ESS 203 - Glaciers and Global Change

Wednesday February 10, 2021

Outline for today

- Highlights of Monday's class – *Caroline Wills*
- Volunteer for today's highlights on Friday – *Abigail Sylvester*
- Ice cores and climate history

Assignment

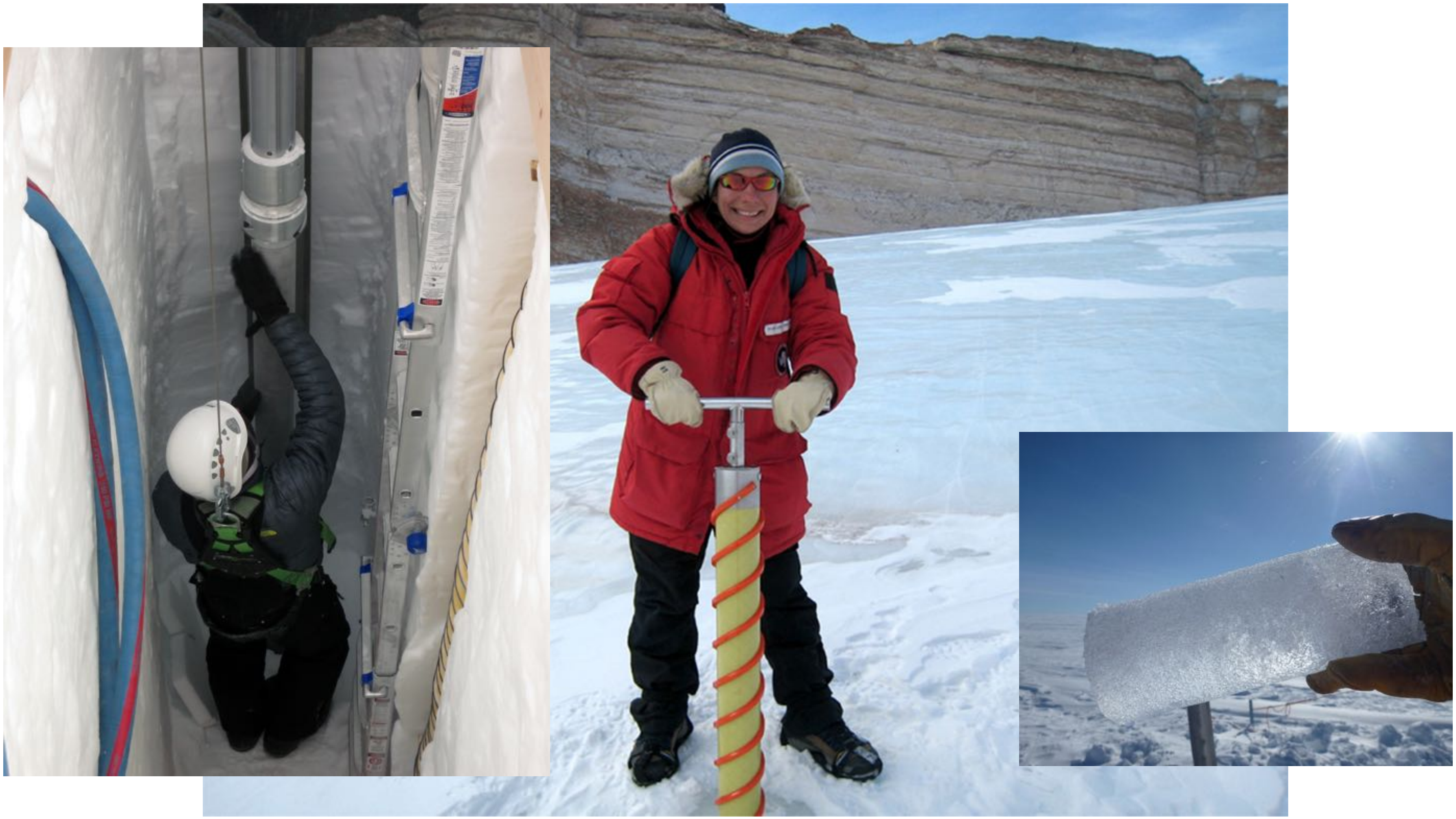
Due Today: HW 15

Due Friday: HW 16

Please read Chapter 9 from ***Frozen Earth***, "Coring for Details". In a paragraph (~200 words) for each, summarize:

- one key result from coring sediments on the sea floor
- one key result from coring polar ice sheets

What is an ice core?



"Researcher Margarita Marinova uses an auger to drill a core from the ice pack at University Valley in the McMurdo Dry Valleys, Antarctica. Credit: Jennifer Heldman, National Science Foundation (NSF)."
https://climate.nasa.gov/, https://spicecore.org/gallery/

SPICEcore drill operation

Emma

Eric

http://spicecore.org/gallery


???
T.J.
Spruce
Sean
NSF
1300
WAIS DIVIDE
1300m DEPTH
END OF BRITTLE
1751-m core
54,000 years

NSF Ice Core Facility – Denver, Colorado

- a facility for storing, curating, and studying meteoric ice cores recovered from the glaciated regions of the world
- NSF-ICF holds over 22,000 meters of ice core from various locations in Antarctica, Greenland, and North America.

Ice Cores as Paleo-Weather Stations

What features of today's weather might you want to know about in a weather report?

- Temperature
- Precipitation
- Wind
- Pollution or air quality
- Others?

What features of past weather and climate might you want to know about?

Ice Cores as Paleo-Weather Stations

We're going to focus on three aspects of weather/climate:

1. Temperature
2. Precipitation
3. Greenhouse gas concentration

We can't measure the past climate as directly as today's weather. Example:

Temperature of the ice today is not the same as the temperature of the snow when it fell long ago.

- Snow can warm up or cool down as it is buried and converted to ice.
- Past air temperatures re overwritten by more recent air temperatures, i.e. the surface of the world knows only its present (or very recent) temperature.

So if we can't measure temperature with a thermometer, then what do we do?

Proxies

We have to use ***proxies***.
What is a "proxy"?

A measurable quantity that is used as a substitute for another (perhaps unmeasurable) quantity.

What is an example of a proxy?

A mercury thermometer is an example of a proxy. Why?

What to choose for a proxy?

If we want to know what the temperature was in the past:

- We need to identify "something" that collected on the polar ice sheets in the past.

- Some characteristic about the "thing" deposited had to be different when it was deposited at different temperatures.

- The characteristic should always have the ***same value*** for the ***same temperature***.

Let’s make up a proxy to see how it works:

Suppose that in the past, somebody threw a handful of colored beads onto a polar ice sheet every day.

- On warmer days, more beads were red.
- On colder days, more beads were blue.
- On average days more beads were white.

Many years later, we drill through the ice sheet, to discover the temperature history here.

- What is the "thing" that we collect as a temperature proxy?
- What is the characteristic of the "thing" that we want to convert to a temperature?

Suppose bead throwers were fickle, and one day they thought -30^{o}C = 8 blue beads, but the next day they thought -50^{o}C = 8 blue beads.

- Would you still like this proxy?

An actual temperature proxy

It turns out that these beads are very much like a proxy that ice core scientists use to measure past temperature.

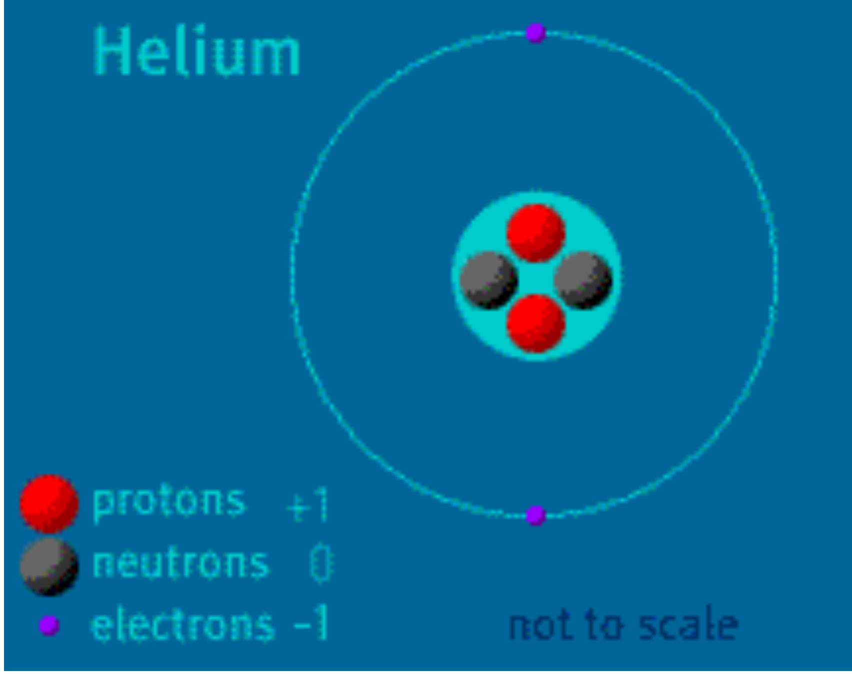
The beads are like water molecules in snow that falls on an ice sheet.

The color of the beads are like isotopes of the oxygen and hydrogen atoms that make up the water molecules.

Composition of Atoms

Remember that the nucleus of any atom is made up of:

- protons (which have a "+" charge)
- neutrons (which have no charge)



http://www.pbs.org/wgbh/aso/tryit/atom/elempartp.html

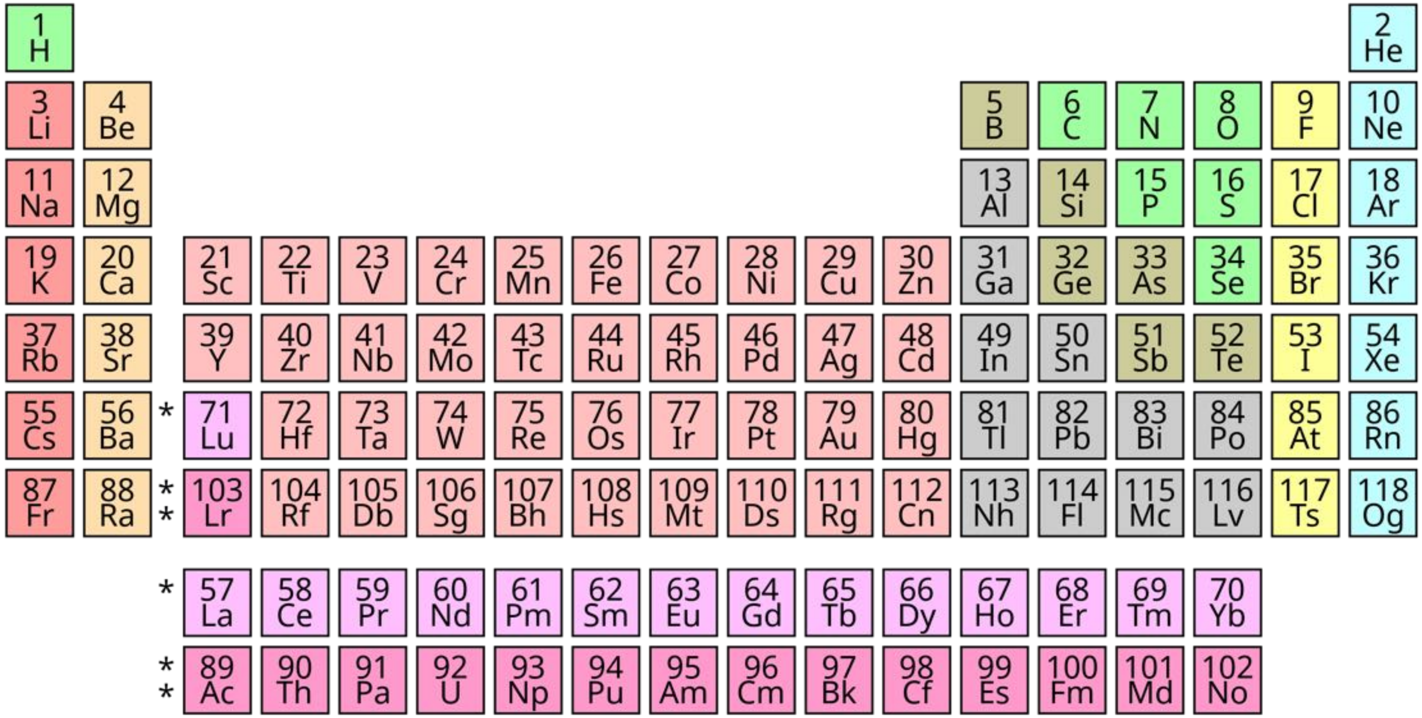
- The nucleus is surrounded by a cloud of electrons (with "-" charge) in orbits specified by rules from quantum mechanics (which will ***not*** be on the next test!).
- The number of electrons is generally equal to the number of protons in the nucleus, in order to preserve the charge balance. What is an "ion"?

The Periodic Table

The number of protons in an atom determines which element it is in the periodic table. What is an isotope?

- An isotope of an element is defined by the number of neutrons.

What is a “stable” isotope? One that is not radioactive.

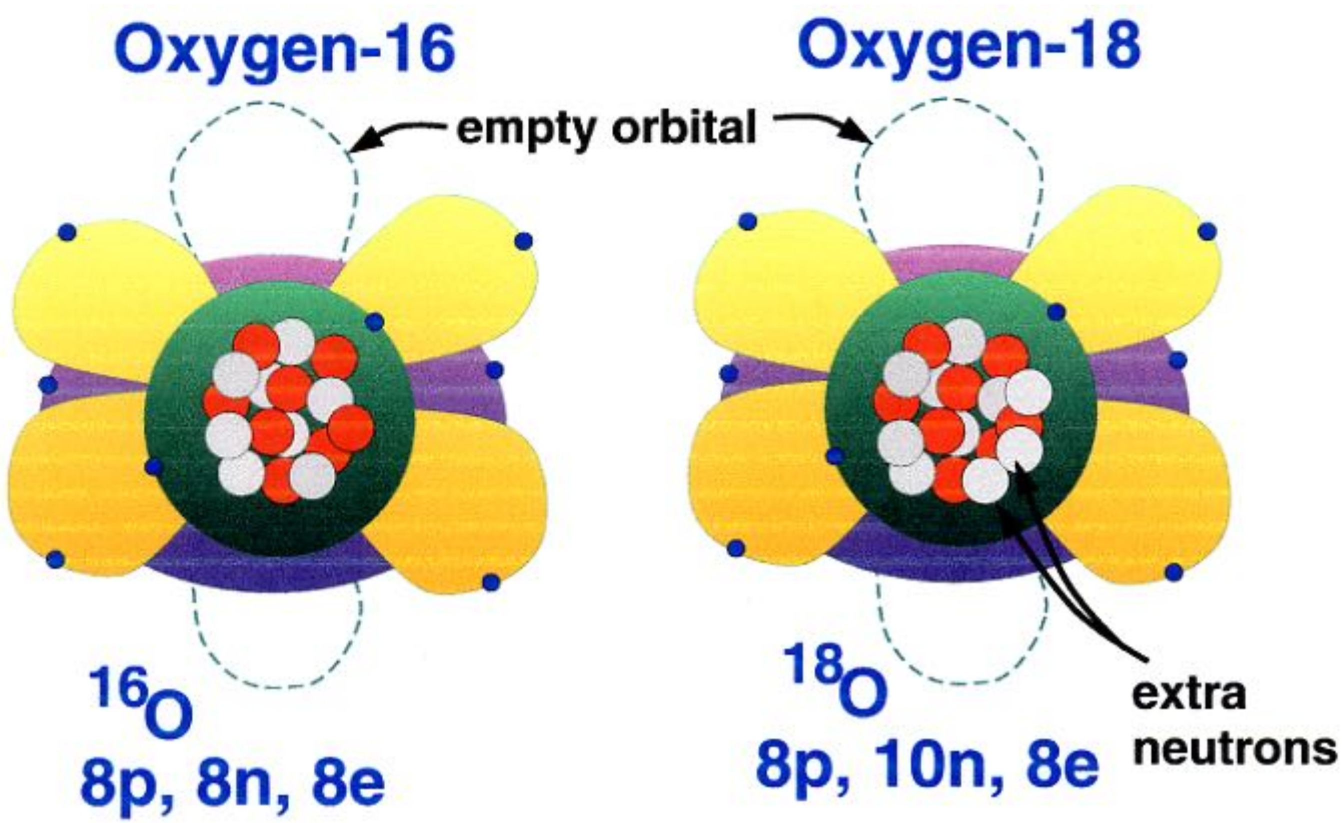


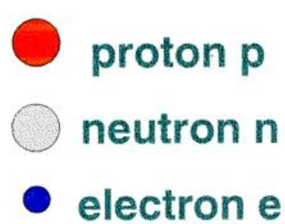
Stable isotopes of Oxygen

OXYGEN atoms in the natural environment are usually one of two stable isotopes: ^{16}O and ^{18}O.

- This is also true for oxygen in water molecules (H_2O).
- The only difference is that ^{18}O has two extra neutrons in its nucleus, making each ^{18}O atom a little bit heavier than an ^{16}O atom.
- There are also a few oxygen molecules with 9 neutrons, but oxygen-17 (^{17}O) is *very* rare.
- Out of 10,000 oxygen atoms:
  - 9,976 will be ^{16}O
  - 20 will be ^{18}O
  - 4 will be ^{17}O

Stable isotopes of Oxygen – ^{16}O and ^{18}O





- chemical behavior determined by **electron** structure, which is the same for all isotopes of a given atom.

$\delta^{18}O$ as a way to report isotope ratios

For ease of measurement, geochemists find it easier to measure isotope ratios than the number of ^{18}O atoms:

$$R = \left(\frac{^{18}O}{^{16}O} \right)$$

- R is the ratio of ^{18}O atoms to ^{16}O atoms in a sample.

It is also easier to reference to a known standard, which results in this definition of $\delta^{18}O$:

$$\delta^{18}O = \left[\frac{R_{sample} - R_{standard}}{R_{standard}} \right] \times 1000$$

The standard is called
"Vienna Standard Mean Ocean Water", or V-SMOW.

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Scientists multiply this value by 1000 to report $\delta^{18}O$ in units of permille (‰), which nicely gives values with an order of magnitude of 10 (rather than 0.01).

$\delta^{18}O$ values

$$\delta^{18}O = \left[\frac{R_{sample} - R_{standard}}{R_{standard}}\right] \times 1000$$

What does $\delta^{18}O = 0$ indicate about R_{sample} vs. $R_{standard}$?

- $R_{sample} = R_{standard}$

What does a ***positive*** value of $\delta^{18}O$ indicate about R_{sample} vs. $R_{standard}$?

- $R_{sample} > R_{standard}$ (there is relatively more ^{18}O in the sample)

What does a ***negative*** value of $\delta^{18}O$ indicate?

- $R_{sample} < R_{standard}$ (there is relatively less ^{18}O in the sample)

An actual temperature proxy - Refined

It turns out that the colored beads are very much like a proxy that for temperature.

The beads are like oxygen atoms in water molecules that fall on an ice sheet as snow.

With oxygen isotopes, it is the fraction of heavy (^{18}O) to light (^{16}O) isotopes that tells us the temperature.

But why does $\delta^{18}O$ of snow change with temperature?

Metaphor: It's a Nutty World

You are watching the Super Bowl along with a Bowl of Super-Duper® Mixed Nuts.

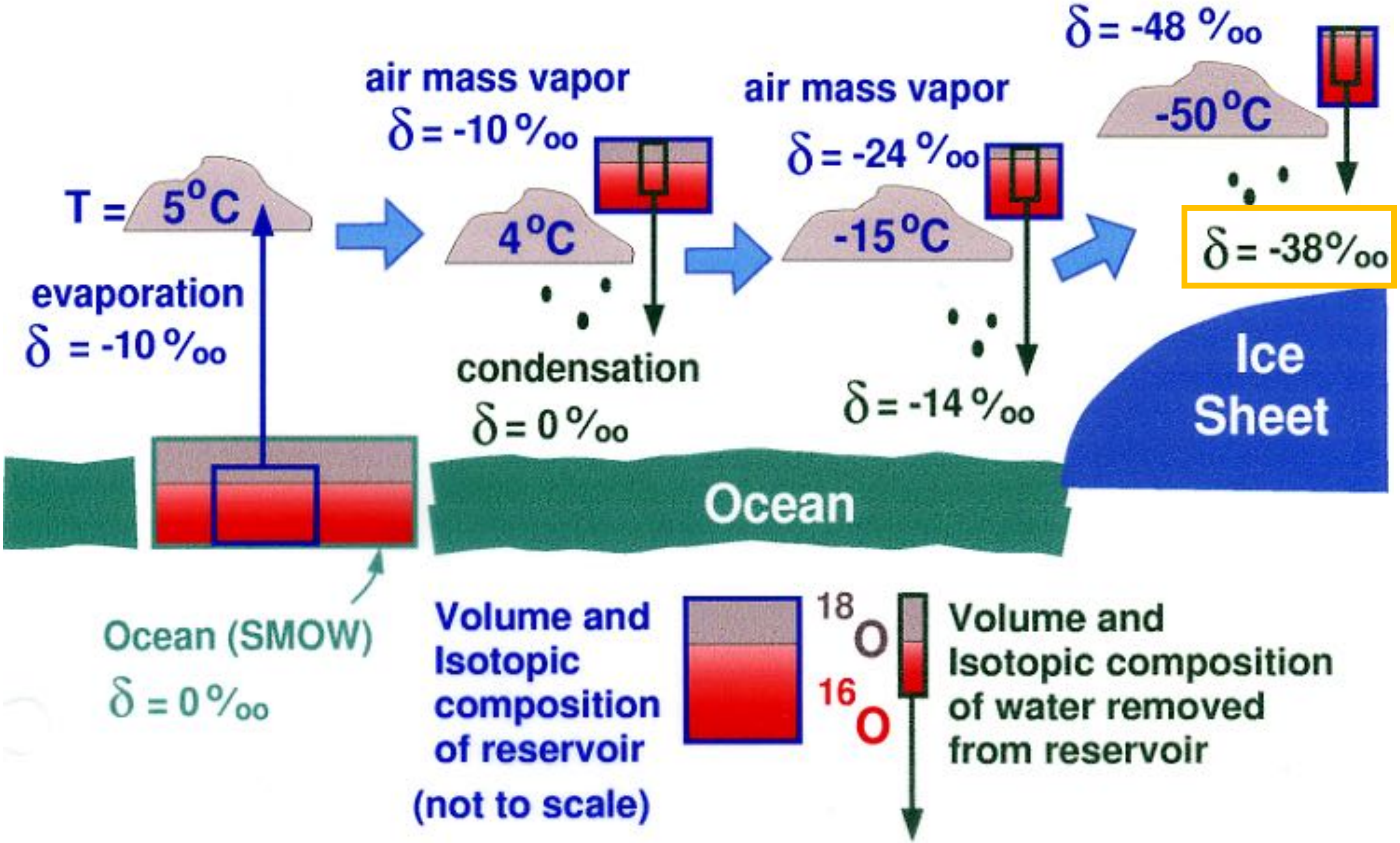
- Every 15 minutes, you reach in, stir up the nuts, and then you take out a handful.
- You then also reach back into the bowl and pick out a few extra cashews, and add them to your handful.
- You eat your handful of nuts.
- What has just happened to the cashews as a fraction of the remaining nut mix?
- The remaining nut mixture is progressively more depleted in cashews after every handful.
- The decreasing fraction of cashews in the bowl can be related directly to the number of handfuls that you have extracted, or to the time into the game.

$\delta^{18}O$ and Cloud Temperature

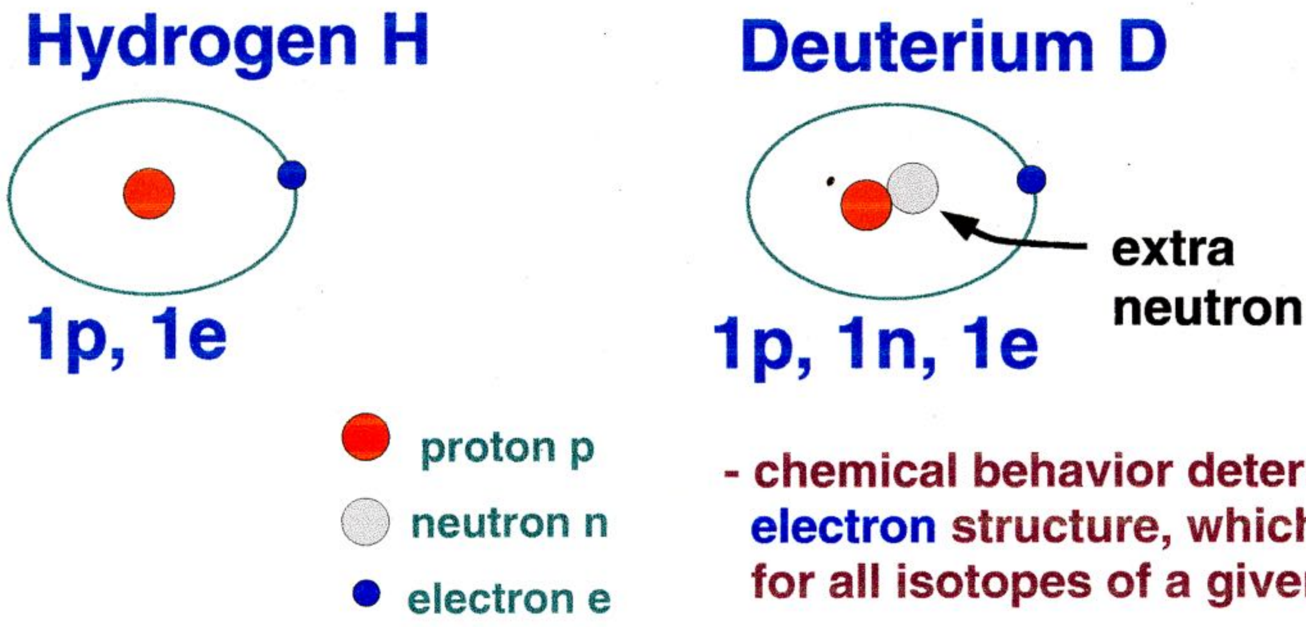
Water vapor evaporates from a tropical or temperate ocean.

- Vapor moves toward the polar regions in storm systems.
- Whenever an air mass cools by 1^{o}C, a predictable fraction of the vapor condenses, and falls out as rain or snow.
- The heavy isotope preferentially falls out in the rain or snow in a predictable way. [like your extra cashews].
- The remaining vapor in the cloud is progressively more depleted in the heavy isotope as the air mass cools. [like the cashews remaining in your nut bowl]
- The isotopic composition $\delta^{18}O$ of the precipitation can be related directly to the amount of rain or snow that has fallen from the clouds, or to the temperature in the clouds where the droplets condensed from water vapor.

$\delta^{18}O$ as a Temperature Proxy



Hydrogen Isotopes also record Temperature



- chemical behavior determined by electron structure, which is the same for all isotopes of a given atom.

$$R = \left(\frac{^2H}{^1H}\right) = \left(\frac{D}{H}\right)$$

$$\delta D = \left[\frac{R_{sample} - R_{standard}}{R_{standard}}\right] \times 1000$$

Stable Isotopes and Environmental Research

As we know, an H_2O molecule can contain ^{18}O or ^{16}O.

In the 1950's scientists knew that:

- When it rains, the water molecules (H_2O) containing an ^{18}O atom tend to fall out preferentially in the rain.

They asked the questions:

- Where does rain water come from?
- Can meteorologists track water back to its source using ^{18}O?

What do you think?

Willi Dansgaard's Mystery

A young Danish physicist was interested in isotopes as a tracer in rainwater in the 1950's.

Here is one of his early, very sophisticated experiments on rainwater in Copenhagen in 1952.

(Side note from Ed: Although Carlsberg has often funded ice-core science in Denmark, the ^{18}O content, and ultimate fate of initial contents of this high-tech laboratory instrument have been lost to the history of science …☺)

W. Dansgaard. 2005. *Frozen Annals – Greenland Ice Cap Research.* Niels Bohr Institute, Copenhagen.

On a research trip to Greenland …

to study precipitation, Willi Dansgaard took samples of ice from several icebergs.

- He found large differences in the ratio of ^{18}O to ^{16}O among icebergs.

- Some values were like rain and snow that Dansgaard collected along the coast.

- Others had much less ^{18}O (lower $\delta^{18}O$ values).

What was going on here?

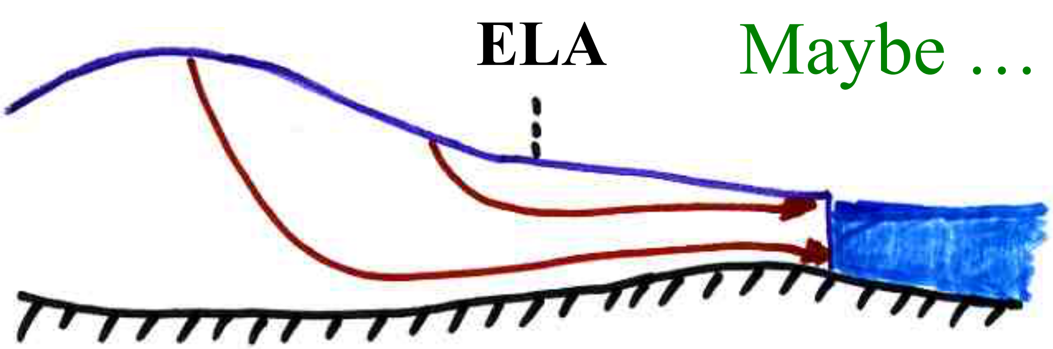
Willi Dansgaard's Icebergs

The icebergs came from glaciers that drain the center of the Greenland Ice Sheet.

- The icebergs with lower $\delta^{18}O$ came from deep in the glaciers.
- The icebergs with higher $\delta^{18}O$ came from shallower in the glaciers.

- Which ice had traveled farther?
- Which ice was older?
- Is this a climate-change story?

Maybe …

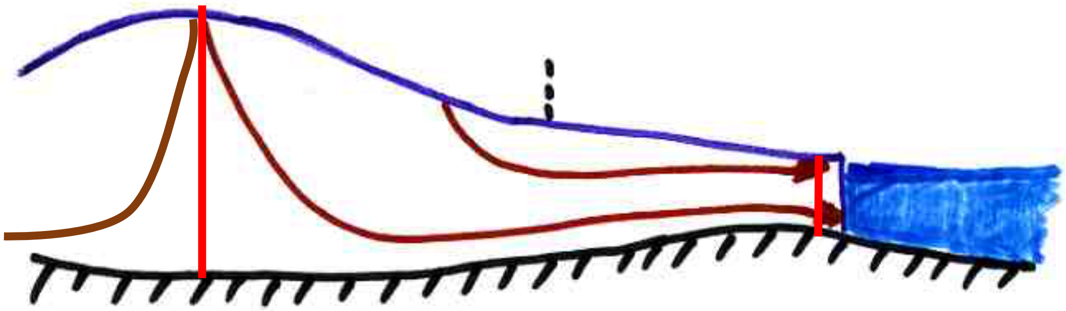


Ice Cores as Paleo-Weather Stations

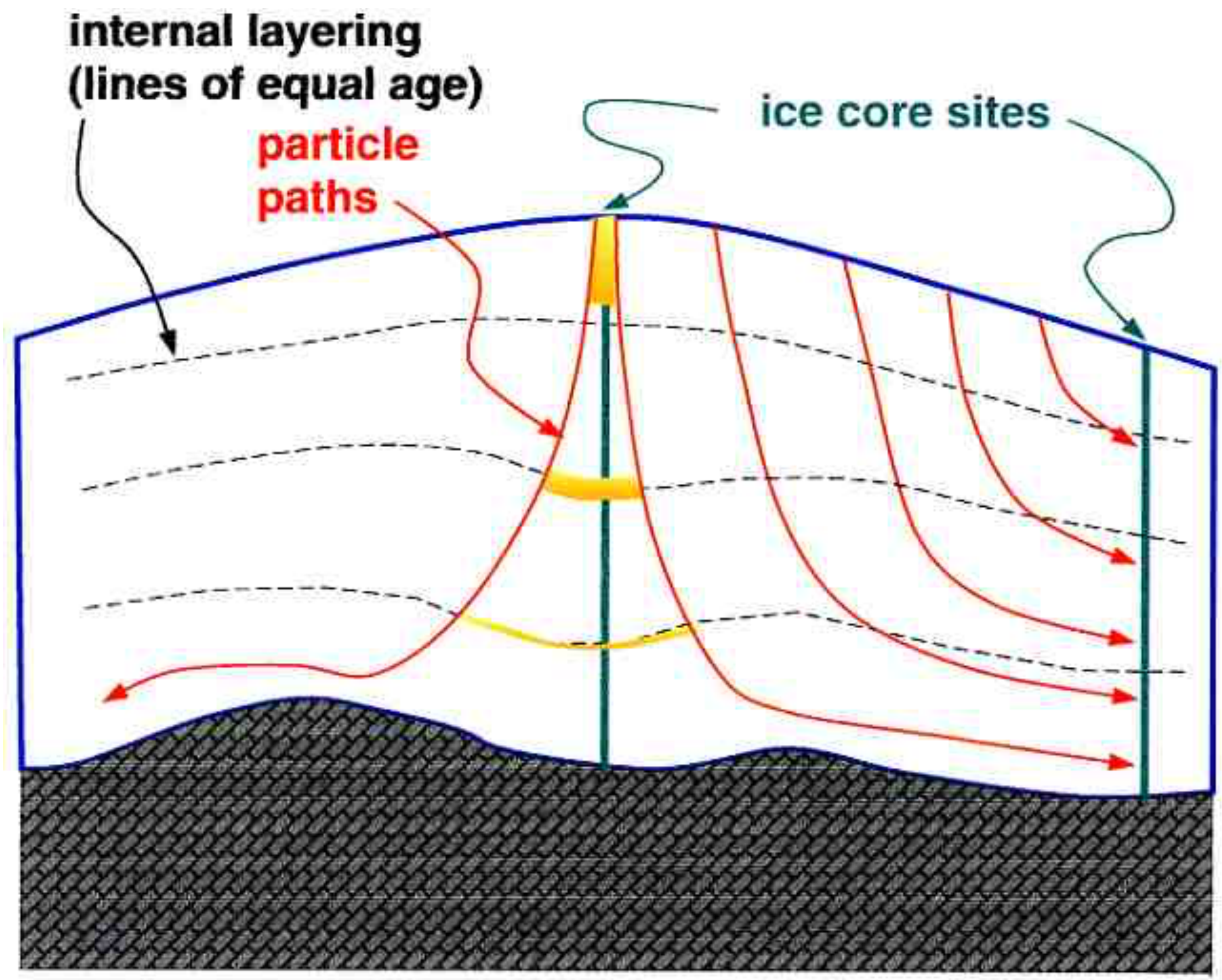
We're going to focus on three aspects of weather/climate:

1. **Temperature ($\delta^{18}O$ proxy)**
2. Precipitation
3. Greenhouse gas concentration

Before we get to other proxies, let's use the last question to talk about how to choose a site to drill an ice core.



Choosing an Ice-Core Site



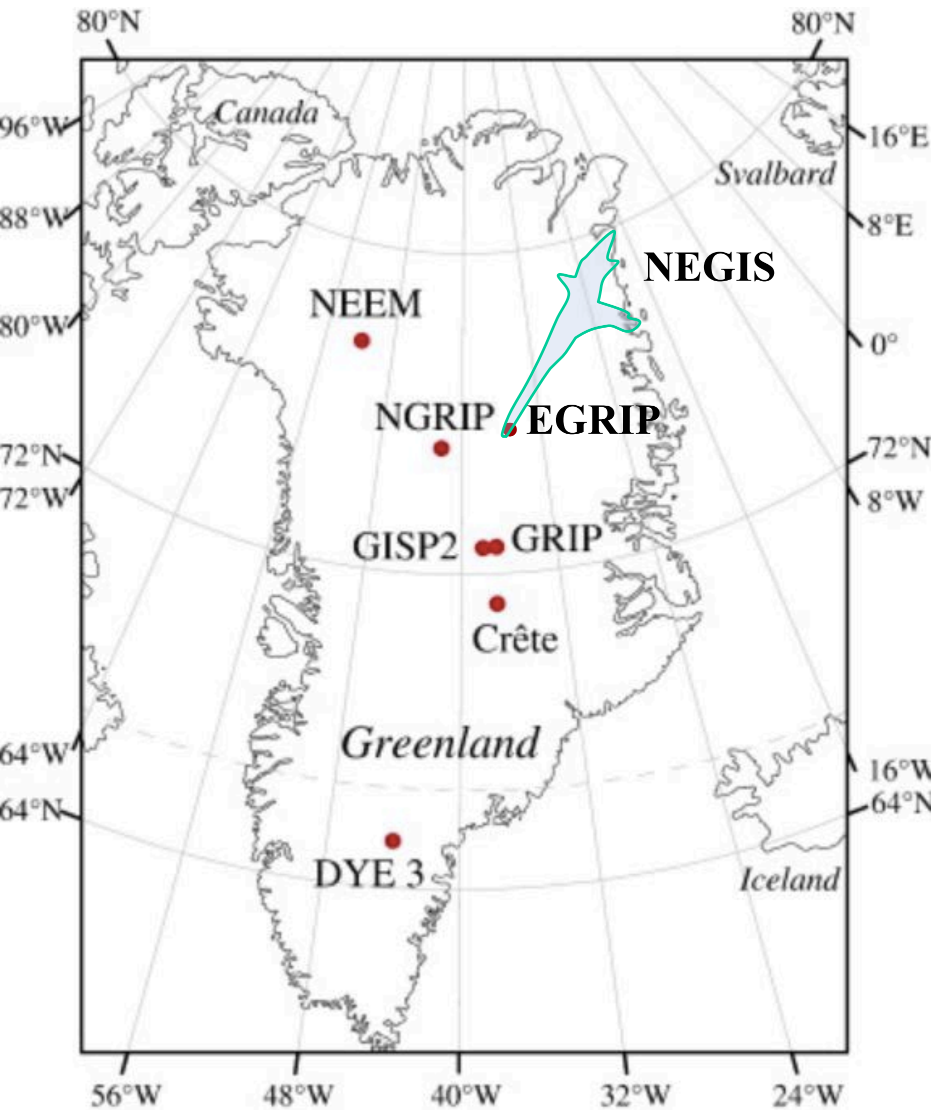
Near the summit is often best.

- Climate signal relates to the same place for ice of all ages.

Layers get thinner over time due to flow.

- When are layers too thin to resolve annual signal?

Willi Dansgaard's Legacy



South Dome core - 1983

- Dye 3 (Cold War radar site).
- Core went back into last ice age.

Summit - GRIP 1992/GISP2 1993

- 2 cores, 30 km apart. 110 ka ice.
- Fast climate changes are not ice-flow artifacts.

NGRIP - 2003

- Recovered ice from end of previous warm interglacial period (>110 ka BP).

NEEM – drilling finished in 2012

- Found ice from entire previous warm interglacial period.

EGRIP – 2016 -

- Currently underway
- Studying NEGIS(ice-stream) onset.

Ode to Willi Dansgaard's Carlsberg Bottle

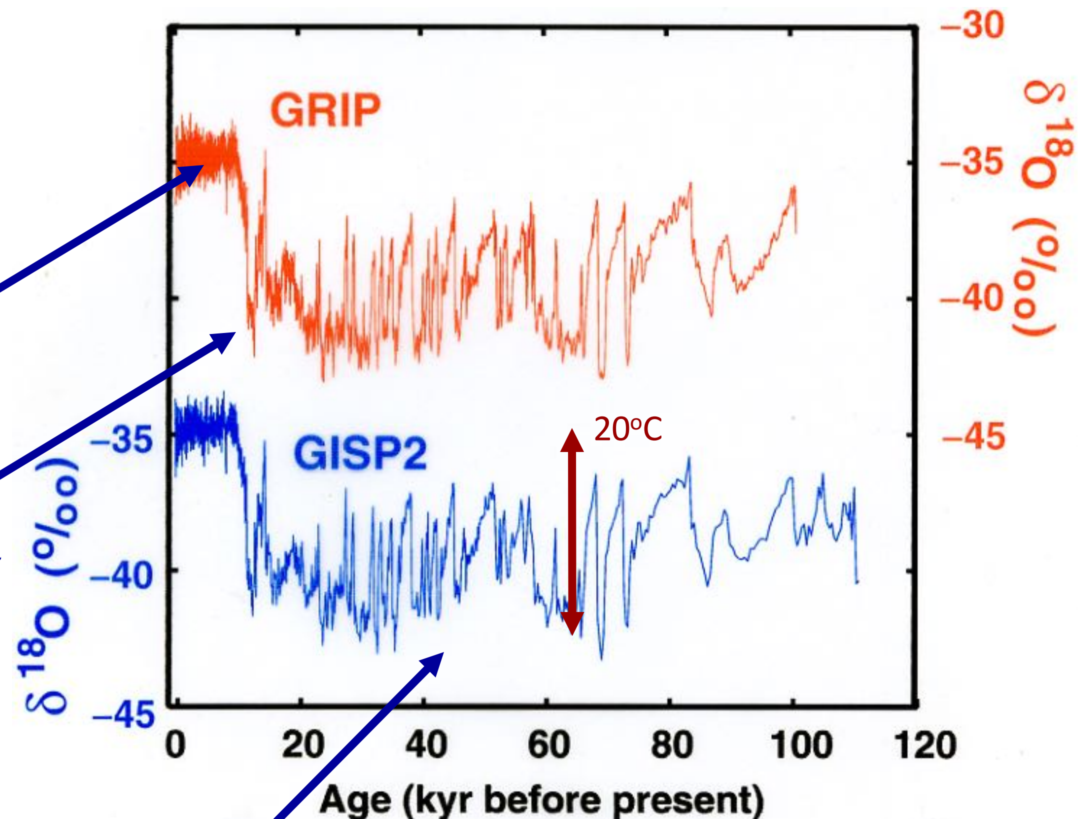
H has one nucleon, *He* has four,
O has sixteen, but sometimes two more.
What does it matter, they don't chemically care …
But, evaporate both from mid-ocean spray,
and send storms to Greenland, cooling air on the way.
Water condenses, forming rain, day by day.
Extra Eighteens on the drops stow away,
And not liking flight, bail out of the play.
Sixteen stays aloft, with no remorse
Proudly proclaiming "we'll stay the course".
The colder it gets, fewer Eighteens remain.
Then a snowflake falls to the icy plain …
Where by our ratio, cloud temperature we proclaim.

Go $d^{18}O$! Go Willi!

(Anon)

Going backwards in the Time Machine

$\delta^{18}O$ – a proxy for past temperatures in Greenland



Holocene 0-10ka BP

- Climate stable and warm.
- Human civilizations and agriculture are possible.

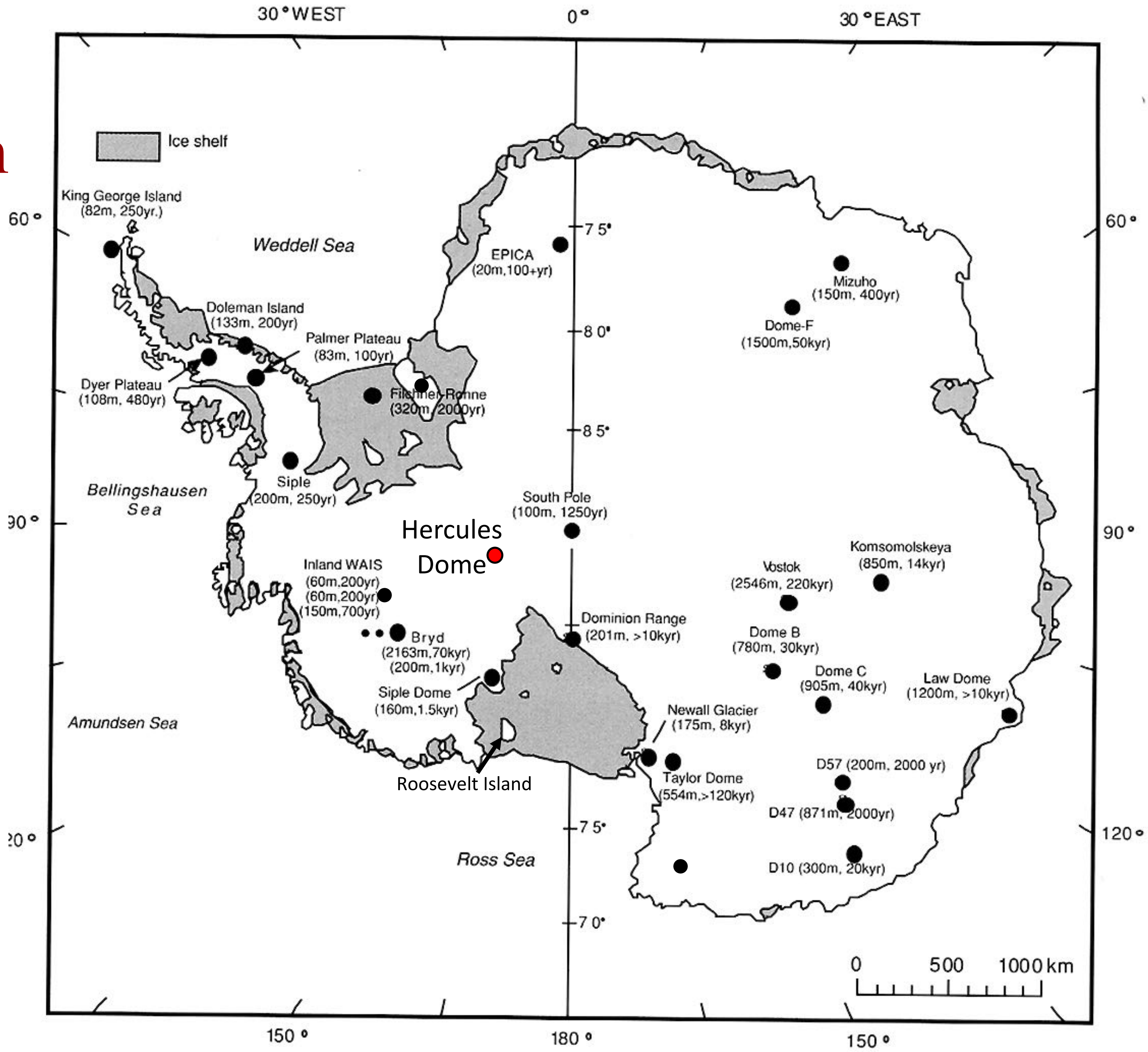
Younger Dryas 11.6-12.9 ka

- Last gasp of the Ice Age.

Wisconsin (Last) Ice Age, 18-110 ka

- Dansgaard-Oeschger events: huge and fast transitions in climate in just a few years (sometimes in less than a decade).
- All humans are hunter-gatherers

Ice Cores in Antarctica



What story Does Antarctica Tell?

Vostok Station

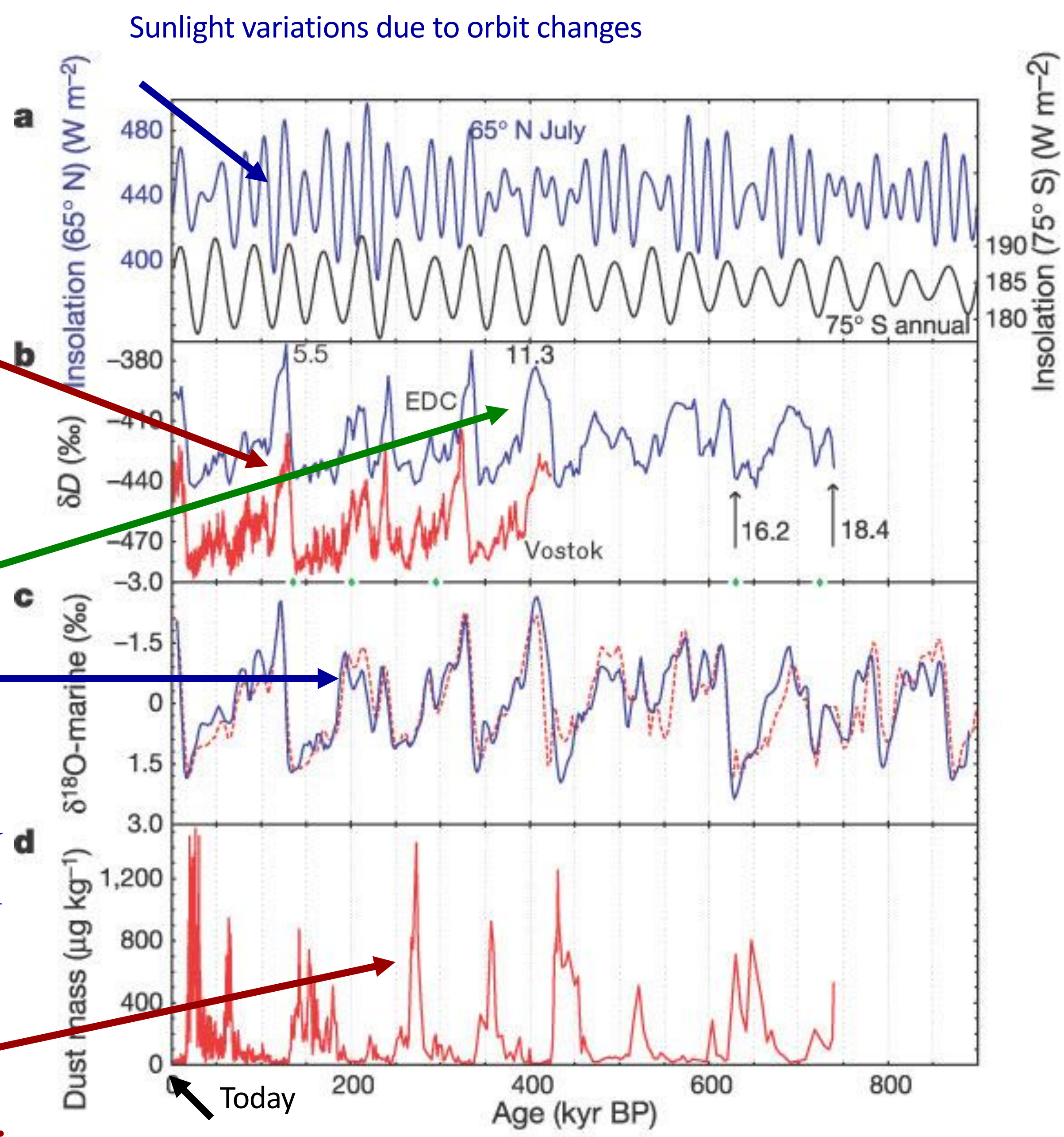
- 4 glacial cycles

EPICA Dome C

- 8 glacial cycles

- Isotopes from ocean floor record the volume of ice on land in ice sheets. We will cover this soon.

- Dust in ice reveals windiness in the past.



Nature 429, 623-628 (10 June 2004) Eight glacial cycles from an Antarctic ice core