From Isotopes to Temperature: Using Ice Core Data!

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Learning Objectives

Objectives:

- **Provide a hands-on learning activity where students interpret ice core isotope records and infer temperature changes based on modern day regional isotope-temperature relationships**

- **Expose students to millennial (thousand-year) scale climate variability and the primary forces driving those variations**

- **Gain insight into how Earth's temperature responds to orbital forcing over thousands of years**

From Isotopes to Temperature: Using Ice Core Data!

Working with a Temperature Equation

Much of our quantitative information about past climates comes from analysis and interpretation of stable isotopes in geologic materials. In this module you will become familiar with the kind of equation that relates the concentration of oxygen isotopes in an ice core to the temperature of the water when it precipitated.

<u>Quantitative concepts and skills</u>
Number sense: Ratios
Algebra: Manipulating an equation
Data analysis: Linear regression
Visualization
  Line graphs (Rayleigh Fractionation)
  XY- plots (Ice Core Data

Overview

- **Stable isotope ratios in geologic materials (ice cores, sediment cores, corals, stalagmites, etc) have the potential to tell us a lot about how our planet has changed over time.**

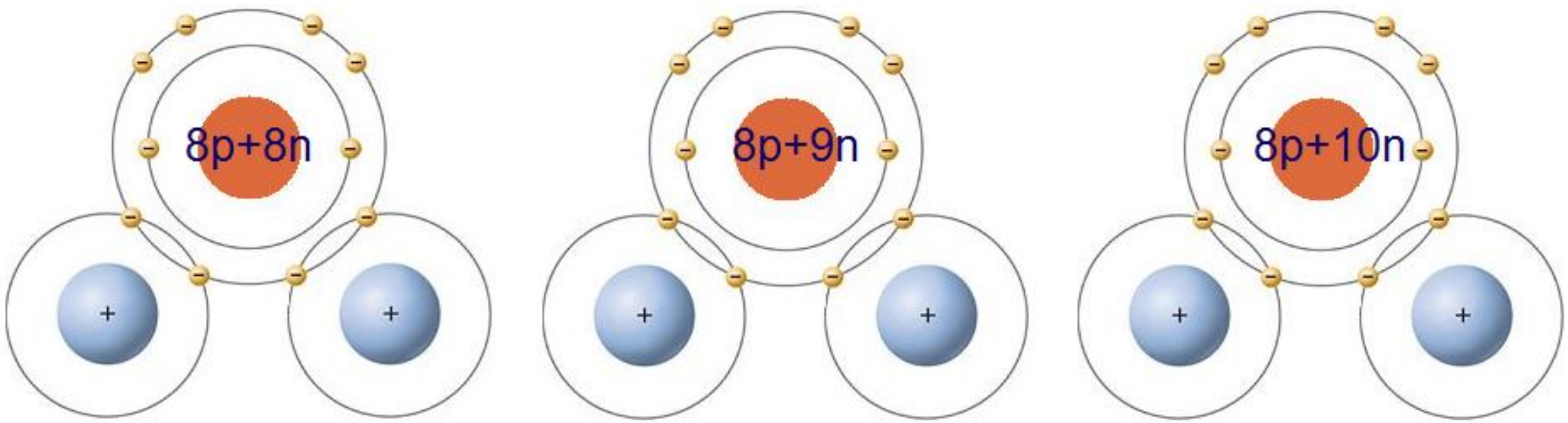
- **One common use of stable isotope analyses is to determine past temperature as a function of time and, therefore, a history of climatic change.**

- **This module will introduce the basic concepts of oxygen isotope behavior, how to translate isotope values to temperature values, and variables that impact temperature reconstruction.**

- **The dataset you will be using is from the Dome Concordia (Dome C) Ice Core, along with snow pit/ice core data from transects in East Antarctica.**

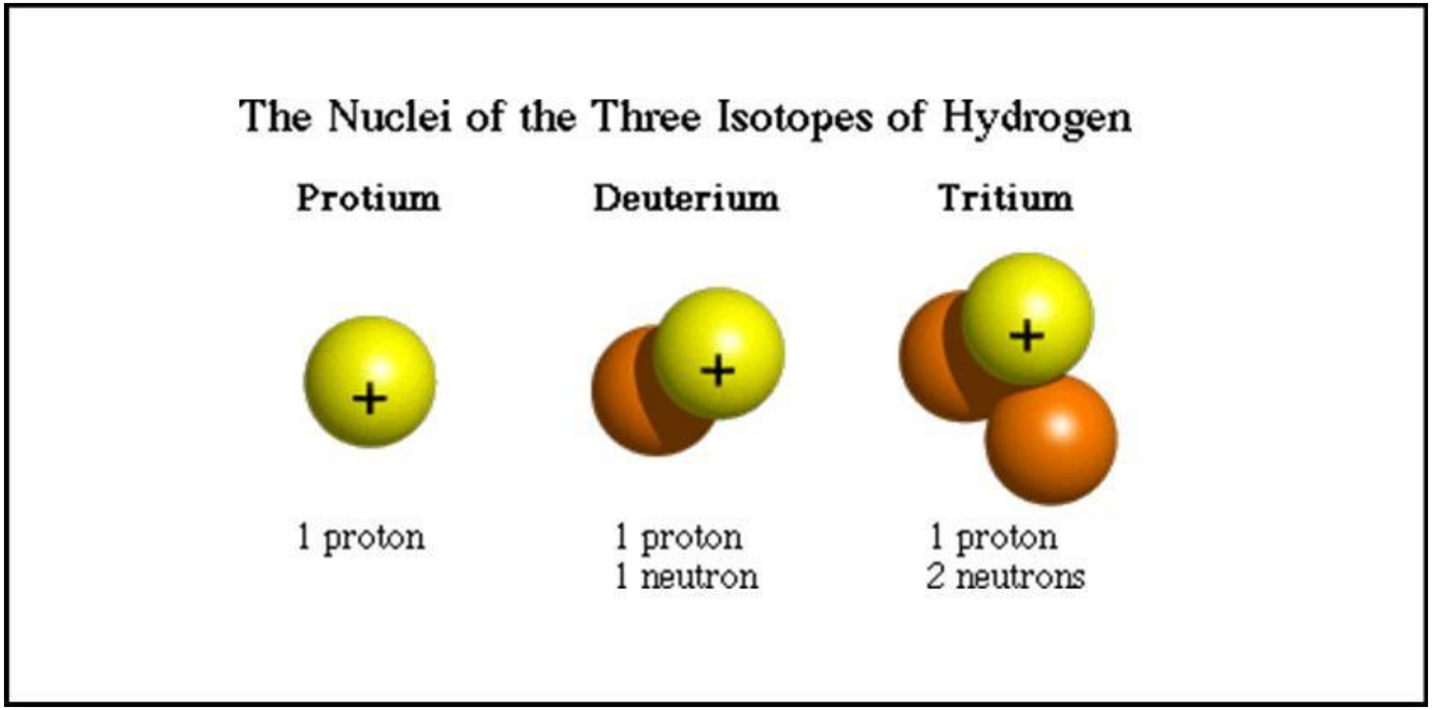
Oxygen Isotope Abundance in a water molecule

For every 10,000 water molecules we would find:



$H_2{}^{16}O$		$H_2{}^{17}O$		$H_2{}^{18}O$
9977	:	3	:	20

Oxygen Isotope Abundance in a water molecule



- All hydrogen atoms have 1 proton, but can differ in the number of neutrons.
- Deuterium and Tritium are the rare heavier isotopes of hydrogen

Quantifying the ^{18}O Abundance and Delta (δ) Notation

- Temperature reconstructions rely on variations in the isotope ratio (*R*) of ^{18}O to ^{16}O preserved in snow/ice.

- Variations in the $^{18}O/^{16}O$ ratios are smaller than the ratios themselves.

- Instead of using the small values of *R* to report the varying ^{18}O abundance, geochemists use $\delta^{18}O$, a relative difference ratio:

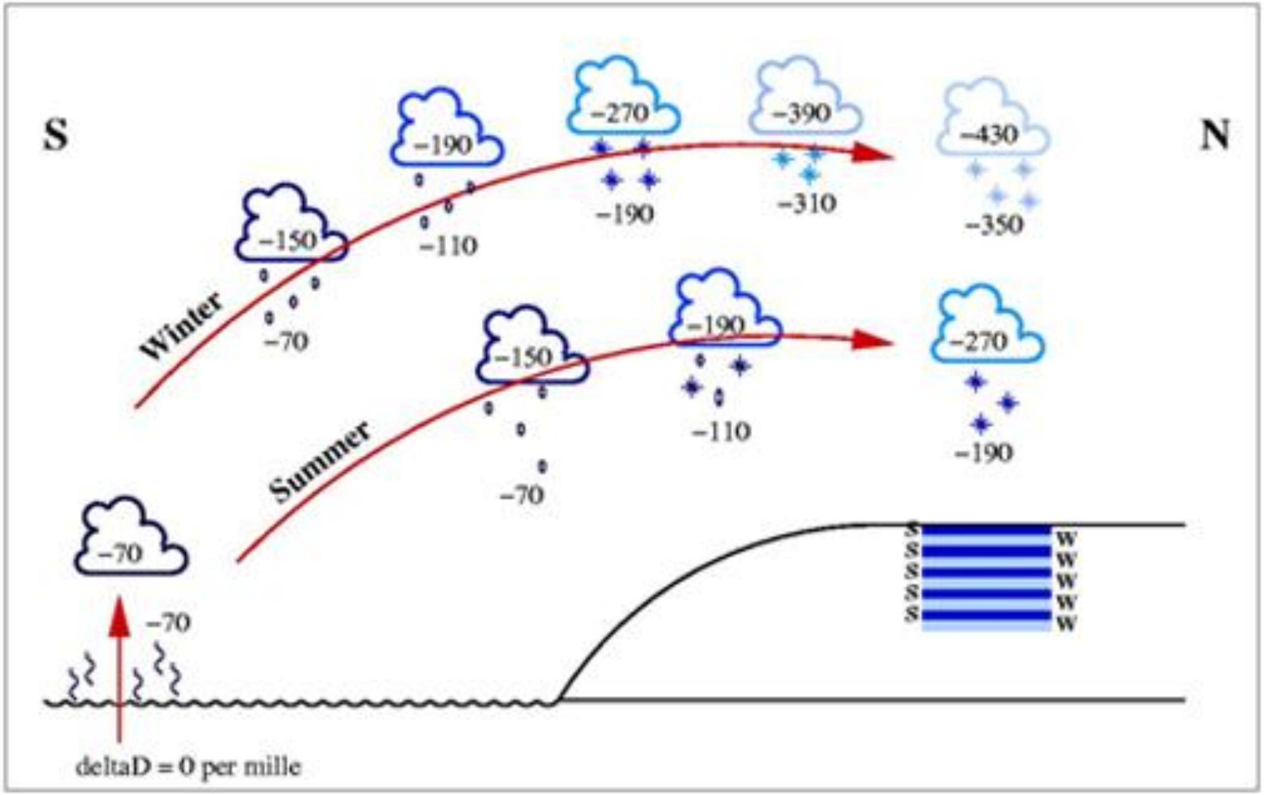
$$\delta^{18}\mathrm{O}\ ‰ = \frac{R_{\mathrm{sample}} - R_{\mathrm{standard}}}{R_{\mathrm{standard}}} \times 1000$$

Quantifying the ^{18}O Abundance continued

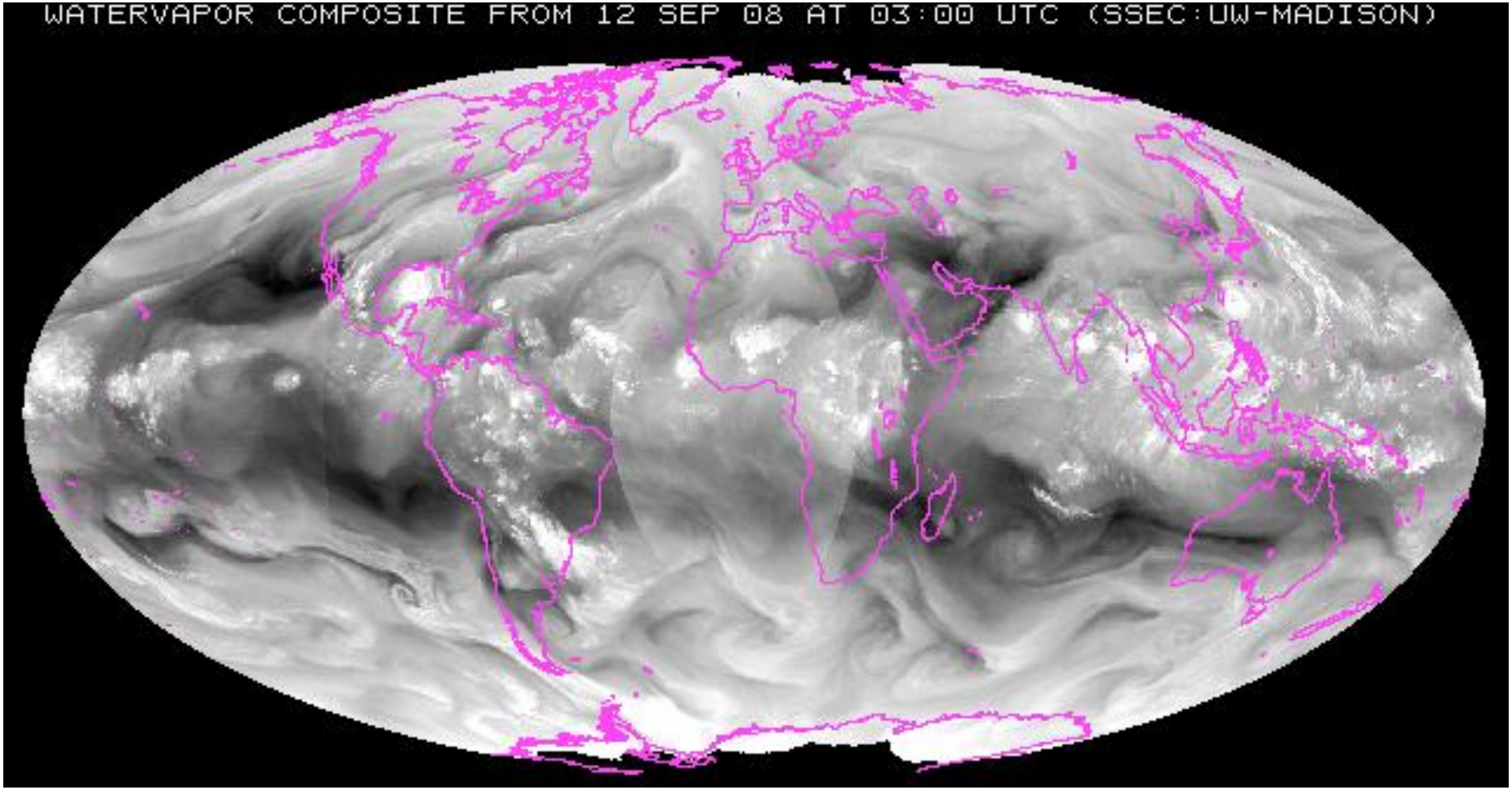
- Thus $\delta^{18}O$ is the difference of the oxygen-isotope ratios between a sample and standard relative to the ratio in the standard; it is a ratio derived from ratios.
- The value of $\delta^{18}O$ is stated as *per mil* (‰, parts per thousand in the same way that % is per cent, for parts per hundred.
- The isotope ratio mass spectrometer, which measures the oxygen-isotope abundance, reports out the per mil $\delta^{18}O$ of the sample.

The ratio of heavy to light water isotopes in the snow/ice can tell us about:

- Conditions at the moisture source (evaporation)
- How the snow got there (transport)
- Temperature at the site (condensation)

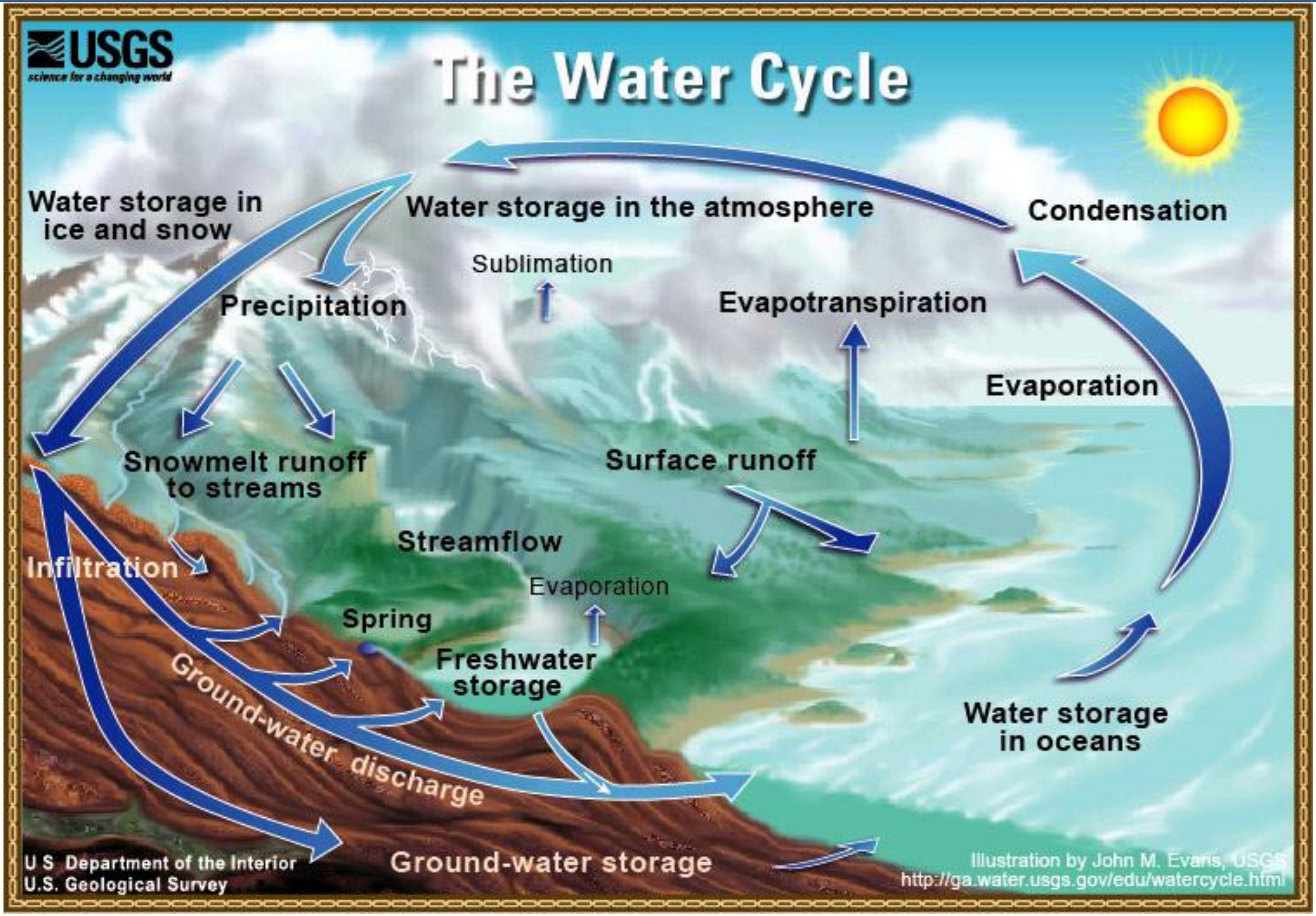


Water Vapor & Isotope Fractionation (a.k.a. distillation) in the Hydrologic Cycle.

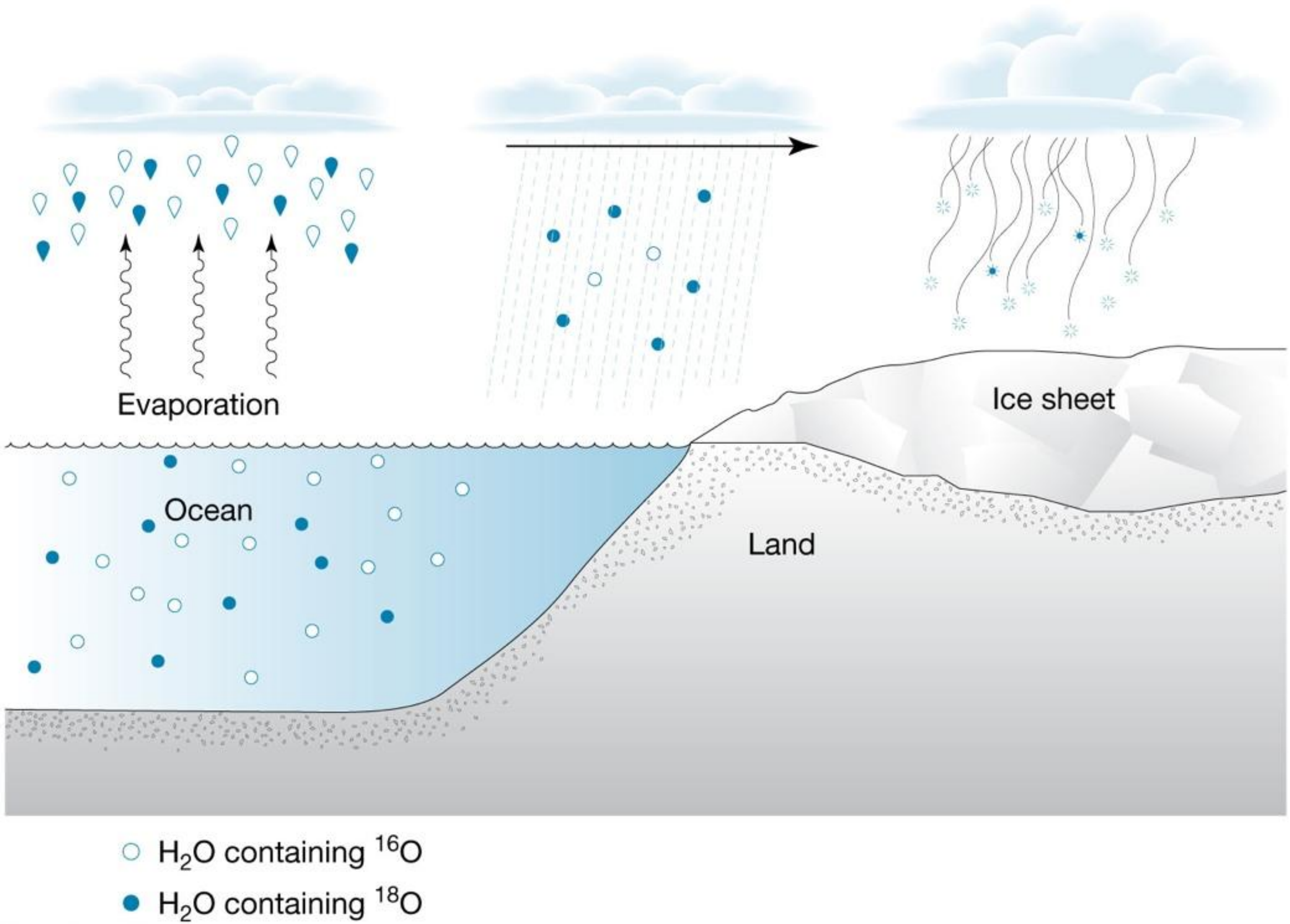


Hydrologic cycle distributes water around the globe

Processes of evaporation, transport, and condensation drive the fractionation of water isotopes



Oxygen Isotopes in precipitation en-route to Antarctica / Greenland



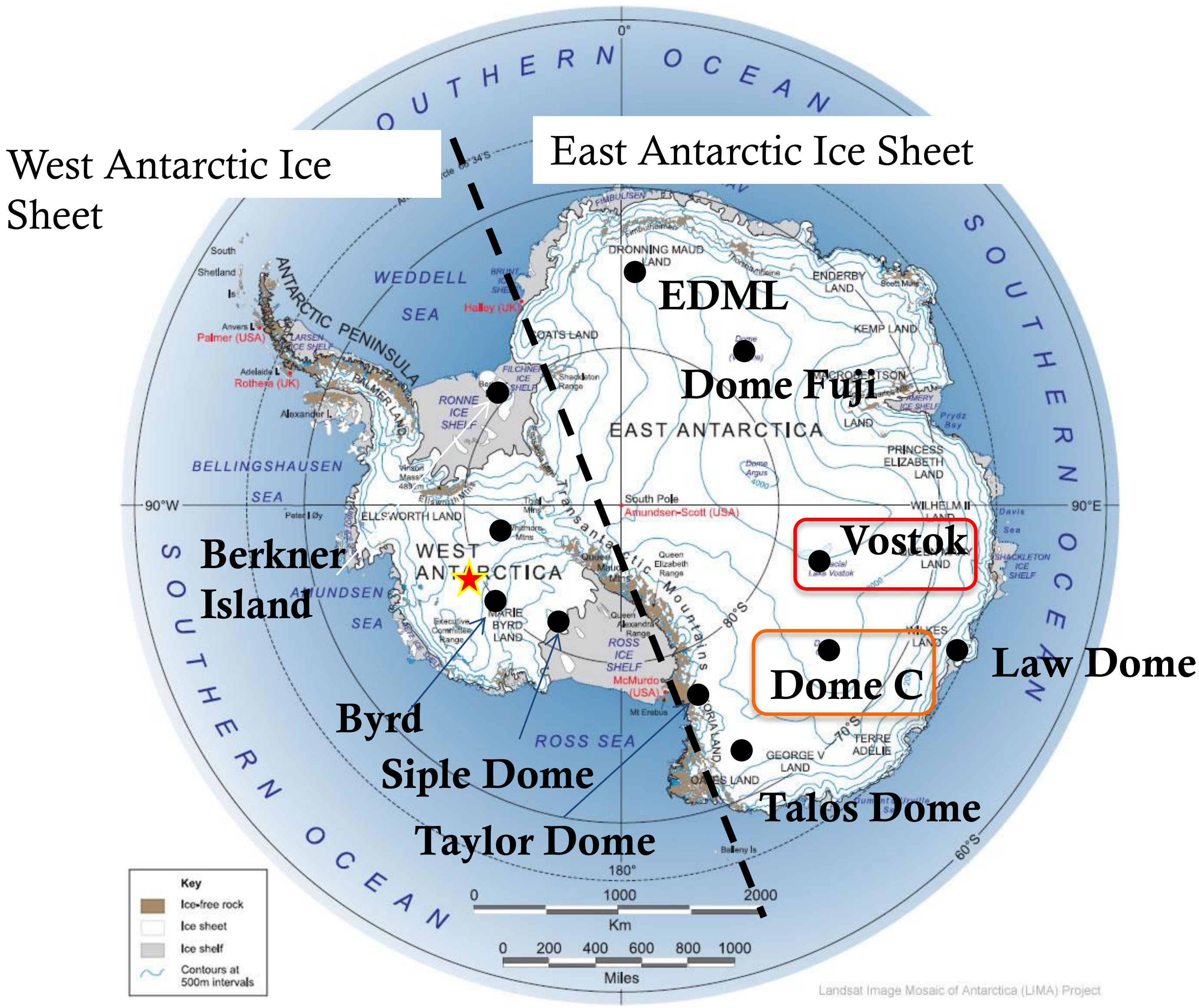
How have temperatures and CO_2 changed in the past?

To answer this question what would we need to know?

- Which natural systems record temperature?
- Which ones record both temperature *and* CO_2 variations?
- If we want to go back thousands of years, what are the main temperature proxies that have long climate records?
- Where has snow and ice been preserved for long periods of time?

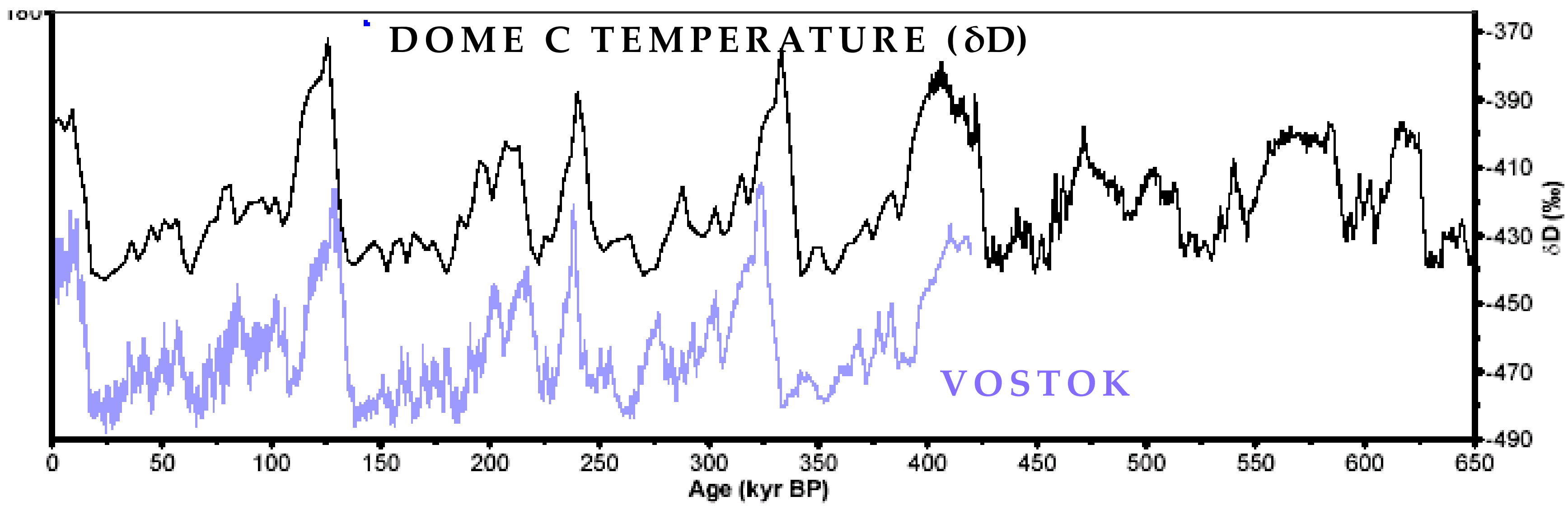
Let's go check out some ice core sites in Antarctica!

Locations of Deep Ice Core Sites in Antarctica



How is Temperature related to δD records from ice cores?

- Here the deuterium (D) is shown for both cores, the shorter record is from Vostok and the extended record from Dome C
- How do we get "Dome C Temperature" from the δD measurements?

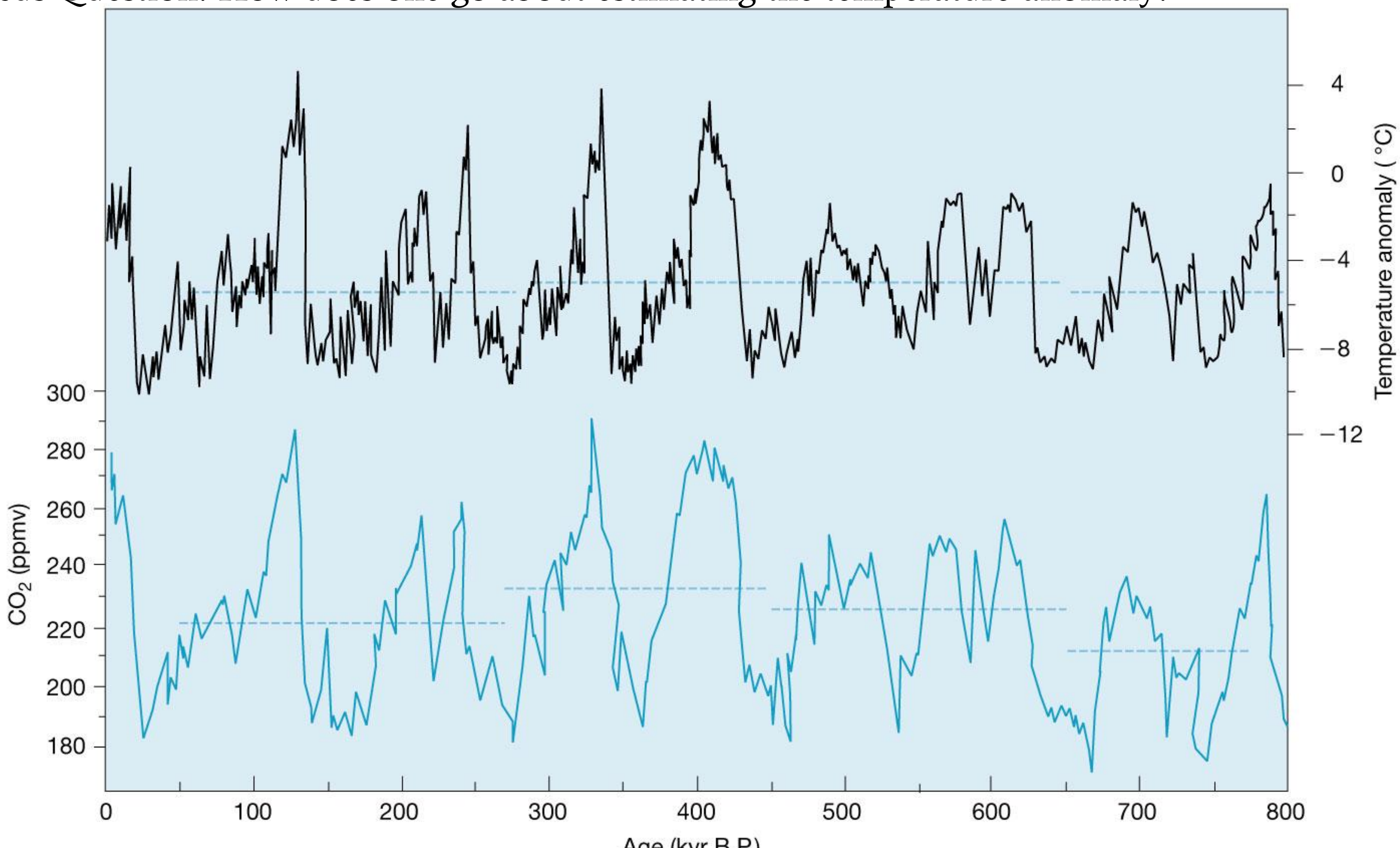


SIEGENTHALER ET AL., SCIENCE 2005 (EPICA GAS CONSORTIUM)

Glacial-Interglacial Cycles: The Ice-Core Temperature Record from Vostok and Dome C

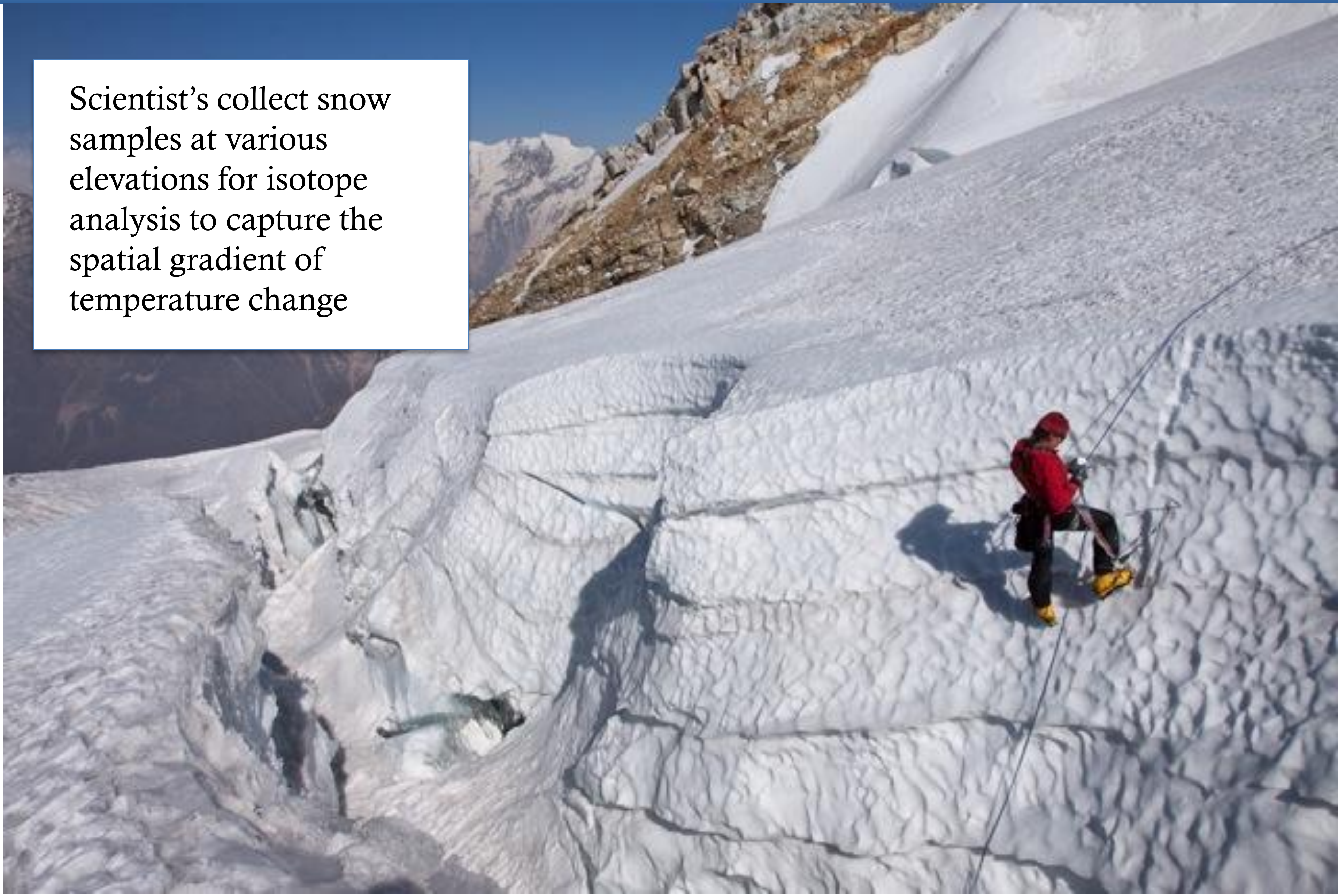
"The top curve shows the estimated change in local temperature, as determined from the deuterium content of the ice." p14 Kump Earth Systems

Focus Question: How does one go about estimating the temperature anomaly?

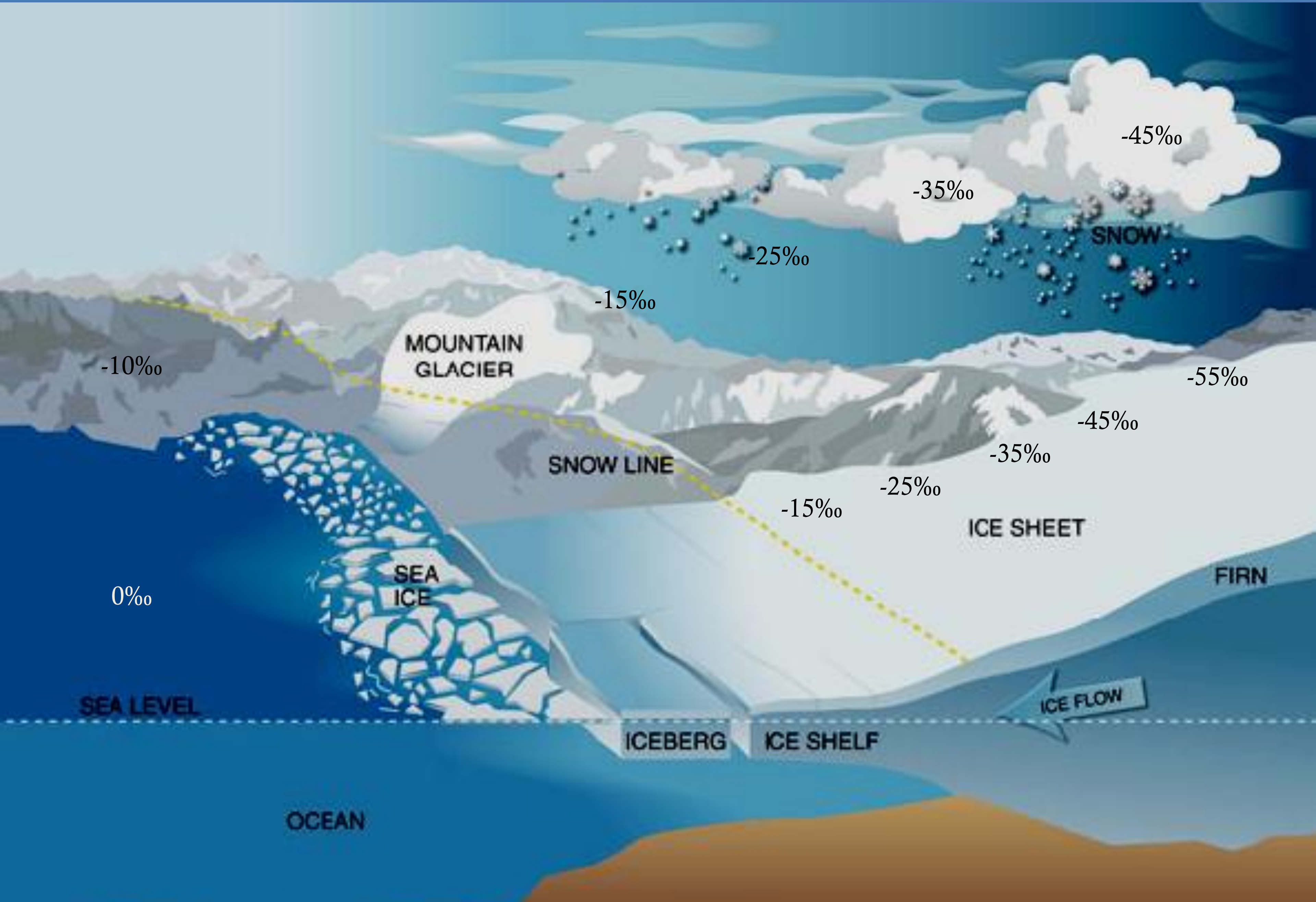


Lab 1. From Isotopes to Temperature: Using Snow/Ice Data!

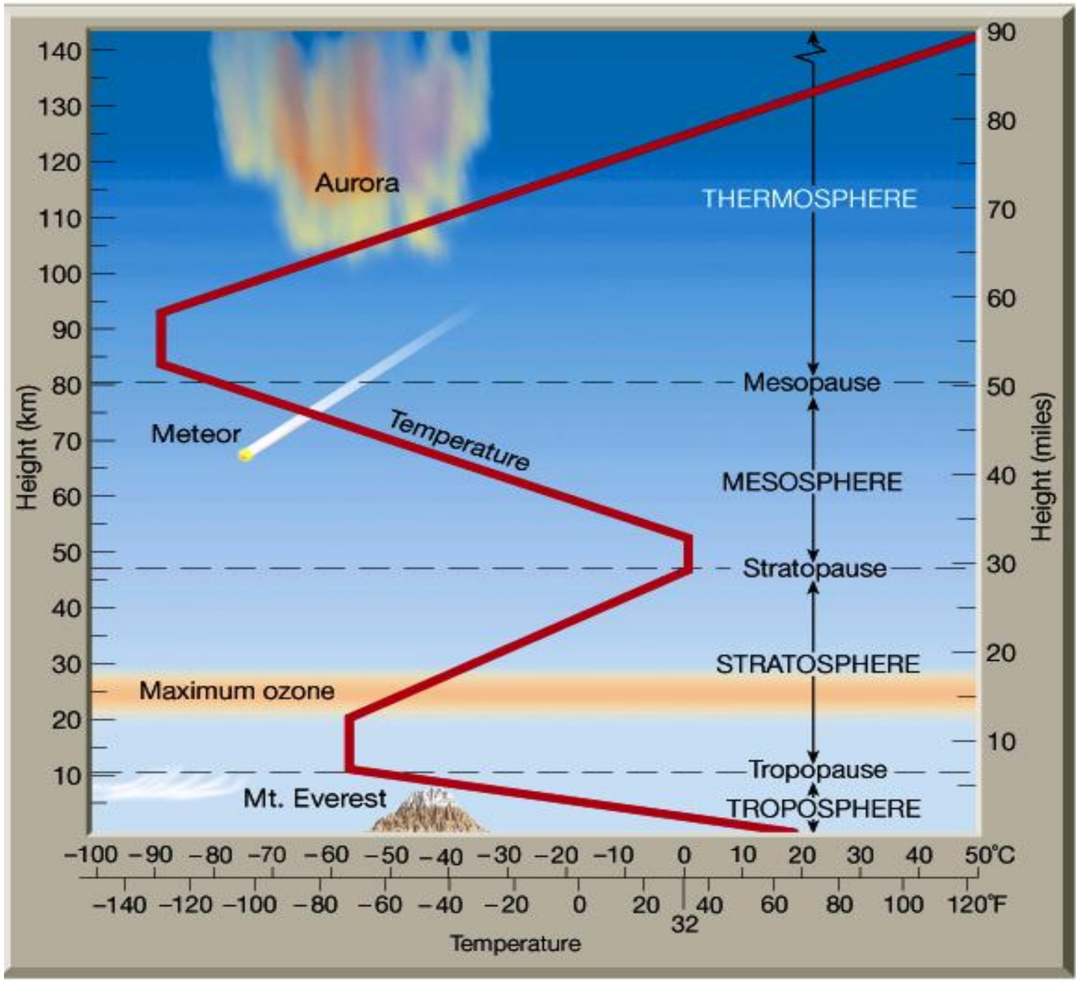
Scientist's collect snow samples at various elevations for isotope analysis to capture the spatial gradient of temperature change



Antarctic Topography & Isotopes

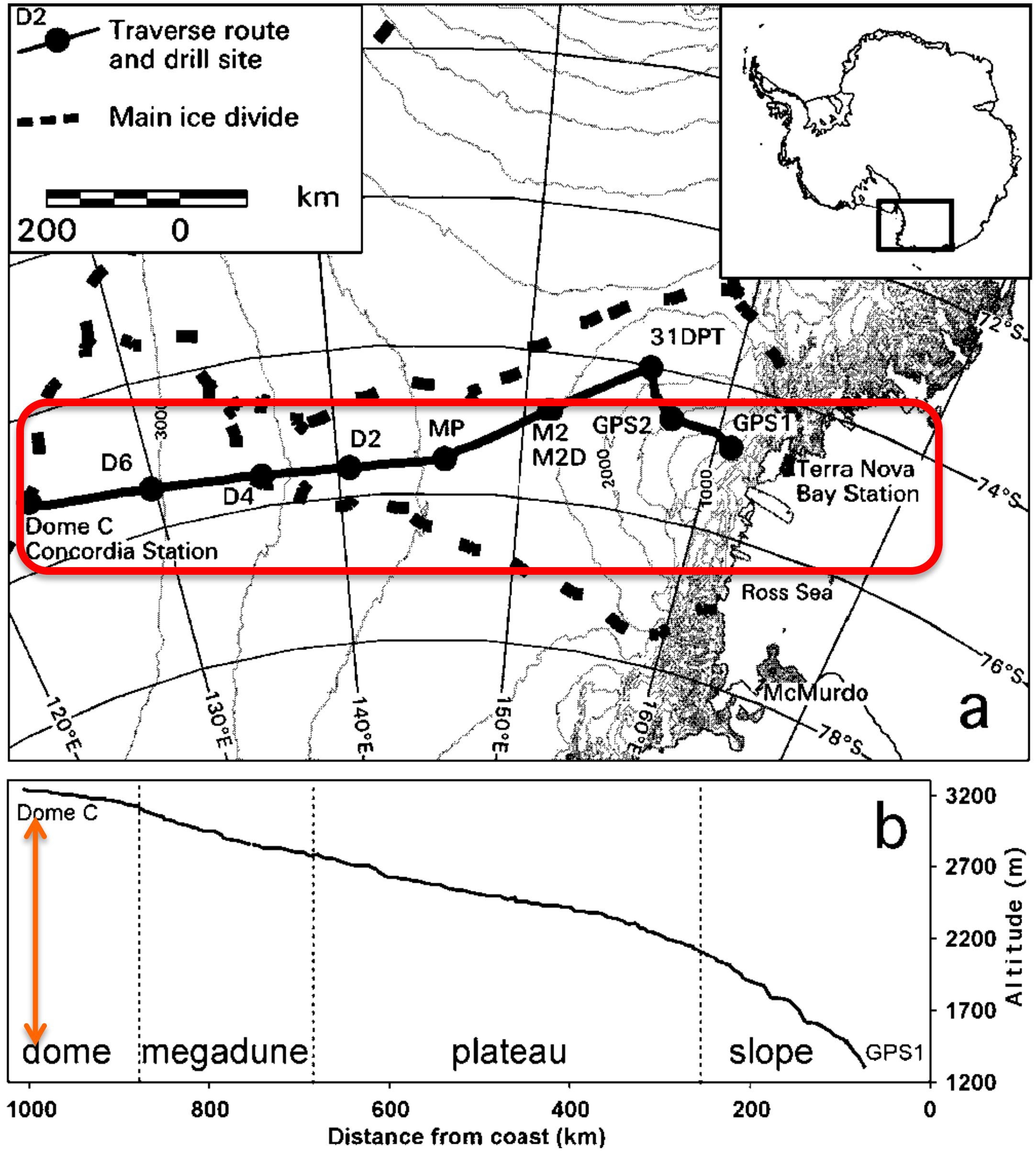


Lapse Rate = Change in Temperature(˚C) due to Change in Elevation



Air temperature cools with increasing elevation in troposphere

Snow Pit Transects to Dome C from Terra Nova Bay



Map of Dumont d'Urville to Dome C

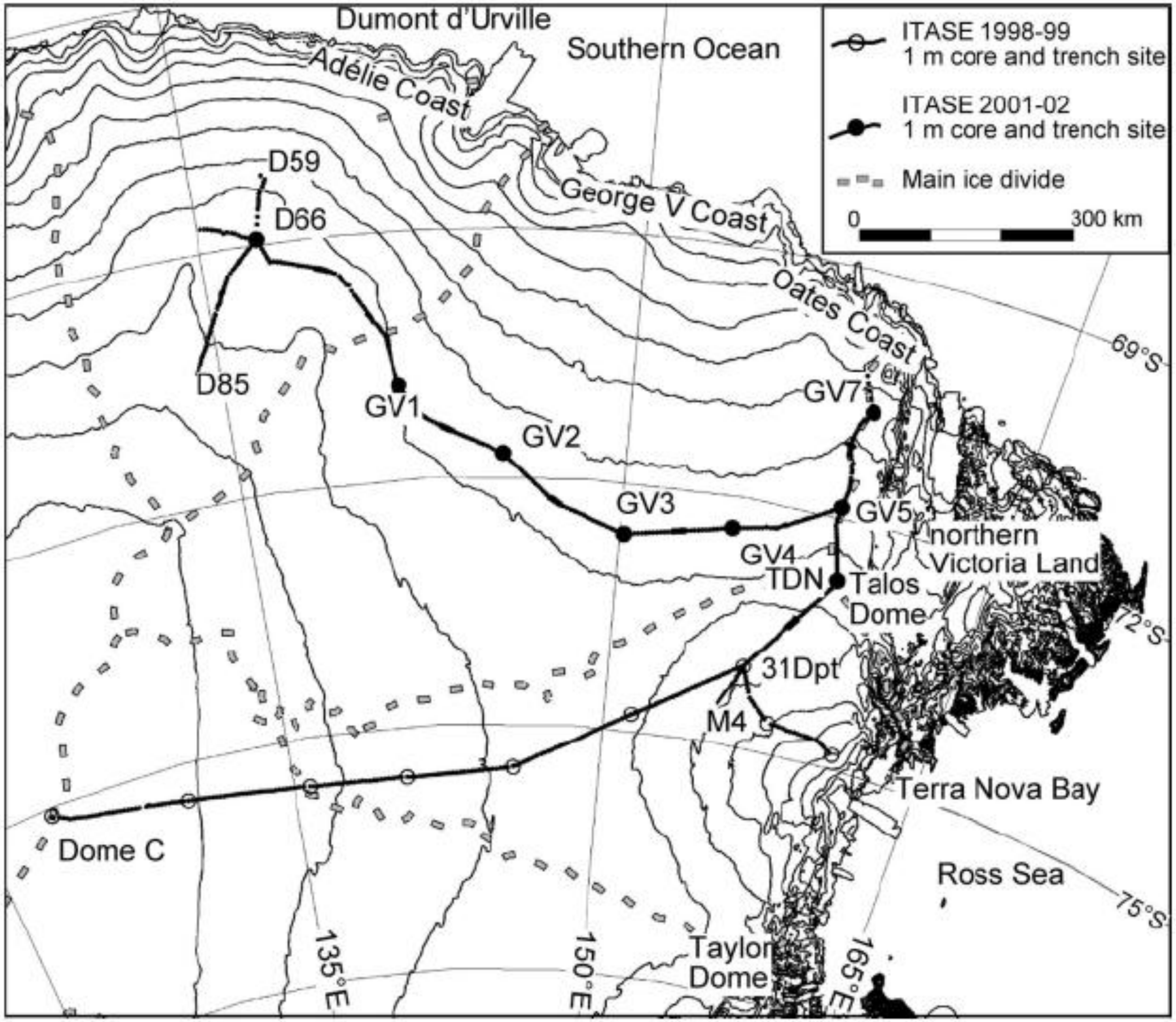
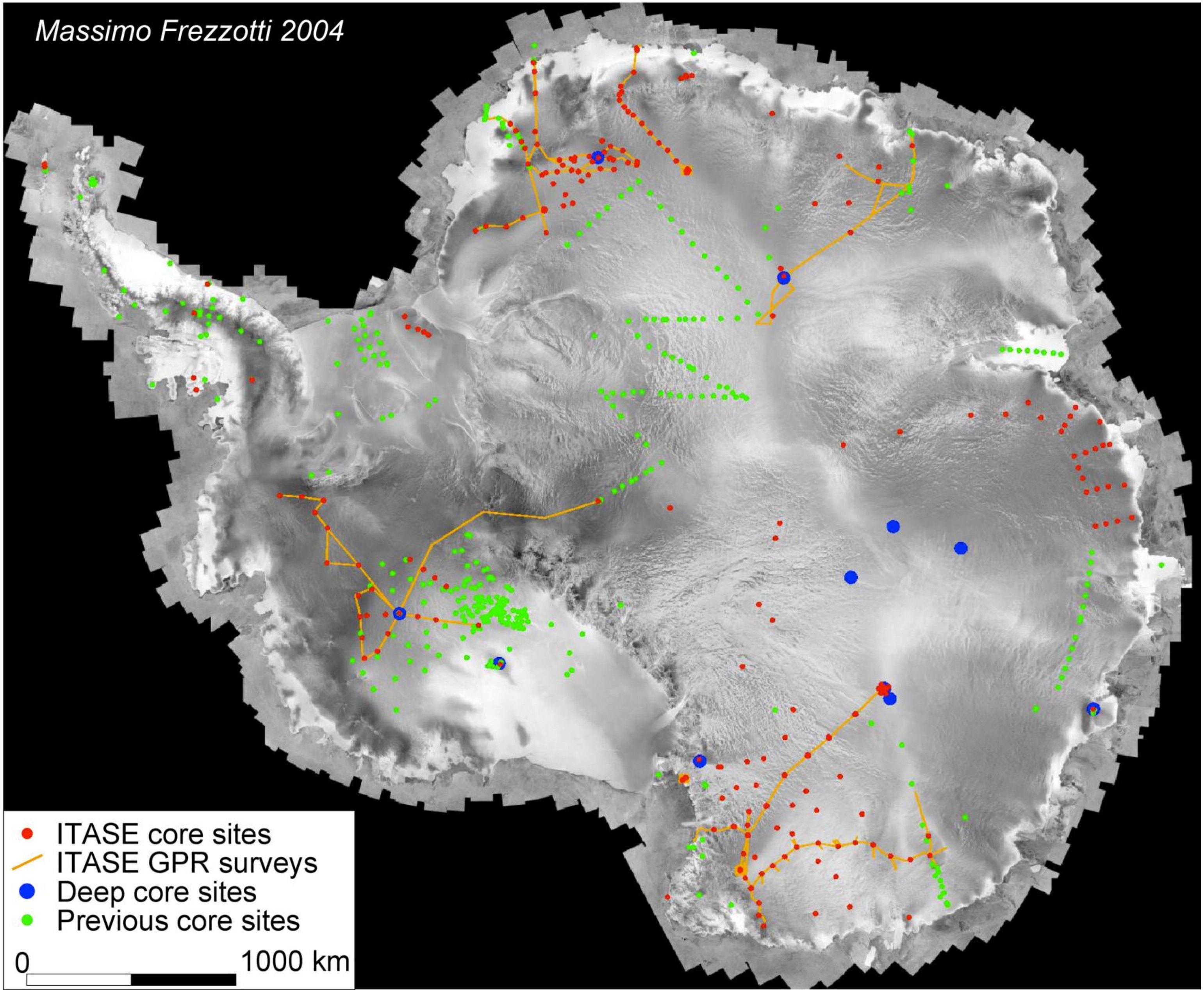
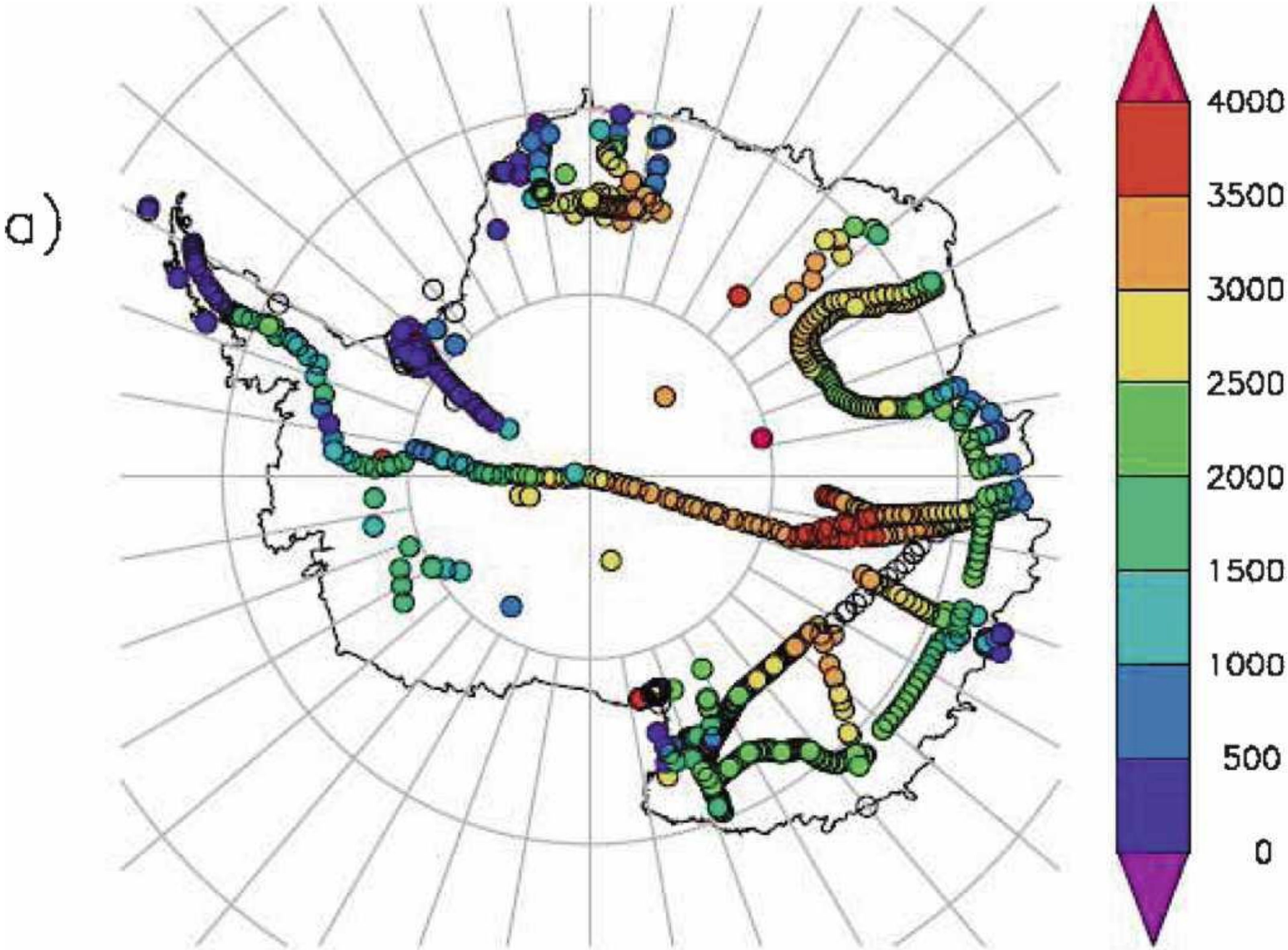


Fig. 1. Map of the sampled area. Dots indicate snow-pit sites sampled during the 2001/02 ITASE traverse. The GV7–M4 transect is referred to as transect NS-2, the D59–D85 transect as NS-1, and the D66–GV5 transect as WE. Contour line interval is 250 m. The elevations of Talos Dome and Dome C are 2316 and 3233 m, respectively.

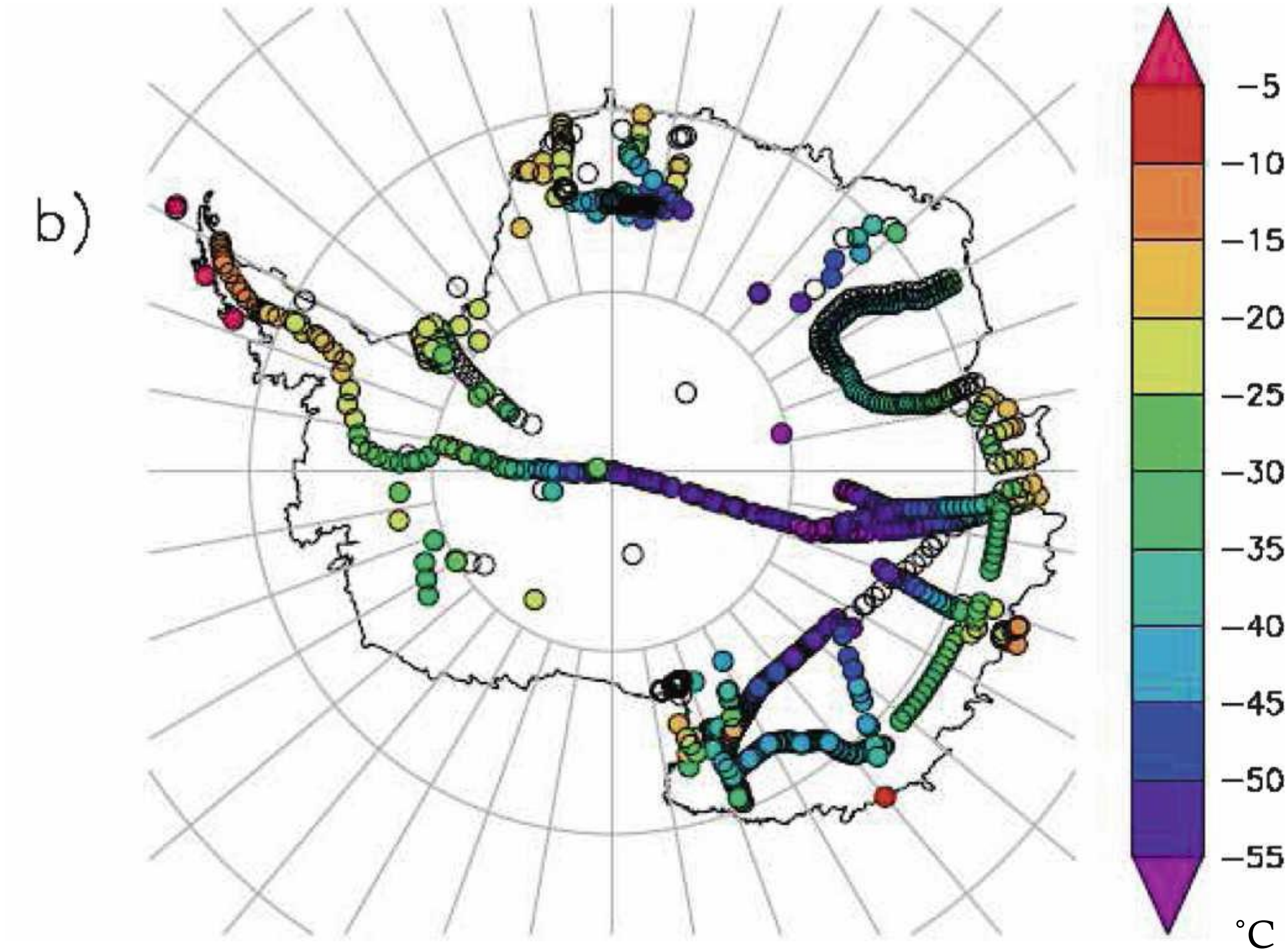
a) ITASE transects around Antarctica



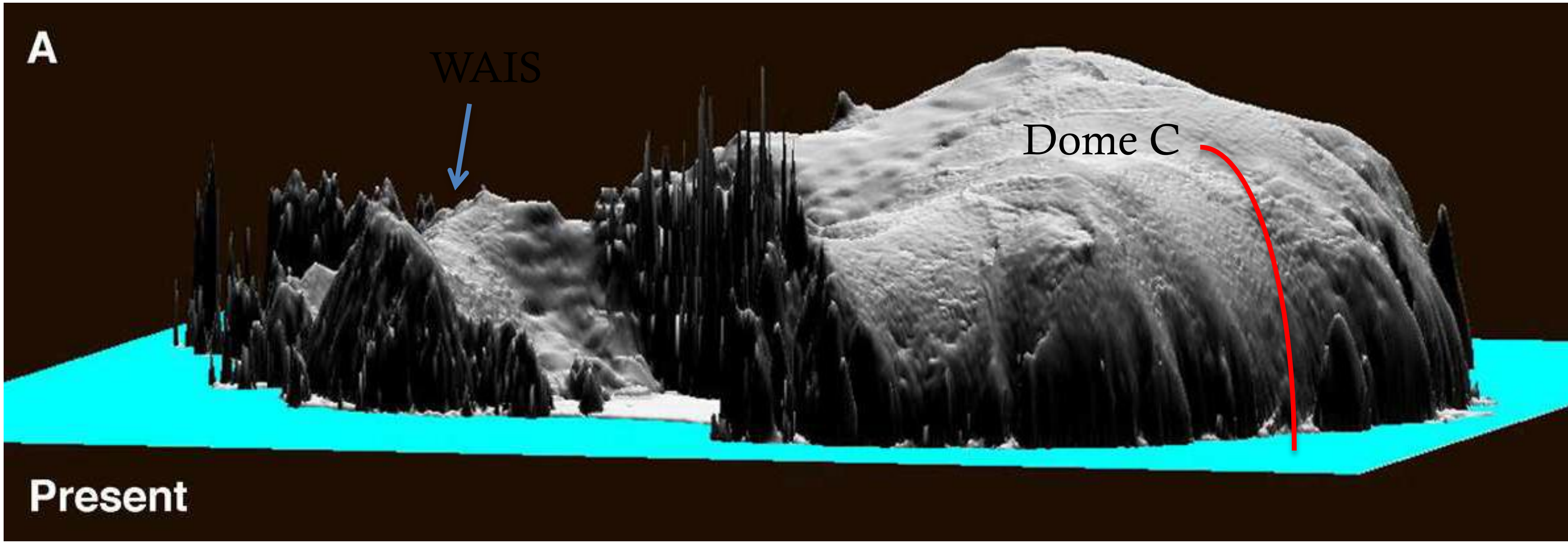
a) Elevation (m) of surface snow samples in Antarctica



a) Annual Mean Surface Temp (˚C) in Antarctica

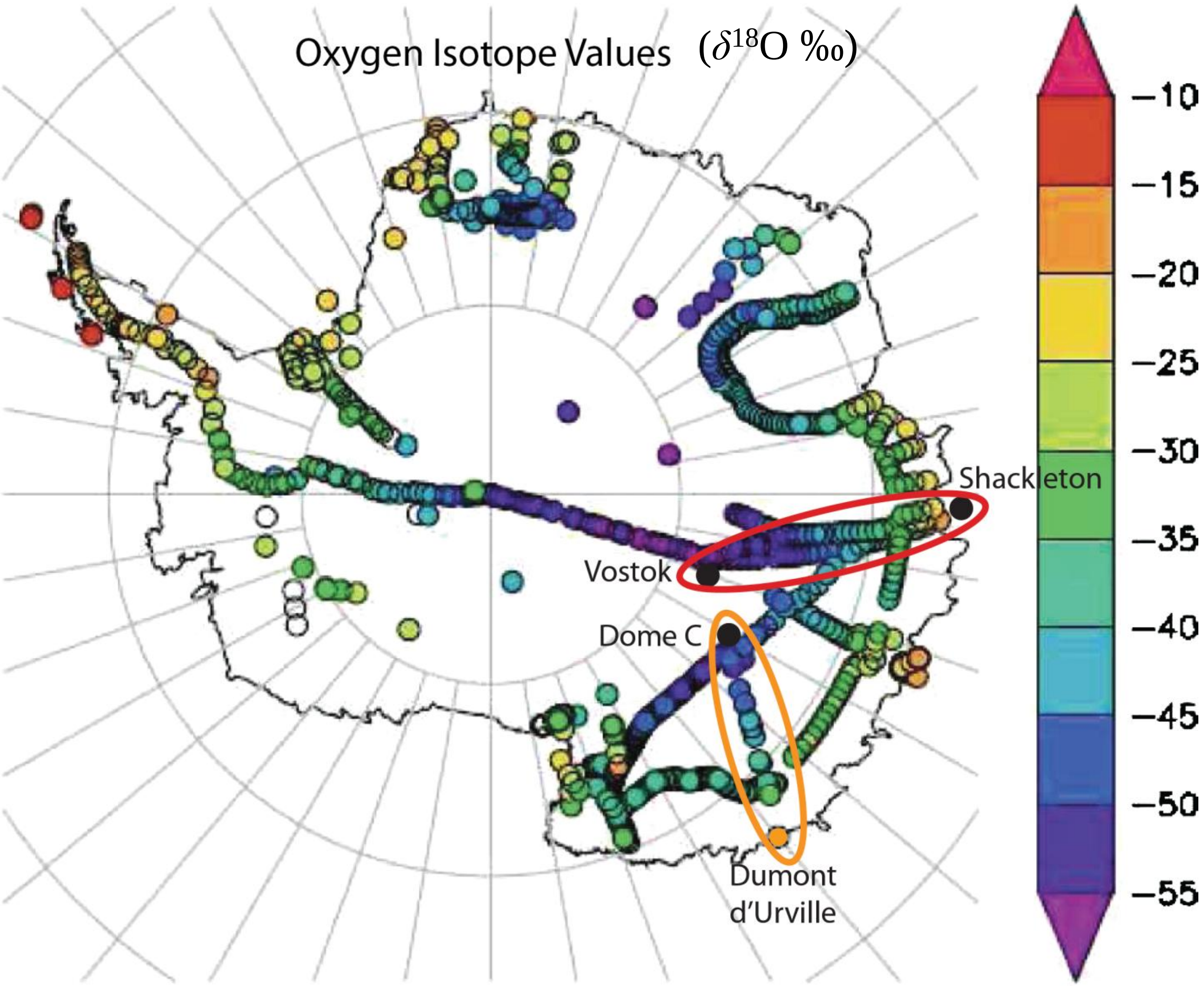


Modern elevation of snow surface snow in Antarctica



If we assume that elevation, seasonality of precipitation, and moisture source were relatively similar back in time, then we can use the modern isotope relationship to infer past temperature changes.

Determining Modern Isotope/Temperature Relationship using the $\delta^{18}O$ and Temperature data



Isotope content of snow versus local surface temperature

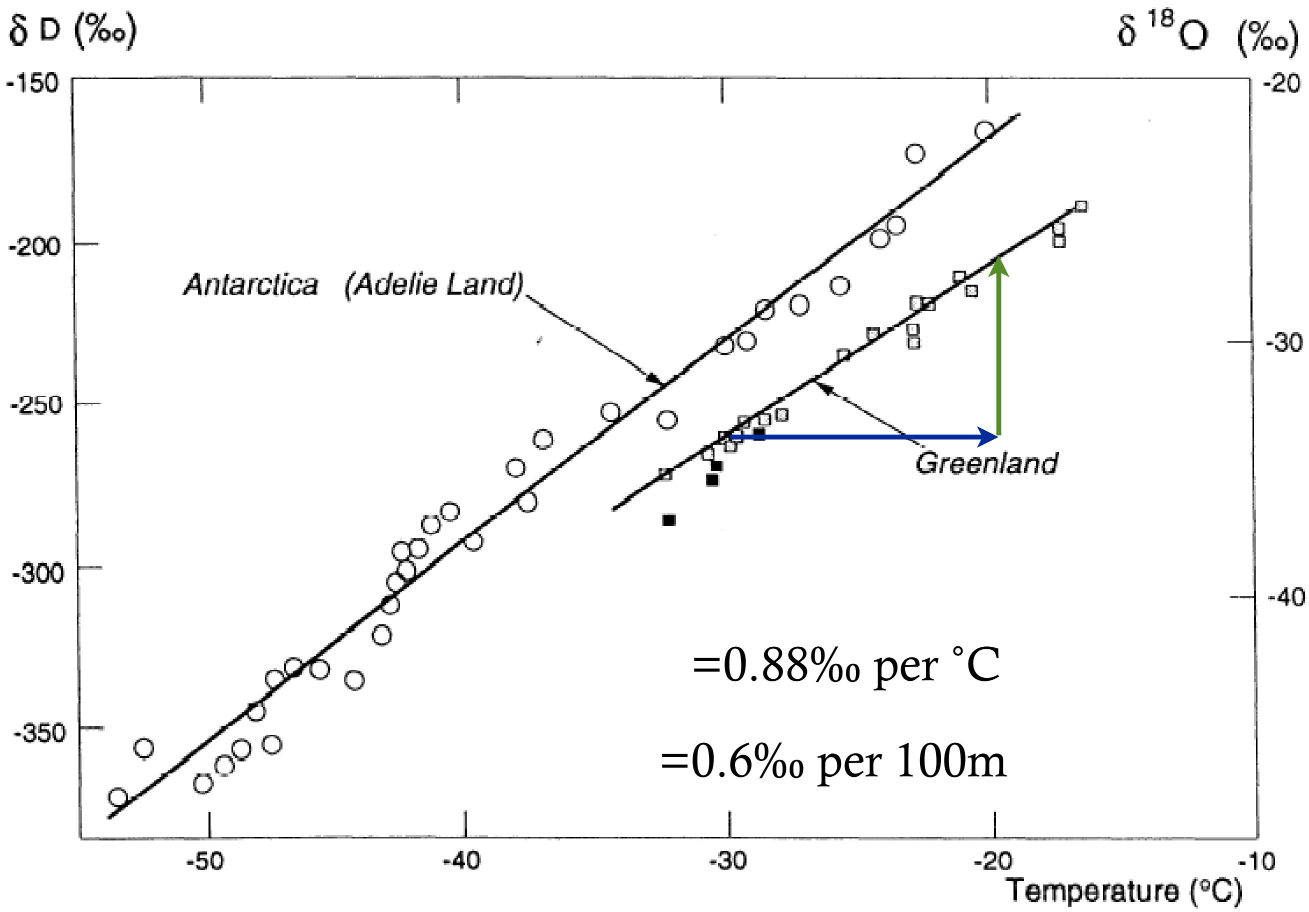
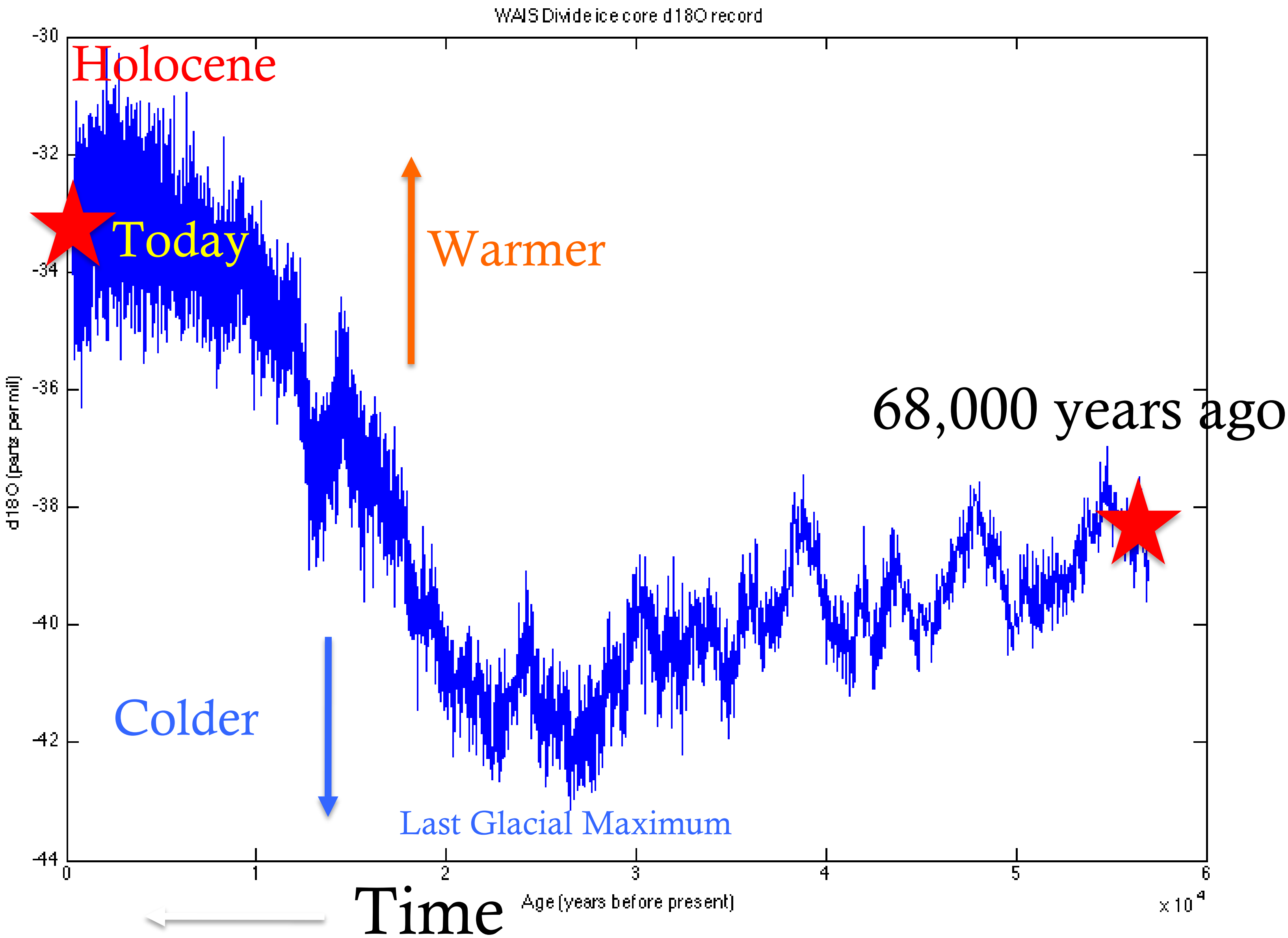


Figure 1. Isotope content of snow versus local surface temperature (annual average). Antarctic data (δD, left scale) are from *Lorius and Merlivat* [1977], and Greenland data ($\delta^{18}O$, right scale) are from *Johnsen et al.* [1989].

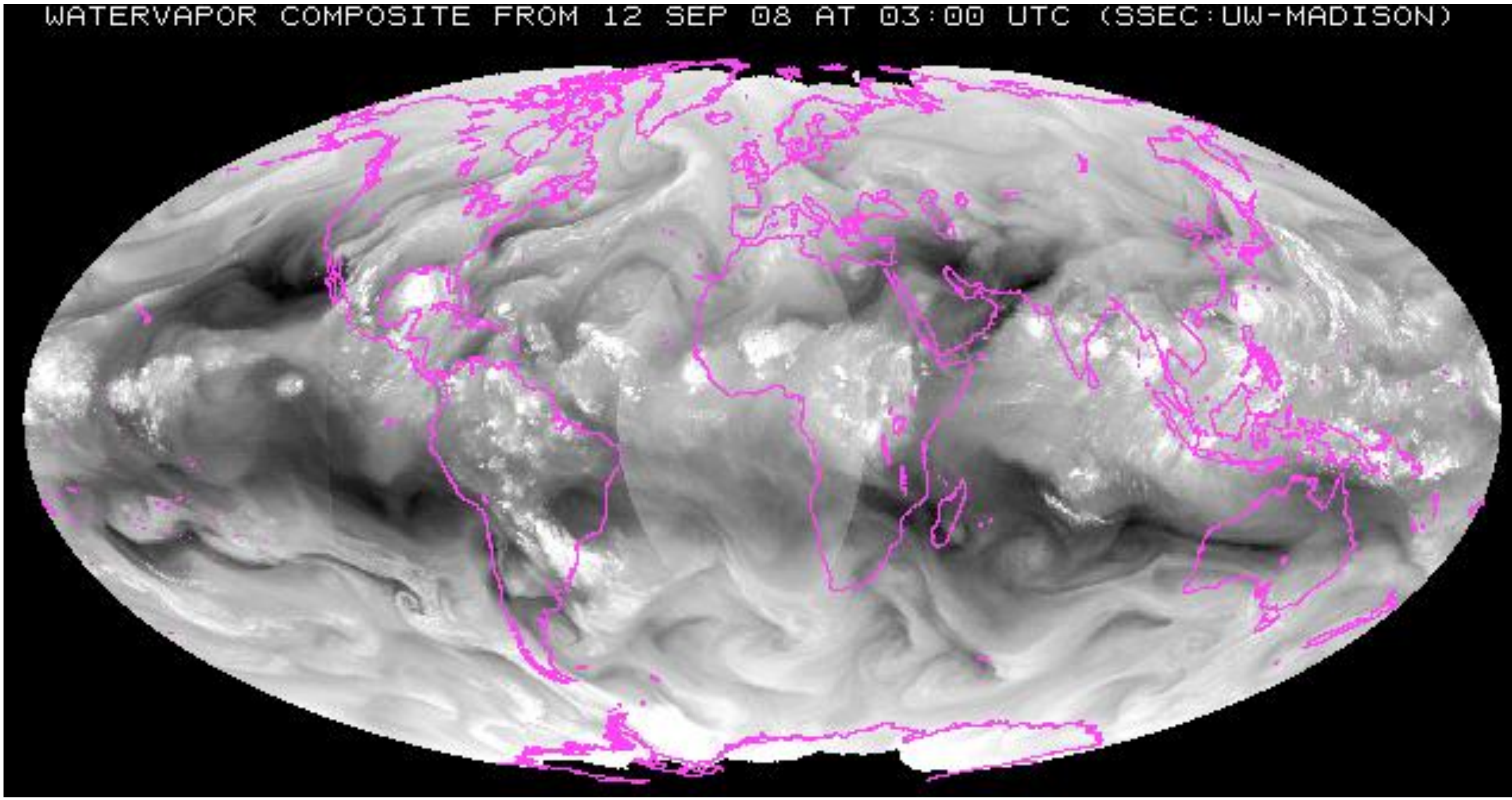
- We use modern relationships to infer past climate conditions.
- This is the concept of uniformitarianism

Inferring temp from the WAIS Divide isotope record

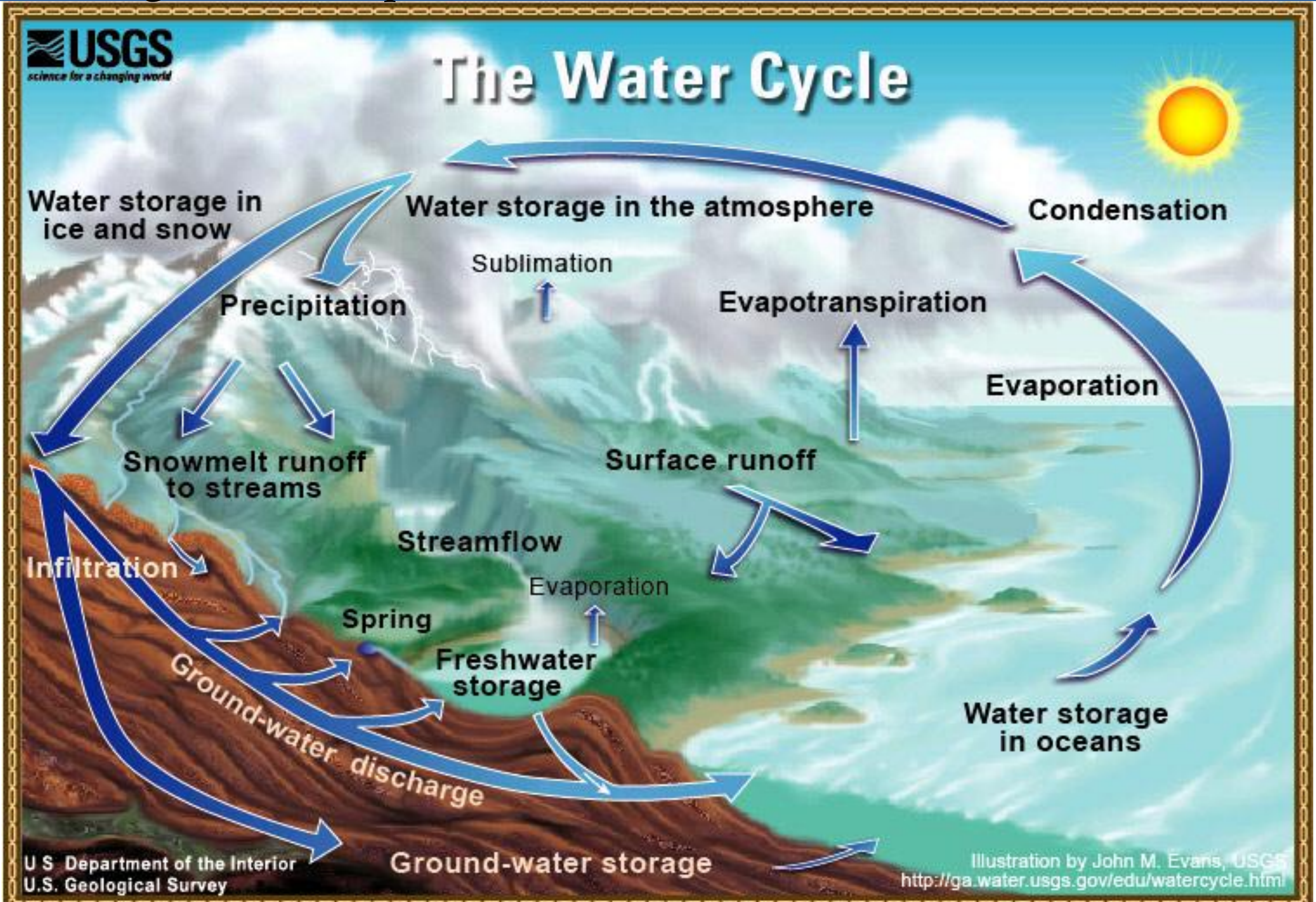


Lab 2. Isotope Fractionation in the Hydrologic Cycle.

Now that we know that temperature (in conjunction with elevation) and transport change the isotopic content of the water molecule we need to quantify the relationship

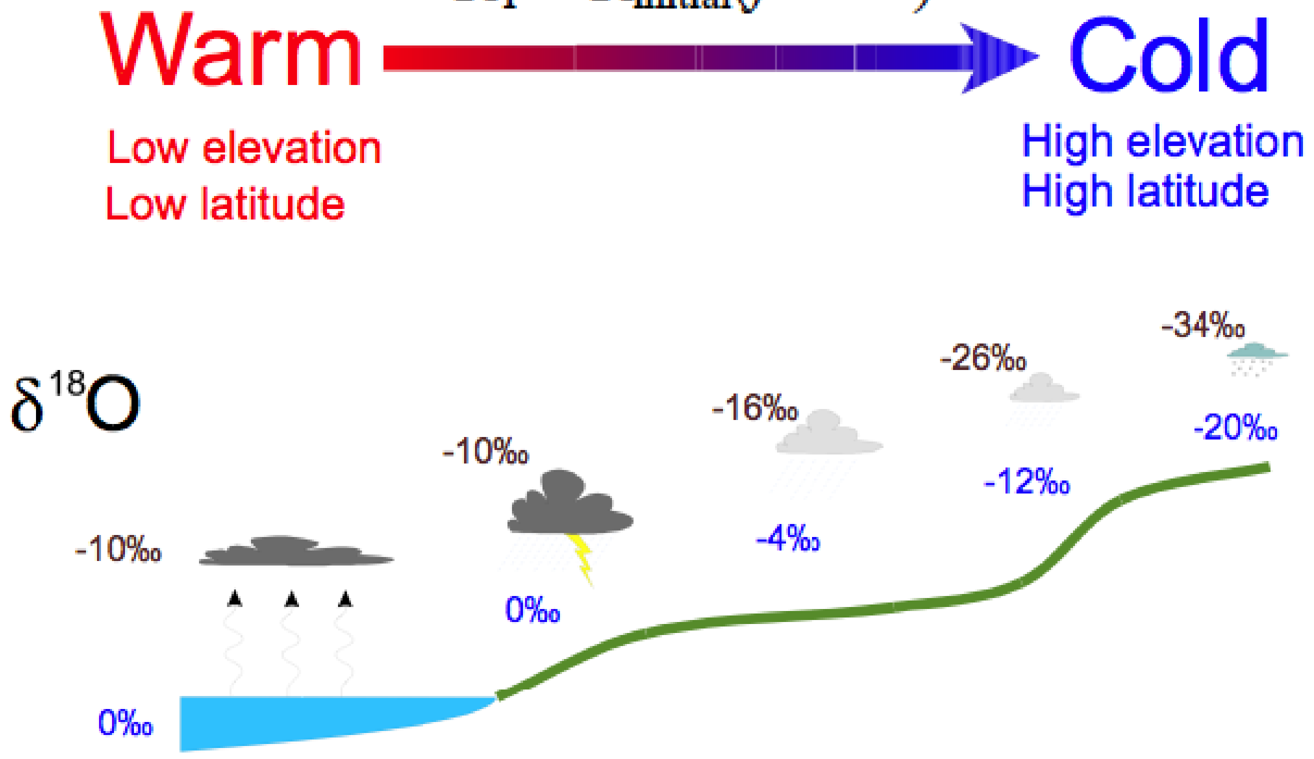


Process of evaporation, transport, and condensation are key to distilling water isotopes



Rayleigh distillation effect on water isotopes

$$R_T = R_{initial}(f^{\,alpha-1})$$

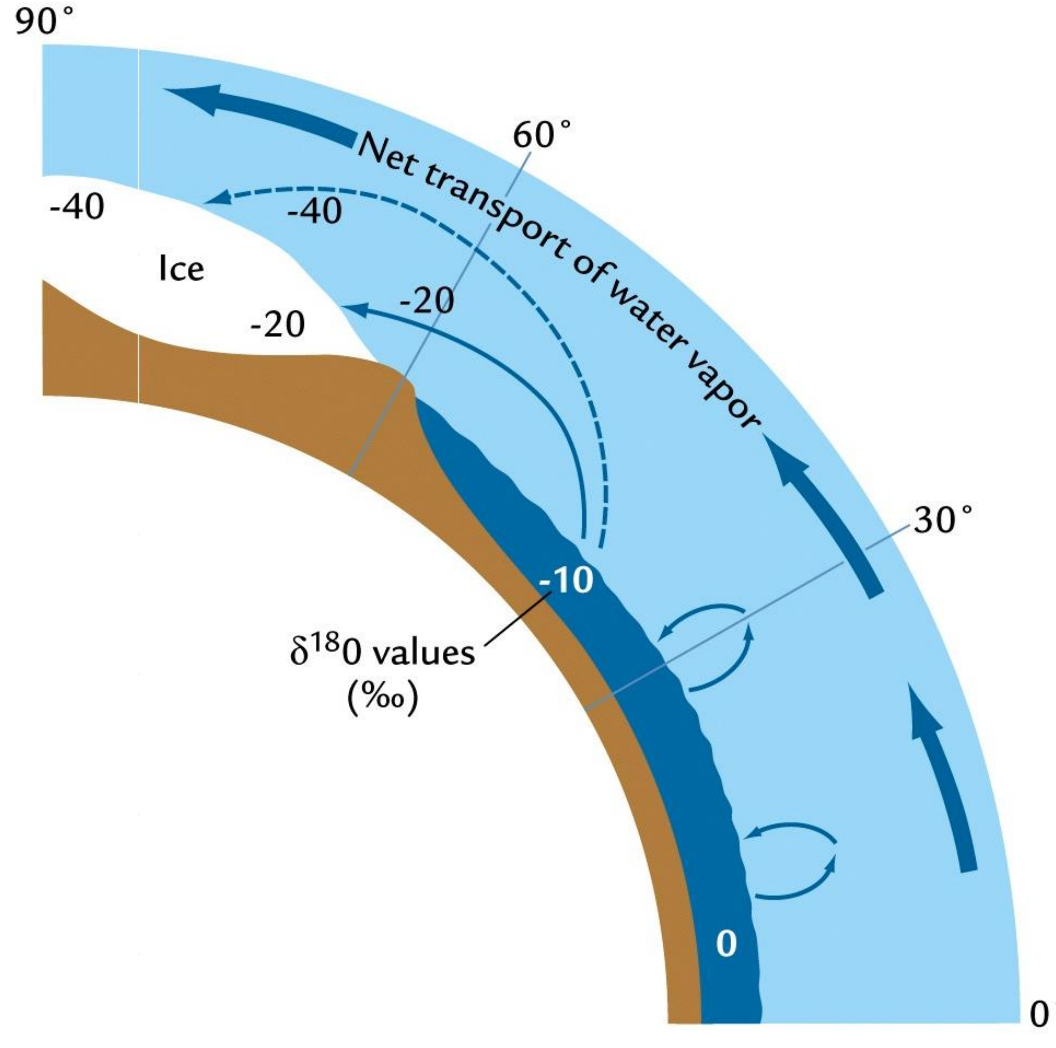


- Rayleigh fractionation is the process where water isotopes in an air mass get progressively more depleted (more negative) through the process of heavier isotopes being preferentially removed over time

Oxygen Isotopes in a water molecule

Water Vapor is Depleted (more negative) as its transported to:

- **Higher Elevations**
  &
- **High Latitudes**



Quantifying the ^{18}O Concentration

- **Temperature reconstructions rely on variations in the isotope ratio (*R*) of ^{18}O to ^{16}O preserved in snow/ice. The $^{18}O/^{16}O$ ratio of oxygen atoms among the H_2O molecules of ocean water is extremely small: only about 0.2% of the oxygen atoms are ^{18}O; the remaining 99.8% are ^{16}O.**
- **Variations in the $^{18}O/^{16}O$ ratios, of course, are smaller than the ratios themselves.**
- **Instead of using the small values of *R* to report the varying ^{18}O concentrations, geochemists use $\delta^{18}O$, a relative difference ratio:**

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

- **Thus $\delta^{18}O$ is the difference of the oxygen-isotope ratios between a sample and standard relative to the ratio in the standard; it is a ratio derived from ratios. The value of $\delta^{18}O$ is stated as *per mille* (‰, parts per thousand in the same way that % is per cent, for parts per hundred.**
- **The mass spectrometer, which measures the oxygen-isotope concentration, reports out the per mille $\delta^{18}O$ of the sample.**