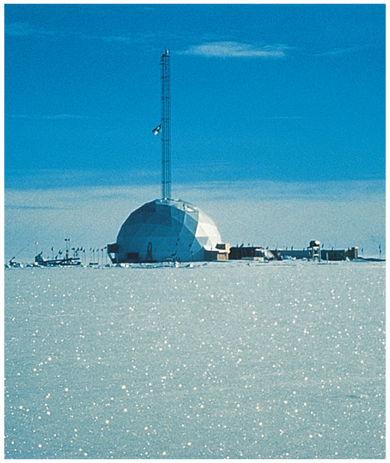
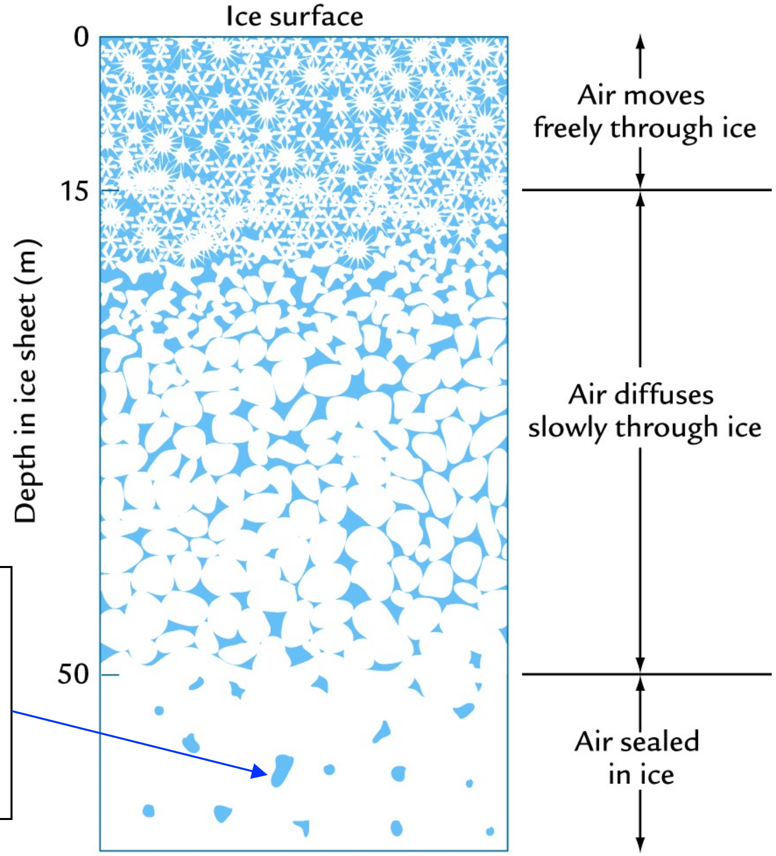
Lecture 20: Ice Core Records & Carbon Isotopes and Orbital Changes in Deep Water

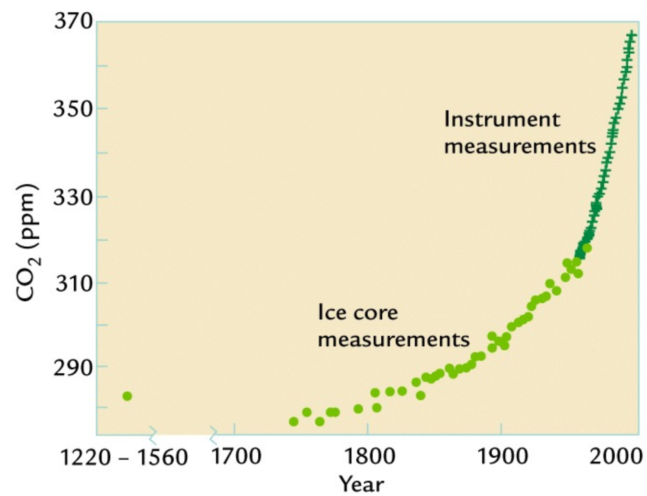
Reading: Chapter 10 (p. 175-190);
Appendix II: p. 363-364

Ice Core and Instrumental CO_2 and CH_4 Measurements

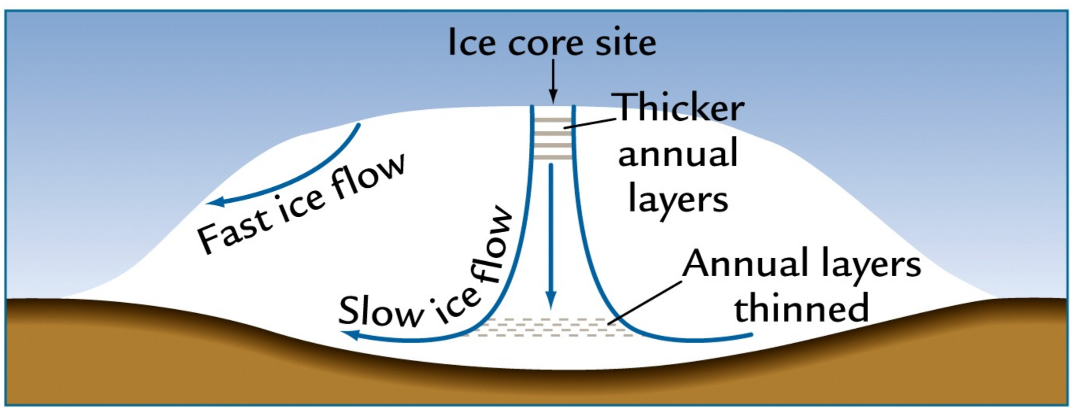


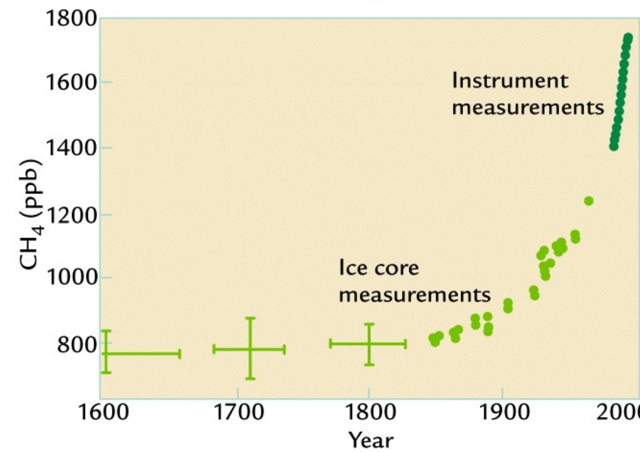


Mid-18th century: 280 ppm
Early 20th century: 300 ppm
1958: 315 ppm
Now: ~381 ppm (in 2006)

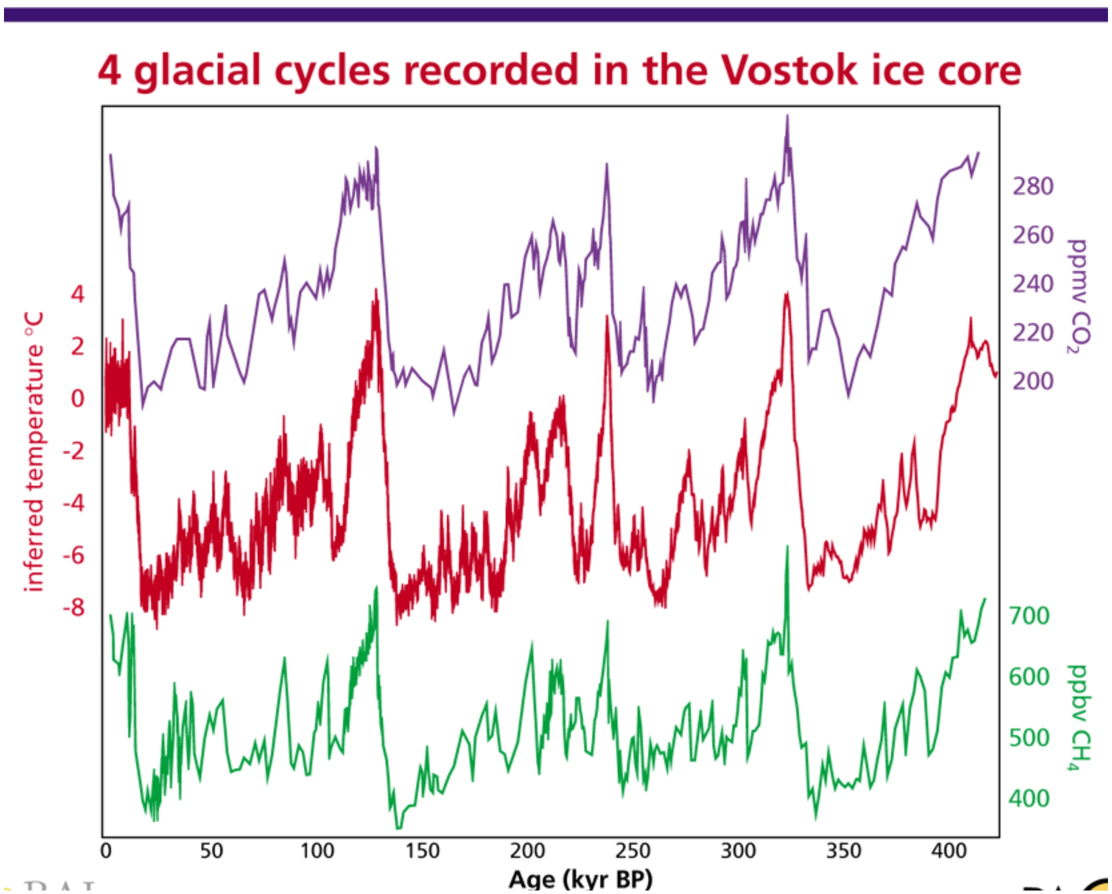


Atmospheric CO_2 is ~2000 years younger than the ice layers





Temperatures over last 400,000 years



- Carbon dioxide has varied from ~ 180 – 310 ppmv.
- 385 ppmv (in 2008)

- Inferred temperature has varied from ~ 8ºC cooler than present during glacial periods to ~ 4ºC warmer during interglacial periods.

- Methane has varied from ~ 350 – 800 ppbv; ~ 1790 ppbv (in 2008)

Orbital-Scale Changes in CO_2

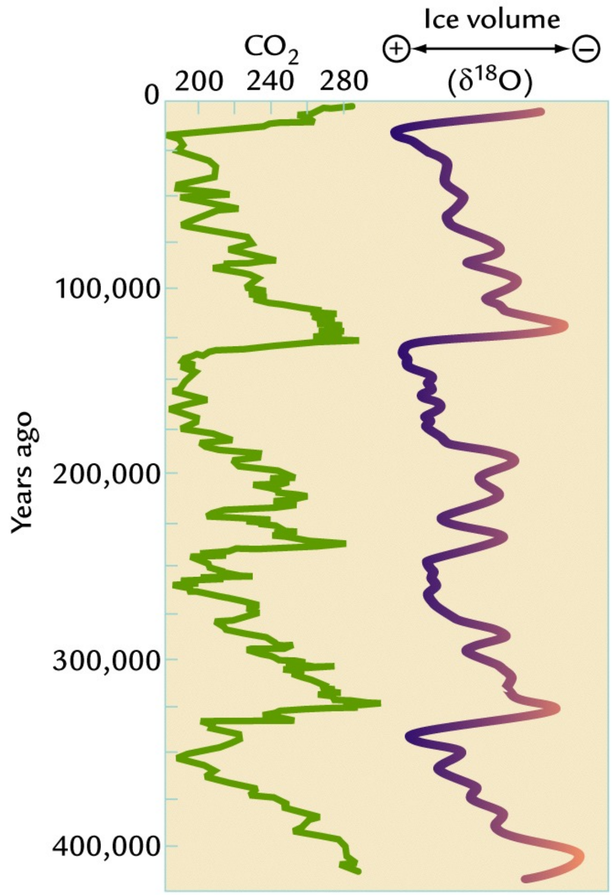
Vostok Ice in Antarctica

Four 100,000-year cycles

23,000-year cycle not prominent

Maxima: 280-300 ppm

Minima: 180-190 ppm



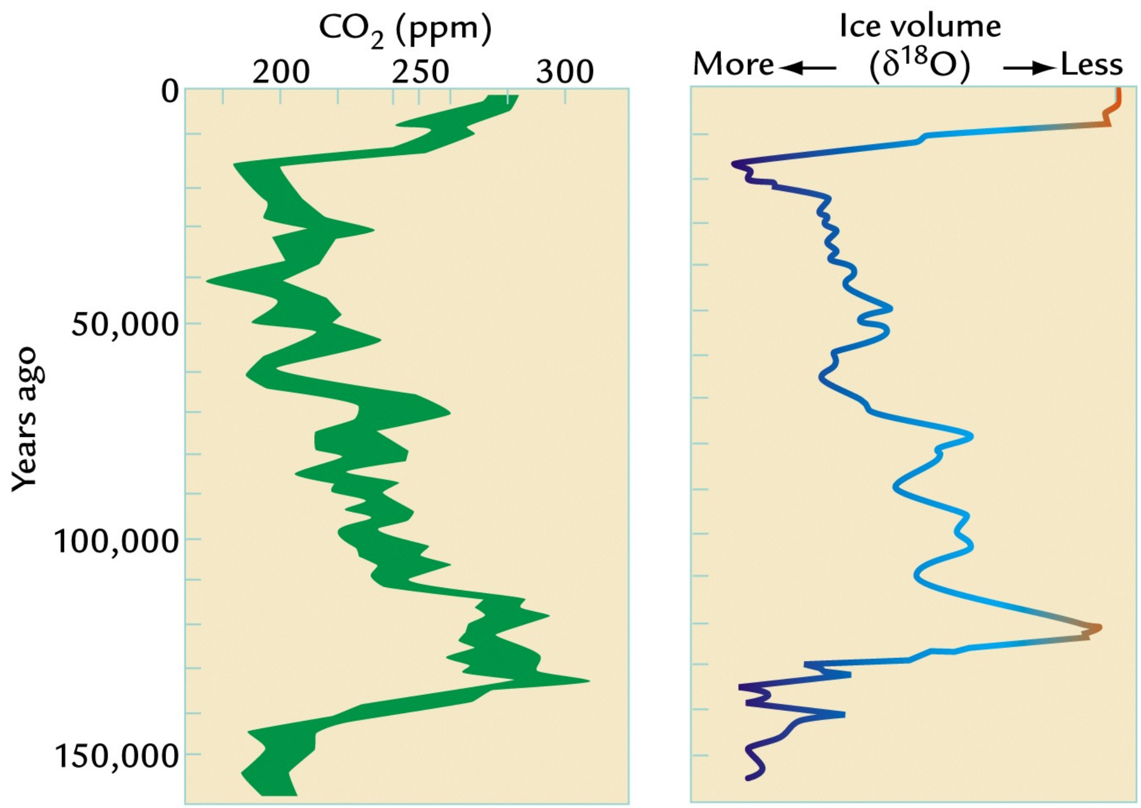
Major CO_2 cycles match marine $\delta^{18}O$ (ice volume) cycles in an overall sense

Which is driving which?

Difficulties:

Low accuracy in dating in Antarctica

Dust reacts with CO_2 bubbles in Greenland



How do we determine the carbon sources/sinks? - Carbon Isotope Ratios

Isotopes are forms of a chemical element that have the same atomic number but differ in mass.

Carbon is made up of two stable isotopes: carbon 12 (also known as ^{12}C → 6 protons + 6 neutrons; a "light" carbon);

Carbon 13 (aka ^{13}C → 6 protons + 7 neutrons; a "heavy" carbon).

12 and 13 are atomic masses of isotopes ^{12}C and ^{13}C.

The relative amounts of these two isotopes in a sample of water, air, vegetation is a function of climate/environment

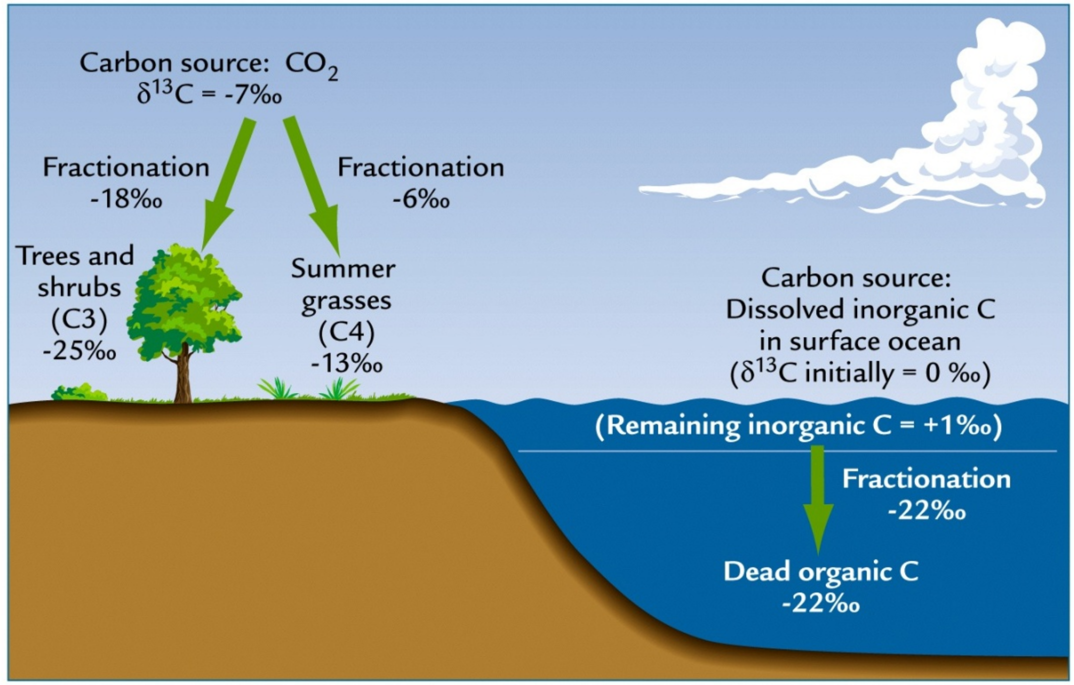
^{12}C ~99% ^{13}C ~1%

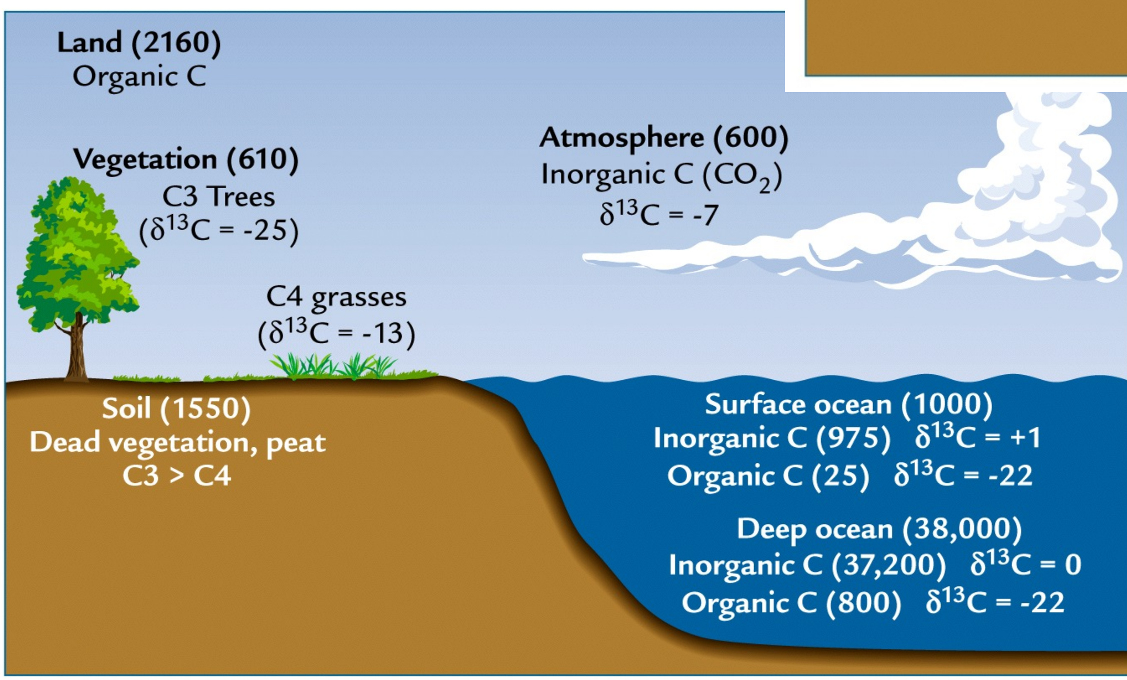
$^{13}C/^{12}C = 0.01$

The relative amounts are expressed as $\delta^{13}C$, which compares $^{13}C/^{12}C$ with a laboratory standard.

Typical δ^{13}C Values in the Climate System

Enrichment process (isotope fractionation): The lighter ^{12}C is incorporated in living tissues more easily during photosynthesis.





δ^{13}C values:

All land: –25‰
All oceans: 0‰

How Could CO_2 Vary Over Orbital-Scales?

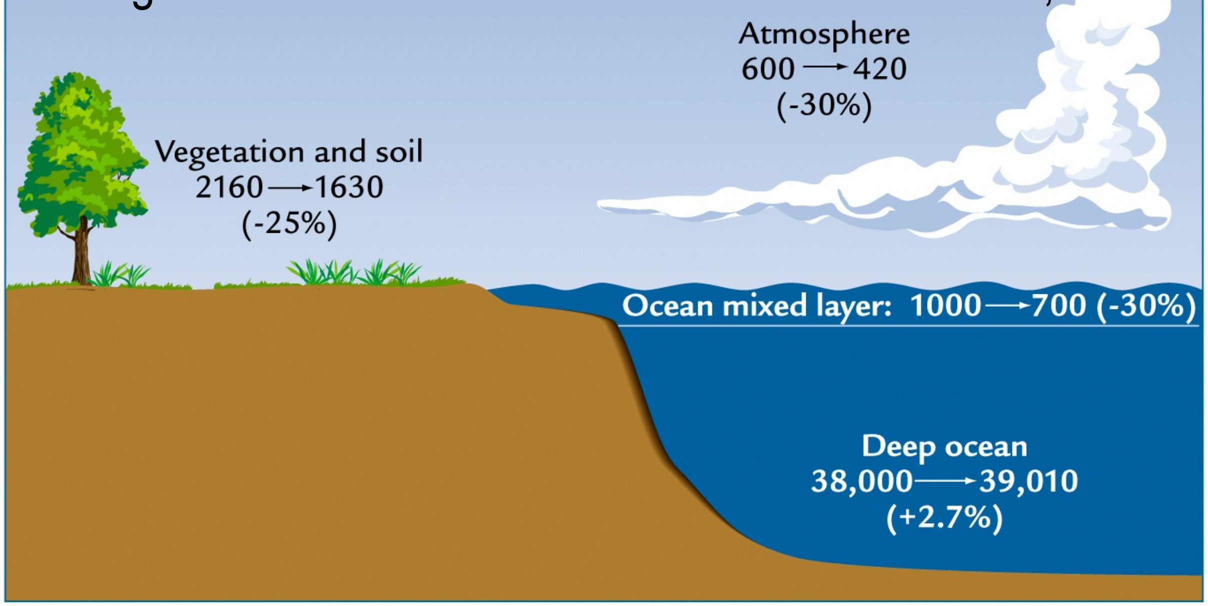
Atmosphere: 30% decrease (90 ppm)

TABLE 11-1 Physical Causes of Lower CO_2 Levels in the Glacial Atmosphere

Properties of ocean surface waters	CO_2 change (parts per million)
Cooling by ~2.5°C	−22
Increase in salinity by 1.1‰	+11
All physical properties	−11

Temperature and salinity of surface oceans explains 10% of the reduction.

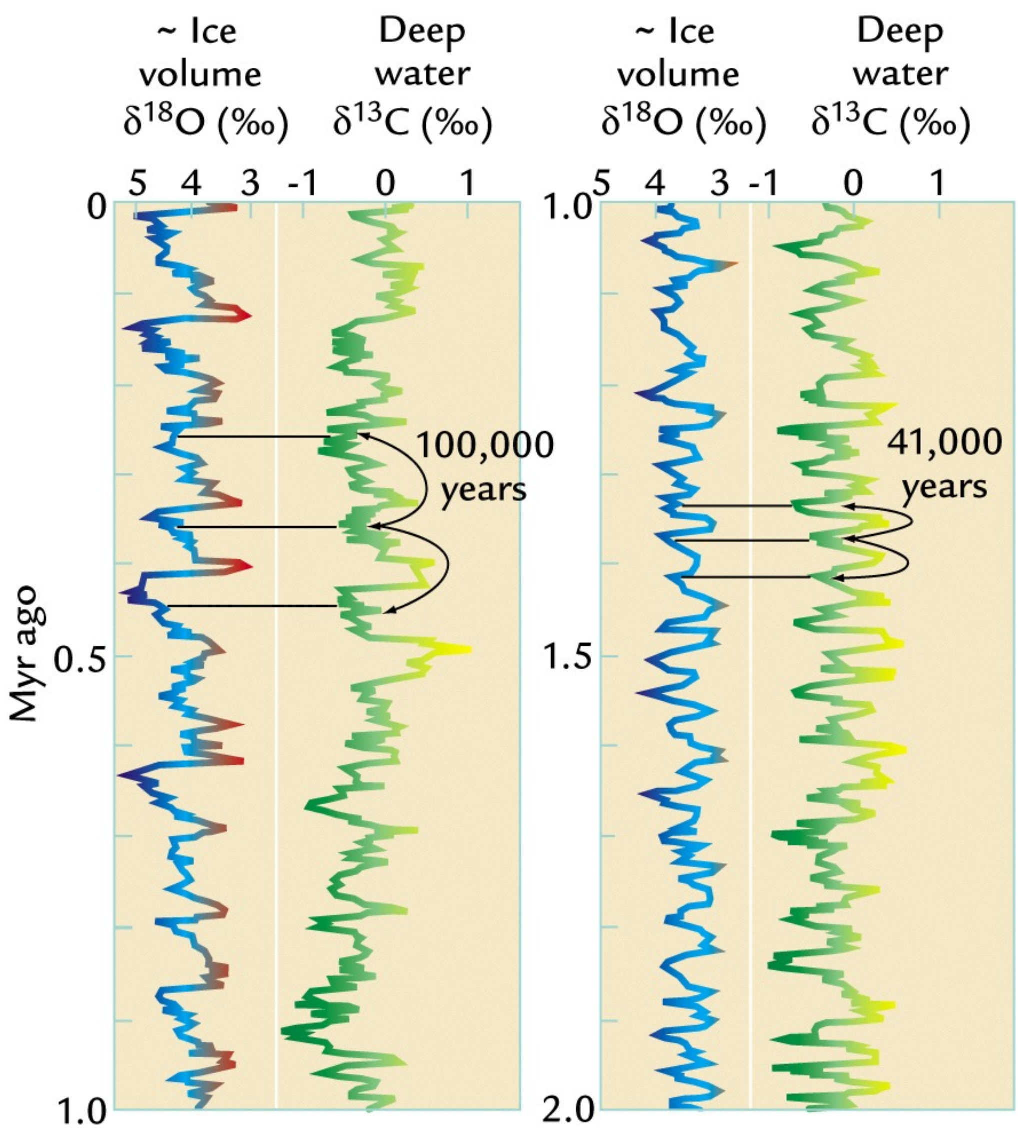
Change of carbon between current and LGM climate, $\delta^{13}C$

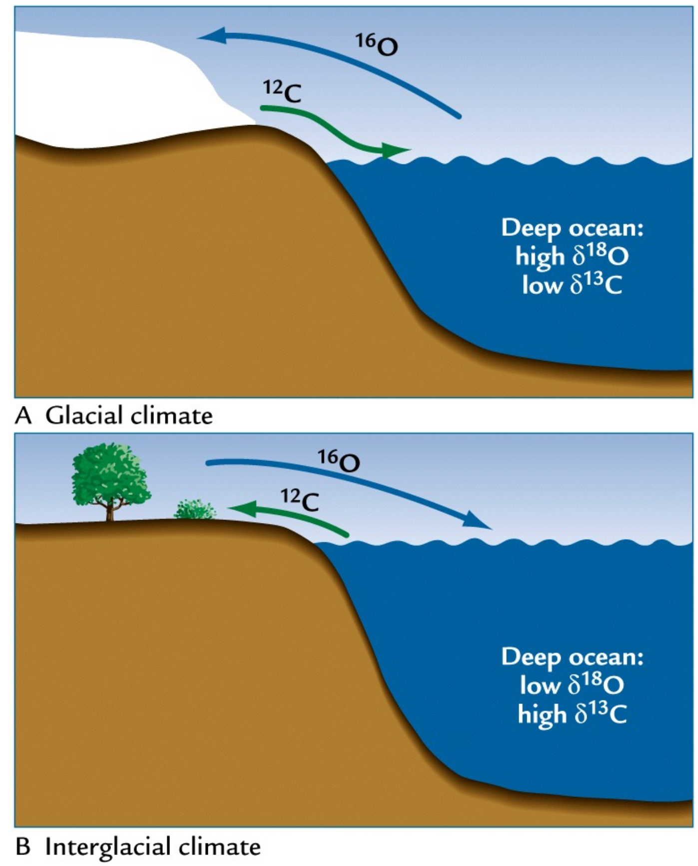


Strong carbon pump, iron fertilization and stronger upwelling of deep ocean water.

The atmosphere (and other) carbon is stored in deep ocean.

Carbon Transfers During Glaciations

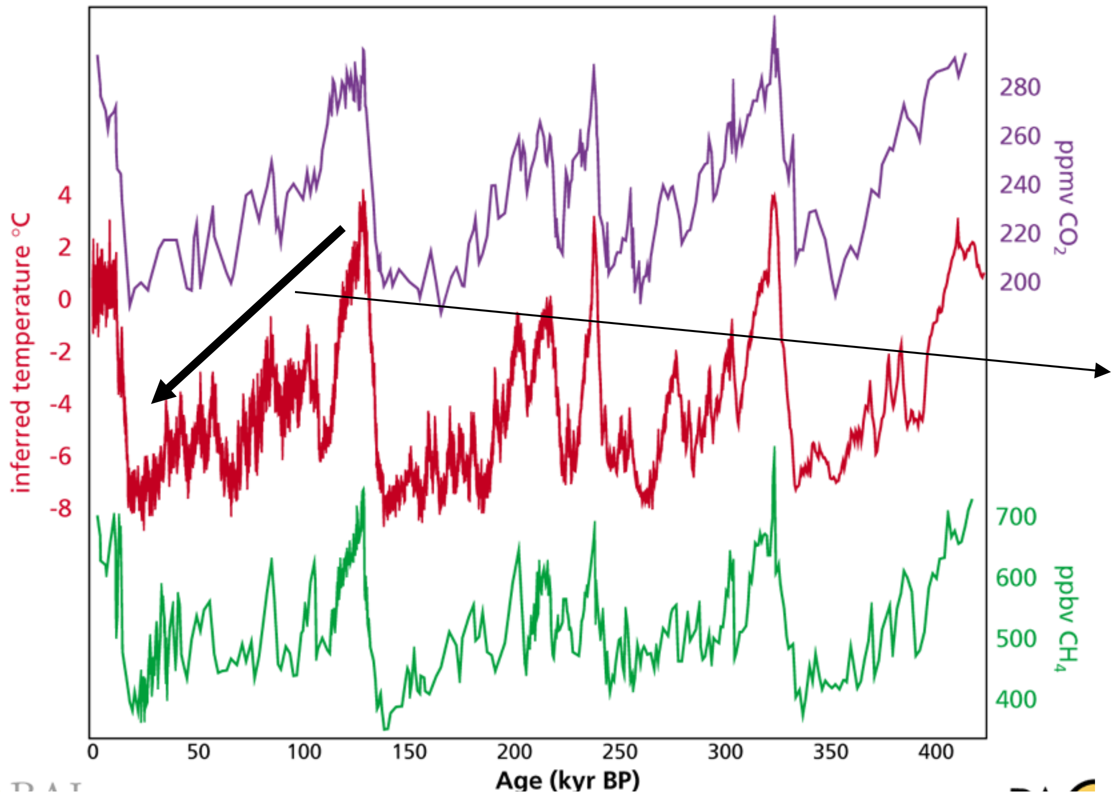




$\delta^{13}C$ (carbon transfer) matches $\delta^{18}O$ (ice volume) cycles. More negative $\delta^{13}C$ → more positive $\delta^{18}O$

Temperatures over last 400,000 years

4 glacial cycles recorded in the Vostok ice core



- Carbon dioxide has varied from ~ 180 – 310 ppmv.
- 385 ppmv (in 2008)

Iron Hypothesis: Iron fertilization of ocean biota

During glacial periods, more dust → more iron fallout into the oceans → more phytoplankton → more photosynthesis → lower CO_2 → colder climate → windier → more dust

- Methane has varied from ~ 350 – 800 ppbv; ~ 1790 ppbv (in 2008)

Orbital-Scale Changes in CH_4

Vostok Ice in Antarctica

Six cycles since the last interglacial period

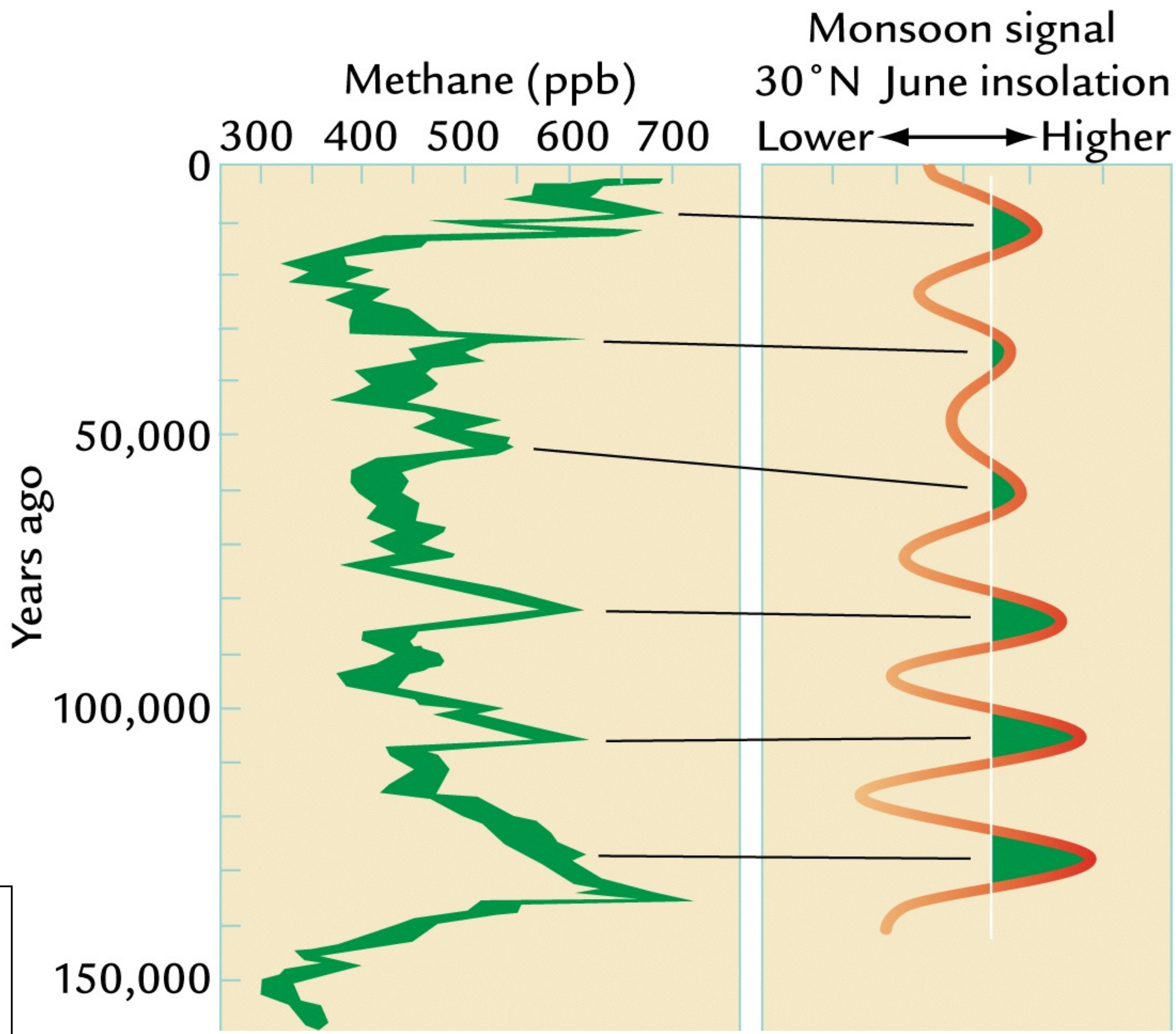
Maxima: 550-700 ppb

Minima: 350-450 ppb

23000 years/cycle

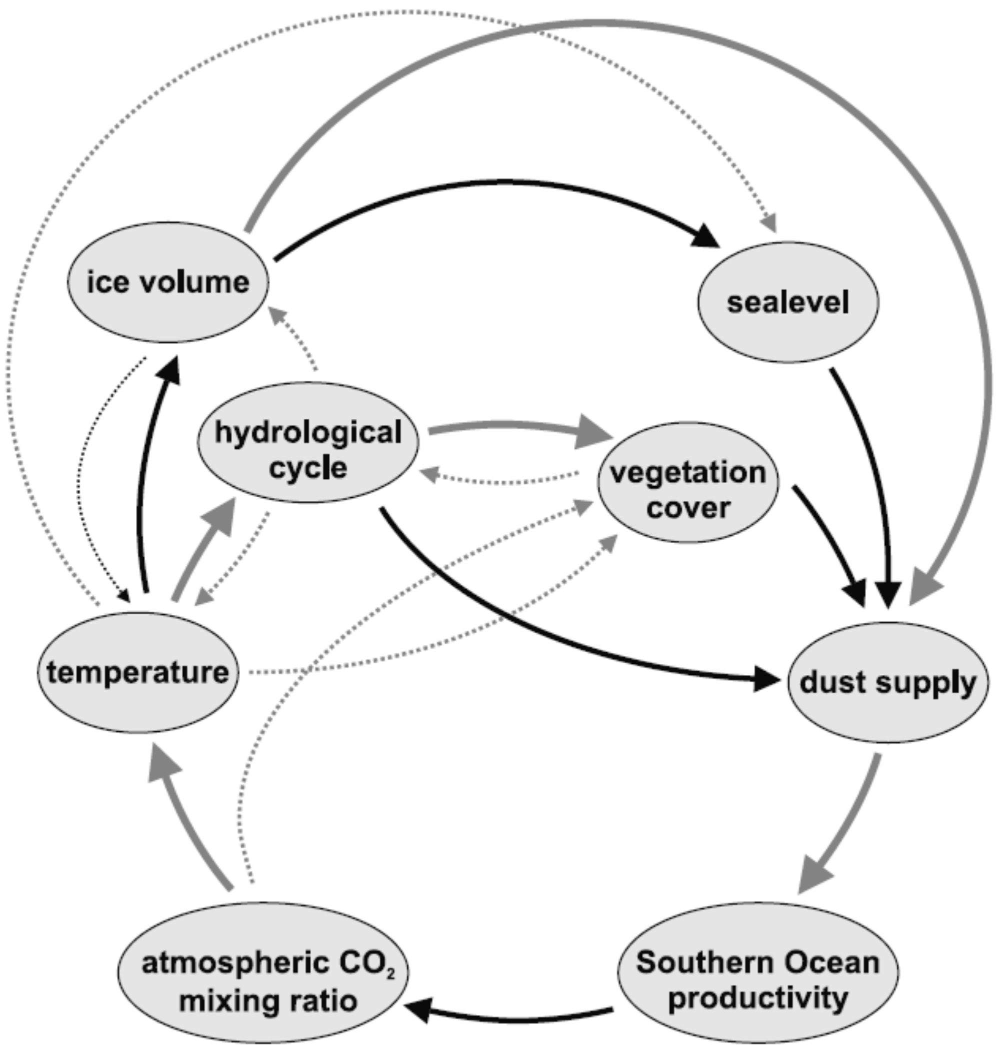
Peak methane values match peaks of monsoons

Changes in methane levels are caused by changes in summer monsoon in the tropics



Heavy monsoon rainfall → more bogs → more vegetation decay → more CH_4

Feedbacks between dust, climate and CO2



Discussion-Summary:

- How is air bubble formed in ice core? Why is air bubble formed in ice core about a few hundreds to 2000 years younger than the ice itself?
- What control the carbon isotope fractionation? What are the typical d13C values for deep and surface ocean, land, grass and tree? Why is deep ocean rich in ^{13}C and vegetation and surface water is more ^{13}C depleted?
- What might cause decrease of atmospheric CO_2 during glacier maximums? List of mechanisms and key evidences.
- What cause methane change on glacial-interglacial scale? Do you thin that methane response to climate change would be faster or slower than carbon?