ESS 203 - Glaciers and Global Change

Friday February 12, 2021

Outline for today:

Monday is a holiday, so

- Highlights of last Wednesday's class – *Abigail Sylvester*

- Volunteer for today's highlights next Wednesday – *Lynn Nguyen*

- Inferring past precipitation from ice cores
- Air bubbles in ice cores, and history of greenhouse gases

Assignment

Due Today: HW 16

Due Wednesday: read chapter 7 "*The Ice Age Cycles*" and complete a short writing assignment.

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 → Accumulation Rate**
3. Greenhouse gas concentration

Finding the Past Accumulation Rate

How does accumulation rate differ from precipitation rate?

- Not all precipitation accumulates
  - Blowing snow
  - Melting and runoff

If we want to know the accumulation rate in the past on the ice sheet, we need to find:

- How much snow/ice accumulated
- How much time passed
- Then we can calculate:

  accumulation rate = amount of snow / time

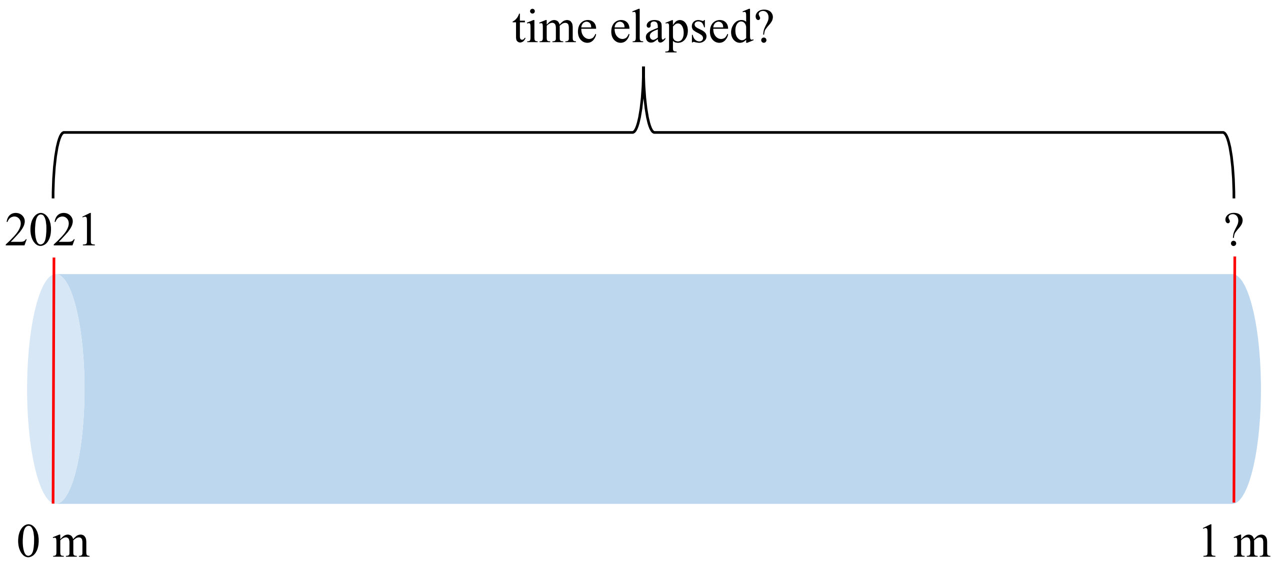
Finding the Past Accumulation Rate

How much snow/ice accumulated

- Equivalent to the length of a section of core

How much time passed

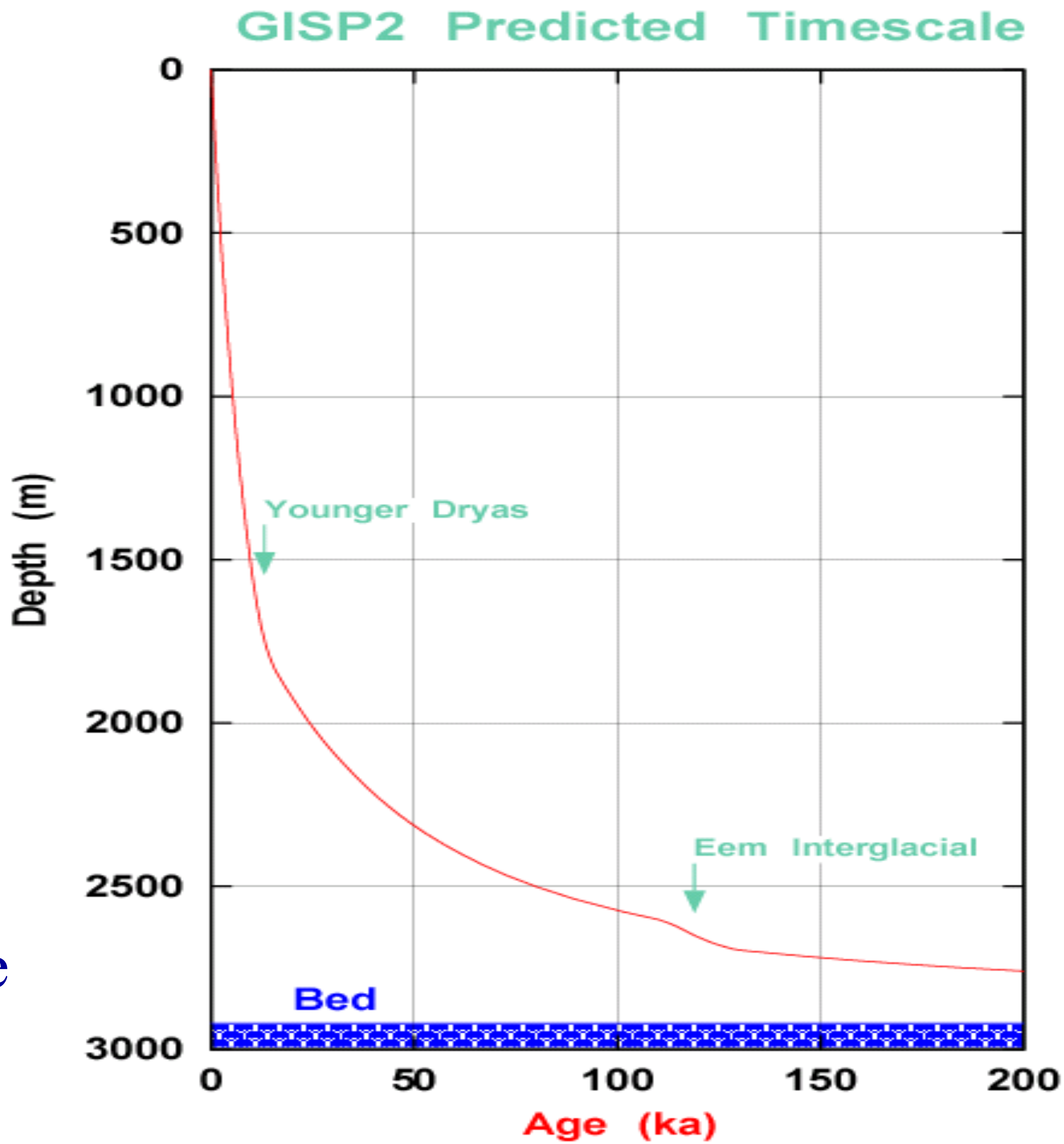
- This one is trickier…



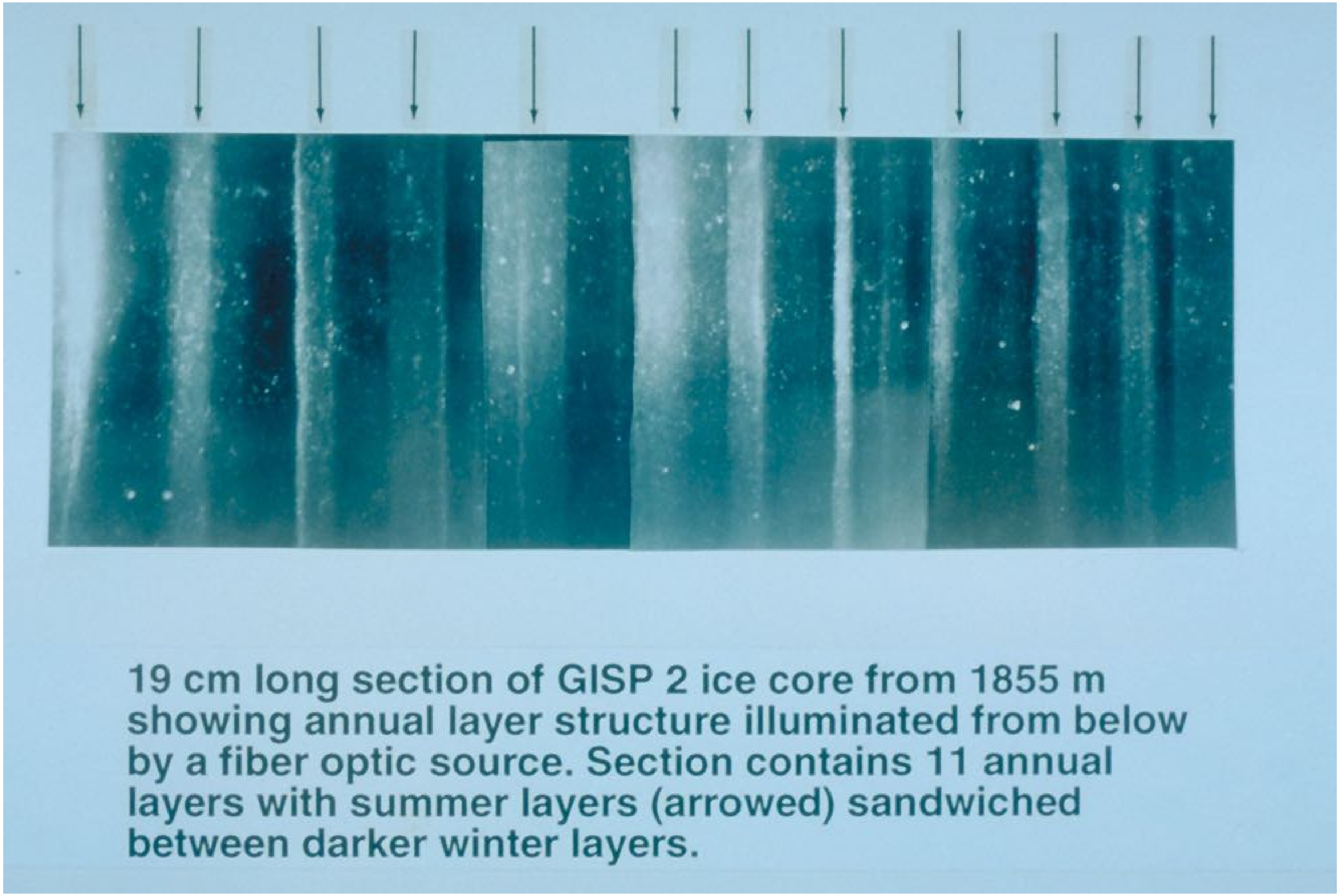
What is a depth-age scale?

Depth-age relation from an ice-flow model →

- At different depths in the ice cores, we need to know the age.
- This is from a model, how do we do this for a real ice core?

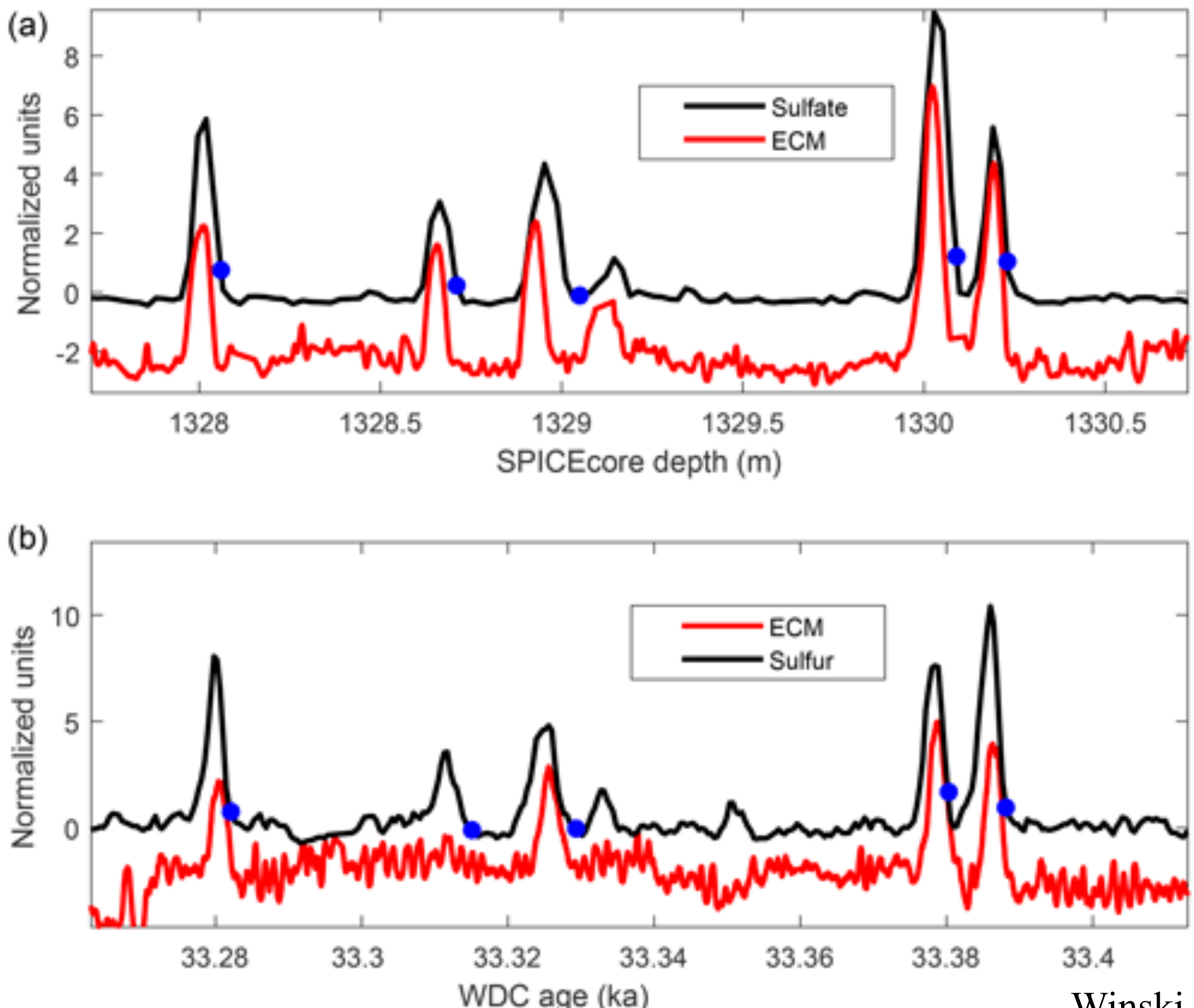


Dating an ice core: 1) Count the layers



GISP2 ice core, ~20,000 years old

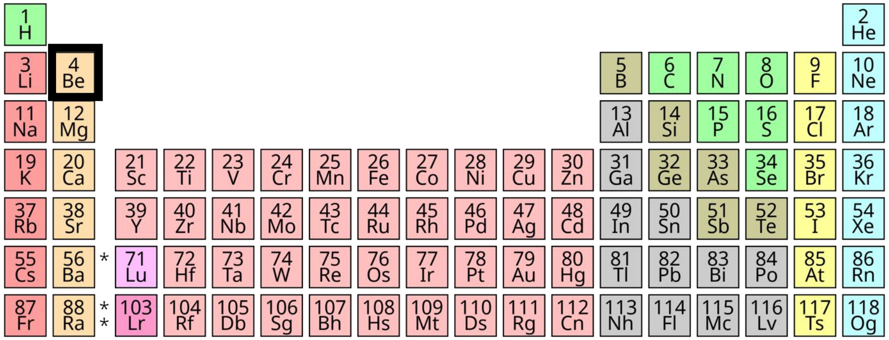
Dating an ice core: 2) Volcanic matching

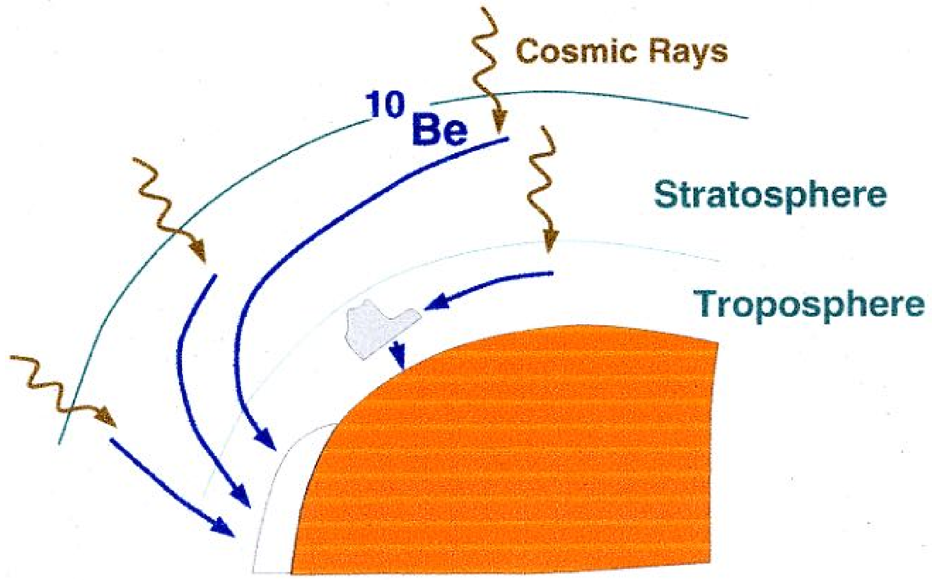


Winski et al. (2019)

Dating an ice core: 3) ^{10}Be

- Formed in the stratosphere at a constant rate
- Attaches to sulfate aerosols and falls to onto the ice sheets
- Allows scientists to know how much time has passed if they measure some amount of ^{10}Be in a section of the ice core.





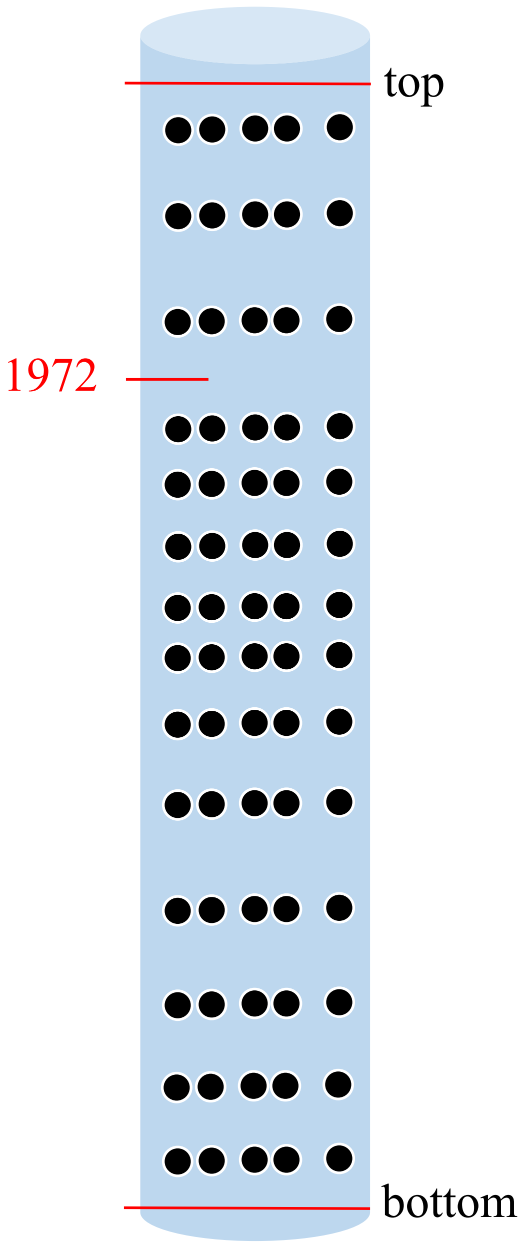
Past Accumulation Rate

Several methods that allow us to date an ice core.

- Annual layer counting
- Volcanic matching
- ^{10}Be

It is a combination of these and other methods that allows scientists to accurately date ice cores.

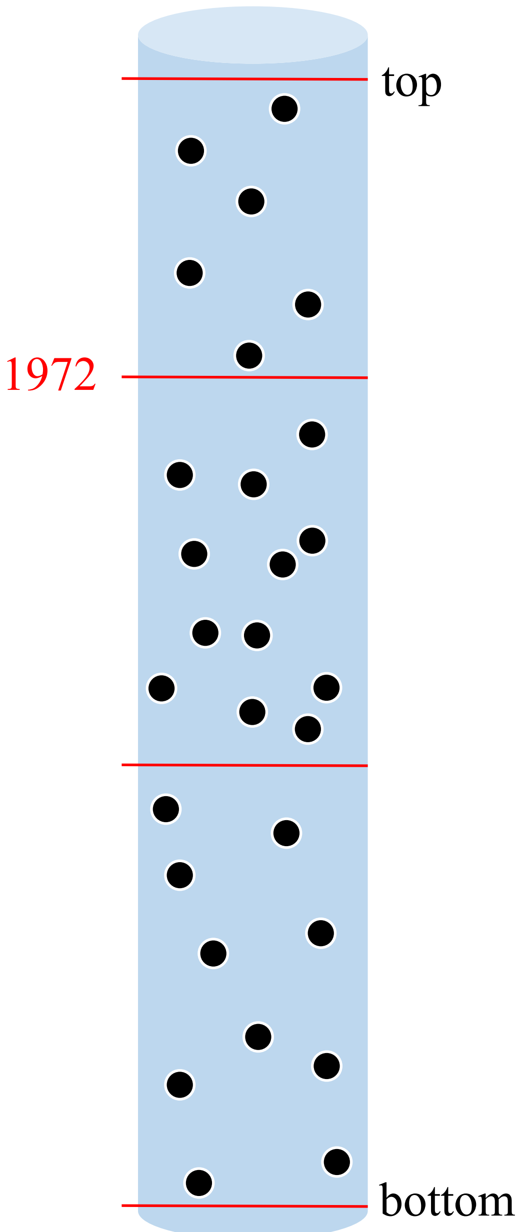
Let's put these methods into practice.



Annual Layers

In the winter, more dust falls on the ice sheet (black points), while in the summer, we see no dust in this core. One summer date is known from a volcanic event.

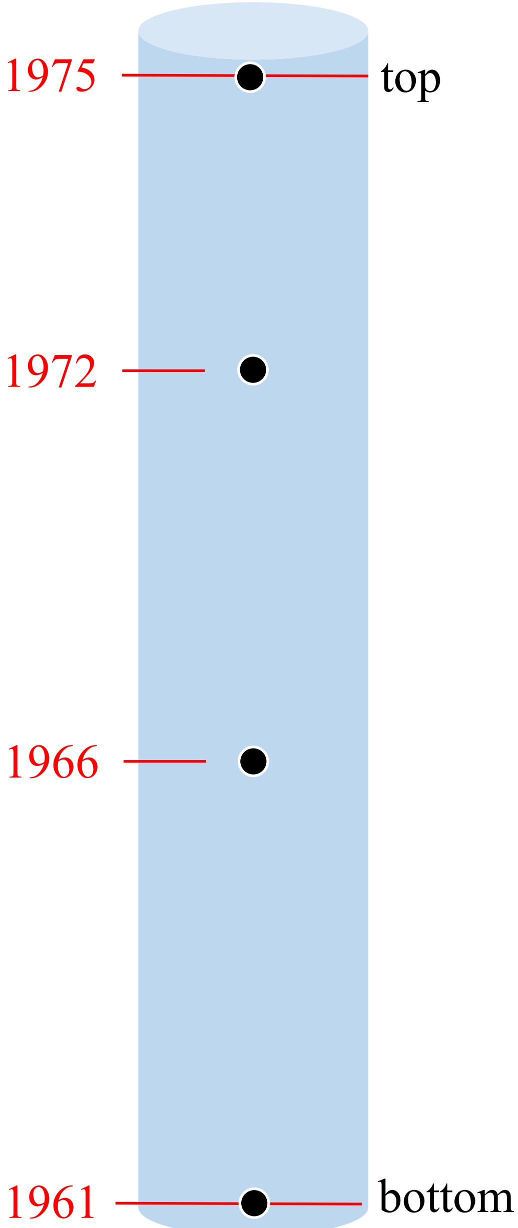
- What is the age of the summer layers at the top and bottom of the ice core?
- Qualitatively describe any changes in accumulation rate you observe.
- What assumptions did you make when dating this core?



^{10}Be

^{10}Be accumulates at a rate of about 2 dots per year (for this example). One summer date is known from a volcanic event.

- What is the age of each red line?
- Qualitatively describe any changes in accumulation rate you observe.
- What assumptions did you make when dating this core?



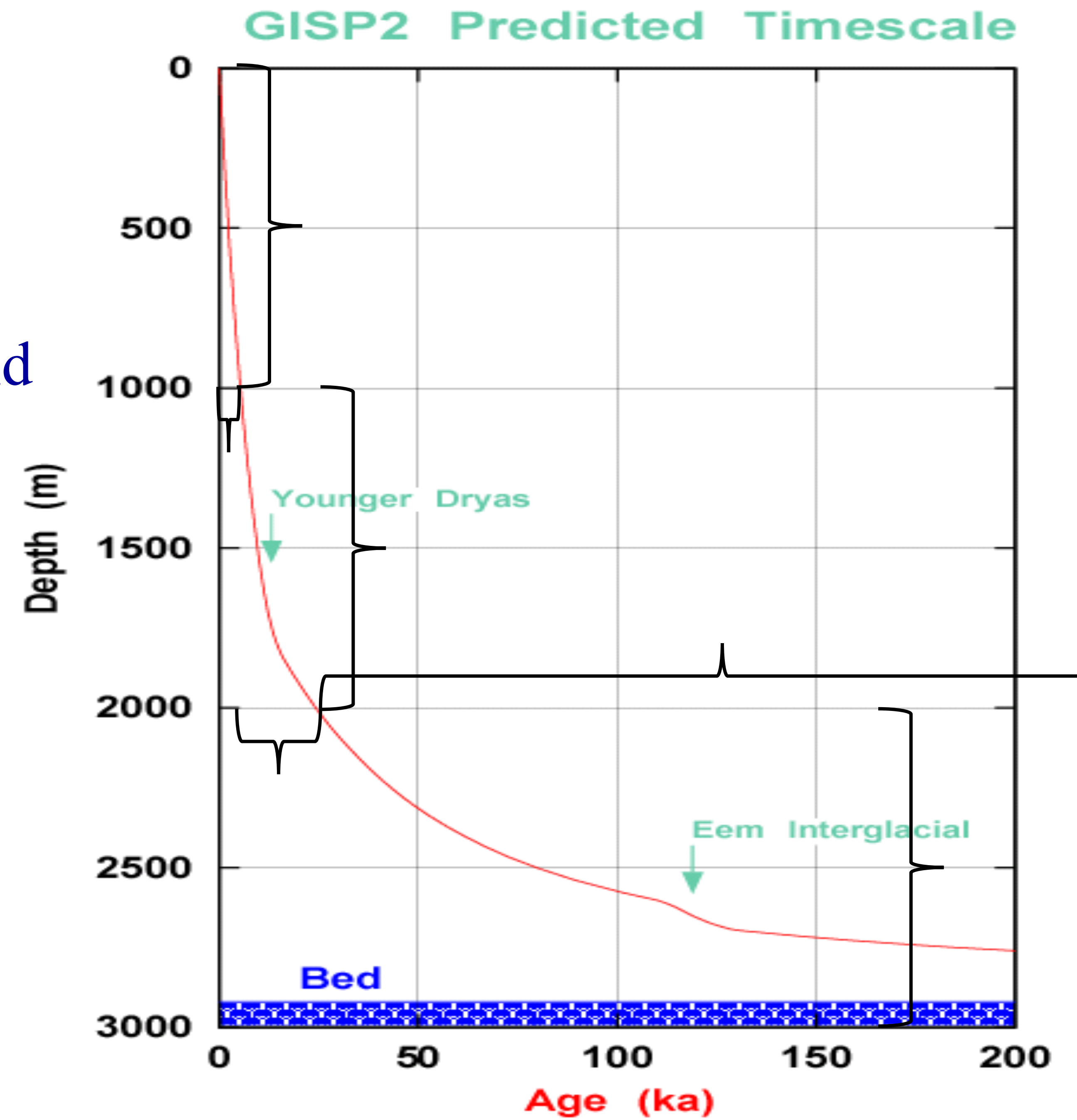
Volcanic Dating

Four volcanic layers have been dated in this section of core. Each date is a summer date.

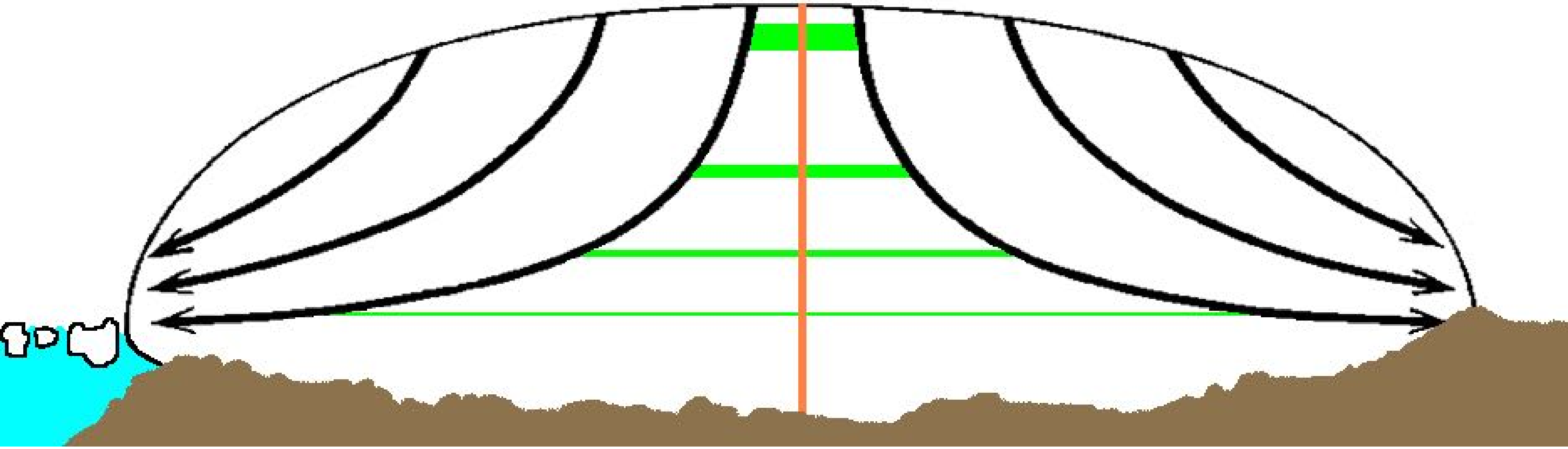
- How many winters occurred between each summer date?
- Qualitatively describe any changes in accumulation rate these dates indicate.

Is it really that simple?

- Taken at face value, what would this curve tell us about past snow accumulation rates?
- Why should you be skeptical of this interpretation?

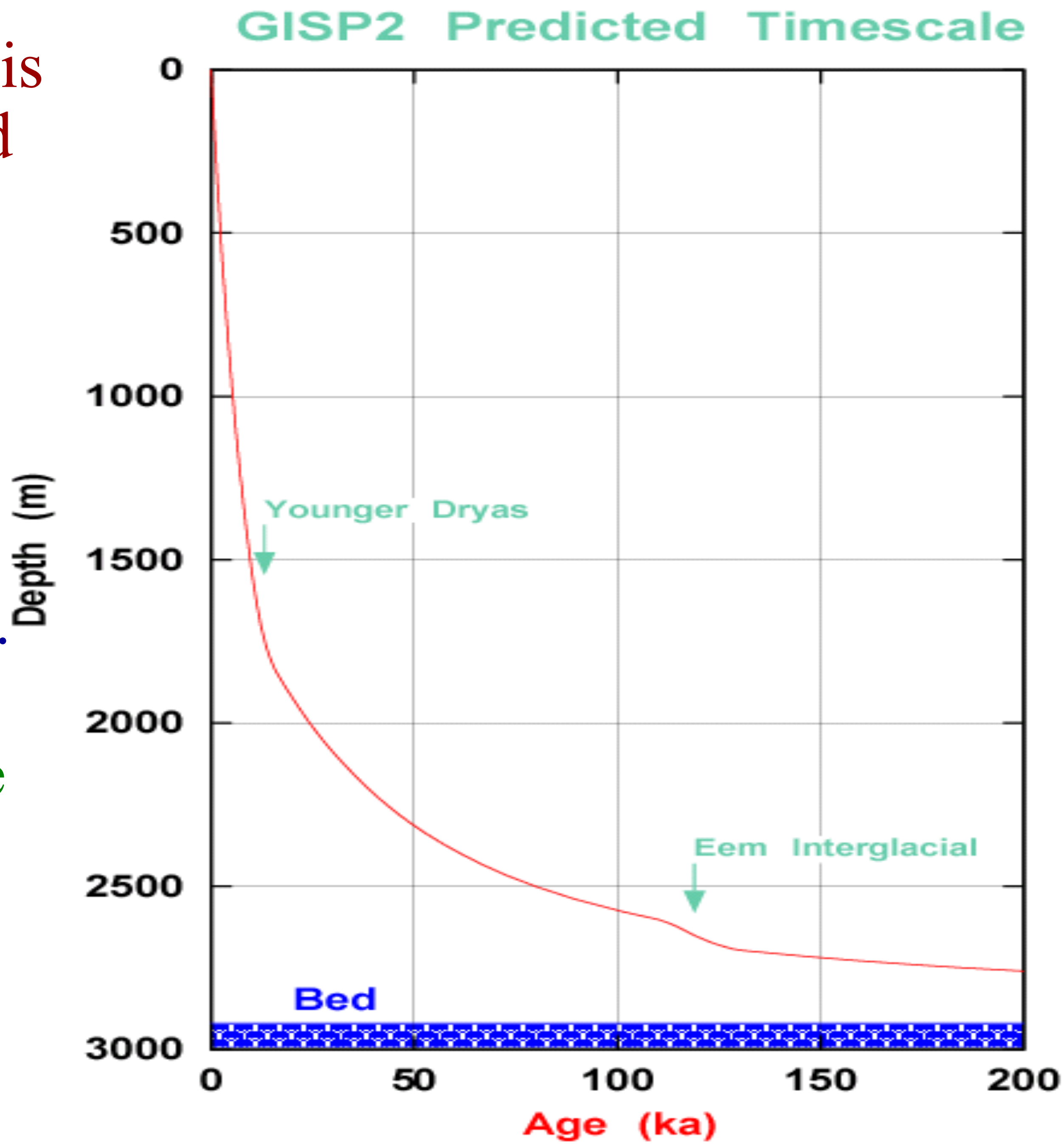


As ice flows, it stretches and thins…



The structure of this curve is dominated by thinning.

- To figure out the accumulation rate, we must ***unthin*** this curve.
- You'll think more about thinning & depth-age scales in the lab next week.



Summary of Calculating Accumulation Rates

We've found several ways to date an ice core.

- Annual layer counting
- Volcanic matching
- ^{10}Be

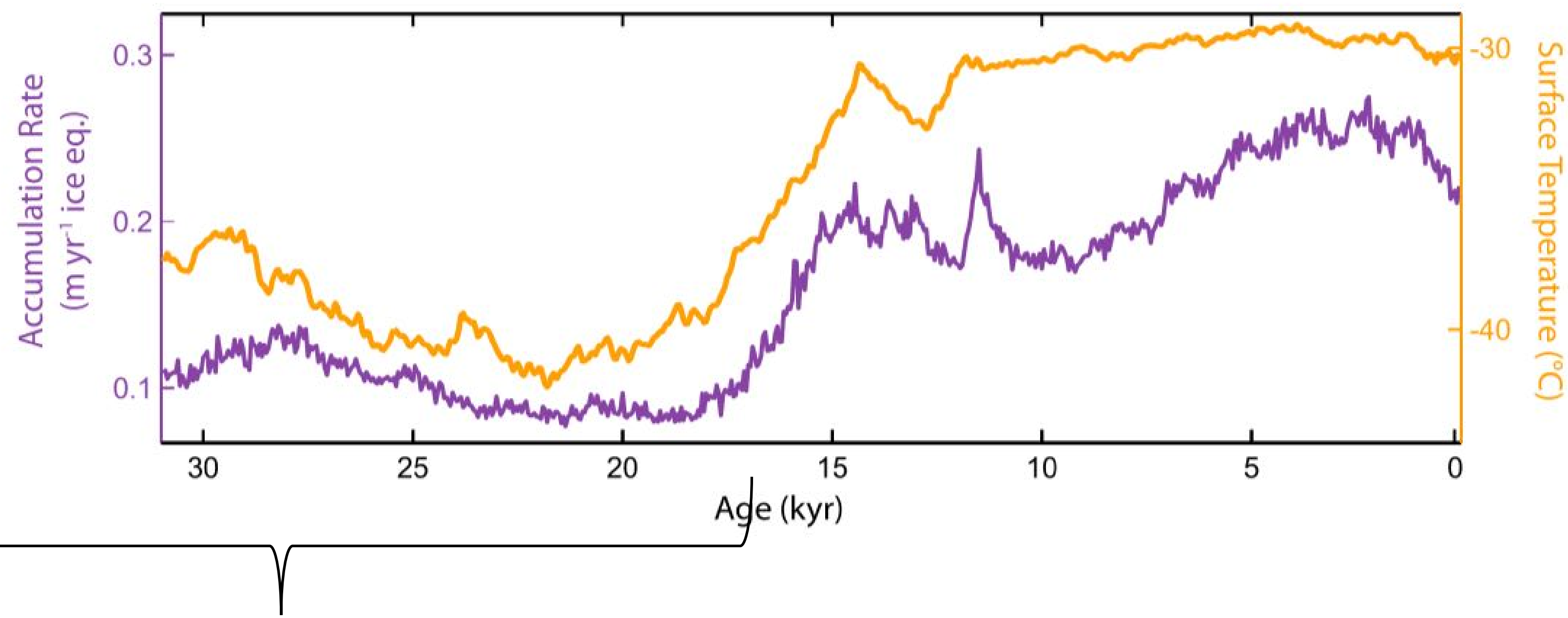
Then we can find the accumulation rate:

accumulation rate = amount of snow / time

But first, we need to ***unthin*** the ice core.

Accumulation rate & Temperature

WAIS Divide Ice Core, Antarctica



Last Ice Age

Fudge et al. (2016)

Earth was ***Drier*** in the Ice Age?!

What's going on?

- Shouldn't Earth have been wetter or snowier to have larger ice sheets during an ice age?

When have you encountered the heaviest snowfall?

- When its really cold? Or
- When temperature is just below freezing?

When can atmosphere carry more water vapor?

How can glaciers grow with less snowfall?

Ice Cores as Paleo-Weather Stations

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

1. Temperature ($\delta^{18}O$ proxy)
2. Accumulation Rate (depth-age scale)
3. **Greenhouse gas concentration**

Earth's Atmosphere in the Past

How could we learn about changes in composition of Earth's atmosphere in the past?

Collect air in bottles, save for future scientists.

- Doesn't help us to look back very far. Our ancestors were not planning far enough ahead.

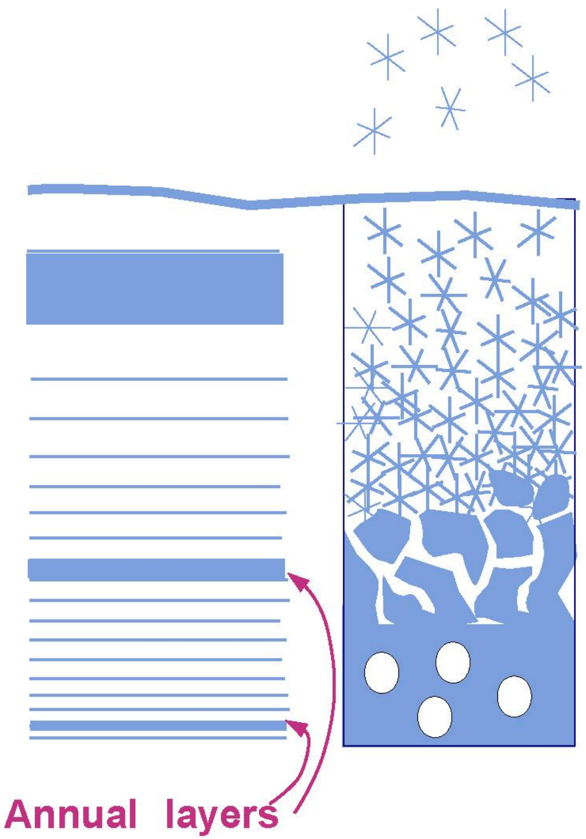
Find bubbles of air trapped in naturally sealed containers.

- Containers must not react chemically with the air.
- Containers must be really well sealed.
- Guess where we can look…

What can we measure in the air bubbles?

Carbon dioxide: CO_2
(rock weathering, plant growth & decay, ocean uptake)

- Did CO_2 lead or follow temperature changes in pre-industrial times?



Methane: CH_4
(vegetation decay, swamps, termites)

- Why would it change in an Ice Age?

$\delta^{18}O$ of oxygen gas: O_2
(a proxy for plant respiration)

- Respiration removes the lighter ^{16}O in preference to ^{18}O, increasing the relative amount of ^{18}O in the atmosphere.

Global Variation of Records

We are not surprised if climate changes (e.g. temperature, precipitation, windiness, etc.) are different at different places on Earth.

The composition of the atmosphere can also change with time (e.g. CO_2 and CH_4 are rising today).

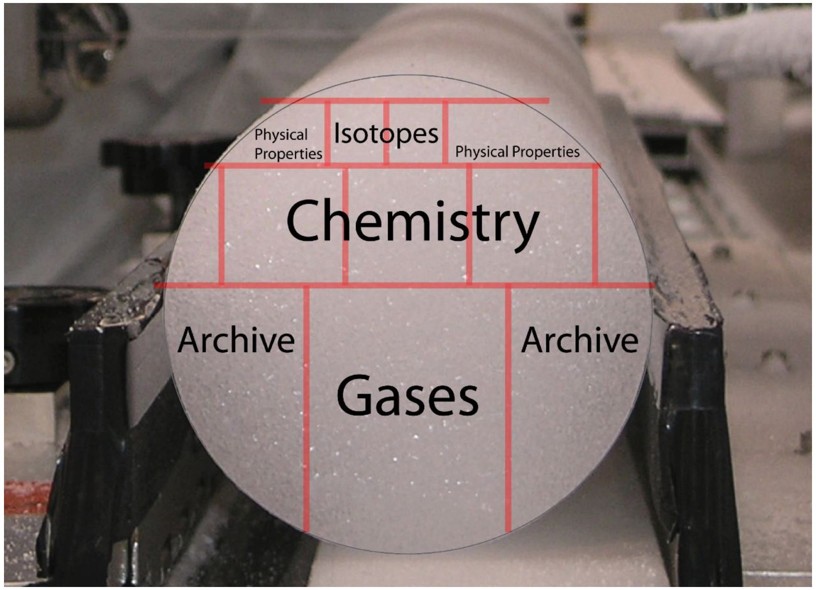
- CO_2 stays in the atmosphere for 4-200 years
- CH_4 stays in the atmosphere for ~12 years

Would you expect the composition of atmosphere to differ much from place to place at any one time? Why or why not?

Synchronization of Climate Records

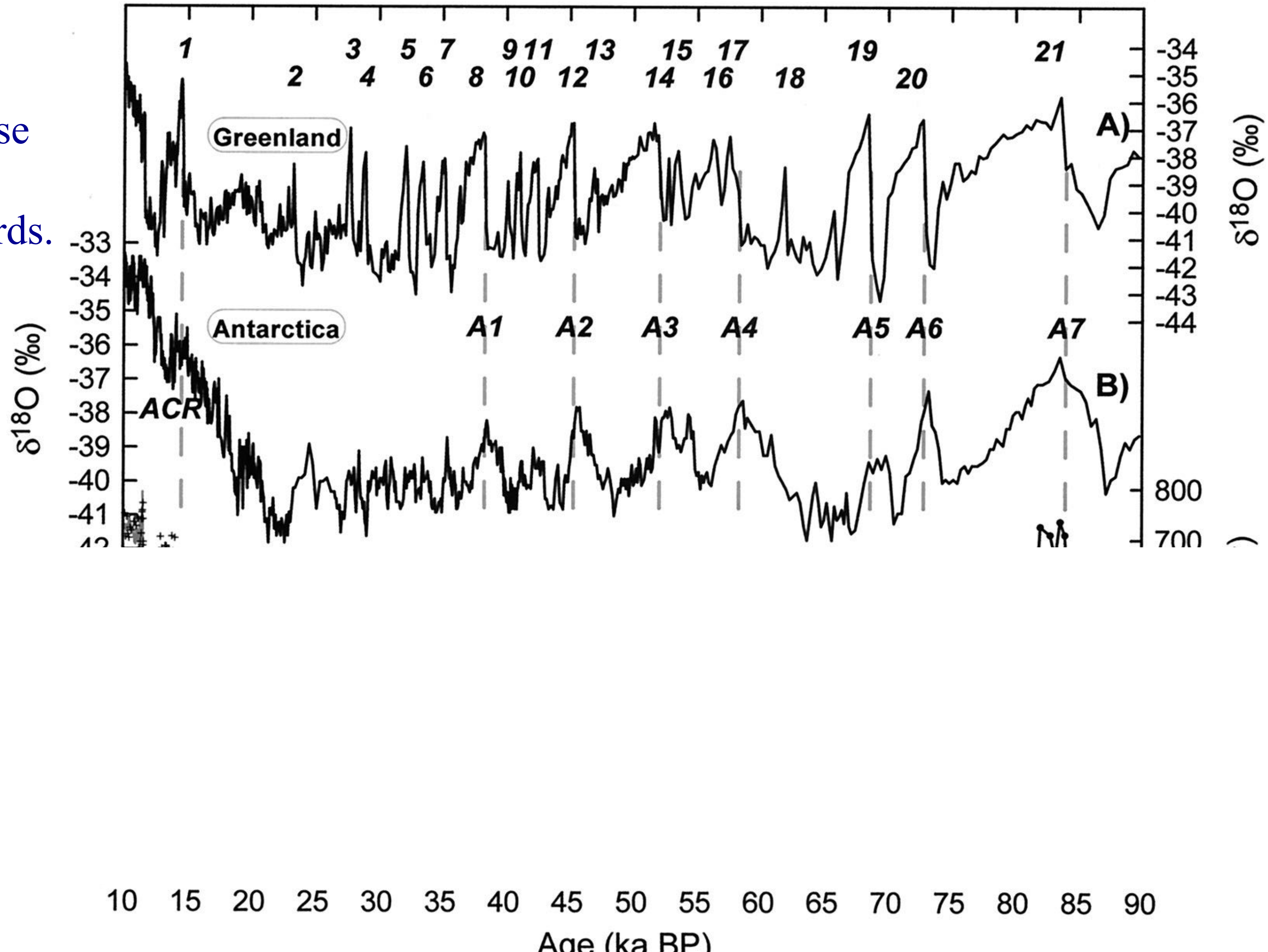
So if you measure gases in one ice core, you know the whole story of Earth's atmosphere.

Yet scientists keep measuring gas from bubbles from more ice cores …



Gas-based North-South Correlation

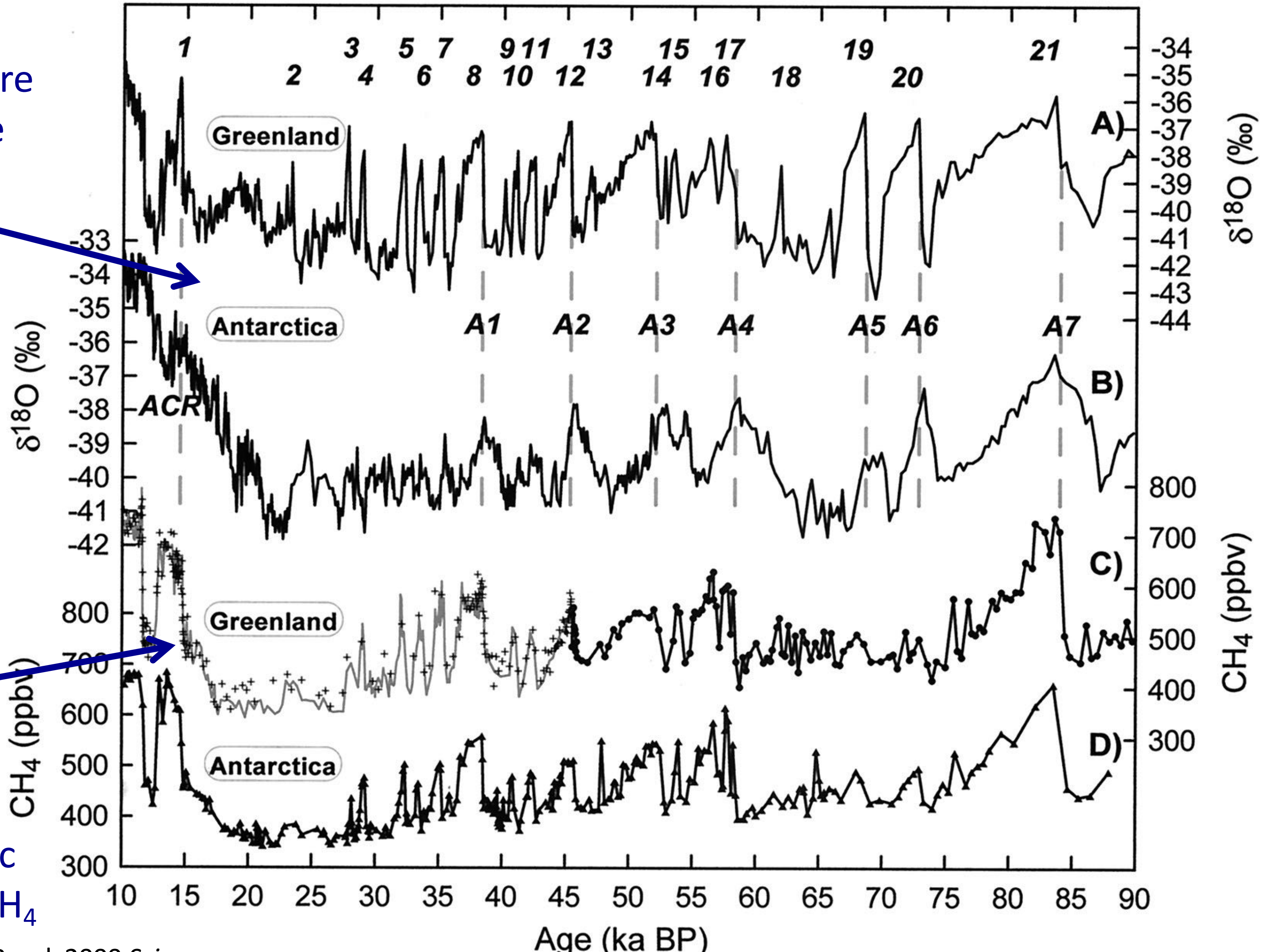
Difficult to compare these two oxygen isotope records.



Blunier and Brook 2000 *Science*.

Gas-based North-South Correlation

Then compare temperature records

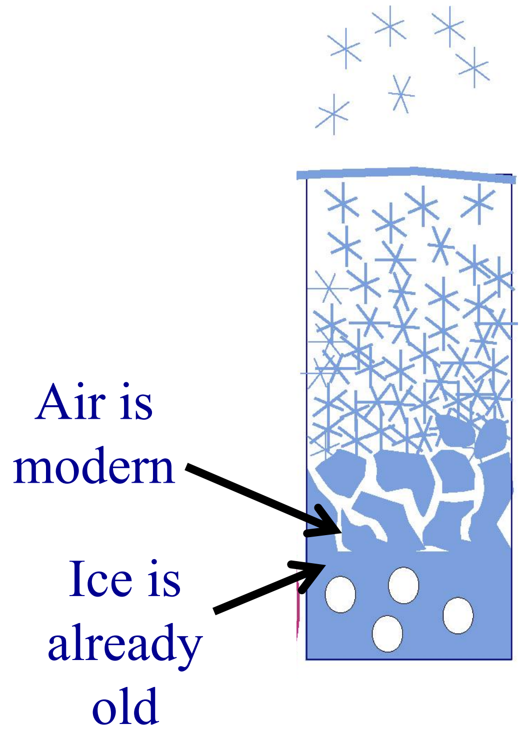


Line up Greenland and Antarctic cores with CH_4

Blunier and Brook 2000 *Science*.

Ice age - Gas age Difference

- The air being trapped today is part of today's atmosphere
- The ice that traps today's air is already old (older than the air)



This offset in age is called the "*ice age-gas age difference*" or "*Δage*" and it can be 100s to 1,000s of years

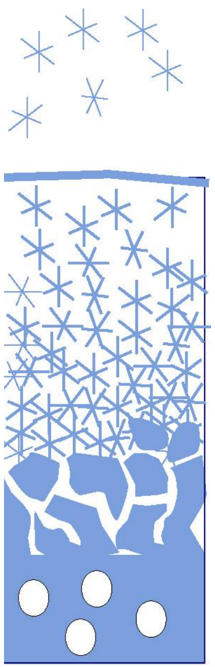
How does this complicate ice core synchronization?

If we don't know the *Δage*, then synchronizing gas records won't help synchronize the ice records.

How do we learn the age of the gas?

Scientists know:

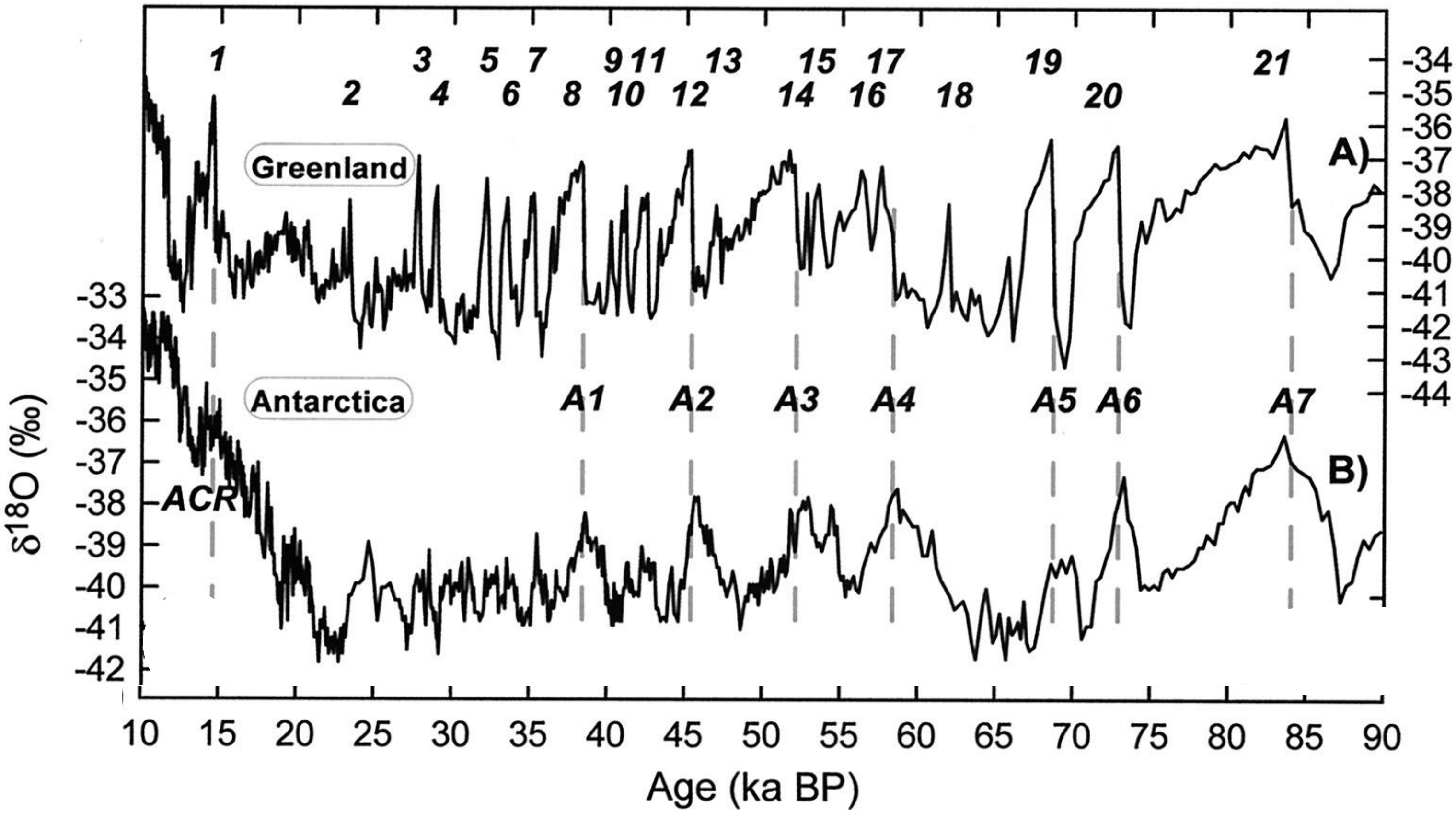
- Δage depends on the speed of snow compression
- speed depends on temperature and accumulation rate



Would you expect Δage to differ between ice ages and interglacial times?

An active area of research is figuring out Δage with a small enough uncertainty to ***understand the timing of climate change between the Northern and Southern hemispheres*** and to ***figure out what aspects of climate change first and "drive" the other changes***.

Gas-based North-South Temperature Correlation

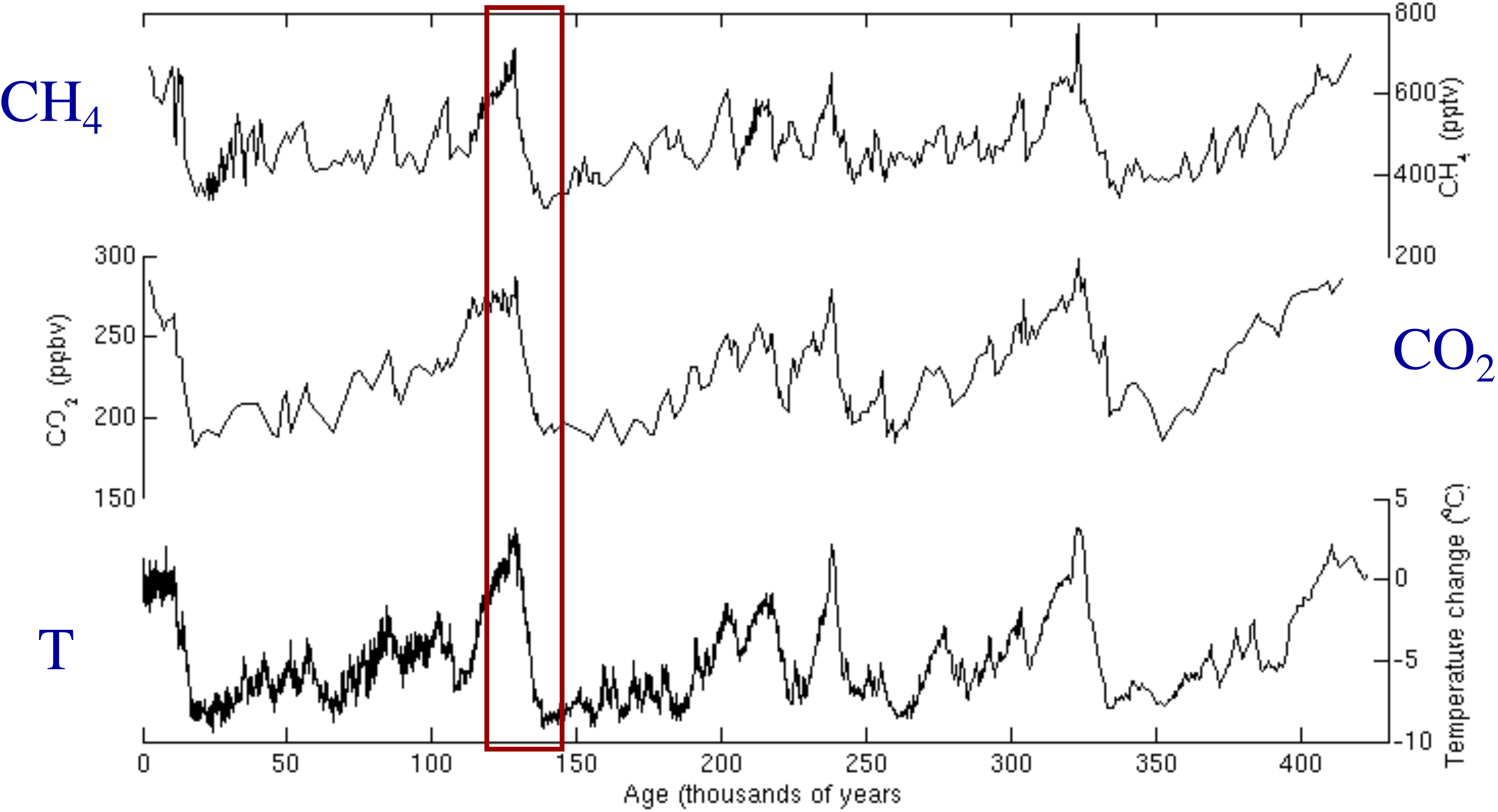


What's the relationship?

- Antarctica warms first.
- Both North and South see the big events.
- Climate changes were faster and larger in Greenland.

Blunier and Brook 2000 *Science*.

Greenhouse Gases and Ice-Age Temperature



Vostok ice core

Ice Cores as Paleo-Weather Stations

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

1. Temperature ($\delta^{18}O$ proxy)
2. Accumulation Rate (depth-age scale)
3. Greenhouse gas concentration (air bubbles)

What have we learned?

Ice cores tell us about temperature, precipitation, and atmosphere composition over the past 500,000 years and more

- Some climate changes can be very fast.
- North and South see the same big picture of warming and cooling (with associated moistening and drying).
- Patterns differ on centennial and millennial time frames.
- Greenhouse gases change along with temperature.

But

- do greenhouse gases drive climate?
- do greenhouse gases respond to climate?
- or both?