OLLI WEST: EARTH CLIMATE – WEEK 3

Tuesday September 29th, 2015

Paul E. Belanger, Ph.D.

1. Data and proxy data
2. Present signs of climate change
3. Ocean acidification

Data and proxy data

- Data: Measurements – present and past
  - Thermometry
  - Ice bubbles,
  - Field measurements, etc.

- Data Proxies: indirect measurements made from collected data to reconstruct past climates:

  geochemical proxies

  biological proxies

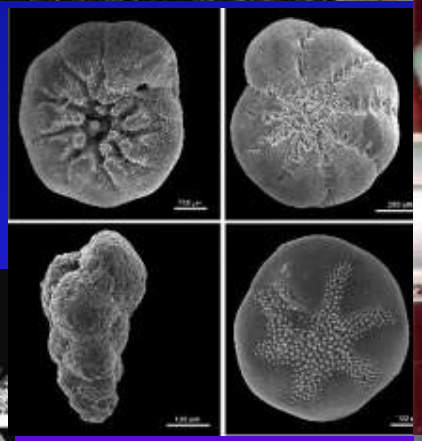
  lithologic proxies

Data and proxy data

Data has it’s errors

Proxy data has even more errors

Scientific History of Climate change – PROXY DATA



SOME OF THE EARLIEST PROXY DATA WAS FROM TERRESTRIAL DEPOSITS

- Strandlines/shorelines
- Moraines
- Till
- Kettle lakes, etc.
- Ice rafted debris/dropstones

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

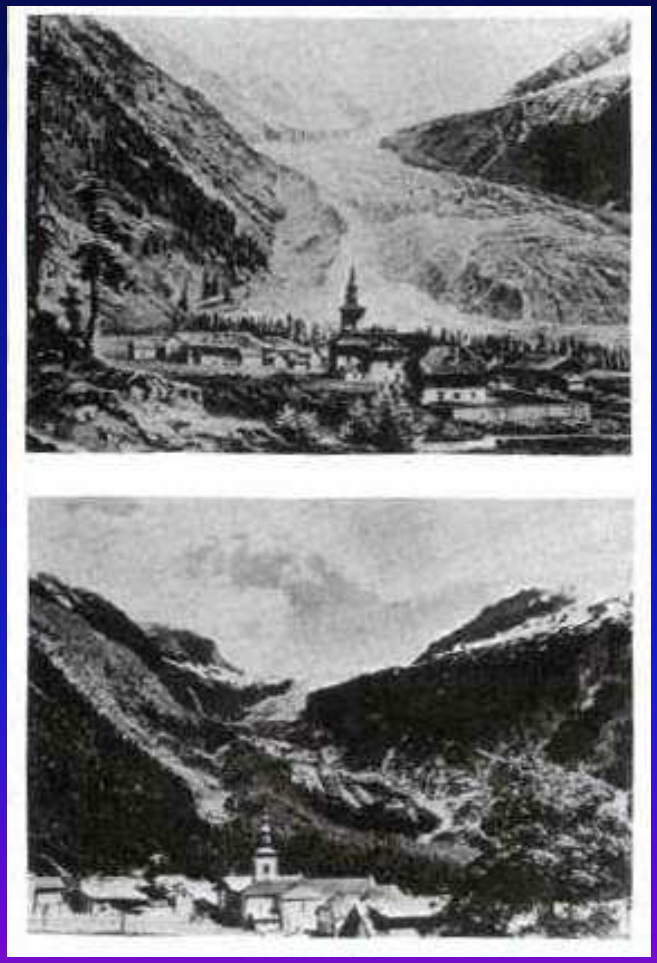
Louis Agassiz

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

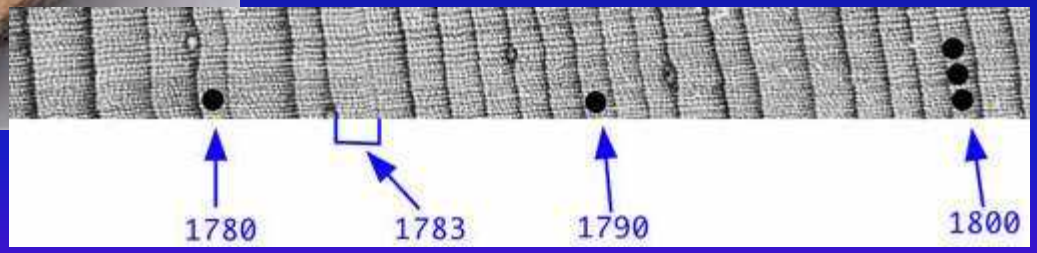
Photographic proxy data/evidence



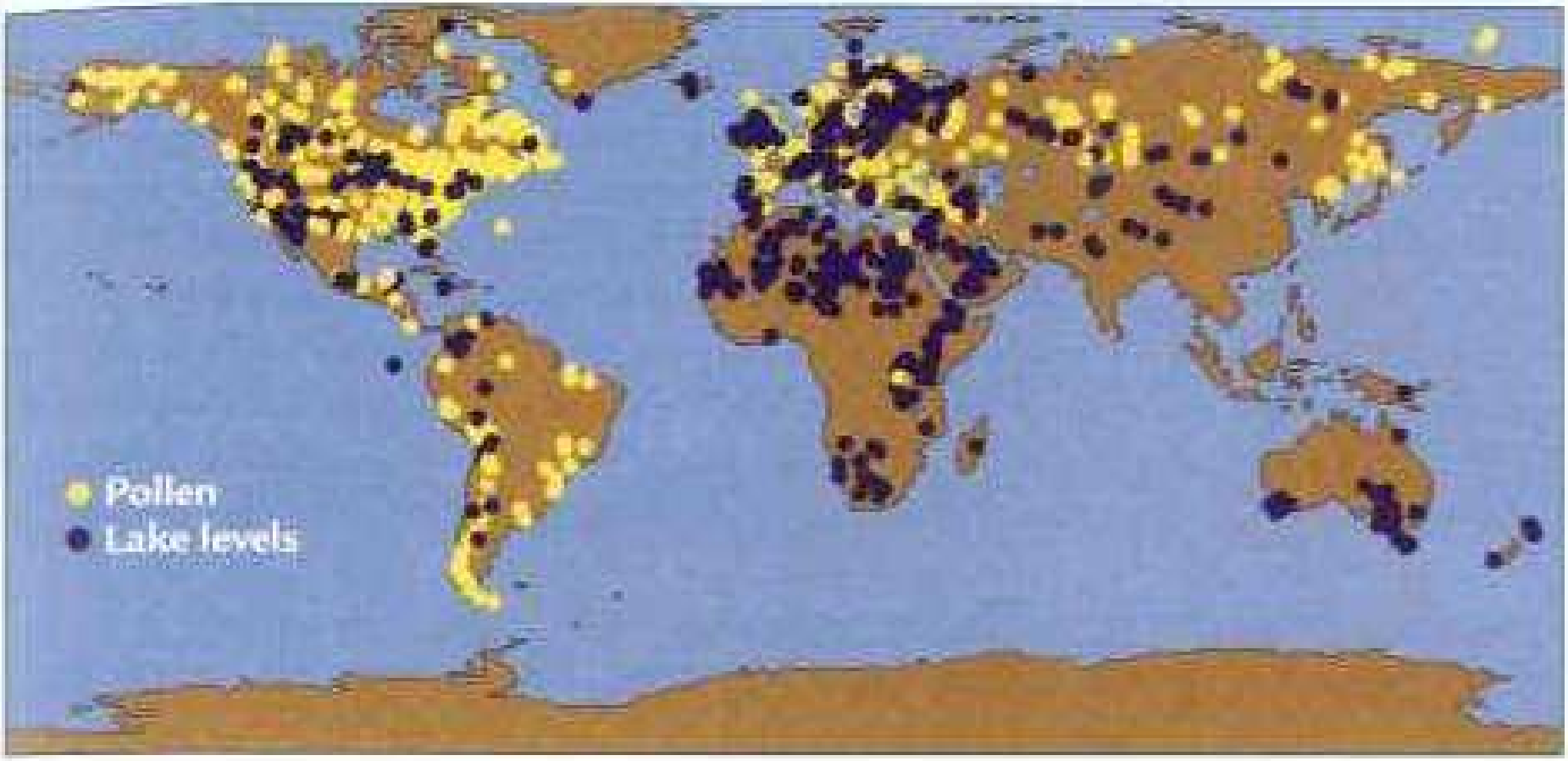
Ruddiman, 2008

EARLY PROXY DATA:

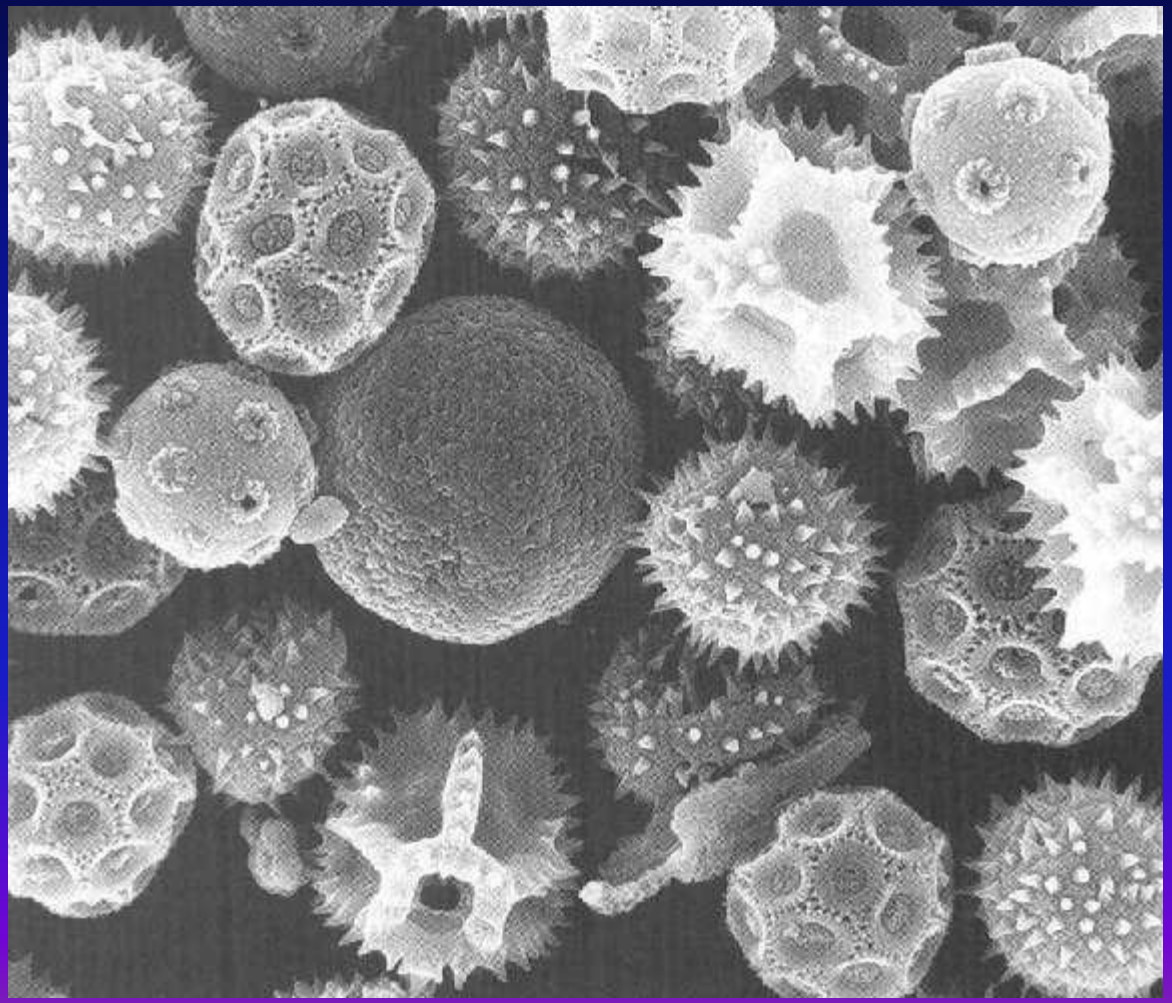
TREE RINGS



Pollen & Lake core data



Ruddiman, 2008

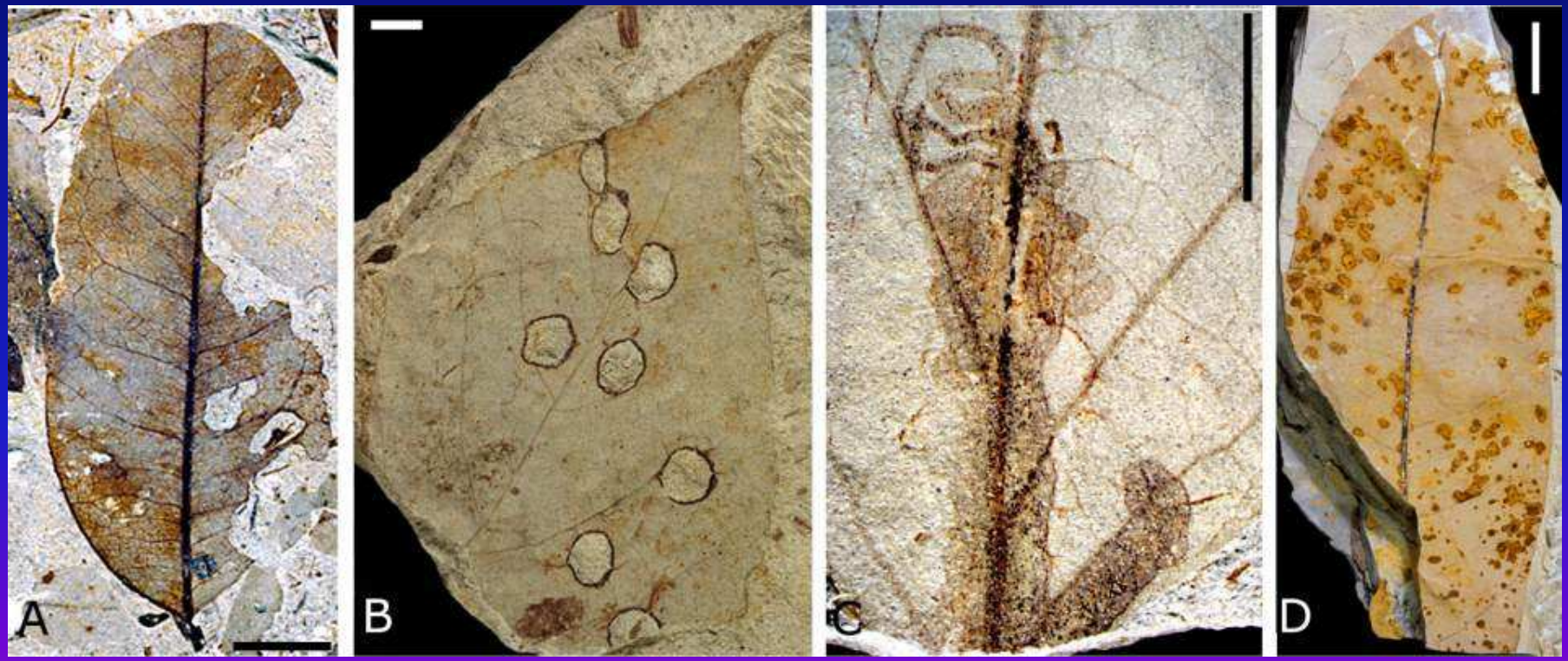


PROXY DATA:

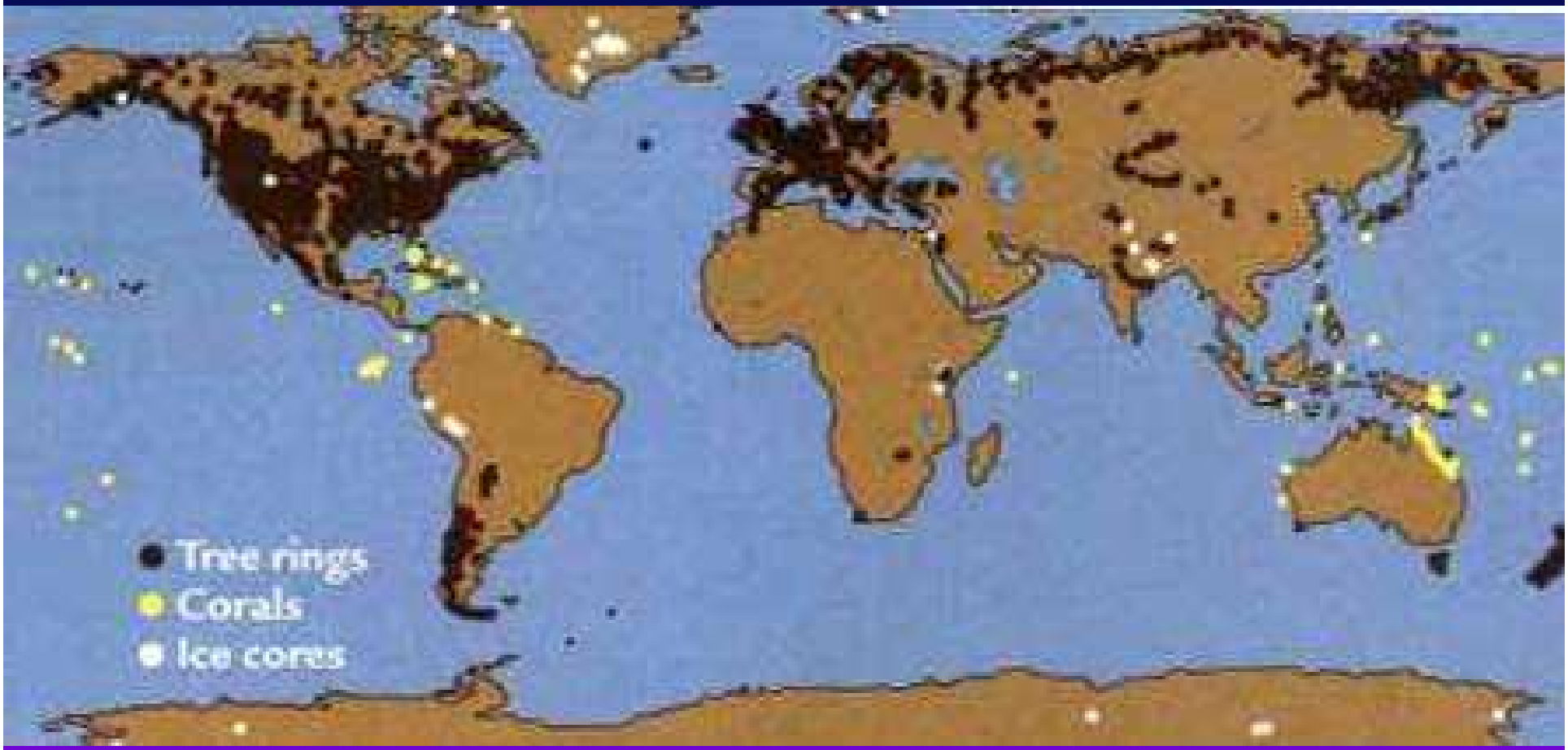
POLLEN DATA

PROXY DATA:

LEAVES



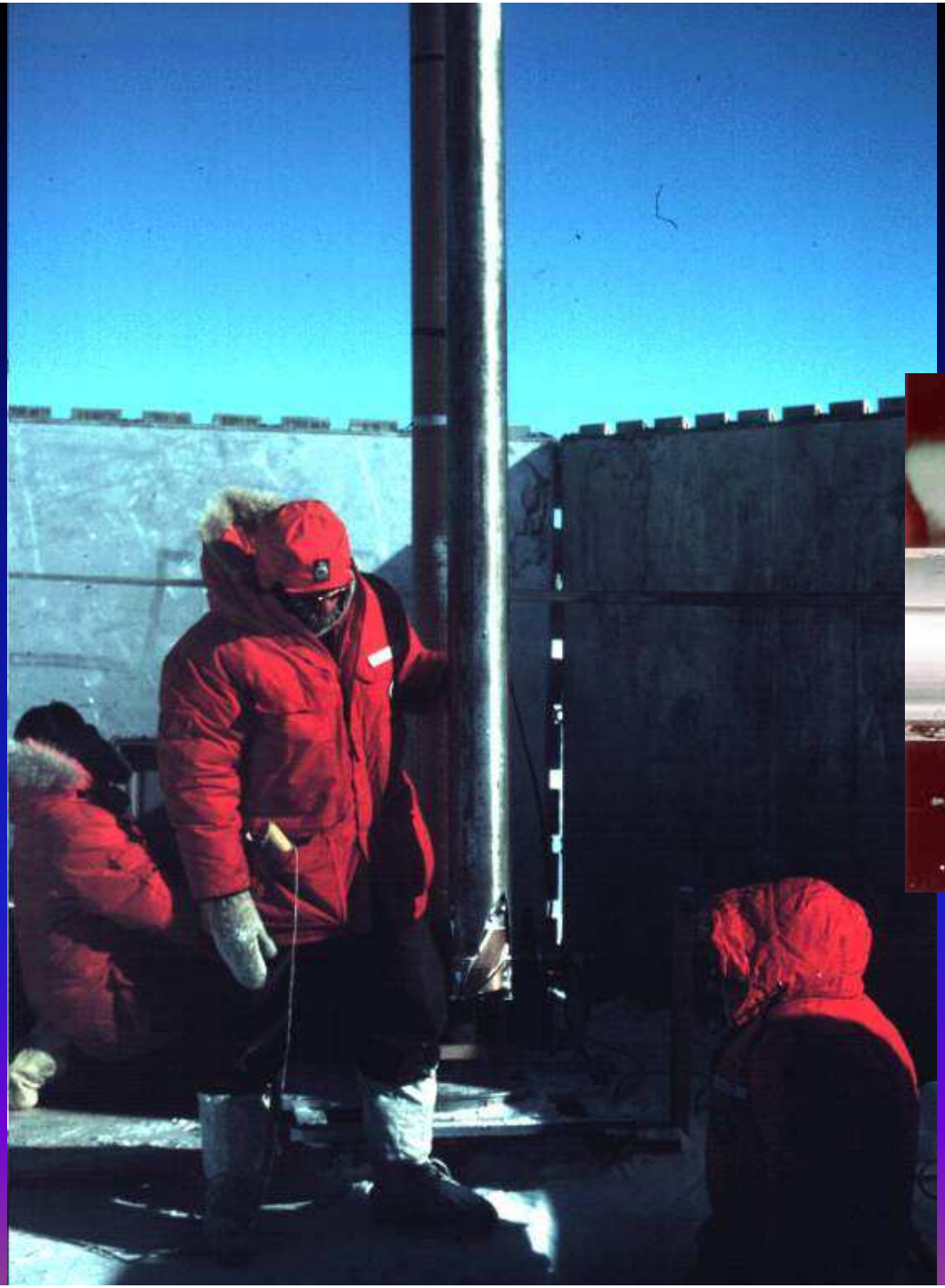
Tree rings, corals, ice cores

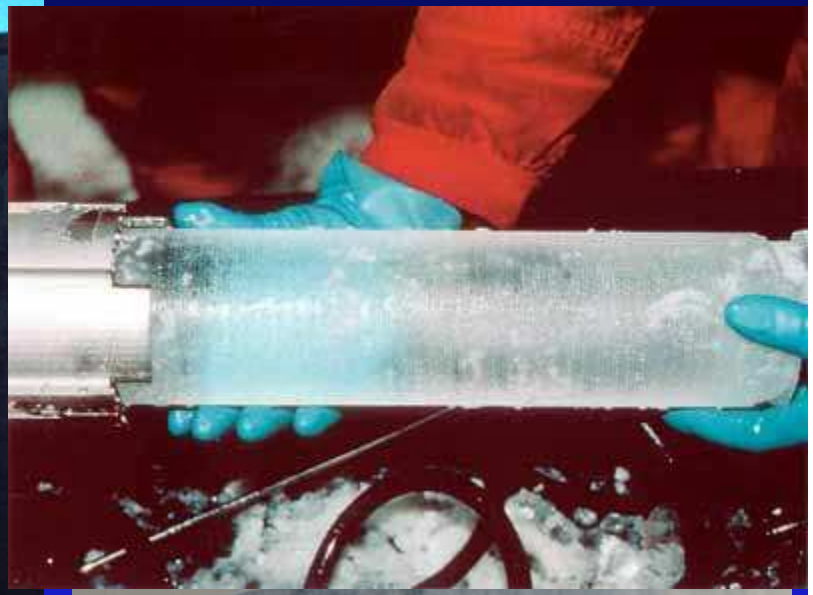


Ruddiman, 2008

PROXY DATA:

ICE CORES





TERRESTRIAL DATA

North American:	European:
Wisconsin	Wurm
Illinoian	Riss
Kansan	Mindel
Nebraskan	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).

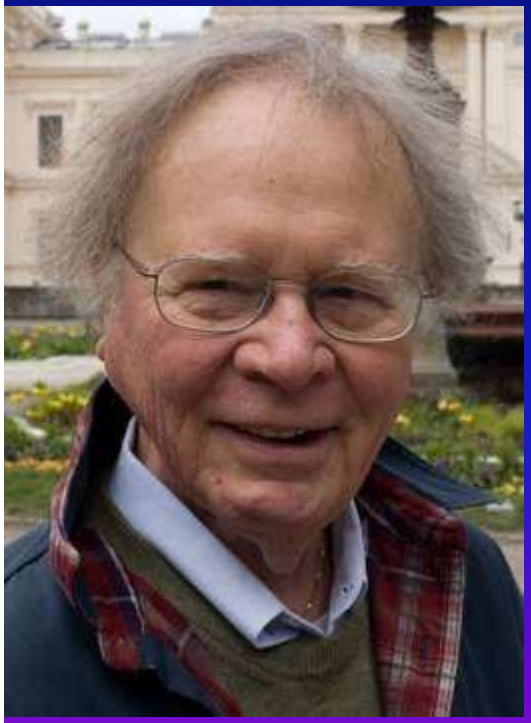
Cesare Emilani:

Paleontologist, Chemist

Father of Paleoceanography

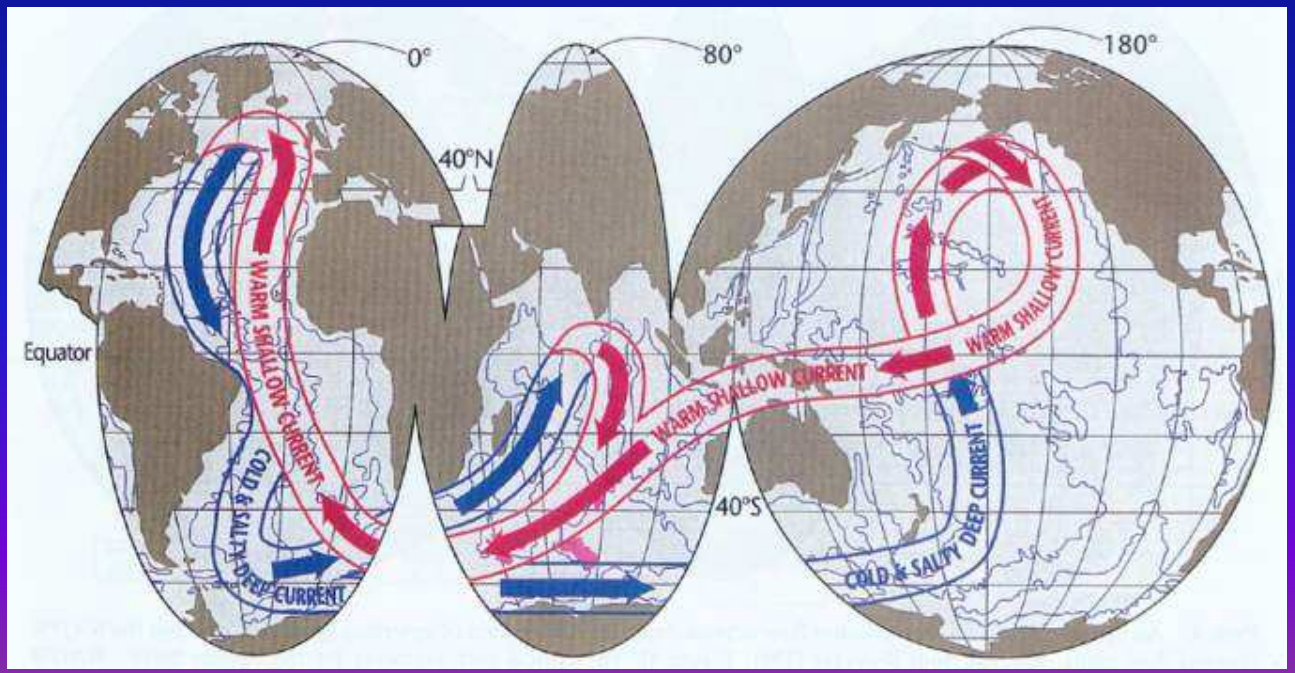
Other Paleoceanographers

Wally Broecker



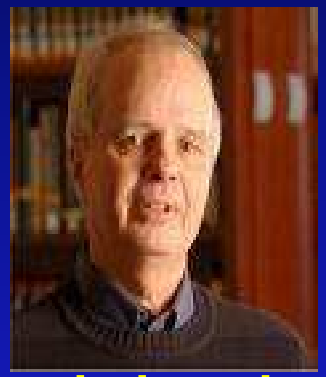
Thermal-haline

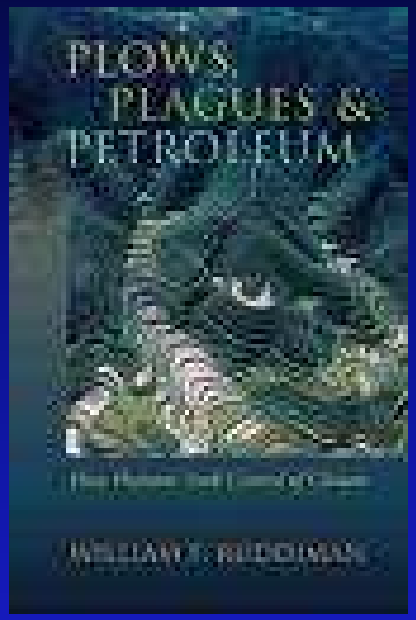
"conveyor" belt of circulation



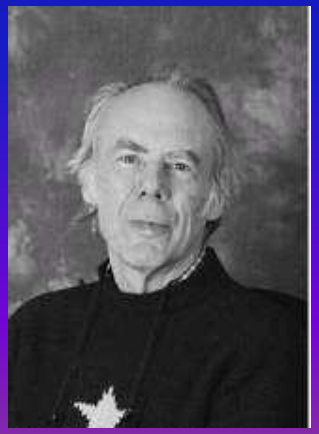
Other Paleoceanographers

Bill Ruddiman





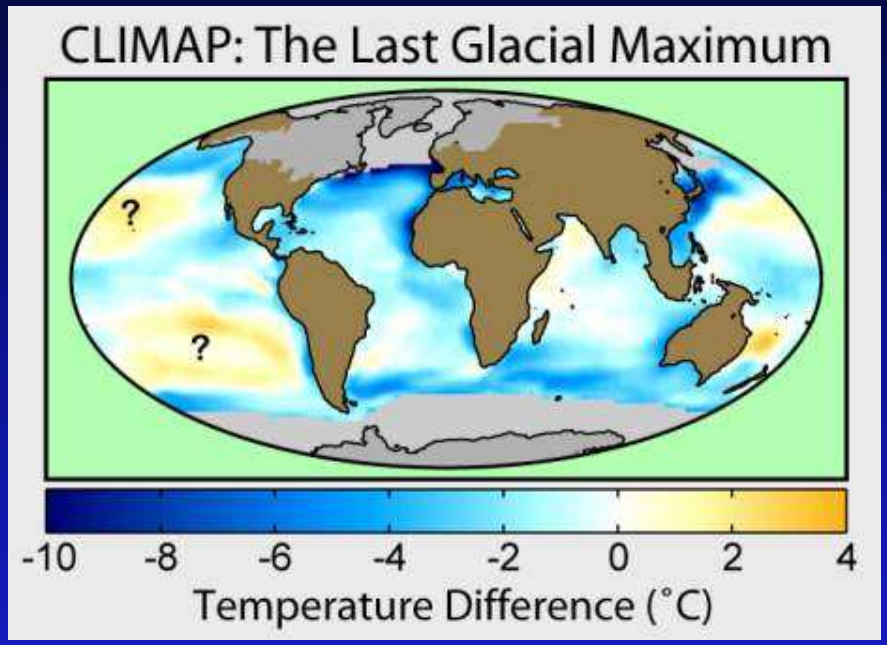
Nick Shackleton

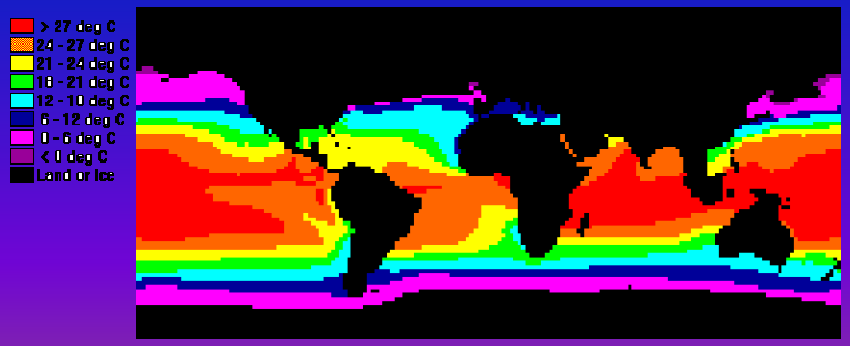


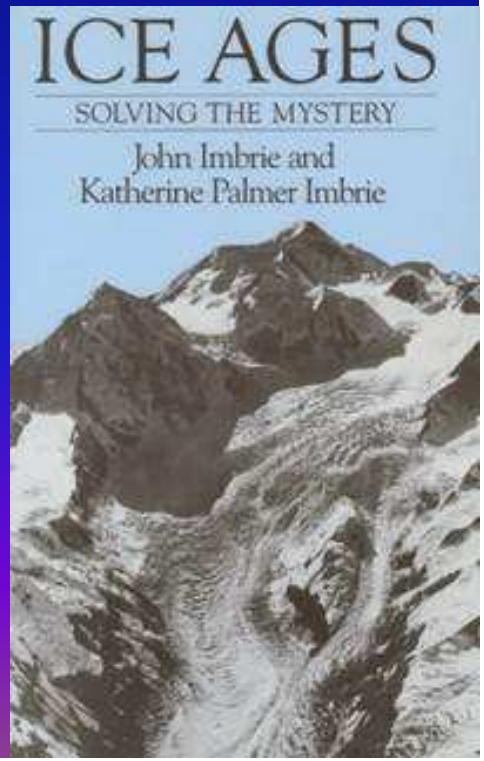
Other Paleoceanographers

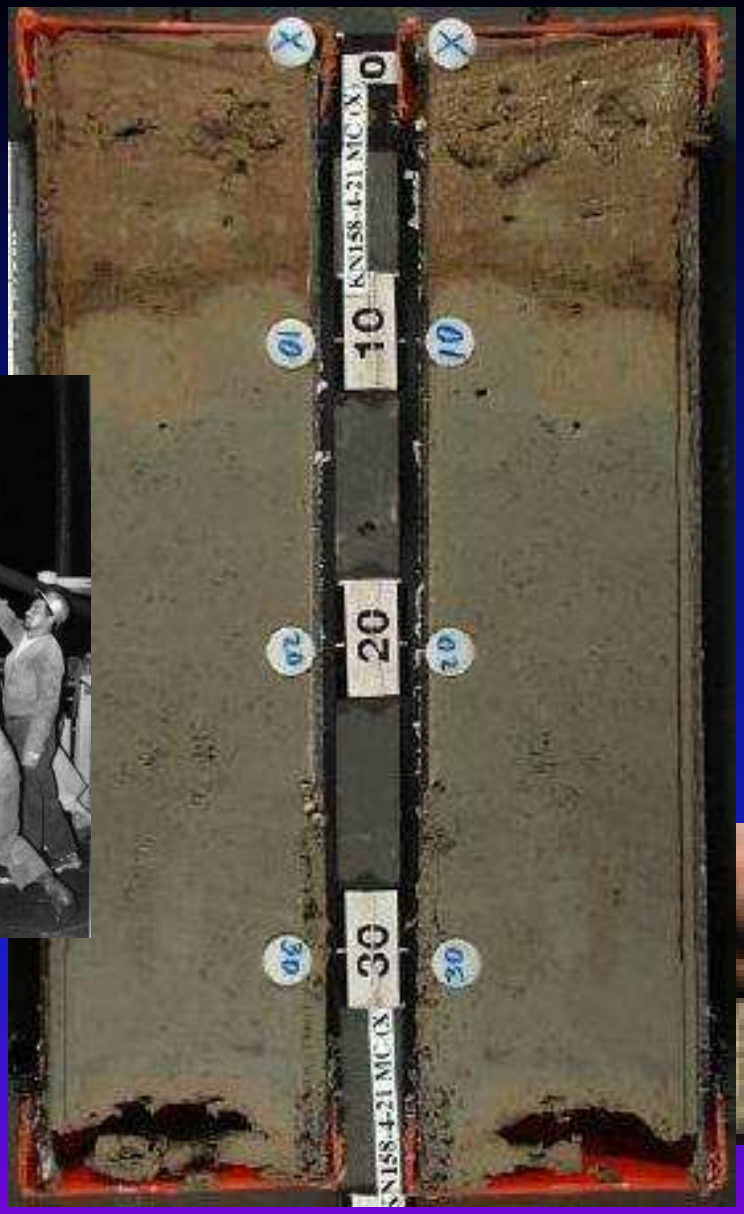
John Imbrie:

CLIMAP









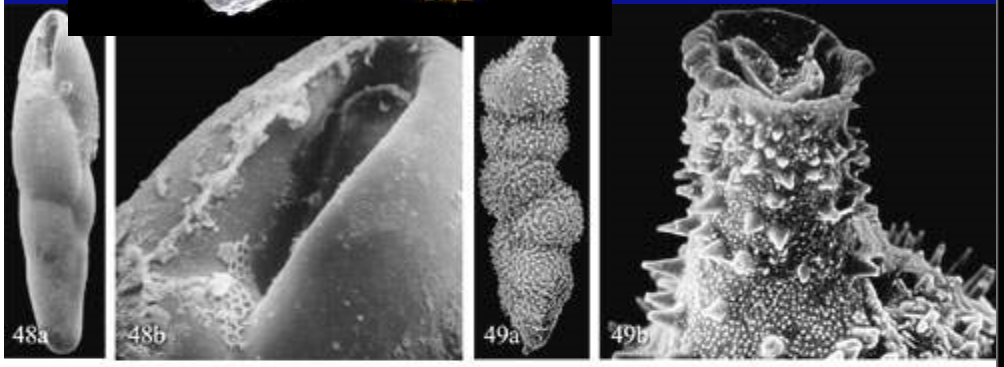
PROXY DATA:

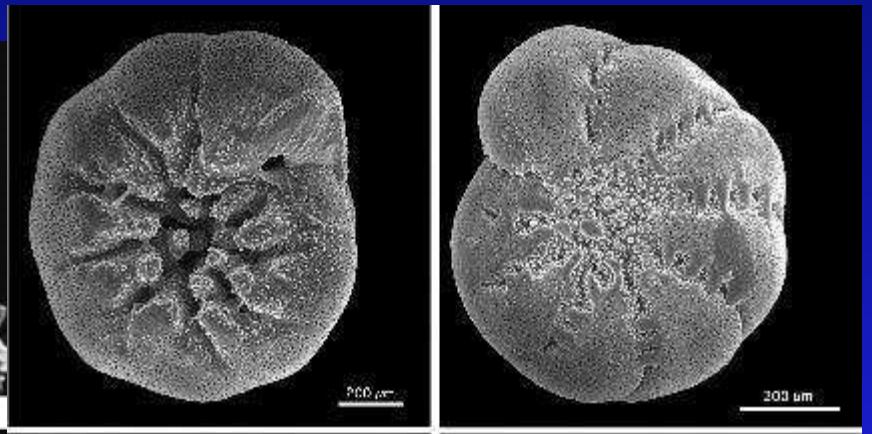
CORE DATA

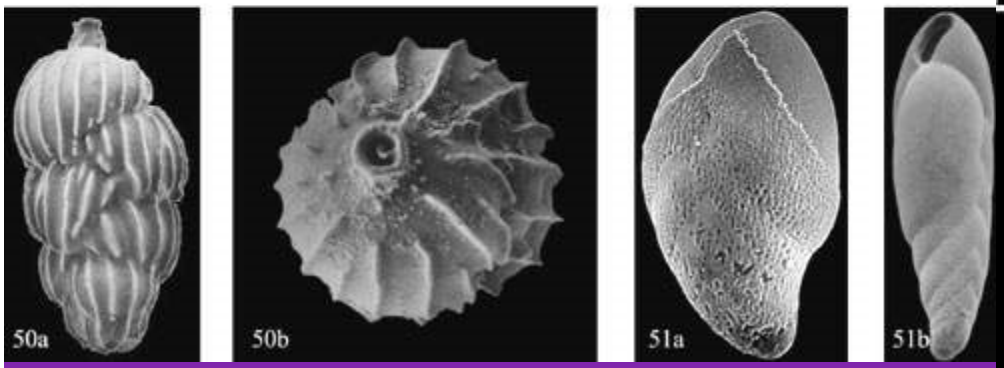
PROXY DATA:

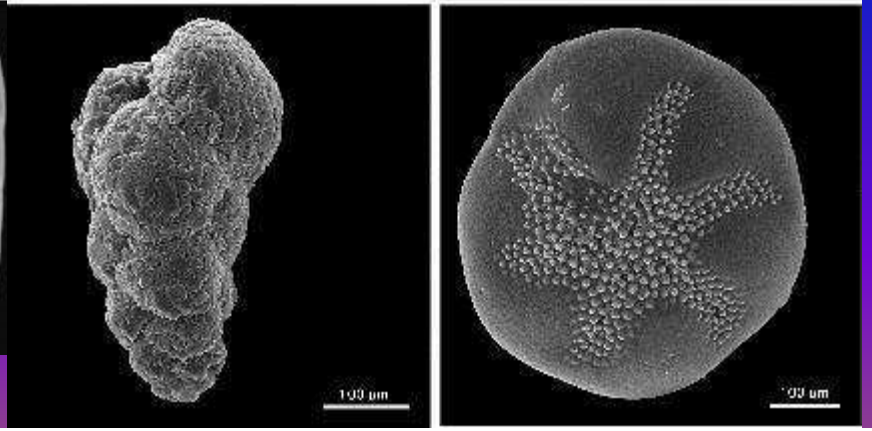
BENTHIC

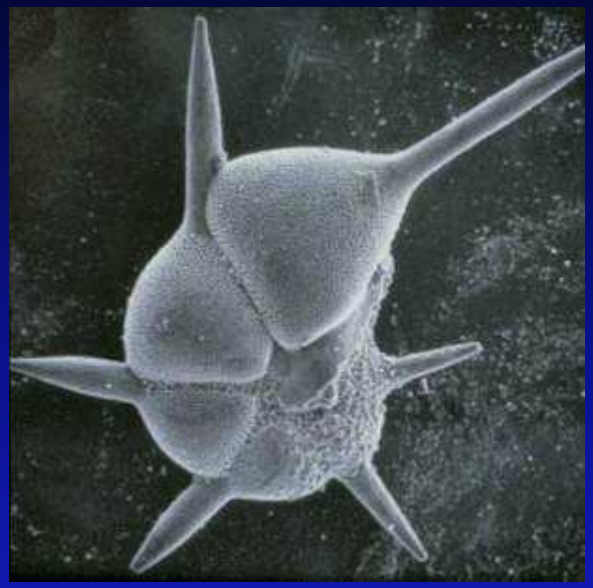
FORAMS









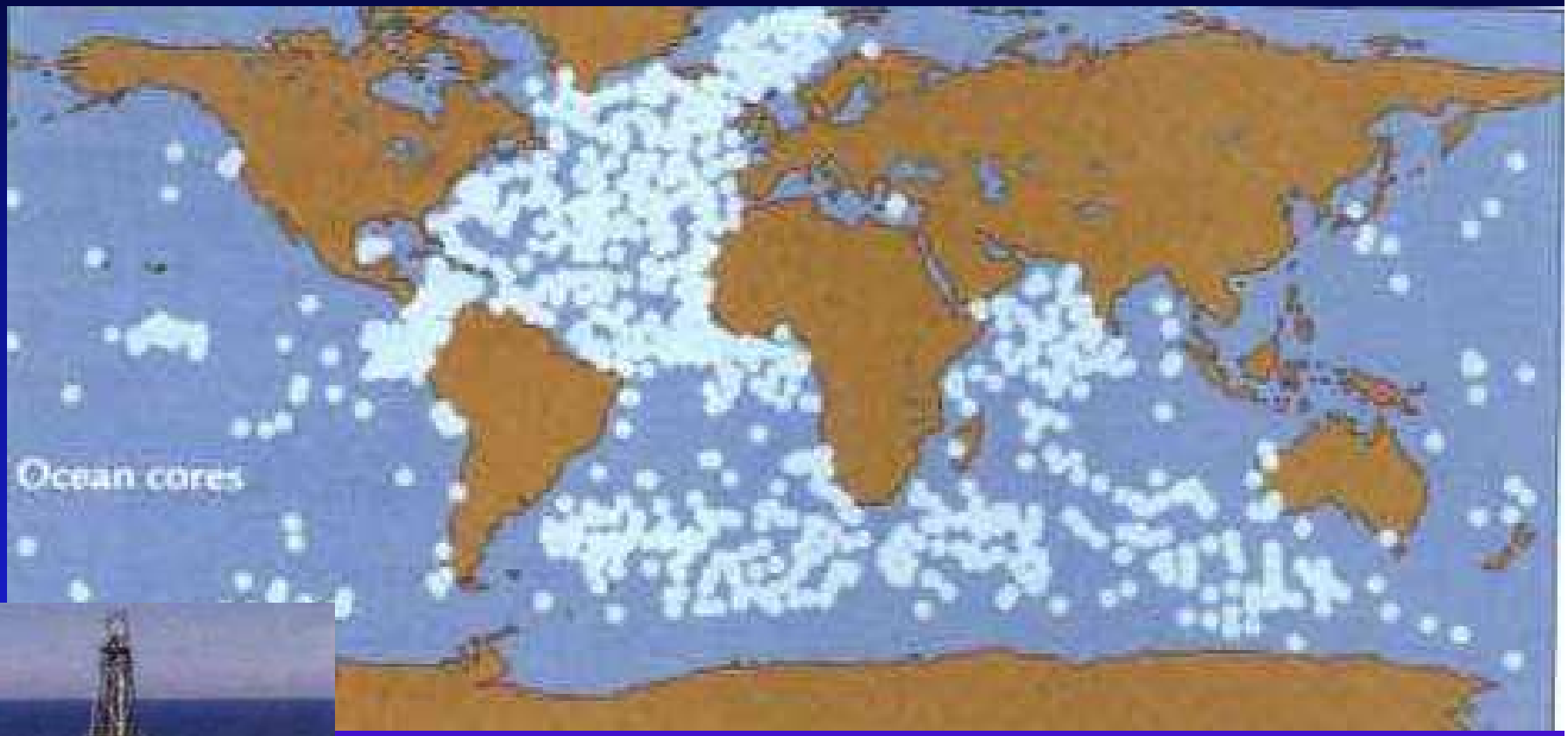


PROXY DATA:

PLANKTONIC

FORAMS

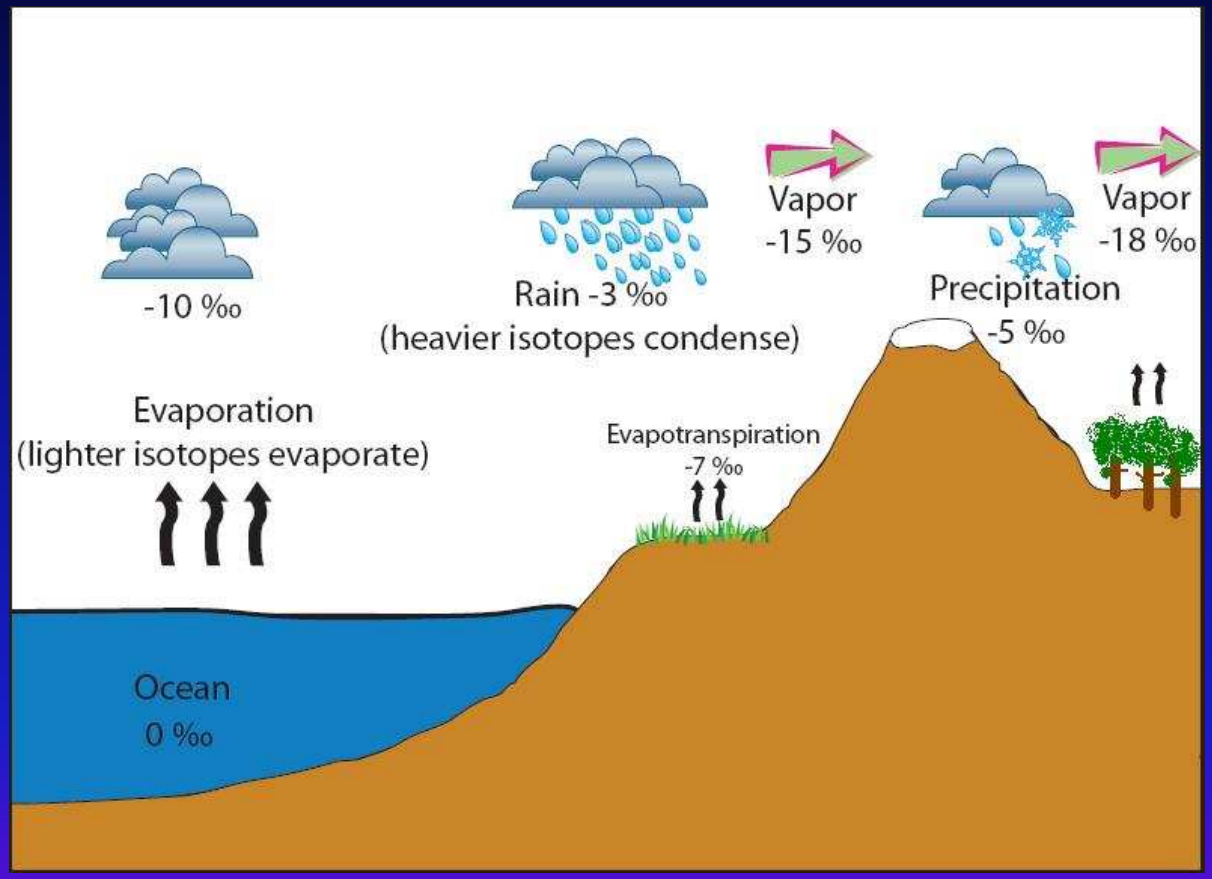
Deep Sea Coring



Ruddiman, 2008

Isotopic fractionation

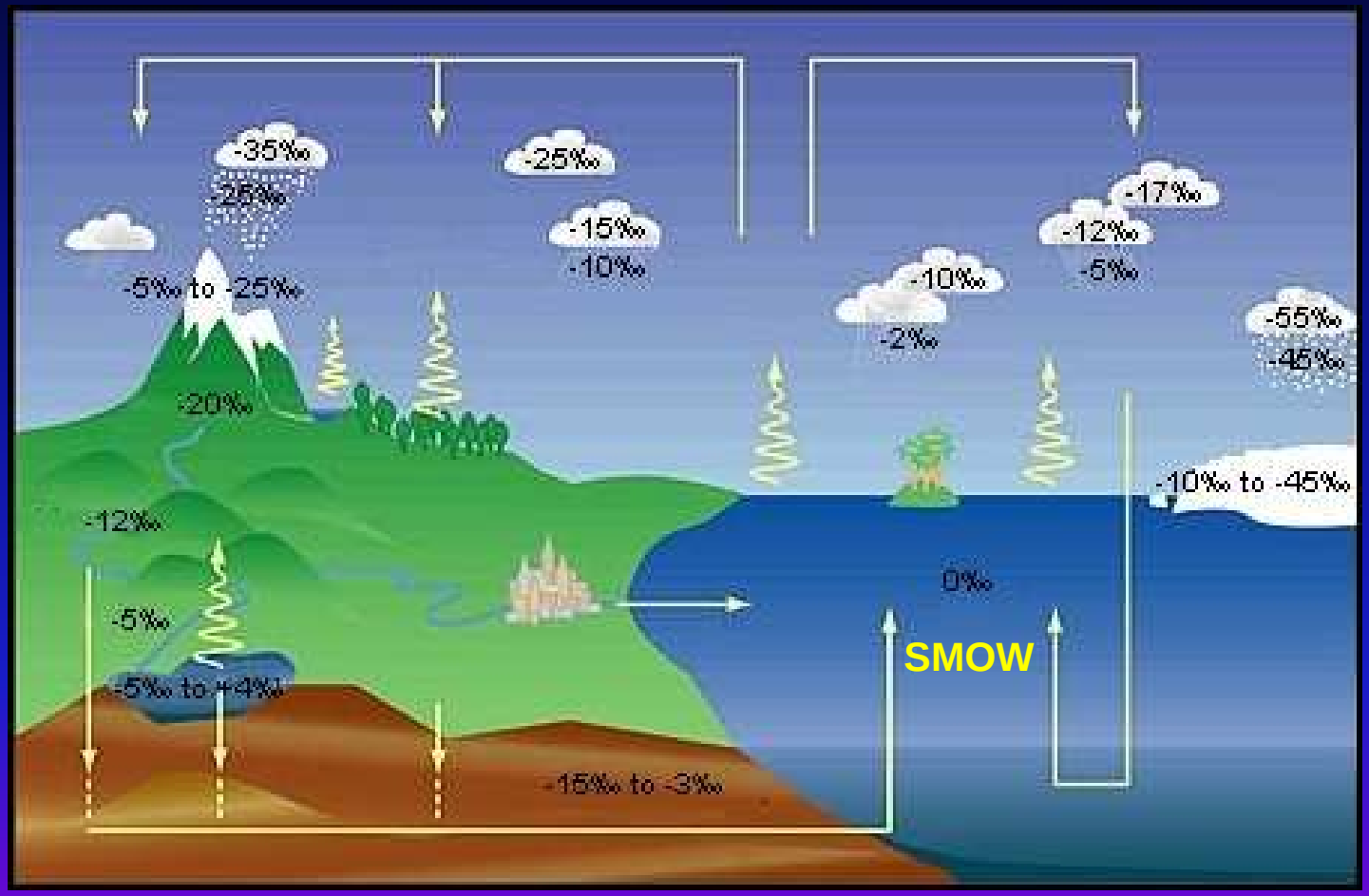
How Rain, snow and ice gets progressively lighter in the ratio of O^{18}/O^{16}



- Normal Oxygen has 6 protons and 6 neutrons referred to as O^{16}.
- The rarer stable isotope of oxygen has 2 extra neutrons and is referred to as O^{18}

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

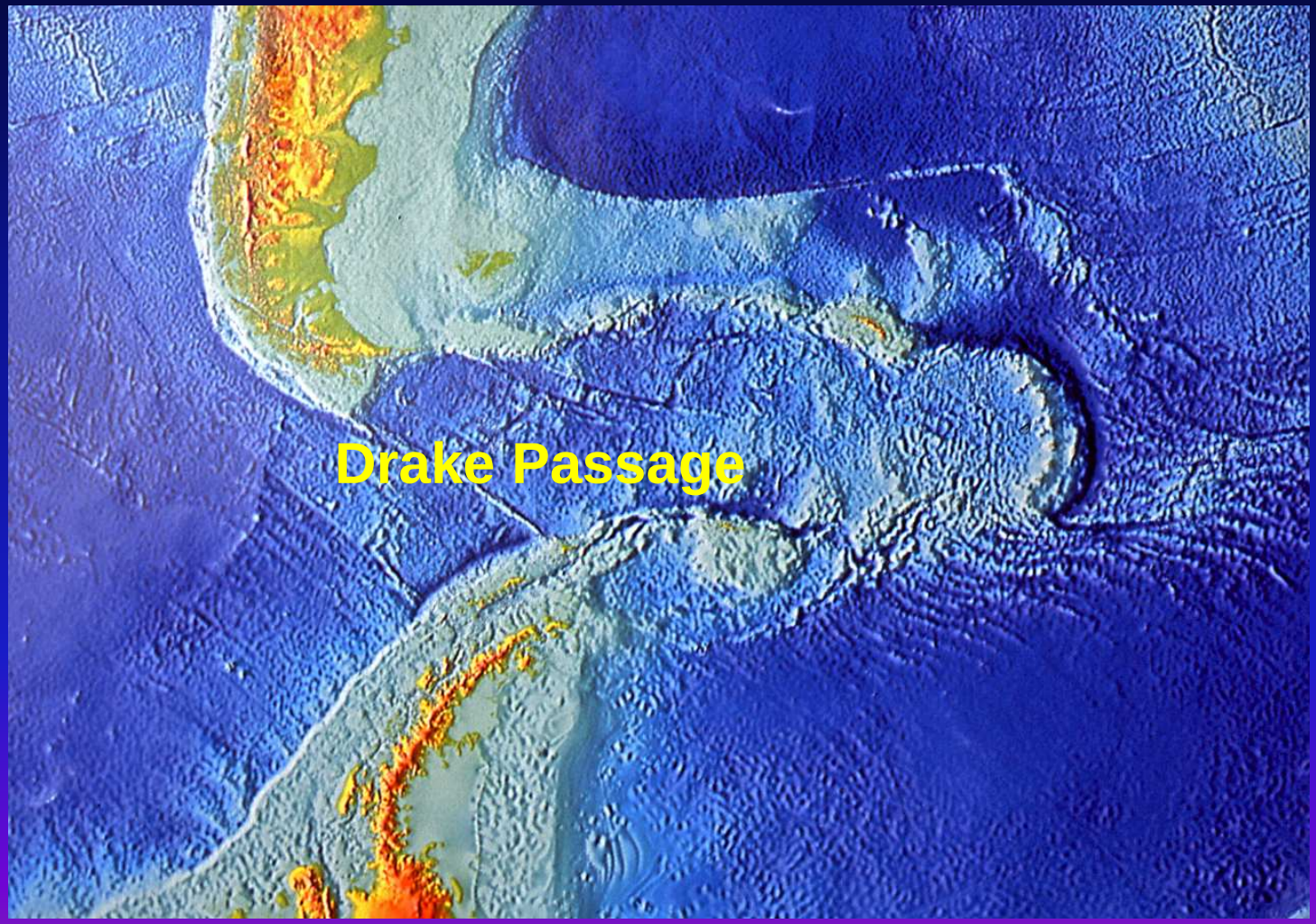
How Rain, snow and ice gets progressively lighter in the ratio of O^{18}/O^{16}



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

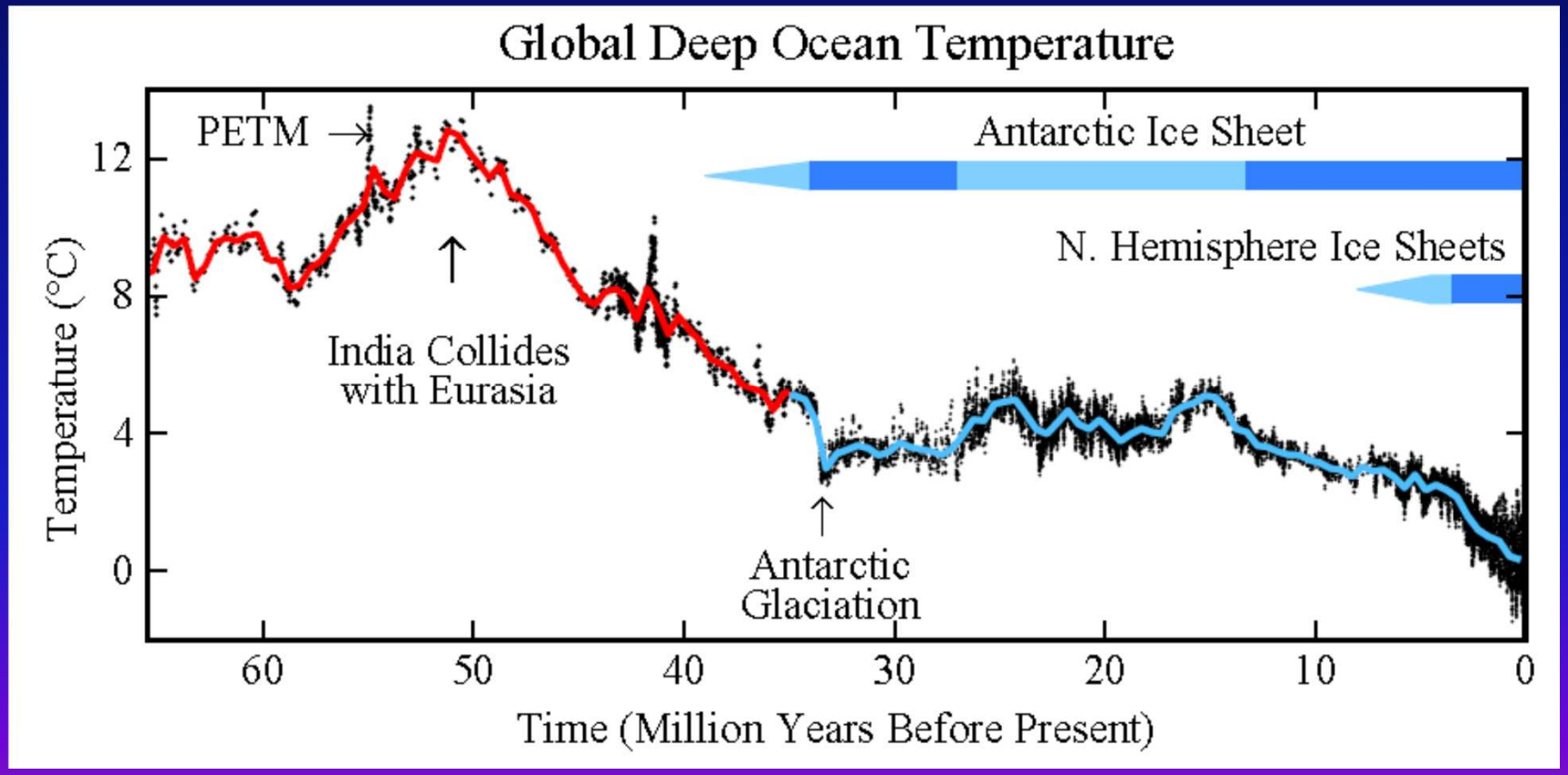
Scher and Martin, 2006

On opening of the Drake Passage



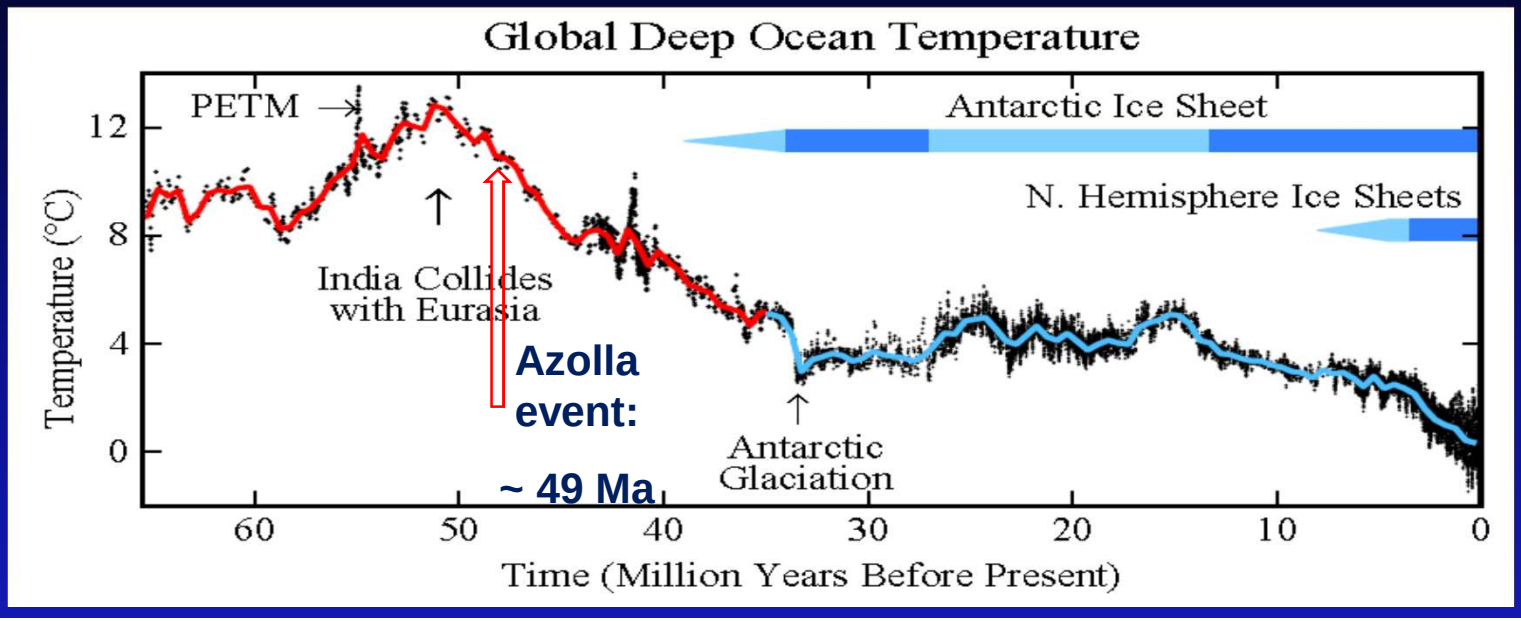
Scher and Martin, Science, v.312 p428, April 2006

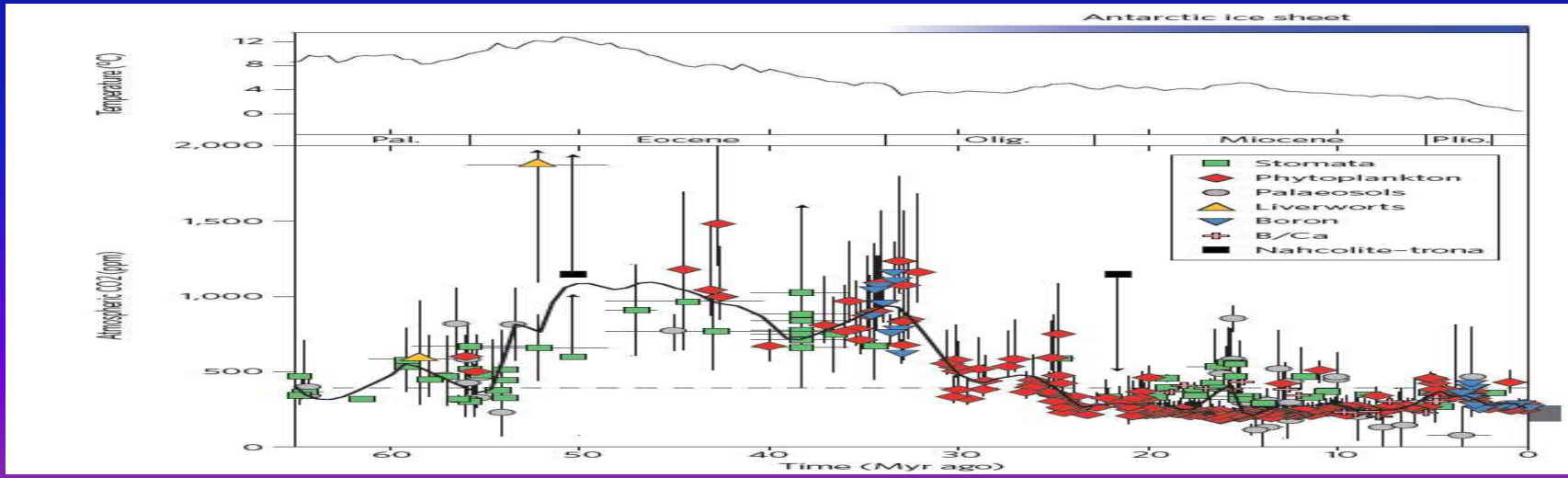
…throws a curve ball in interpreting the graph of data below
…we continue to learn/refine



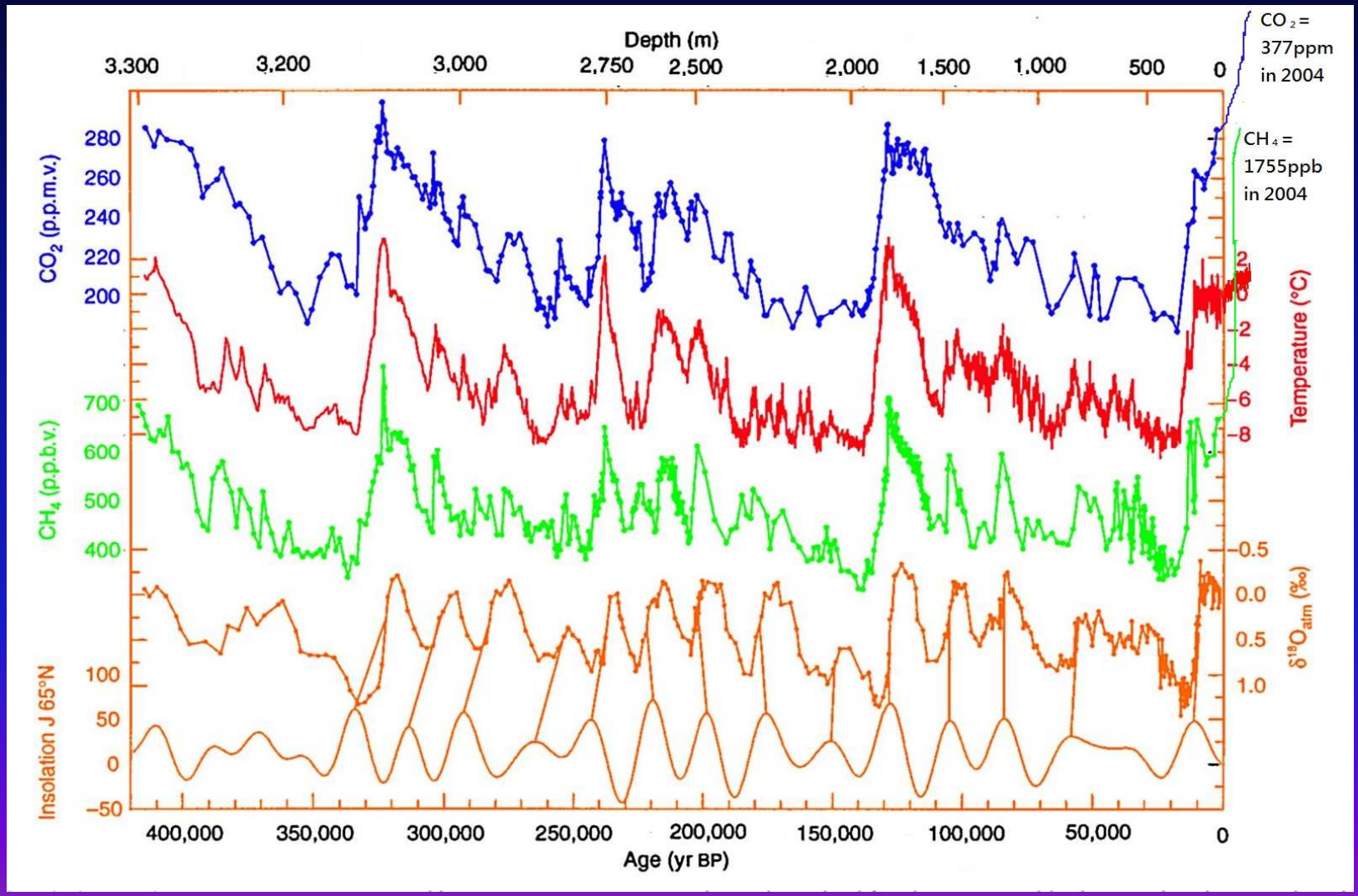
Geochemical data to make proxy measurements of temperature or sea level fall/rise and/or ice volume

What's data vs. interpretation





What's data vs. interpretation



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

Causes for the increase of CO_2 during interglacials and vice versa

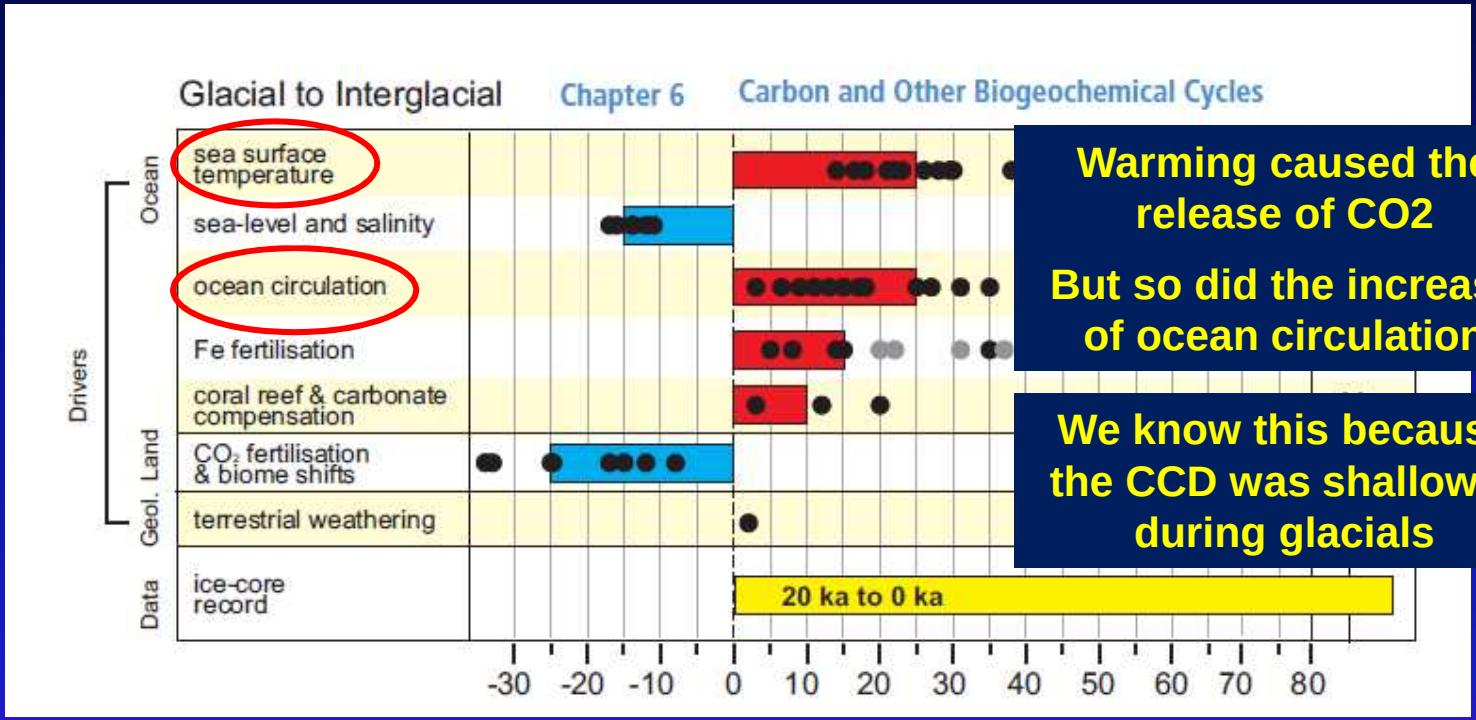
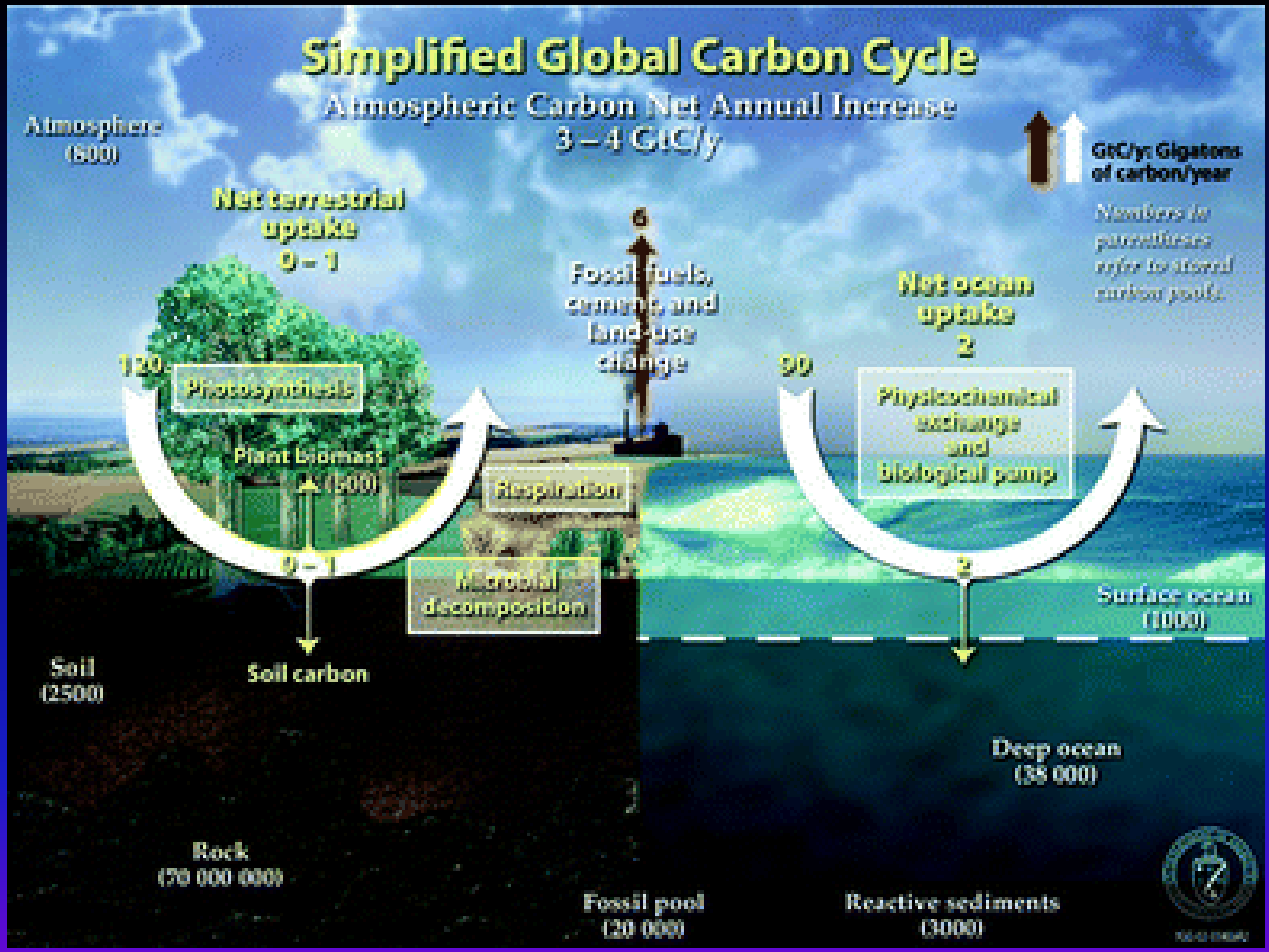
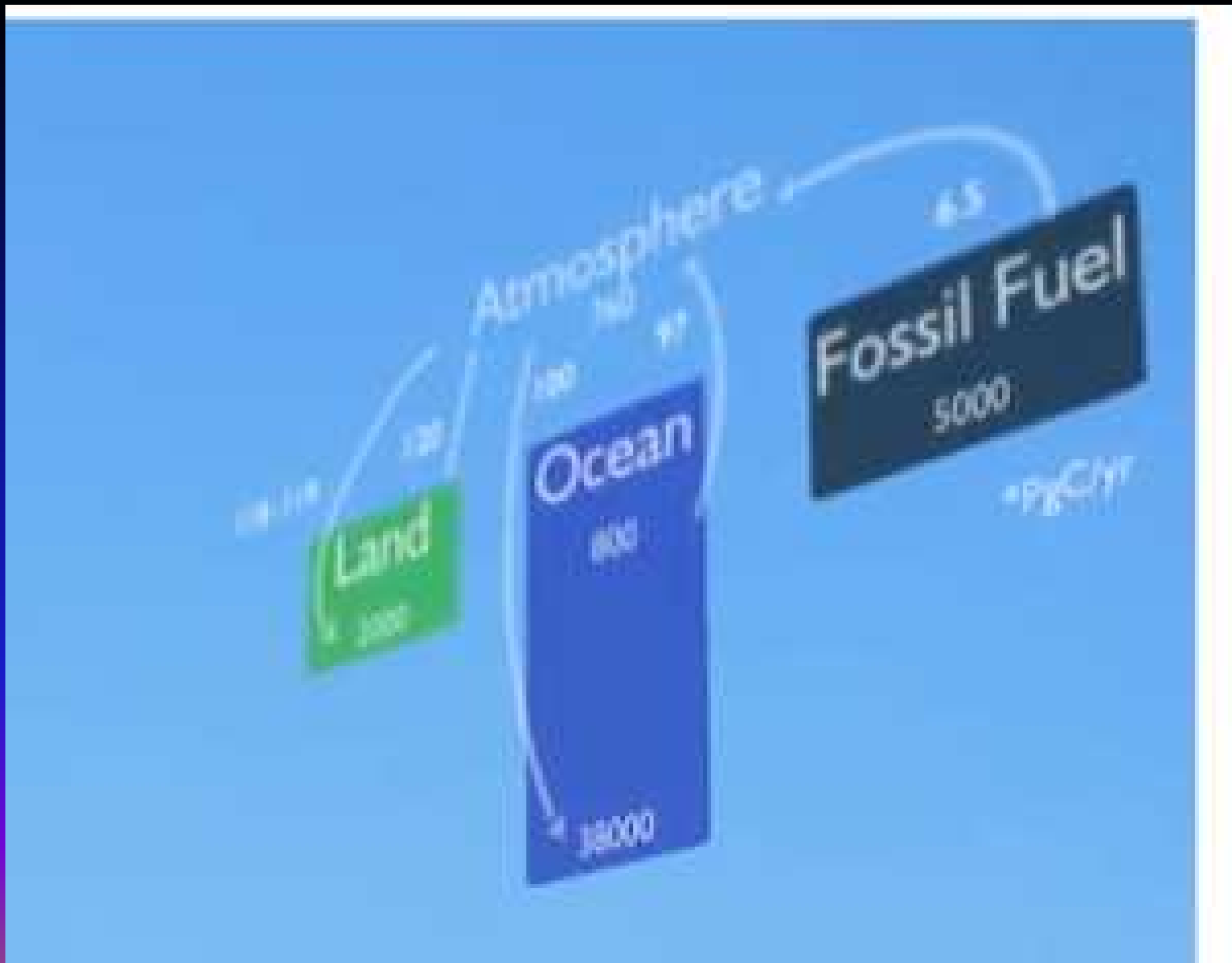


Figure 6.5 | Mechanisms contributing to carbon dioxide concentrations changes from Last Glacial Maximum (LGM) to late Holocene (top) and from early/mid Holocene (7 ka) to late Holocene (bottom). Filled black circles represent individual model-based estimates for individual ocean, land, geological or human mechanisms. Solid colour bars represent expert judgment (to the nearest 5 ppm) rather than a formal statistical average. References for the different model results used for explaining CO_2 changes from LGM to late Holocene are as per (Kohfeld and Ridgwell, 2009) with excluded model projections in grey. References for the different model results used for explaining CO_2 changes during the Holocene are: Joos et al. (2004), Brovkin et al. (2002, 2008), Kleinen et al. (2010, 2012), Broecker et al. (1999), Ridgwell et al. (2003), Schurgers et al. (2006), Yu (2011), Ruddiman (2003, 2007), Strassmann et al. (2008), Olofsson and Hickler (2008), Pongratz et al. (2009), Kaplan et al. (2011), Lemmen (2009), Stocker et al. (2011), Roth and Joos (2012). Confidence levels for each mechanism are indicated in the left column — H for *high confidence*, M for *medium confidence* and L for *low confidence*.

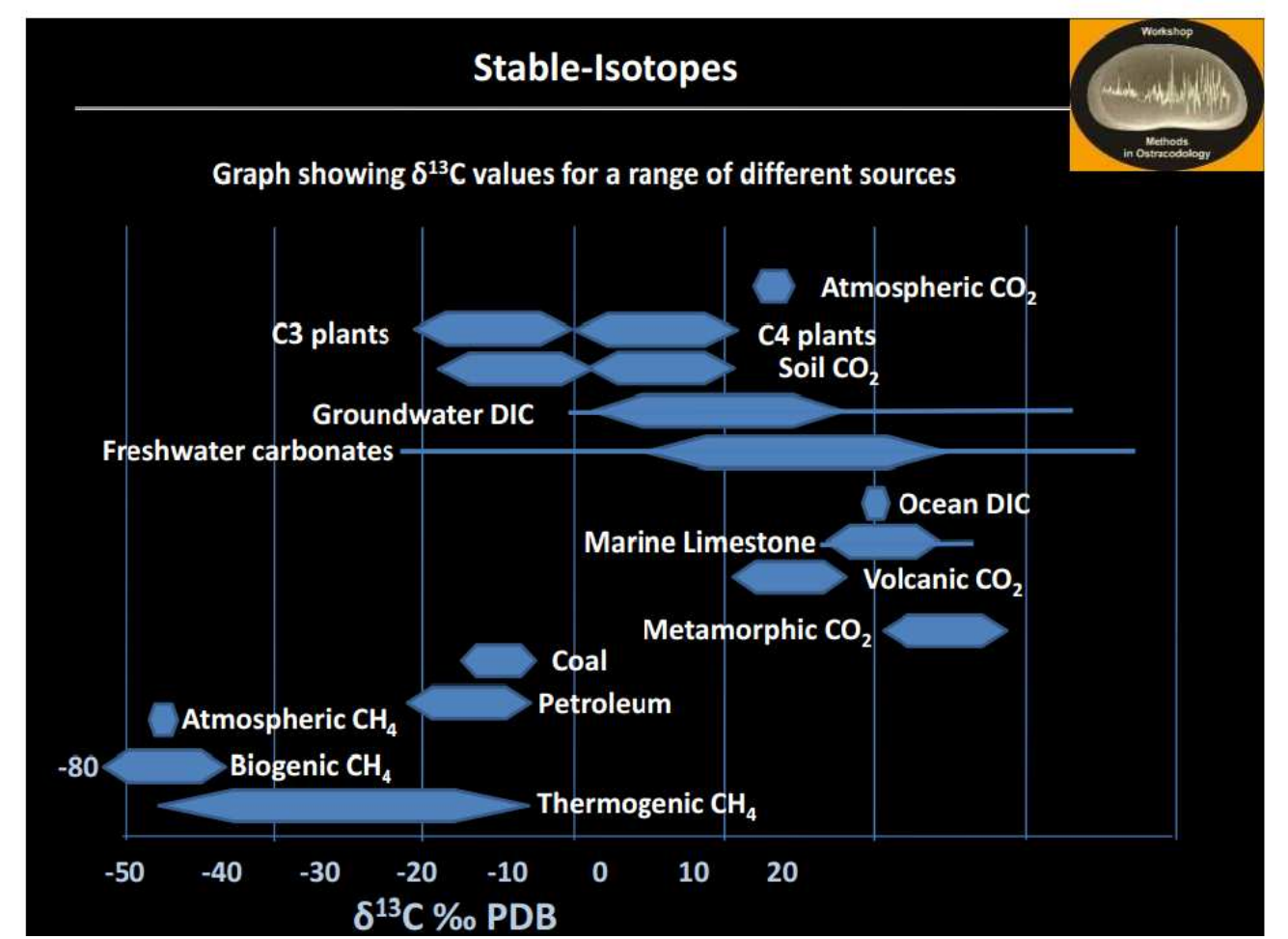


http://www.pmel.noaa.gov/co2/story/Ocean+Carbon+Uptake


Atmosphere
Land
Ocean
Fossil Fuel
5000

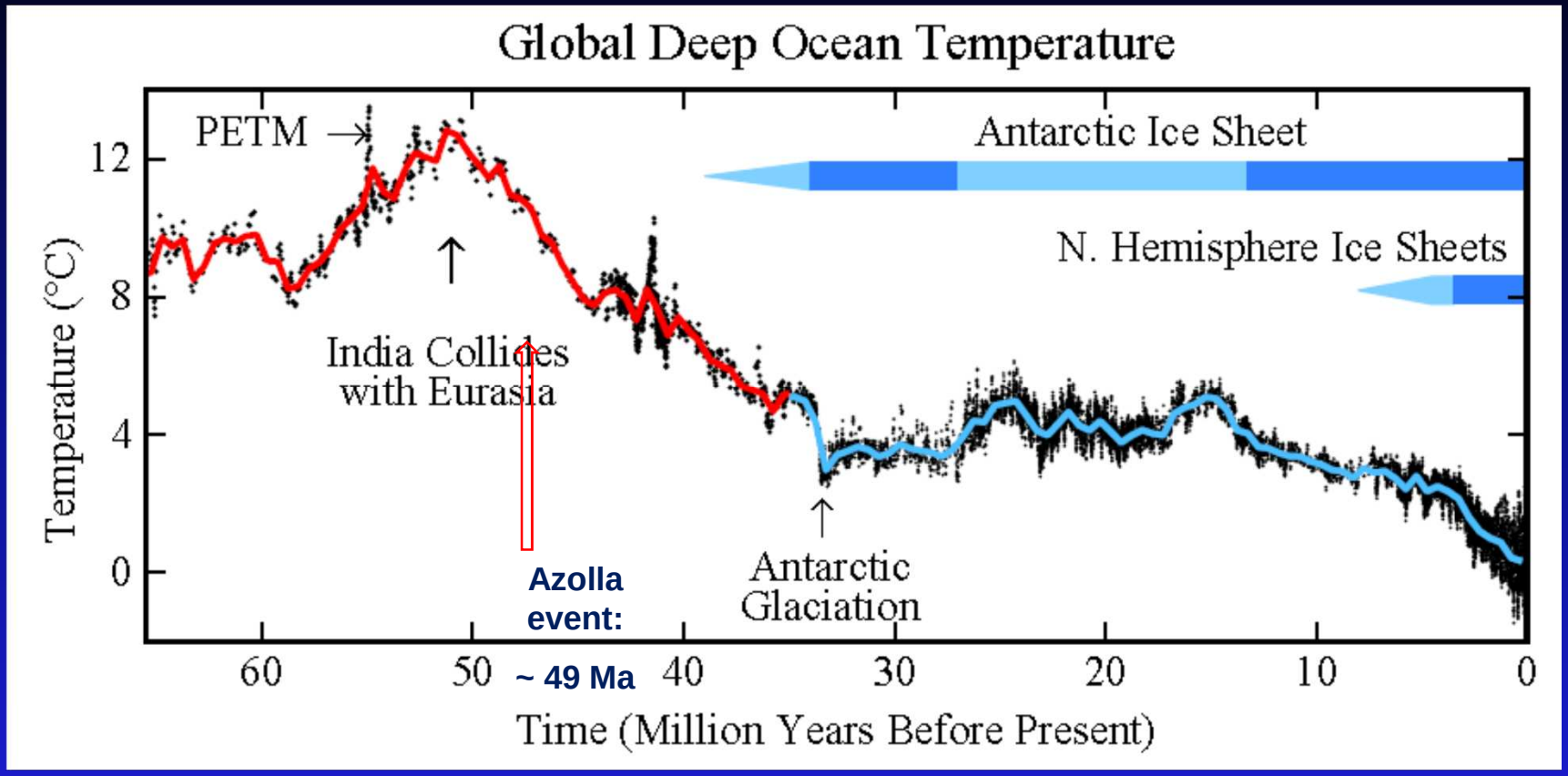
How C^{13} varies; PDB is the standard to compare to – it's a Belemnite $CaCO_3$ fossil:

Understanding this helps make better interpretations



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 ice core lab field trip
5. Today: 400 ppm and growing



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.

So – what changed?

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

Weathering/Precipitation increased:

- India colliding into Asia/Himalayas
- Continents to higher latitudes: mechanical aided weathering increases chemical weathering

Long-term Carbon Cycle: rocks

Two generalized reactions…

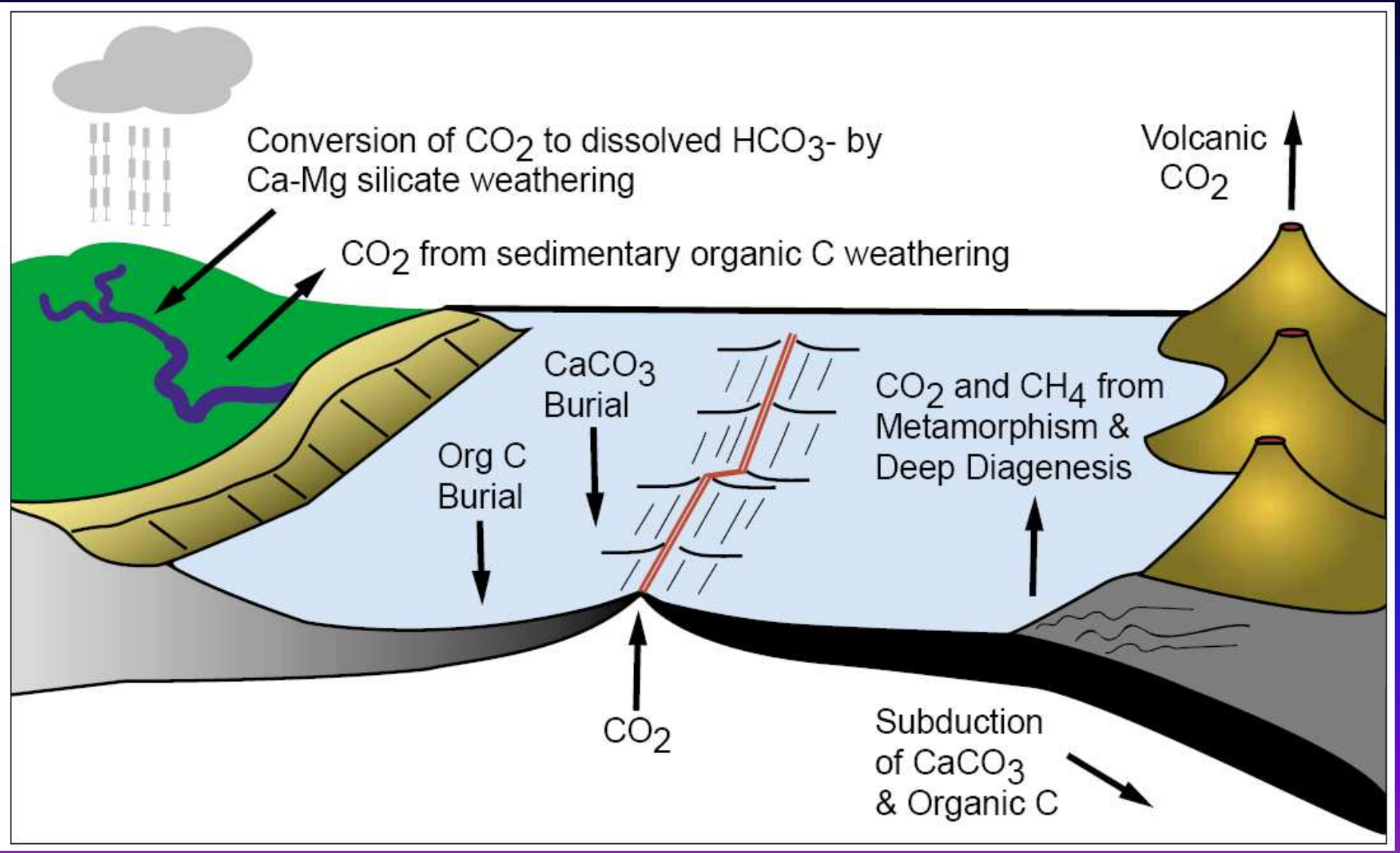
Photosynthesis/Respiration

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

Weathering/Precipitation

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

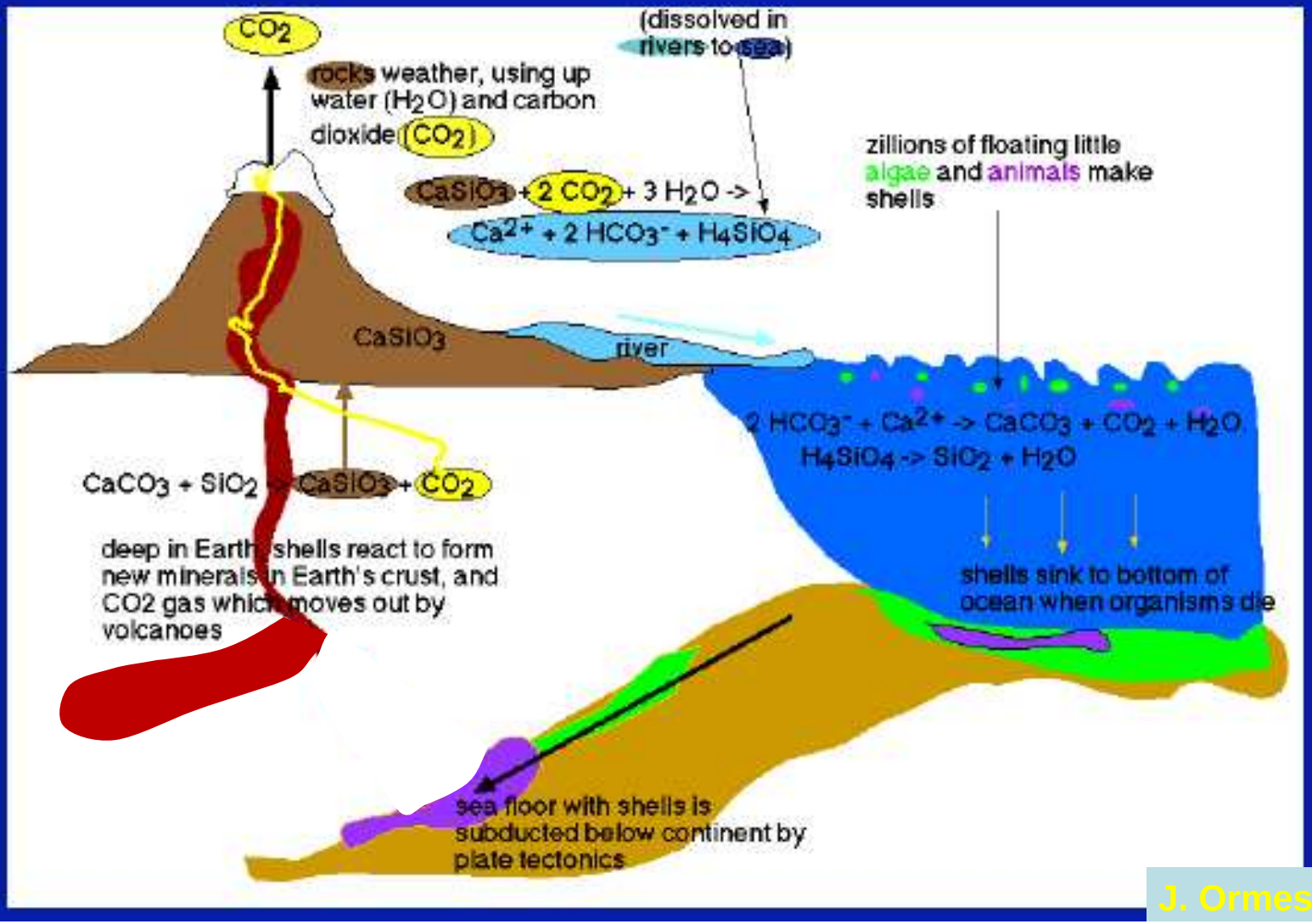
Long-term carbon cycle: *rocks*



Berner, 2001

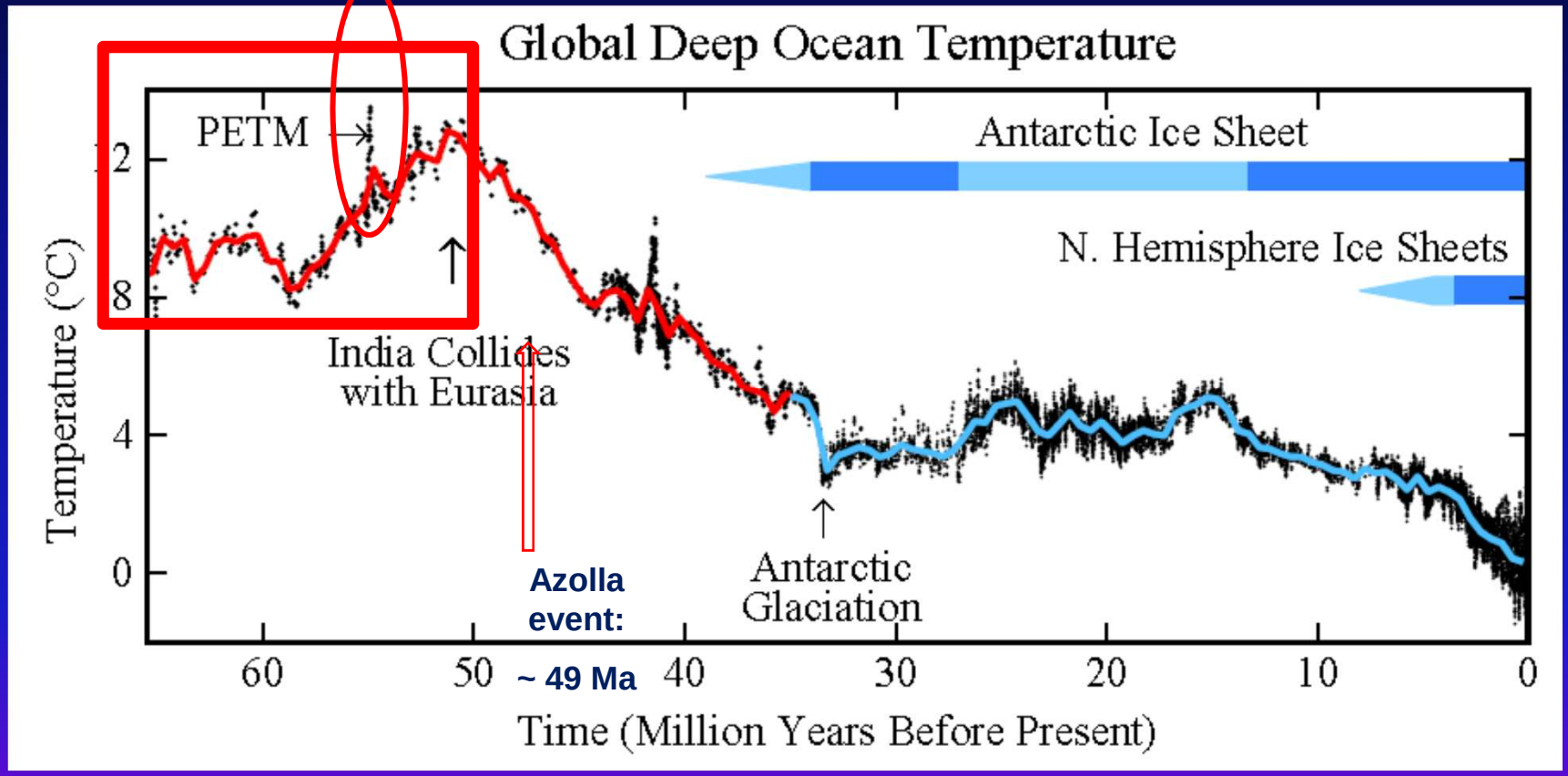
Silicate weathering

Regulates atmospheric CO_2 on geologic time scales.



J. Ormes, 2015

THE PETM HYPERTHERMAL EVENT



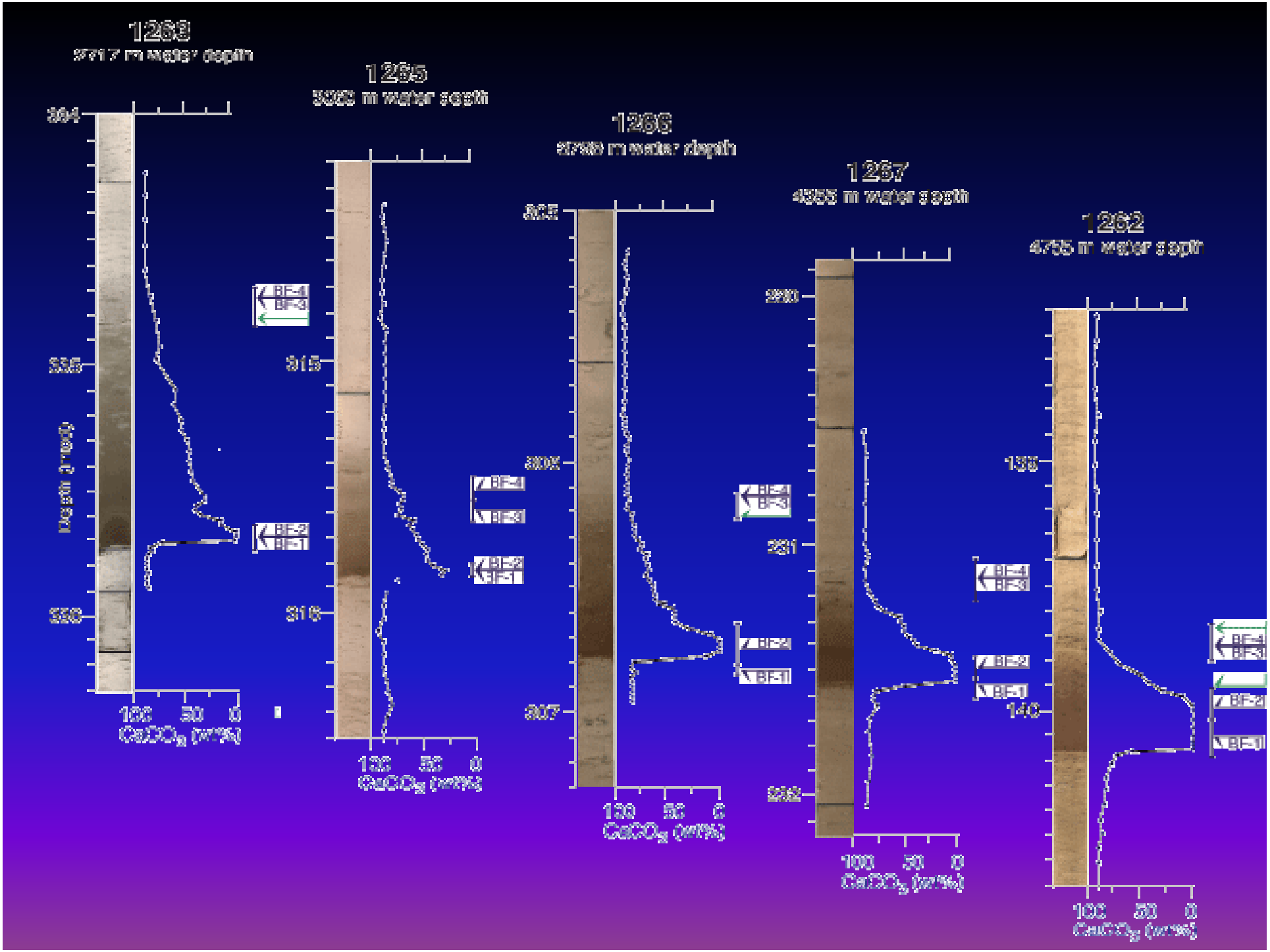
So what are these hyperthermals like the PETM?

Paleocene-Eocene Thermal Maximum

- Negative carbon isotopes
- Indicative of methane release
- Calcium compensation depth rises
- = more clay rich sediments vs. carbonates
- Ocean acidification
- Onset rapid; <20,000 years
- Recovery longer: ~100,000-200,000 years

https://en.wikipedia.org/wiki/Paleocene%E2%80%93Eocene_Thermal_Maximum


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

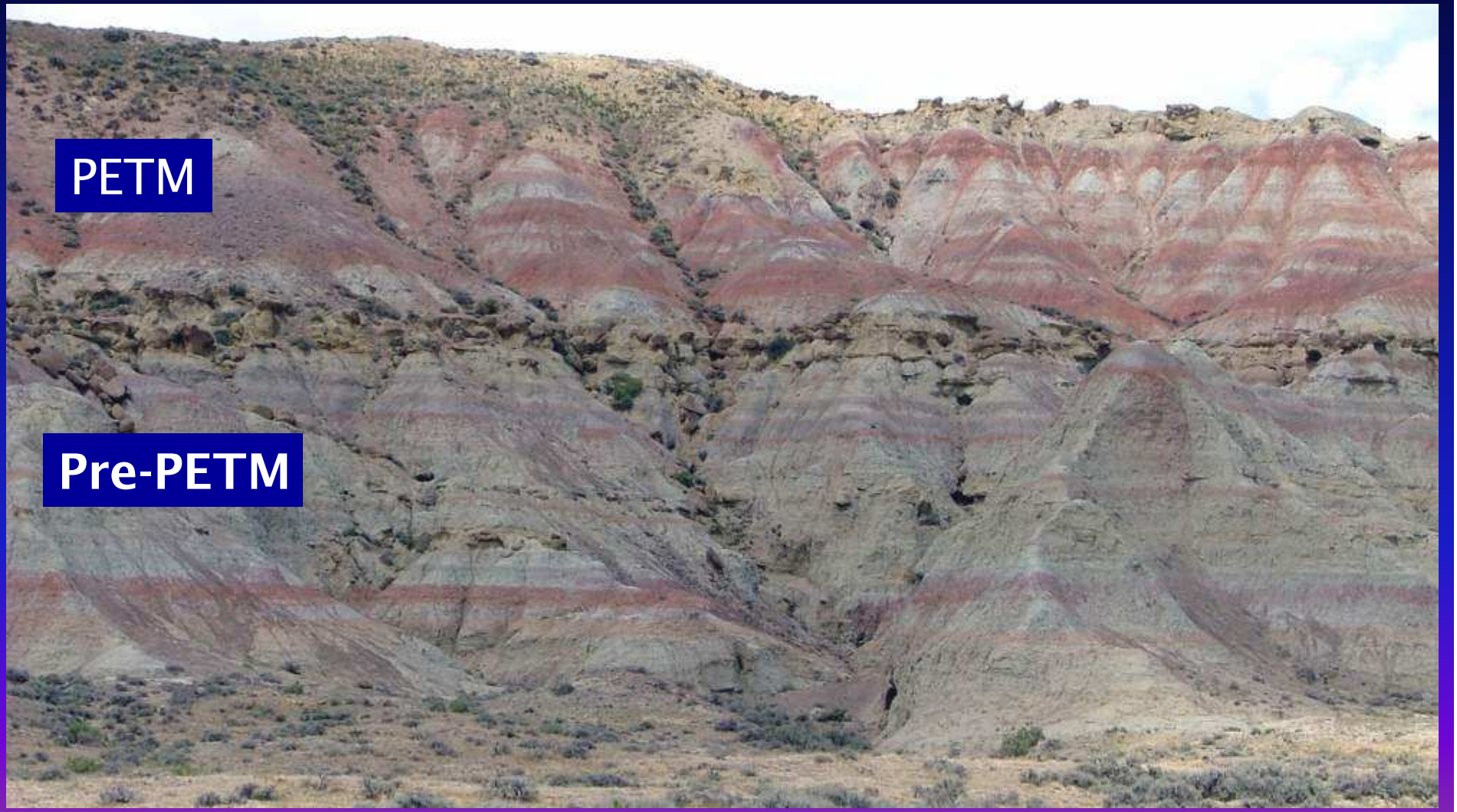

1263
3717 m water depth
1265
3323 m water depth
1266
3748 m water depth
1267
4355 m water depth
1262
4755 m water depth
Depth (mcd)
CaCO3 (wt%)
BF-4
BF-3
BF-2
BF-1

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

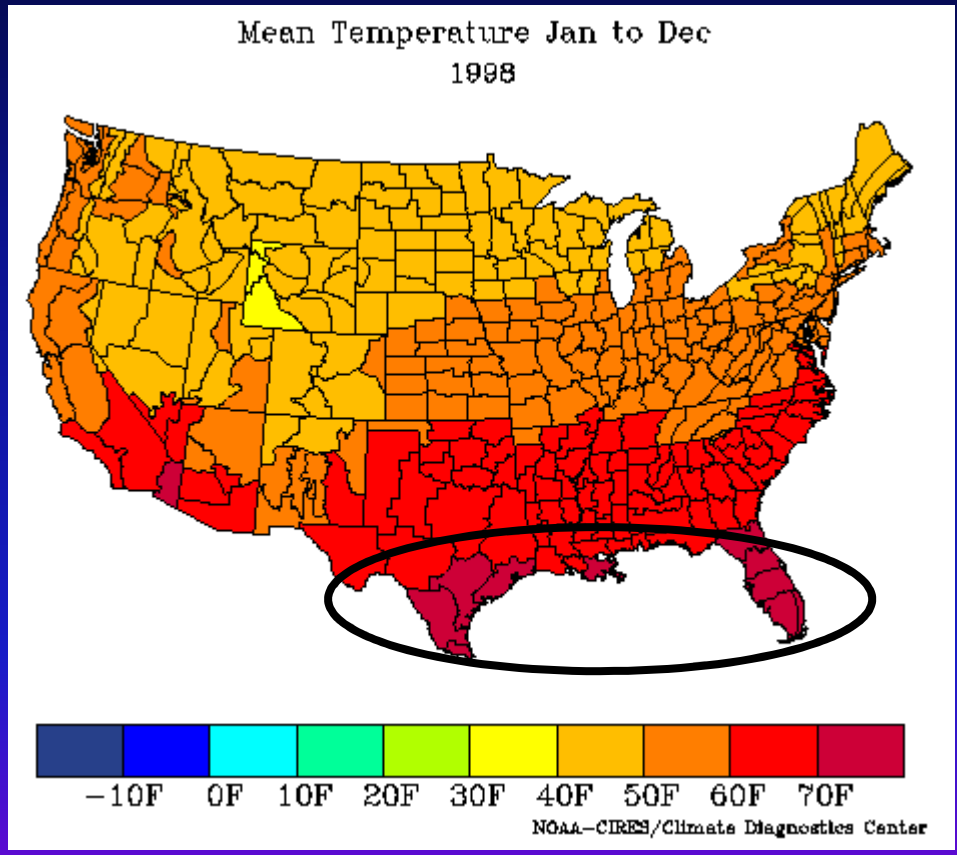
Paleosol Density



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
- Locally the Dawson D2 formation may be because of the PETM



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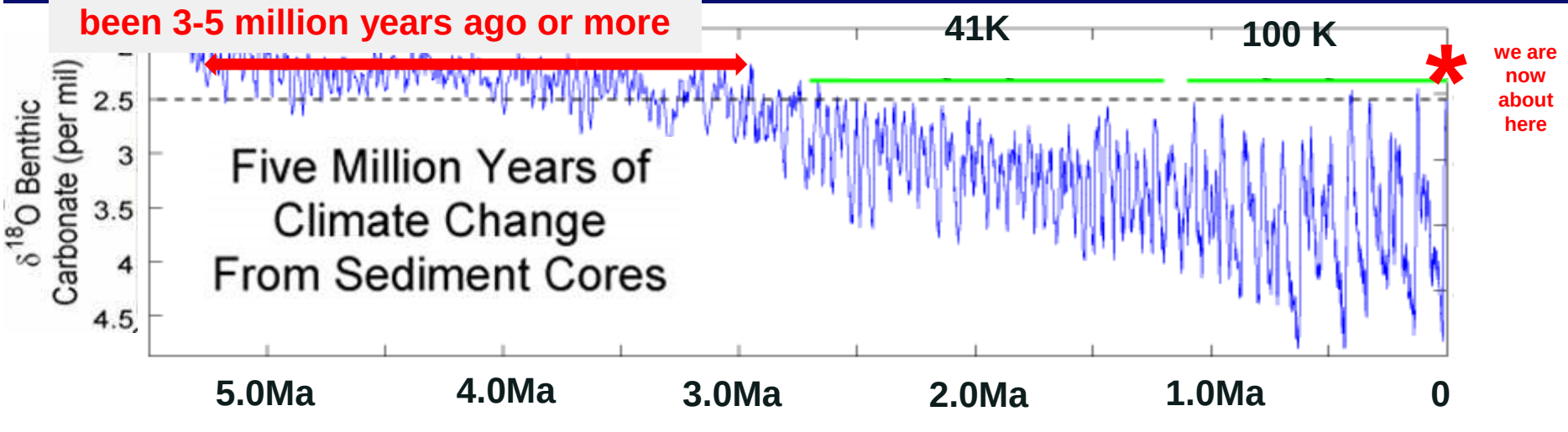
Climate Changes from Ocean Sediment Cores, since 5 Ma. Milankovitch Cycles

the last time inferred temperatures will have been this high – once equilibrium is reached, will have been 3-5 million years ago or more



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

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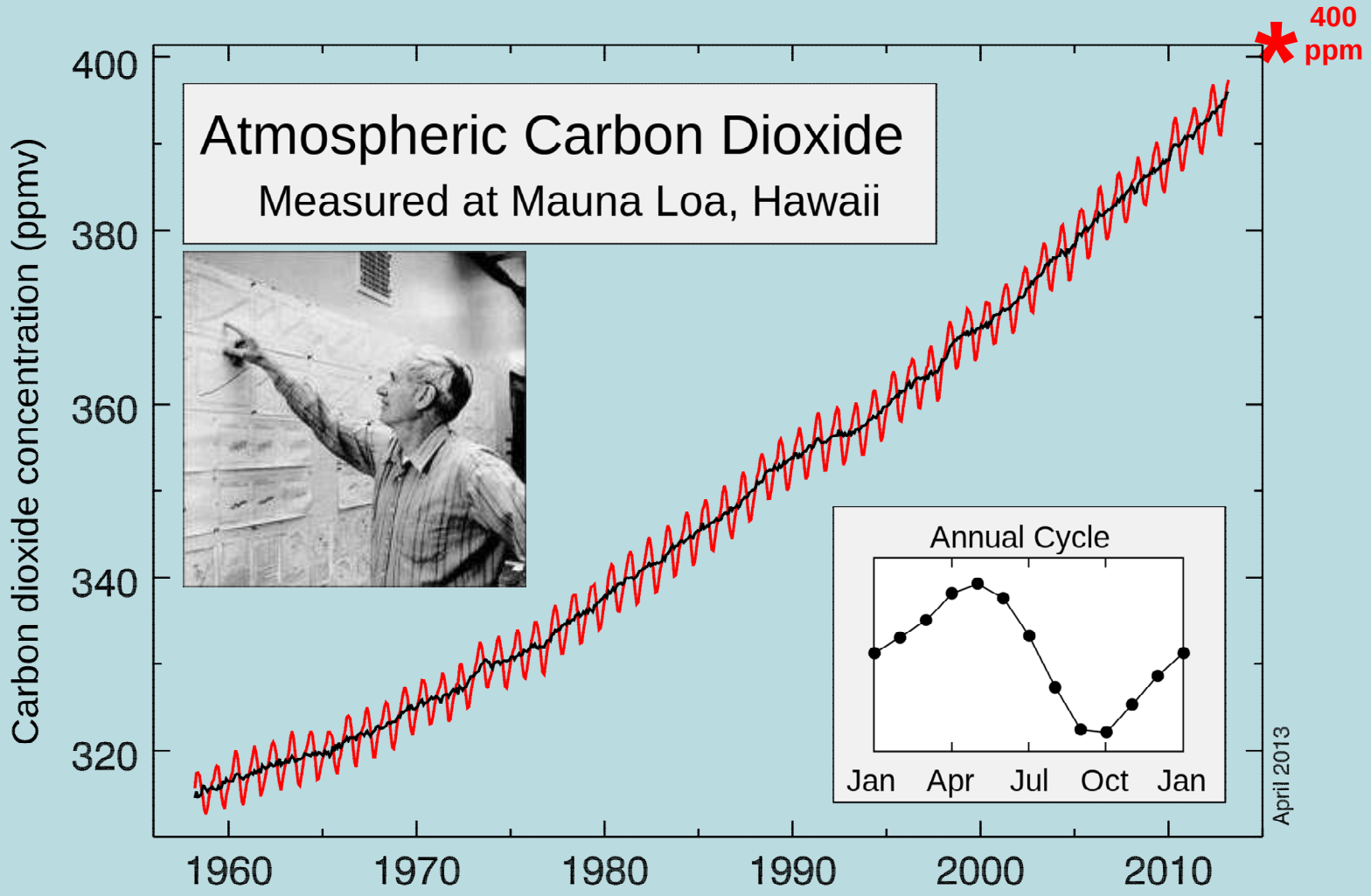
OLLI WEST: Signs of Climate change

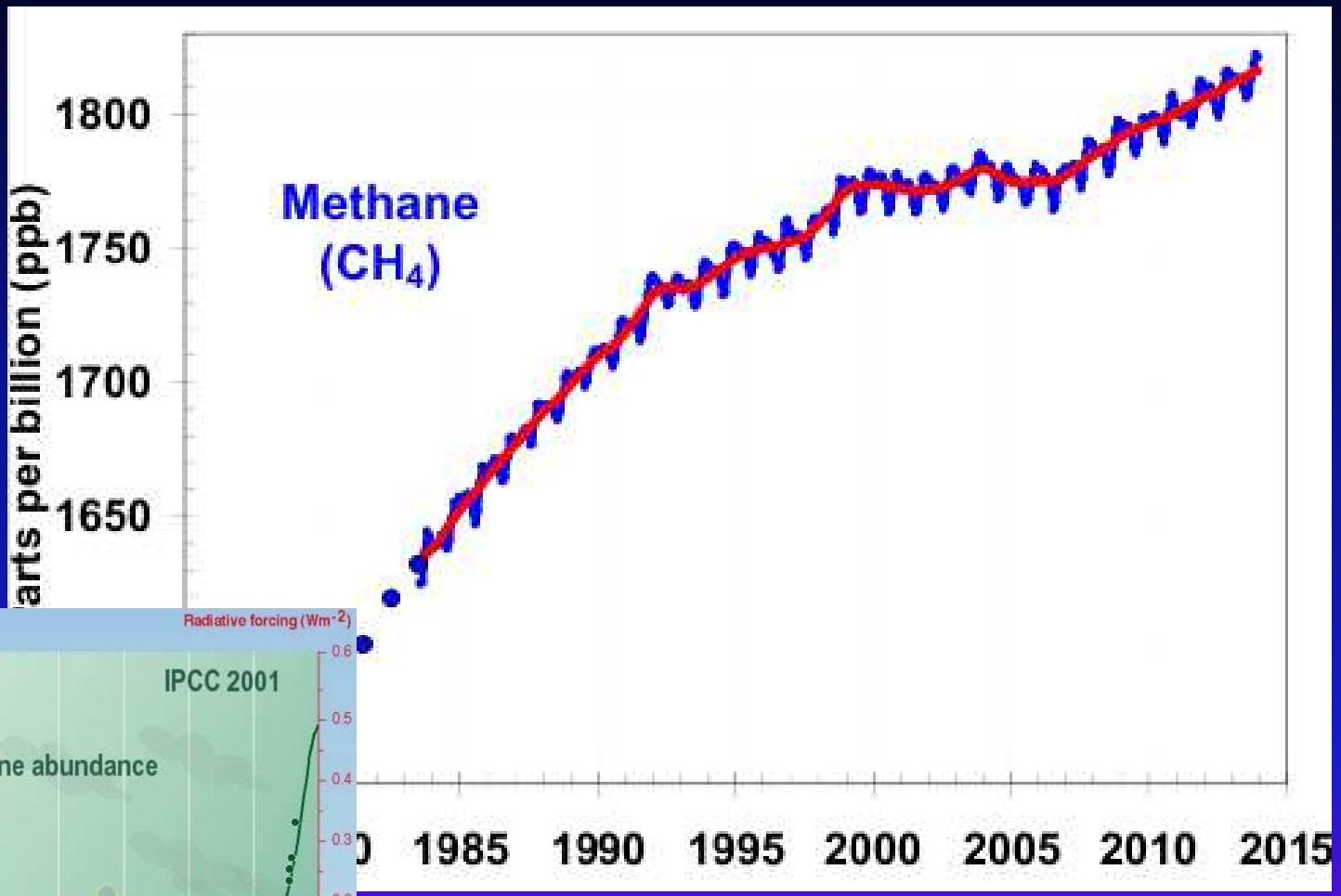
- **We are changing the climate:**
  - **CO_2**
  - **CH_4**
  - **And resulting temperature increases**

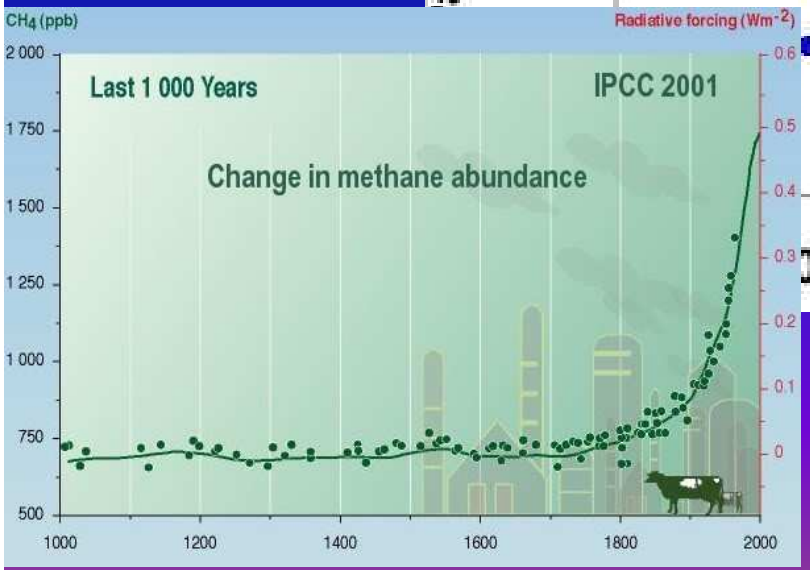
Lest we forget: CO_2 is still going up



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

What about Methane?

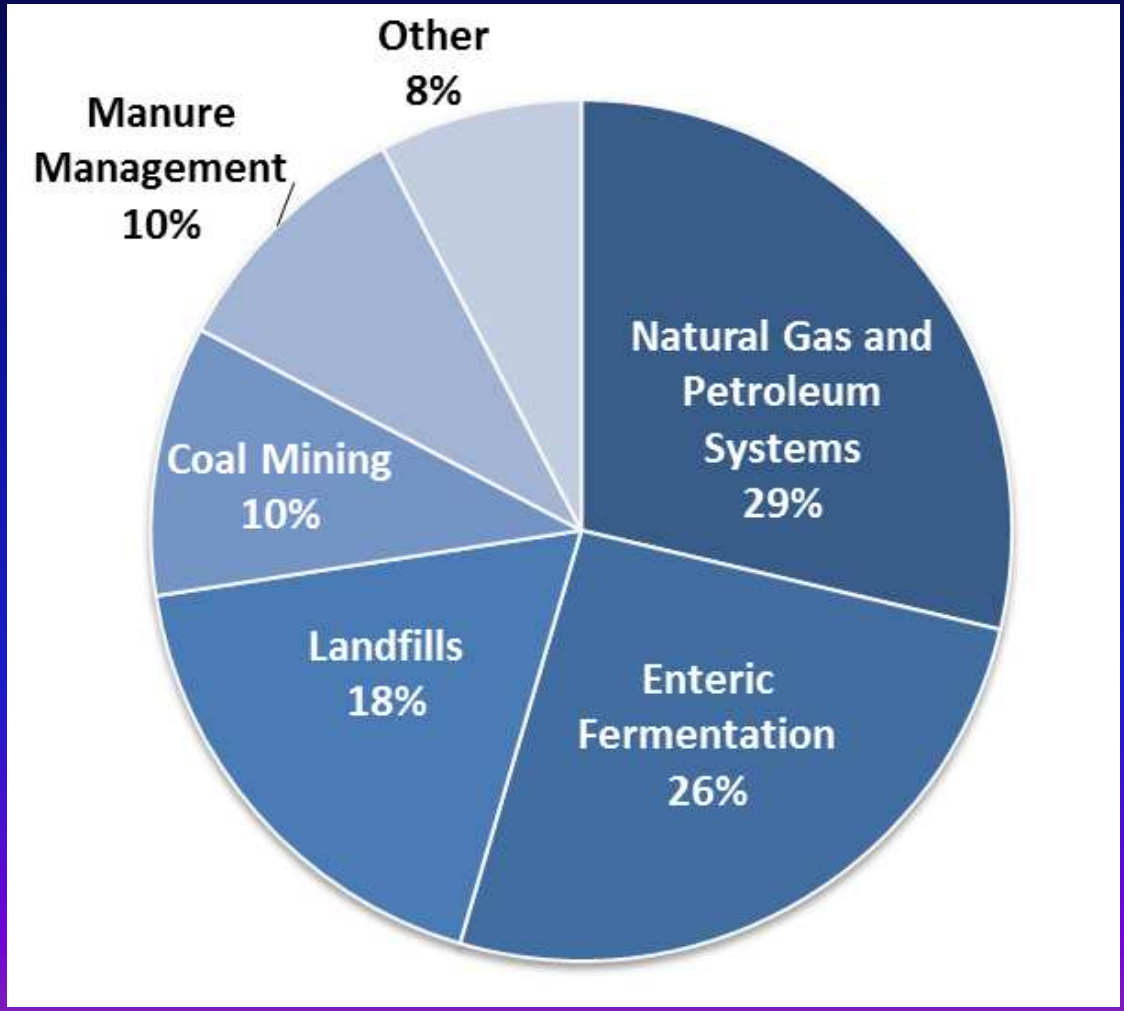




http://www.esrl.noaa.gov/gmd/aggi/aggi.html

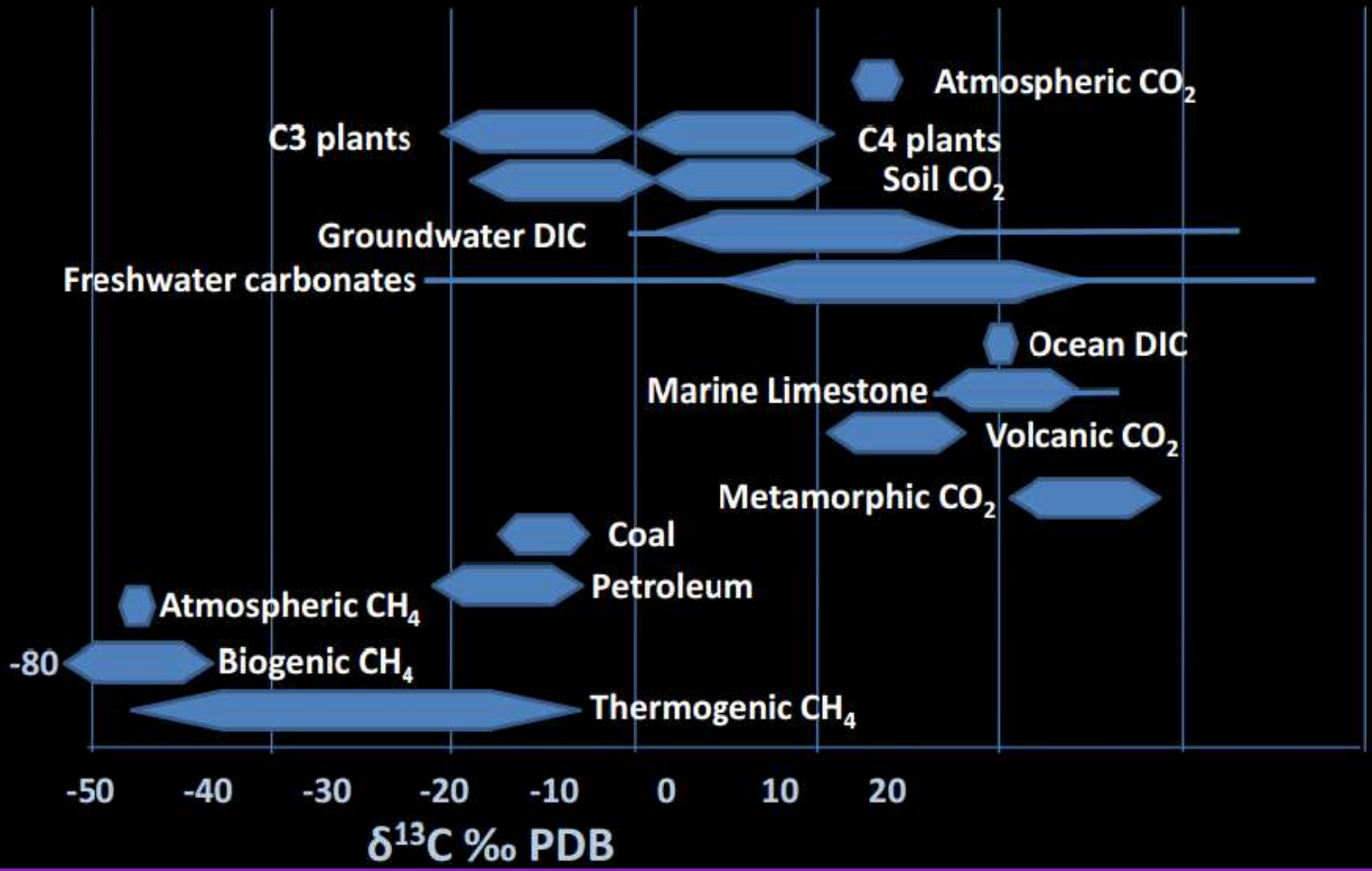
http://clathrates.blogspot.com/2012/04/threat-of-methane-release-from.html

SOURCE OF METHANE



Stable-Isotopes

Graph showing $\delta^{13}C$ values for a range of different sources

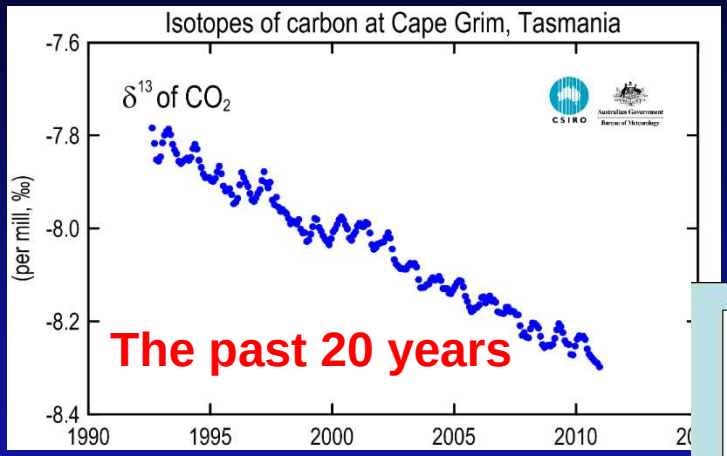


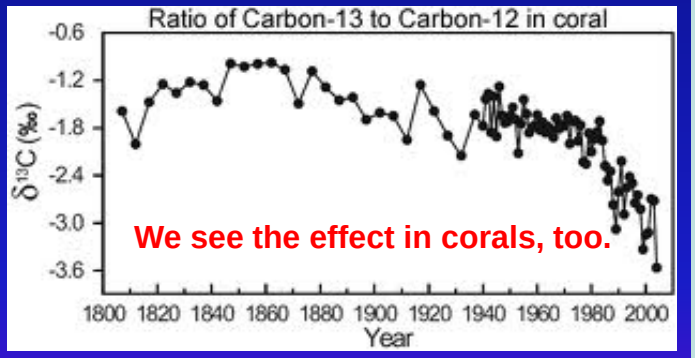
How do we know we are causing it?

- CO_2:
  - Isotopically more negative Carbon (see next slide)
  - Reduction of C^{14} in atmosphere – dead carbon

- And if you believe in the laws of Physics (see first handout and video on GHGs) then it's the main reason along with positive feedbacks for Global warming (and ocean acidification)

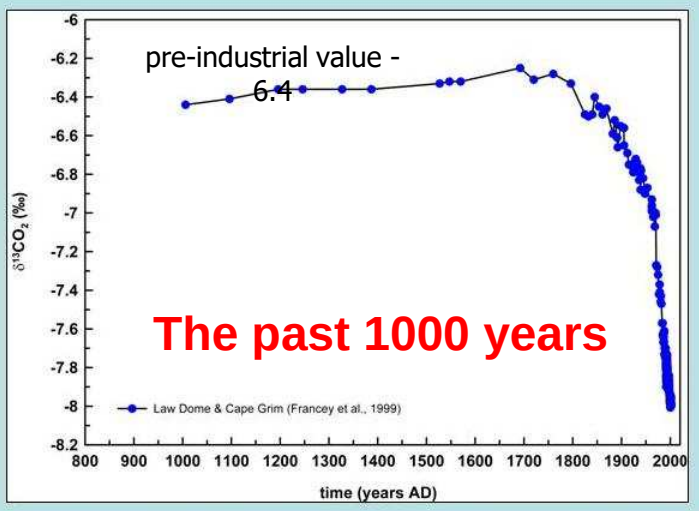
http://www.cmar.csiro.au/research/capegrim_graphs.html





"Evidence for ocean acidification in the Great Barrier Reef of Australia", G. Wei et al. 2009, Geochimica et Cosmochimica Acta, **73**, 8, 15 April 2009, Pages 2332–2346

http://www.bridge.bris.ac.uk/projects/pcmip/experiments.html

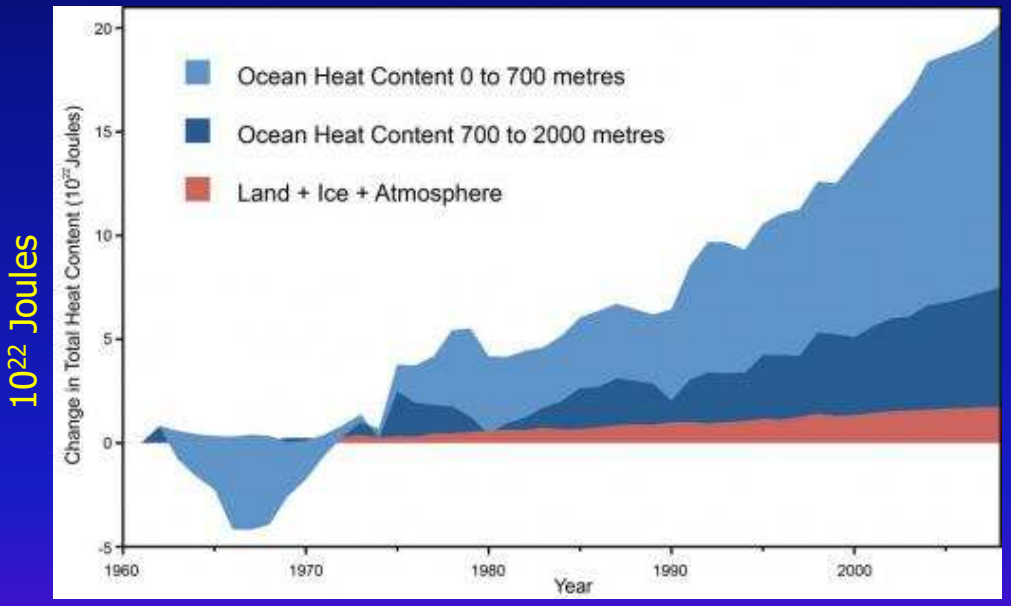


Reconstruction of the carbon isotope (C-13) of atmospheric CO2 from the Law Dome ice core (Francey et al., 1999) and the Cape Grim ambient air measurements (Allison et al., 2003).

The ocean is taking up the heat

90% of the energy is going to heat the oceans; the rest heats the land and air.

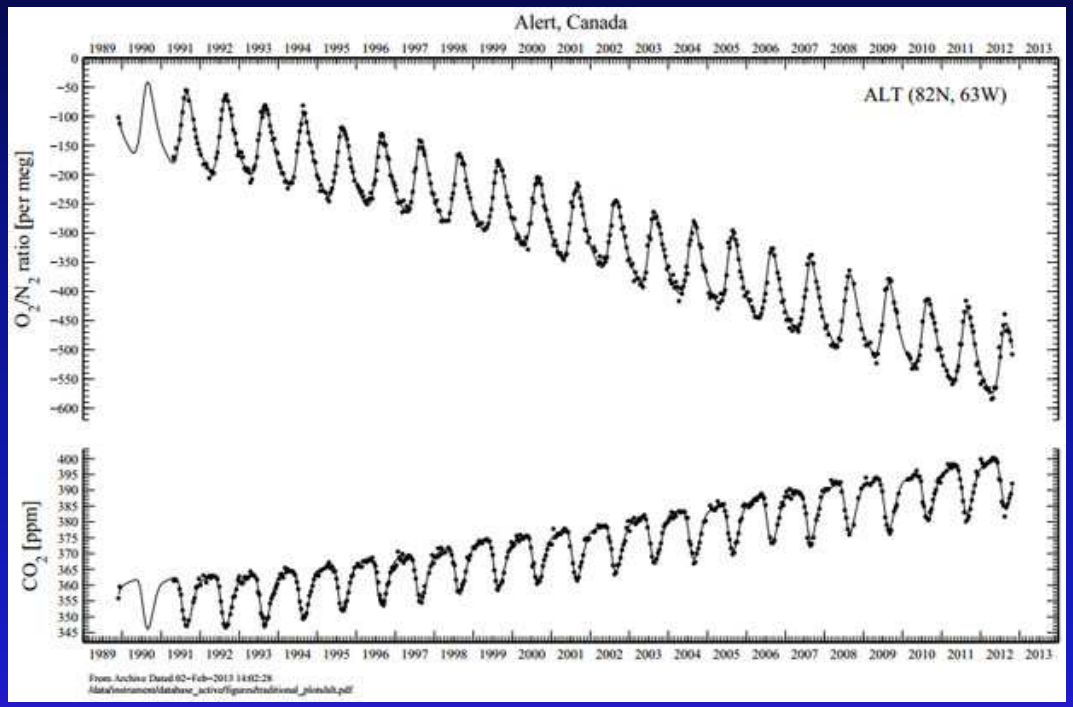
A few % is melting ice.



http://www.realclimate.org/index.php/archives/2013/09/what-ocean-heating-reveals-about-global-warming/

OTHER EVIDENCE

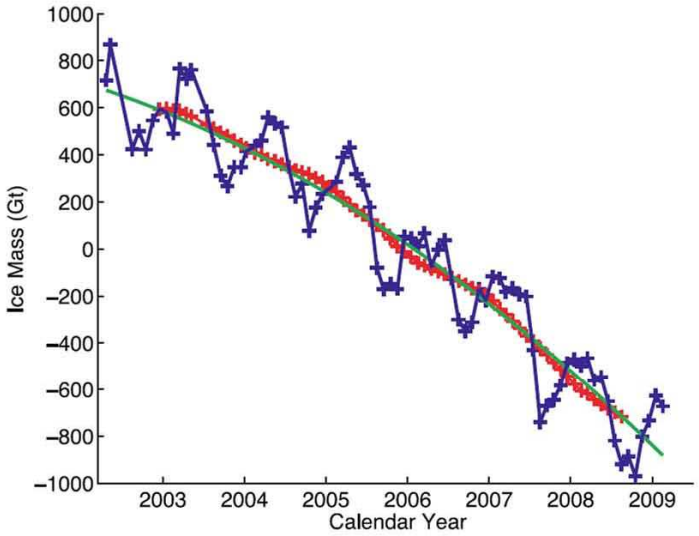
Oxygen used by burning



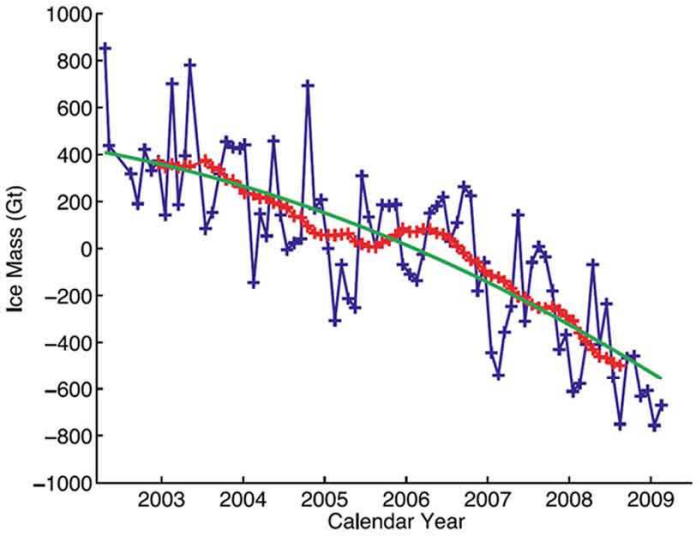
The observed downward trend is 19 'per meg' per year. This corresponds to losing 19 O_2 molecules out of every 1 million O_2 molecules in the air/year.

http://scrippso2.ucsd.edu

Rapidly Increasing Polar Ice Loss



Greenland

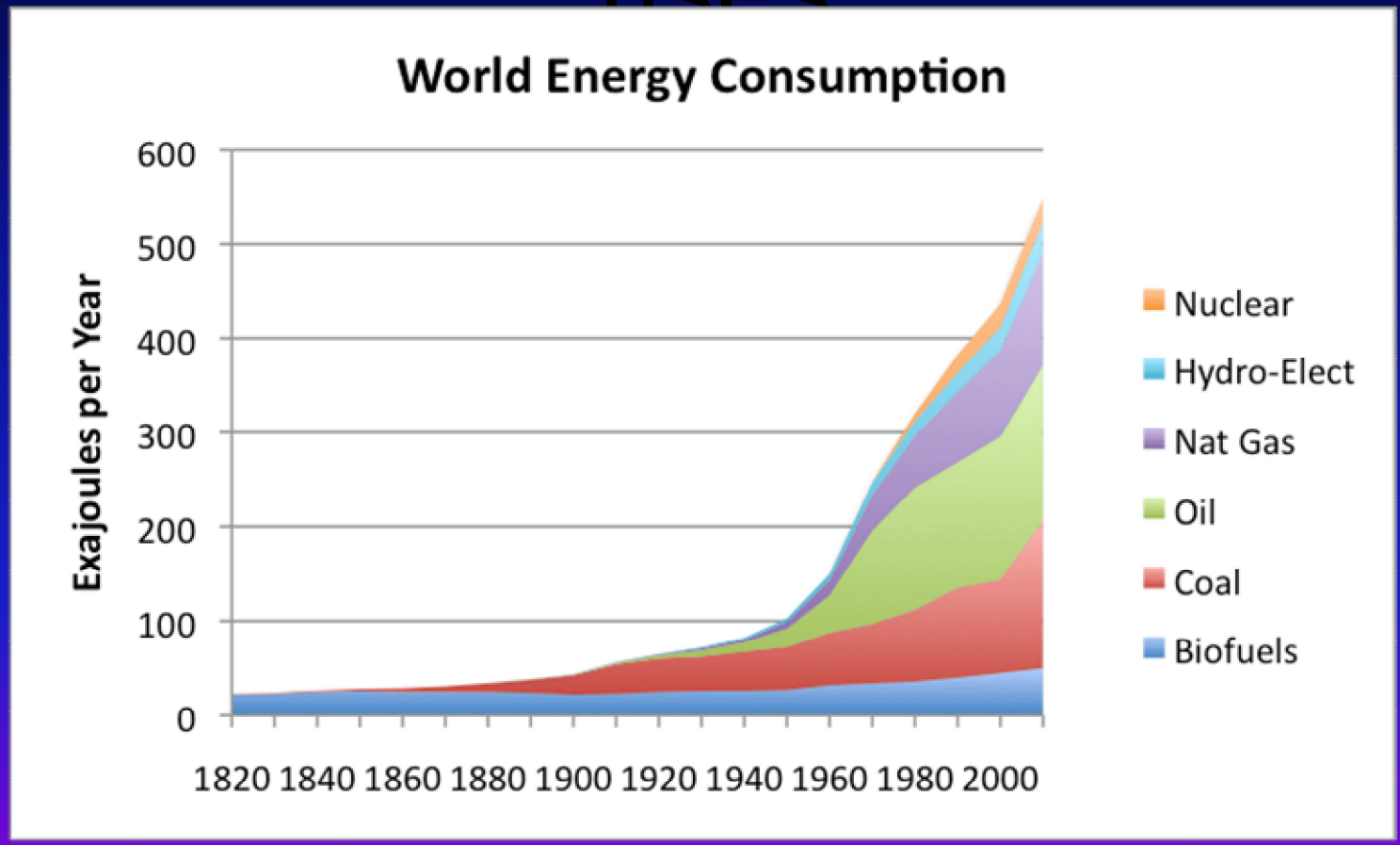


Antarctica

This data shows ice lost from Greenland and Antarctica. The information comes from the new GRACE satellites. These satellites are gravity measuring satellites that are 100 times more sensitive than the previous generation of gravity measuring satellites. What this data shows is a continuous loss of ice from both ice sheets, but more importantly, the loss rate is accelerating. Greenland lost 230 gigatons and Antarctica lost 140 gigatons in 2009. The acceleration in 2009 was 56 gigatons per year. A gigaton is one billion tons. The City of Los Angeles uses one gigaton of water per year. Combined, the ice loss raises sea level by 1.1 mm per year, every year, and this rate is increasing by 15% per year. This means that we will crass the barrier island stability threshold about 2012 or 2013. Reference: *Velicogna, Increasing rates of ice mass loss from the Greenland and Antarctic ice sheets revealed by GRACE, Geophysical Research Letters, October 2009*.

http://takvera.blogspot.com/2014/01/antarctic-ice-mass-accelerating.html

Energy consumption rises

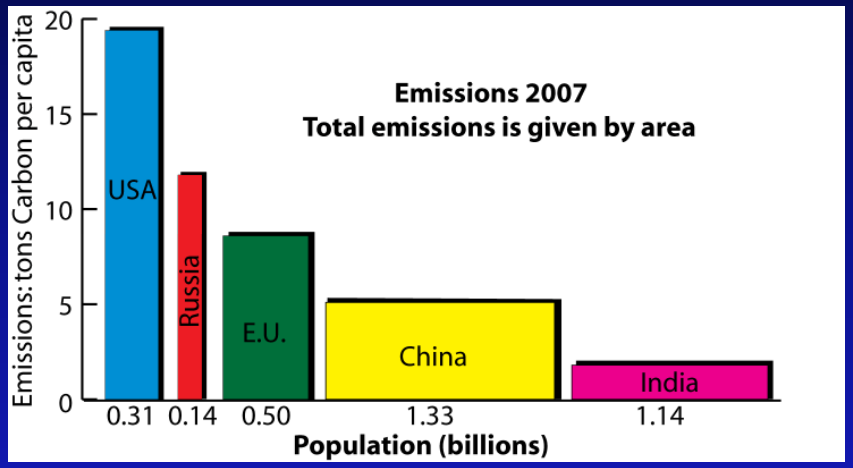


China biggest emitter

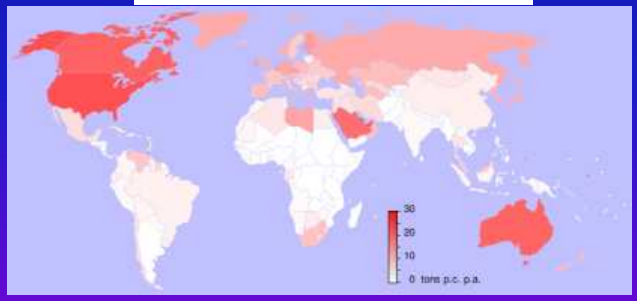
2007 emissions: Population matters!

- 14% more than US
- Per capita Pop.

U.S.:	19.4	0.31
Russia:	11.8	0.14
E. U.:	8.6	0.50
China:	5.1	1.33
India:	1.8	1.14
	tons	Billions



Tons of CO_2 per capita



Netherlands Environmental Assessment Agency 2008

Human production of CO_2

- Atmosphere as a waste dump
- Solid waste produced annually about 1 billion metric tons
- Fossil fuel burning -> 30 billion metric tons/year
  $(30 \times 10^9)/(300 \times 10^6) = 100$
- By mass in the USA (20x)

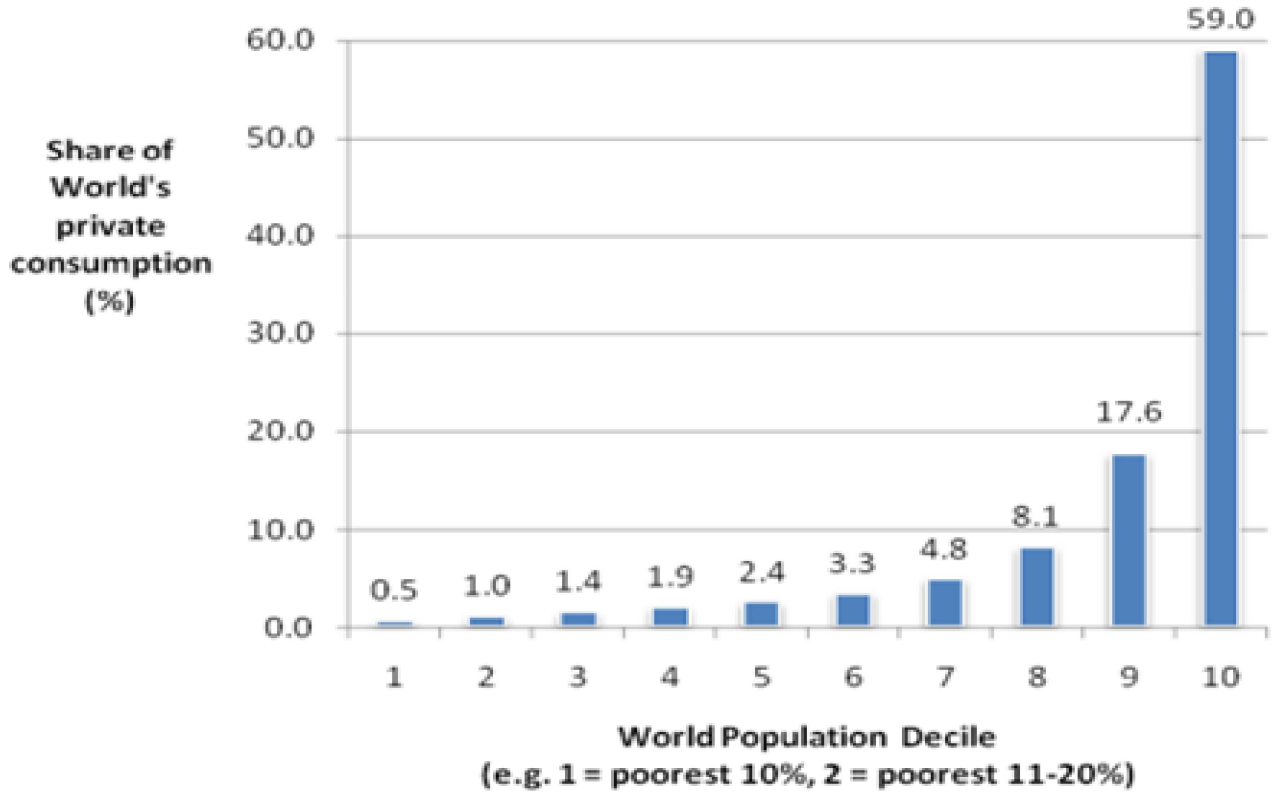
– 250 M tons of trash to landfills (not including the recycled waste 87 M tons)

– 5200 M tons of CO_2 emitted from burning fossil fuels

Coal and oil drove an amazing expansion of human possibilities

Got to love 'em: These fuels have supported an exploding population and a fantastic lifestyle for many (but not all).

Inequality of Consumption, 2005



Source: World Bank Development Indicators 2008

Current Population Situation

20th Century growth rate was "super exponential"

until inflection point circa 1980

Human species

0.5 billion: 1600

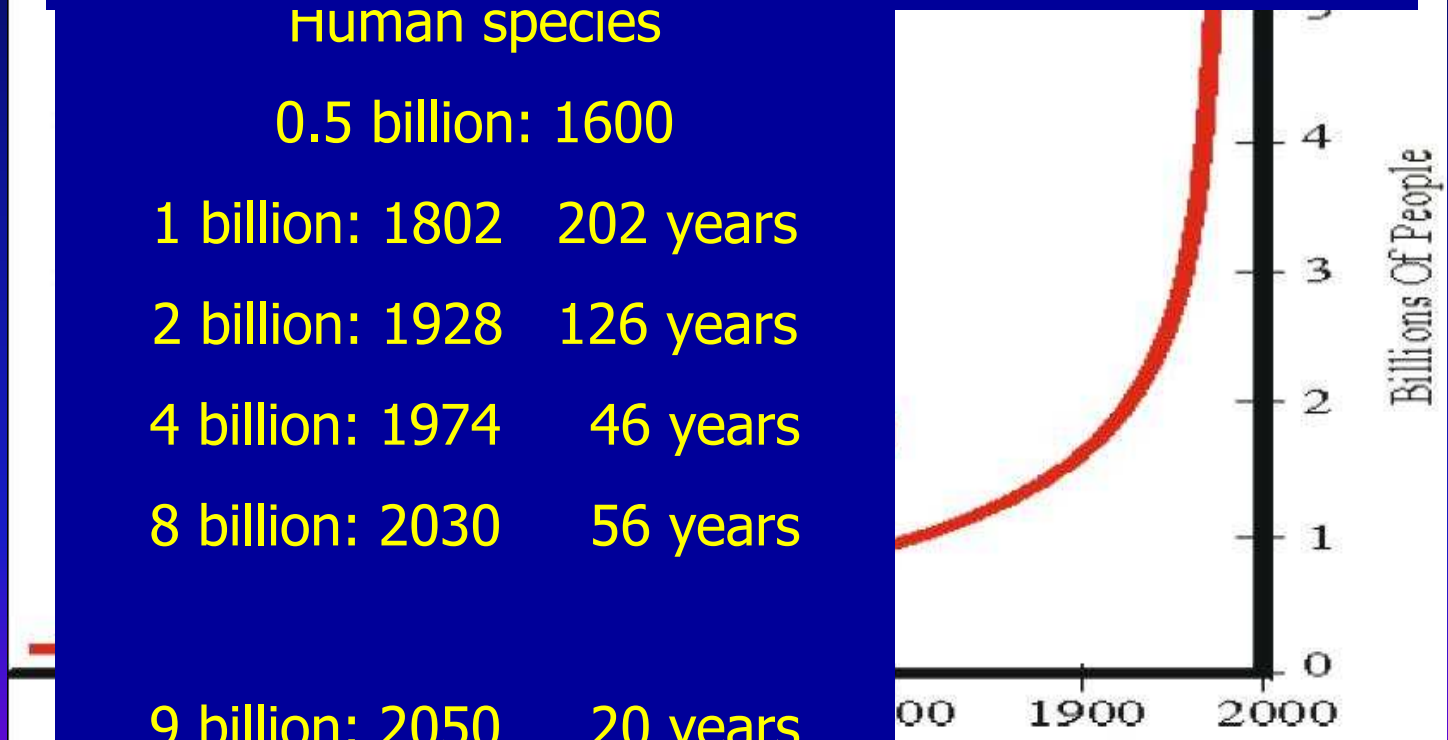
1 billion: 1802 202 years

2 billion: 1928 126 years

4 billion: 1974 46 years

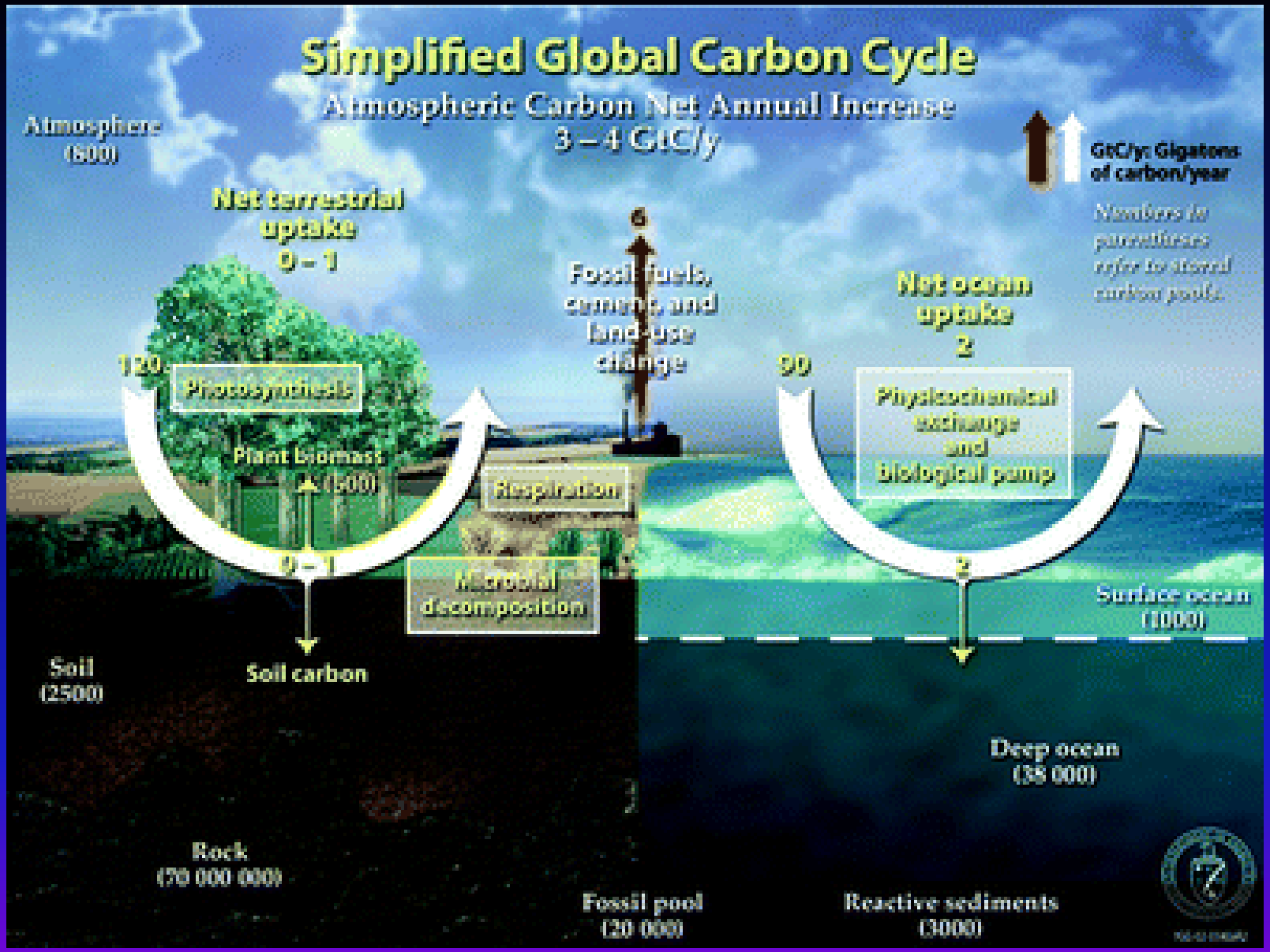
8 billion: 2030 56 years

9 billion: 2050 20 years



Ocean acidification

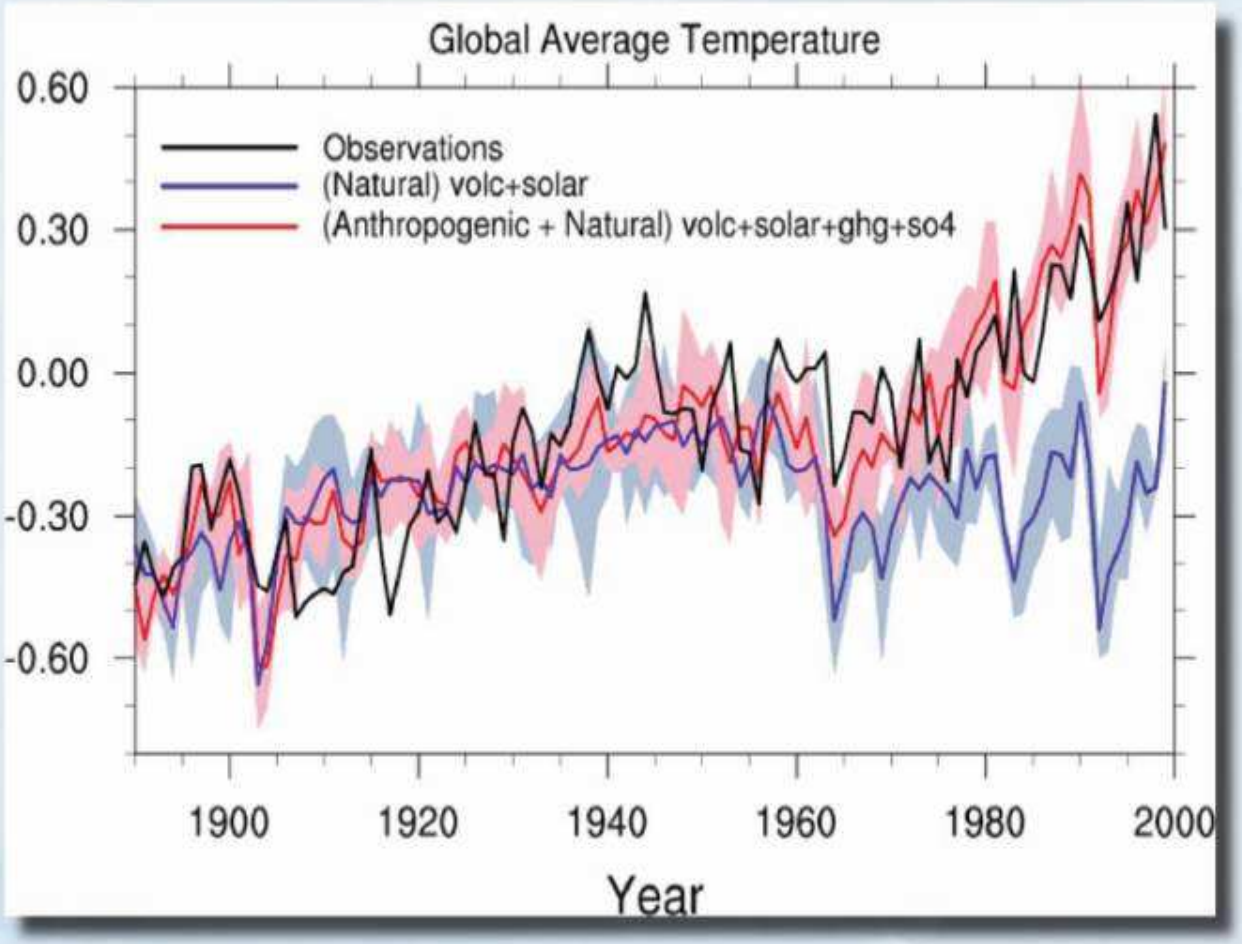
- **$CaCO_3 + H_2CO_3 = Ca^{+2} + 2HCO^{-}_3$ [1]**
- **H_2CO_3 is carbonic acid - a relatively weak naturally occuring acid that forms by the reaction between water and carbon dioxide: $H_2O + CO_2 = H_2CO_3$ [2]**
-



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

Simulations of the 20th century: Time

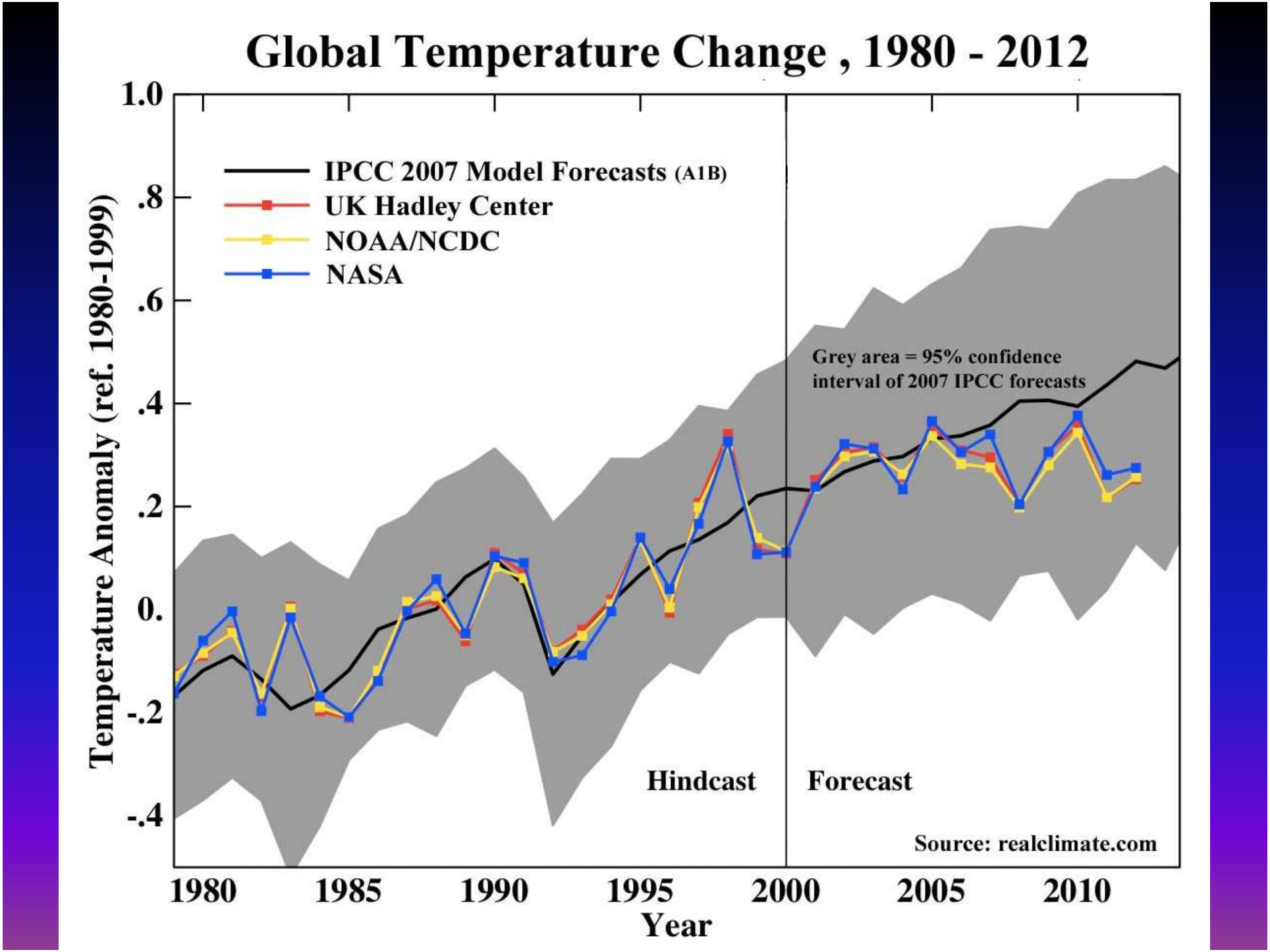
NCAR



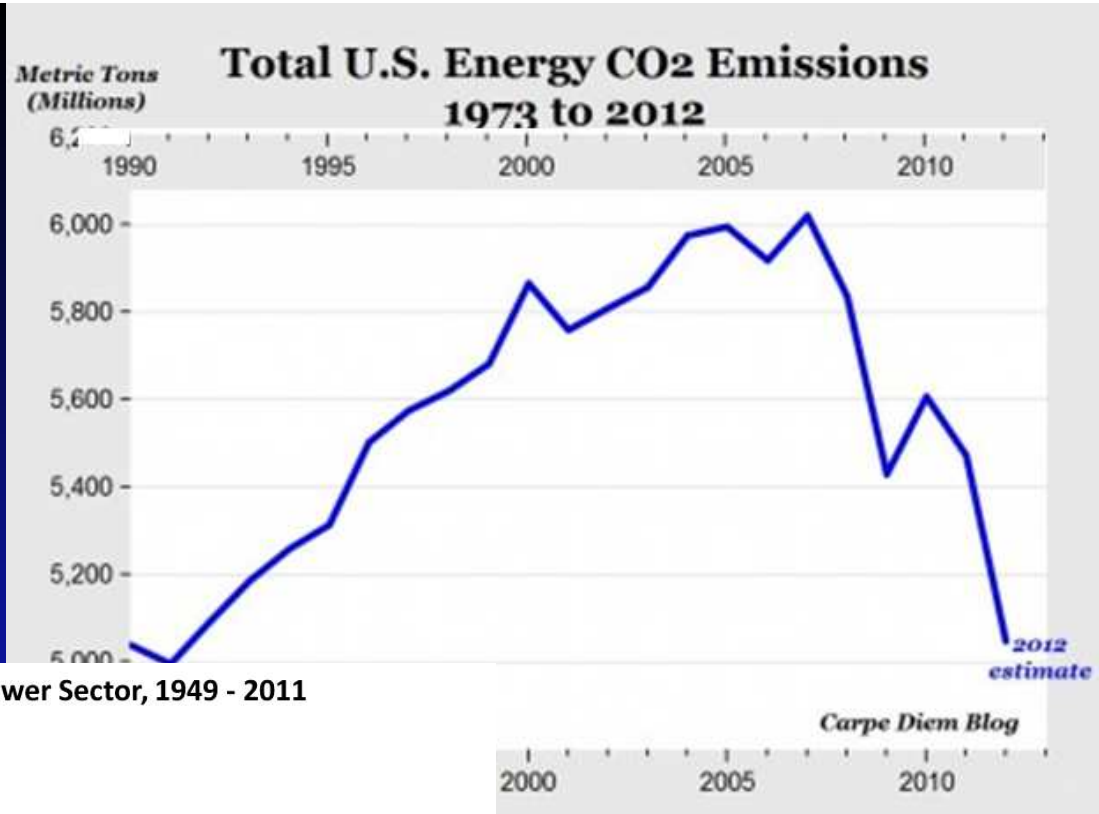
All forcings

Natural only

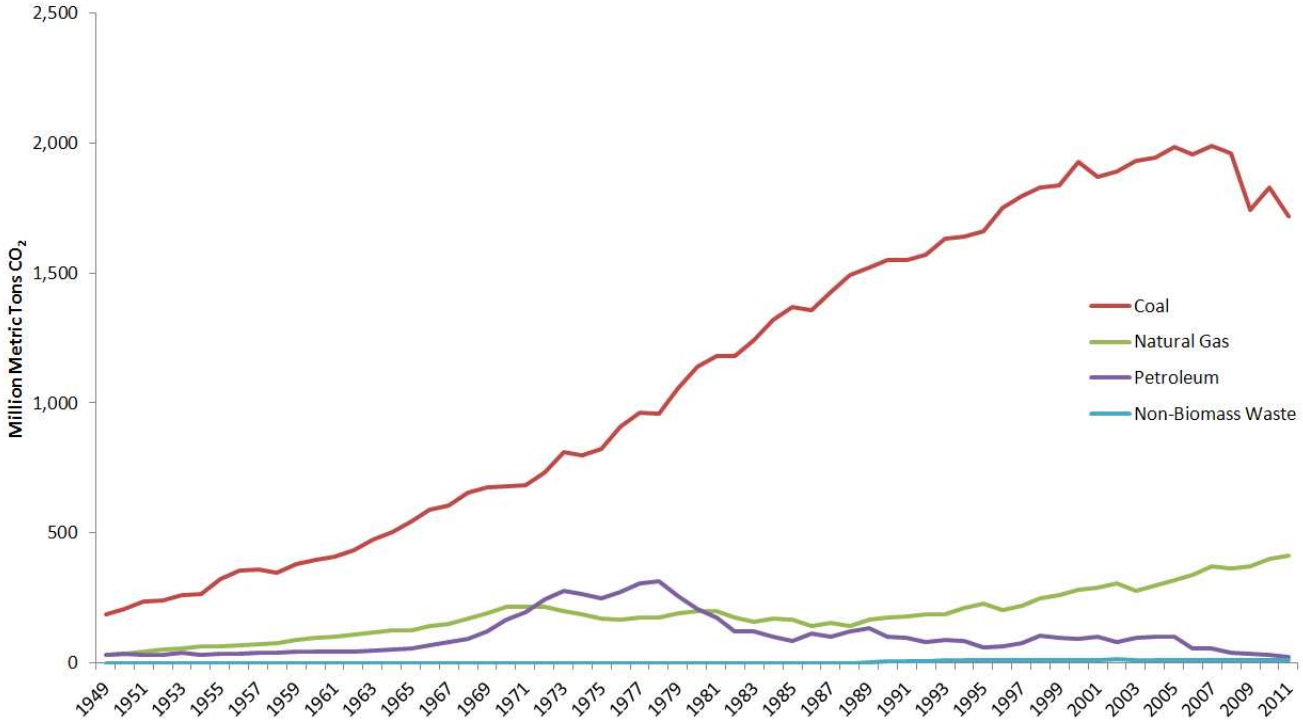
Meehl et al. 2004


Global Temperature Change , 1980 - 2012
1.0
.8
.6
.4
.2
0.
-.2
-.4
Temperature Anomaly (ref. 1980-1999)
IPCC 2007 Model Forecasts (A1B)
UK Hadley Center
NOAA/NCDC
NASA
Grey area = 95% confidence interval of 2007 IPCC forecasts
Hindcast
Forecast
Source: realclimate.com
1980
1985
1990
1995
2000
2005
2010
Year

U.S. CO_2 Emissions have come down



Trends in CO_2 Emissions from the U.S. Electric Power Sector, 1949 - 2011



http://www.texog.com/blog/2012/07/23/shale-boom-helps-us-achieve-largest-co2-reductions-in-the-world/

http://www.c2es.org/facts-figures/us-emissions/electric-power

THE END

WEEK 3

EXTRA

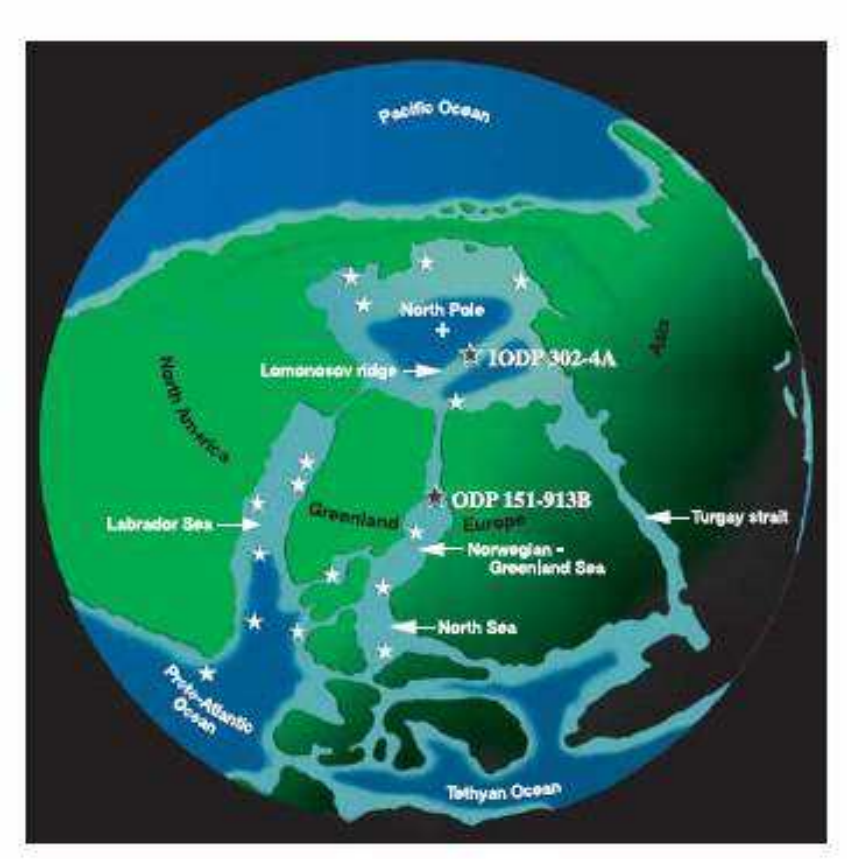
BONUS: THE AZOLLA SEQUESTERING EVENT

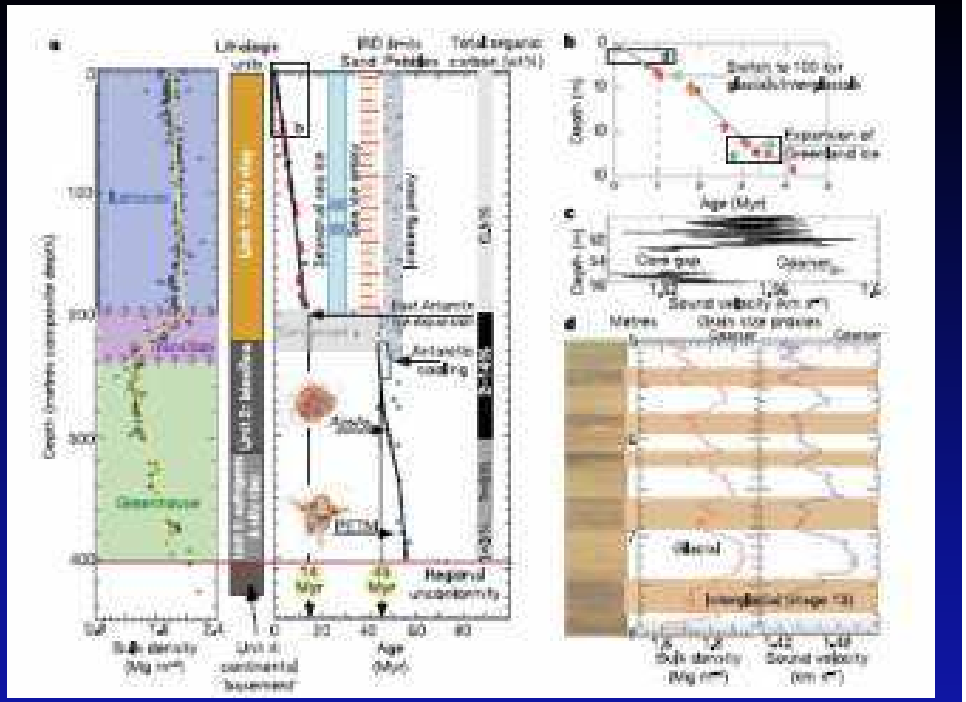
- Read more at: https://en.wikipedia.org/wiki/Azolla_event

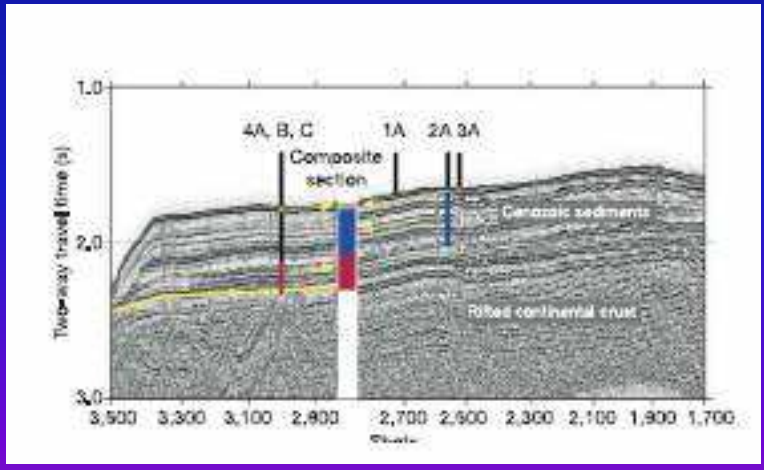
Summary: Acex coring expedition 2004

- Arctic ocean became fresh water on surface
- Fresh, salinity intolerant fern, Azolla, grew and covered the Arctic ocean
- Died off every winter and sunk to the anoxic bottom
- 800,000 years of organic matter preserved
- Sequestered 500-1000 ppm CO_2?

ARCTIC EVENTS







Brinkhuis et al,, 2006

Moran et al., 2006

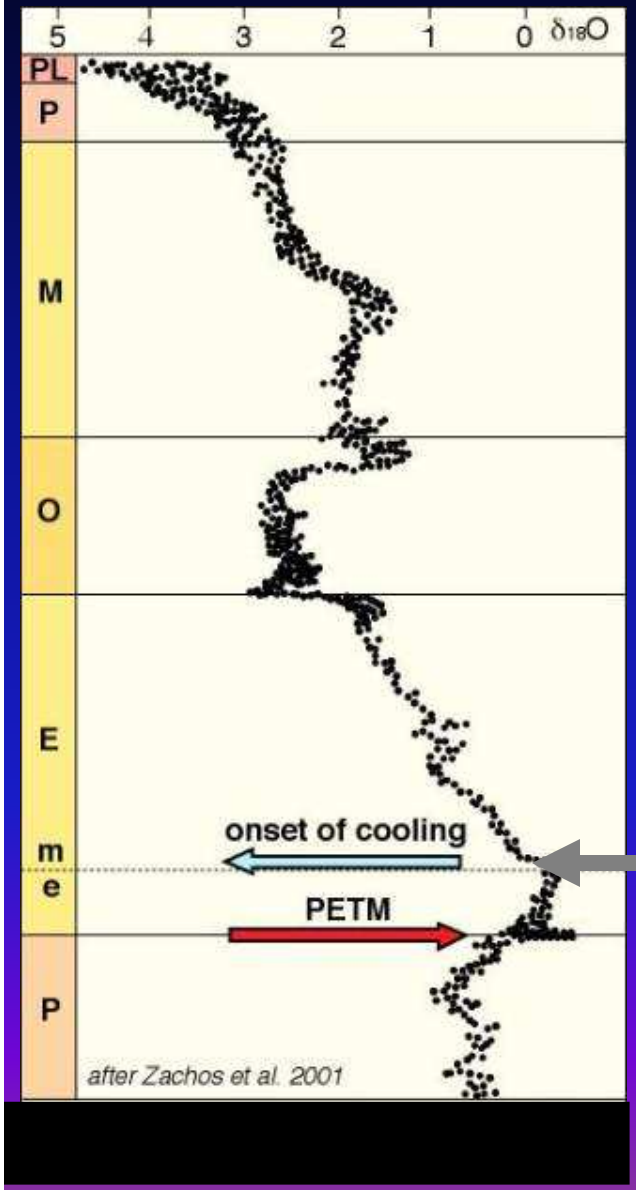
The Arctic Sea 50 million years ago

ACEX Azolla core

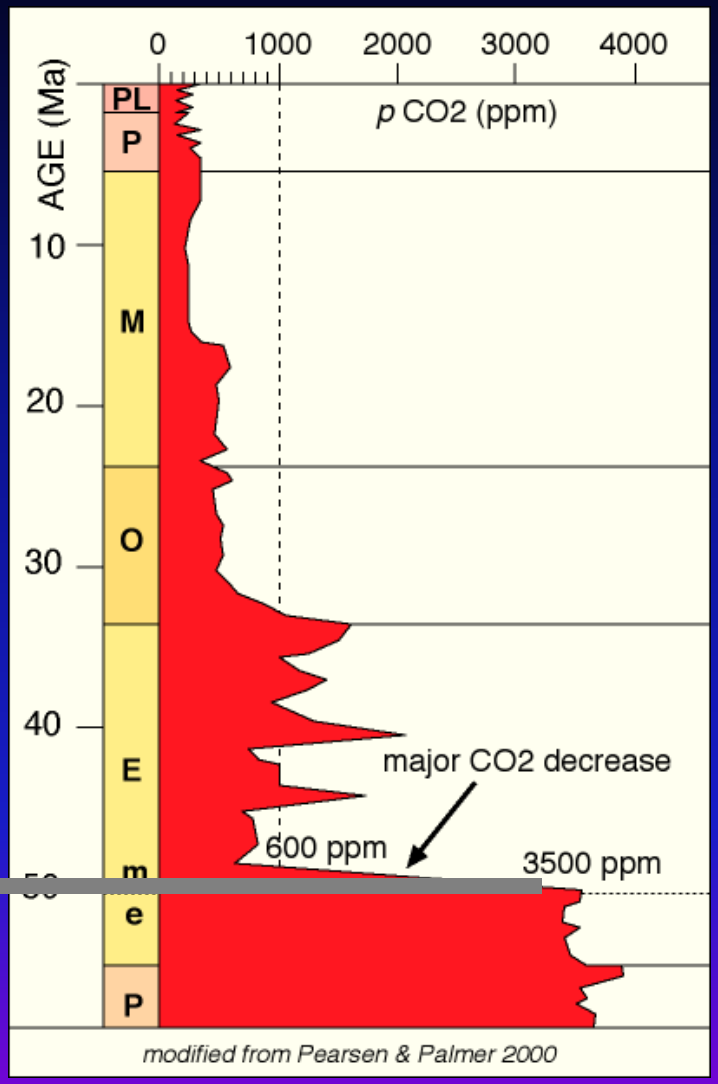
- **>8 meter ACEX core with 90% Azolla**
- **Azolla occurs as laminated layers**
- **indicates Azolla deposited in situ**
- **bottom-water anoxia at ACEX site**

Bujak, pers. Comm.

UNPRECEDENTED DROP IN CO_2

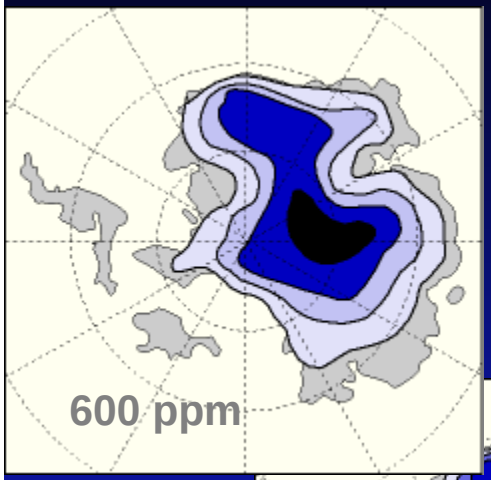


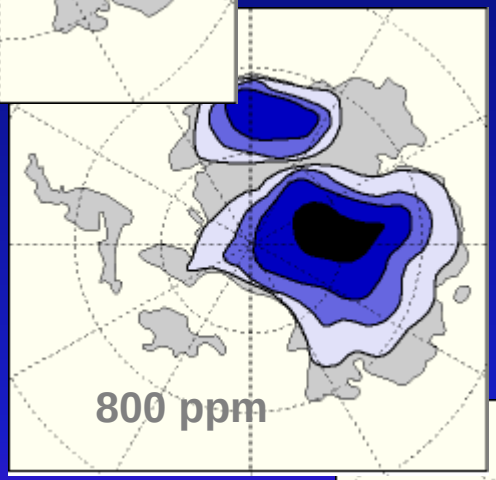
the massive decrease in atmospheric CO_2?

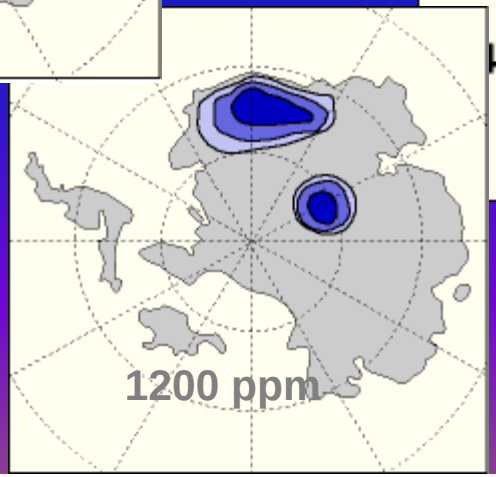


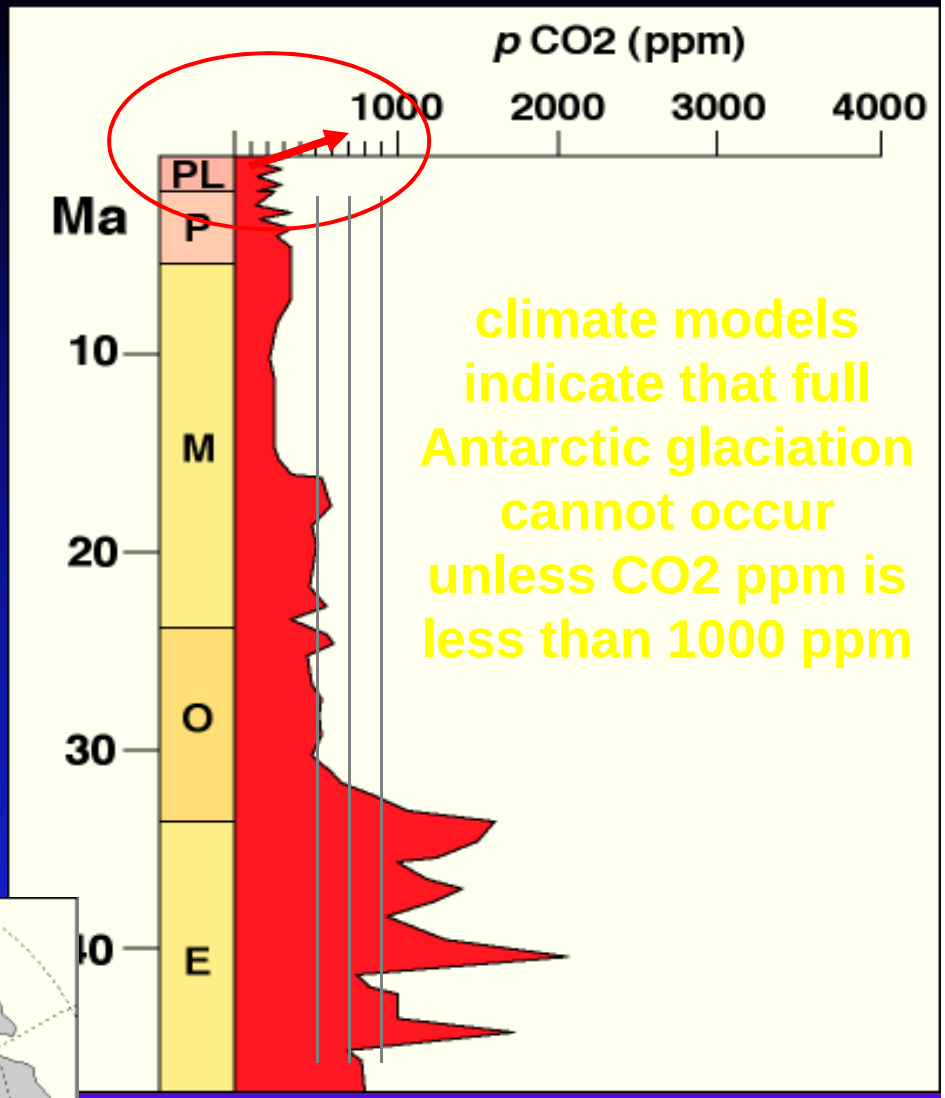
Bujak, pers. Comm.

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









Bujak, pers. Comm.

A Climate knowledge quiz:

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

IS CLIMATE CHANGE ALL DOOM AND GLOOM?

- **Answer: NO!**
- **– but YES it's a challenge and as humans we have always been challenged: read the history books.**
- **That doesn't mean we stick our heads in the sand and ignore the challenges.**
- **We have human ingenuity and adaptability.**
- **Is ignoring and doing nothing an appropriate answer.**
- **Is resigning oneself to abdicating addressing the issue merely a way of dismissing and saying there's nothing we can do.**
- **There are a lot of smart people working to meet those challenges – let me cite 2 that might be "game changers".**
- More at: http://denverclimatestudygroup.com/