A satellite view of Earth from space, showing the Americas and surrounding oceans. The text is overlaid on the image.

Paleoceanography and Climate Change

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OCI03 Friday April 17, 2009

Climate vs. Weather




“Climate” is the average weather condition, such as temperature, precipitation, winds, seasonality... over a series of years, in a region

“Weather” is the short term state of the atmosphere, as temperature, moisture, pressure etc.

Arctic Sea Ice (minimum annual extent, September)



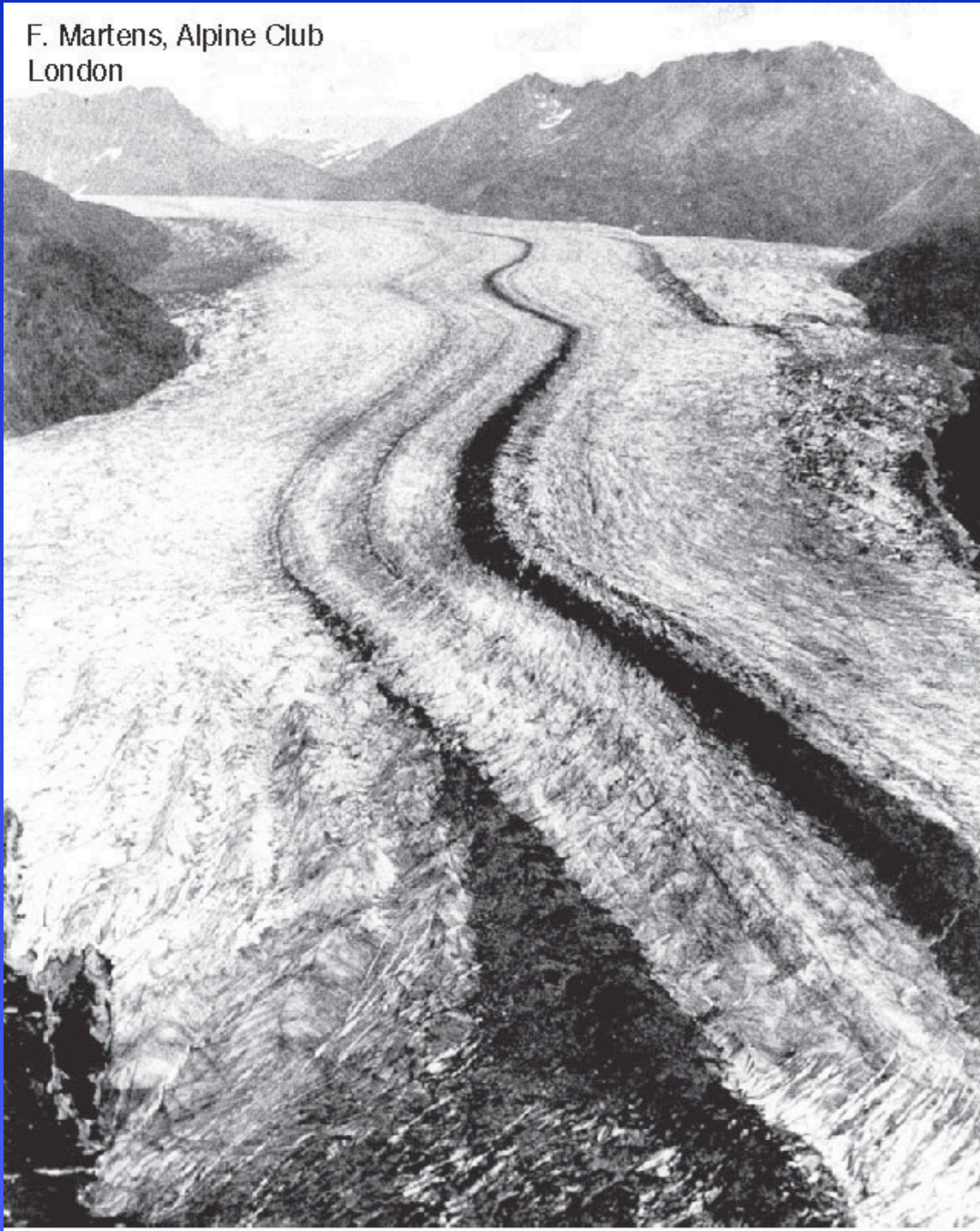
 Median minimum extent of ice cover (1979-2000)

Great Aletsch Glacier (Switzerland)

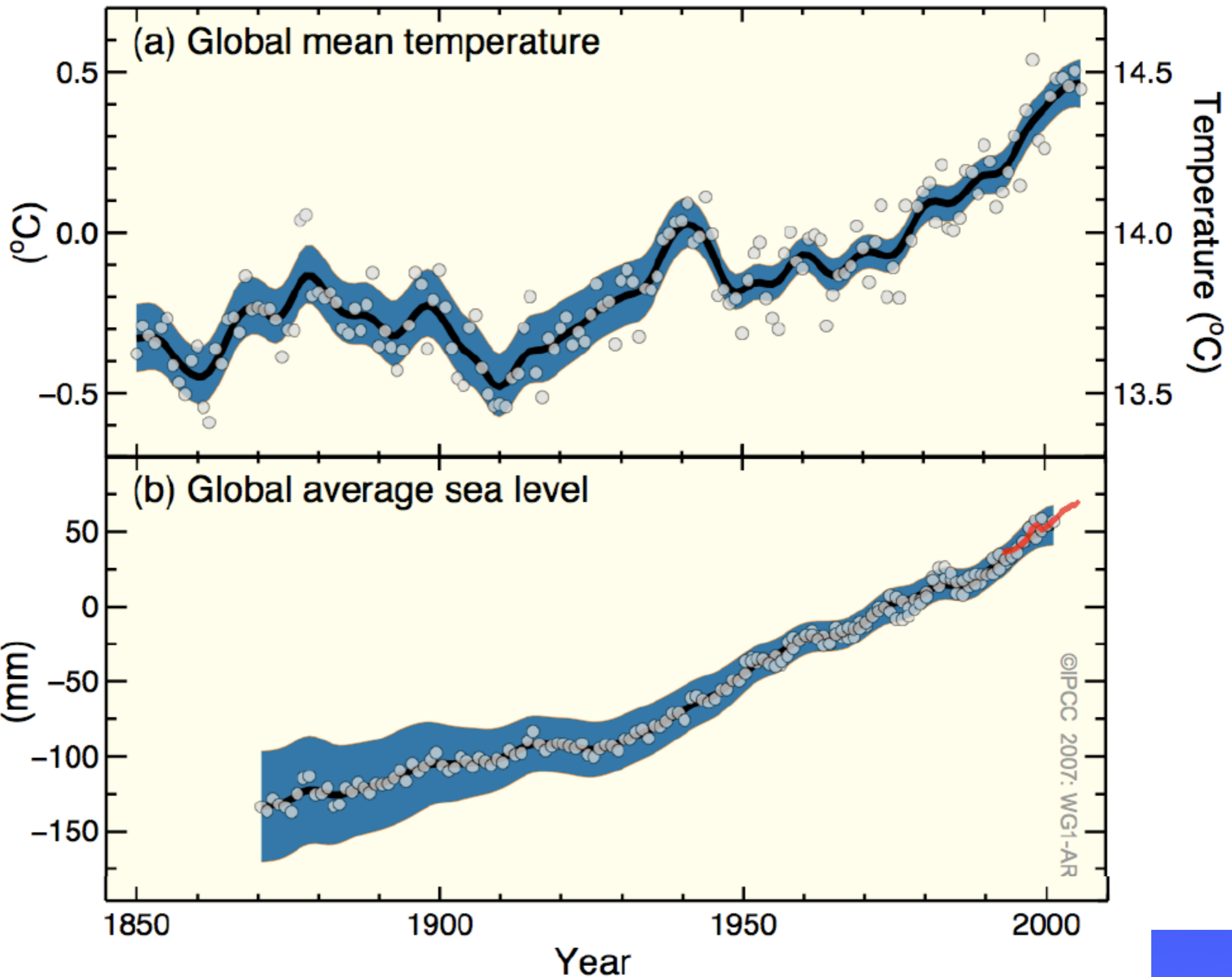
1858

2001

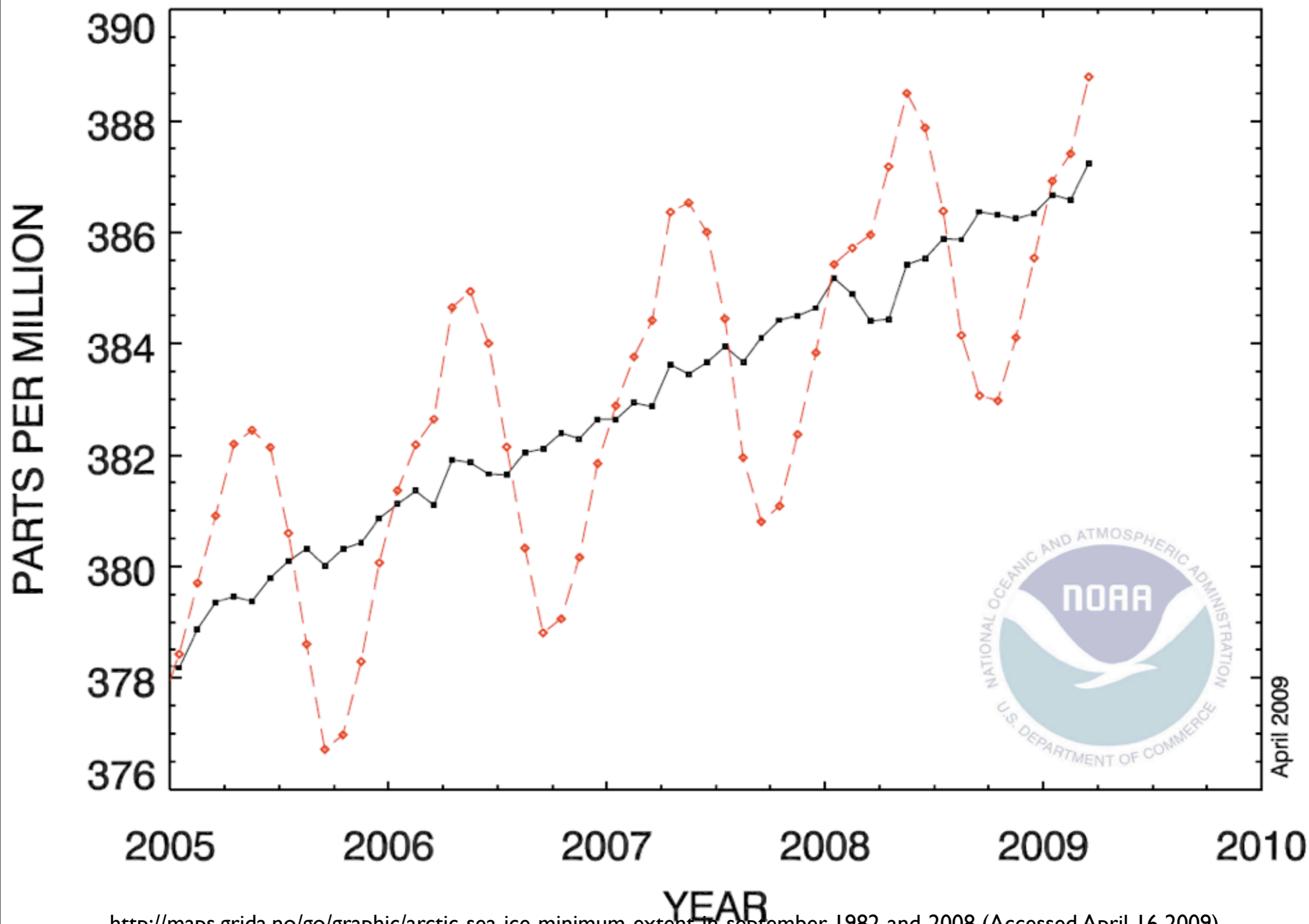
F. Martens, Alpine Club
London



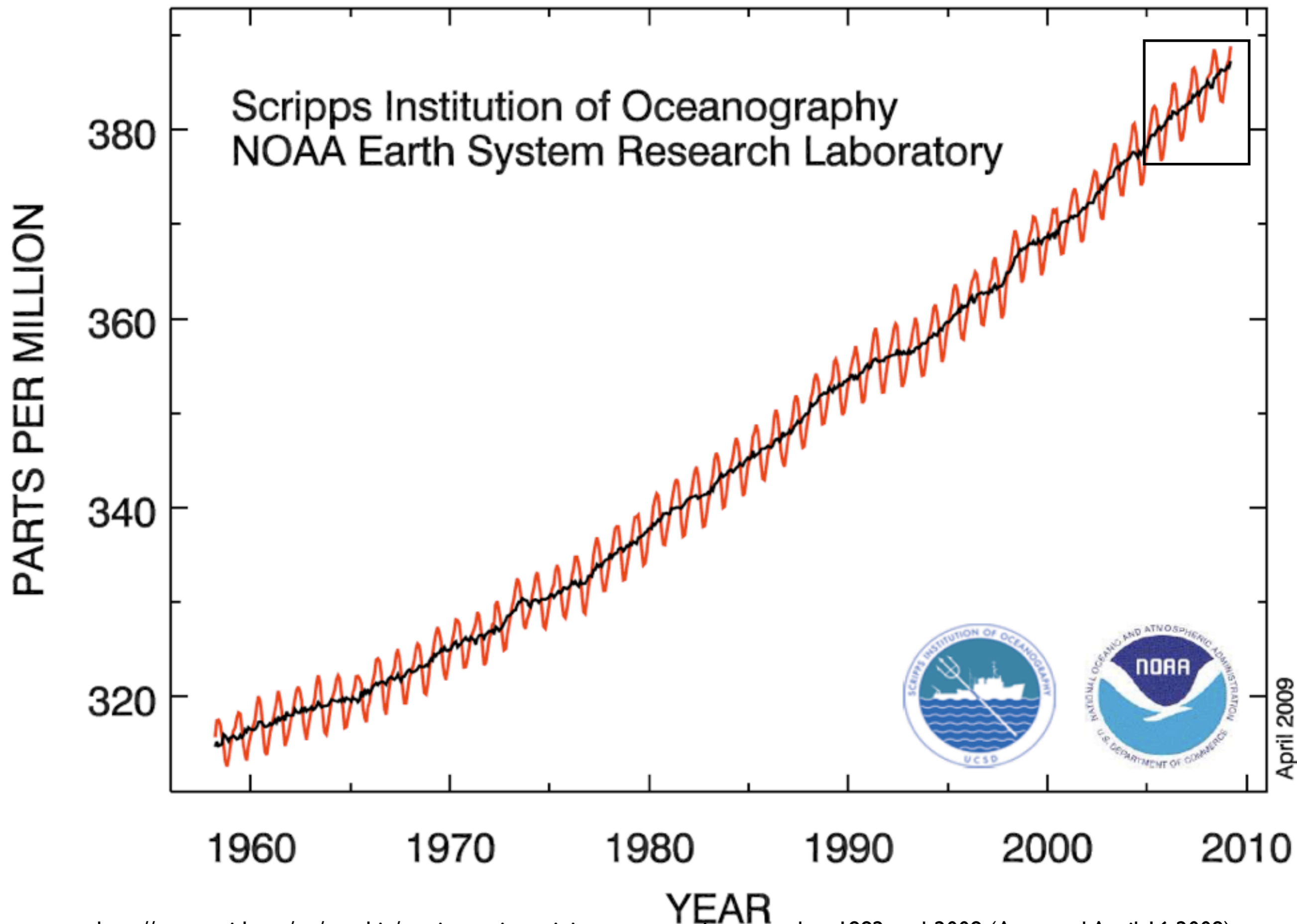
...erence from 1961-1990

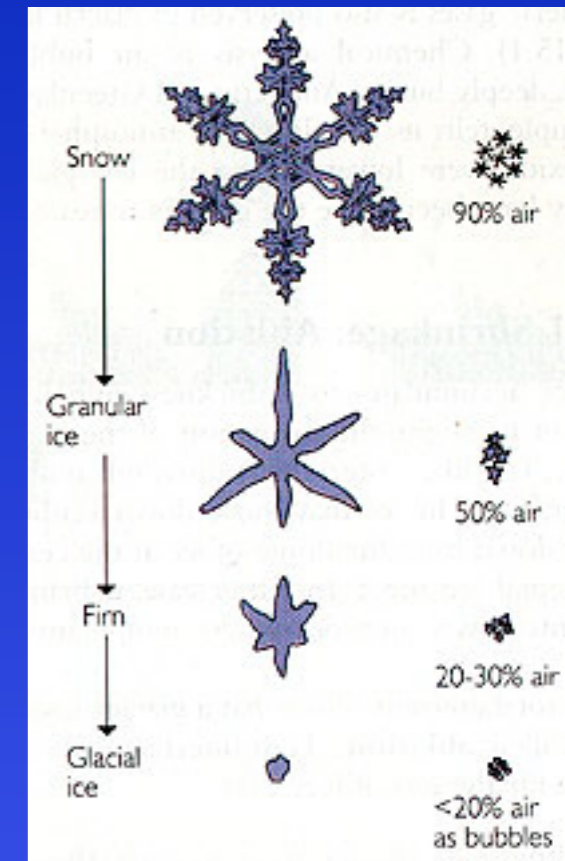
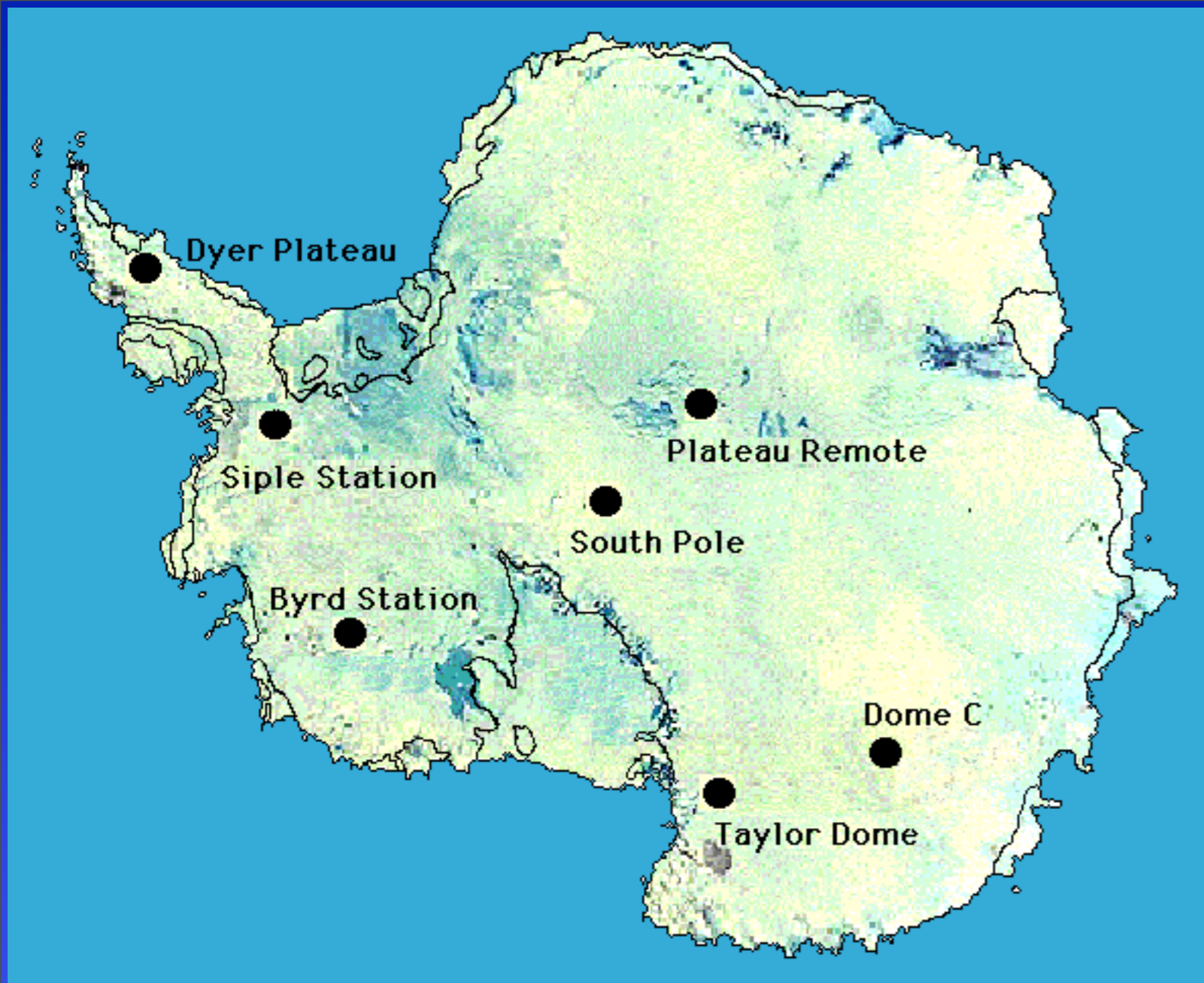


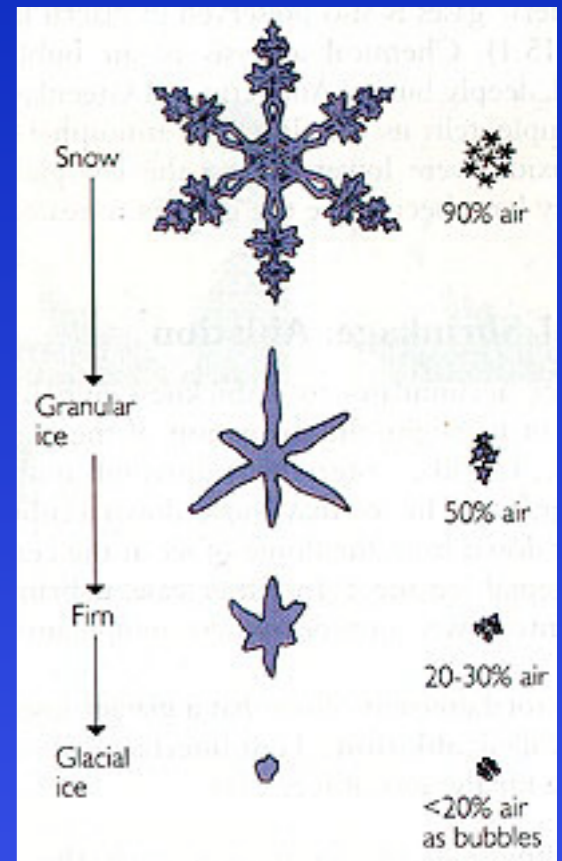
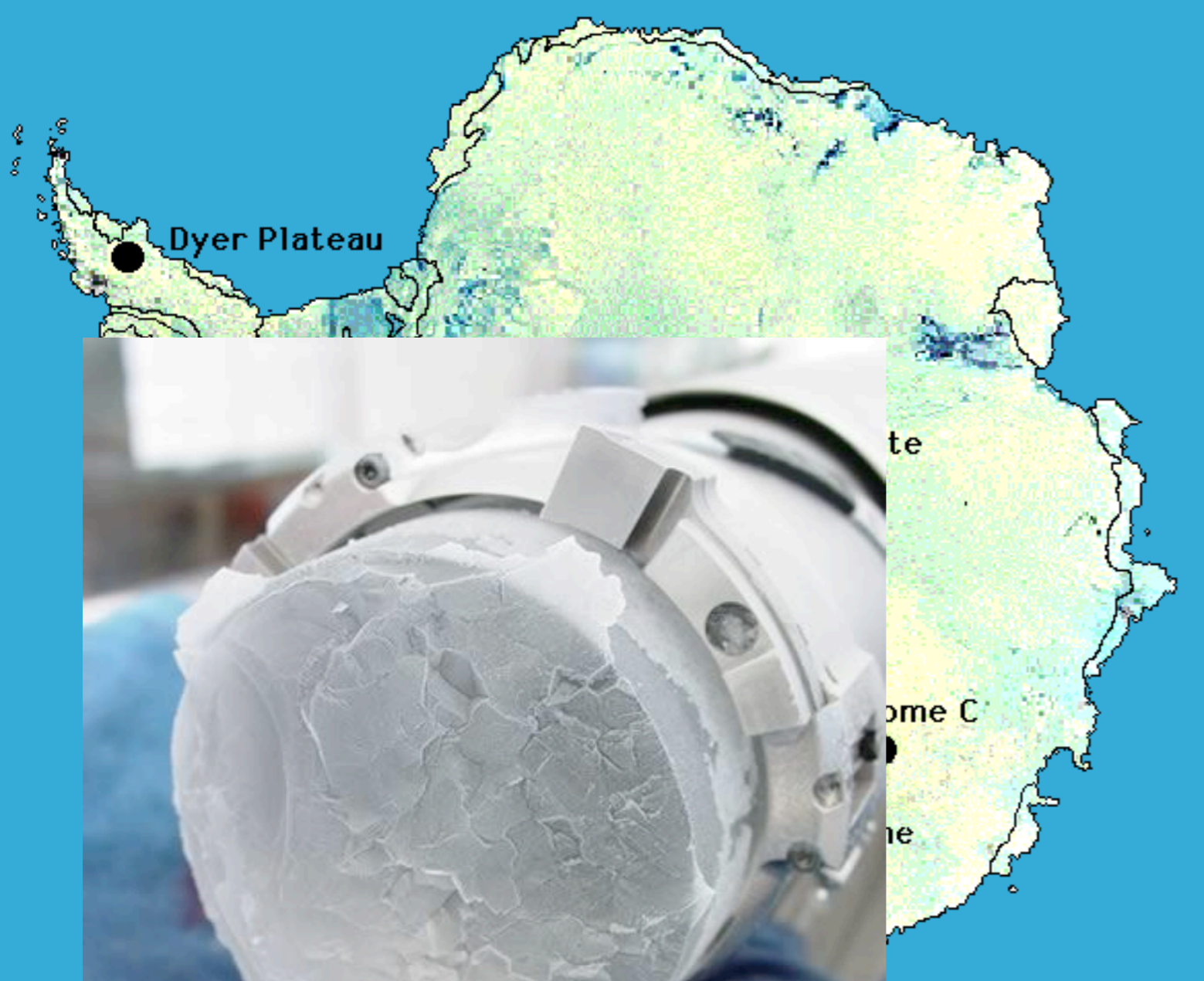
RECENT MONTHLY MEAN CO₂ AT MAUNA LOA

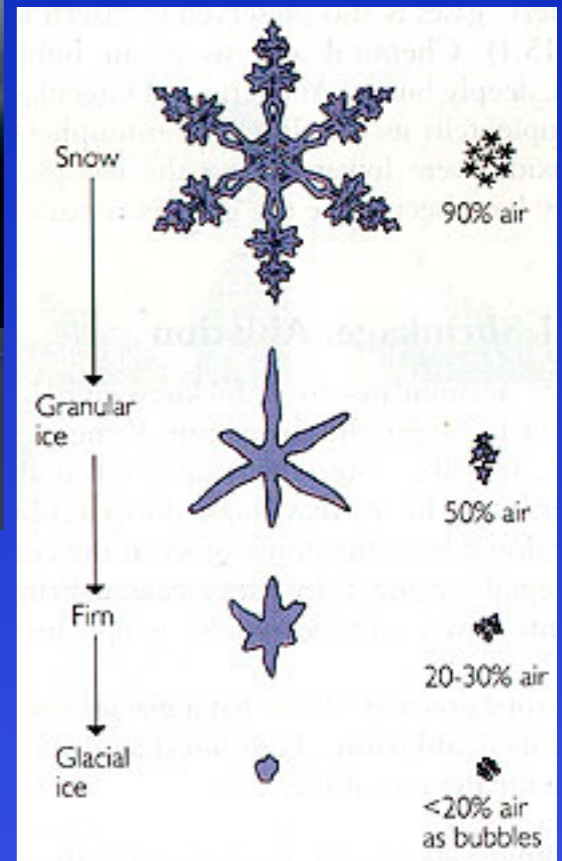
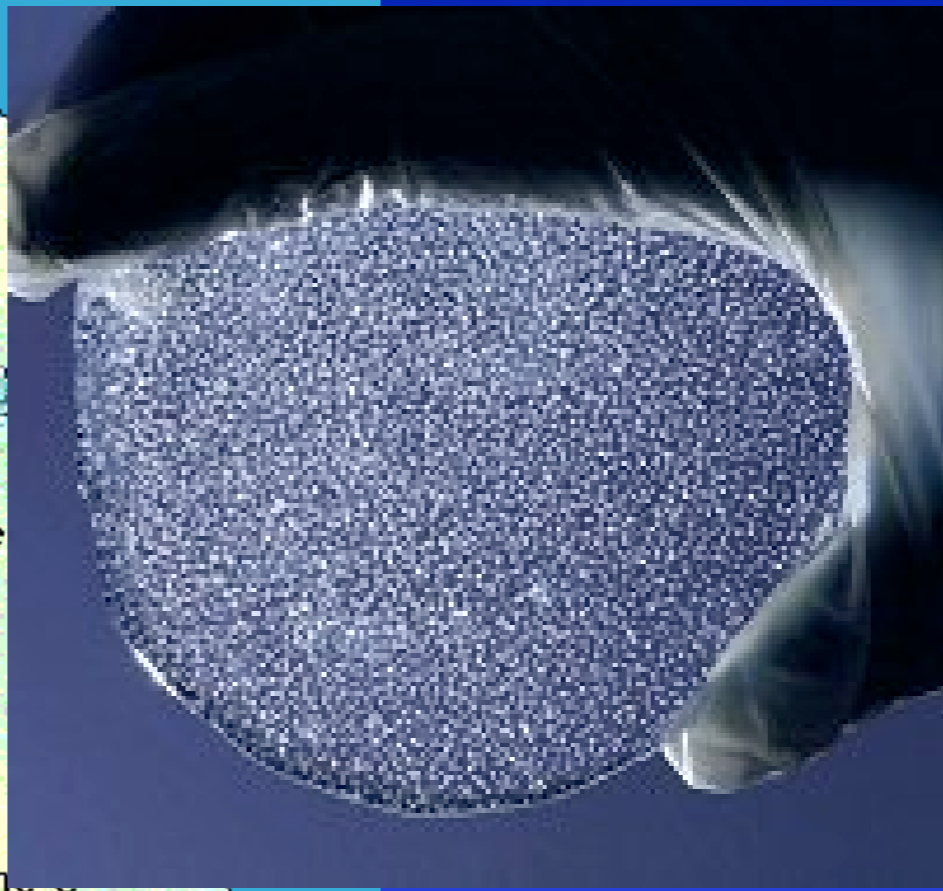
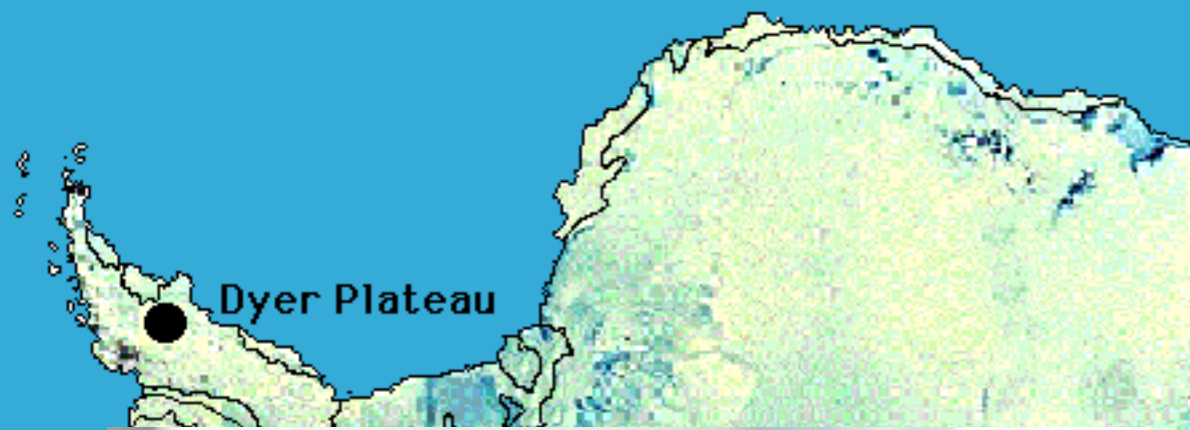


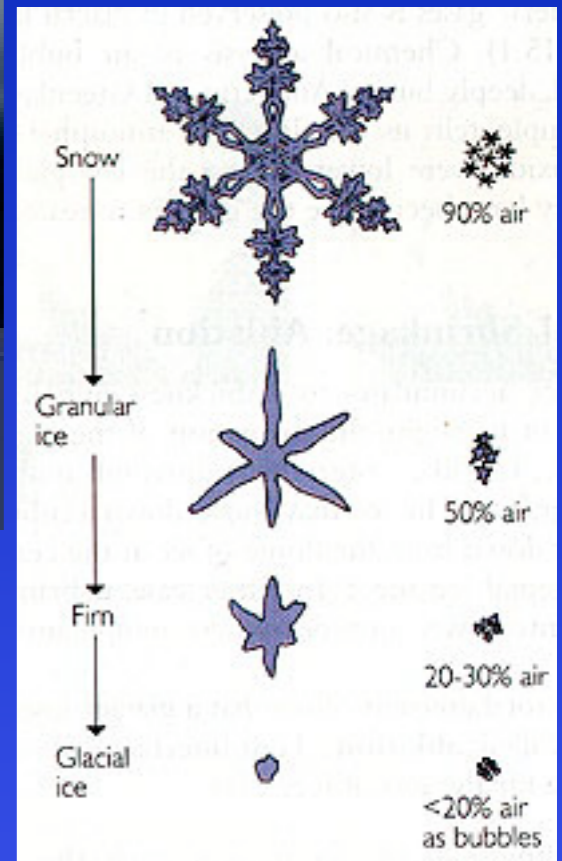
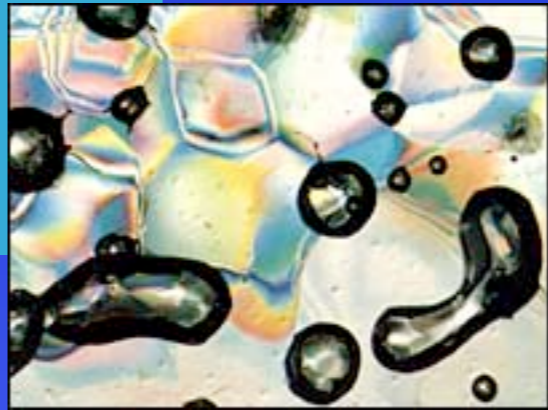
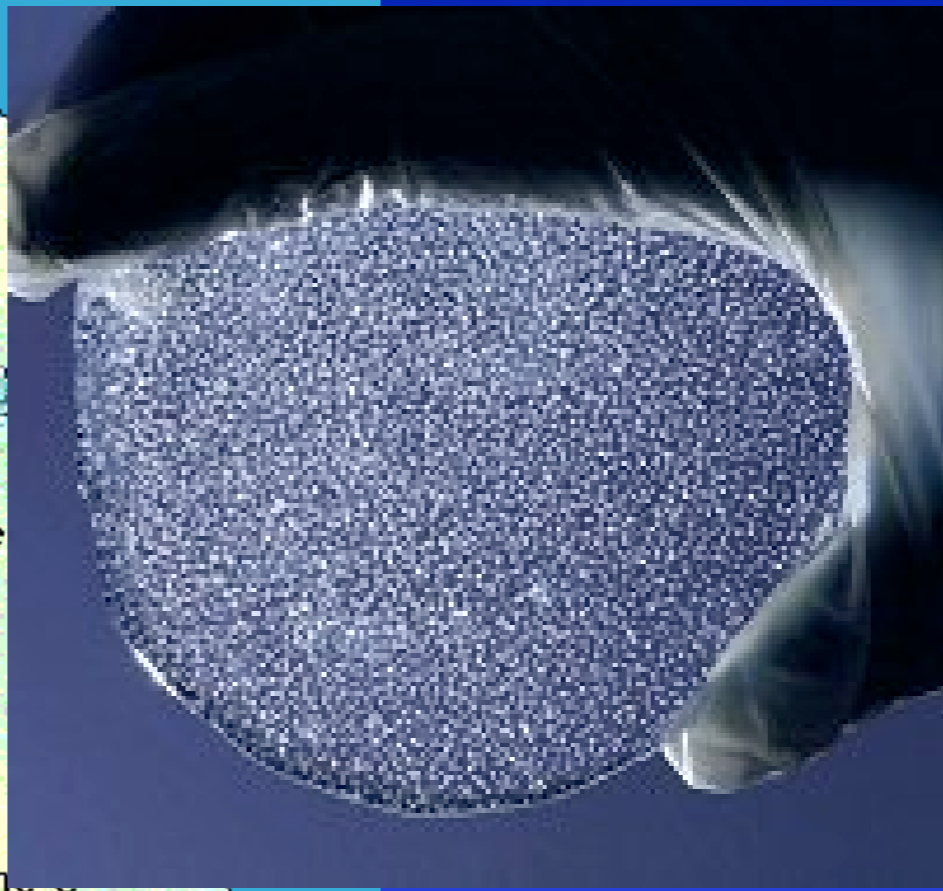
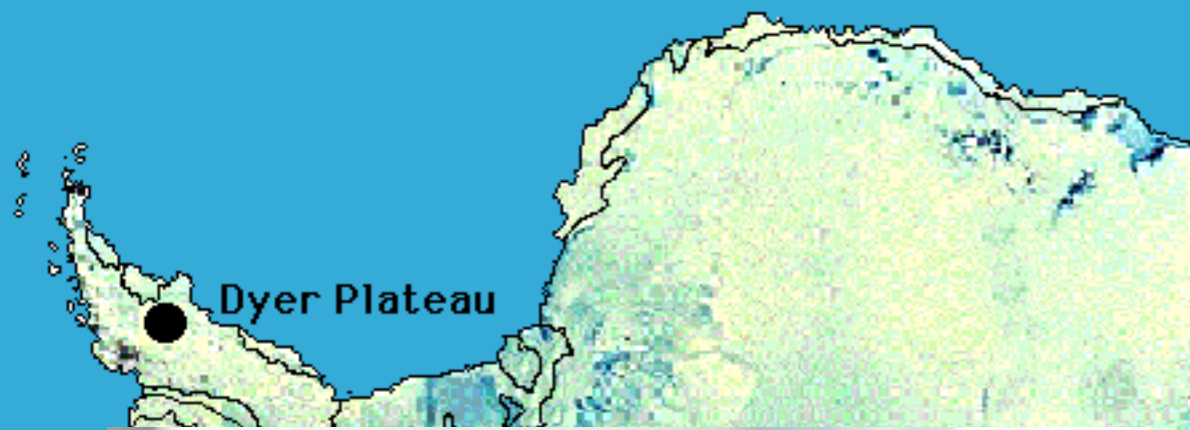
Atmospheric CO₂ at Mauna Loa Observatory

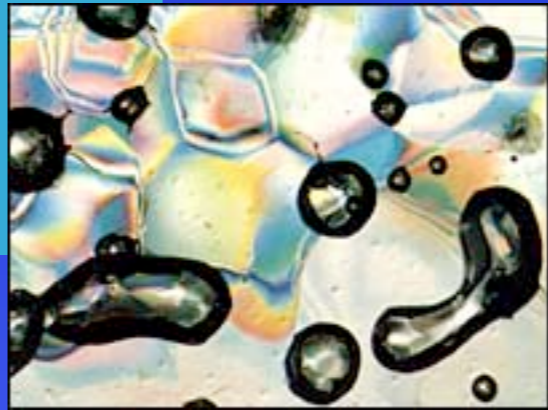
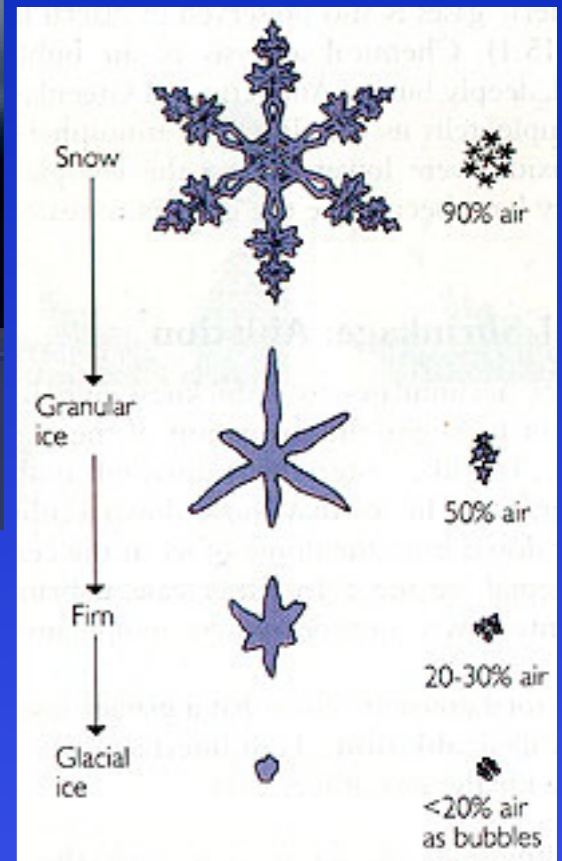
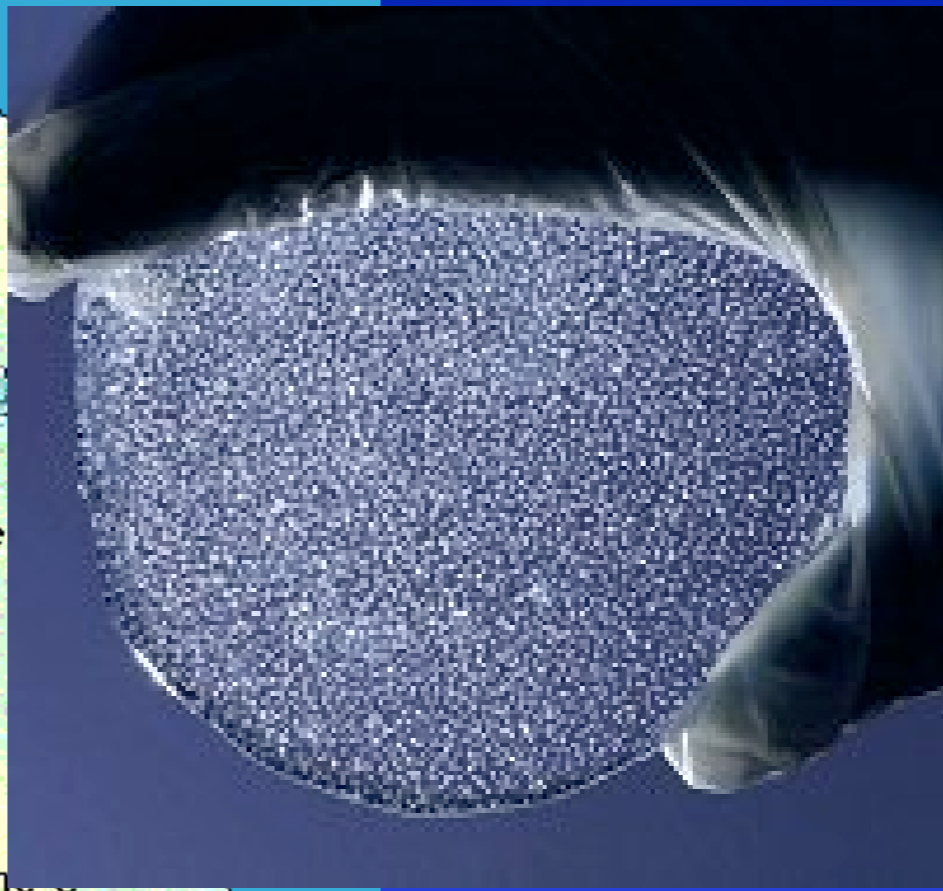
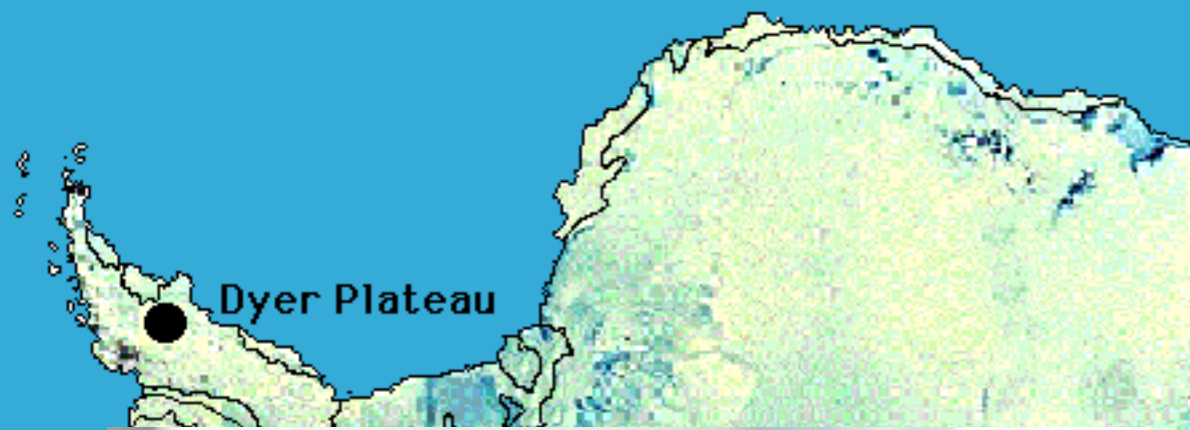




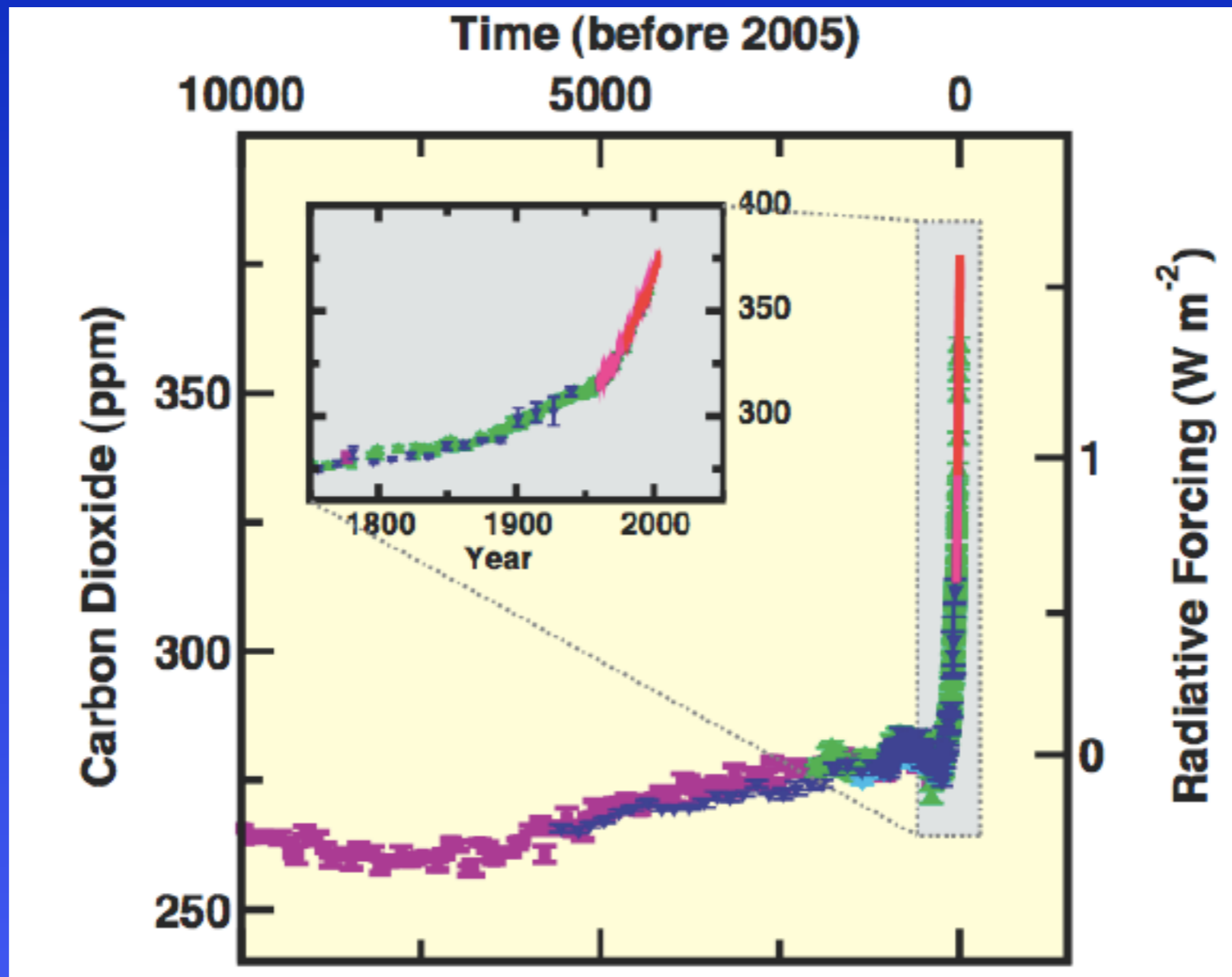








Bubbles in the ice contain ancient air

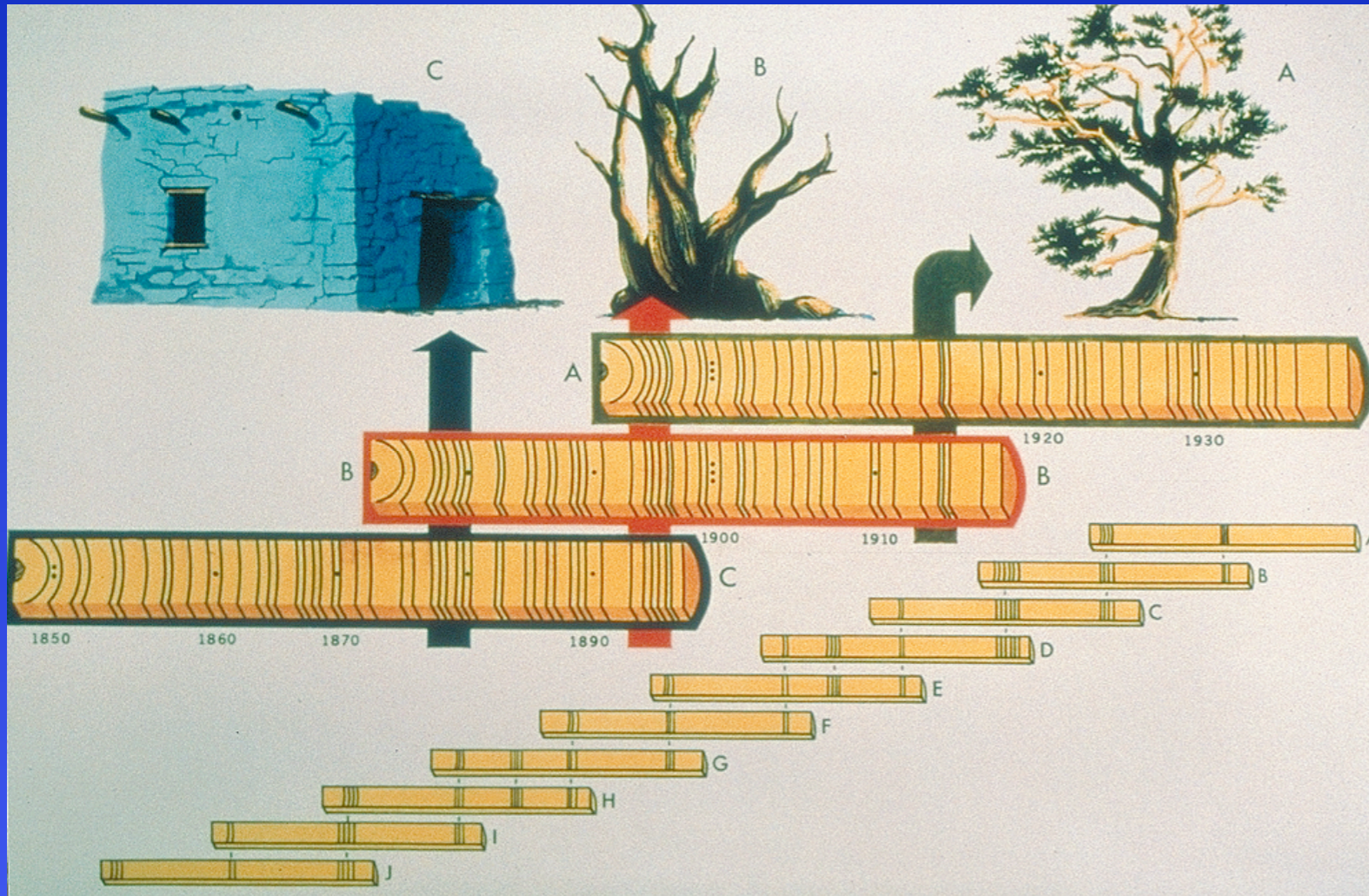


IPCC 2007

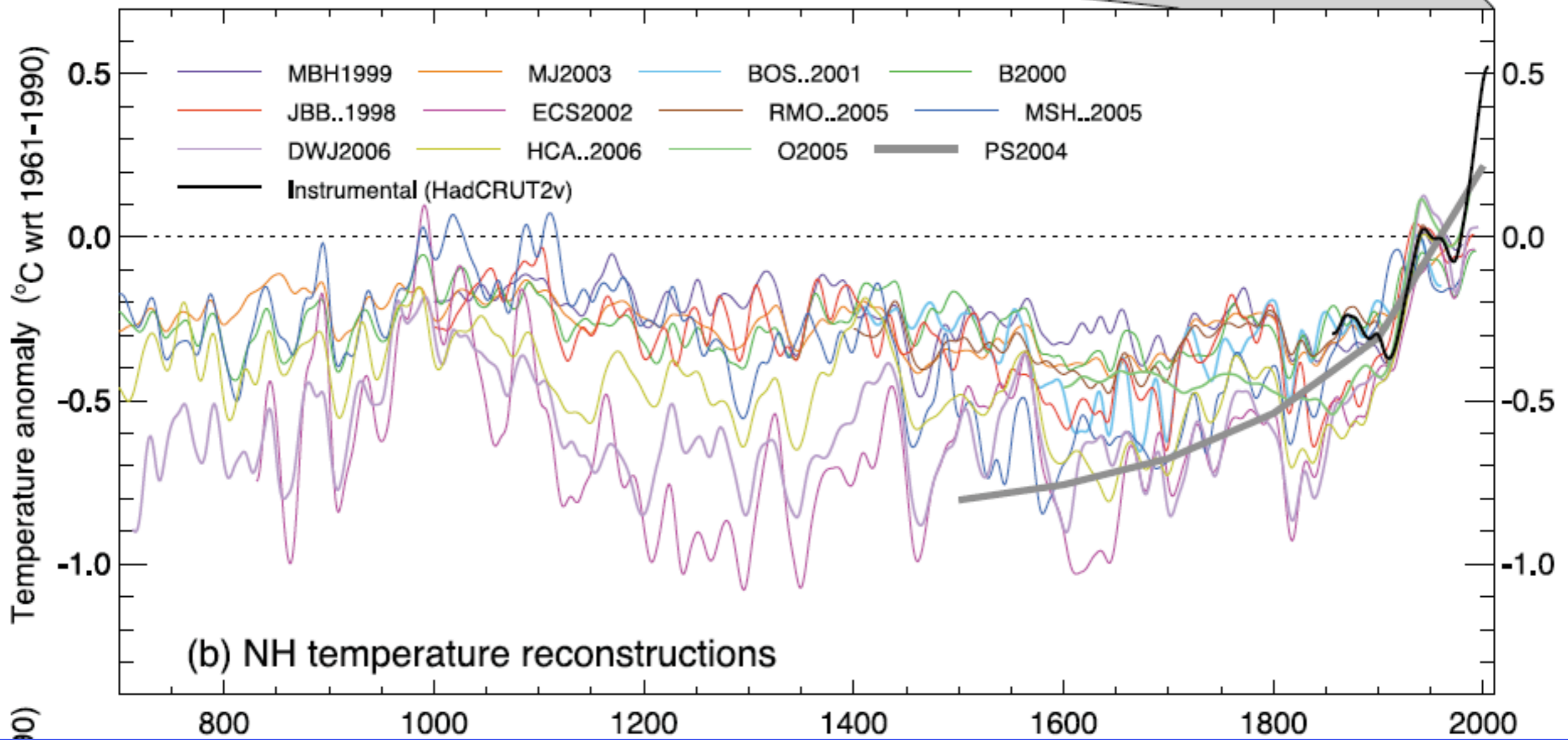
Paleoclimate Proxy Records

- Historical Documents (~1000 years)
- Tree Rings (~10,000 years)
- Corral Reefs (~100,000 years)
- Ice Cores (~800,000 years)
- Ocean Sediments (>3,000,000 years)

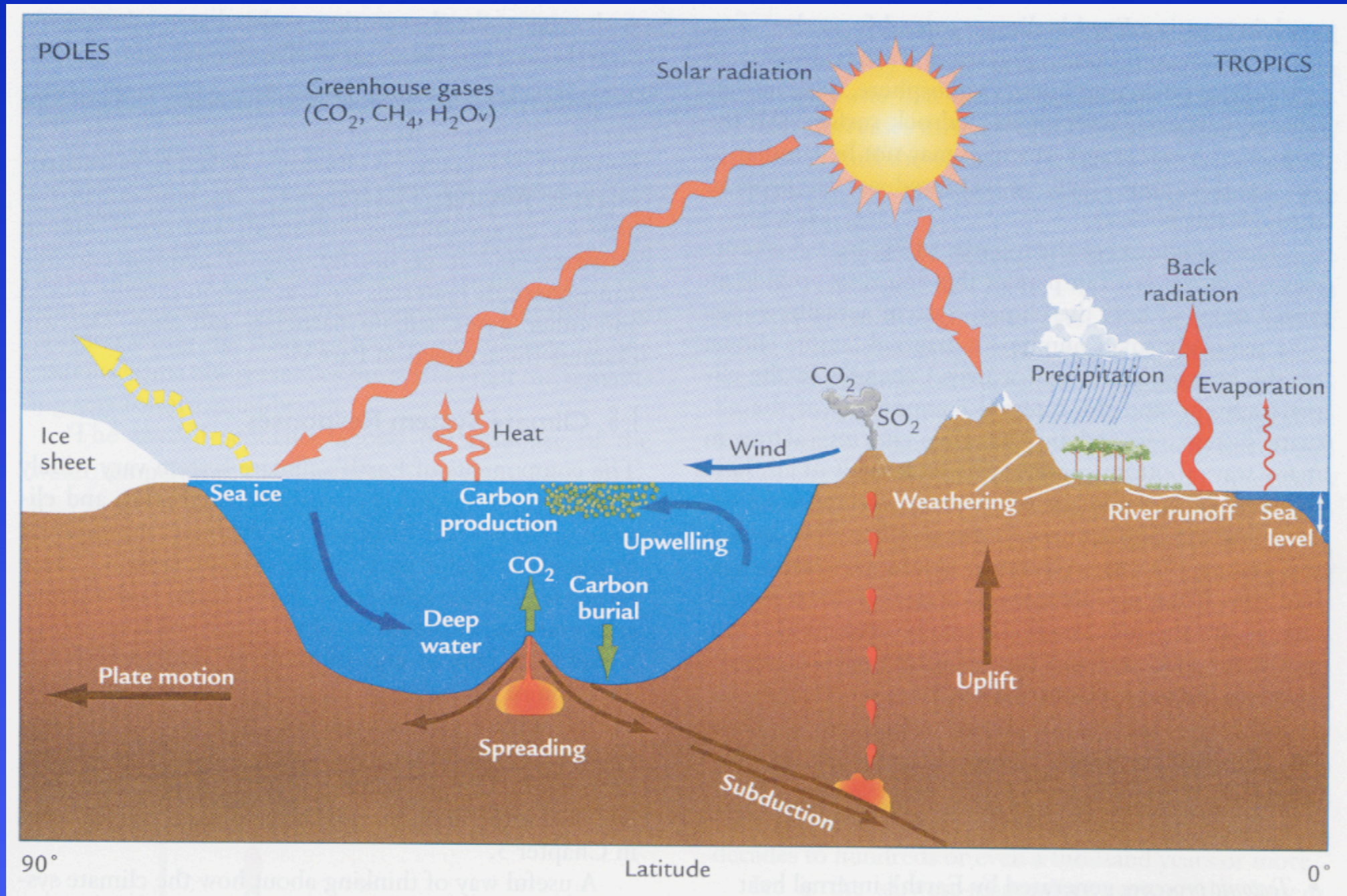
Tree Rings



- Temperature
- Precipitation
- Drought



The Climate System



The Ice Ages

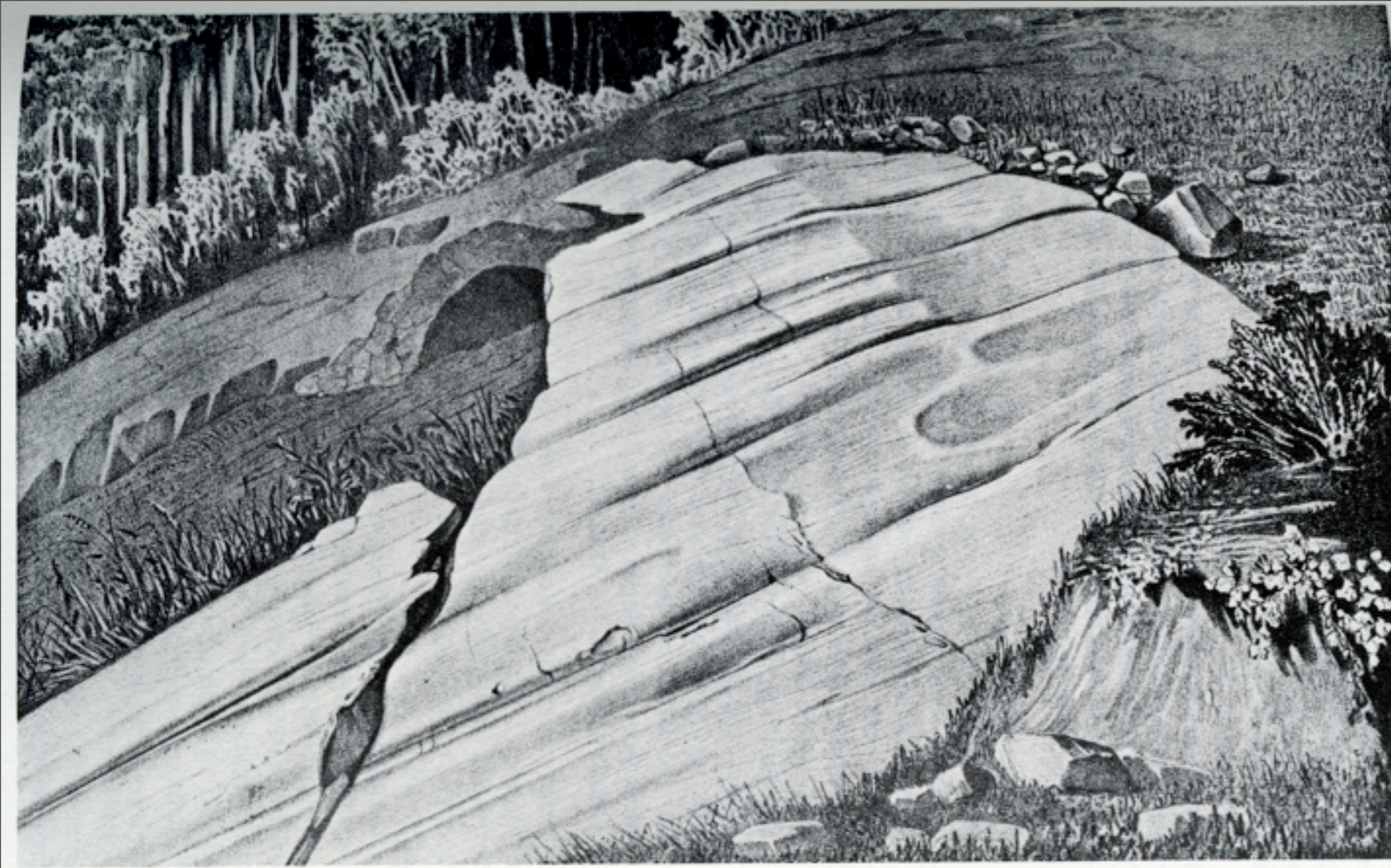


Figure 6. An illustration of polished bedrock near Neuchâtel, Switzerland published by Louis Agassiz in 1840. Agassiz argued that polished and grooved rock surfaces, occurring many miles from existing glaciers, were clear evidence of a former ice age. (From A.V. Carozzi, 1967, with permission of A.V. Carozzi and the University of Neuchâtel.)



Figure 2. Glacial deposit on Cape Ann, Massachusetts: the landscape is typical of areas once covered by ice sheets. (From J.D. Dana, 1894.)



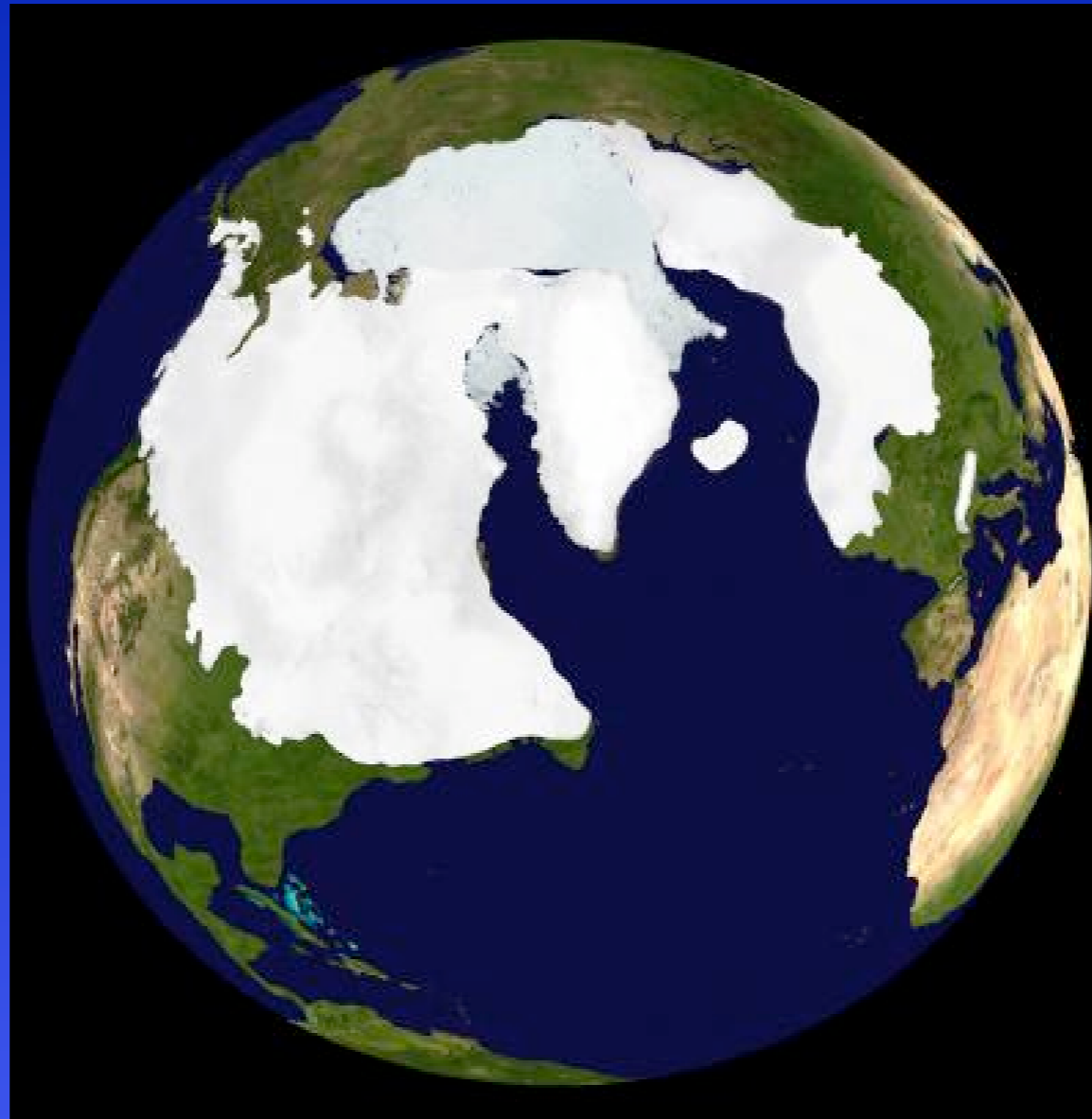
Figure 7. Erratic boulder in Scotland. Louis Agassiz attributed the occurrence of large boulders, many miles from a possible bedrock source, to the action of ice-age glaciers. (From J. Geikie, 1894.)

Wallowa Moraines



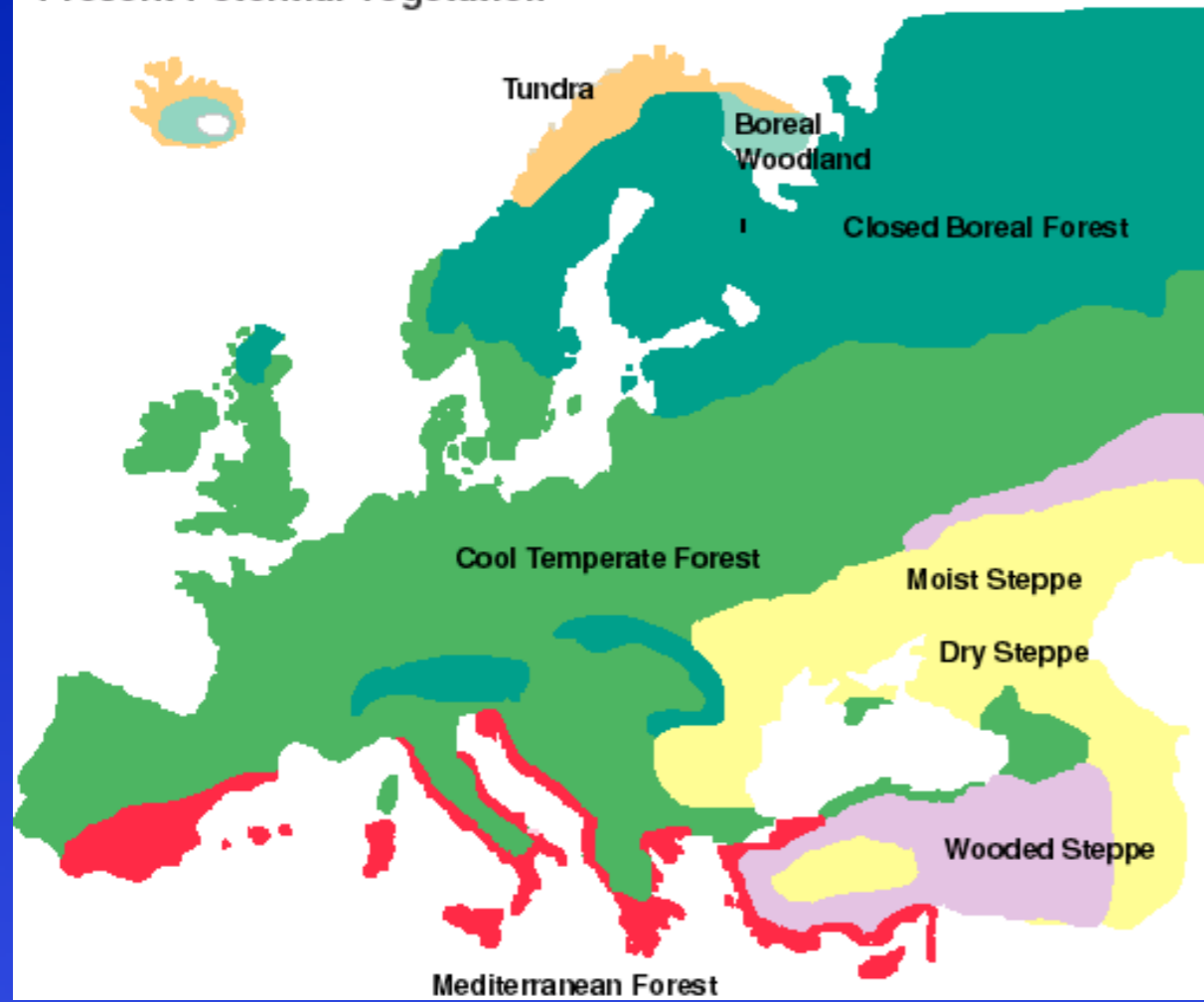
The Last Glacial Maximum

The Last Glacial Maximum (LGM, 20,000 years ago)



Note: Each successive glaciation partially erases record of previous events. How do we get a continuous record of ice sheet growth and decay?

Present Potential Vegetation



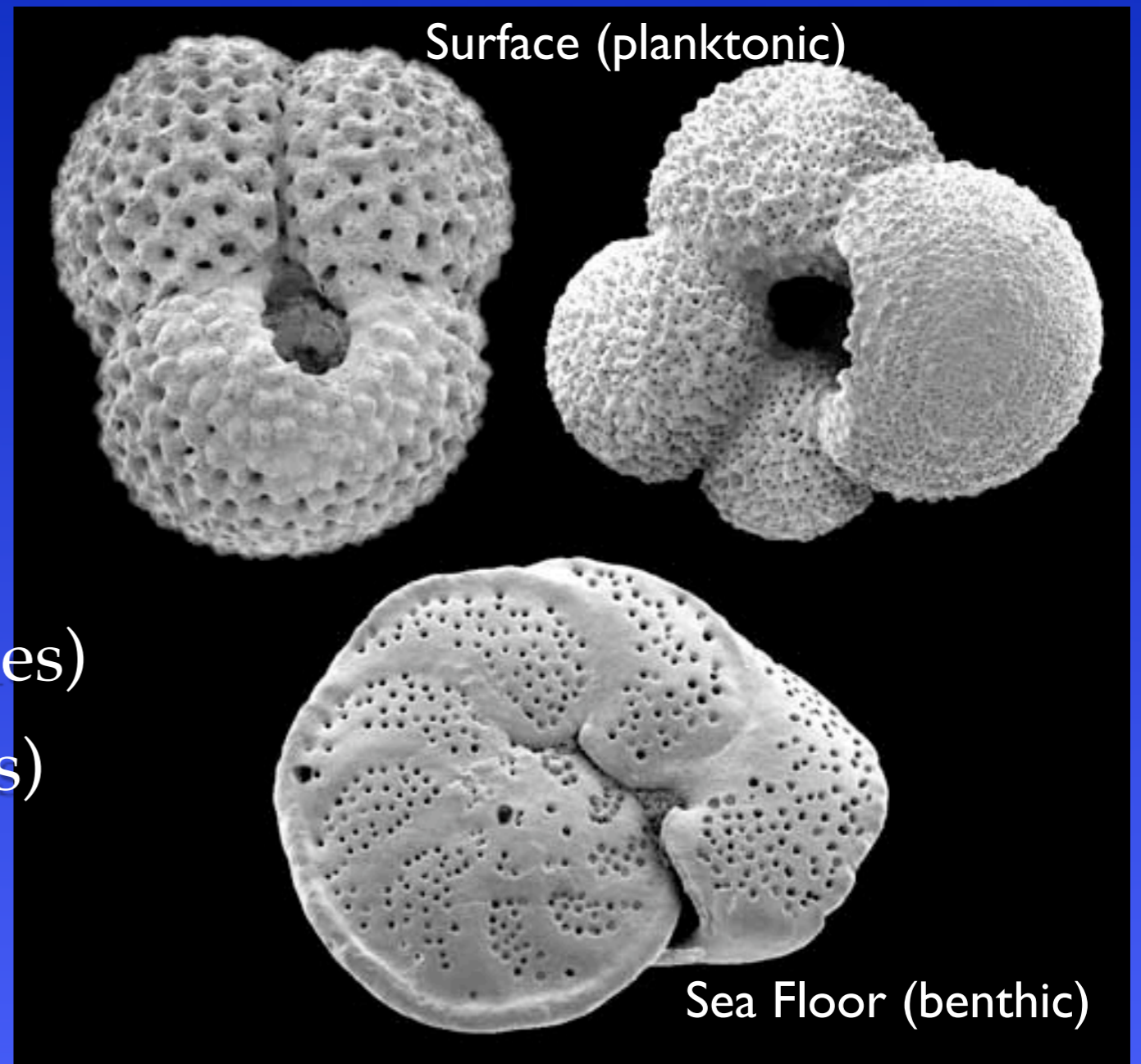
22,000 – 14,000 ¹⁴C years ago



Bugs (Foraminifera)

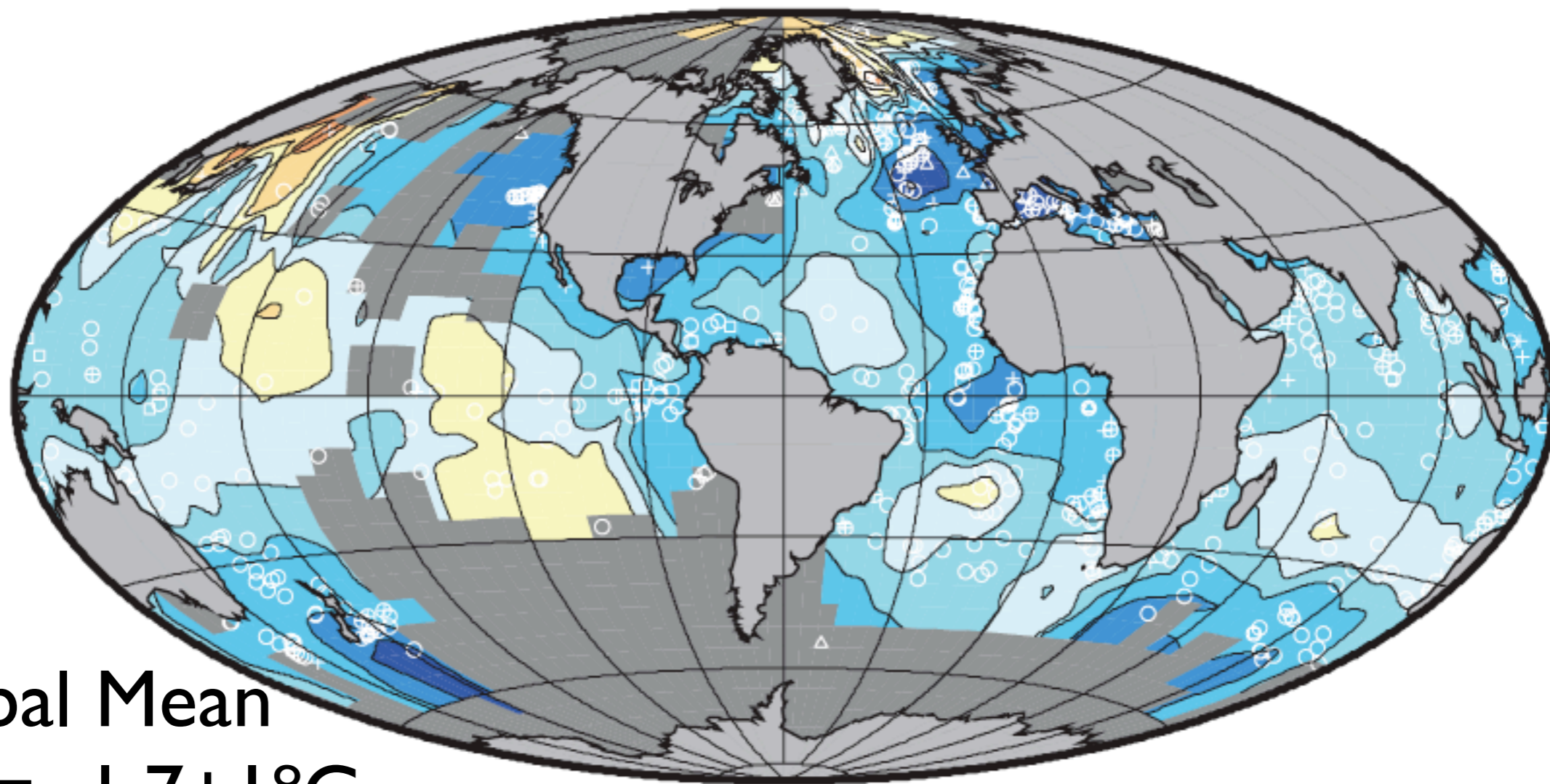


- Some like it hot (tropical species)
- Some like it cold (polar species)



Sea Surface Temperature Change at LGM

c



Global Mean
 $\Delta\text{SST} = -1.7 \pm 1^\circ\text{C}$



Annual Mean

MARGO (2009)

The Deglaciation

Note: Each successive glaciation partially erases record of previous events. How do we get a continuous record of ice sheet growth and decay?

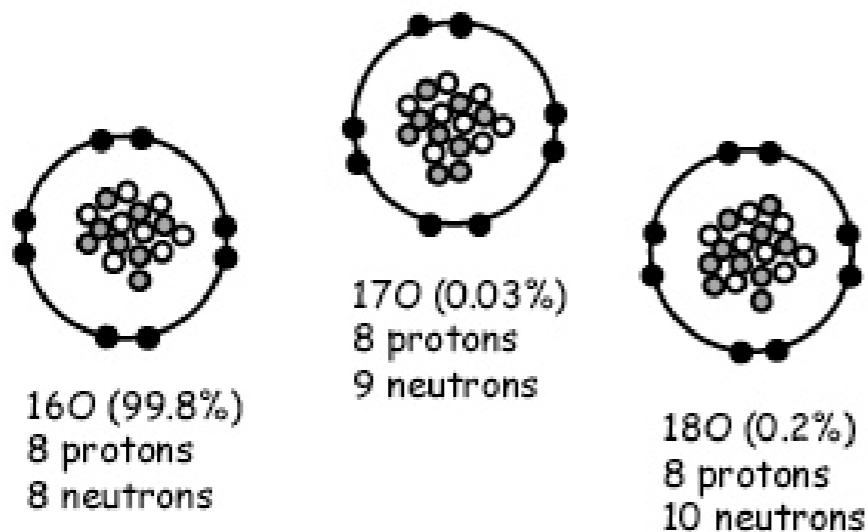
The Deglaciation



Note: Each successive glaciation partially erases record of previous events. How do we get a continuous record of ice sheet growth and decay?

- Isotopes of an element have same number of protons.
- Differ by number of neutrons
- Chemically identical
- Only processes that are mass dependent can separate isotopes

Oxygen Isotopes:



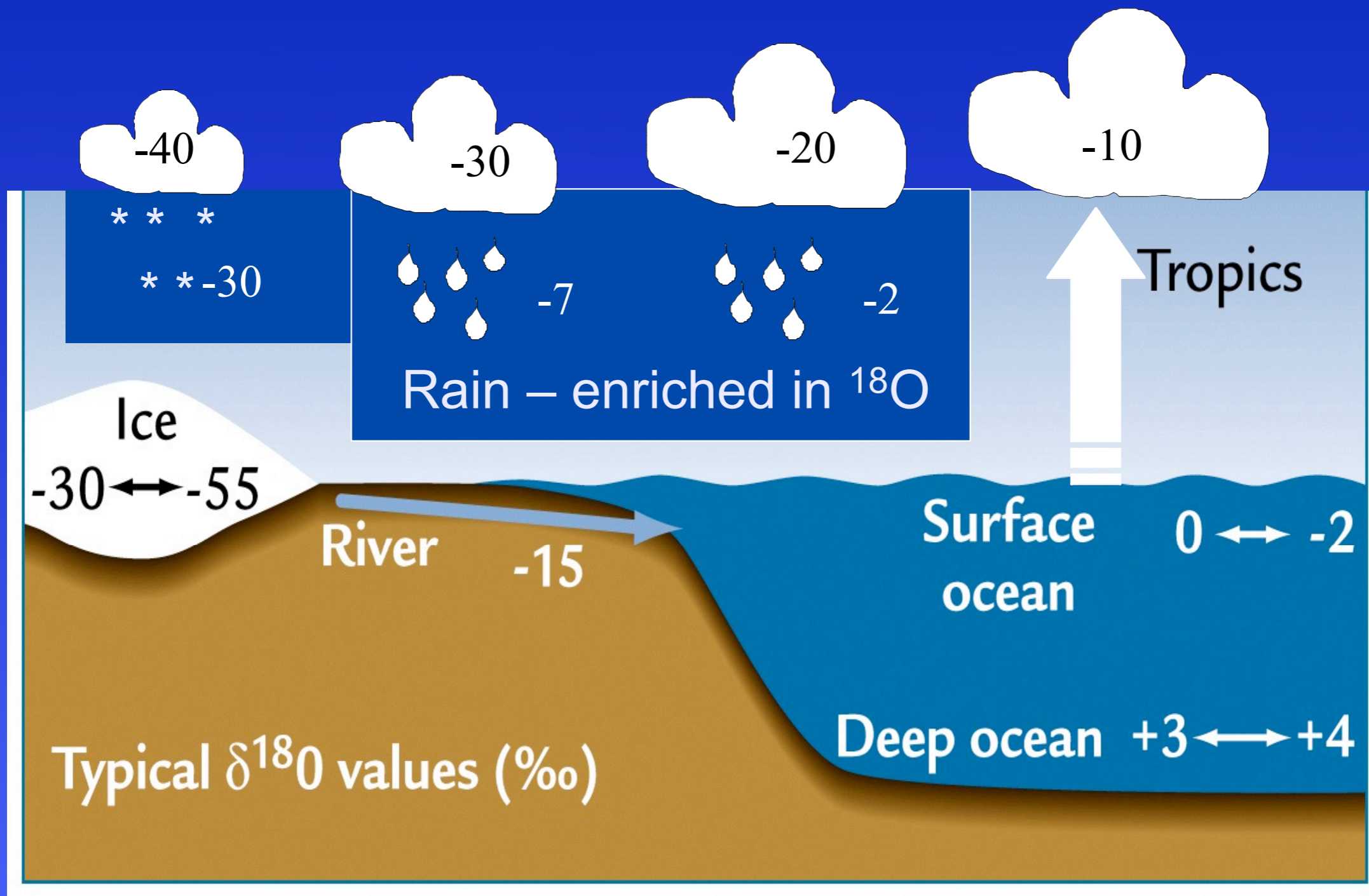
**So what does this have to do with
glaciers?**

**Where does the water in glaciers
come from?**

Isotope Fractionation

- Evaporation -- favors ^{16}O
- Precipitation -- favors ^{18}O

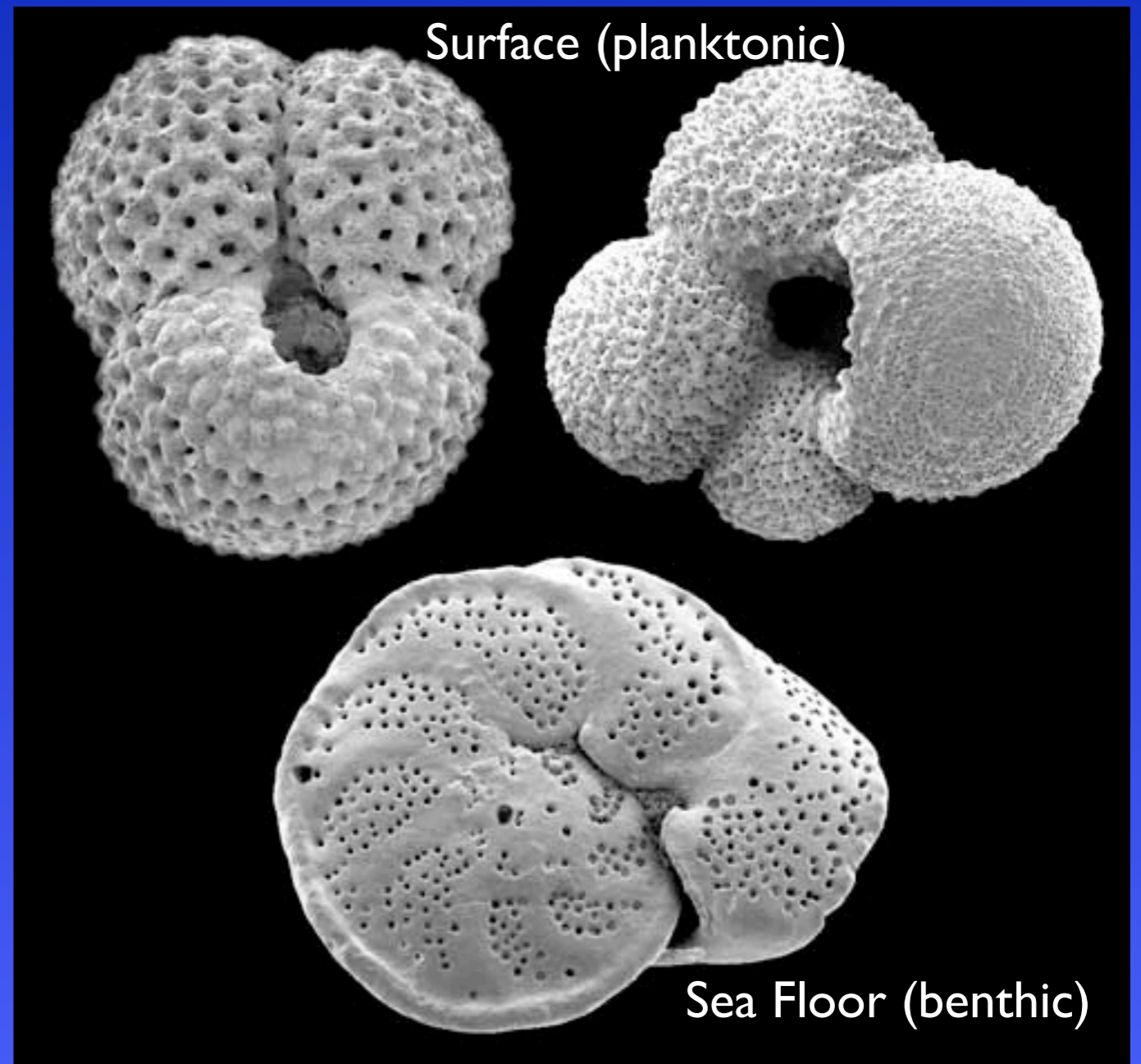
So evaporation makes atmosphere gets “lighter” (more ^{16}O) and oceans “heavier” (more ^{18}O)

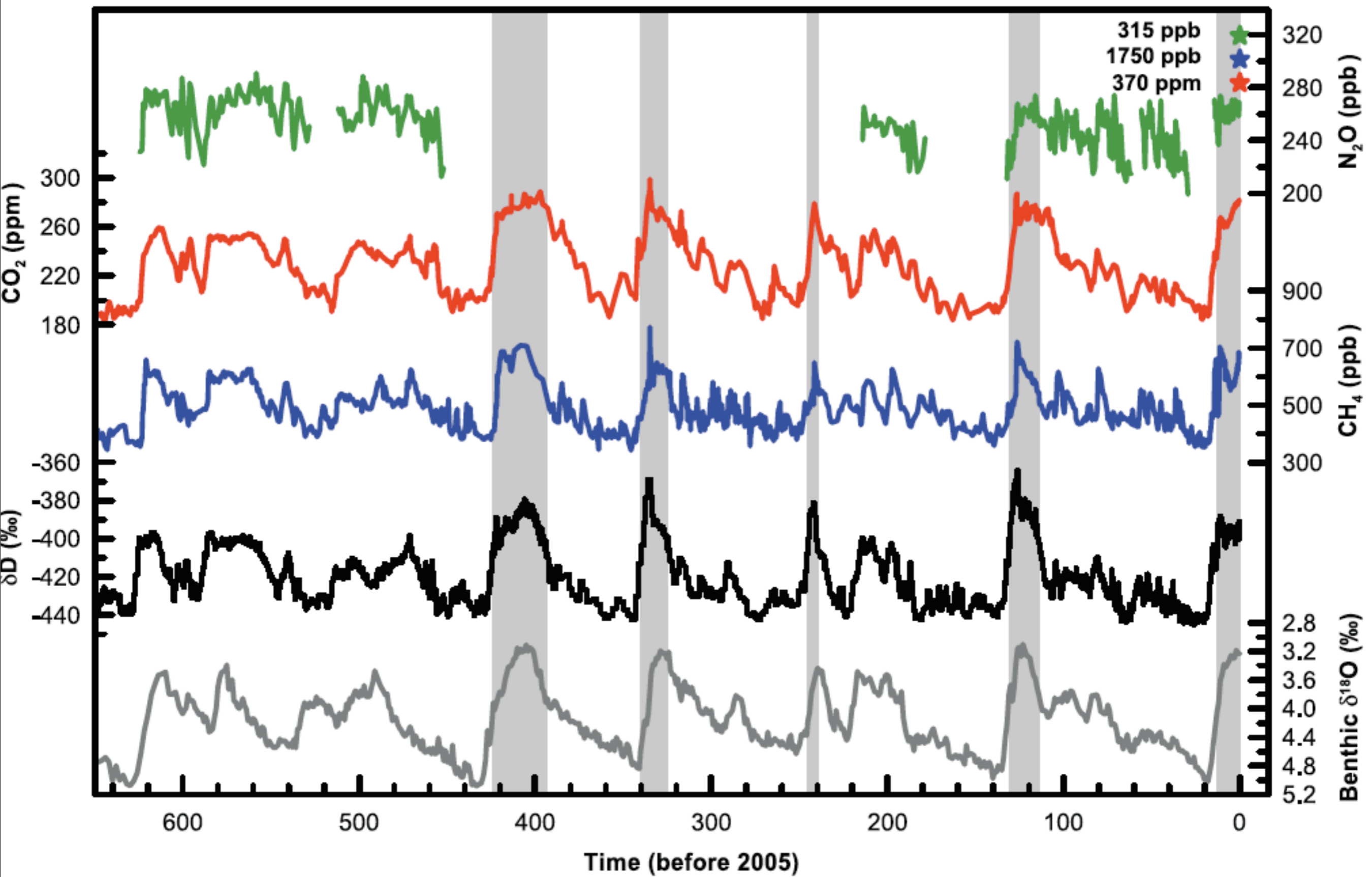


Bugs (Foraminifera)

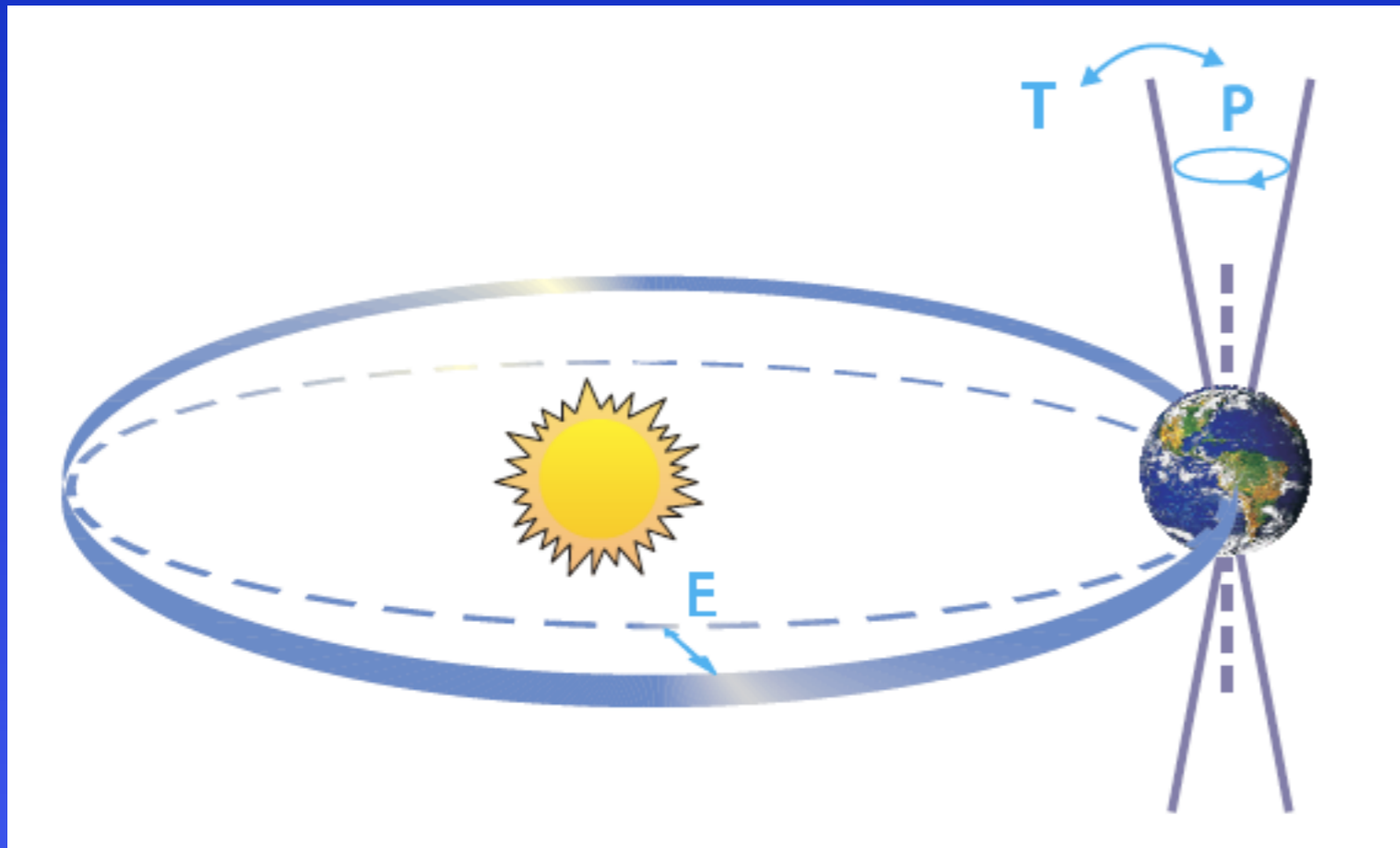


- Calcium Carbonate - CaCO_3
- Oxygen isotope content of the CaCO_3 tracks oxygen isotope content of the seawater.





Earth's Orbit Around the Sun



Eccentricity (100,000 yr)

Tilt (41,000 yr)

Precession (23,000 yr)

Ice Sheet Fluctuations

- Beginning 2.7 Myr
- Dominated by Tilt until 1.0 Myr
- Now dominated by Eccentricity
- Why??

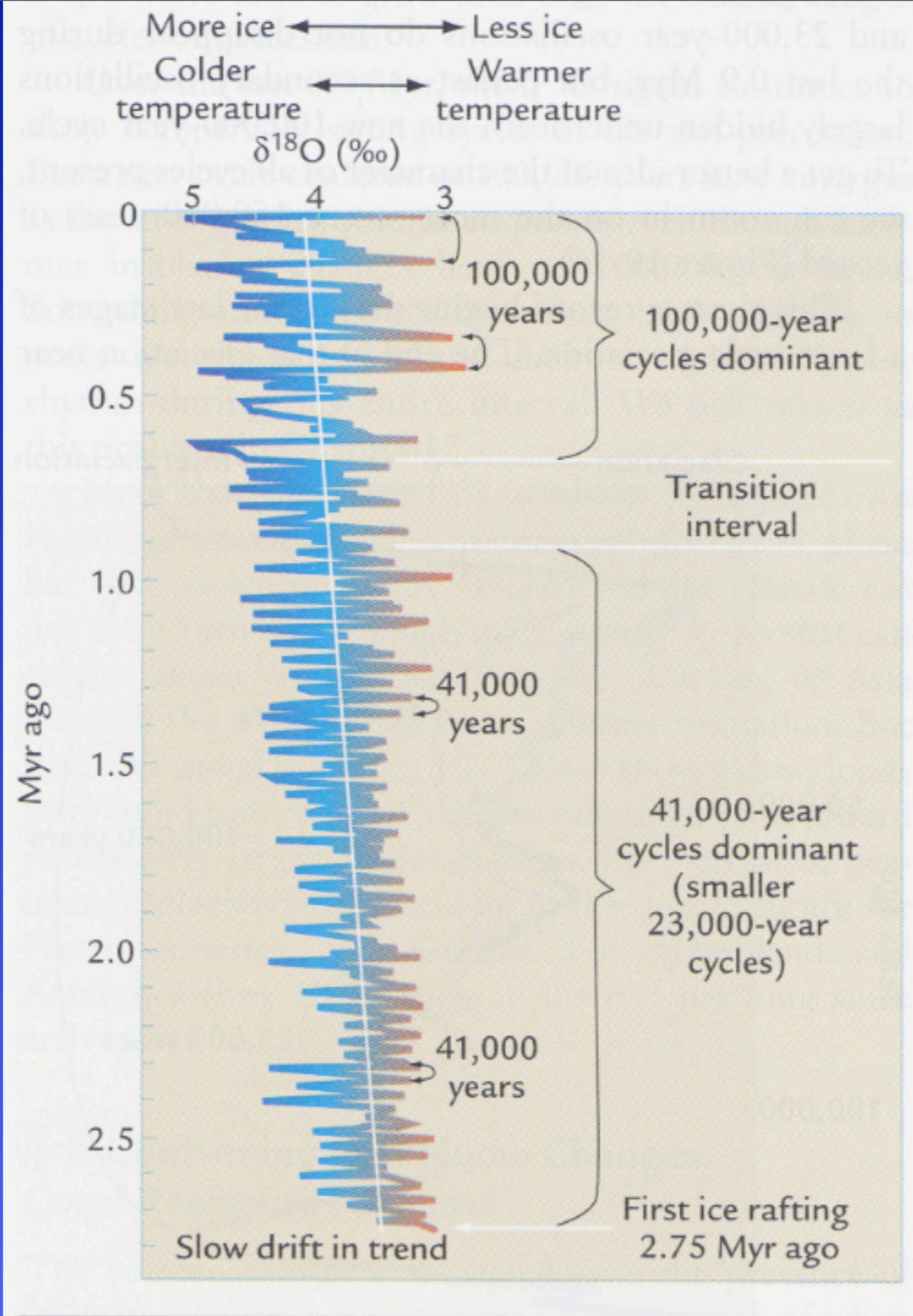
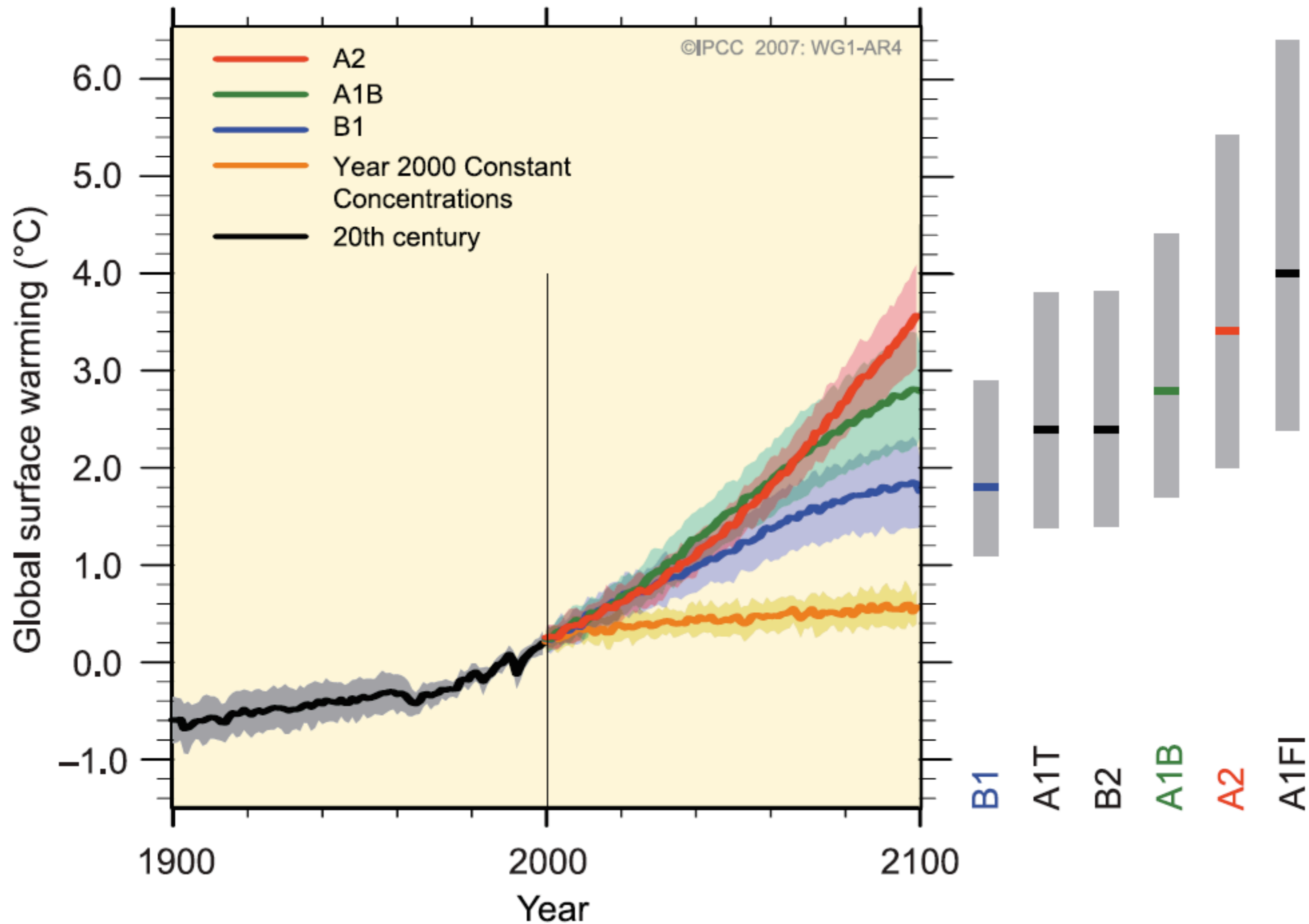


FIGURE 10-15 Evidence of ice sheet evolution: $\delta^{18}\text{O}$ A North

MULTI-MODEL AVERAGES AND ASSESSED RANGES FOR SURFACE WARMING



Summary

- Ocean Sediments reveal natural variability of Earth's climate system
- Succession of ice ages (0-3Ma) determined by changes in Earth's orbit around the sun
- Climate and CO₂ tightly coupled