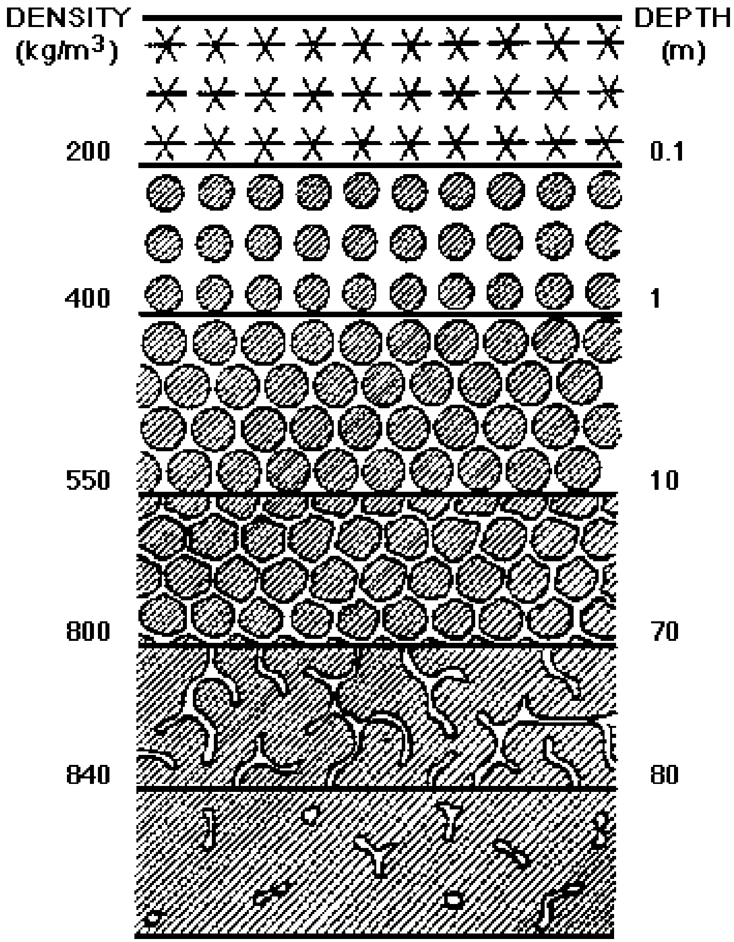
Ice Cores, Stable Isotopes, and Paleoclimate

Ice sheets provide a long term record of water and air that have been compressed and stored over hundreds of thousands of years

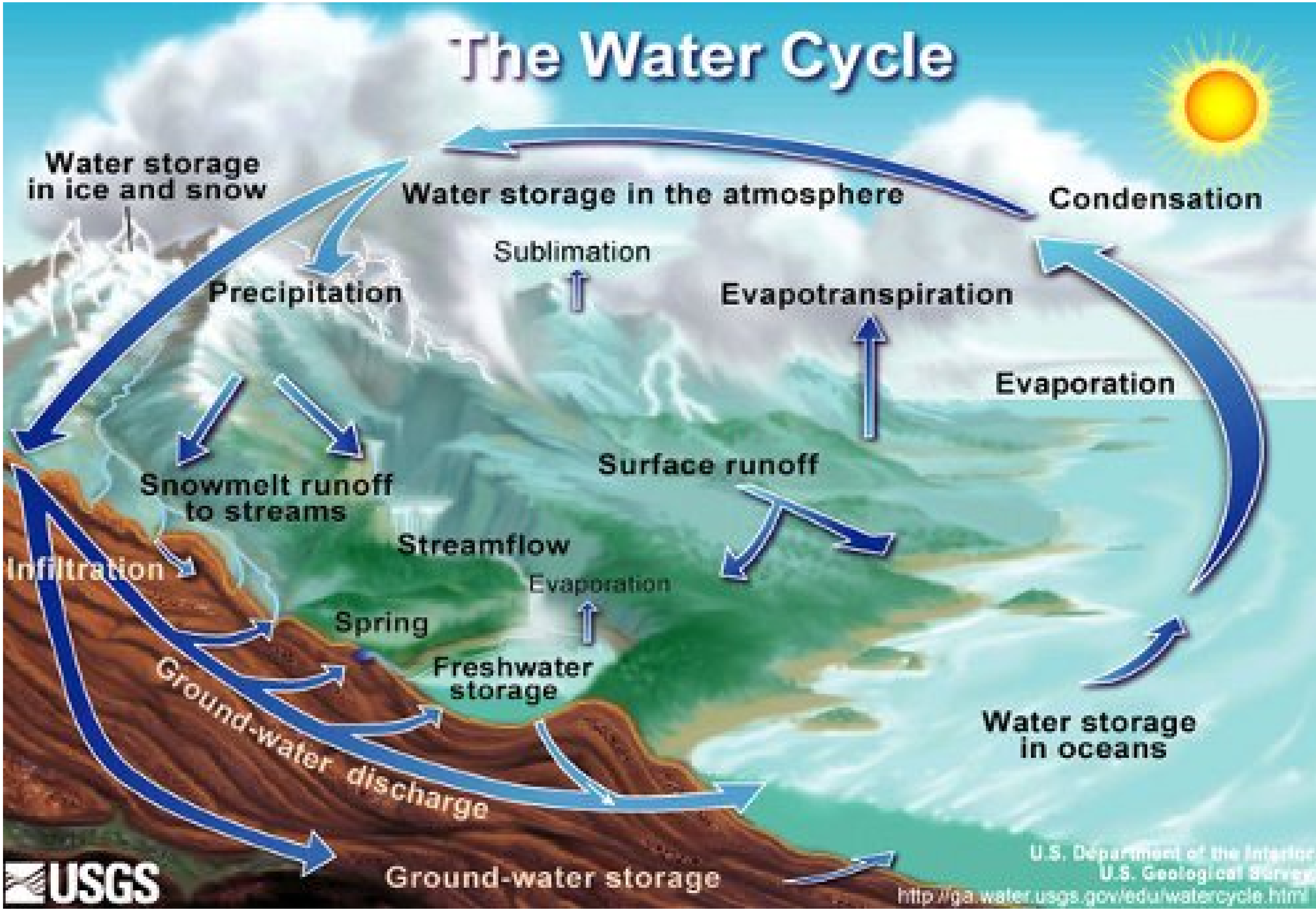


Diagramatic depiction of the gradual lithification of the snow which falls on polar ice caps. The snow recrystalizes to firn which has passages through which air can circulate. When the firn is fully lithified, the air passages are sealed off becoming bubbles.

Similar to Fig. 3.23 in text

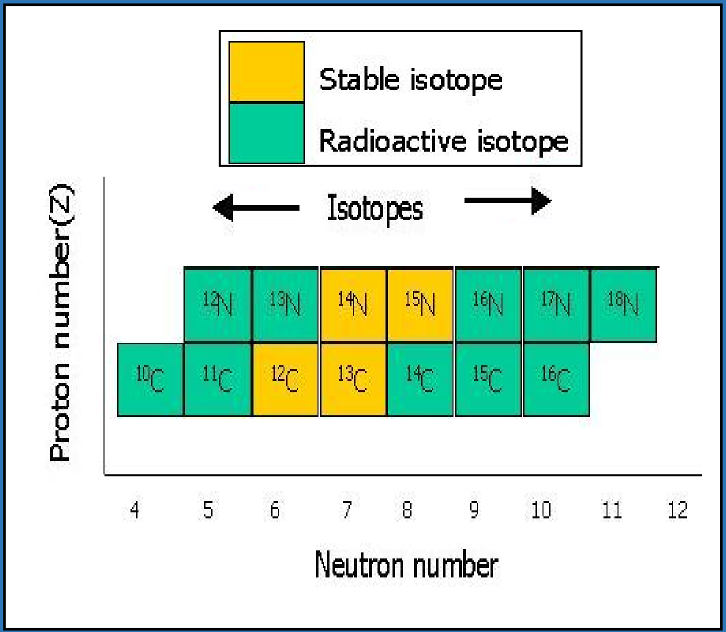
Trapped air has lag time in age with ice, from hundreds to thousands of years

Stable isotope ratios of oxygen in water are especially useful as a proxy for past temperatures



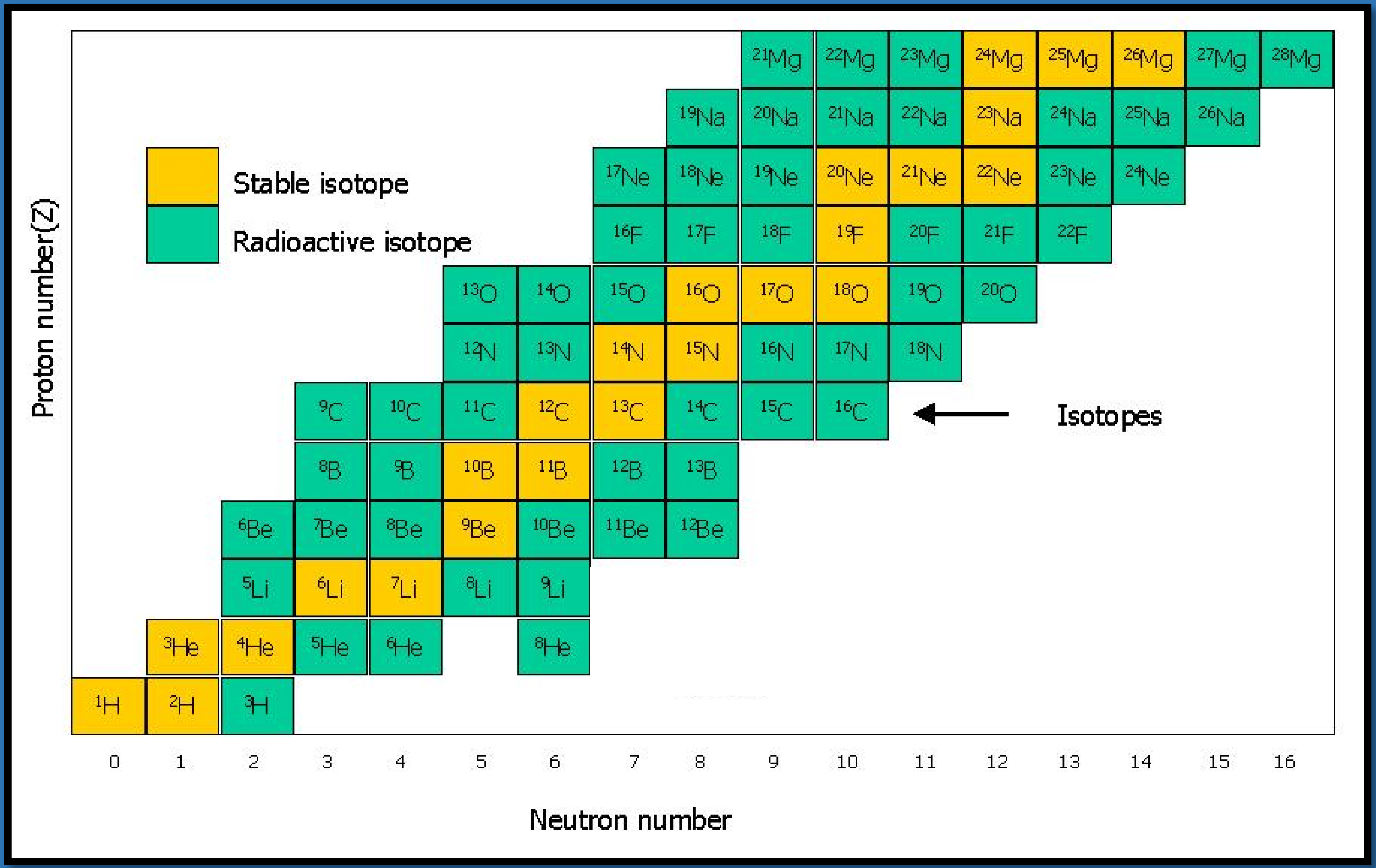
http://www.ces.fau.edu/nasa/module-3/how-is-temperature-measured/isotopes.php

Isotopes are radioactive or stable

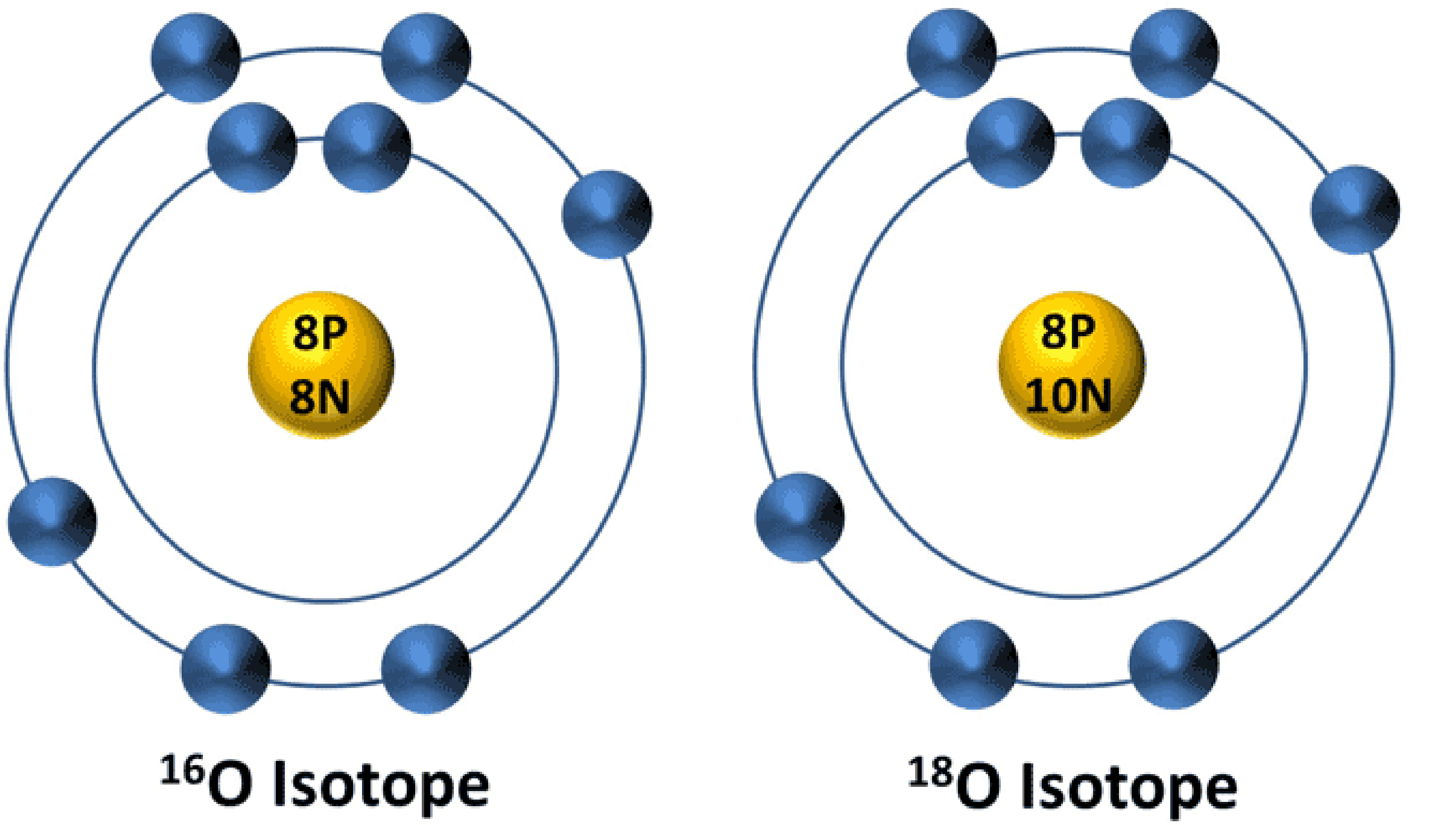


- **<u>Radioactive Isotope:</u>** changes atomic number and/or mass over time (decay)
- **<u>Stable Isotope:</u>** do not change atomic number, only mass, and remain stable over time

Many different isotopes



Oxygen Isotopes



http://www.ces.fau.edu/nasa/module-3/how-is-temperature-measured/isotopes.php

Stable Isotope Terminology

Permil or per thousand is indicated by the symbol ‰

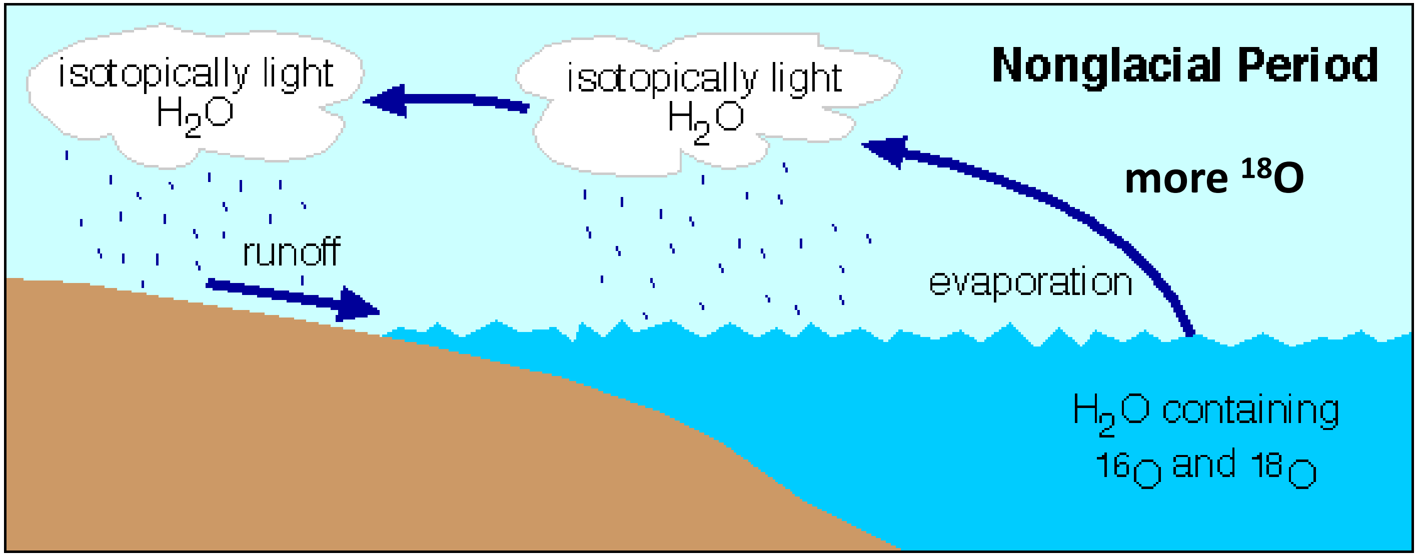
The delta symbol, δ, refers to the ratio of heavy to light isotopes compared to a standard, times 1000

Hence, 10 ‰ is the same as saying 1%

As the ratio of a heavy to light isotopes increase, so does the value of δ, e.g.,

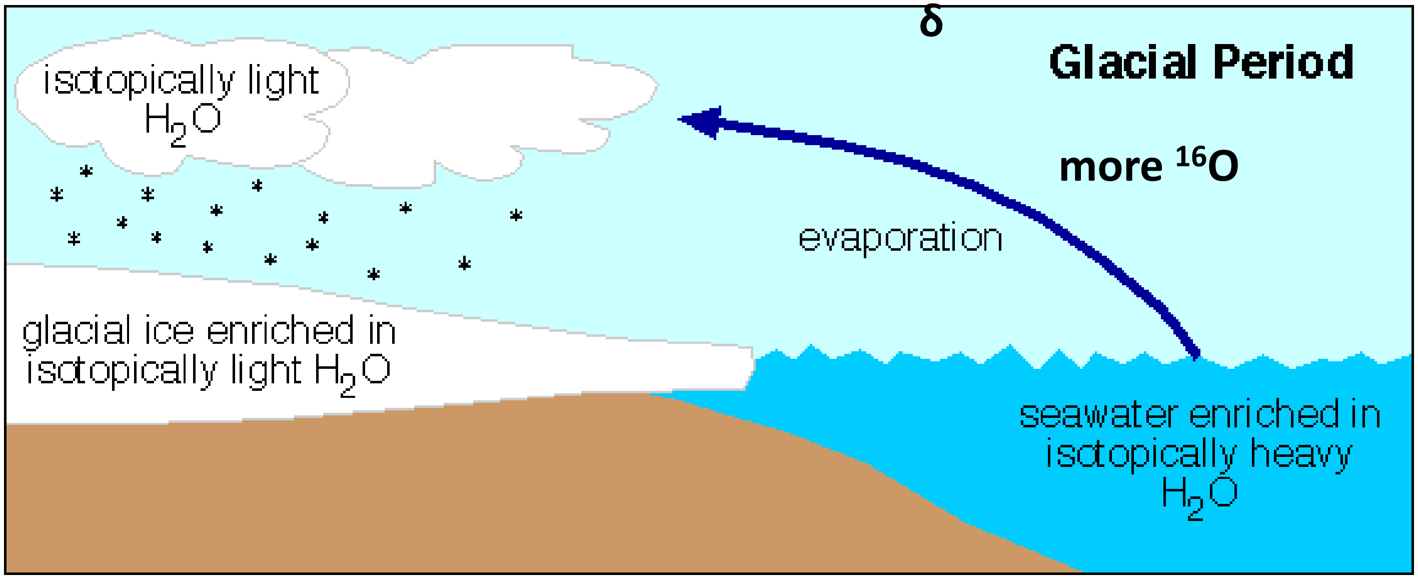
$^{18}O/^{16}O$ in water can change with temperature:

$\delta^{18}O$ ratio will <u>decrease</u> if there is less ^{18}O or more ^{16}O in the water or air



$\delta^{18}O$ increases in glacial ice with greater evaporation

δ

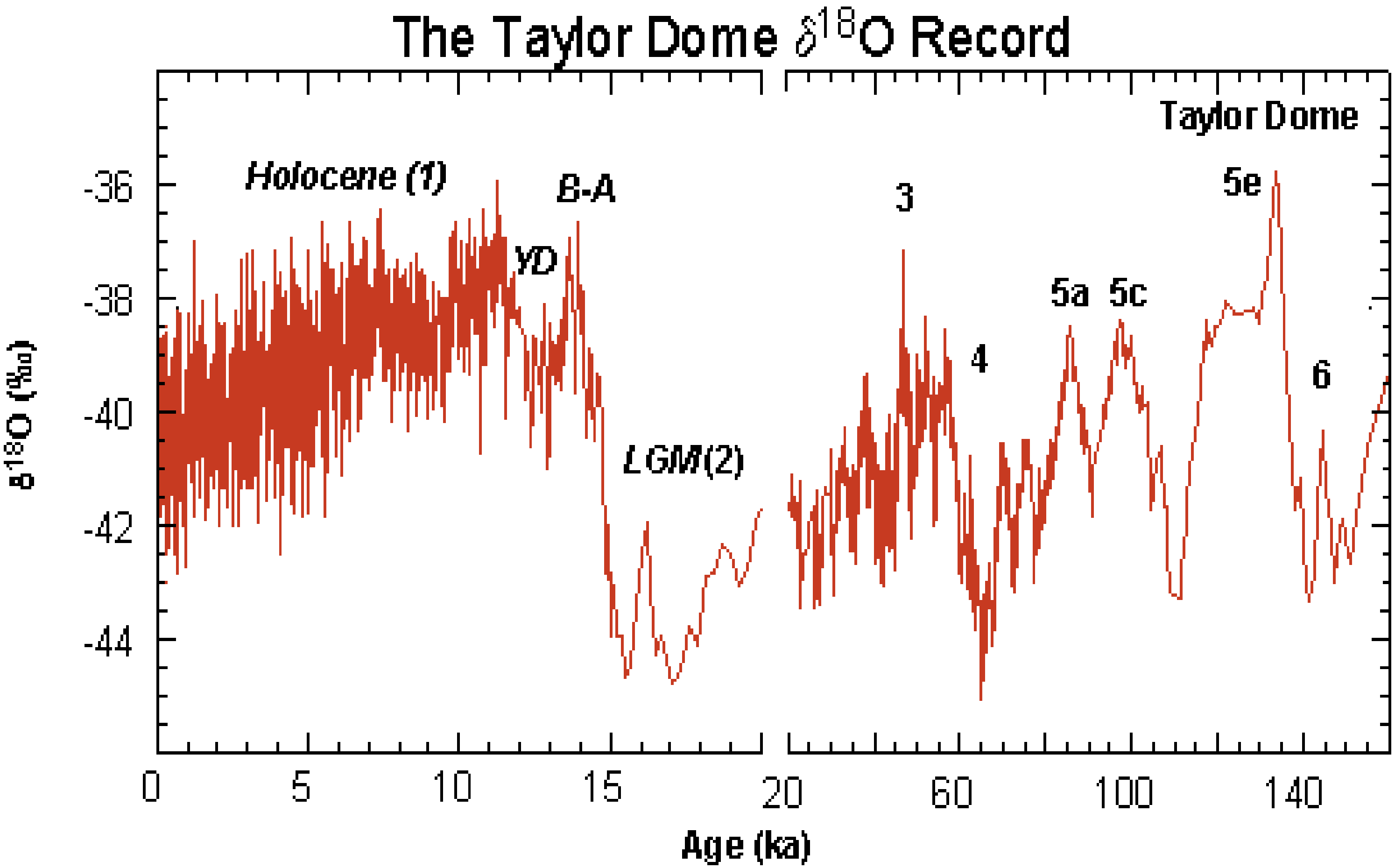


$\delta^{18}O$ decreases in glacial ice

http://myweb.cwpost.liu.edu/vdivener/notes/stable_isotopes.htm

Cold periods result in more of the lighter ^{16}O isotopes in the ice so the ratio of $^{18}O/^{16}O$ decreases

Warming periods are the reverse

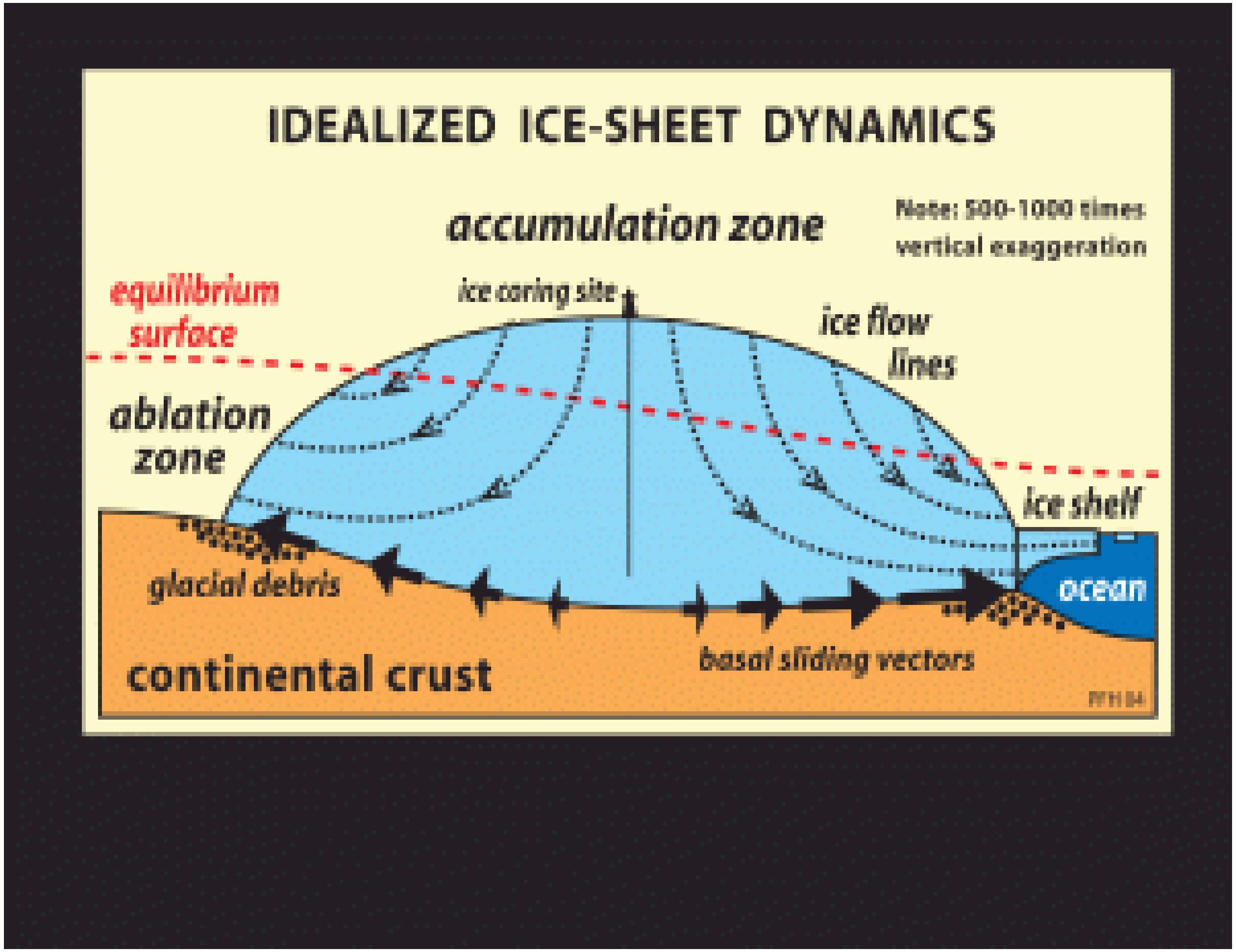


After Figure 6 in E. J. Steig, D. L. Morse, E. D. Waddington, M. Stuiver and P. M. Grootes. 1999. Wisconsinan and Holocene climate history from an ice core at Taylor Dome, western Ross Embayment, Antarctica. *Geografiska Annaler* (in review).

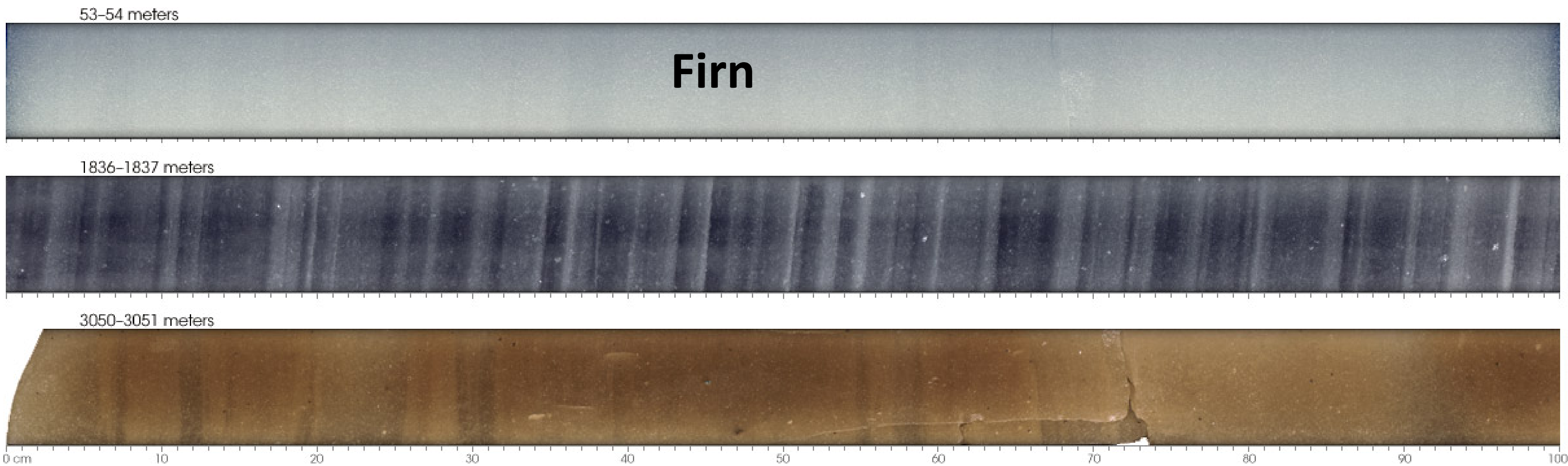
Antarctic Ice Cores and Paleoclimate

http://cdiac.ornl.gov

Where to place an ice-coring site



http://www.antarcticglaciers.org/glaciers-and-climate/ice-cores/ice-core-basics/



The gradually increasing weight of overlying layers compresses deeply buried snow into ice, but annual bands remain. Relatively young and shallow snow becomes packed into coarse and granular crystals called firn (top: 53 meters deep). Older and deeper snow is compacted further (middle: 1,836 meters). At the bottom of a core (lower: 3,050 meters), rocks, sand, and silt discolor the ice. (Photographs courtesy U.S. National Ice Core Laboratory)

http://earthobservatory.nasa.gov

How an ice core drill works

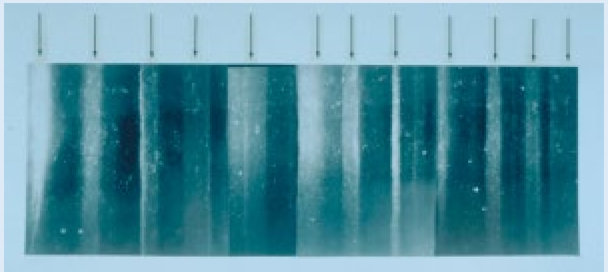
How are ice cores stored and used?

How to determine the age of an ice core

1. Count annual rings

2. Find known volcanic ash, dust, or other signatures that have been dated elsewhere

3. Dust with radioactive isotopes (e.g., Uranium) with known decay rate



This 19 cm long of GISP2 ice core from 1855 m depth shows annual layers in the ice. This section contains 11 annual layers with summer layers (arrowed) sandwiched between darker winter layers. From the US National Oceanic and Atmospheric Administration, [Wikimedia Commons.]

Currently, longest (3.2 km) and oldest ice core in Antarctica is at Dome C, where ice sheet is very thick

Goes back ~800,000 yrs based on annual layers, Uranium dating

These layers become more compacted with depth, heat generated after that melts the layers so record ends

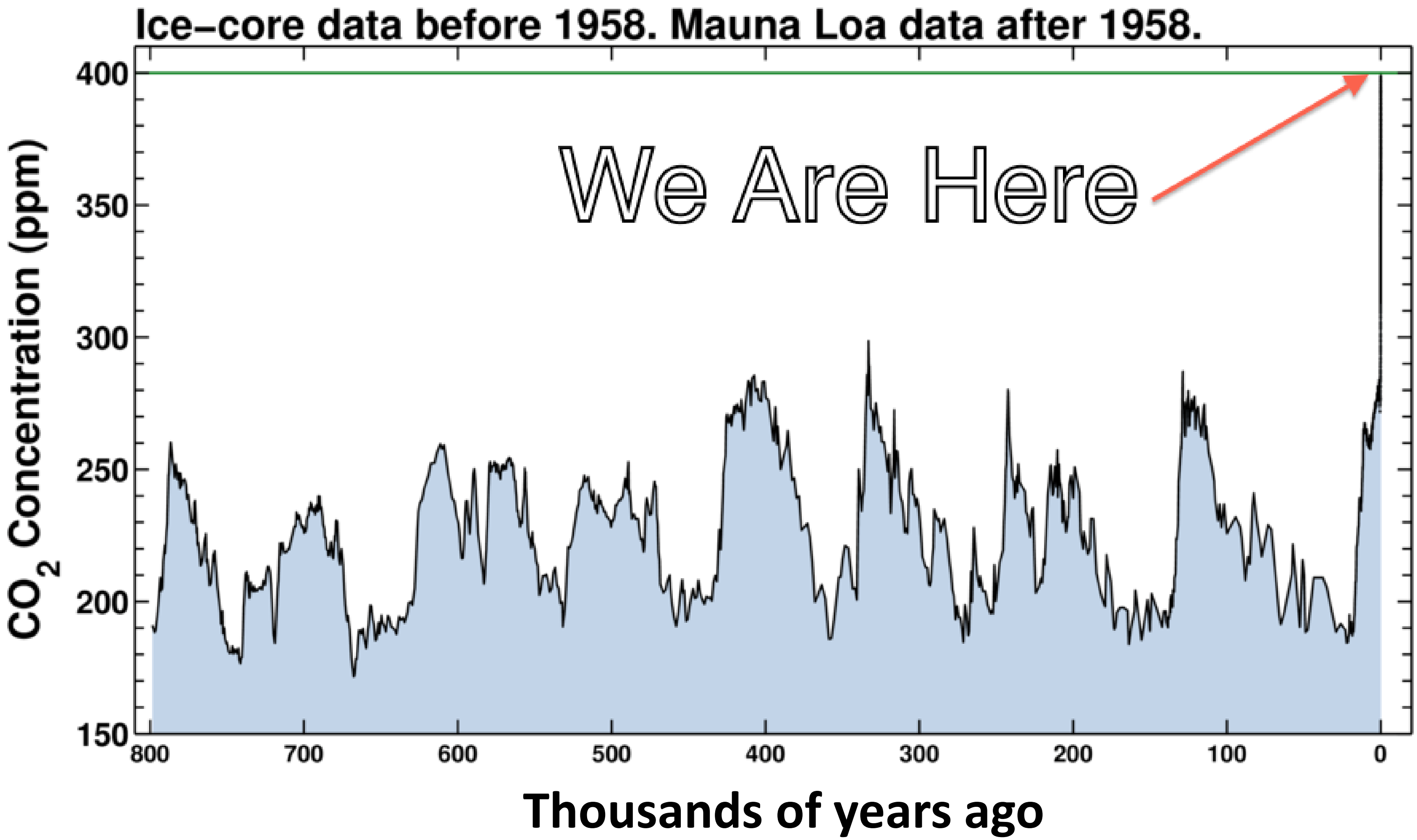
http://www.climate.unibe.ch/?L1=research&L2=rice

However, in some sections of the East Antarctic Ice Sheet, there may be layers going back 1.5 Ma and current research is attempting to find these older layers

Cores provide $\delta^{18}O$ and δD (Hydrogen) in water, CO_2, methane (CH_4), and nitrous oxide (N_2O) concentrations in trapped air (trace gases)

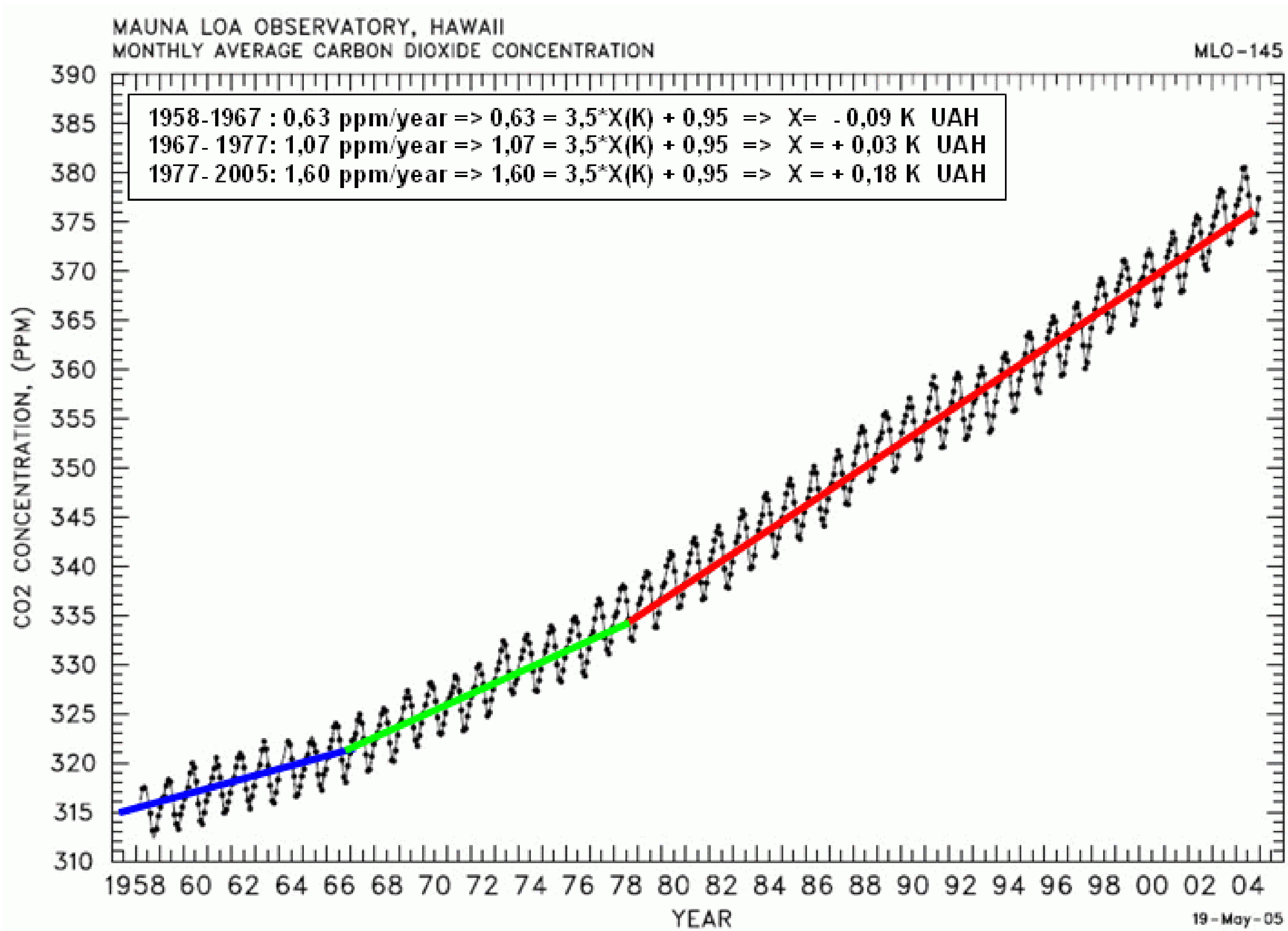
% CO_2 relates to changes in plant biomass
% CH_4 relates to total wetland area and decay
% N_2O relates to soil microbial activities

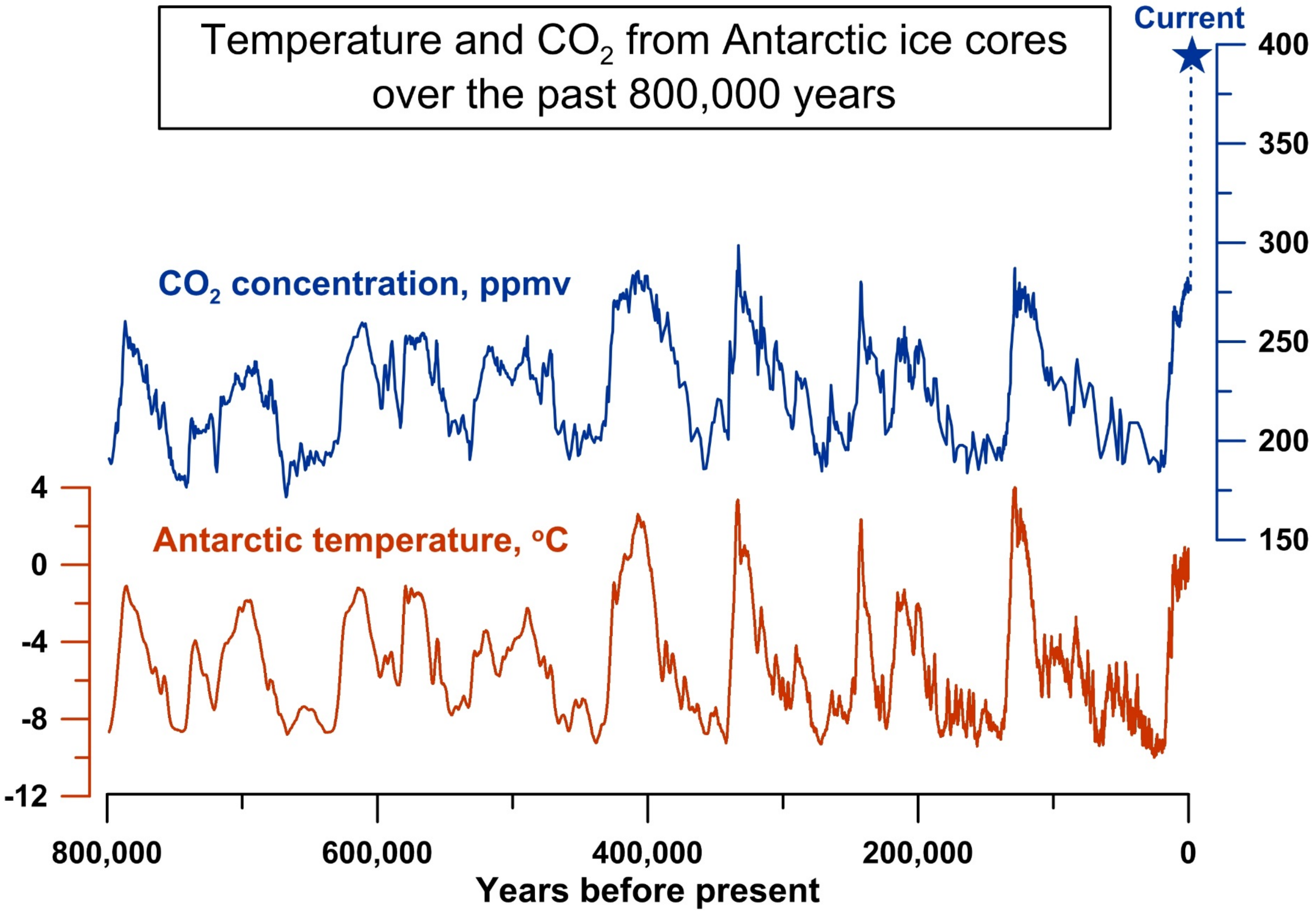
CO_2 with higher resolution



http://mashable.com/2015/05/06/earth-surpasses-carbon-dioxide-milestone/

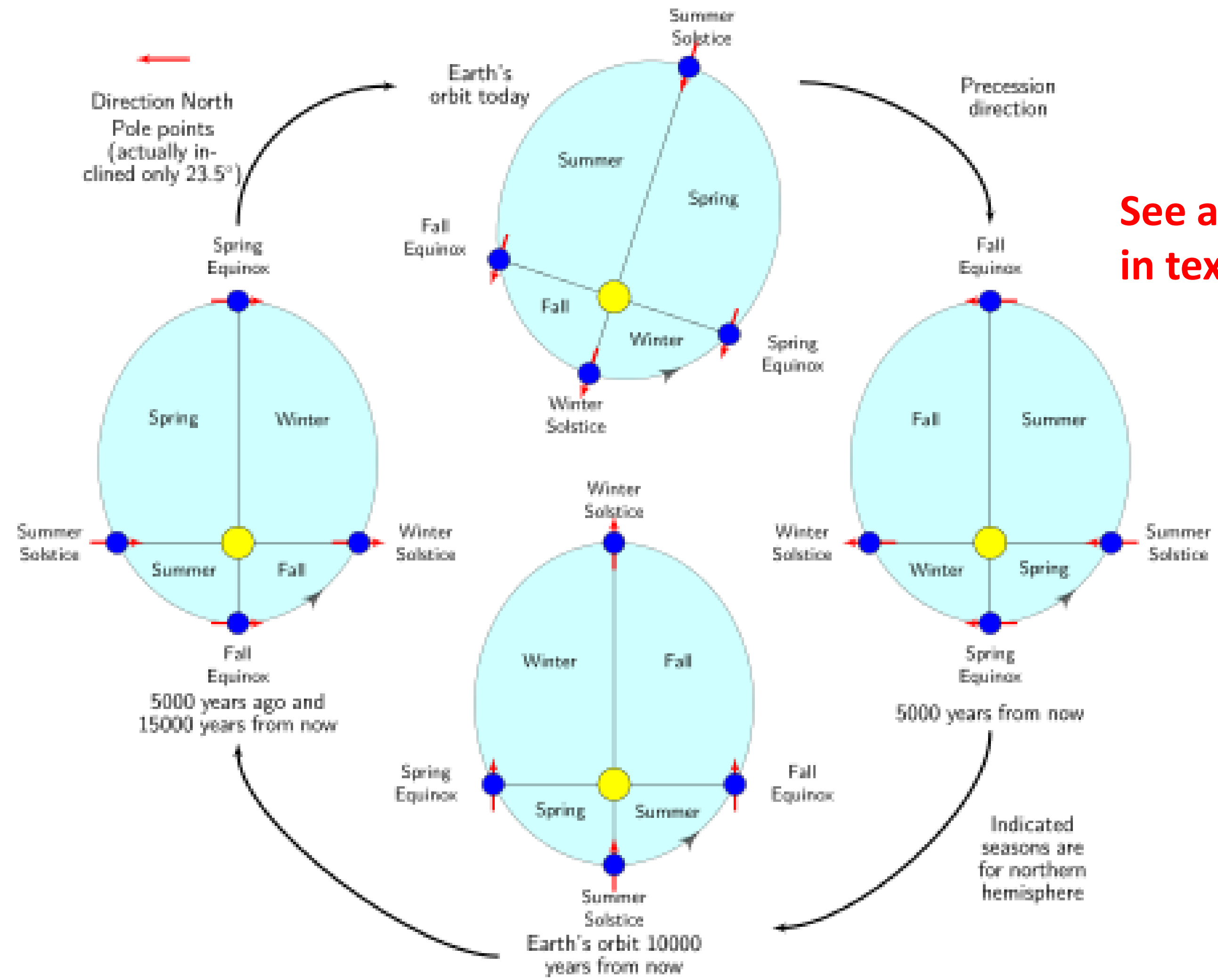
Seasonal and annual changes in atmospheric CO_2





The 800,000-year record of atmospheric CO_2 from the EPICA Dome C and Vostok ice cores, and a reconstruction of local Antarctic temperature based on deuterium/hydrogen ratios in the ice. The current CO_2 concentration of 392 ppmv is shown by the blue star. (data from Lüthi et al., 2008, Nature, 453, 379-382, and Jouzel et al., 2007, Science, 317, 793-797).

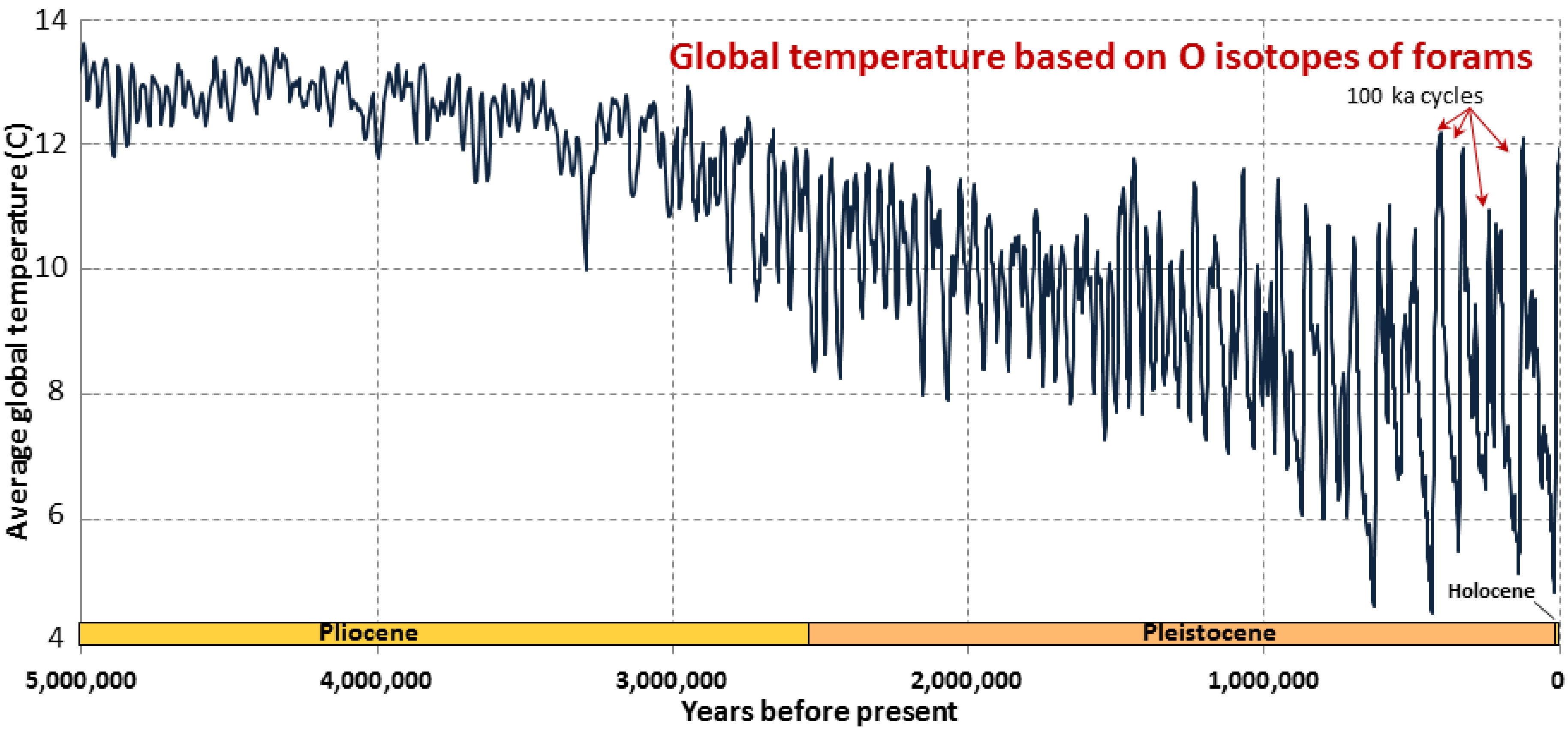
Solar Insolation



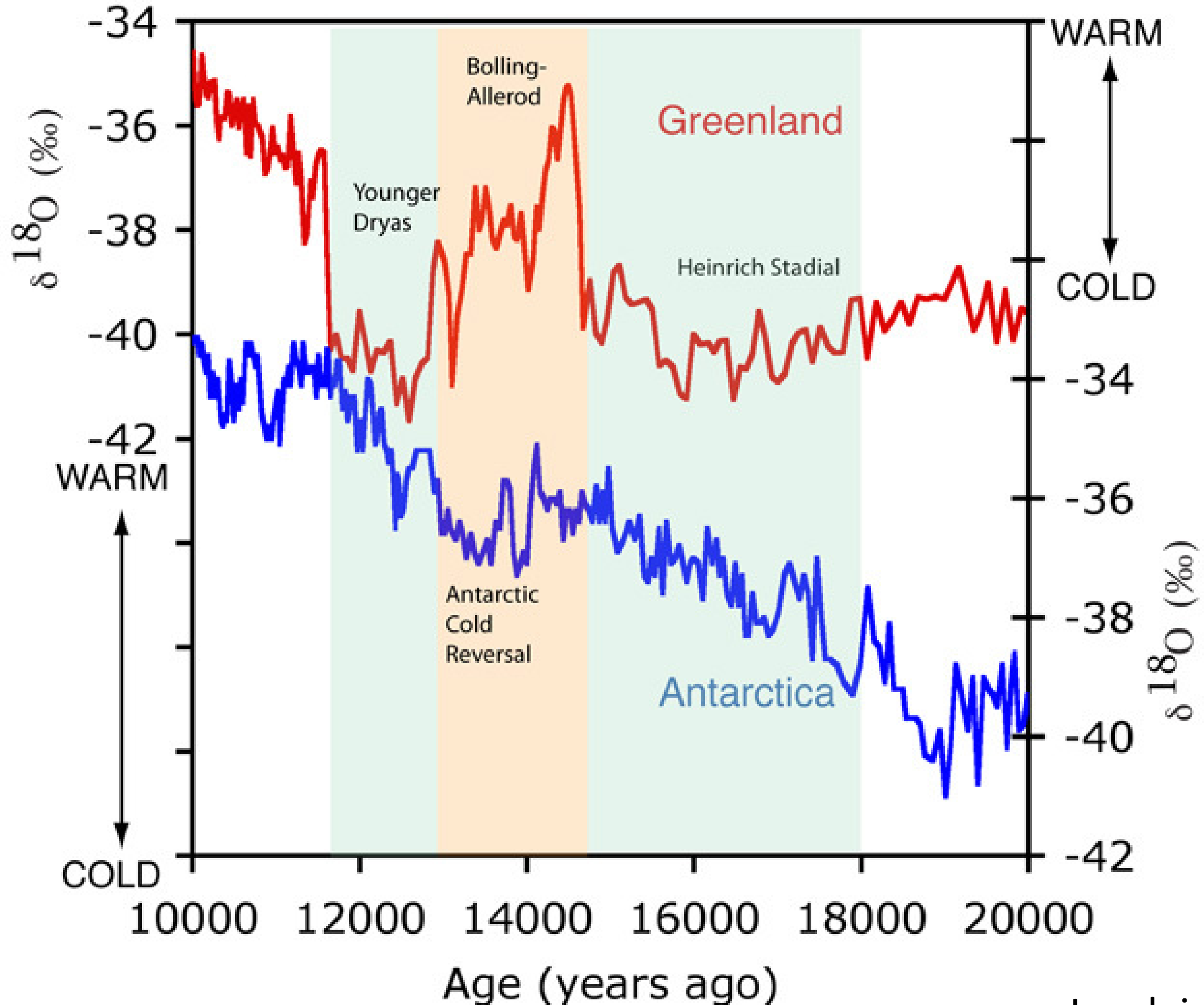
See also Fig. 3.19 in text

Changes in orbit plus wobbling of Earth on its axis results in cyclic changes in insolation and climate: 41,000, 100,000, and 400,000 yr cycles

Ice Ages became frequent beginning ~2.5 Ma, first with 41,000 yr cycles then with 100,000 yr cycles



Bi-polar See Saw in Climate Change



Landais et al. (2015)

Quiz

1. Why is there a time lag in ice cores between age of trapped air and age of the ice?
2. What is $\delta^{18}O$ and how do changes in this ratio relate to warm and cold periods in the past?
3. How do you select the best spot on a glacier for an ice core?
4. How do you determine the age of an ice core?
5. What is the bipolar see saw in climate?