

# Human Impact on Climate: The Evidence

EES 2110

Introduction to Climate Change

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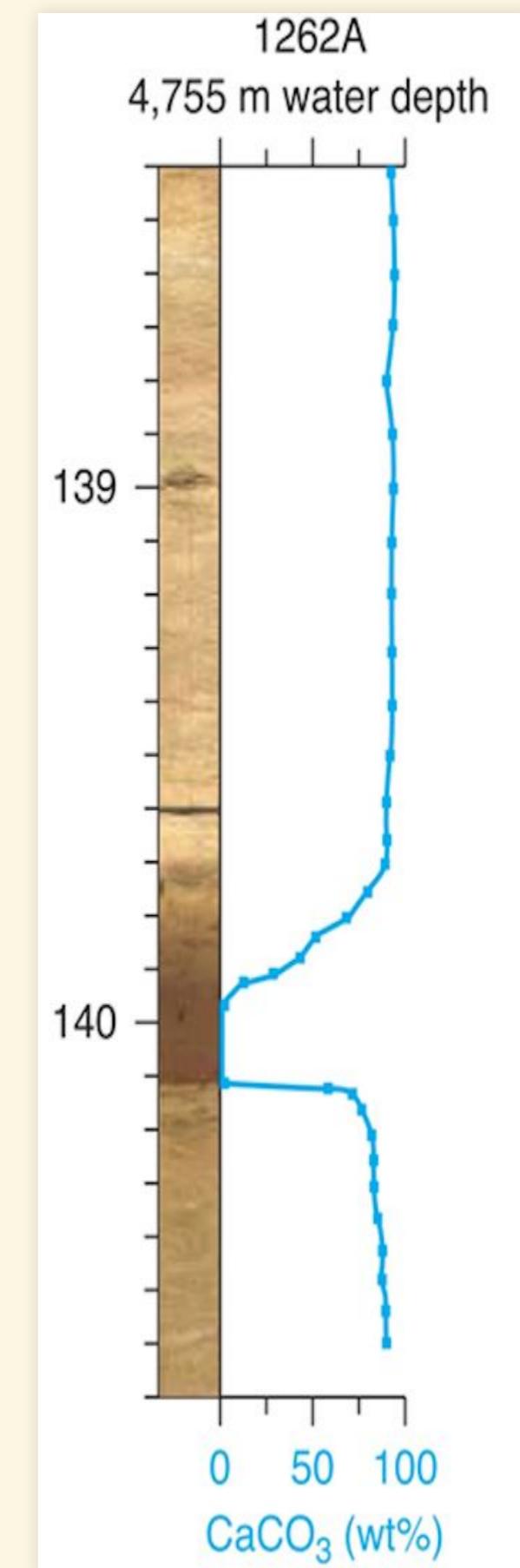
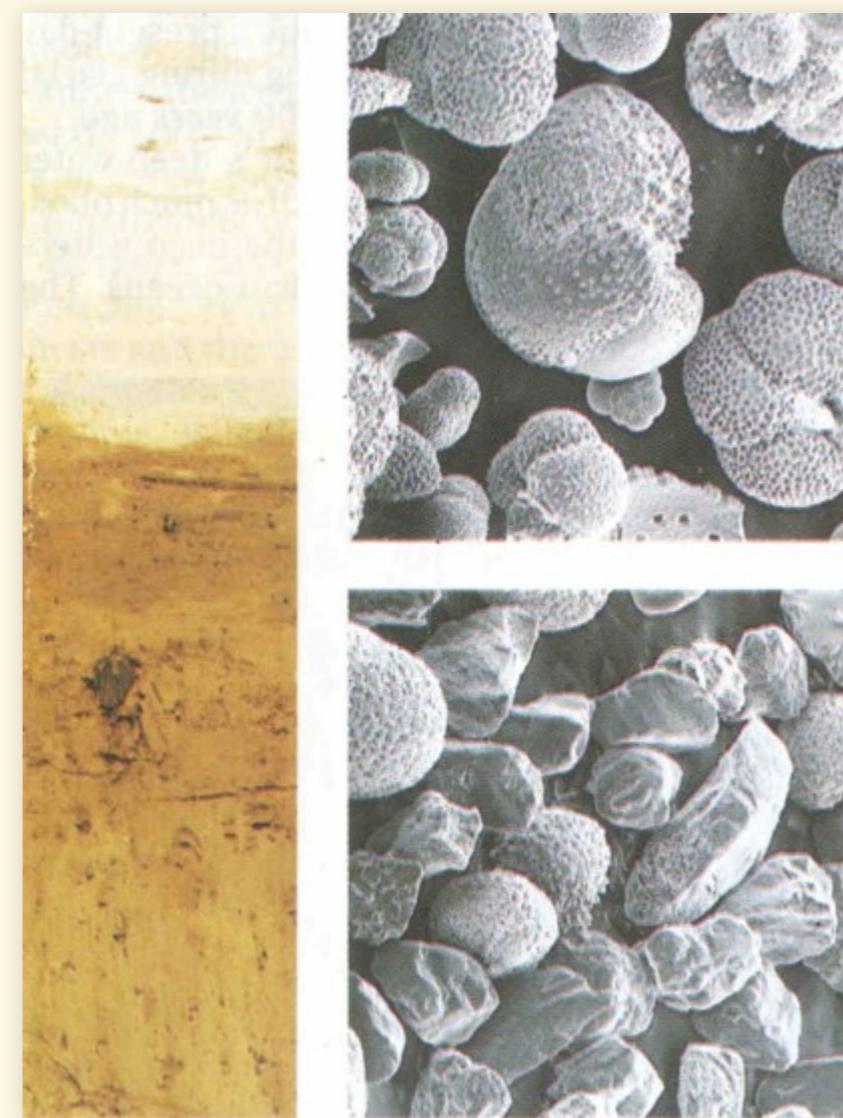
Class #21: Monday, February 27 2023

# The Paleocene-Eocene Thermal Maximum

# The Paleocene-Eocene Thermal Maximum



- Alkaline Ocean:
  - High  $\text{CO}_3^{2-}$ : Reaction runs  $\leftarrow$
  - Carbonates survive on sea floor
- Acid Ocean:
  - Low  $\text{CO}_3^{2-}$ : Reaction runs  $\Rightarrow$
  - Carbonates dissolve
  - Only clay is left
- Red clay layer  $\Rightarrow$  ocean acidification
  - Large burst of  $\text{CO}_2$  into atmosphere.

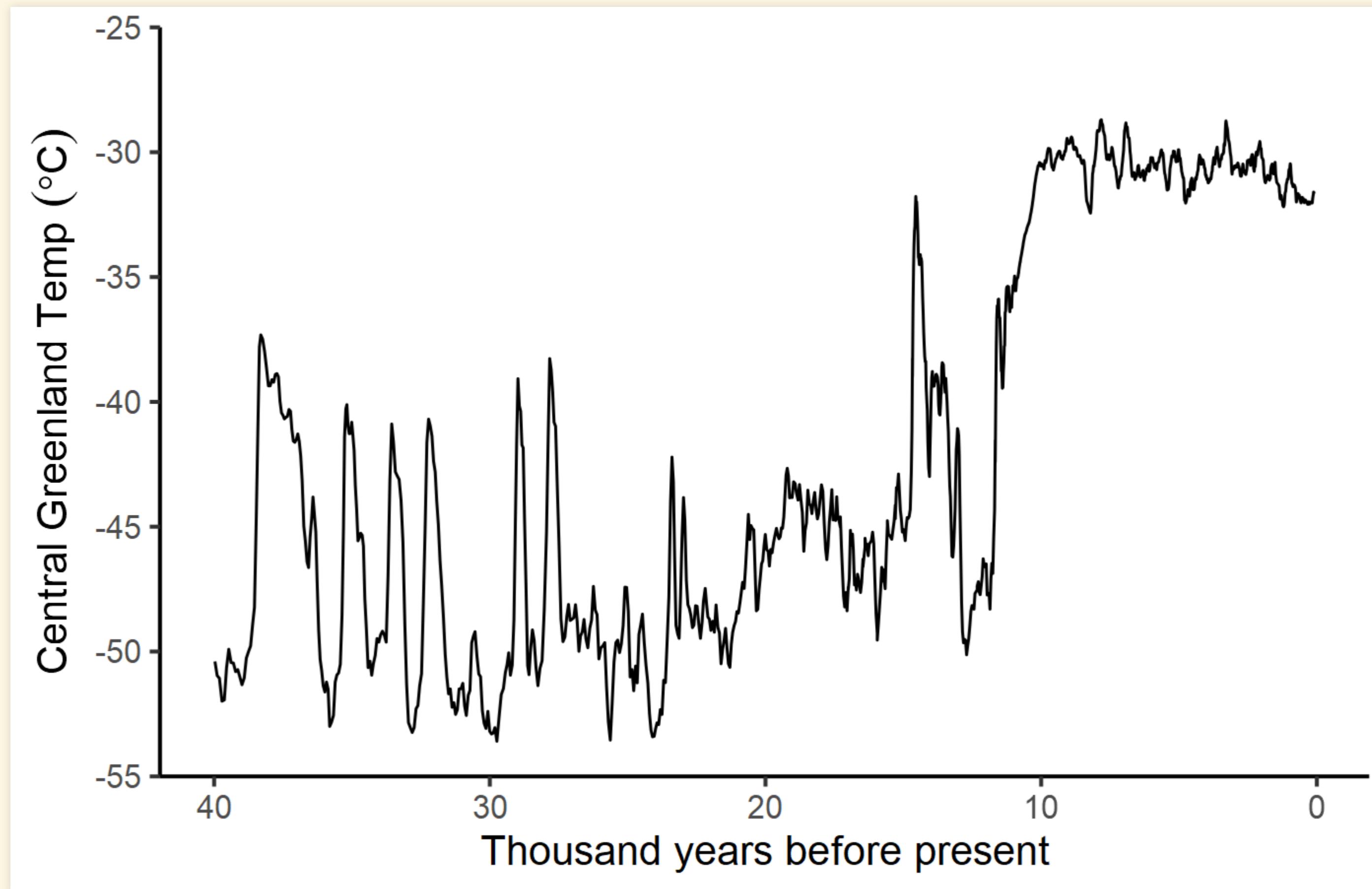


# Paleocene-Eocene Thermal Maximum

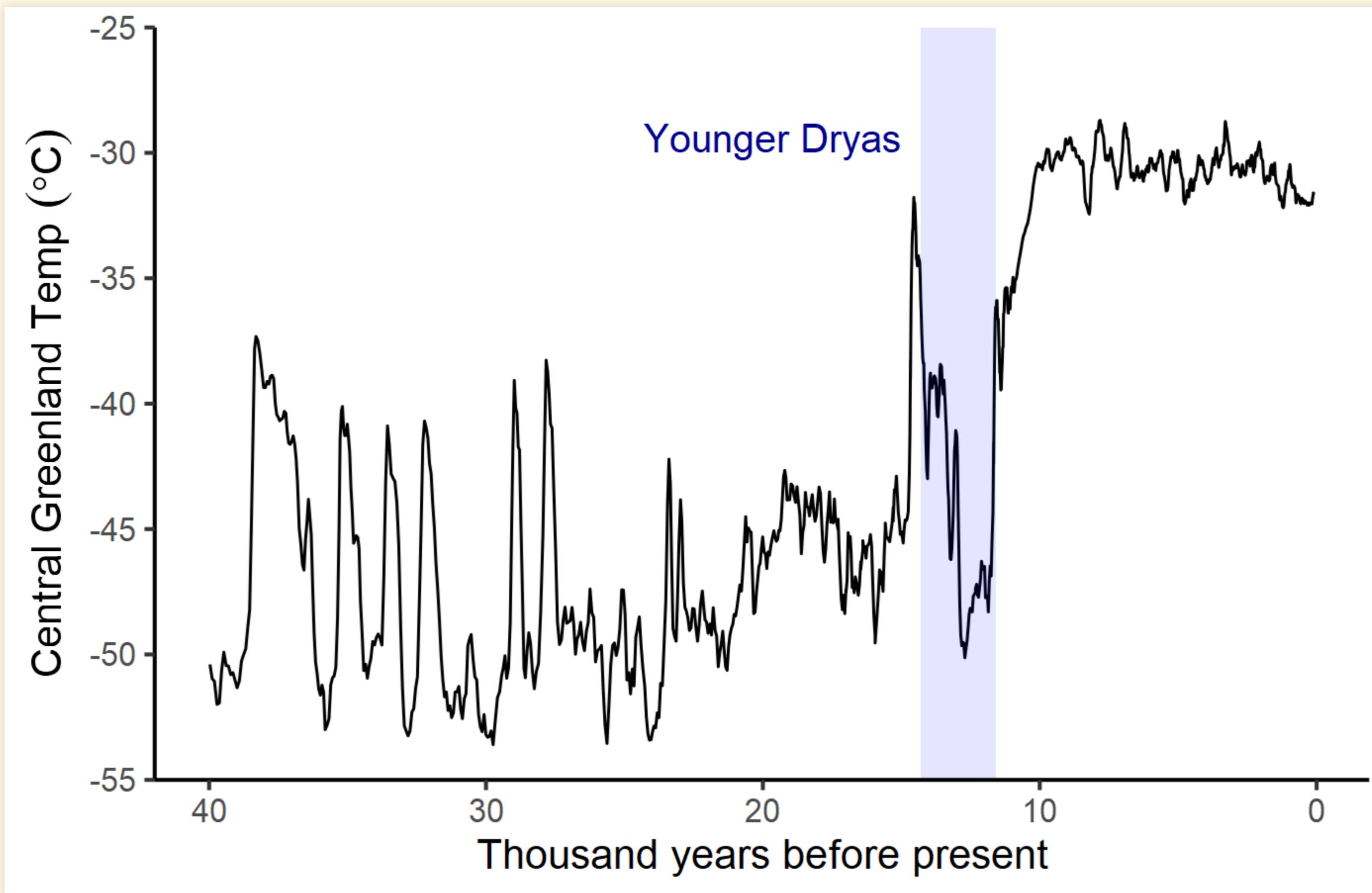
- 55 million years ago
- 1500–4500 GT carbon added to atmosphere in 1000 years
  - Compare:
    - 600 GT in atmosphere in 1700s,
    - 884 GT today
    - Known fossil fuels: ~5000 GT
- Temperature rose 5–9°C (9–16°F)
  - Ocean at North Pole was about 23° C (73° F).
  - Breadfruit & other tropical trees grew in Canada
- Lasted ~120,000 years
  - Transition to cooler temperatures took ~40,000 years
- Eocene → ⋯ → Pliocene → Pleistocene
  - Gradual cooling for 50 million years
  - Ice age glaciation of North America, Europe begins ~2.8 MYA

# Abrupt Climate Change

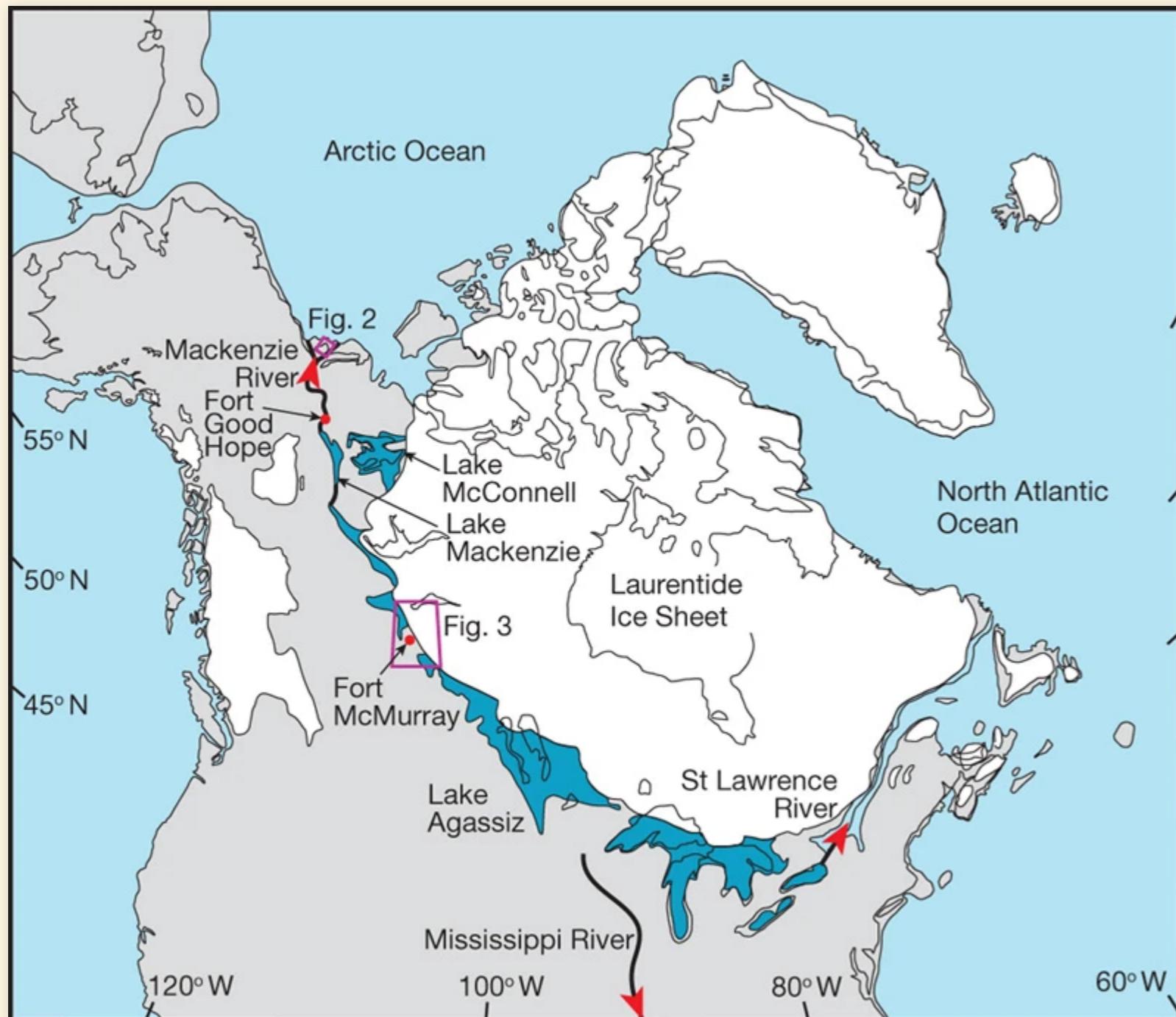
# Abrupt Climate Change



# Abrupt Climate Change



# Younger Dryas

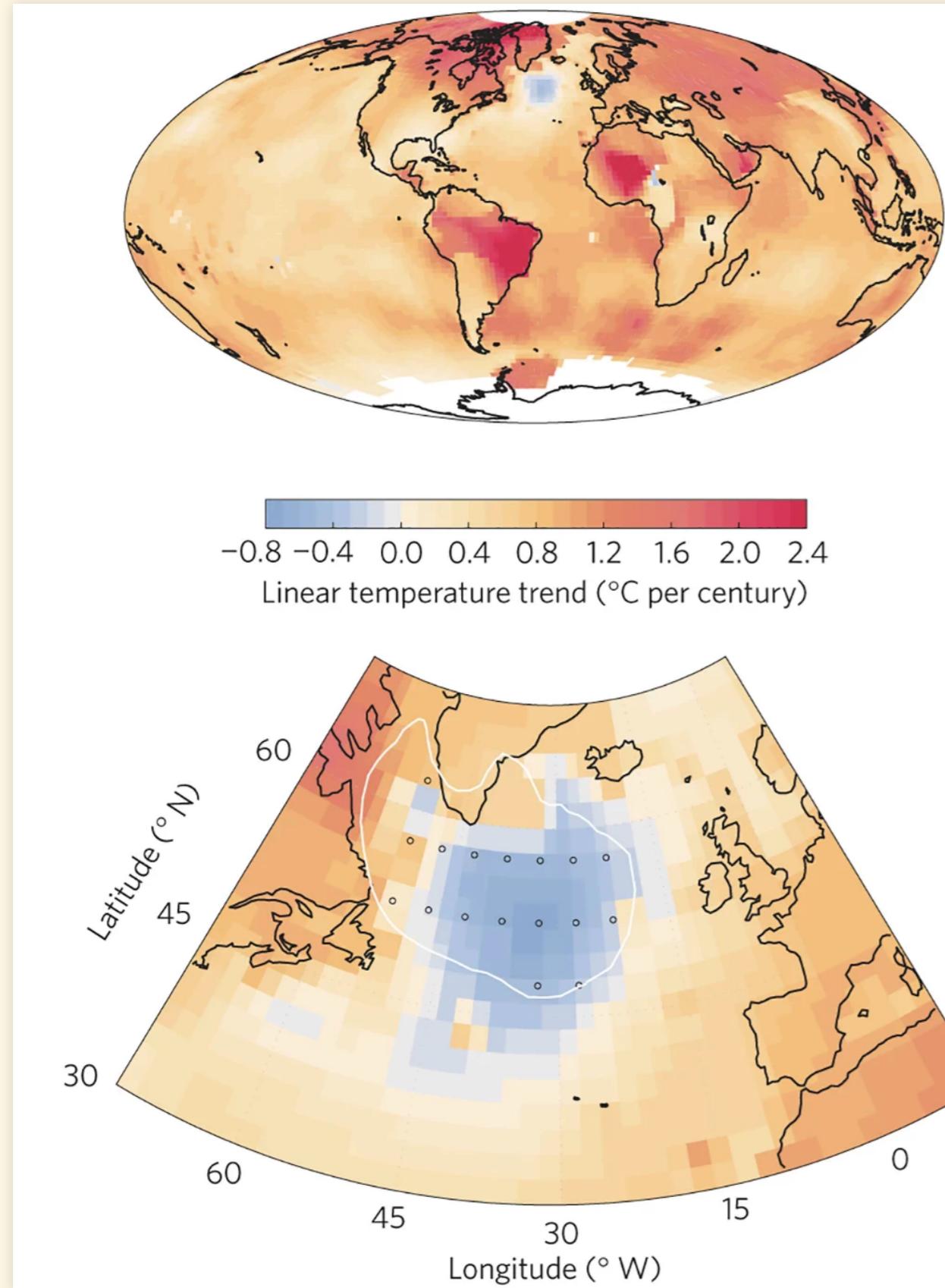


J.B. Murton et al., Nature 464, 740 (2010). doi: 10.1038/nature08954

- 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

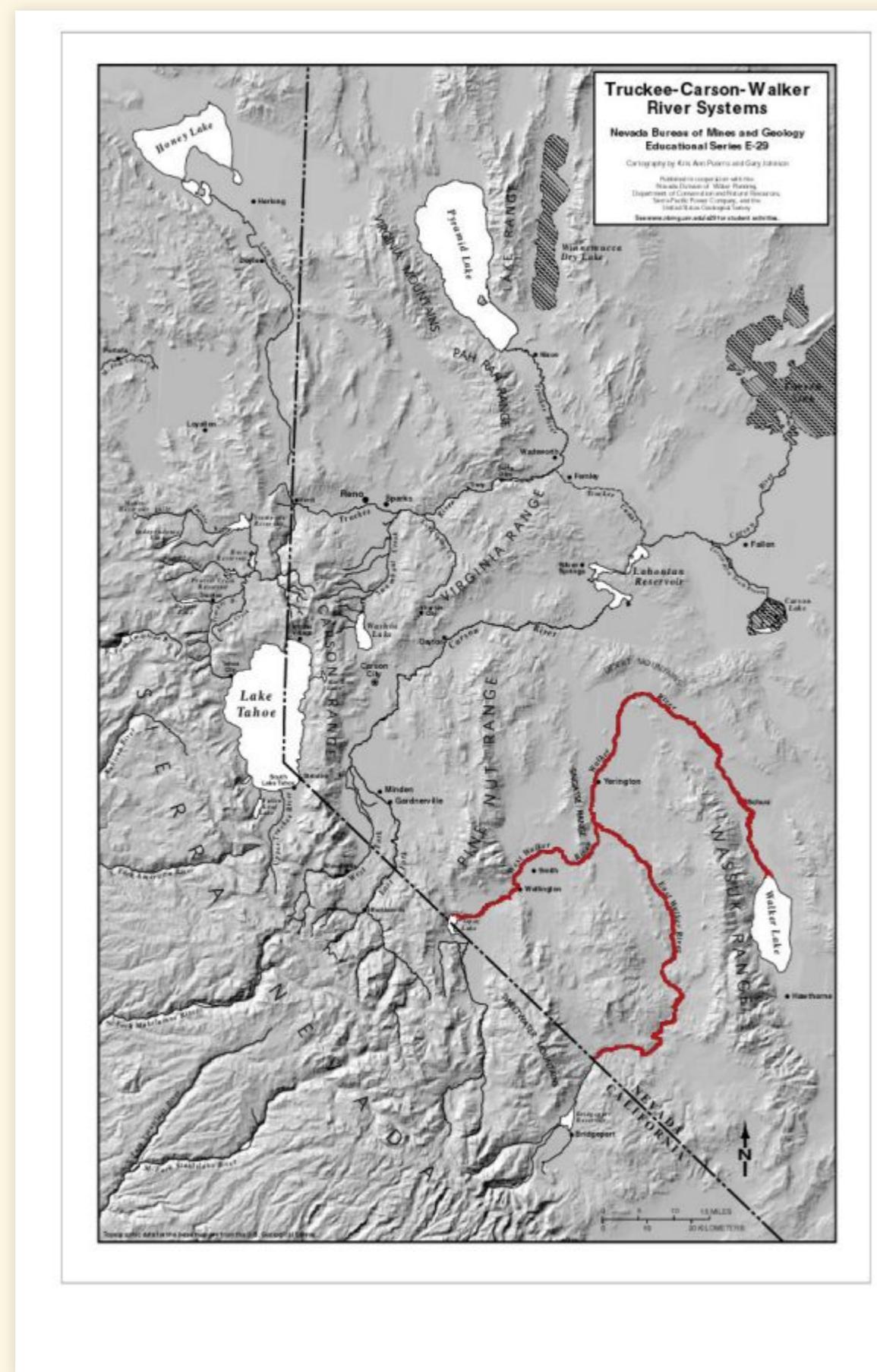
Warming Trend: 1900–2013



- Atlantic circulation (Gulf stream, etc.) has slowed down.
  - Rapid decline since mid-20th century
  - Circulation is the weakest in the last 1000 years.
- 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



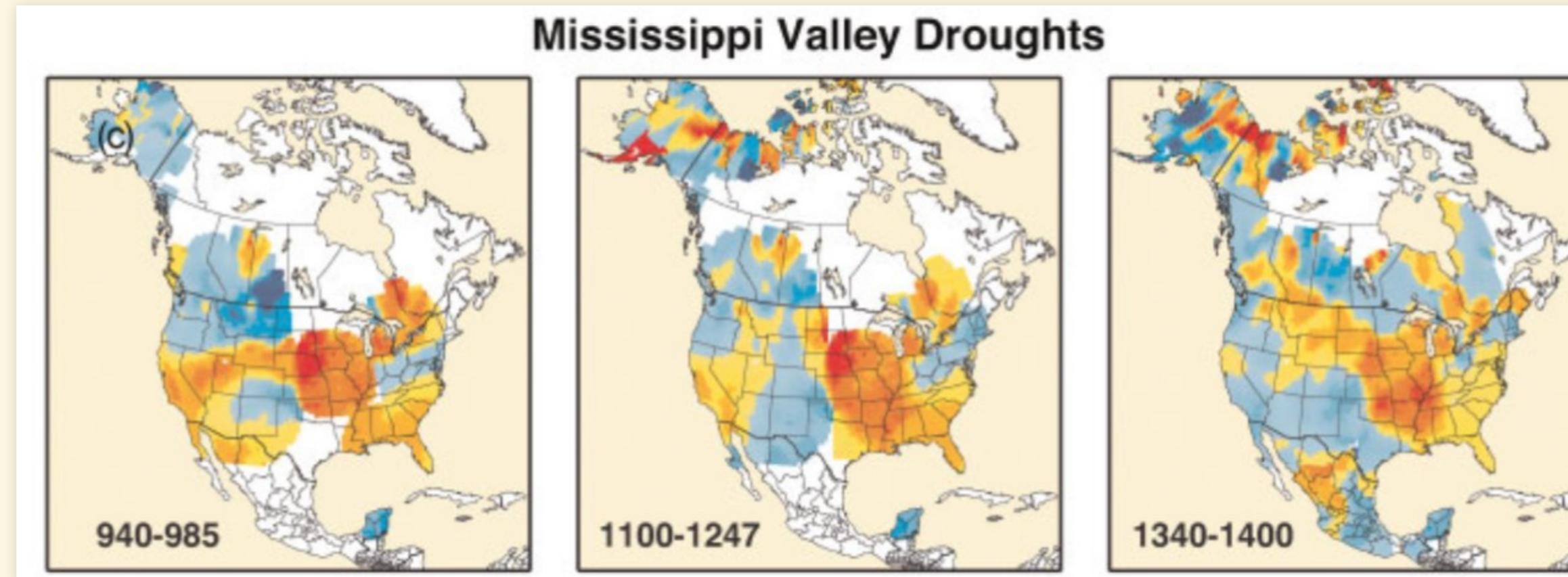
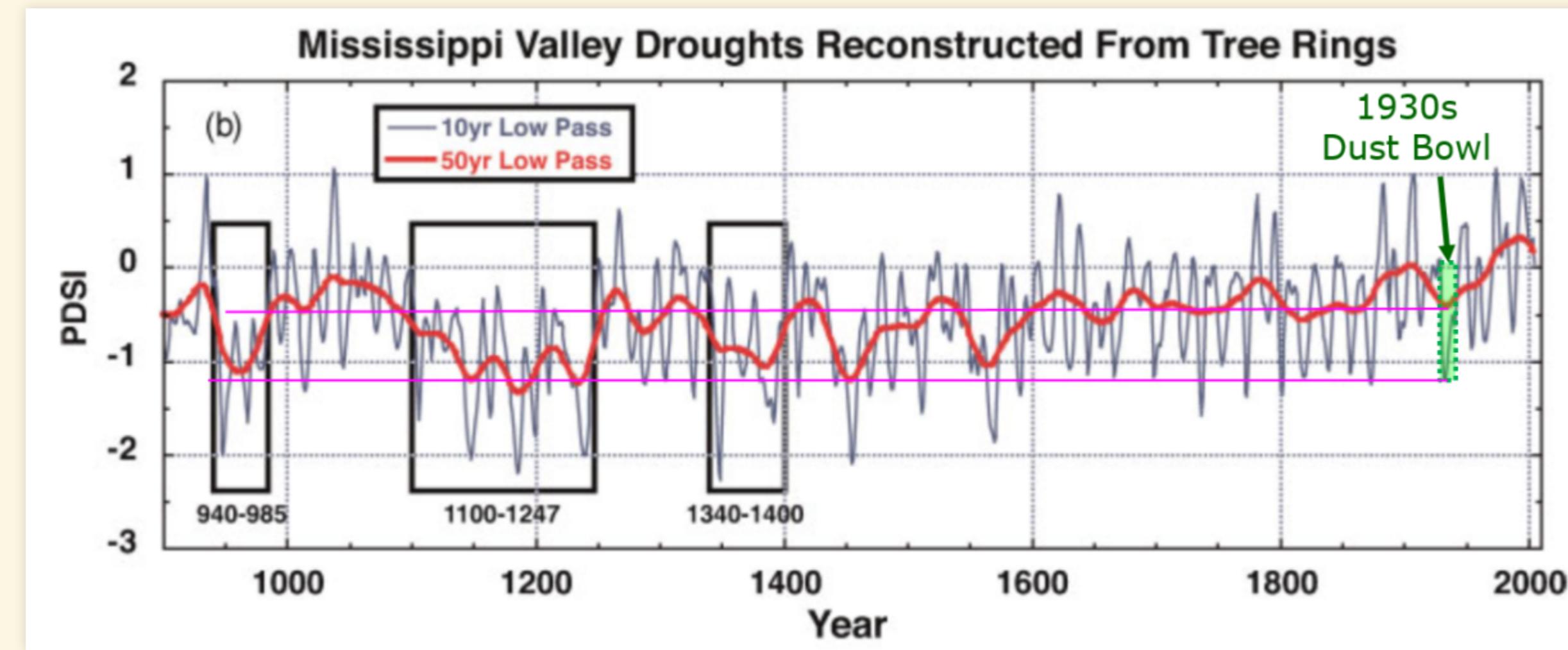
# Lake Tanaya, Yosemite



# Chaco Canyon



# Reconstructing Megadroughts



# Dust Bowl vs. Megadroughts

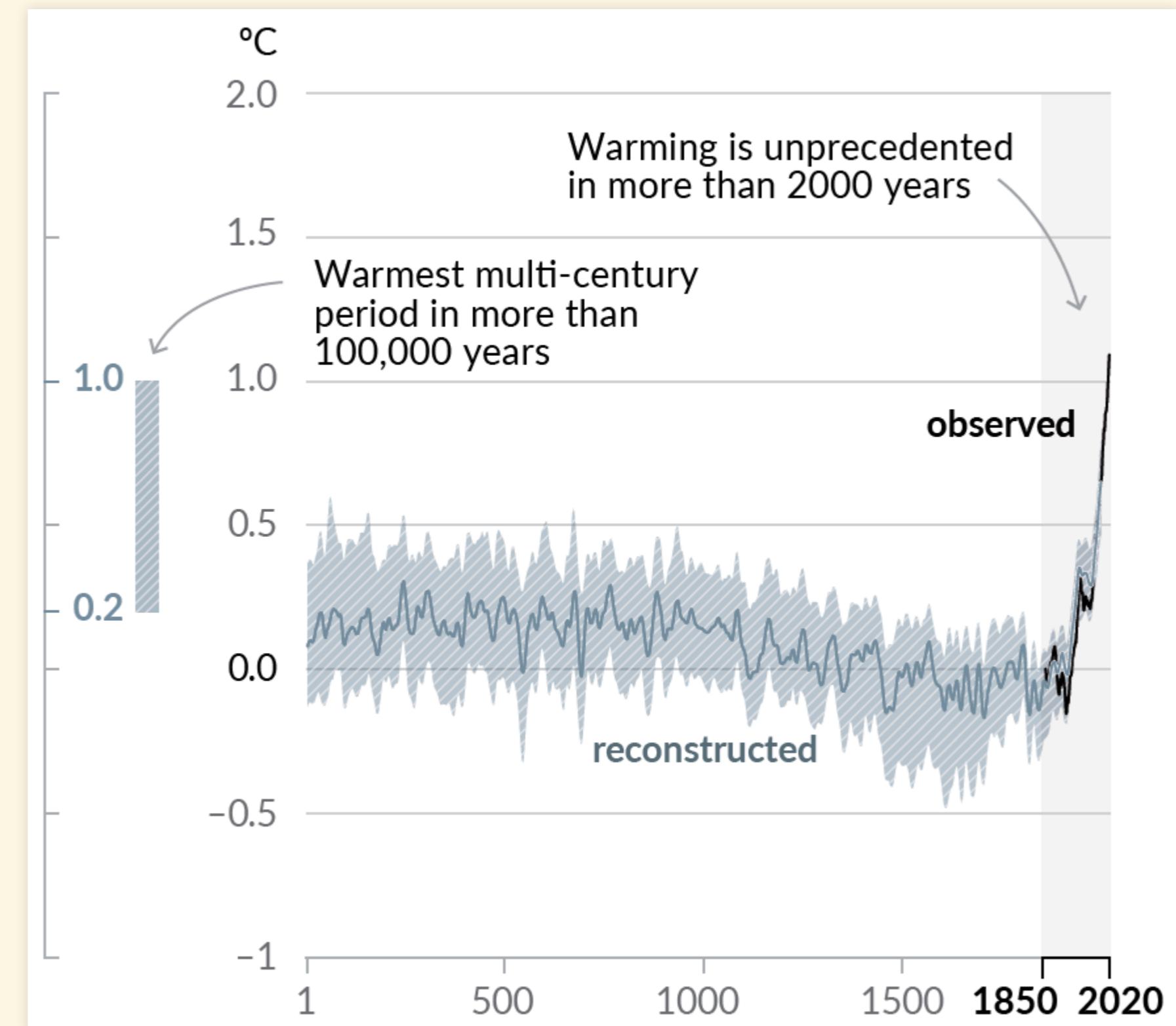
- 1930s “Dust Bowl”
  - 6 years
  - 25% reduction in rainfall in plains states
  - Hundreds of thousands of refugees
- Medieval Megadroughts:
  - Multiple droughts
  - 60 years or longer (up to 240)
  - 40% reduction of rainfall in plains states
- New research (2022):
  - Current drought in the Southwest is the most severe since the medieval megadroughts.

# Evidence for Human Impacts on Climate Change

# Detection and Attribution

- **Detection:**
- Is the climate changing?
- How much has it changed?
- **Attribution:**
- What is causing the climate to change?
- How much of the observed changes are due to human influences?

# Detection

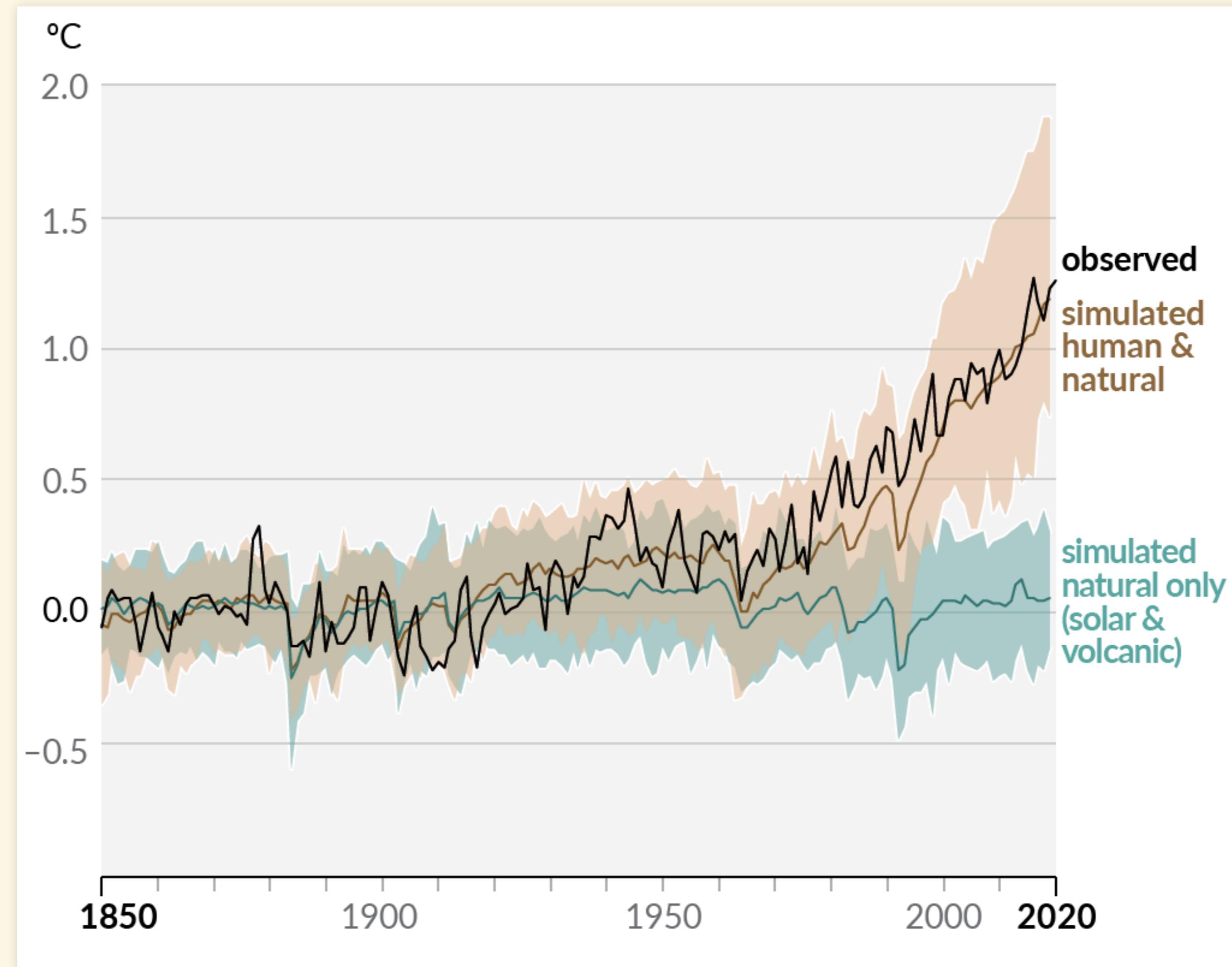


- The last century had warming completely unlike anything in the last 2,000 years.

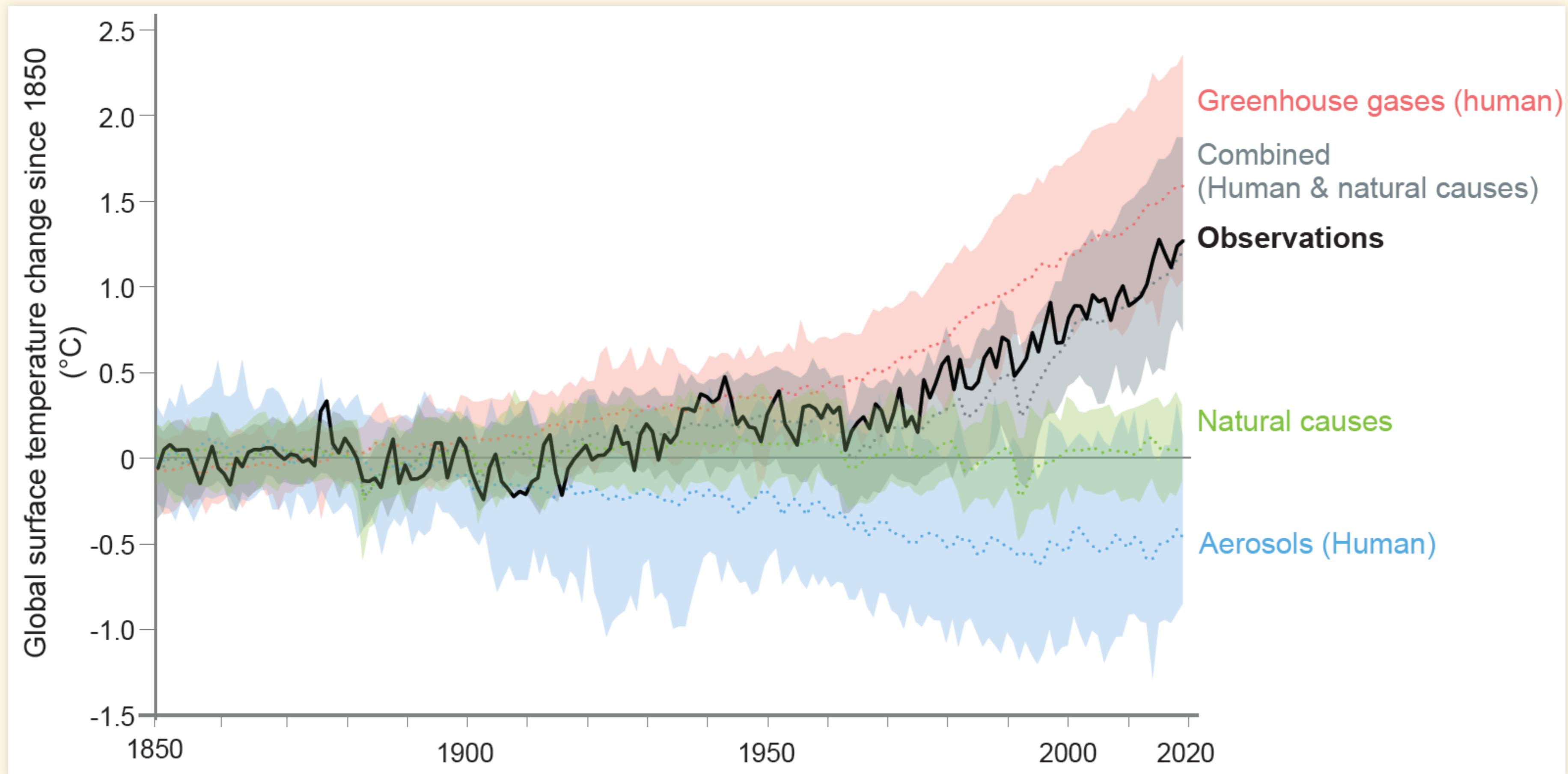
# “Fingerprint” Analysis

- There are many different things that can cause climate change:
  - Greenhouse gases
  - Aerosols (e.g., volcanic winter)
  - Changing brightness of the sun
  - ...
- Each possible cause creates a distinctive pattern in space and time:
  - Some parts of the earth warm more than others
  - Some seasons or times of day warm more than others
- Examples:
  - Does the stratosphere warm or cool when the surface warms?
  - Do the polar regions warm more or less than tropical regions?
  - Do days warm faster than nights?
  - Do winters warm faster than summers?
- **Optimal Fingerprint Analysis:**
  - Identify distinctive patterns that allow us to rule out incorrect theories of what's causing climate change
  - Scientists have studied dozens of patterns and the vast majority are consistent with human causes and inconsistent with natural causes.

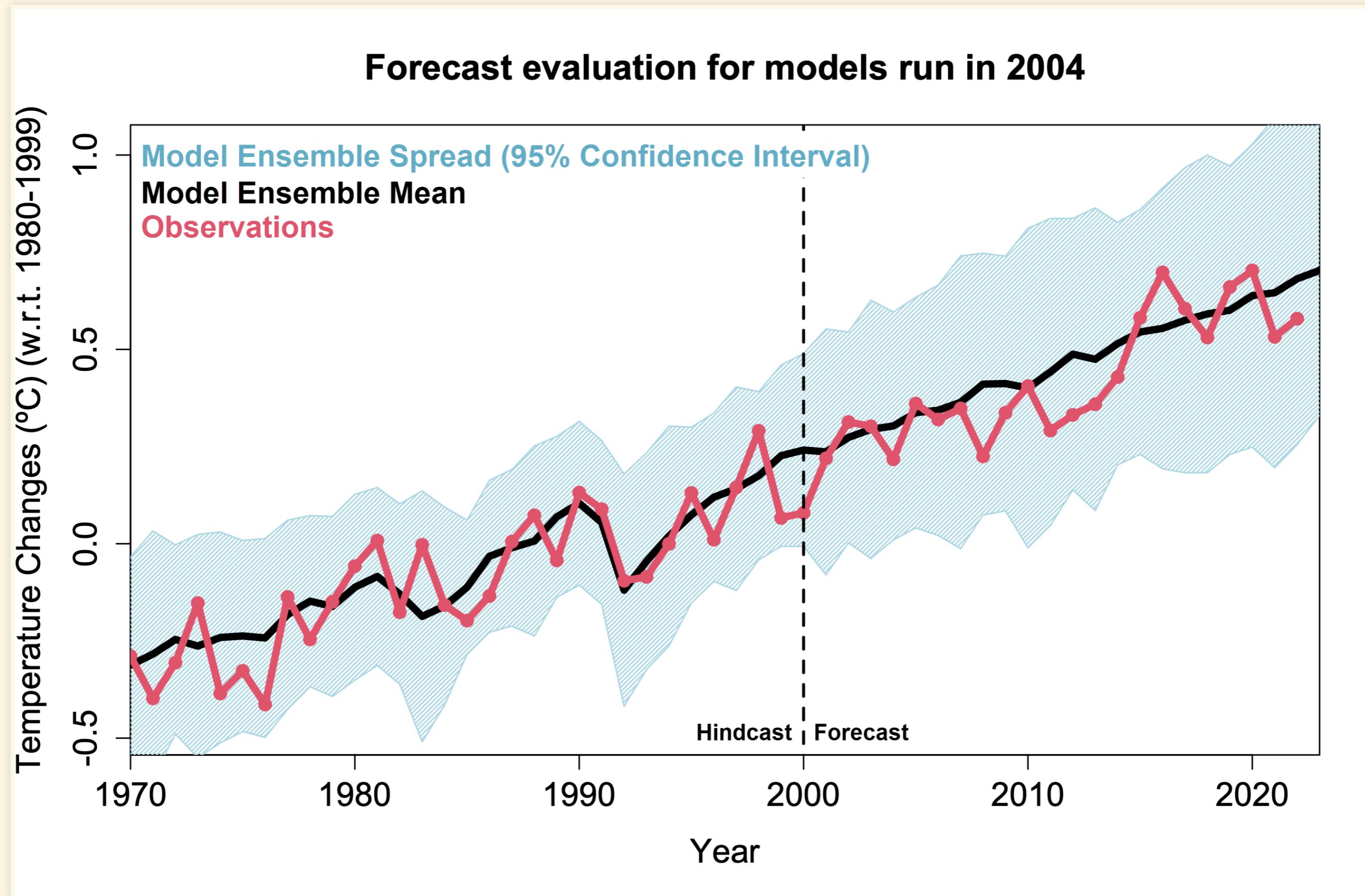
# Smoking Gun



# Smoking Gun in Detail



# Can We Trust Climate Models?



# 50 Years of Model Predictions

