Review of Past Climates

EES 3310/5310

Global Climate Change

Jonathan Gilligan

Class #14: Wednesday, February 24 2021

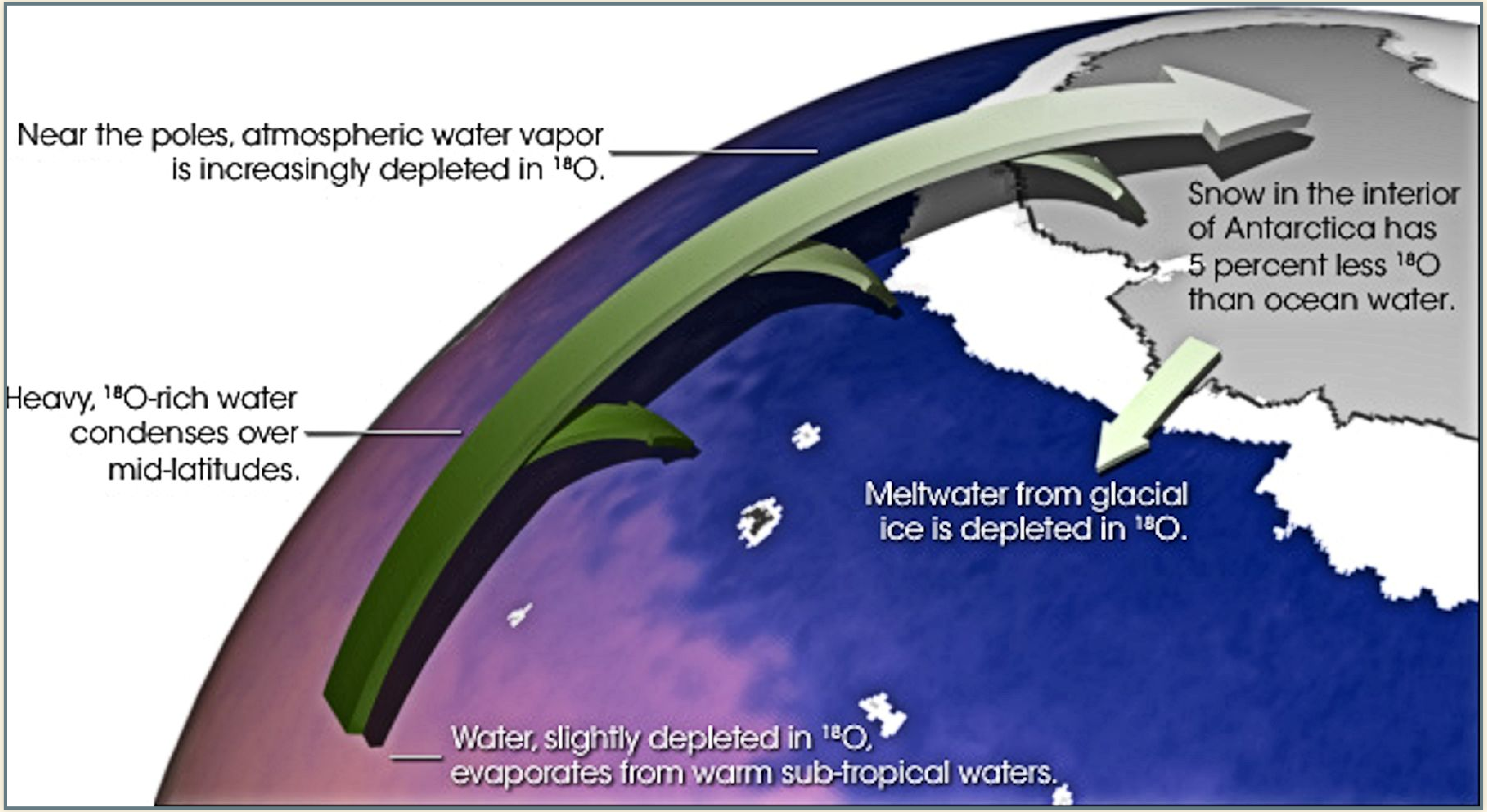
Oxygen & Hydrogen Isotopes

Oxygen & Hydrogen Isotopes

$$\delta^{18}\mathrm{O} = \left(\frac{\left(\frac{^{18}\mathrm{O}}{^{16}\mathrm{O}}\right)_{\mathrm{sample}} - \left(\frac{^{18}\mathrm{O}}{^{16}\mathrm{O}}\right)_{\mathrm{ref}}}{\left(\frac{^{18}\mathrm{O}}{^{16}\mathrm{O}}\right)_{\mathrm{ref}}} \right) \times 1000‰$$

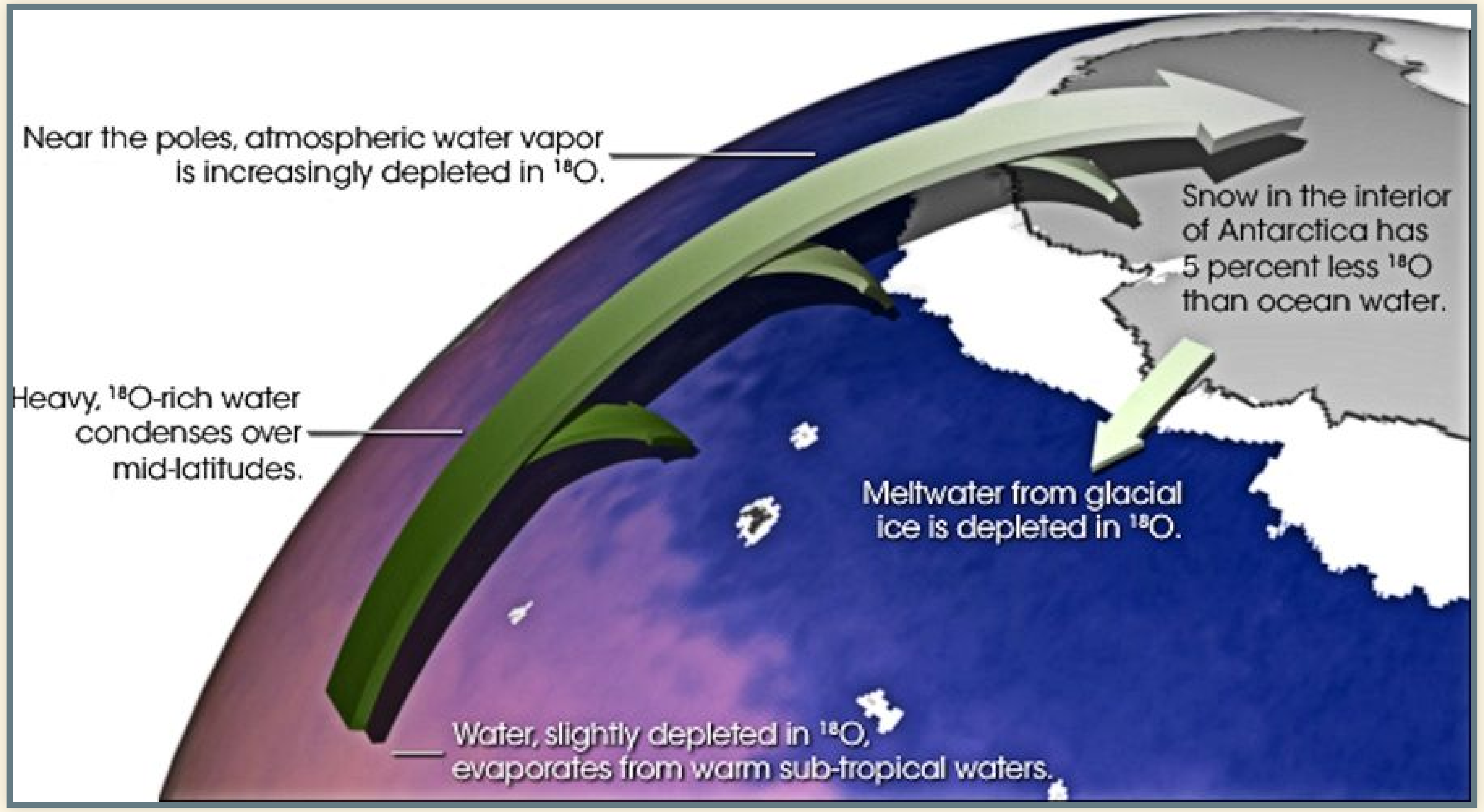
- δ^{18}O compares measured concentration of ^{18}O to the concentration in a reference sample.
- Lighter isotopes (^{1}H and ^{16}O) evaporate faster
  - Vapor has less of heavier isotopes (smaller δ^{18}O, δD)
  - Ocean is richer in heavier isotopes (greater δ^{18}O, δD)
  - Warmer $\longrightarrow$ greater δ^{18}O, δD in vapor

Rain, Snow, Ice

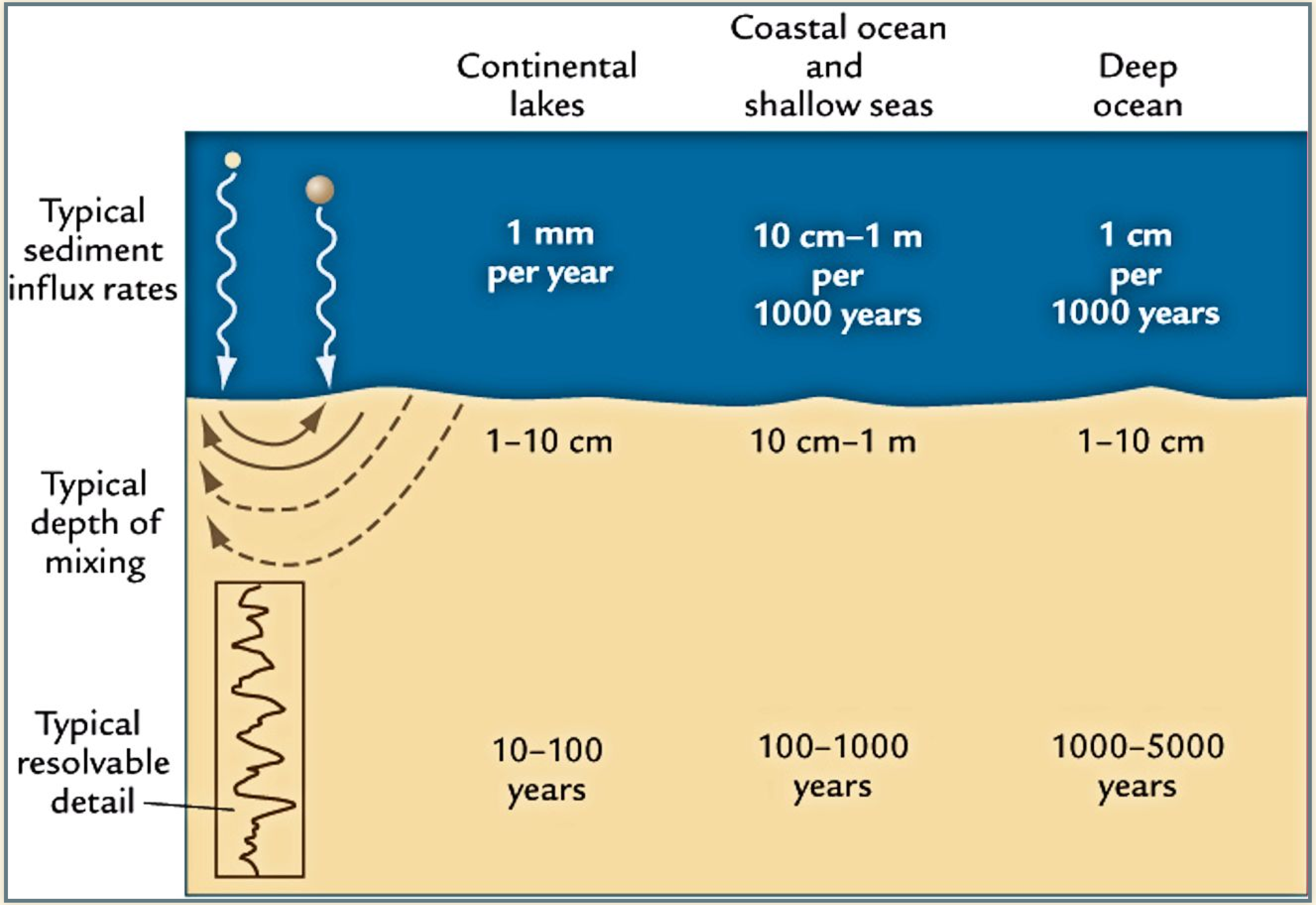


Rain, Snow, Ice

- Rain, snow are richer in heavier isotopes
  - More precipitation $\rightarrow$ less deuterium and ^{18}O left in vapor
  - Farther from source region $\rightarrow$ smaller δD and δ^{18}O.
- Reduction in δD and δ^{18}O depends on air temperature.
  - Different for H and O.
- Comparing δD and δ^{18}O can tell us about both sea-surface temperature and air temperature over glaciers.
- **Higher air temperature over glacier $\rightarrow$ greater δD and δ^{18}O in glacier snow/ice.**

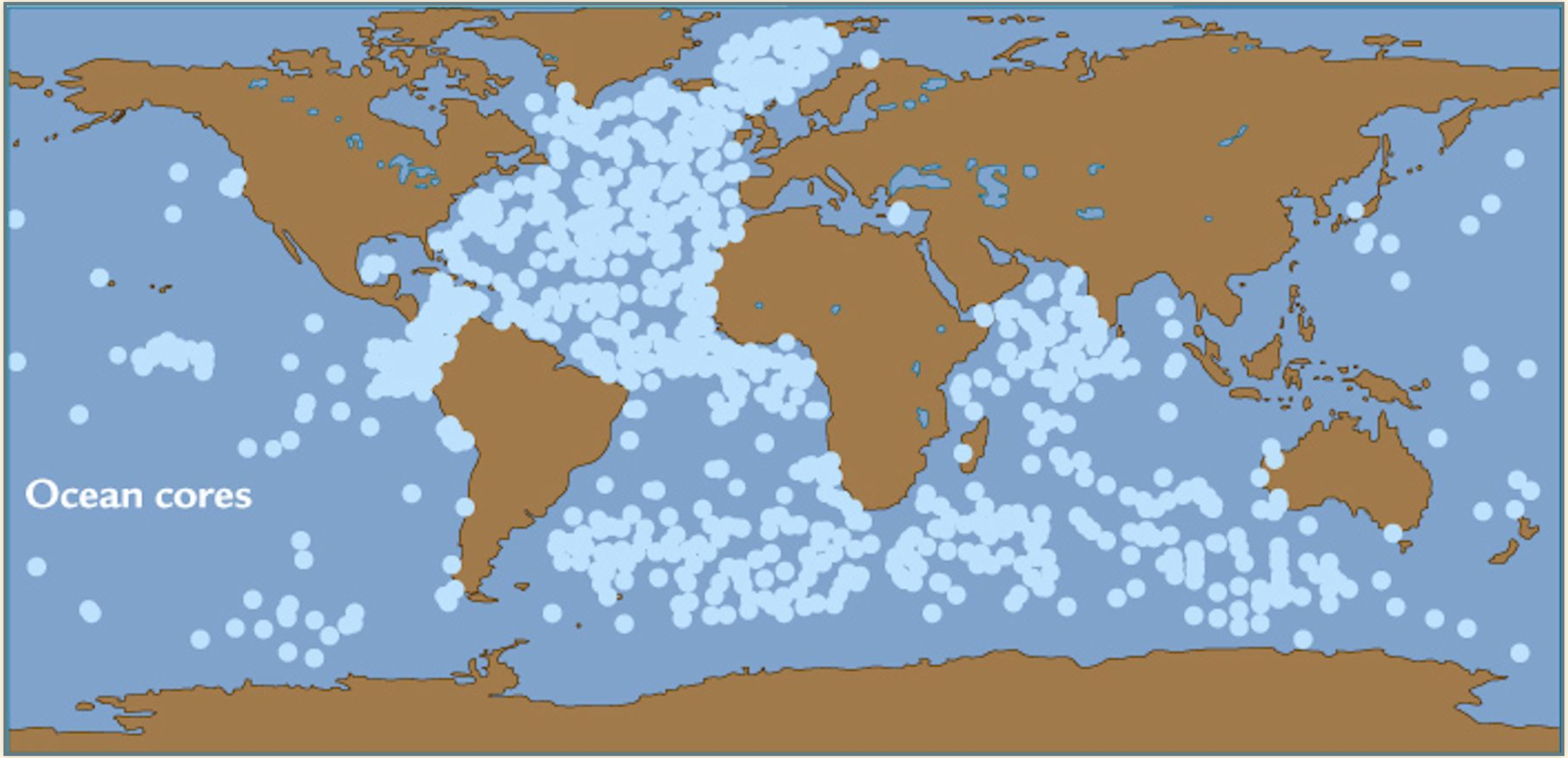


Sediments and History

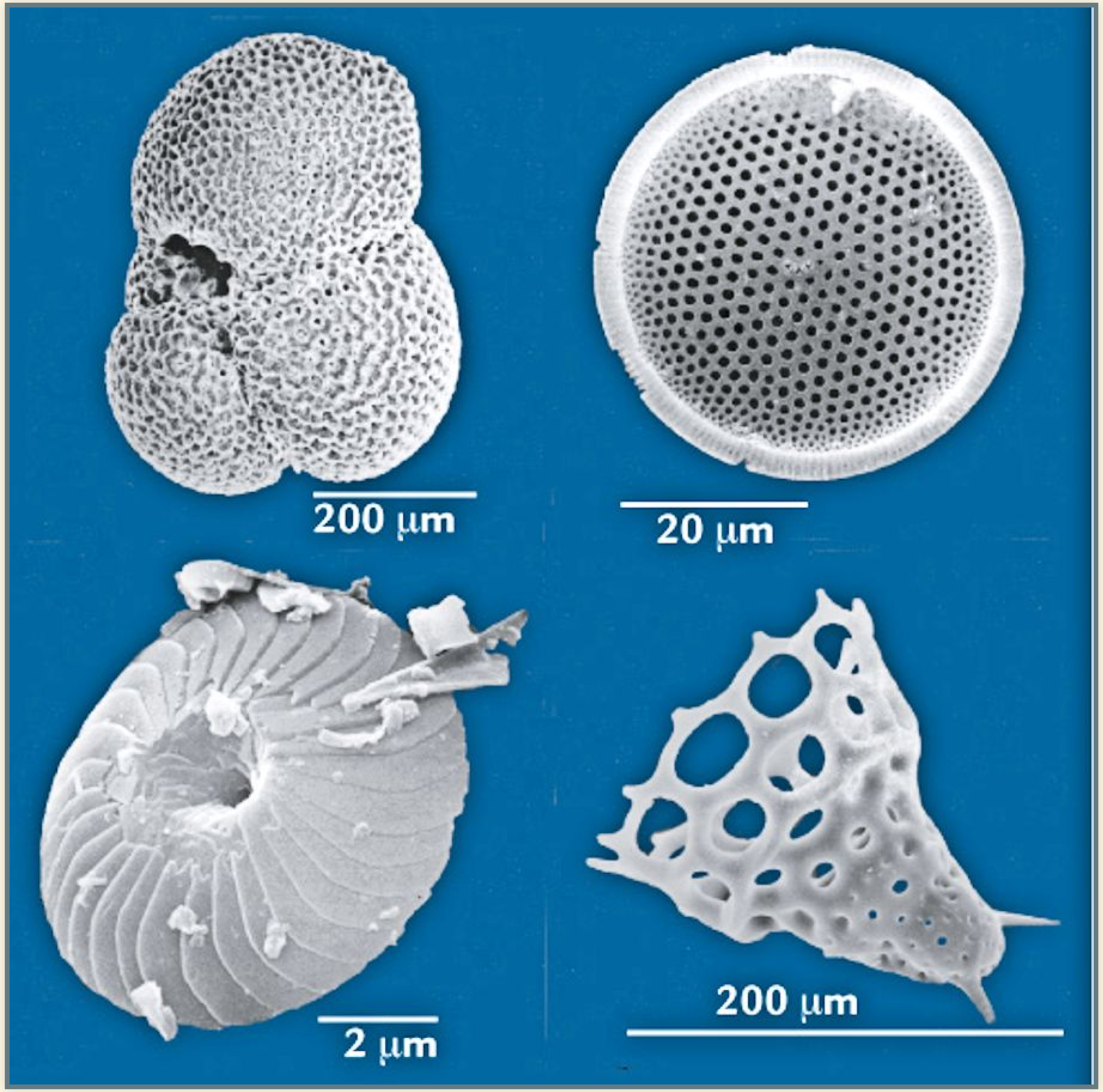


Bottom $\rightarrow$ top = oldest $\rightarrow$ youngest

Ocean Cores for Past Climates

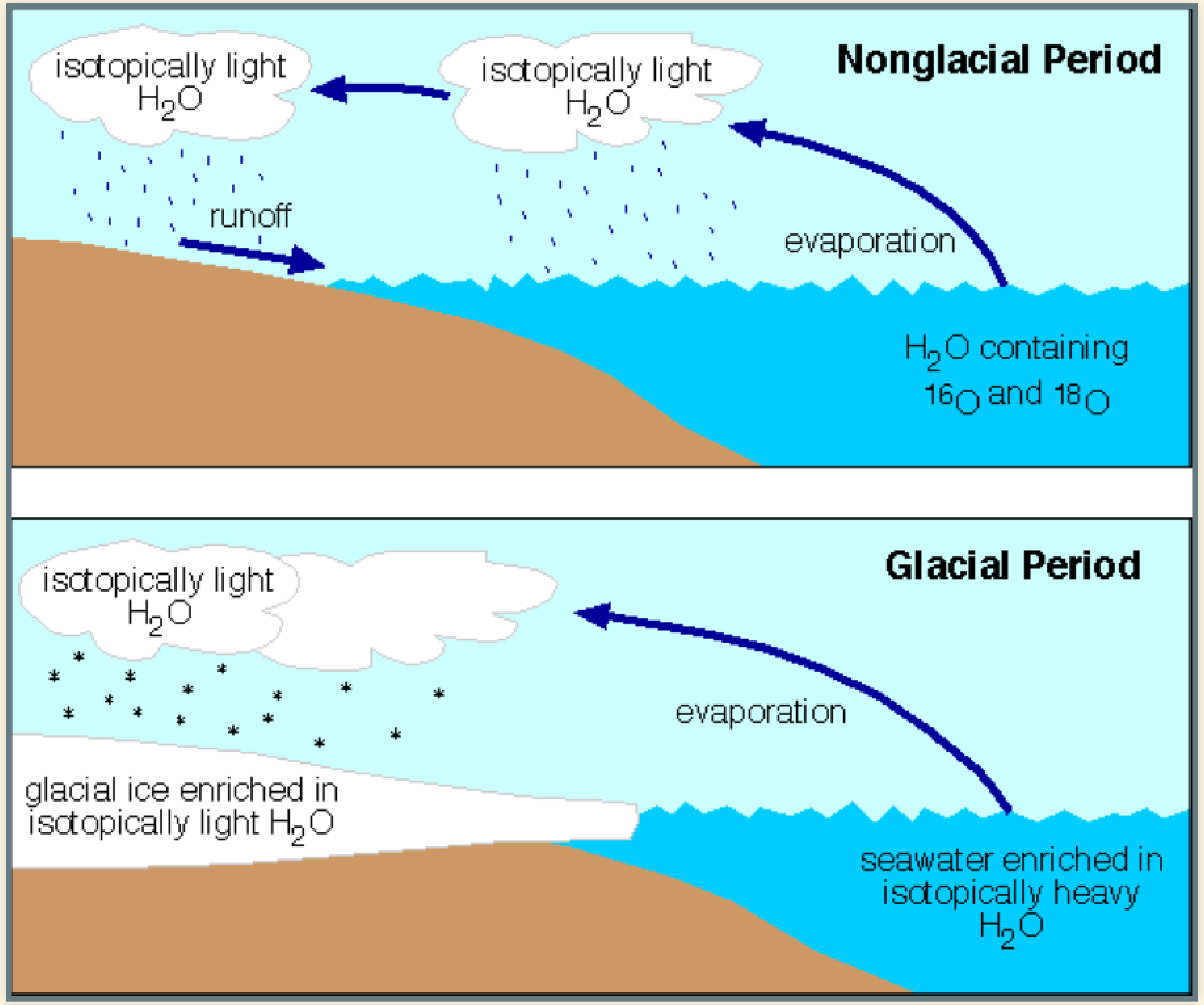


Deep-Sea Sediments

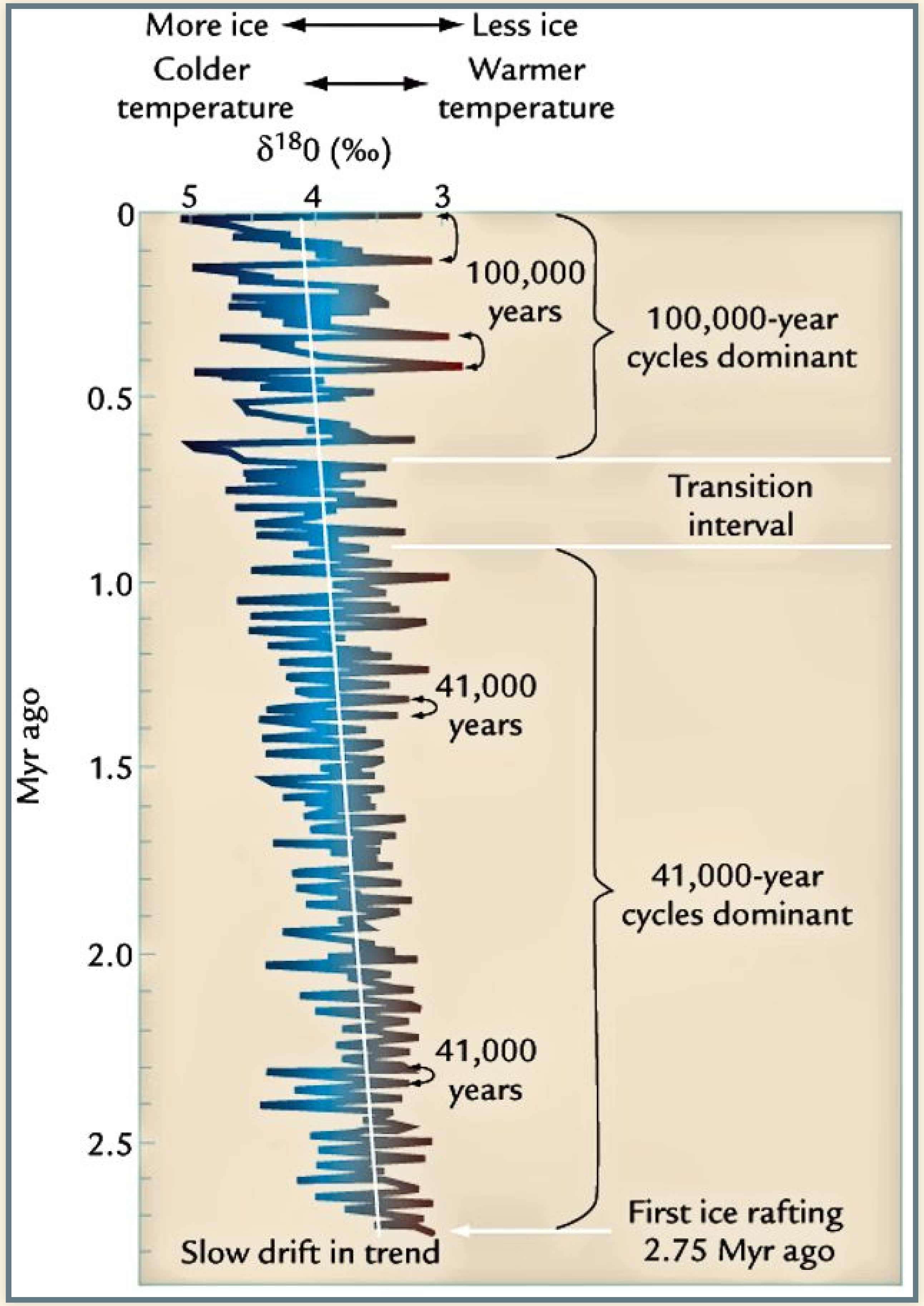


Past Sea Levels

- Water vapor, rain, snow is always isotopically lighter than sea water
- Snow, ice on land remove light isotopes from ocean
- Bigger glaciers:
  - Lower sea-level
  - Greater (positive) $\delta^{18}O$ in ocean sediments
- Smaller glaciers:
  - Higher sea-level
  - Smaller $\delta^{18}O$ in ocean sediments



Sediment Climate Record



Summary of Oxygen Isotopes

- Two different uses:
  - δ^{18}O in **glacial ice** tells us about **air temperature**:
    - Greater δ^{18}O means warmer temperature.
  - δ^{18}O in **sea-floor sediments** (skeletons of deep-sea organisms) tells us about **sea level**:
    - Greater δ^{18}O means lower sea-level.
- During ice-age cycles:
  - ***cold temperatures*** go with ***low sea-level***
    - δ^{18}O is *lower* than usual in glaciers, *greater* in sea-floor sediments.
  - ***warm temperatures*** go with ***high sea-level***:
    - δ^{18}O is *greater* than usual in glaciers, *lower* in sea-floor sediments.
  - But sea-level changes more slowly than temperature, so changes in sediments usually lag behind changes in glaciers.

Questions about Carbon Cycle?

Questions about MODTRAN?

MODTRAN:

- MODTRAN calculates *emissions* and *absorption* of longwave light in the atmosphere.
- Things that don't change during a run:
  - Heat from the sun
    - Set by "locality" of the atmosphere
  - Temperature of the ground and every layer of the atmosphere.
    - Set by "locality" of the atmosphere and "temperature offset"

Locale	I_{out} (W/m^2)	T_{ground} (K)
U.S. Standard Atmosphere	267.98	288.2
Tropical	298.67	299.7
Midlatitude winter	235.34	272.2

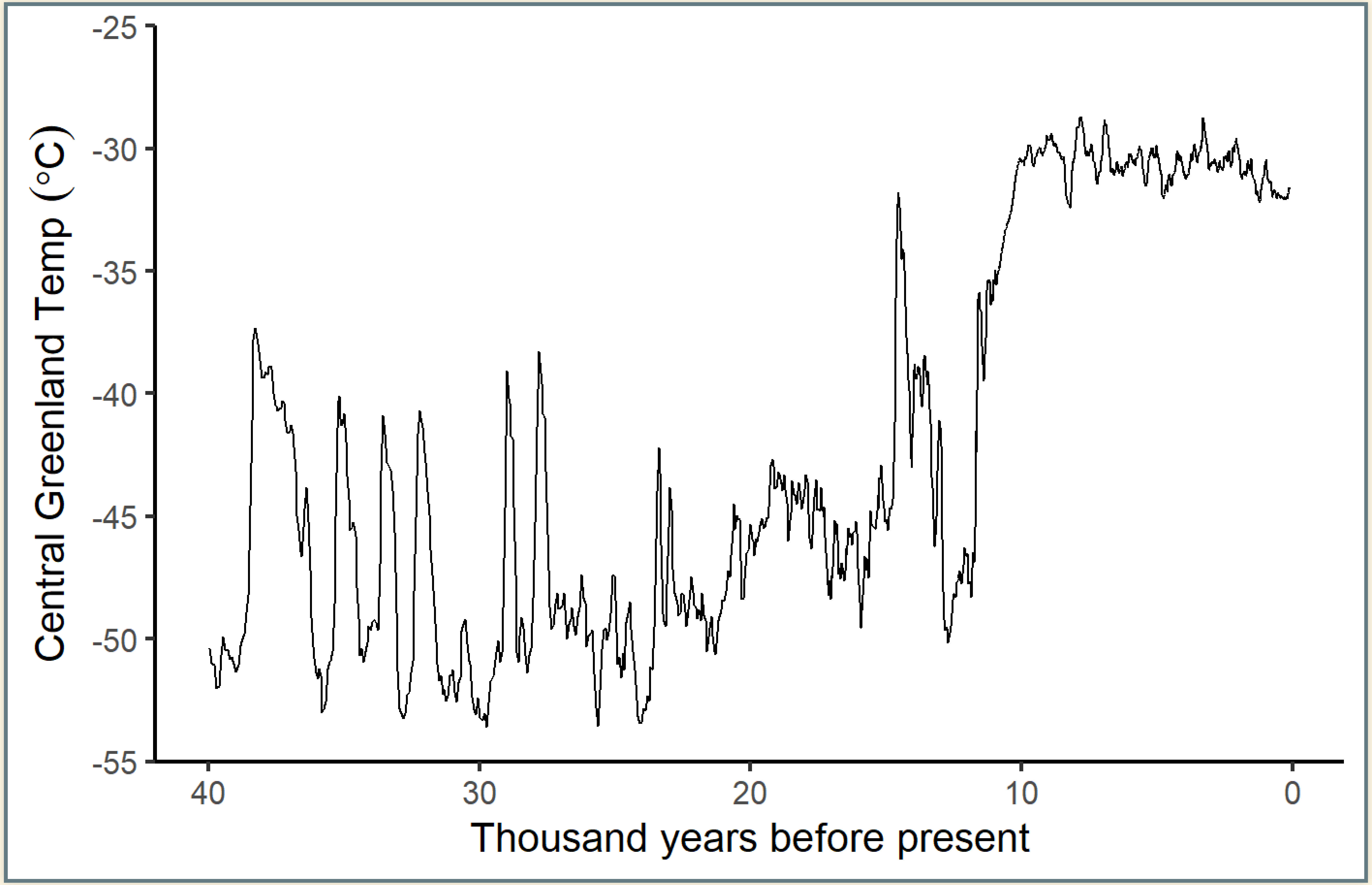
- For every wavenumber, MODTRAN calculates heat emission and absorption up and down at each layer.

MODTRAN:

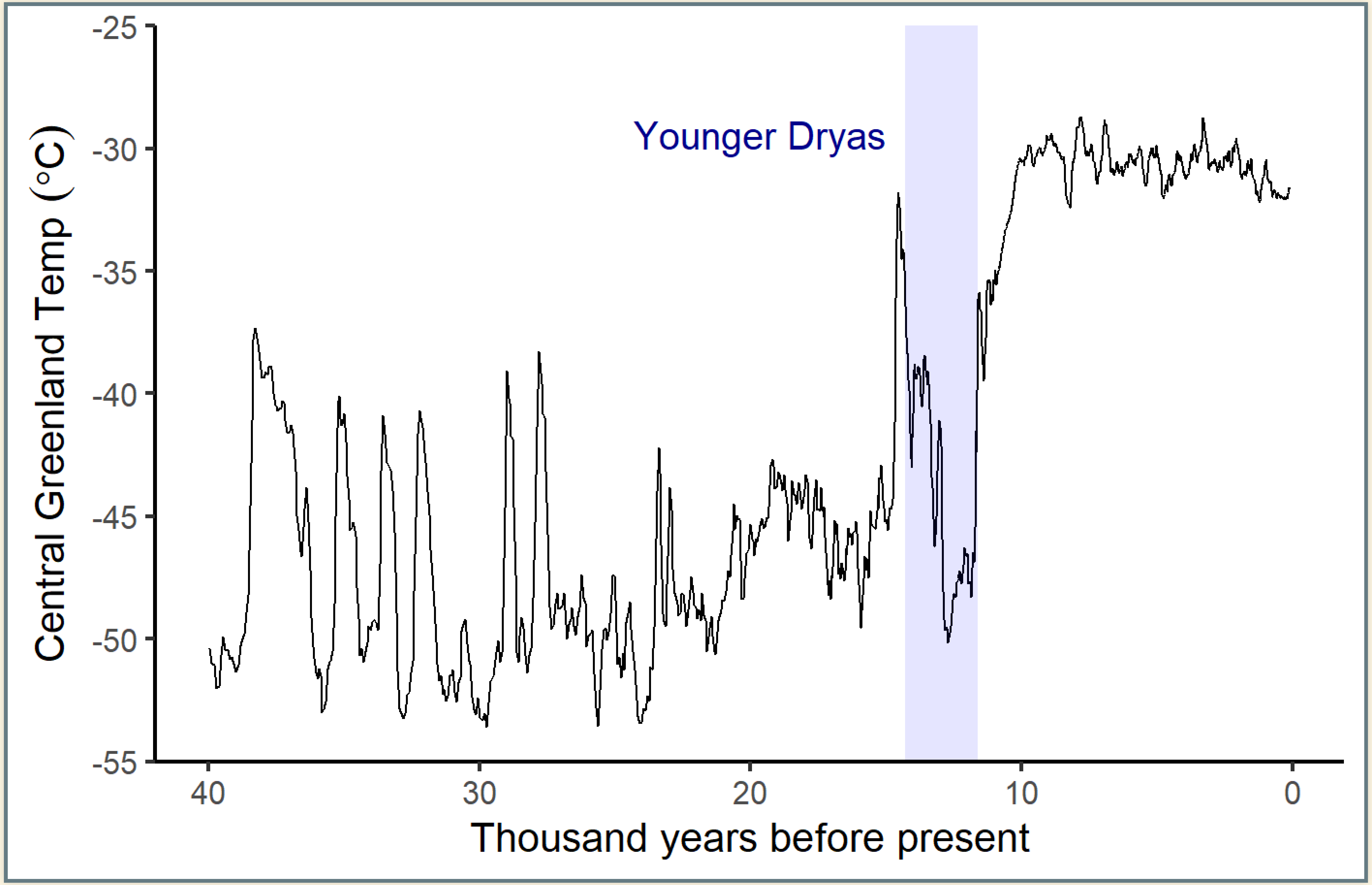
- Emissivity (ε) = absorption
  - Fraction absorbed by layer $= \varepsilon$
  - Radiation emitted by layer $= \varepsilon\sigma T^4$
- ε small (near zero):
  - Little absorption or emission.
- ε large (near one):
  - Almost all incoming radiation is absorbed
  - Emission close to black body at temperature *T*.
- ε is large for wavenumbers where greenhouse gases absorb strongly.
  - Greater concentration $\rightarrow$ larger ε
- ε is small where there is little absorption
  - Atmospheric window
- **Looking down from space:**
  - You see emission at the temperature of the ***highest layer* with large** ε.
  - In atmospheric window, that layer is near the ground
  - With clouds, it's the top of the highest cloud
- **Looking up from ground:**
  - You see emission at the temperature of the ***lowest layer* with large** ε.
  - In atmospheric window, there's no such layer, so you see very little emission
    - You're seeing emission from outer space, which is very cold.
  - With clouds, it's the bottom of the lowest cloud

Abrupt Climate Change

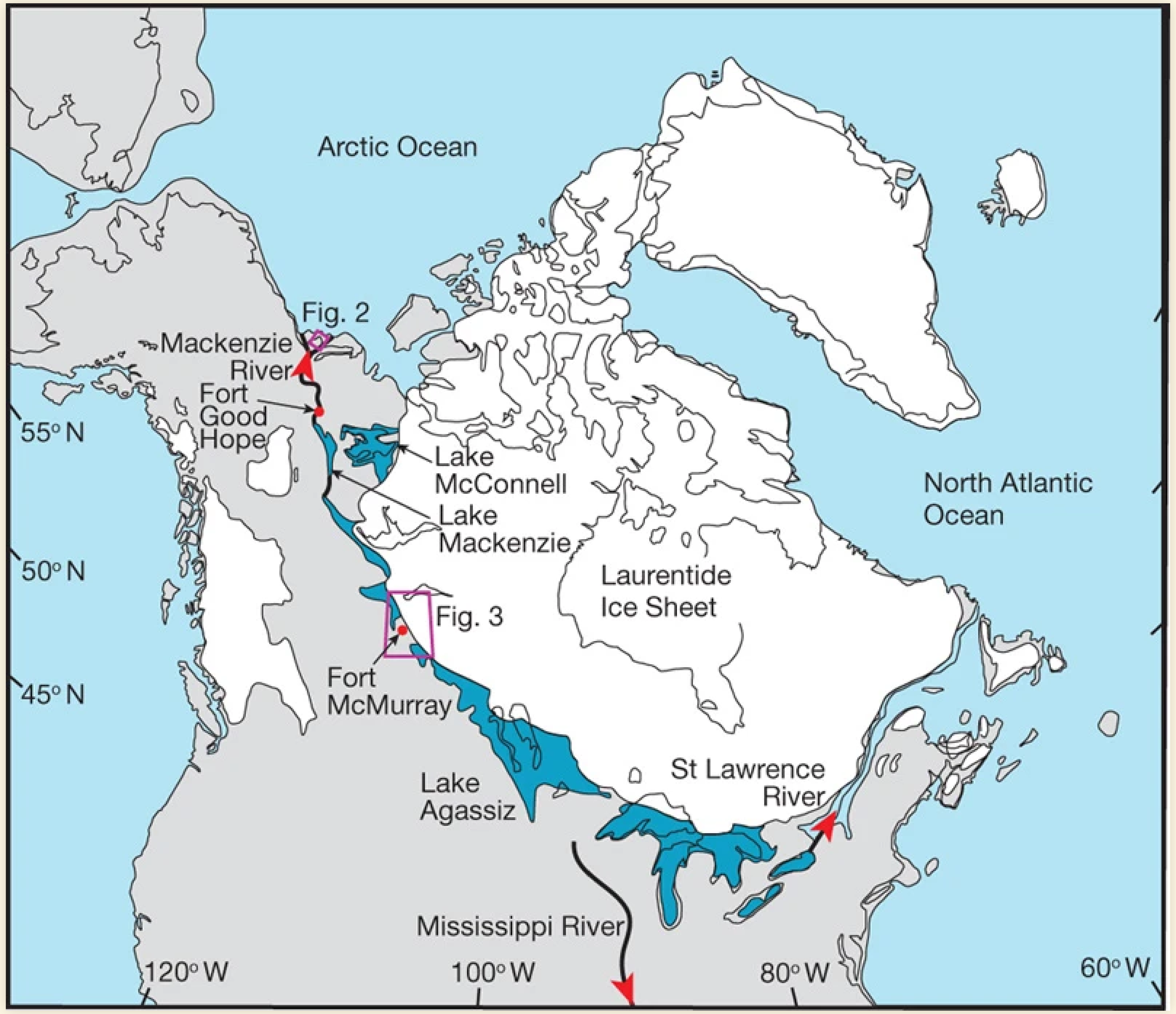
Abrupt Climate Change



Abrupt Climate Change



Younger Dryas

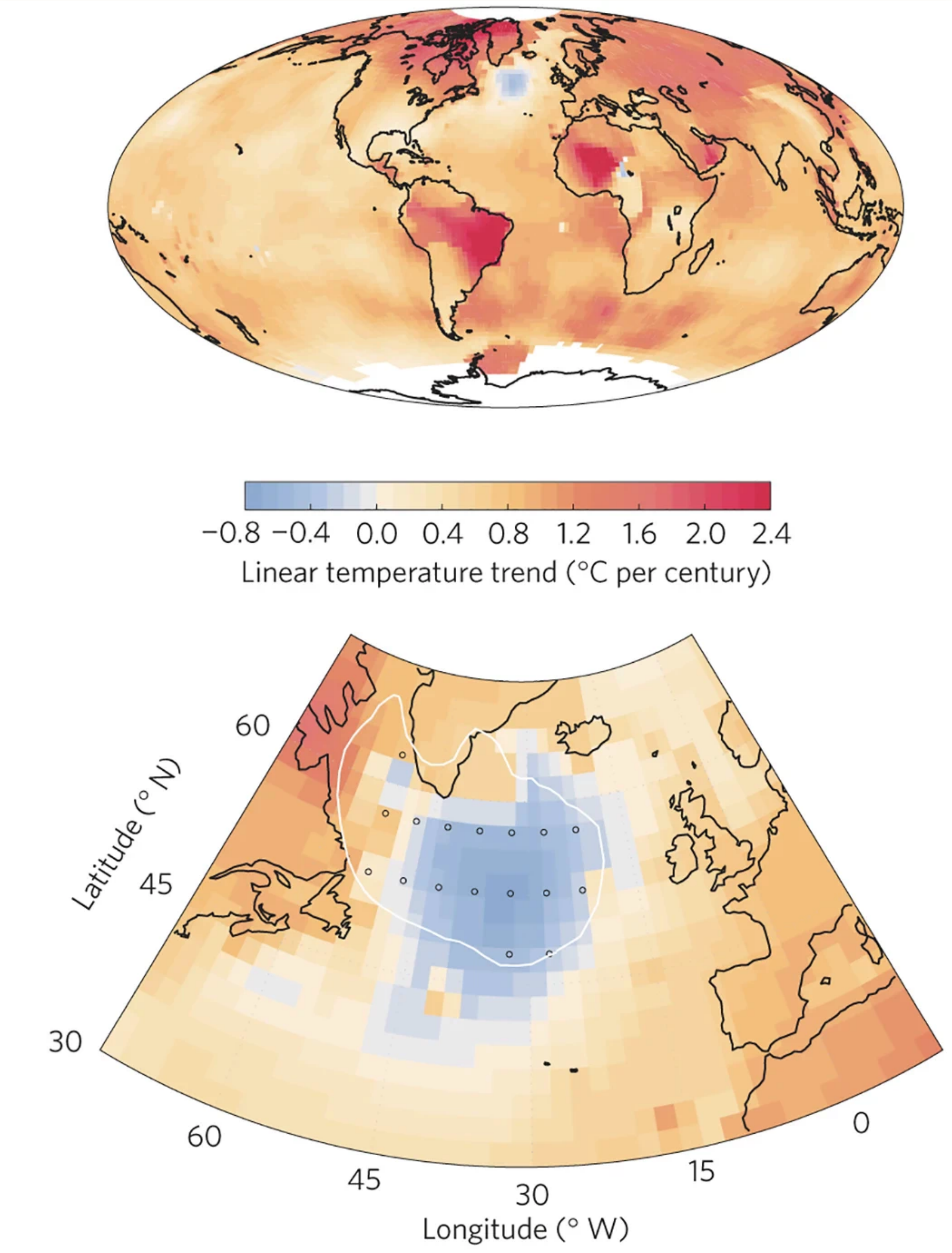


J.B. Murton *et al.*, Nature **464**, 740 (2010). doi: 10.1038/nature08954

- About 14,000 years ago there was rapid warming
- Giant Glacial Lake Agassiz
  - When enough ice melted, Lake Agassiz drained into Arctic and Atlantic Oceans
  - Fresh water diluted salt water
    - Less dense, wouldn't sink
    - Stopped deep-water formation
    - Blocked conveyor belt current
  - Warm currents (Gulf stream, Mediterranean current) bring lots of heat to North Atlantic, Western Europe.
    - Without that heat, cold temperatures returned

Cold Pool in North Atlantic

Warming Trend: 1900–2013

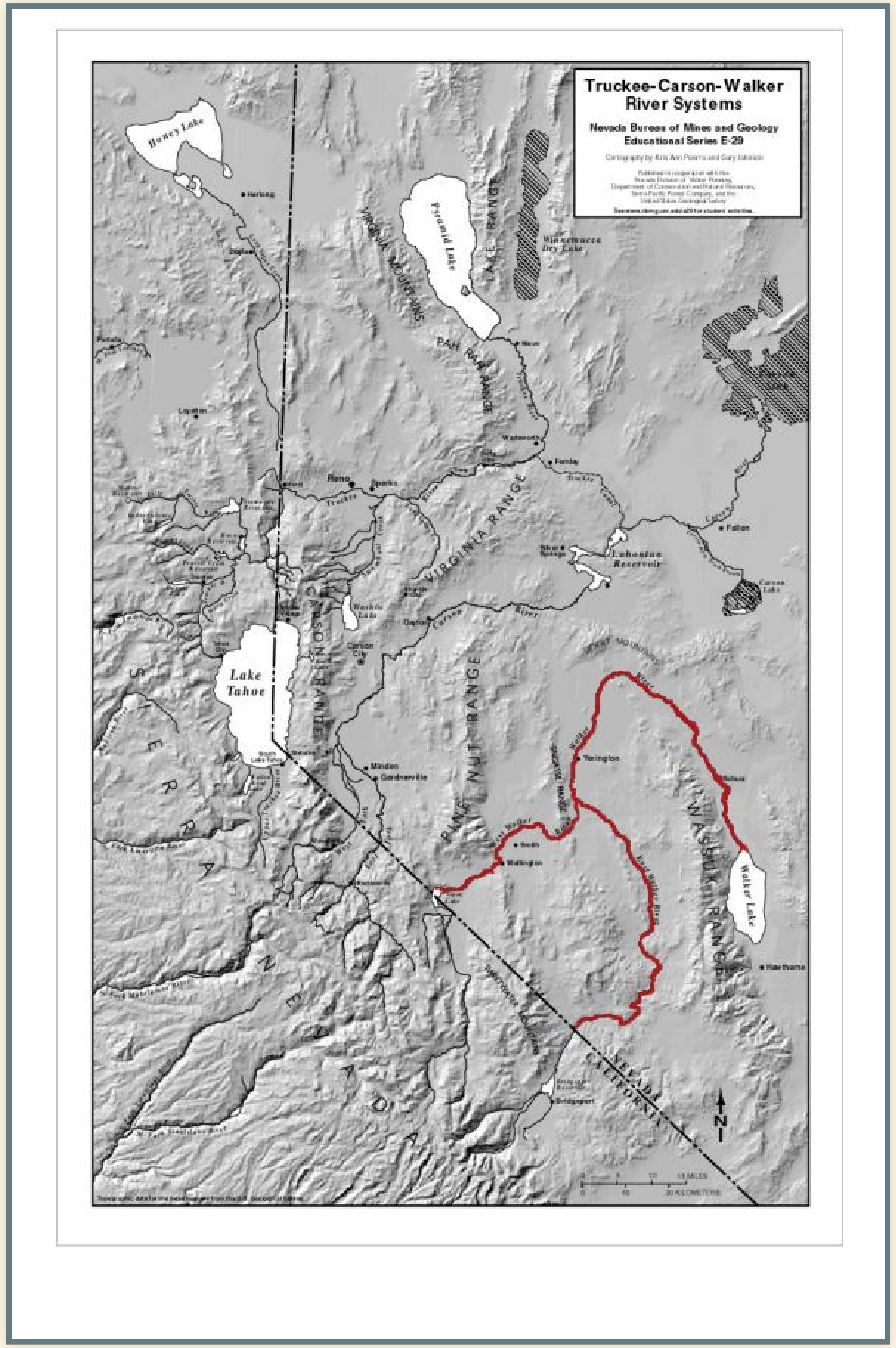


S. Rahmstorf *et al.*, *Nature Climate Change* **5**, 475 (2015). doi: 10.1038/nclimate2554

- Atlantic circulation (Gulf stream, etc.) has slowed down
- Without that heat, a pool of water in the North Atlantic is cooling
- Fresh water from melting ice on Greenland may be partially responsible.

Climate in the Last Millennium

Walker River



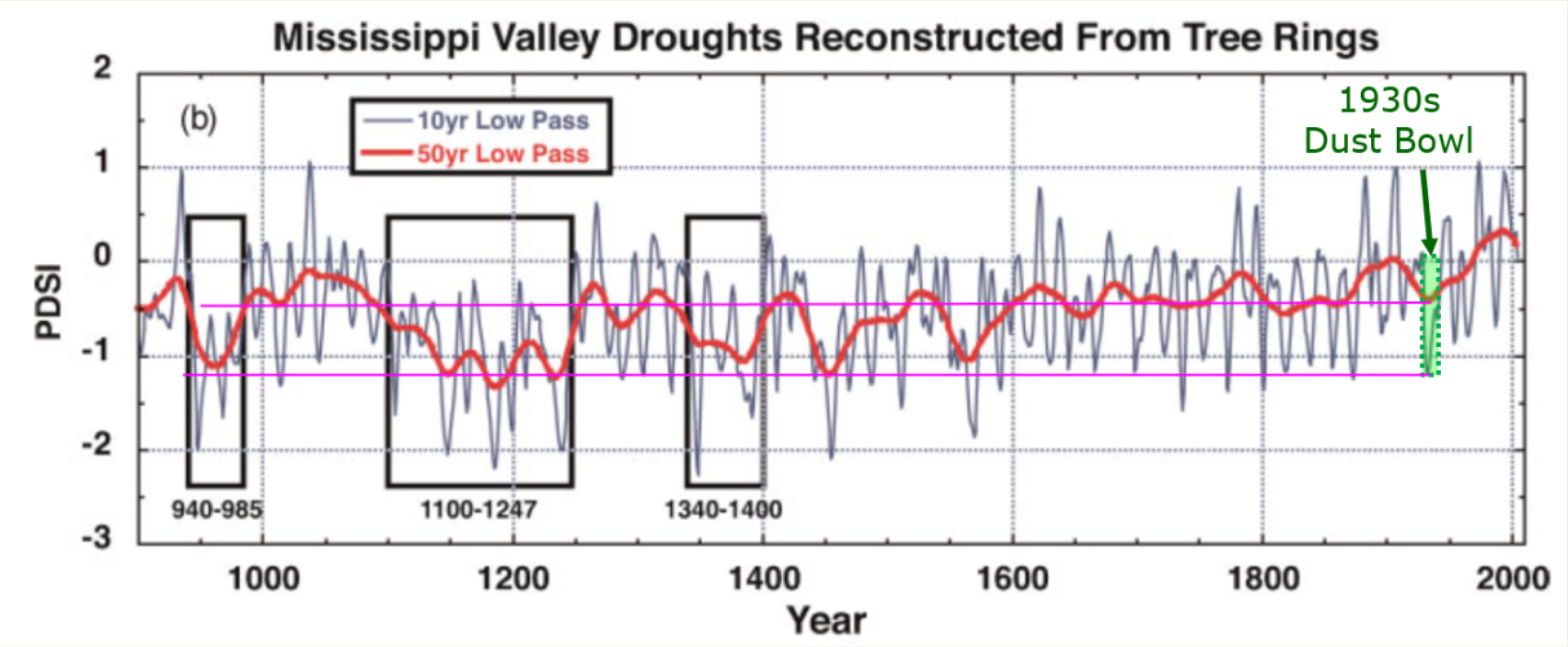
Relict Tree Stumps

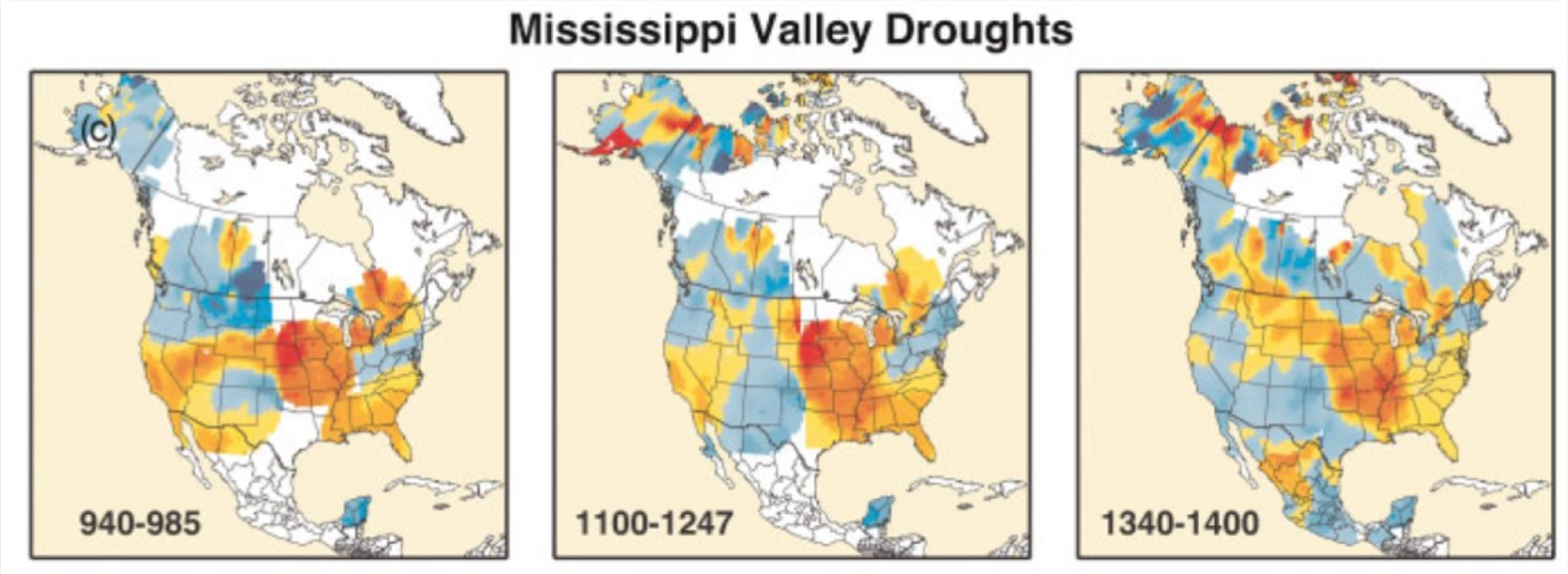
Relict Tree Stumps

Lake Tanaya, Yosemite

Chaco Canyon

Reconstructing Megadroughts





Dust Bowl vs. Megadroughts

- 1930s “Dust Bowl”
  - 6 years
  - 25% reduction in rainfall in plains states
  - Hundreds of thousands of refugees
- Medieval Megadroughts:
  - Multiple droughts
  - 60 years or longer (up to 240)
  - 40% reduction of rainfall in plains states