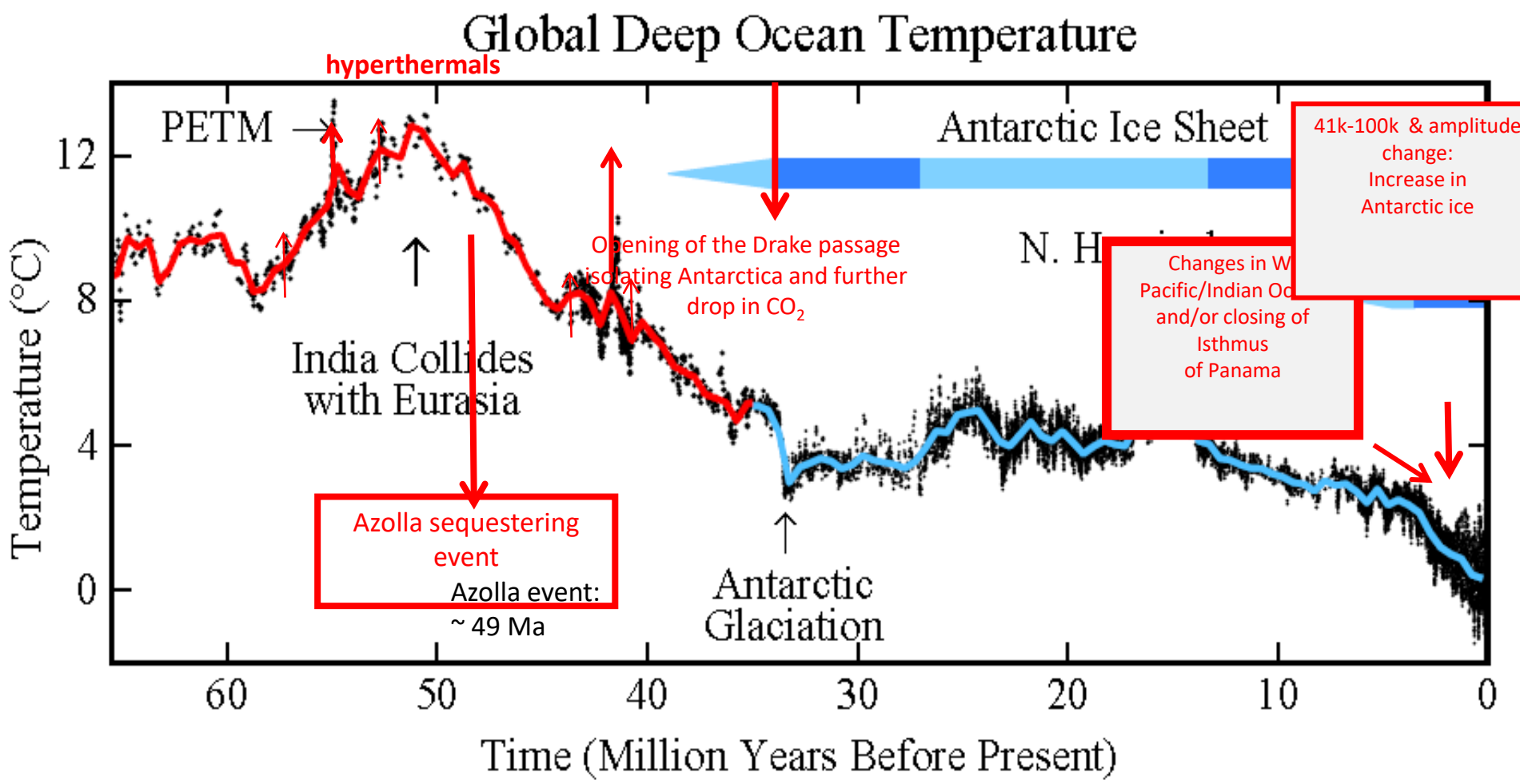

Global Deep Ocean Temperature
PETM
Antarctic Ice Sheet
N. Hemisphere Ice Sheets
India Collides with Eurasia
Azolla event:
~ 49 Ma
Antarctic Glaciation
Temperature (°C)
Time (Million Years Before Present)


Antarctic ice sheet
Pal.
Eocene
Olig.
Miocene
Plio.
Stomata
Phytoplankton
Palaeosols
Liverworts
Boron
B/Ca
Nahcolite–trona
Time (Myr ago)

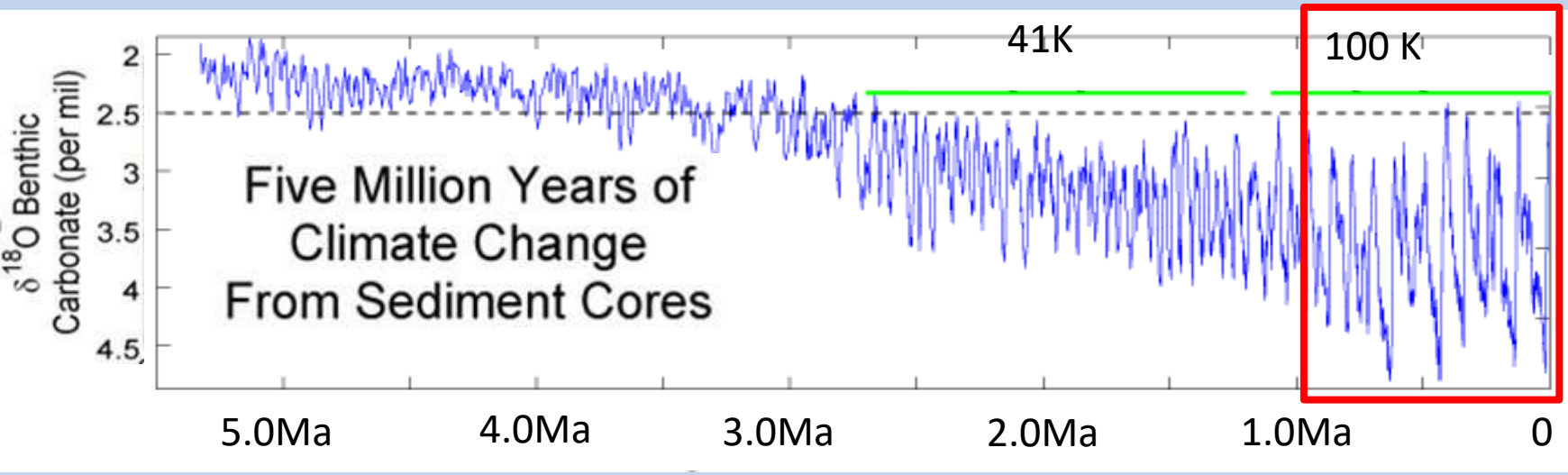
50 million years ago (50 MYA) Earth was ice-free.

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;
THAT'S 0.0001 ppm/year vs. ~2.6 ppm/year.

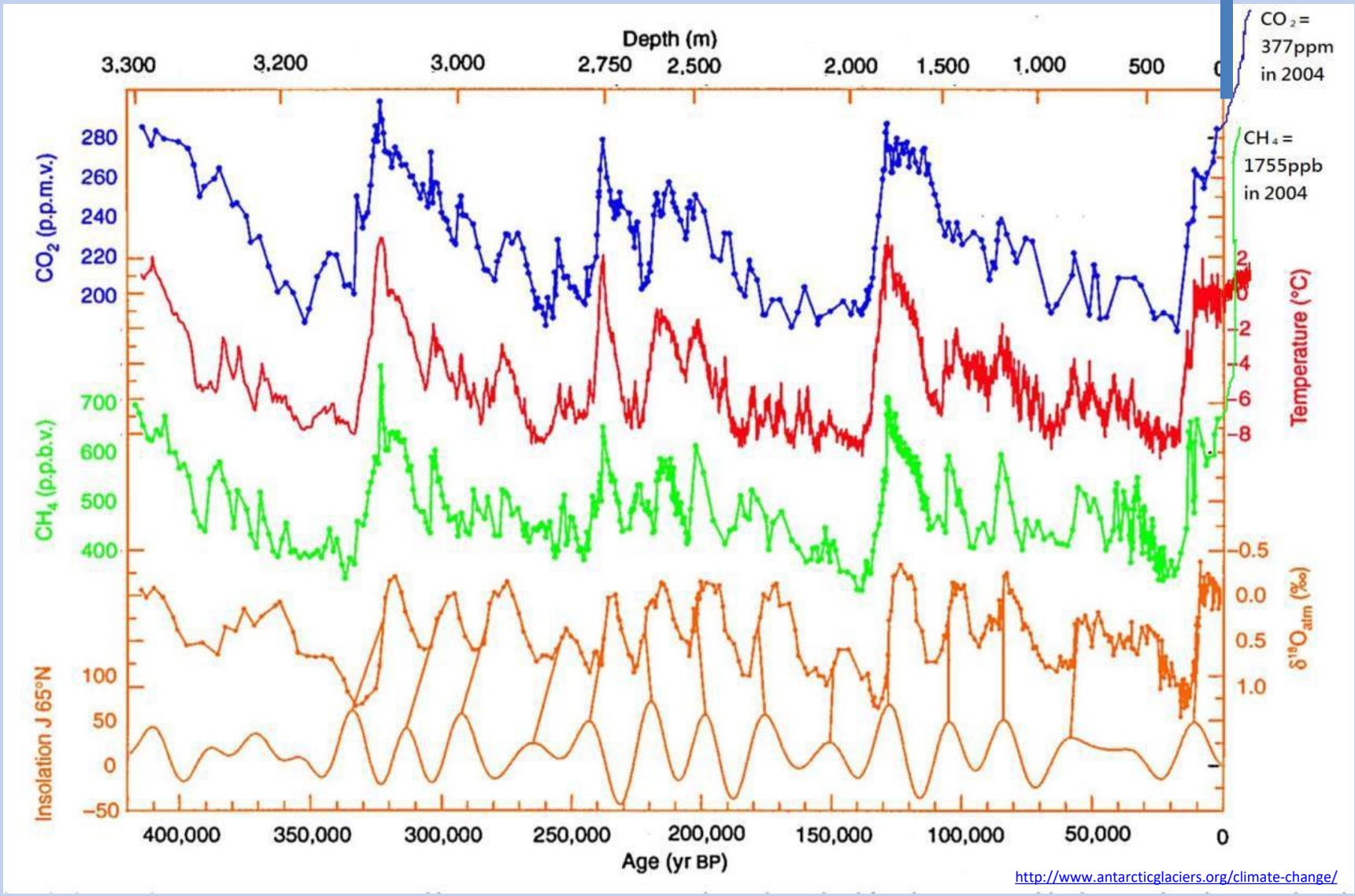


Climate Changes from Ocean Sediment Cores, since 5 Ma. Milankovitch Cycles



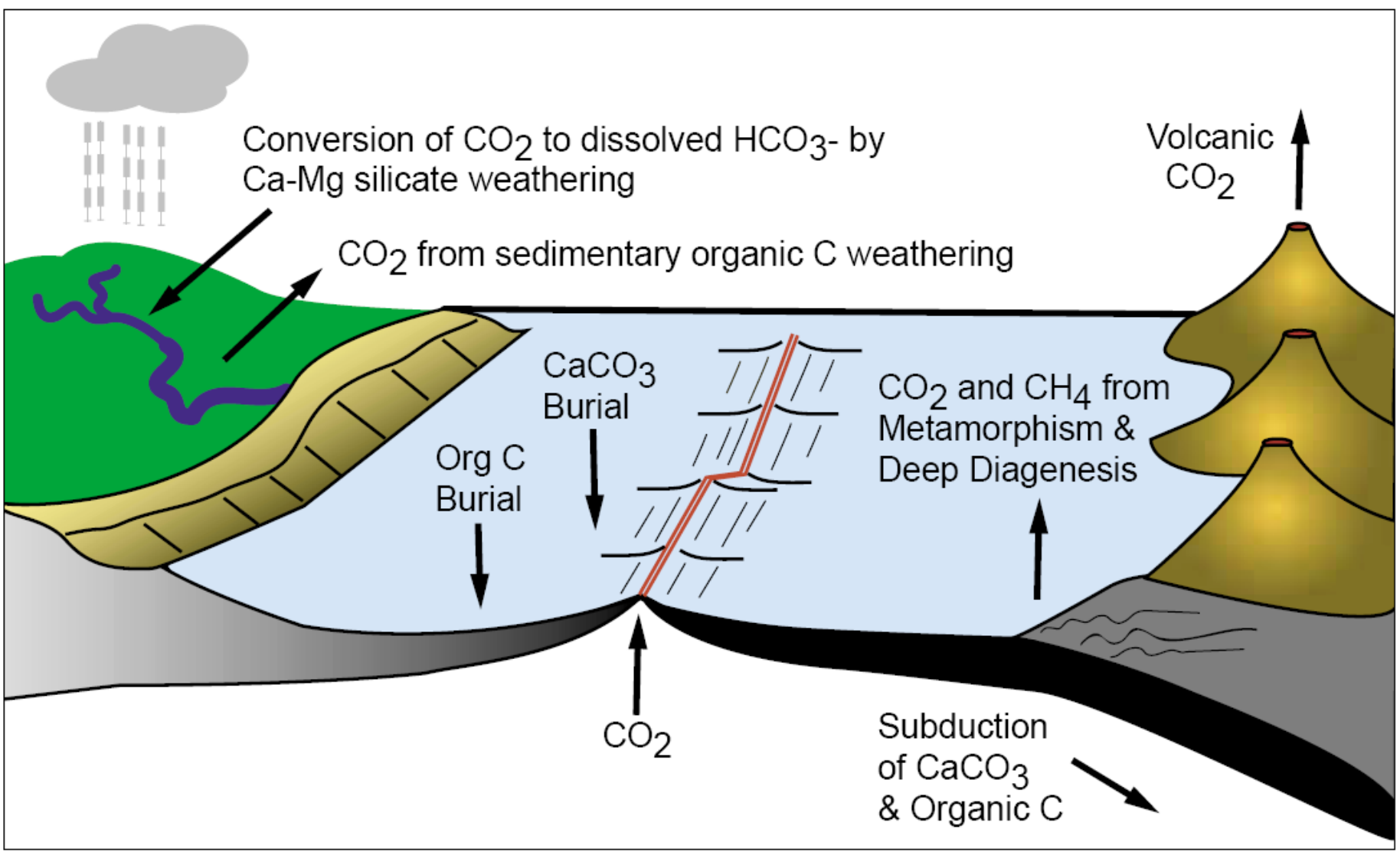
When CO_2 levels get below ~400-600 ppm Orbital parameters become more important than CO_2

412ppm in 2019 *



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

Long-term carbon cycle: *rocks*



Berner, 2001

Precipitation (sink):

$CO_2 + CaSiO_3 \rightarrow CaCO_3 + SiO_2$

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 (last 65 million years):

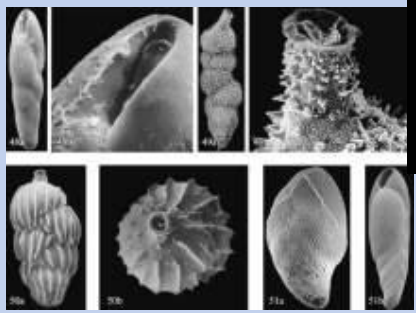
2. **MID-OCEAN SPREADING RATES SLOW DOWN**
   - **Less CO_2 into the atmosphere for volcanoes**

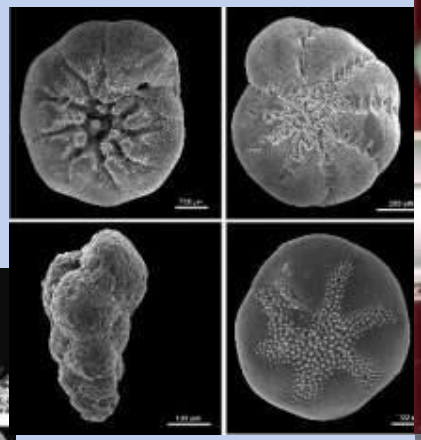
=

CO_2 DRAW DOWN THROUGH TIME!

2. 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

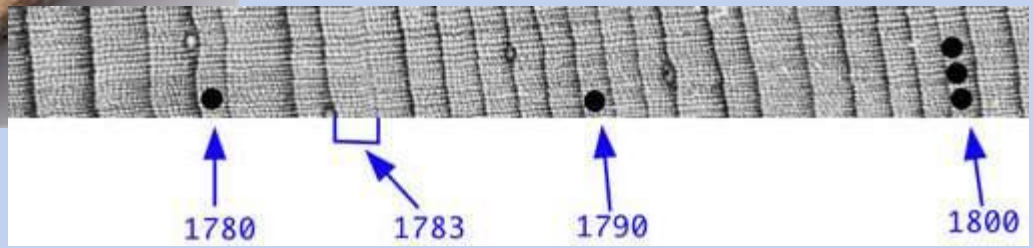
Born	May 28, 1807 Haut-Vully, Switzerland
Died	December 14, 1873 (aged 66) Cambridge, Massachusetts
Fields	Paleontology, Glaciology, Geology, Natural History
Alma mater	University of Erlangen-Nuremberg

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

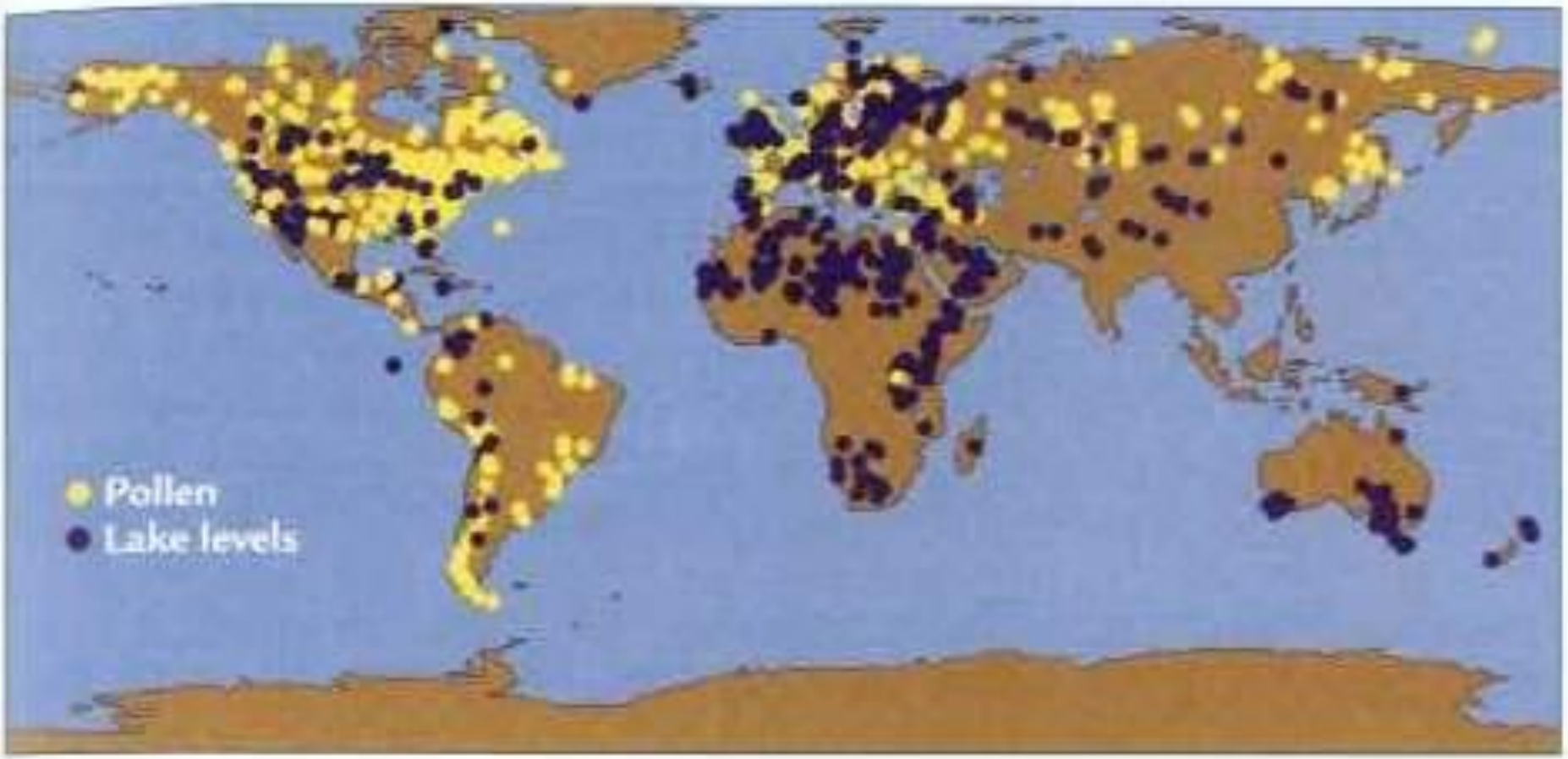
Photographic proxy data/evidence

Ruddiman, 2008

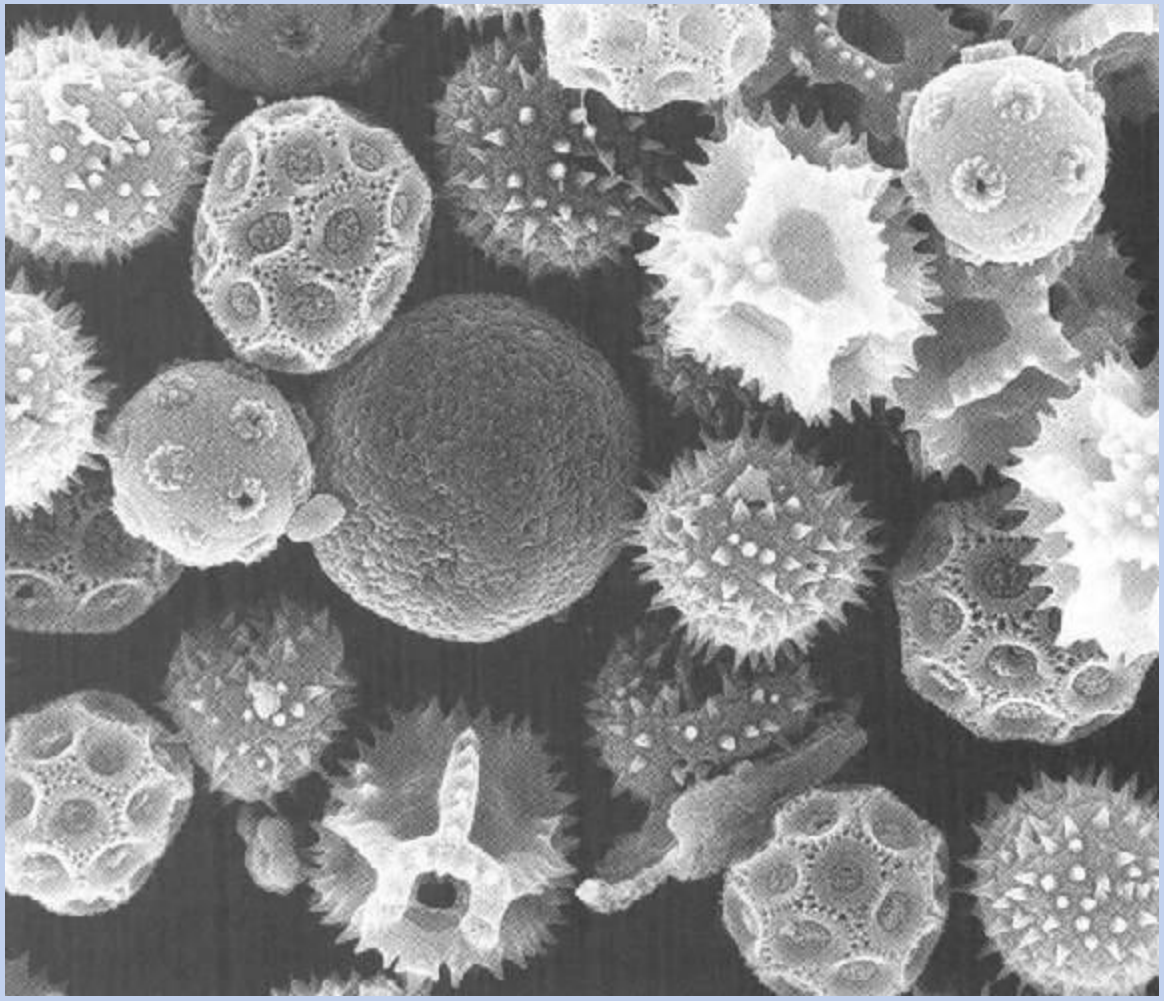
EARLY PROXY DATA: TREE RINGS



Pollen & Lake core data

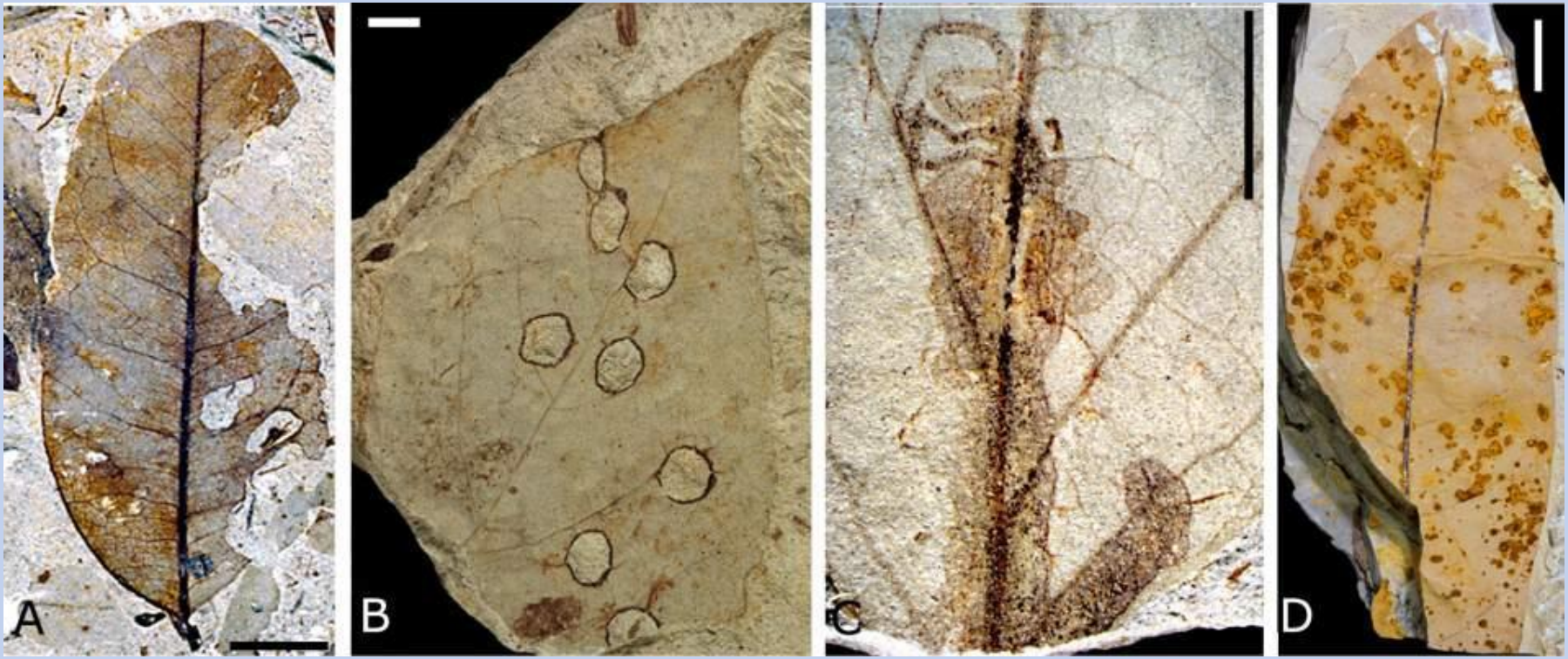


Ruddiman, 2008

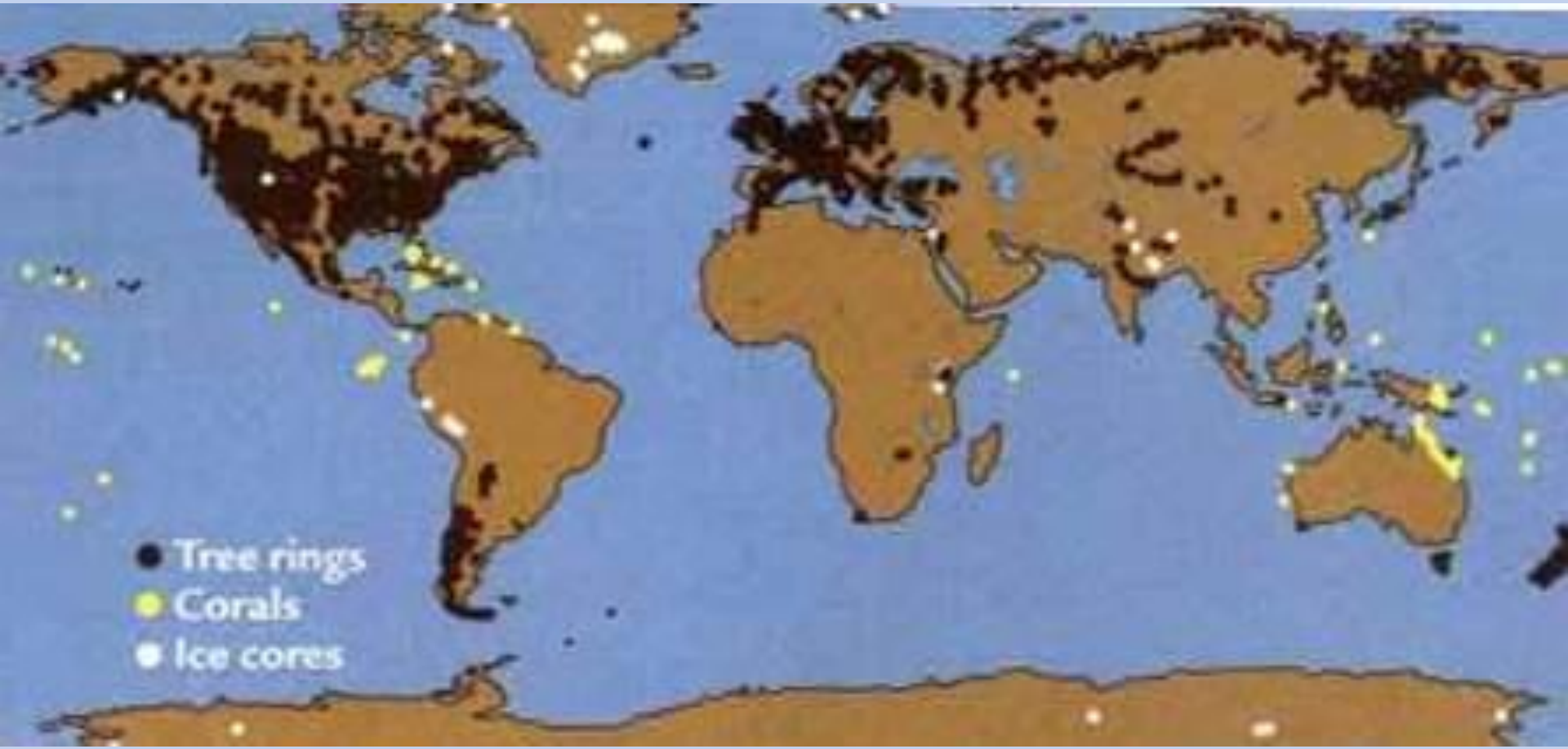


PROXY DATA: POLLEN DATA

PROXY DATA: LEAVES

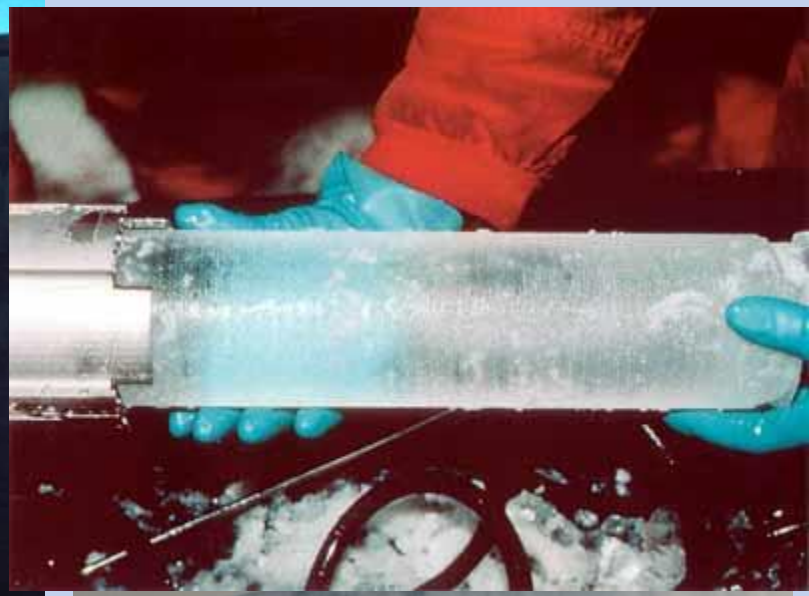


Tree rings, corals, ice cores



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

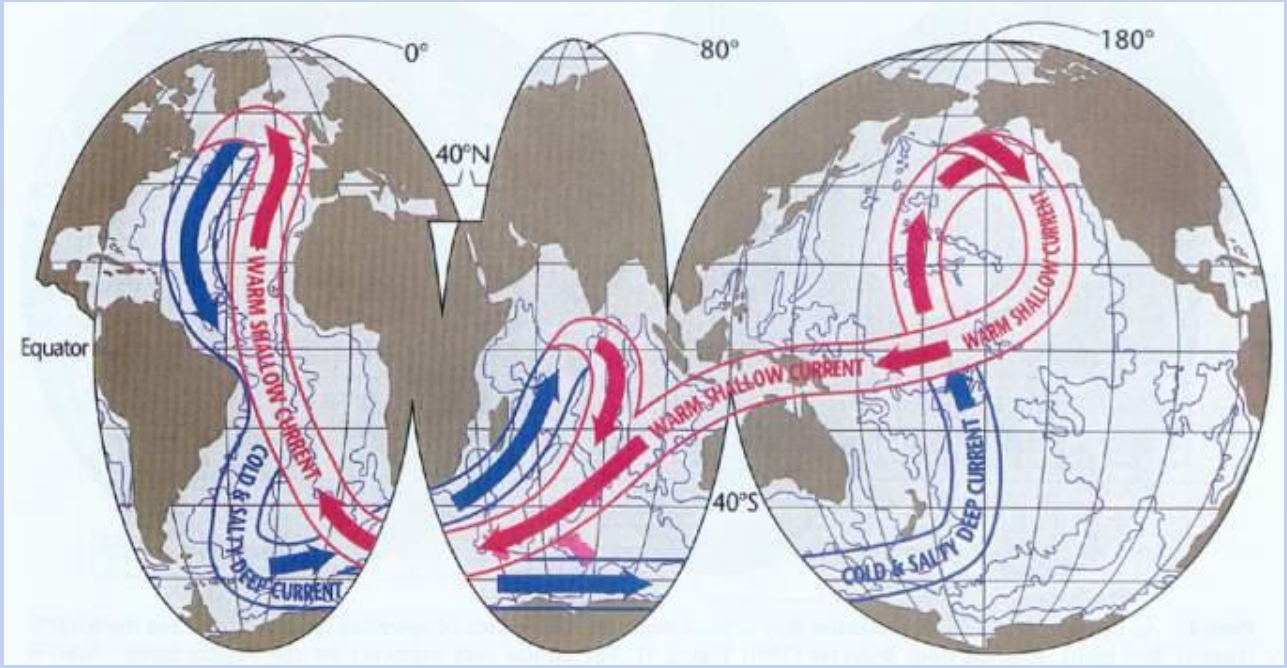
Father of Paleoceanography

Other Paleoceanographers

Wally Broecker

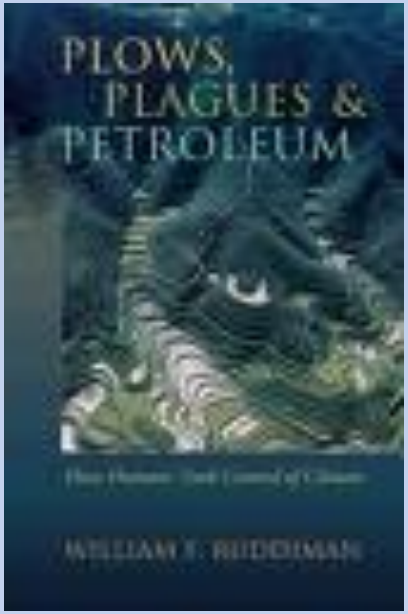
Thermal-haline

"conveyor" belt of circulation

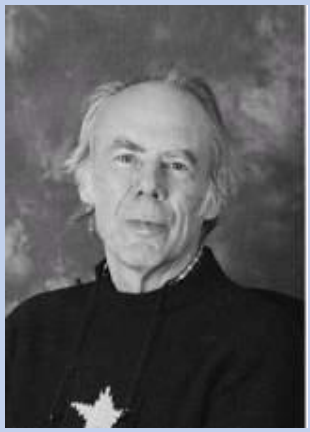


Other Paleoceanographers

Bill Ruddiman



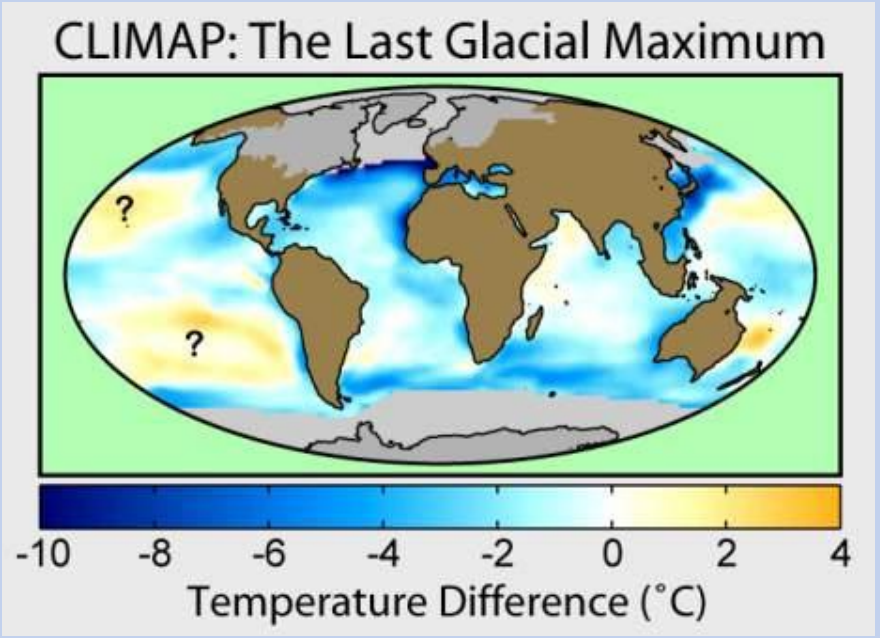
Nick Shackleton

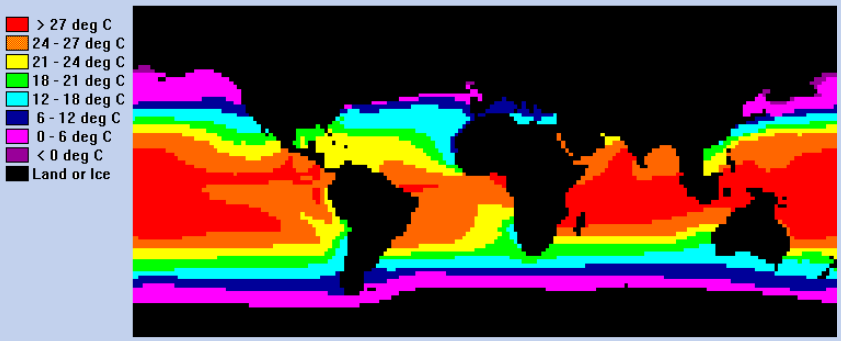


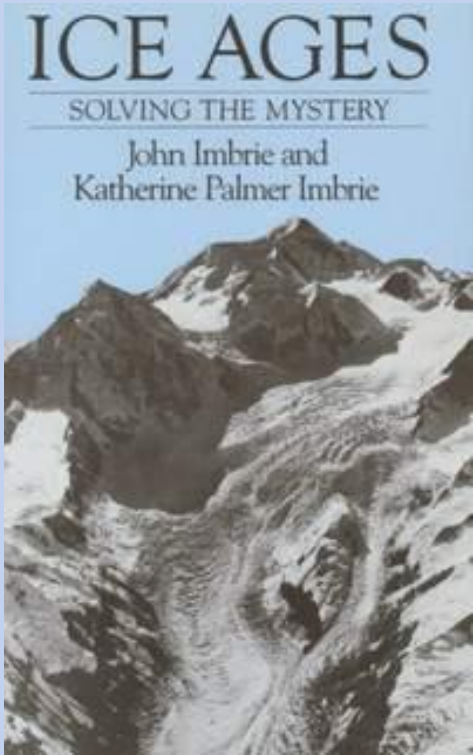
Other Paleoceanographers

John Imbrie:

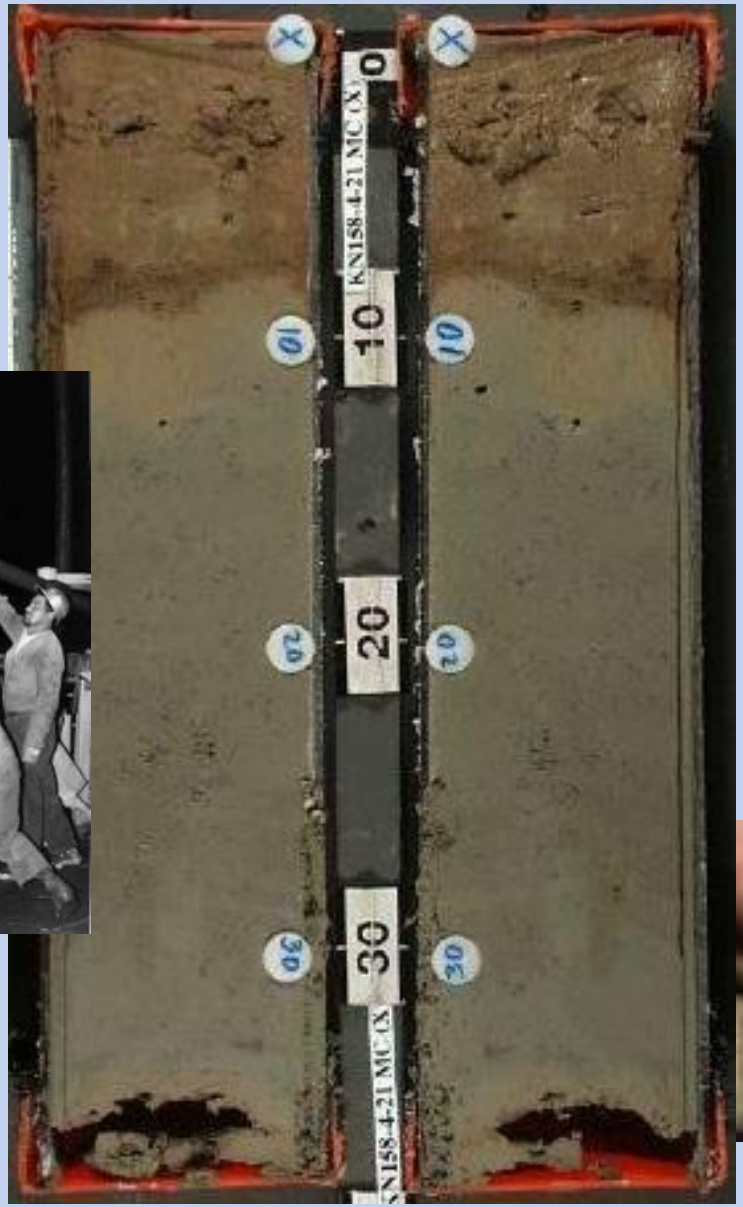
CLIMAP



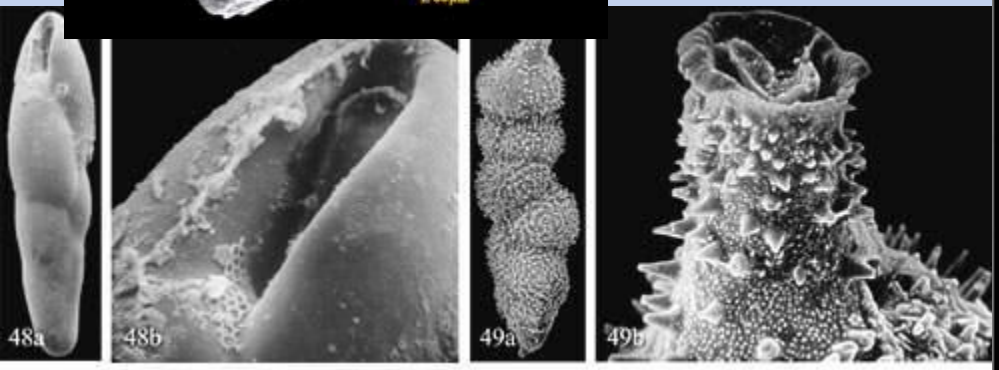


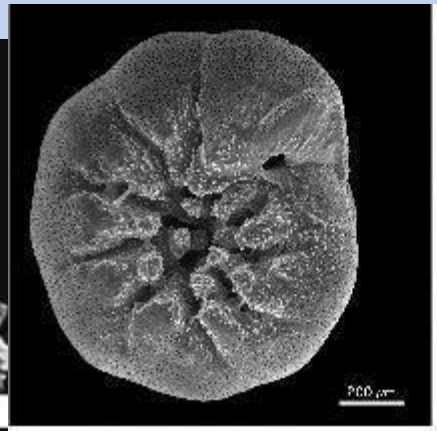


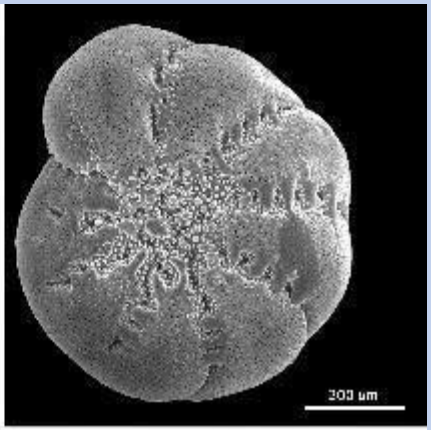
PROXY DATA: CORE DATA

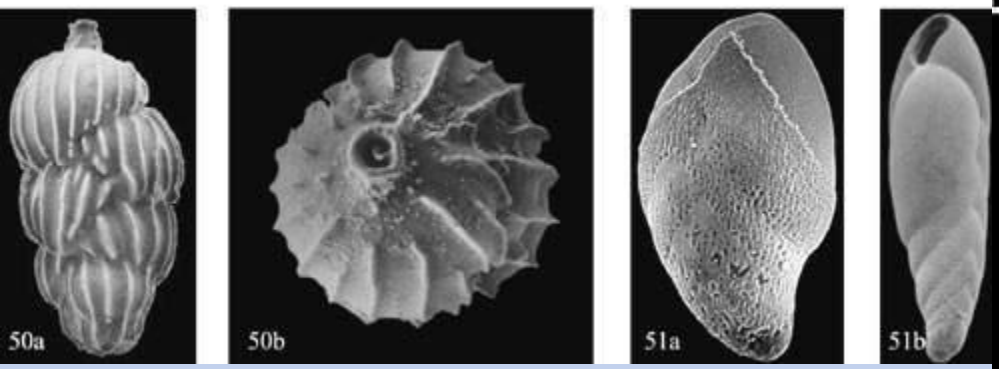


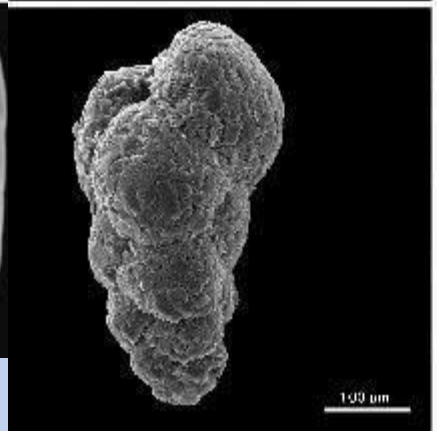
PROXY DATA: BENTHIC FORAMS

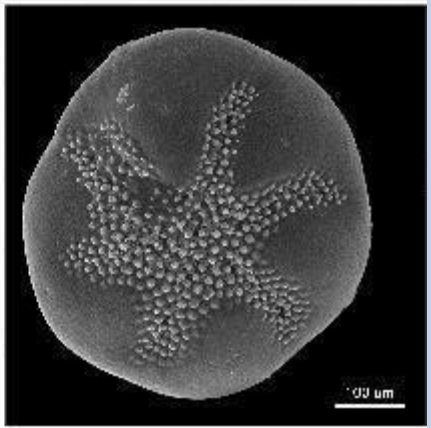


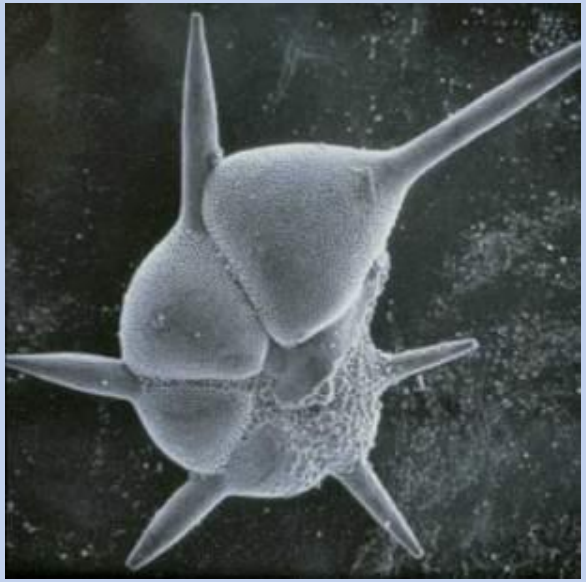




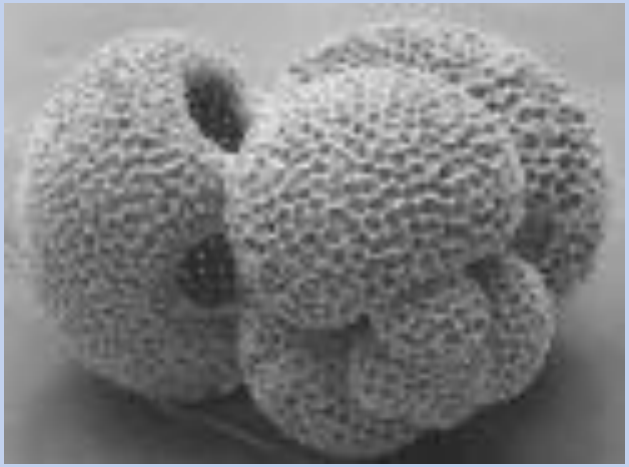




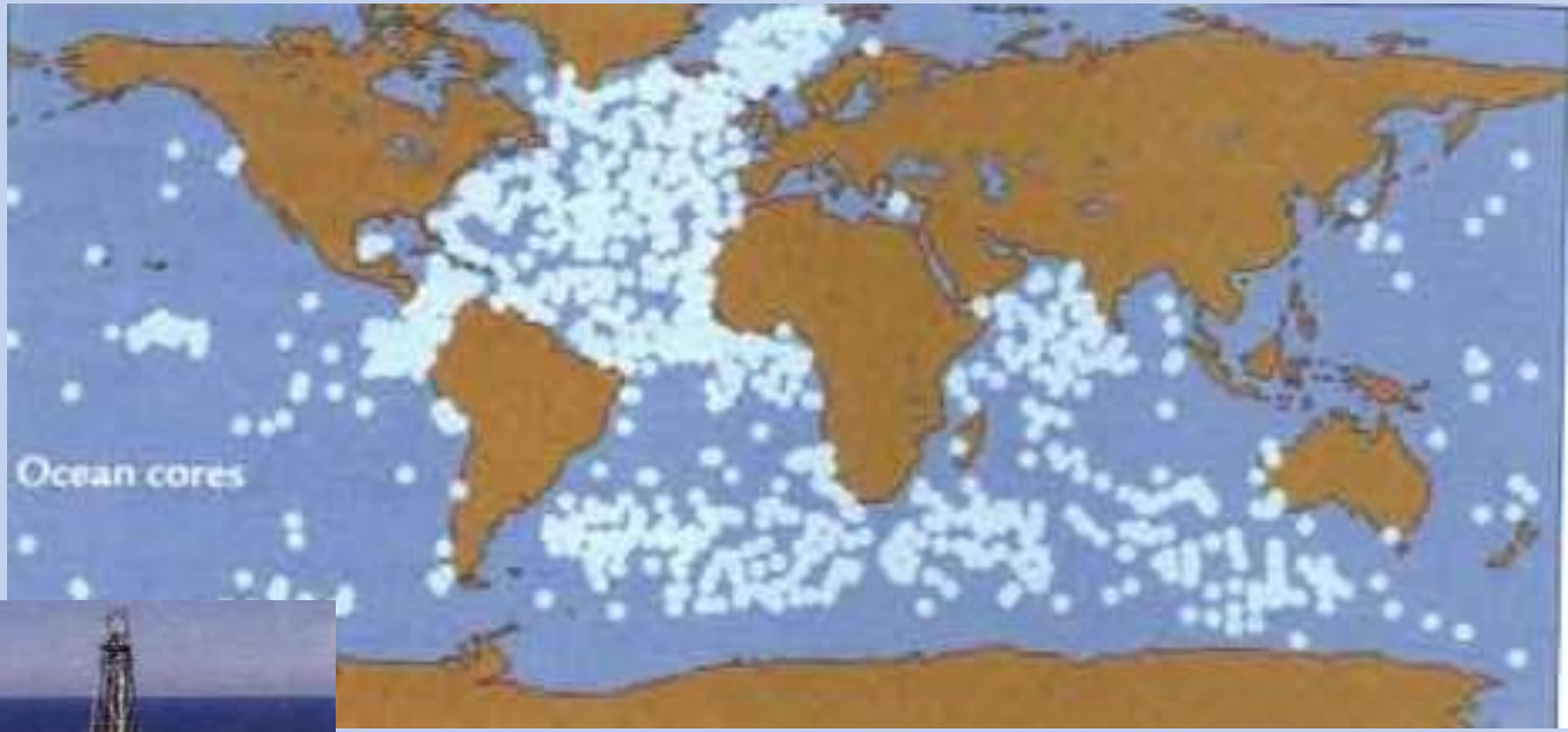




PROXY DATA: PLANKTONIC FORAMS



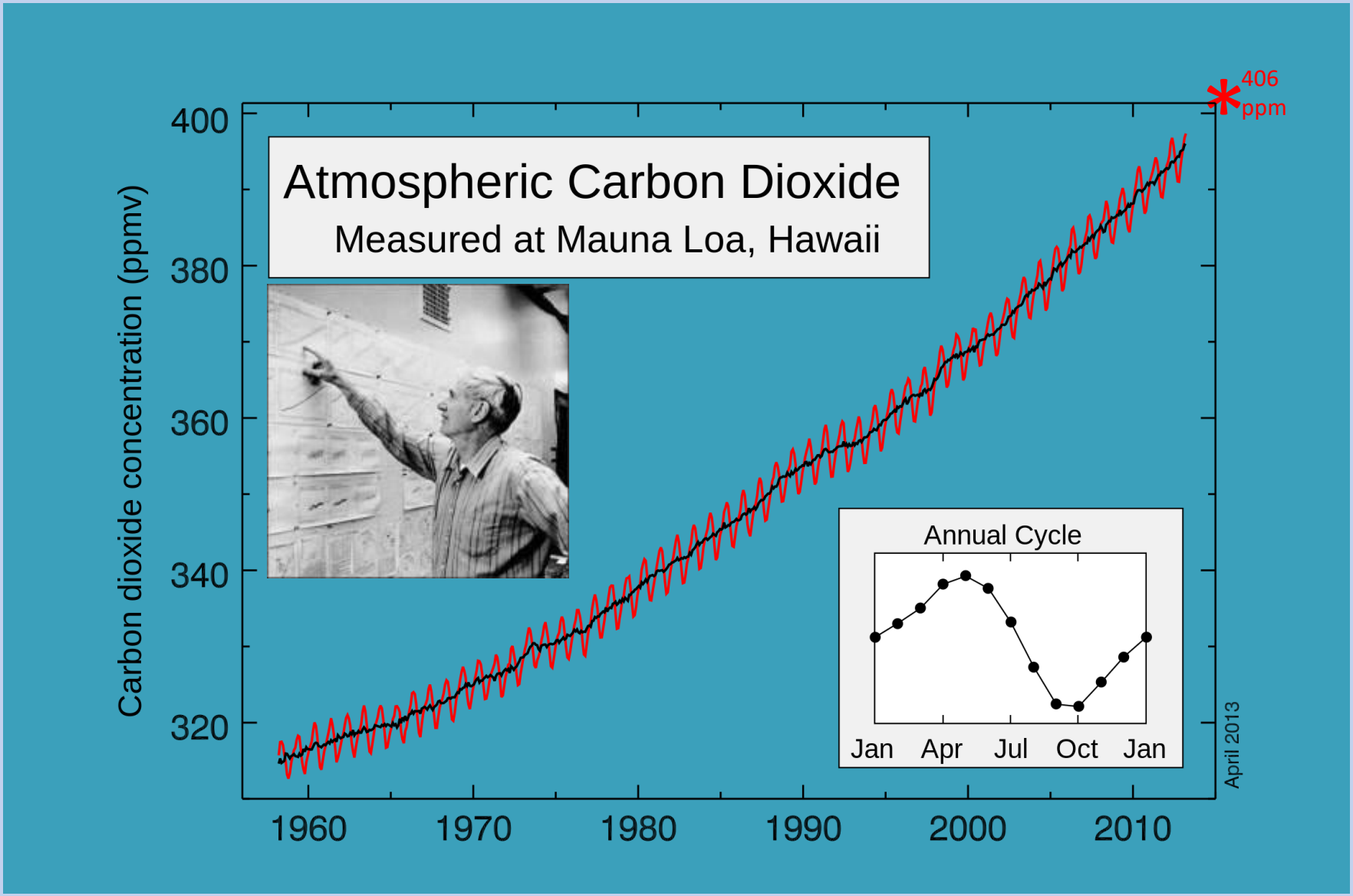
Deep Sea Coring



Ruddiman, 2008

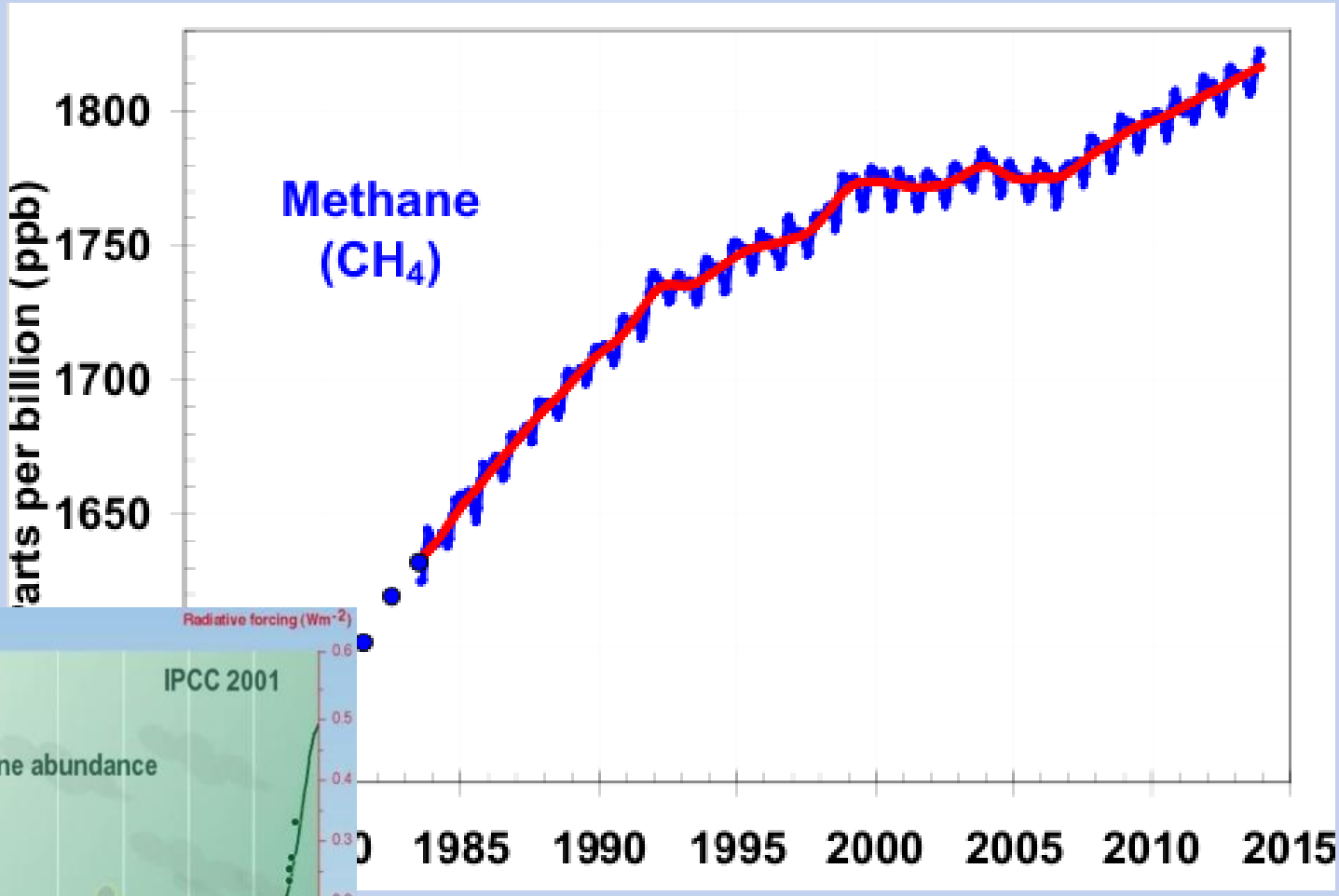
Empirical: real measured data in the modern day

CO_2 measurements from Mauna Loa

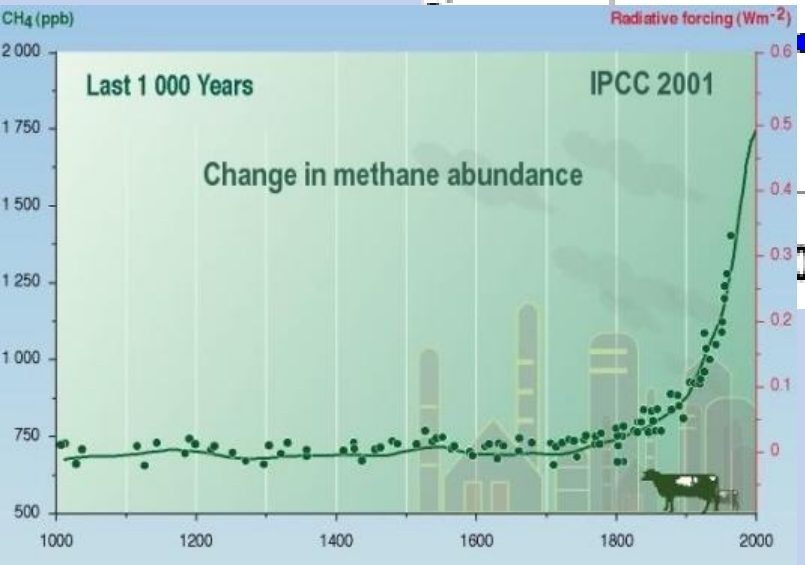


http://en.wikipedia.org/wiki/Keeling_Curve

What about Methane?

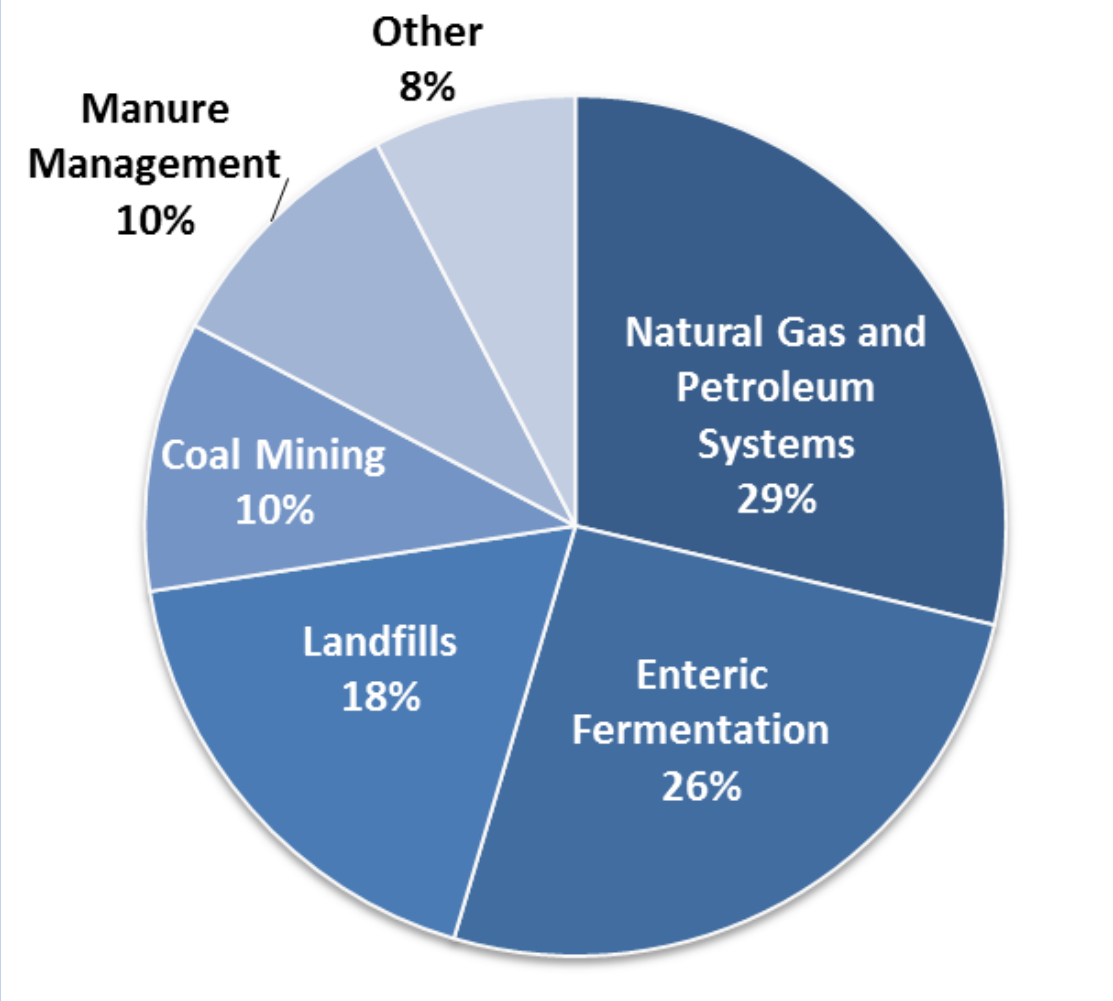


http://www.esrl.noaa.gov/gmd/aggi/aggi.html

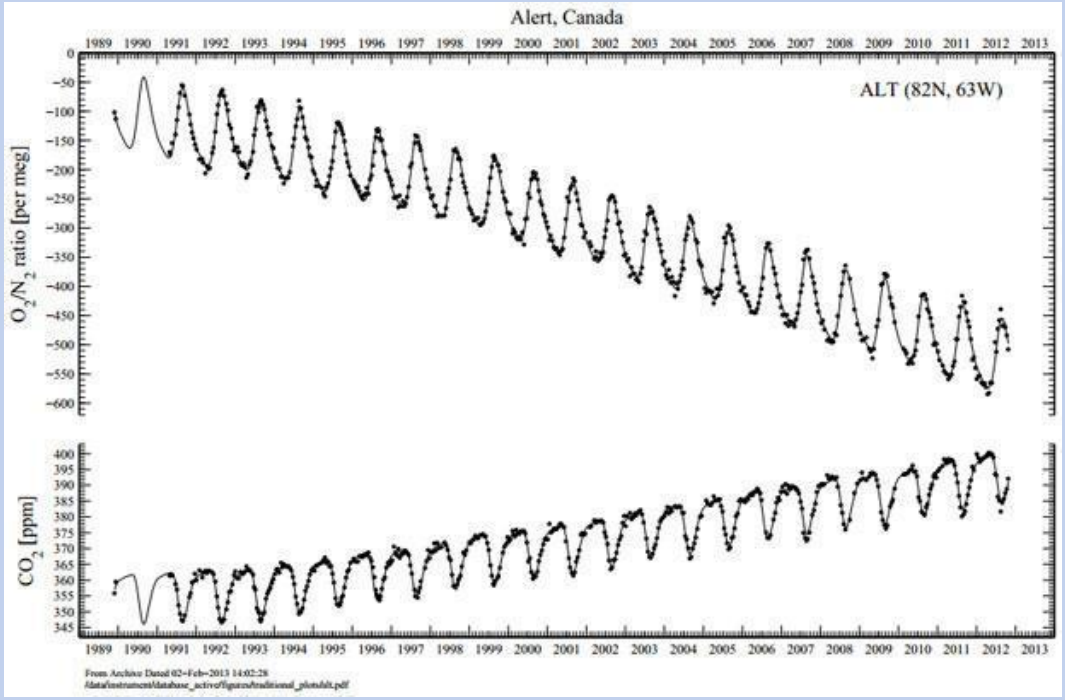


http://clathrates.blogspot.com/2012/04/threat-of-methane-release-from.html

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

3. Rates of change

Unprecedented rates of change

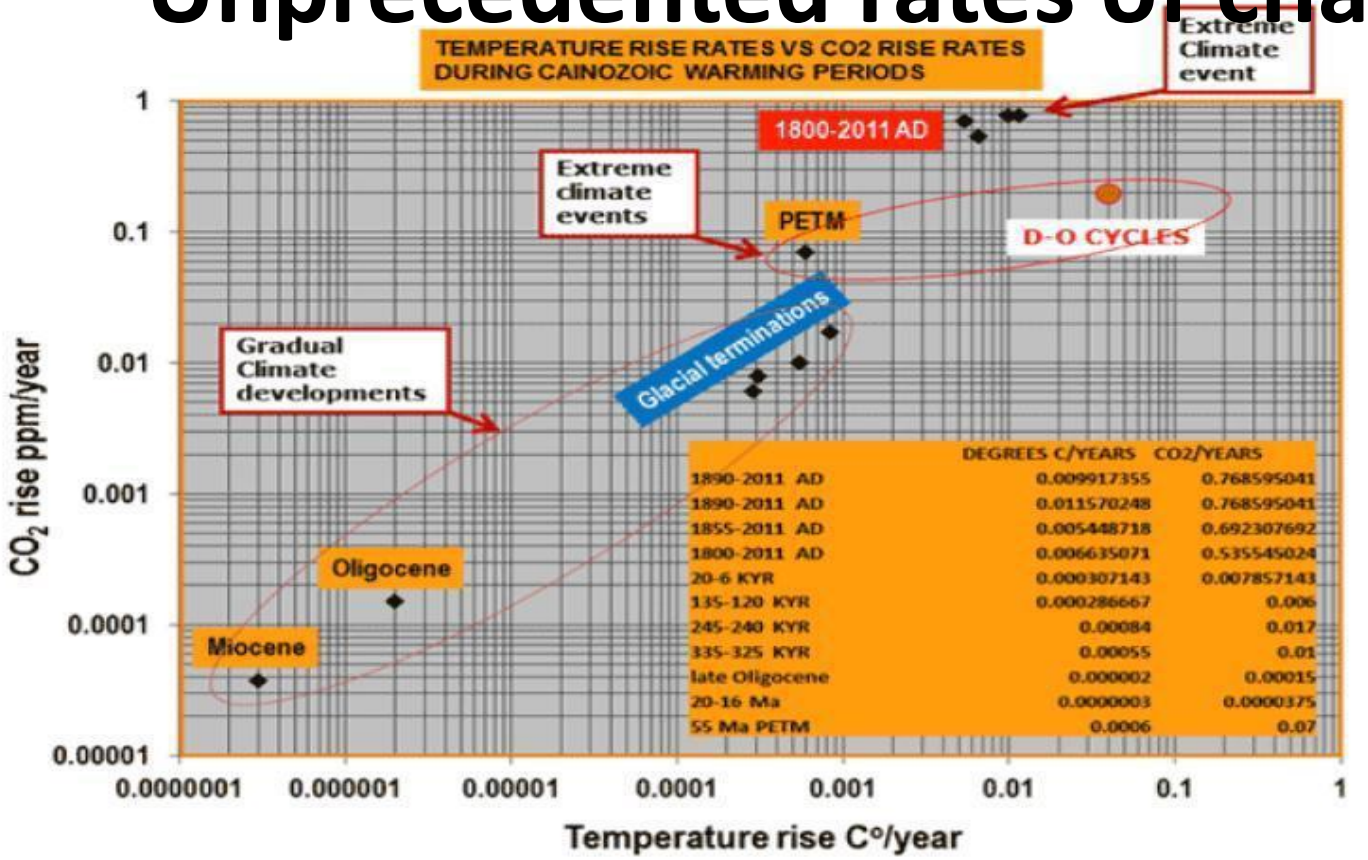
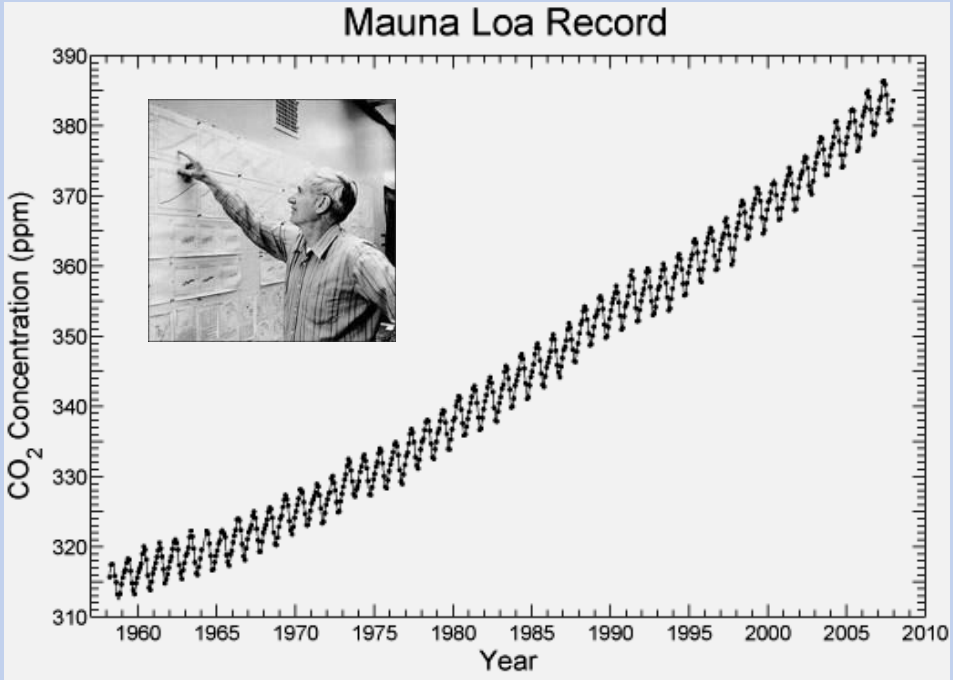


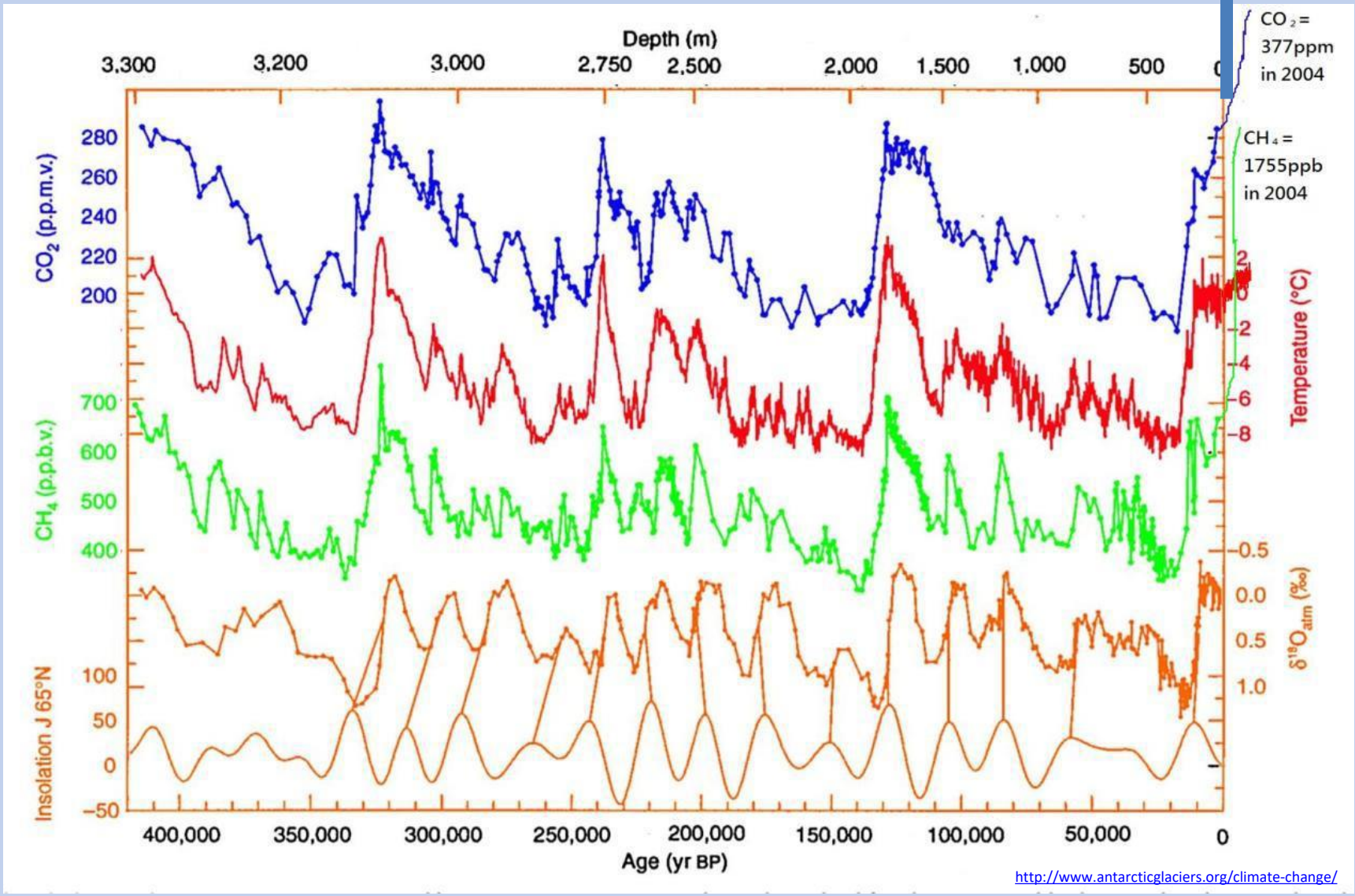
Figure 2: Relations between CO_2 rise rates and mean global temperature rise rates during warming periods, including the Paleocene-Eocene Thermal Maximum, Oligocene, Miocene, glacial terminations, Dansgaard-Oeschger cycles and the post-1750 period.

3: EMISSIONS FROM HUMAN ACTIVITIES LARGELY TO BLAME

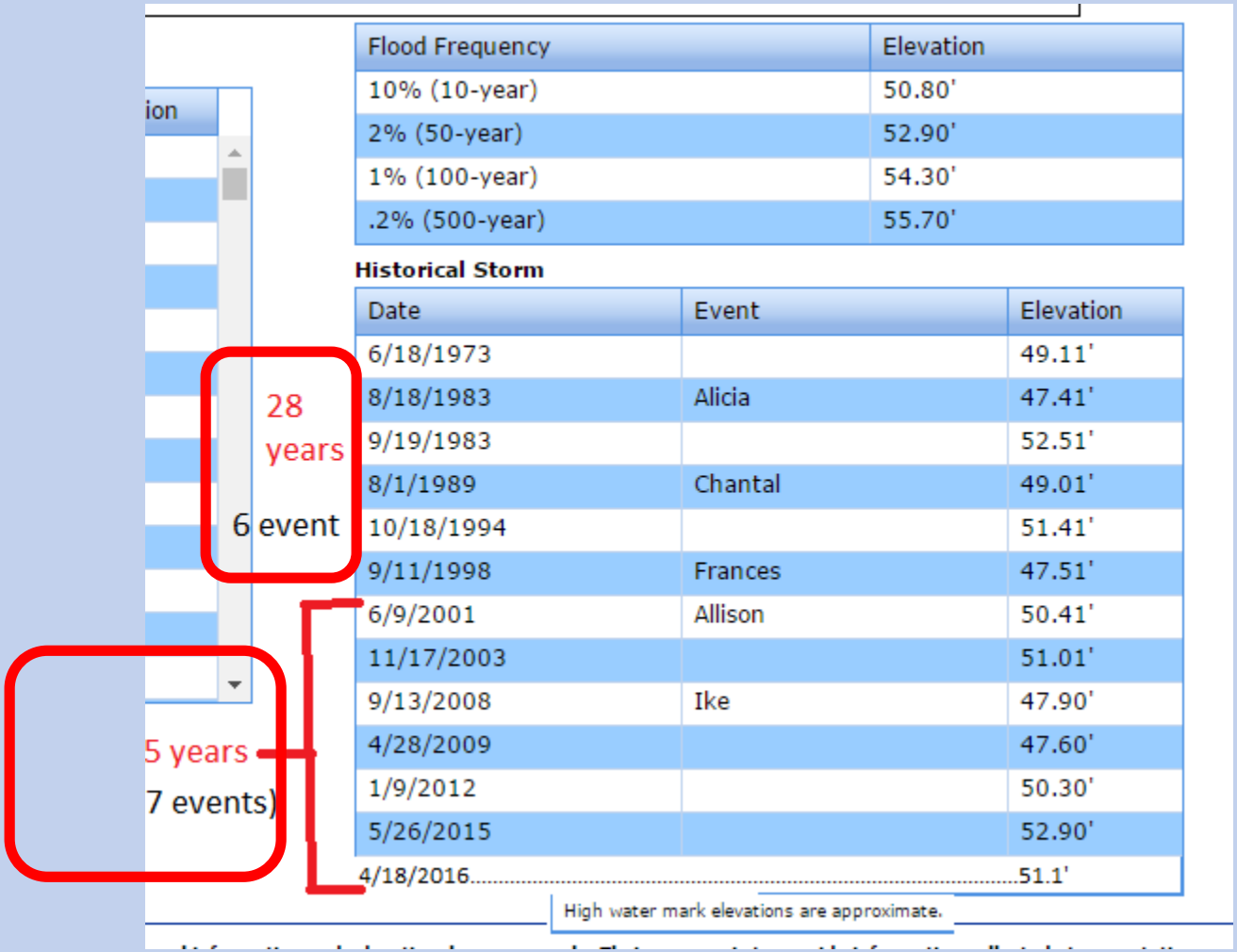
- 40% increase in CO_2, Dead carbon altering atmospheric C^{14}
- That Carbon is more negative/enriched in C^{12}



412ppm in 2019



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



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

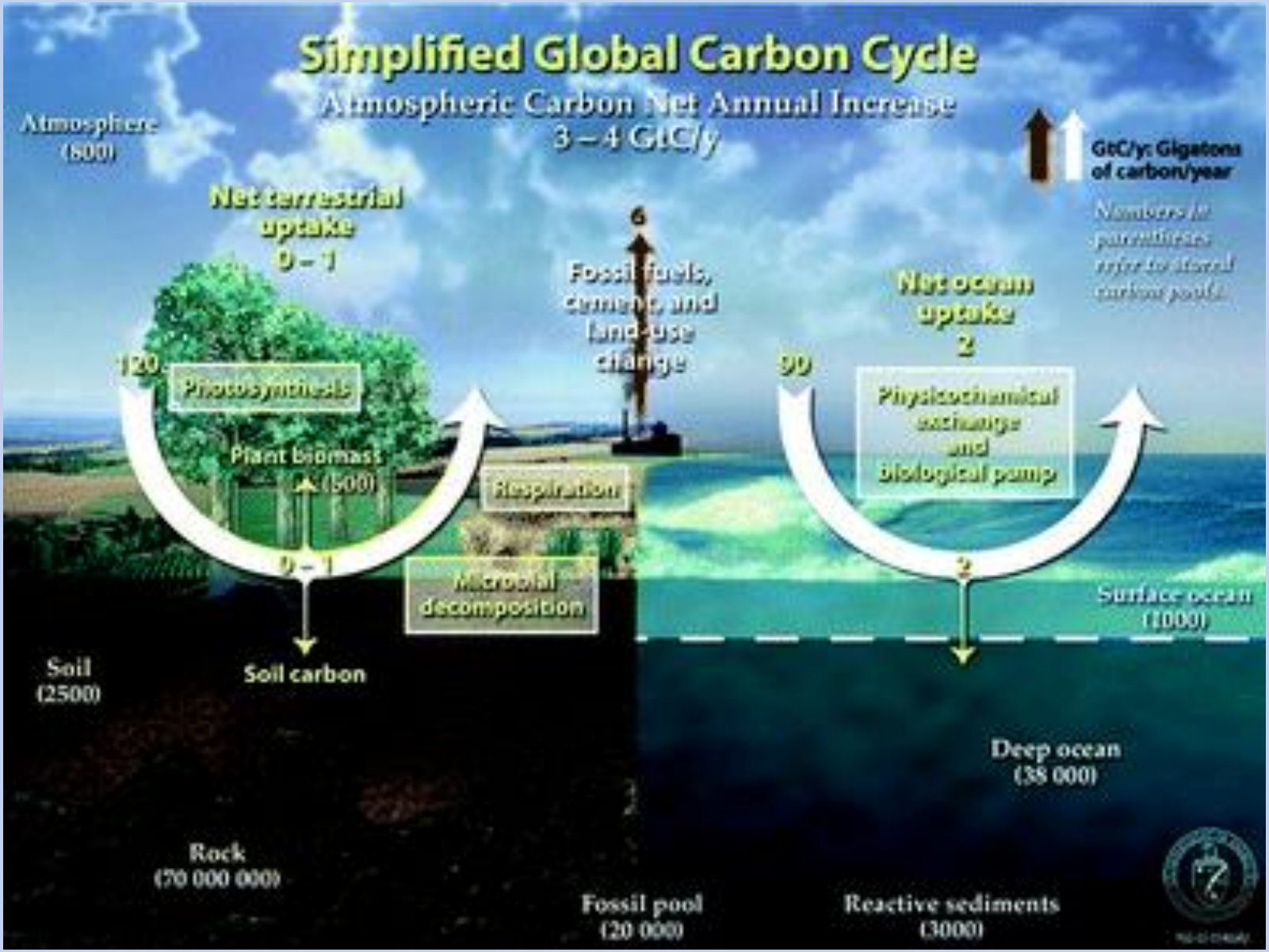
Historical Storm

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

4. Ocean Acidification



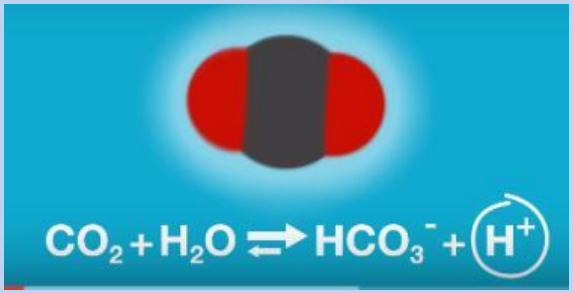
http://www.pmel.noaa.gov/co2/story/Ocean+Carbon+Uptake

Ocean acidification

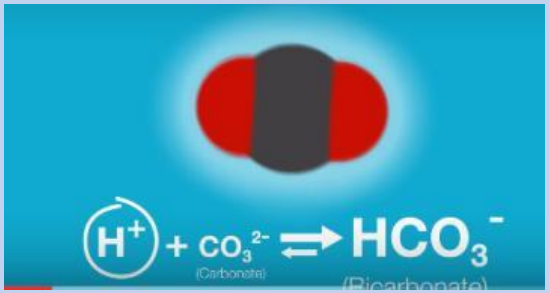
- USEFUL video:
  - Ocean acidificationBASIC: https://youtu.be/W1TZ8g8JYVU
  - AND INTERMEDIATE LEVEL – David Attenborough and others https://youtu.be/aYrLSrgWu0Y from:
  - Ocean acidification: global warming's evil twin:
    - http://www.skepticalscience.com/ocean-acidification-global-warming.htm choose basic or intermediate

VIDEO HIGHLIGHTS: Ocean acidification

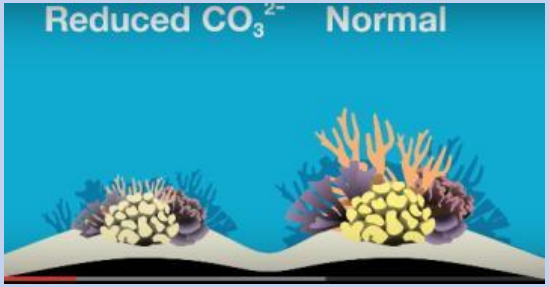
- Adding CO_2 adds H^+ ions making water more acidic (lowers pH)



- 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



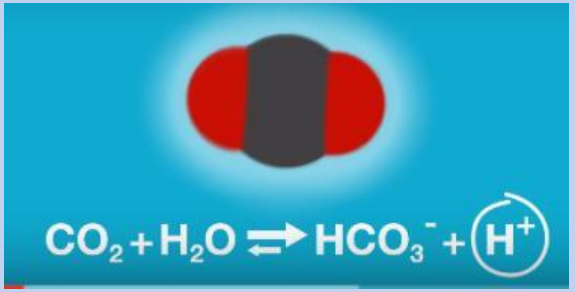
http://www.skepticalscience.com/ocean-acidification-global-warming.htm

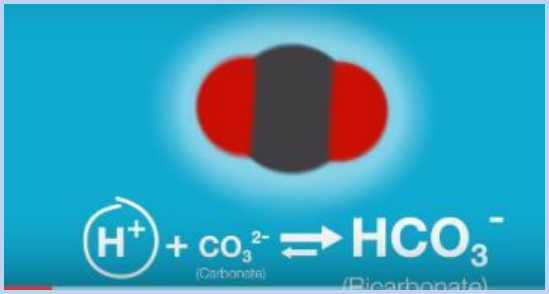
Continued

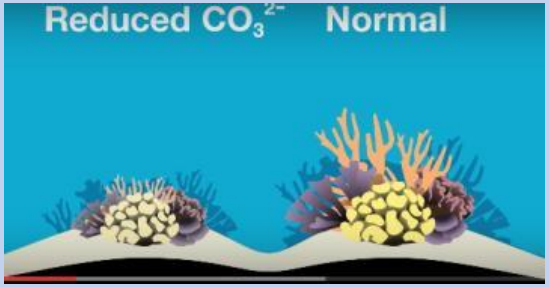
- Takes hundreds of years to equilibrate from weathering – or buffering from the deep sea carbonates as we saw in the PETM

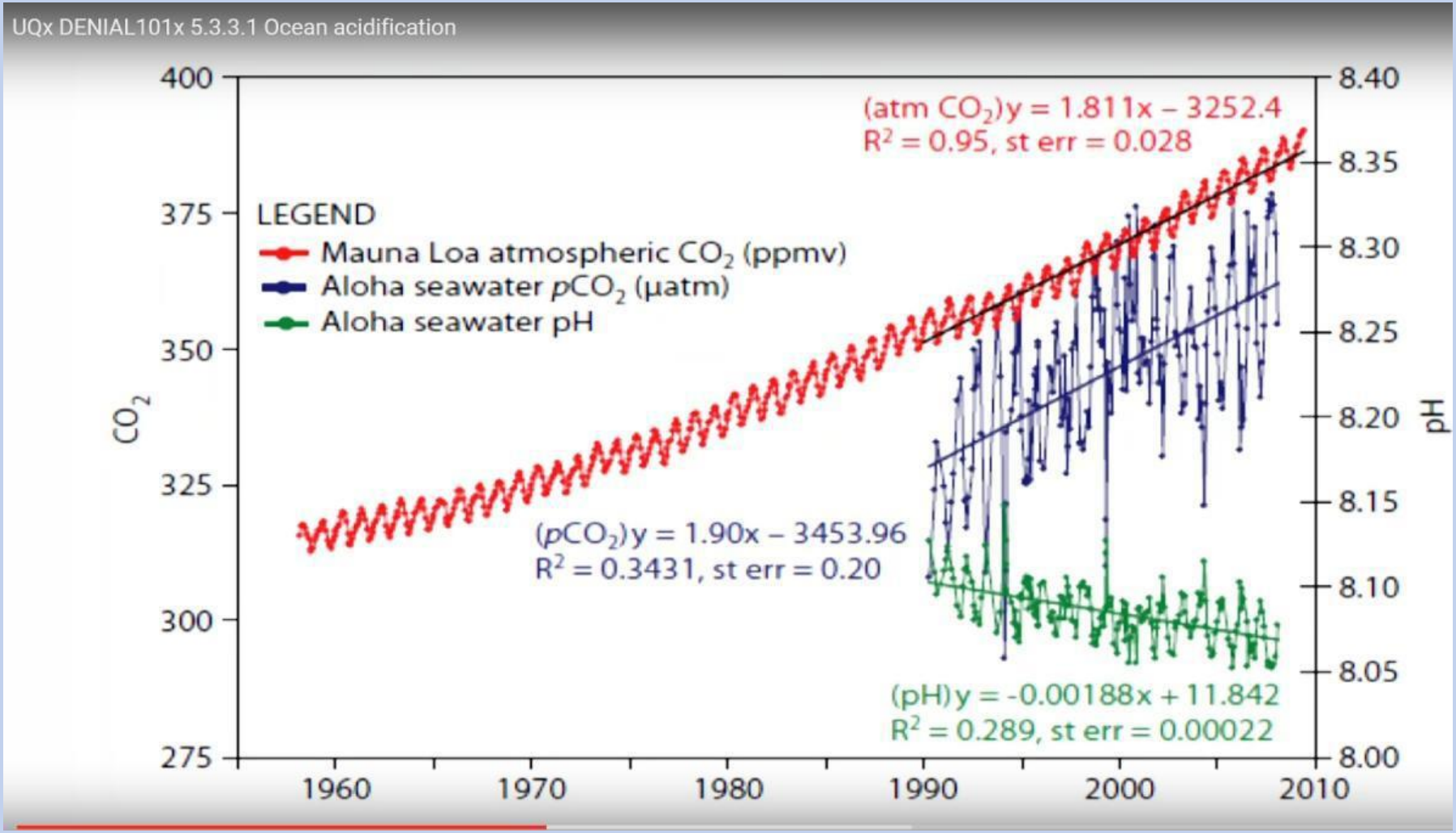
- 0.1 decrease in pH = 26% CO_3^{-2} ions

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





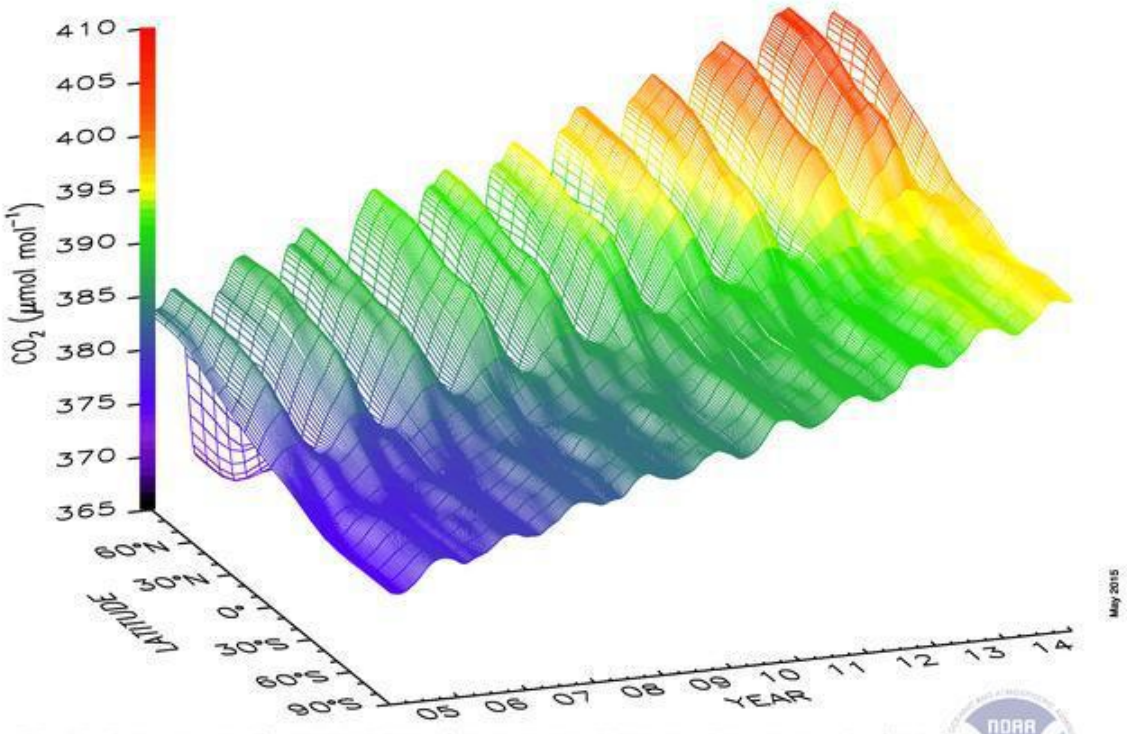




http://www.skepticalscience.com/ocean-acidification-global-warming.htm

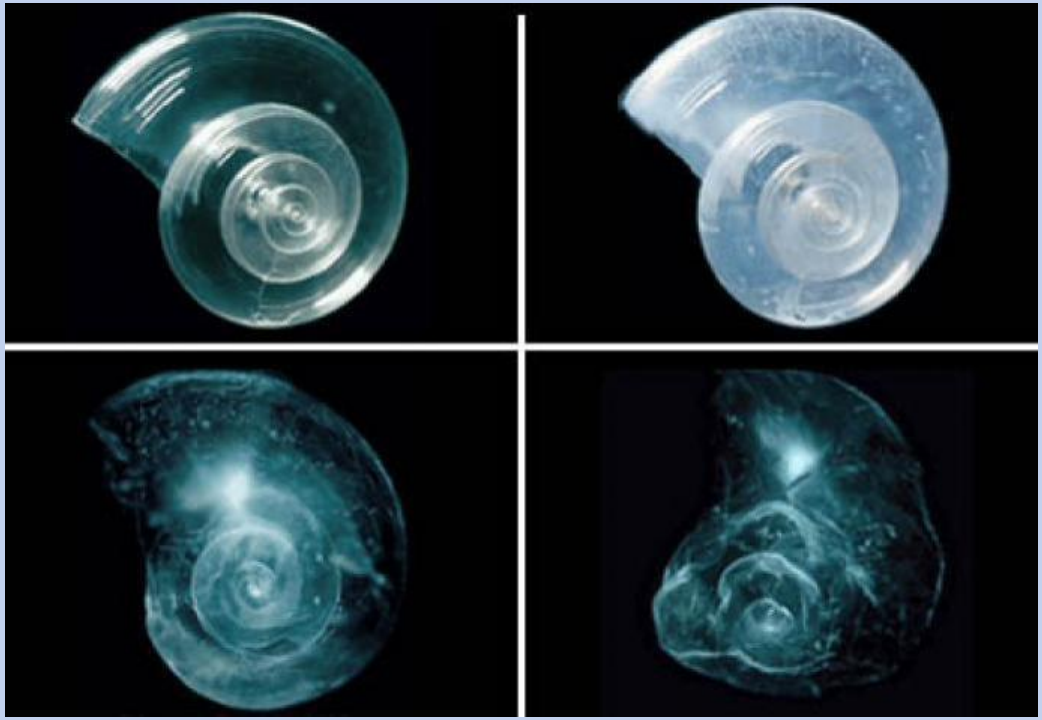
Global Distribution of Atmospheric Carbon Dioxide

NOAA ESRL Carbon Cycle



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/.

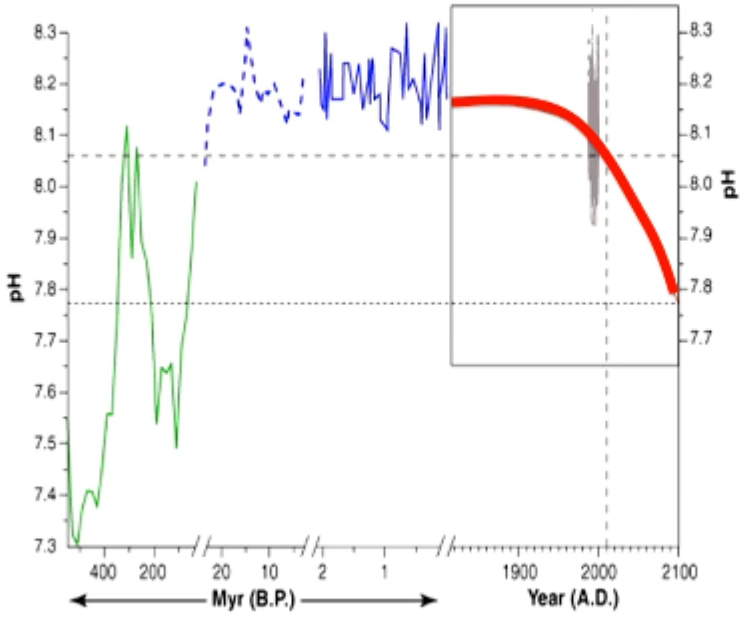
Pteropods



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

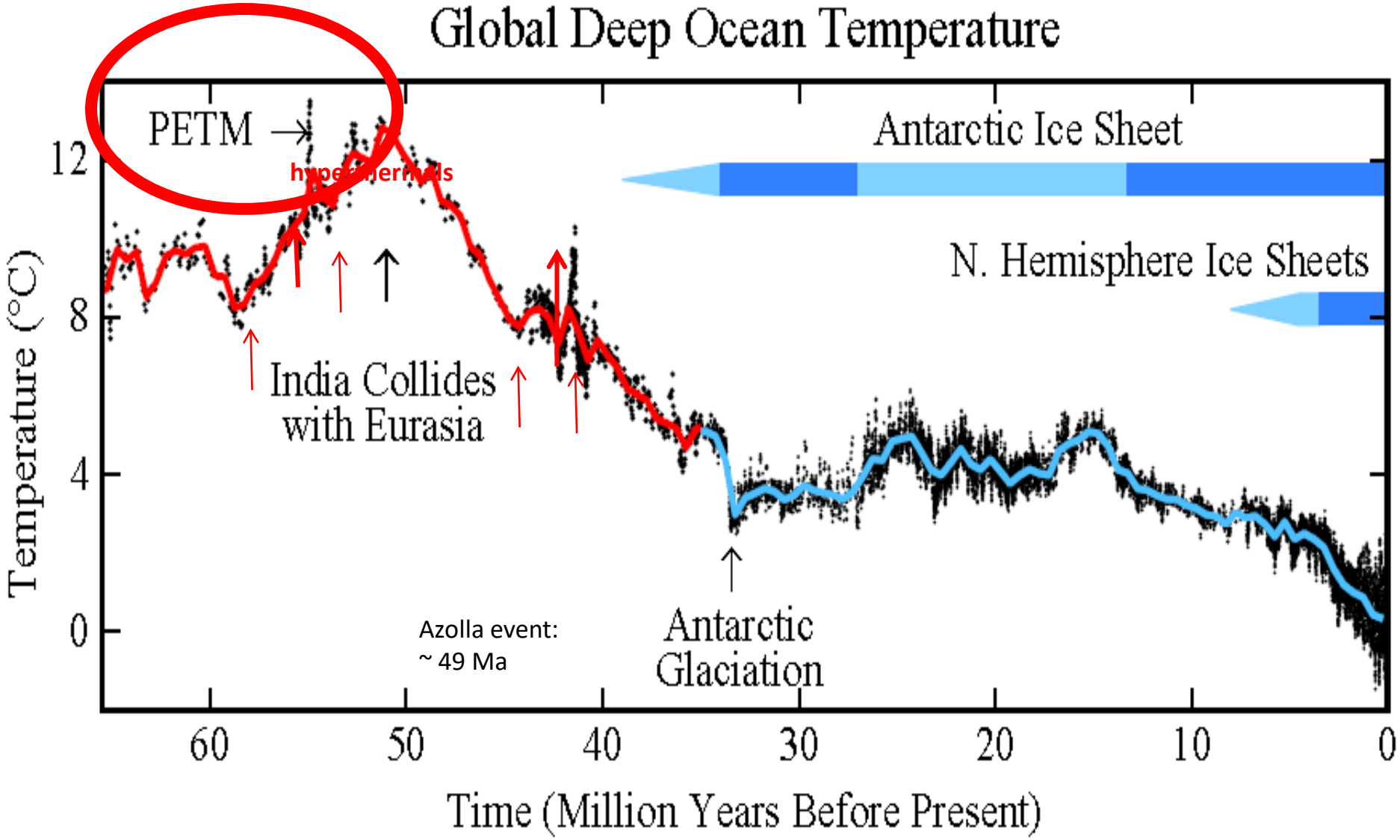
Ocean acidification

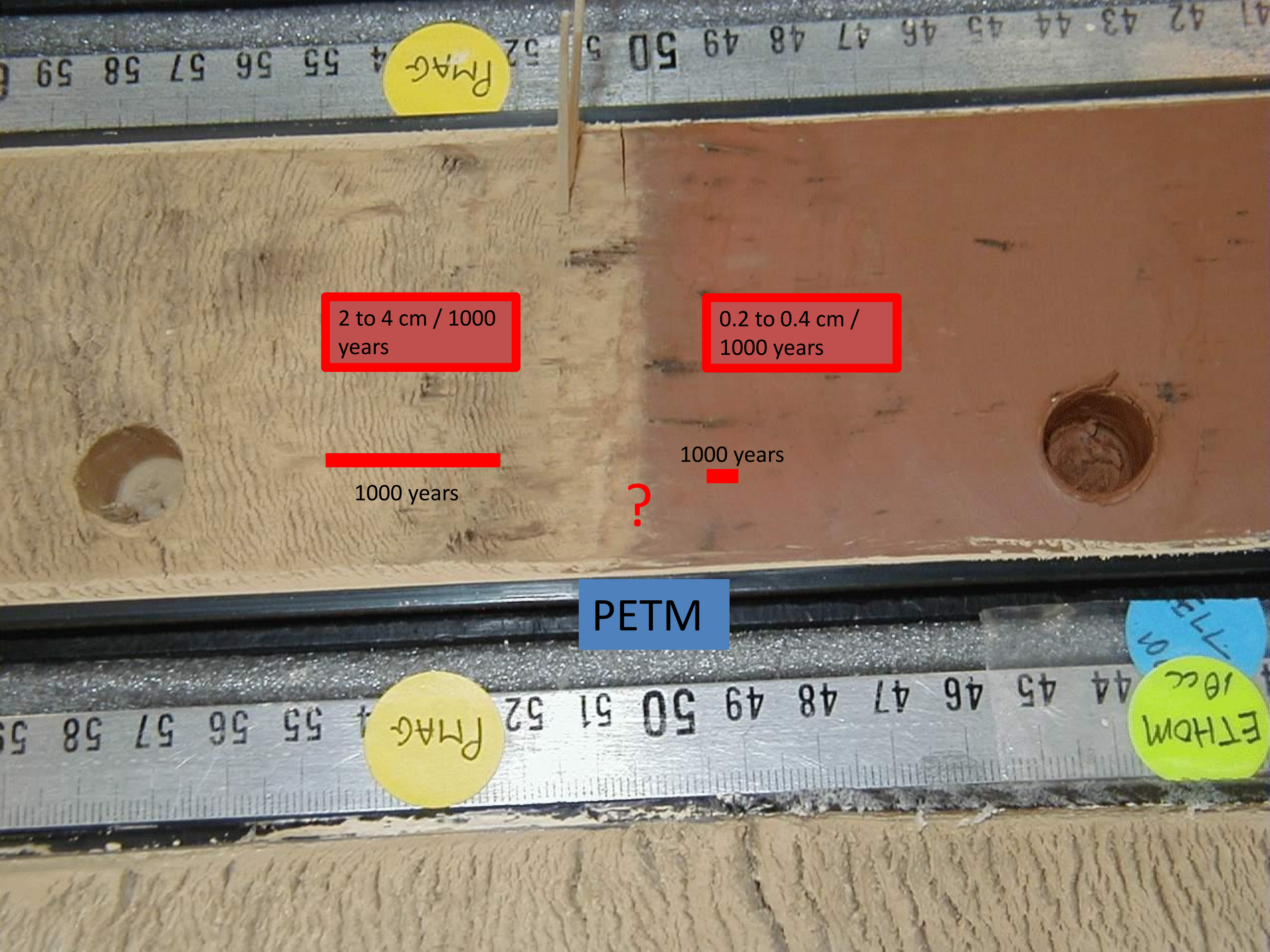
- $CaCO_3 + H_2CO_3 = Ca^{+2} + 2HCO^{-}_3$ [1]
- H_2CO_3 is carbonic acid - a relatively weak naturally occuring acid that forms by the reaction between water and carbon dioxide: $H_2O + CO_2 = H_2CO_3$ [2]
-

AND IT HAPPENED BEFORE:
55 Million years ago
Paleocene/Eocene Thermal Maximum
PETM

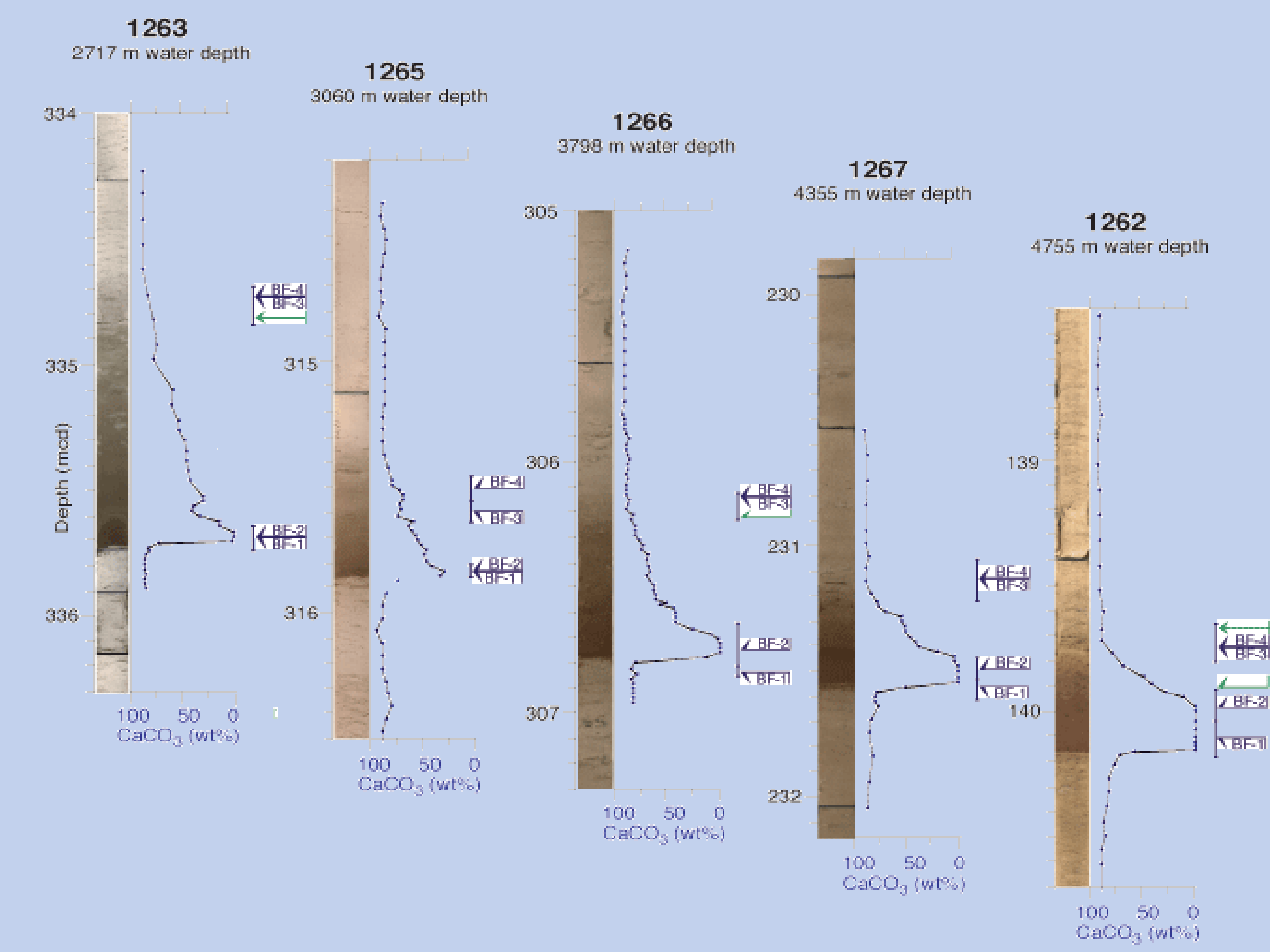
- AN OCEAN ACIDIFICATION EVENT

Paleocene-Eocene Thermal Maximum - PETM





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


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

It took a long time to recover

Past and present; future estimates

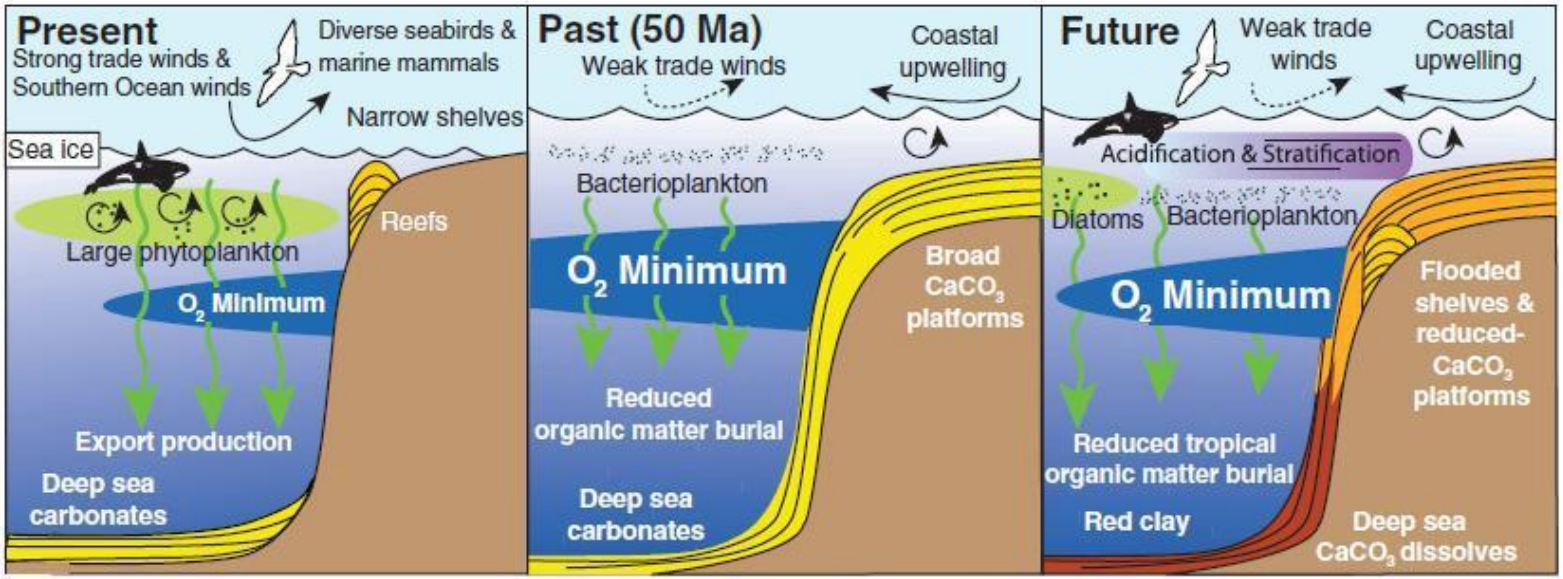
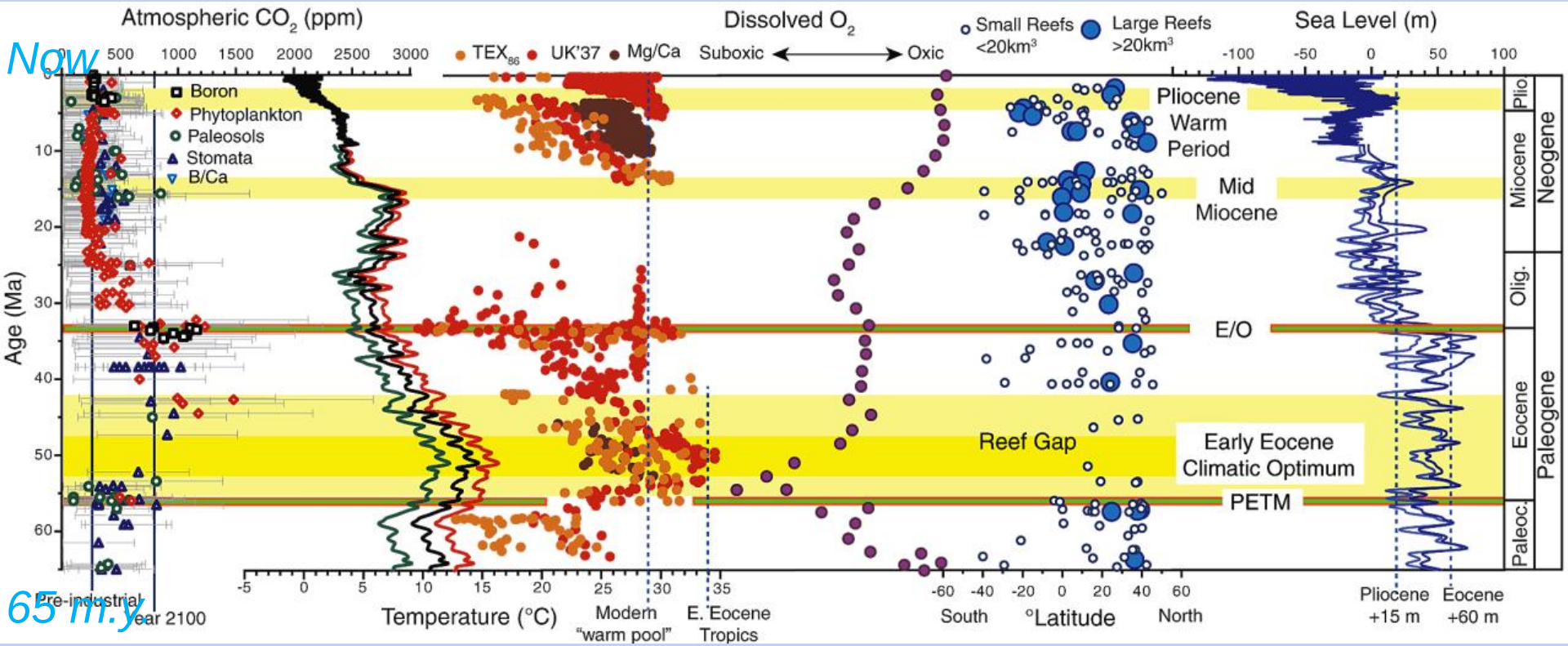


Fig. 1. Comparison of present, past, and future ocean ecosystem states. In the geologic past (middle panel), a warmer, less oxygenated ocean supported longer food chains based in phytoplankton smaller than present-day phytoplankton (left panel). The relatively low energy transfer between trophic levels 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.

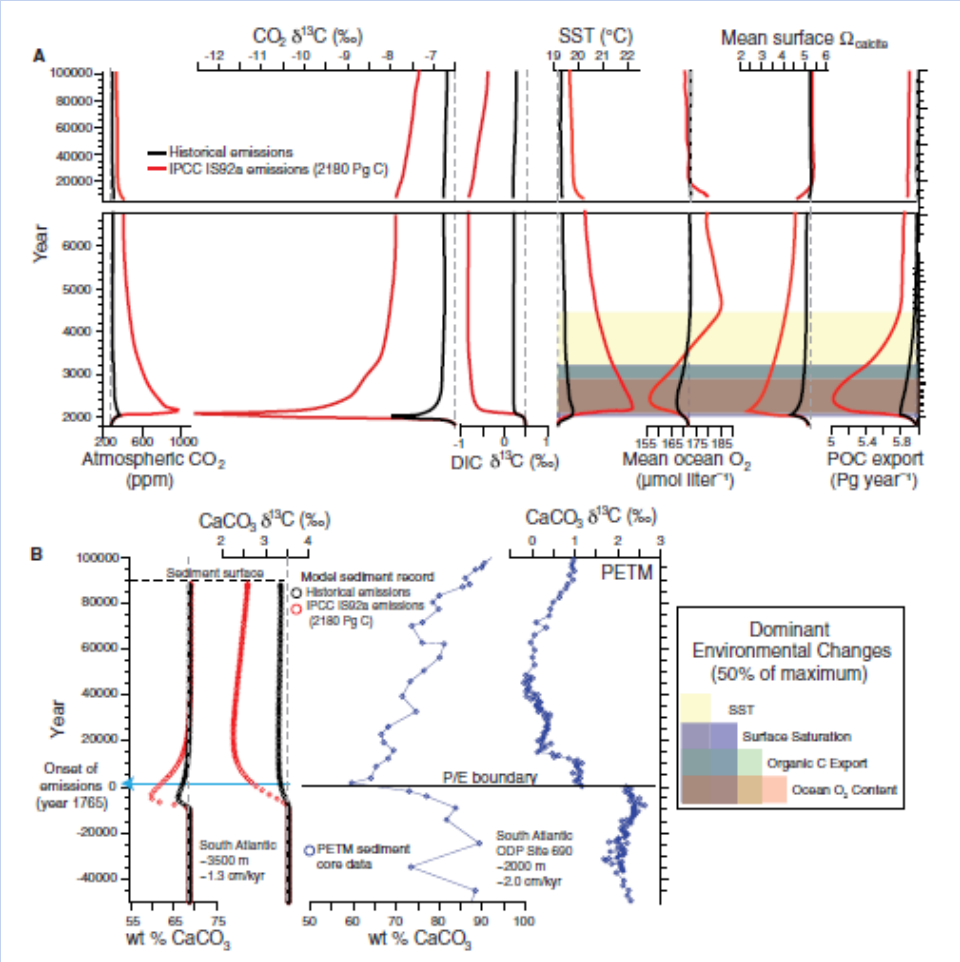


R. Norris et al., Science, 2013

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. IPCC and AR5

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/

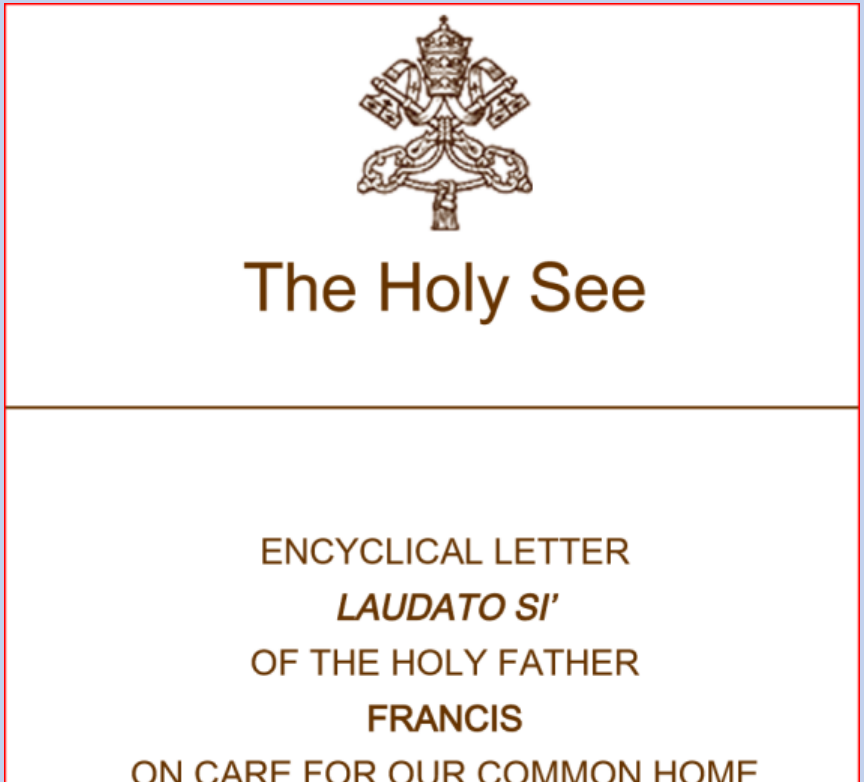
IPCC AR5

- https://www.ipcc.ch/report/ar5/syr/

6. Laudato Si

Laudato Si

- https://denverclimatestudygroup.com/wp-content/uploads/2014/10/2015.05.24-papa-francesco_20150524_enciclica-laudato-si.pdf


The Holy See

ENCYCLICAL LETTER

LAUDATO SI'

OF THE HOLY FATHER

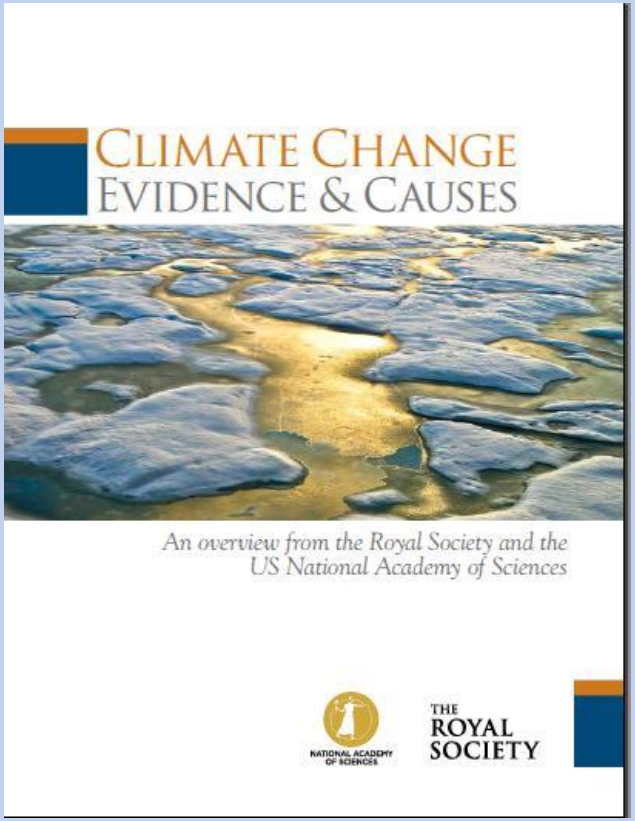
FRANCIS

ON CARE FOR OUR COMMON HOME

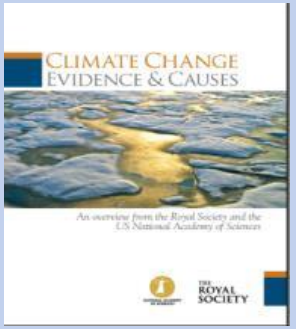
Joint U.S. National Academy of Science and Royal Society 20-point summary:

- 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? .....

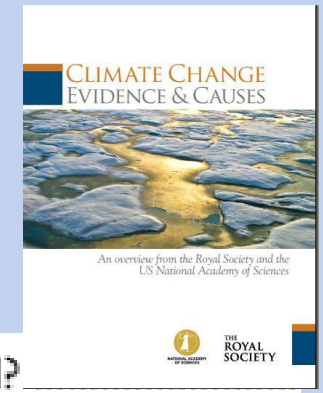
6 Climate is always changing. Why is climate change of concern now? .....

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? .....



11 If the world is warming, why are some winters and summers still very cold?

12 Why is Arctic sea ice decreasing while Antarctic sea ice is not? .....

13 How does climate change affect the strength and frequency of floods, droughts, hurricanes, and tornadoes? .....

14 How fast is sea level rising? .....

15 What is ocean acidification and why does it matter? .....

16 How confident are scientists that Earth will warm further over the coming century? .....

17 Are climate changes of a few degrees a cause for concern? .....

18 What are scientists doing to address key uncertainties in our understanding of the climate system? .....

19 Are disaster scenarios about tipping points like 'turning off the Gulf Stream' and release of methane from the Arctic a cause for concern? .....

20 If emissions of greenhouse gases were stopped, would the climate return to the conditions of 200 years ago? .....

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

- FOR ANSWERS SEE MY OTHER PowerPoint
- Here http://denverclimatestudygroup.com/wp-content/uploads/2015/10/Belanger-joint-NAS-Royal-Society-answers-to-20-points.pdf

Full list of Videos from Skeptical Science

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

- 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!

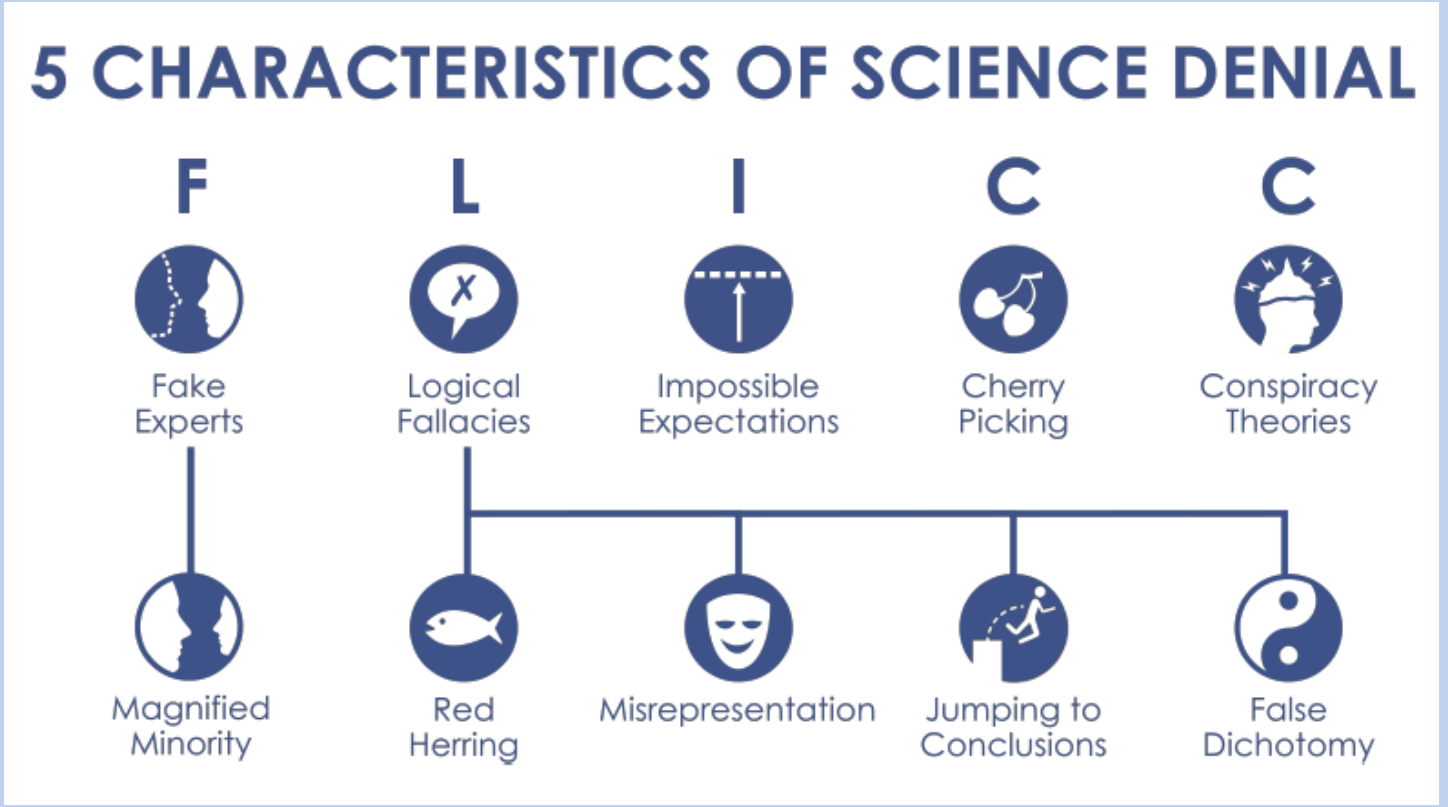
WE SHOWED 20 MINUTES OF THE NEXT VIDEO: DE-Coding the Weather Machine

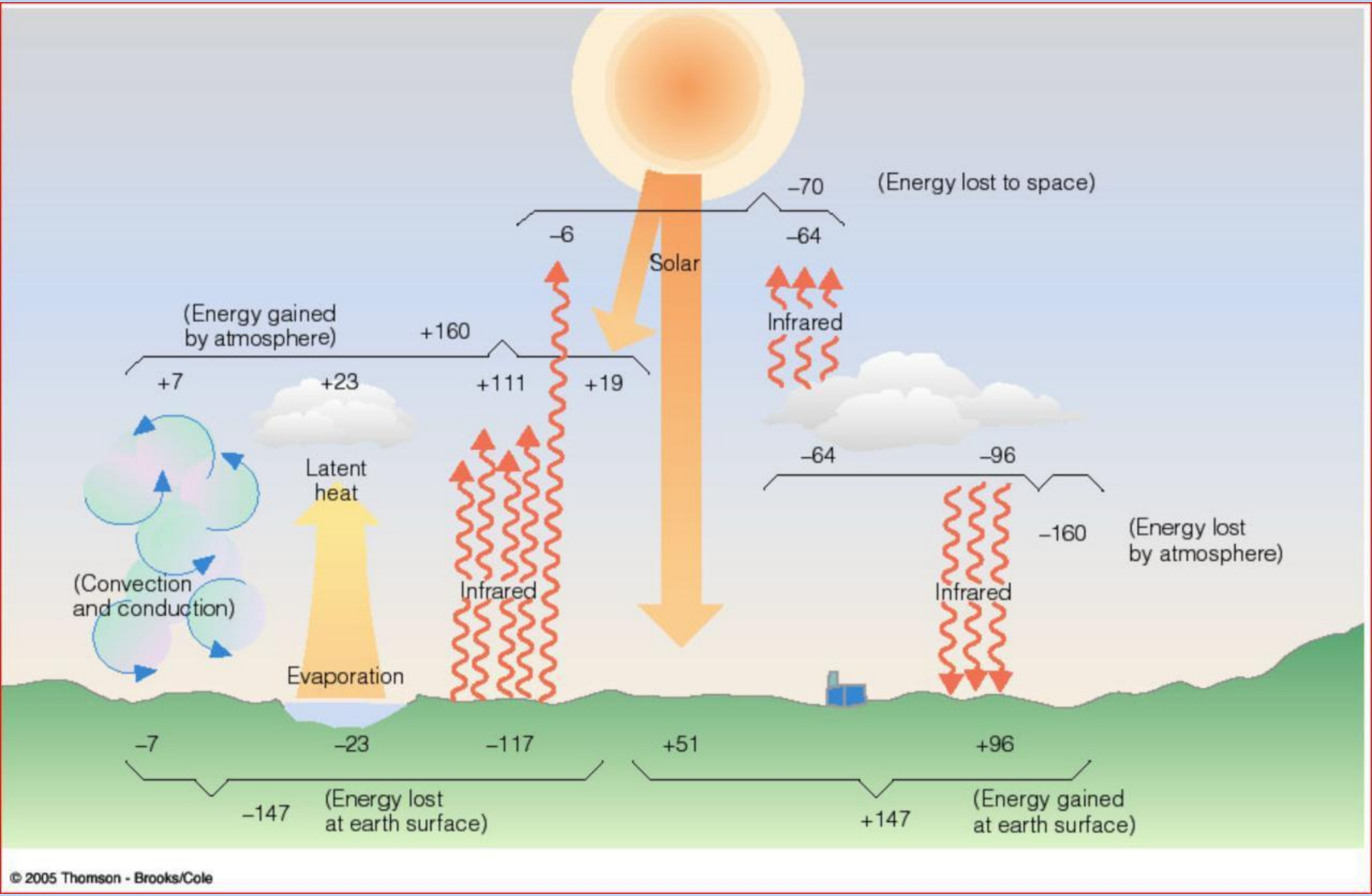
Extreme weather events our changing world

- https://www.pbs.org/video/decoding-the-weather-machine-vgqhot/ :
  - Disastrous hurricanes. Widespread droughts and wildfires. Withering heat. Extreme rainfall. It is hard not to conclude that something's up with the weather, and many scientists agree. It's the result of the weather machine itself—our climate—changing, becoming hotter and more erratic. In this 2-hour documentary, NOVA will cut through the confusion around climate change.

8. Modeling – we will pick up here next week

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



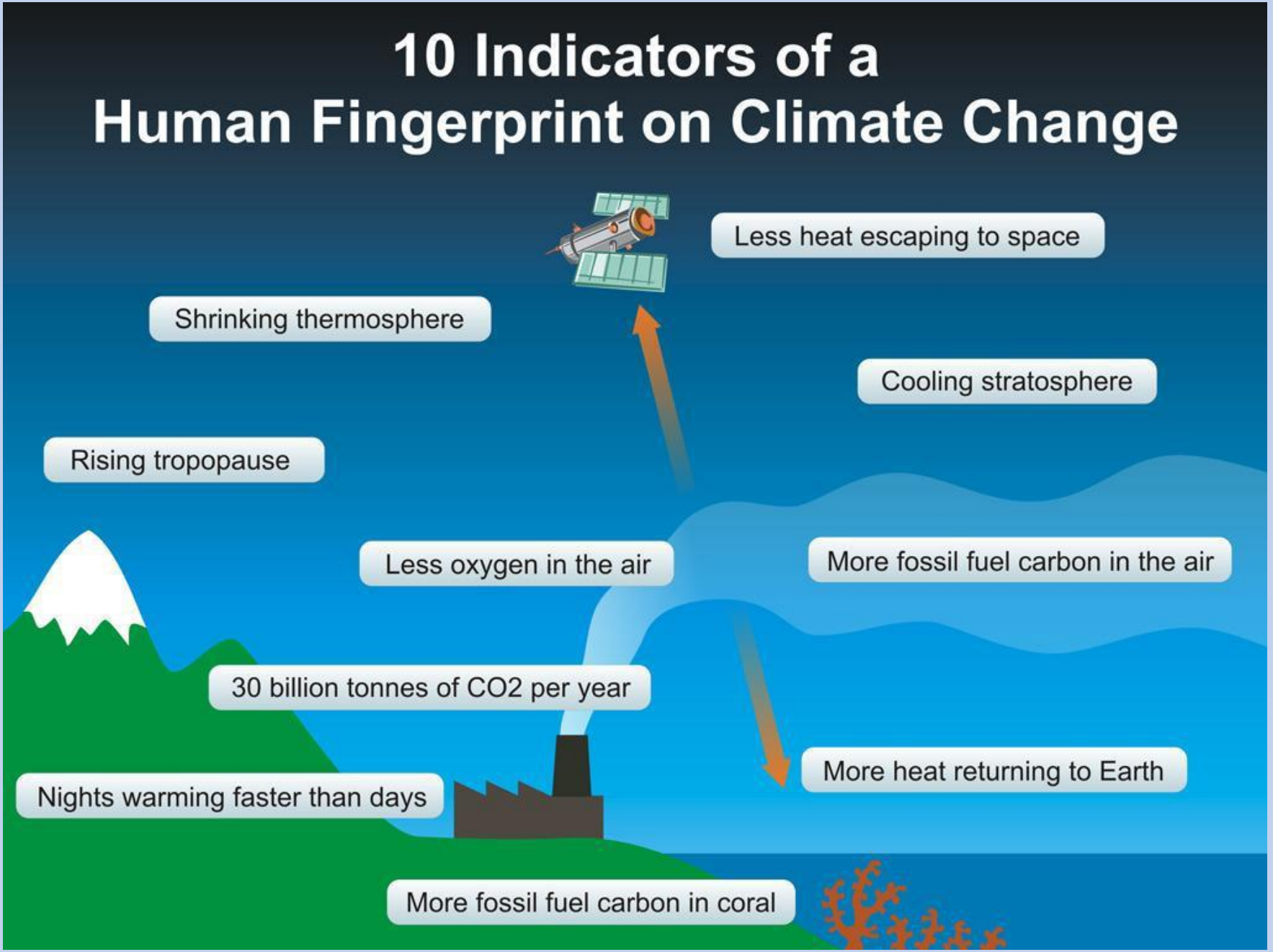


Models – 2 videos

Principles that models are built on – view today (4:43 minutes)
https://www.youtube.com/watch?v=mYU2uawYPlE&feature=youtu.be

From the experts: Climate models – leaving it for you to view at your leisure: 10:30 minutes
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



https://skepticalscience.com/10-Indicators-of-a-Human-Fingerprint-on-Climate-Change.html

1: THE CLIMATE IS WARMING

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