Paleoclimatology- Window to the Future?

David J. Nicosia

Warning Coordination Meteorologist

NOAA-National Weather Service Binghamton NY

Objectives

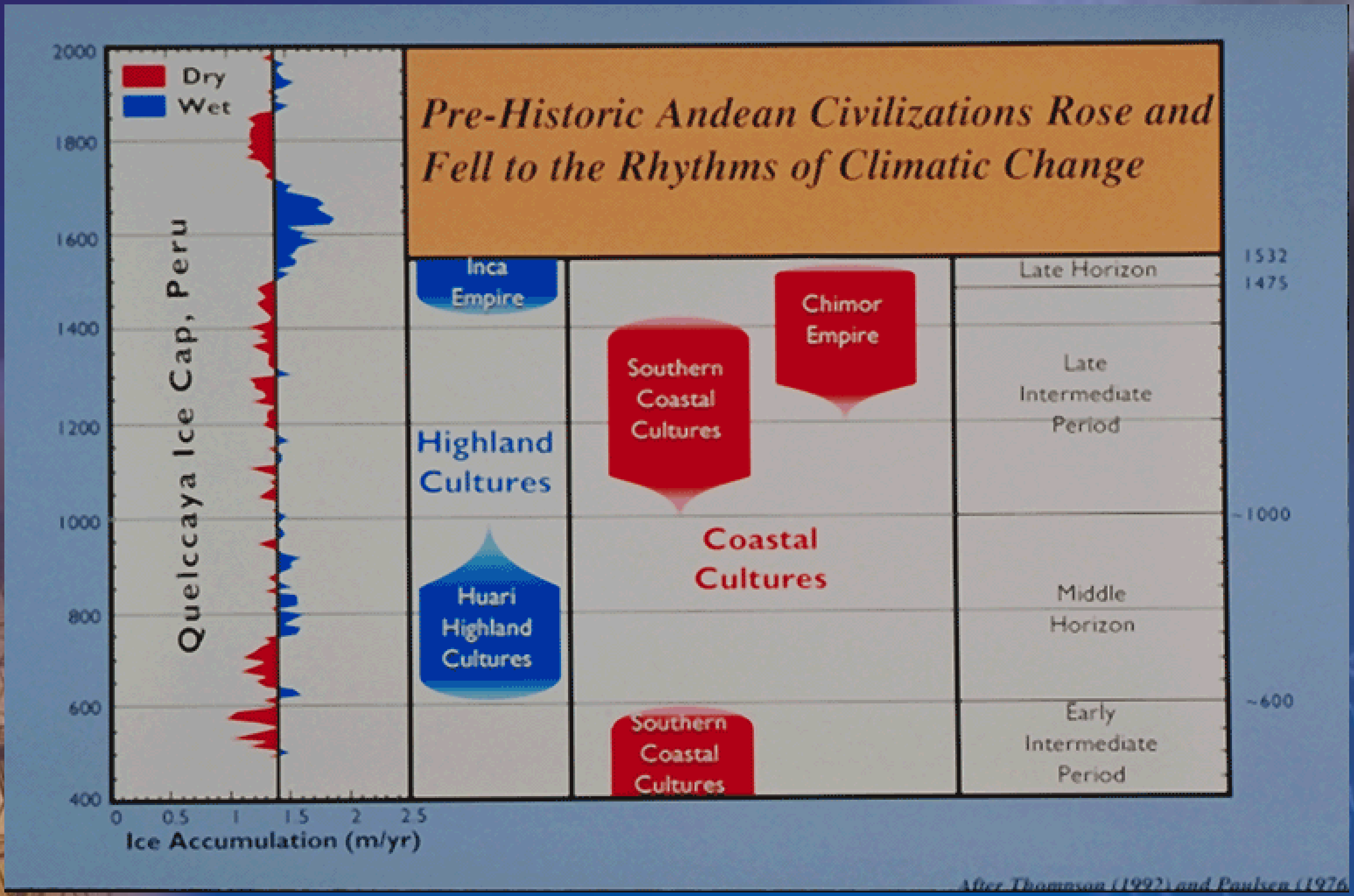
- **Participants will learn the following:**
  - ***Why Climate Change is important to humanity.***
  - ***Basic components of the Earth's Climate System and how they interact.***
    - **3 external forcing factors**
    - **3 internal feedback mechanisms**
  - ***Understand how paleo-climatic proxies are used to reconstruct climate.***
  - ***Changes in the Earth's Climate.***
    - **Climate change over millions of years.**
    - **Climate change over the past 100,000 years.**
    - **Causes of rapid climate change.**
  - ***Paleo-climatic applications to today's climate change problem.***

What is the Significance of Climate Change?

Source: NOAA

- Temperature increases will have significant impacts on human activities: where we can live, what food we can grow and how or where we can grow food, and where organisms can potentially live.
- To be prepared for the effects of these potential impacts we need to know how much the Earth is warming, for how long the Earth has been warming, and the cause of the warming.
- Answers to these questions provide us with a better basis for making decisions related to issues such as water resource management and agricultural planning.
- Let's look into the past to learn about possible future changes…
- Abrupt climate change? Is this possible??

Fall of Civilizations Tied to Climate Change

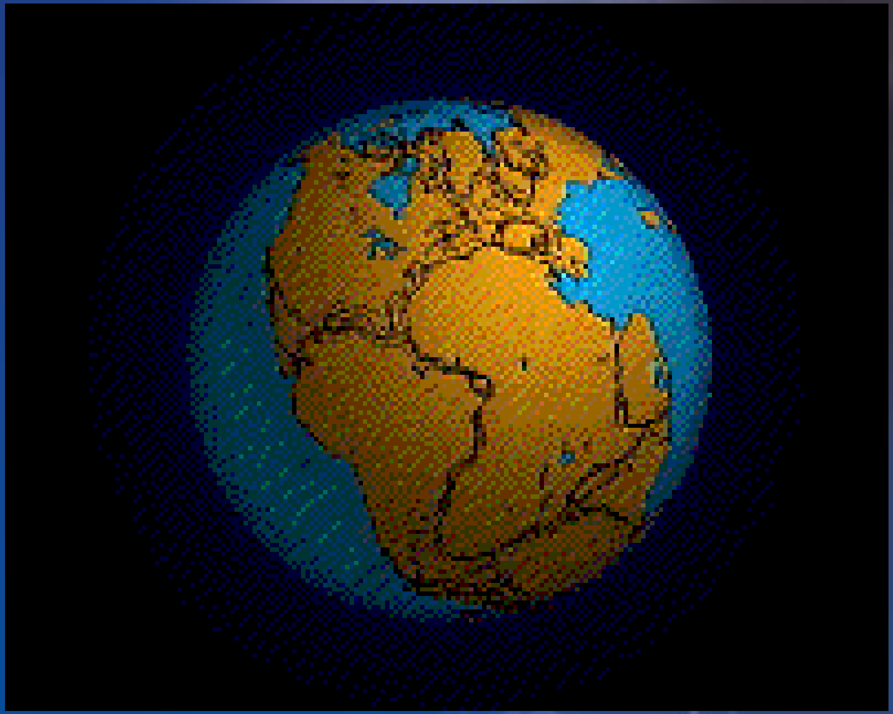


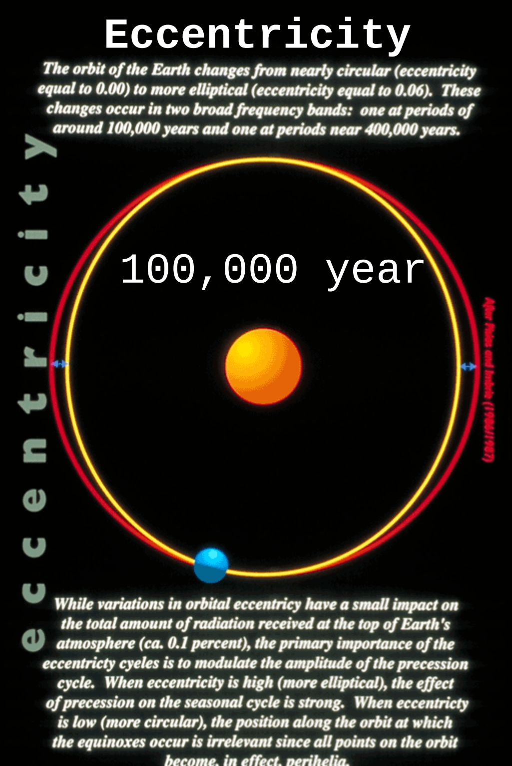
Earth's Climate is always changing!!

- **Climate change is normal and part of the Earth's natural variability.**
- **The geologic record includes tremendous evidence for large-scale climate changes.**
  - ***Warm conditions with lush vegetation, dinosaurs, and corals living at high latitudes during the mid Cretaceous (120-90 million years ago).***
  - ***Last 2.5 million years glacial cycles.***
  - ***"Recently" cold conditions during the last glacial maximum (20,000 years ago).***
  - ***More recently during the Little Ice Age (roughly 1450 - 1890 AD) historic and instrumental records, predominantly around the North Atlantic.***

Climate Forcings- Final Stages of Pangaea Breaking Up

- Affects how much land is at the high latitudes
- Determines whether ice sheets can form or not.

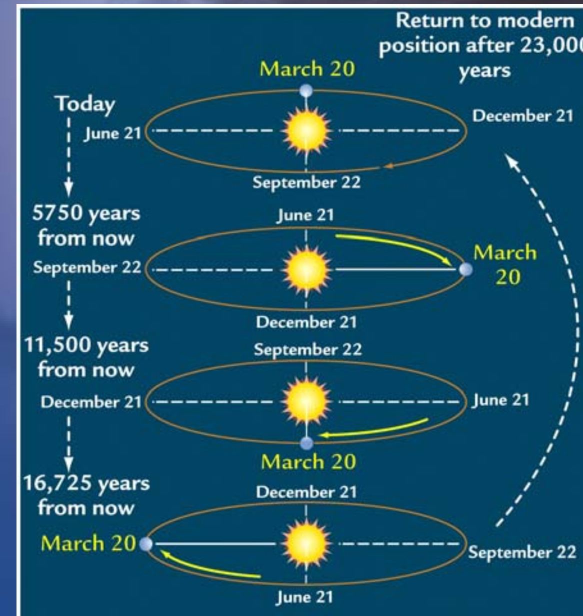




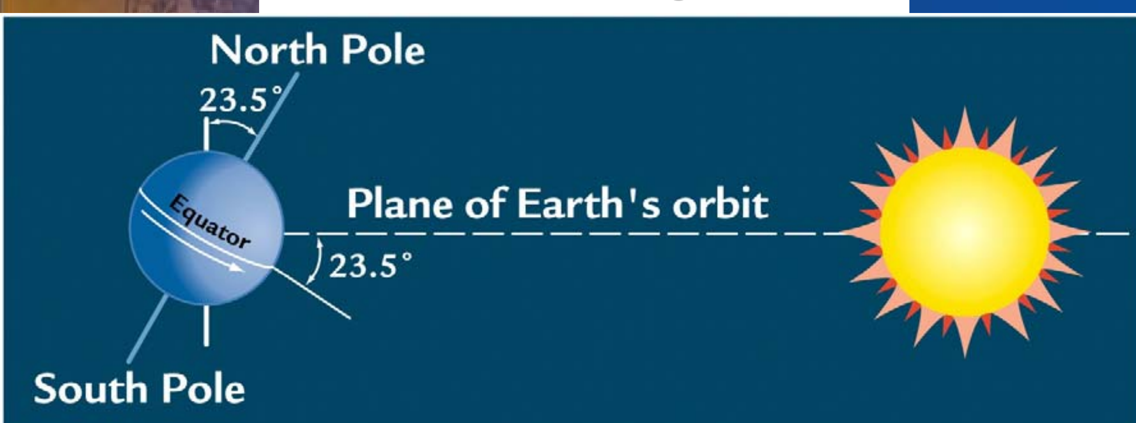
Orbital Forcing

- Eccentricity
  - *100,000 and 400,000 year periodicity*
- Precession of the equinoxes
  - *19,000 and 23,000 year periodicity*
- Obliquity
  - *41,000 year periodicity*

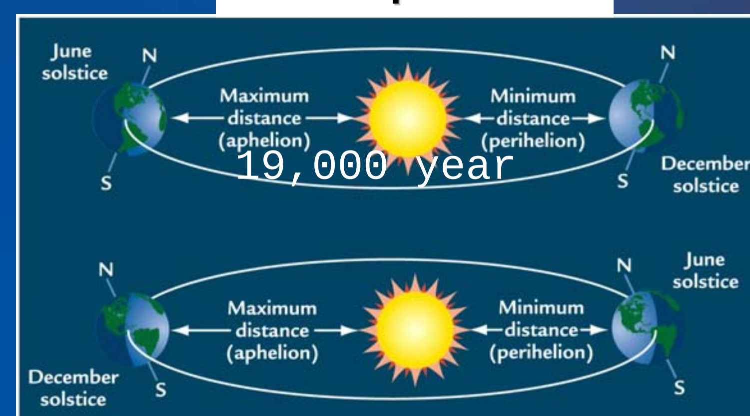
Precession of the equinoxes



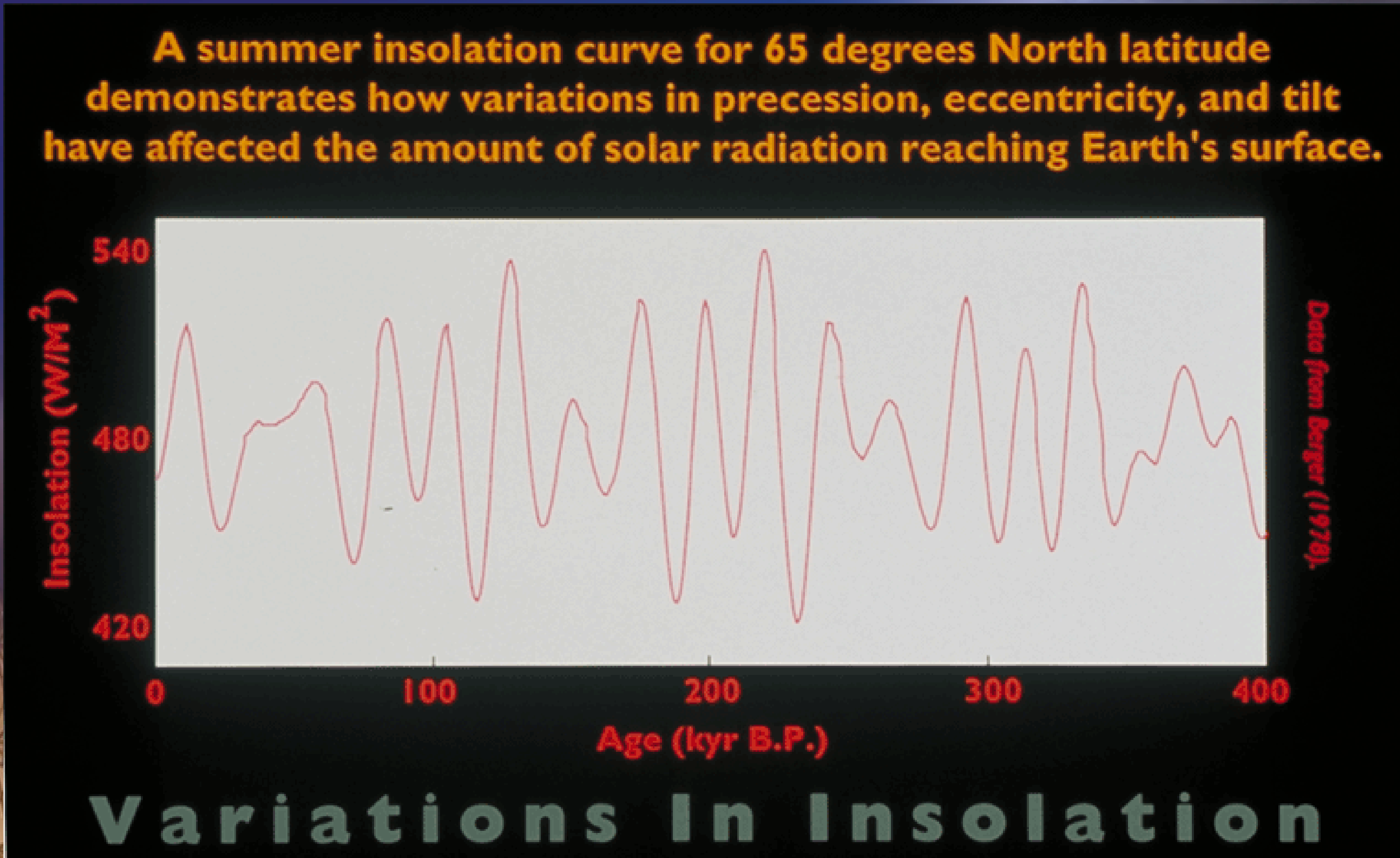
Obliquity
22.2 to 24.5 degrees



Precession of the equinoxes



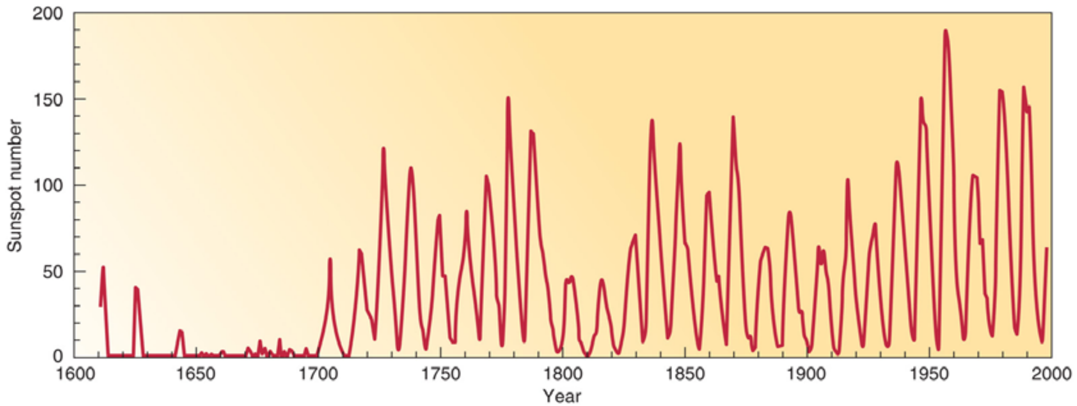
Variations in Insolation at 65 N



Solar Forcing

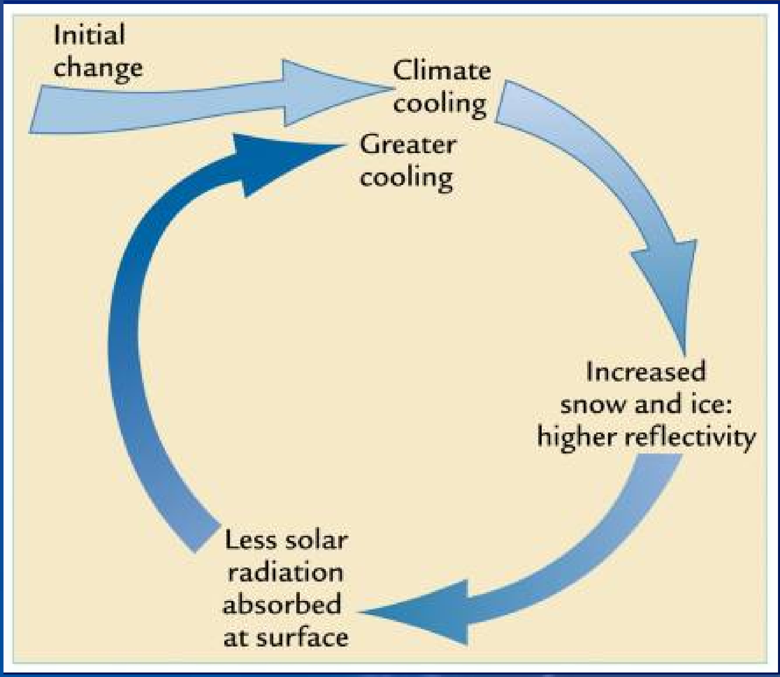
- *Driven by internal dynamics of Sun*
  - Controls: total insolation
- *Leads to millennial variations in climate change*
- *Medieval warm period, little ice age and to some extent modern warm period.*

(a)

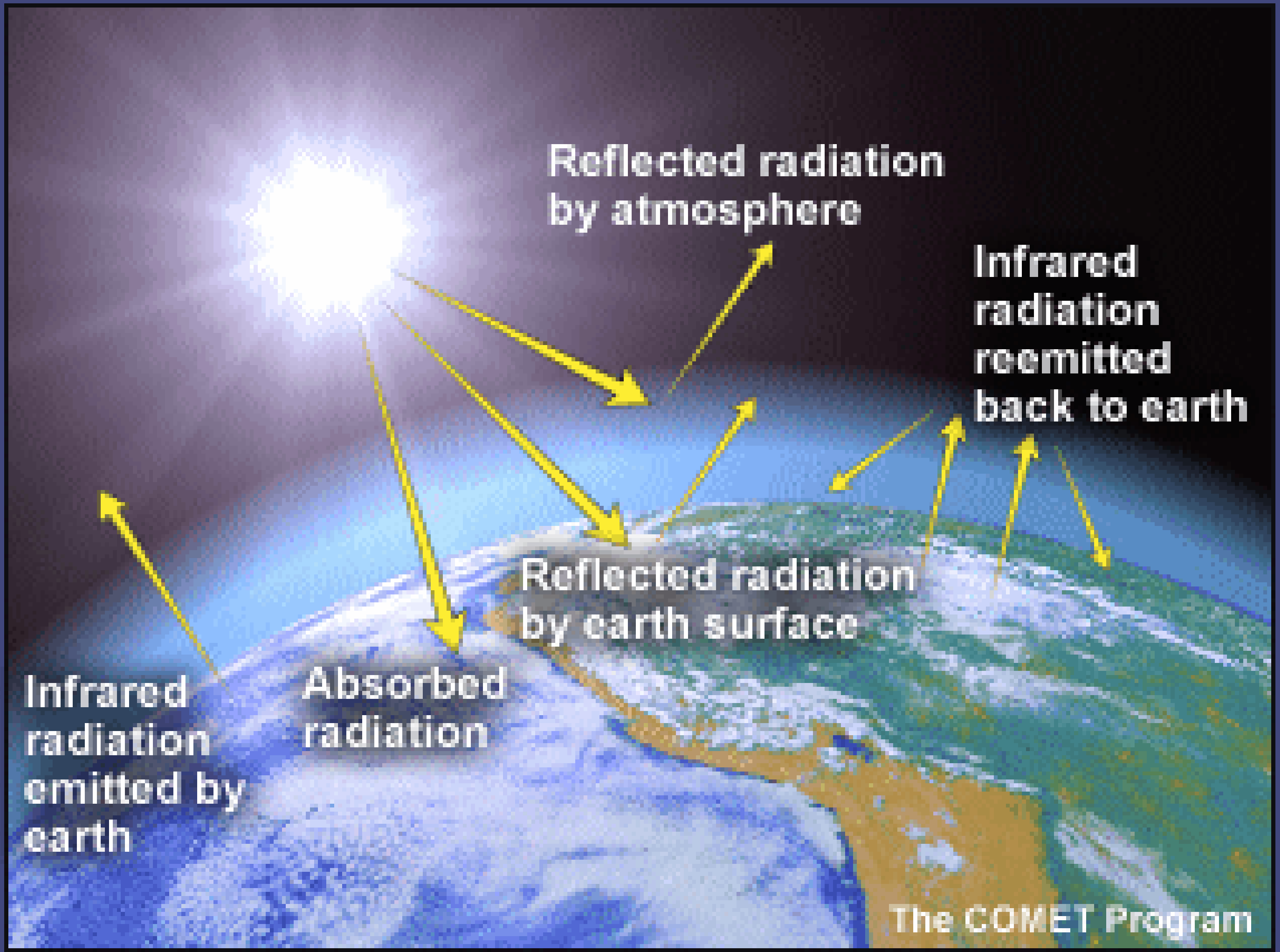


Internal feedback Mechanisms: "Ice-Albedo" Effect

- Insolation received at 65 degree N latitude during the summer.
- Critical to whether snow melts from one winter season to the next in Northern North America and Eurasia.
- If the snow does not melt from one winter to the next, ice sheets begin to form.
- Ice albedo feedback kicks in.

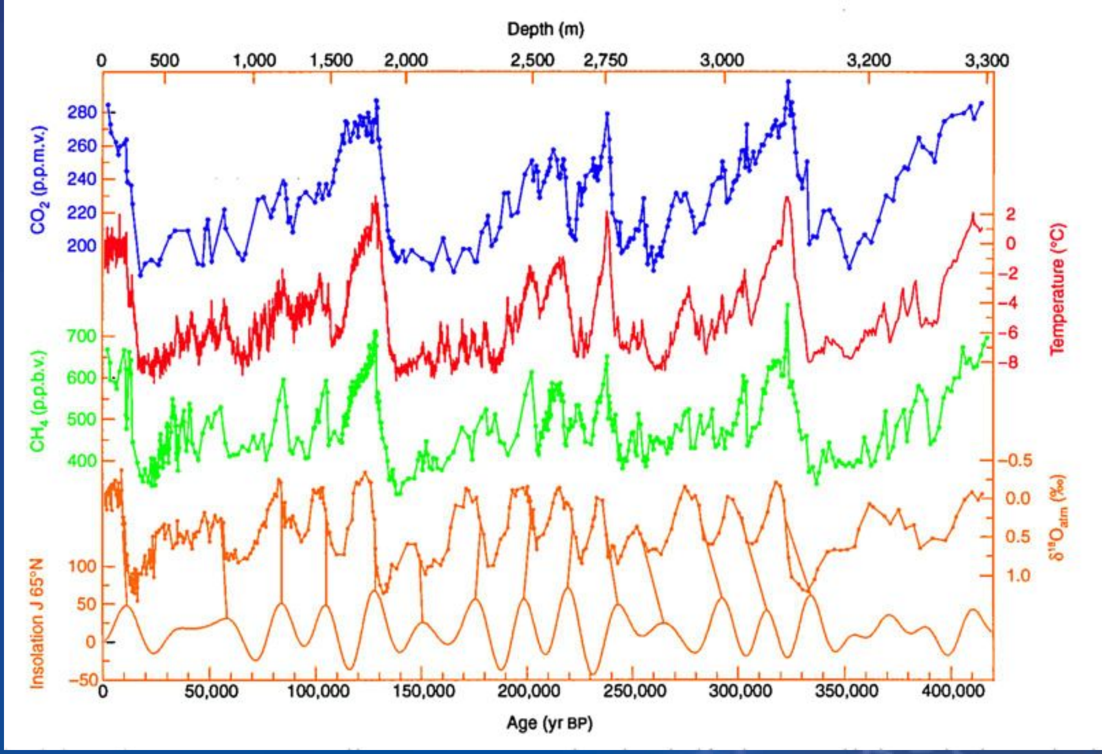


“Greenhouse” Effect



Greenhouse gas Variations

- Interglacial Periods
  - *Less land exposed - sea levels higher (carbon sink)*
  - *Warmer ocean temperatures*
    - less soluble to gases
  - *Greenhouse gases increases*
- Glacial periods
  - *more land exposed - sea levels lower (carbon sink)*
  - *colder ocean temperatures*
    - more soluble to gases
  - *Greenhouse gases decline*

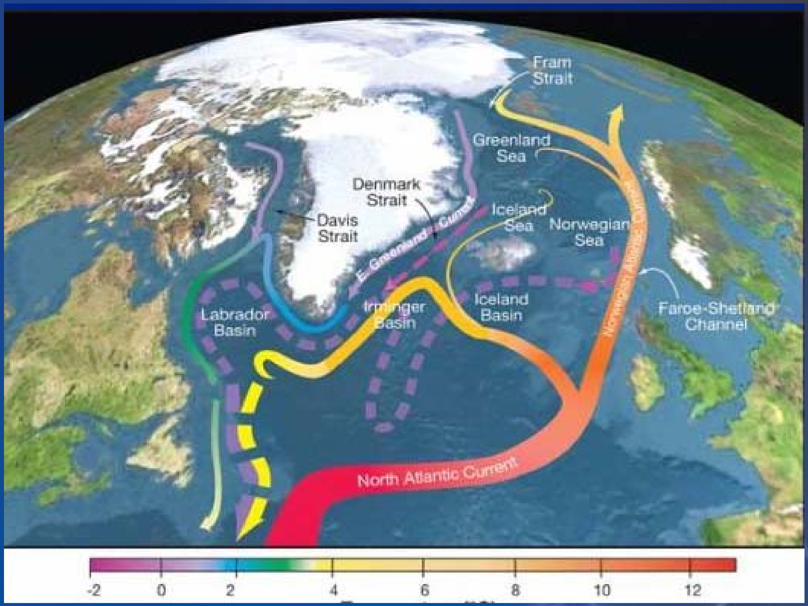


CO_2 to Water Vapor Feedback

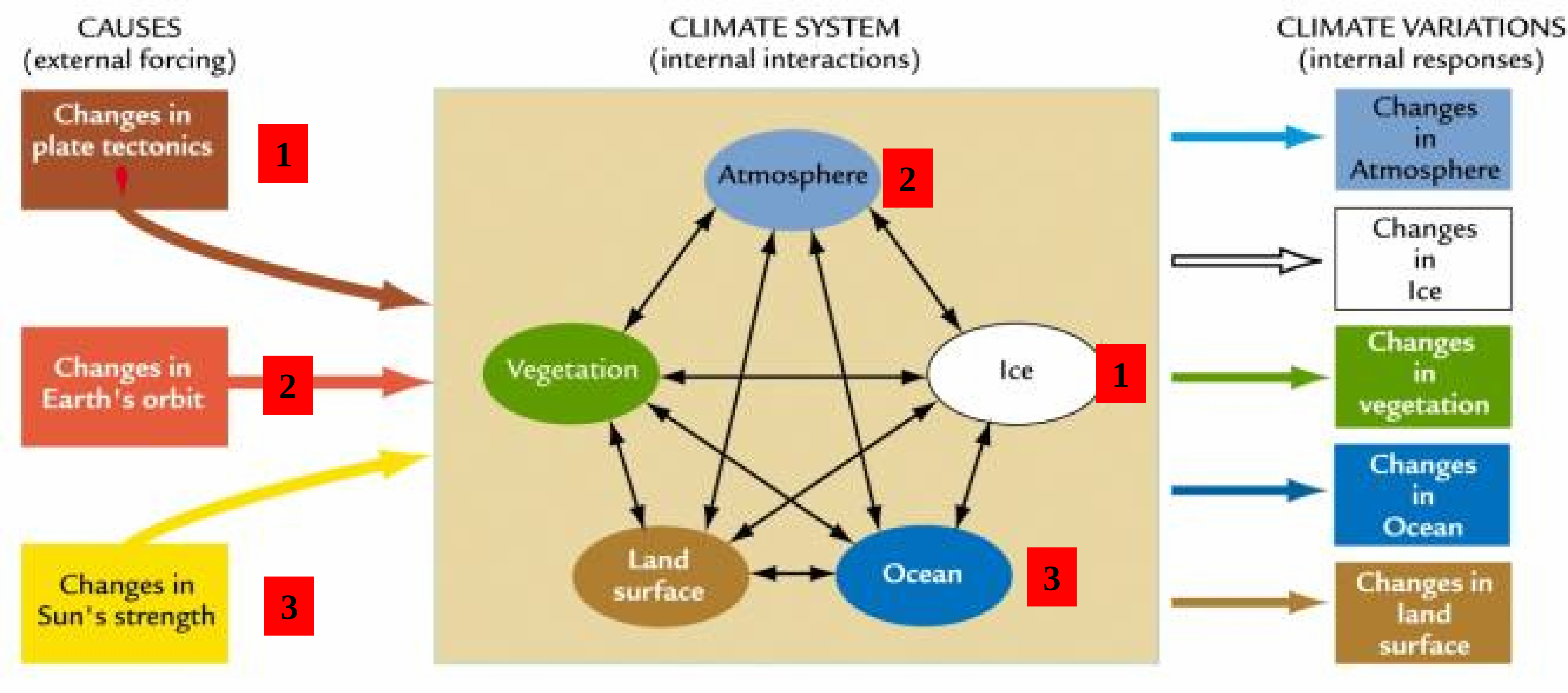
- **Changes in atmospheric CO_2 concentration amplify existing climate trends through the water vapor feedback.**
  - ***Warmer (colder) temperatures lead to more (less) water vapor through evaporation.***
  - ***Amplify the climate signal from the changing greenhouse effect***
  - ***Extent CO_2 to H_20 water vapor feedback not known***
  - ***Role of cloud cover not known.***

Variations in the Thermohaline Circulation

- Warmer waters in North Atlantic Ocean brings more precipitation, clouds and higher temperatures to the northern hemisphere
- More snow can lead to ice albedo feedback which can initiate glaciations.
- Anti-phase temperatures with southern hemisphere.
  - *Antarctica is colder when NH is warm and vice-versa*
  - *Heat is transported farther north and away from Antarctica which is thermally "isolated" by the great southern oceanic current.*



Climate System Fundamentals



- Discussed the above 3 internal feedbacks/oscillations
- Important to remember there are more and different combination of feedbacks/interactions between all of them.

Paleo-climatology

- *Paleoclimatology is the study of past climate, for times prior to instrumental weather measurements.*
- *Paleoclimatologists use clues from natural "proxy" sources such as tree rings, ice cores, corals, and ocean and lake sediments to understand natural climate variability.*
- *Studying past climate change reveals the complexities of the earth's climate system.*
- *Understanding the past is key for the future.*
- *"The farther backward you can look,*
  the farther forward you are likely to see."
  - Winston Churchill

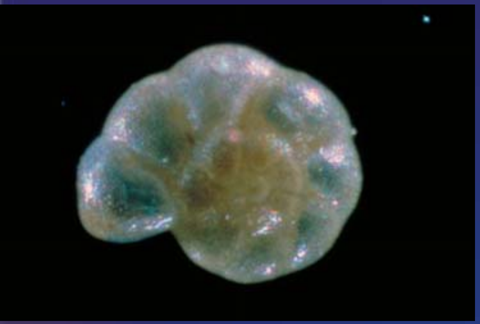
What is a Climate Proxy?

- Climate 'proxies' are sources of climate information from natural archives which can be used to estimate climate conditions.
  - *Marine cores*
    - Isotopes, foraminifera
  - *Ice cores*
    - Ancient atmospheric composition, isotopes, dust etc.
  - *Lake and bog sediments*
    - tree pollen
  - *Tree rings*
  - *Human archives such as historical records or diaries*

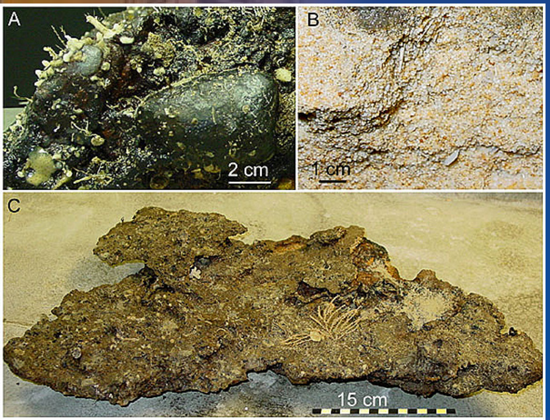
How do we reconstruct climate back millions of years?

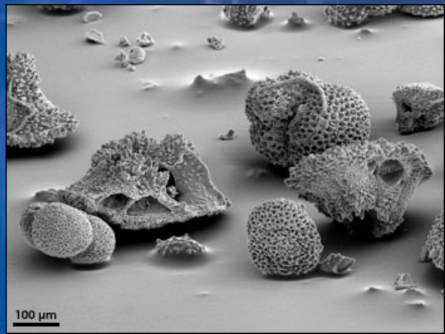
- Marine Cores
  - *Advantage: Can go back millions of years*
  - *Disadvantages: poor resolution*
    - Foraminifera
    - Delta O^{18}
    - Ice rafted debris

Foraminifera- Marine Cores



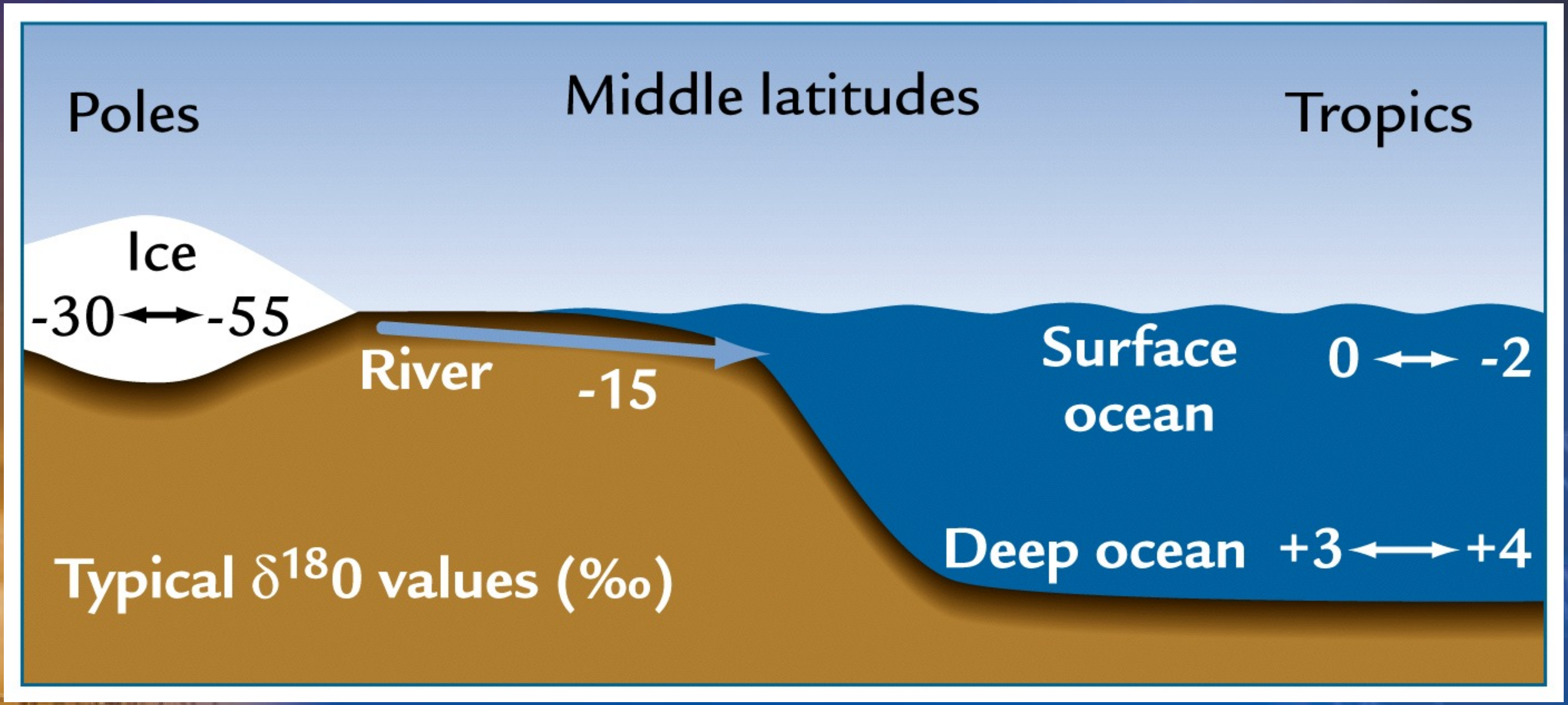
- Fossilized remains examined in marine cores
- Shells extract Oxygen (O) from ocean waters
  - ✓ Benthic- bottom dwelling forams
  - ✓ Planktoonic- surface dwelling forams
- Temperature sensitive species
- Ratio of O^{18} to O^{16} in the shells changes based on temperature of the ocean water
- **Ratio of O^{18} to O^{16}** changes due to the global volume of ice
- Compare O isotope ratio from shells (proxy) to ratio in today’s forams (standard)

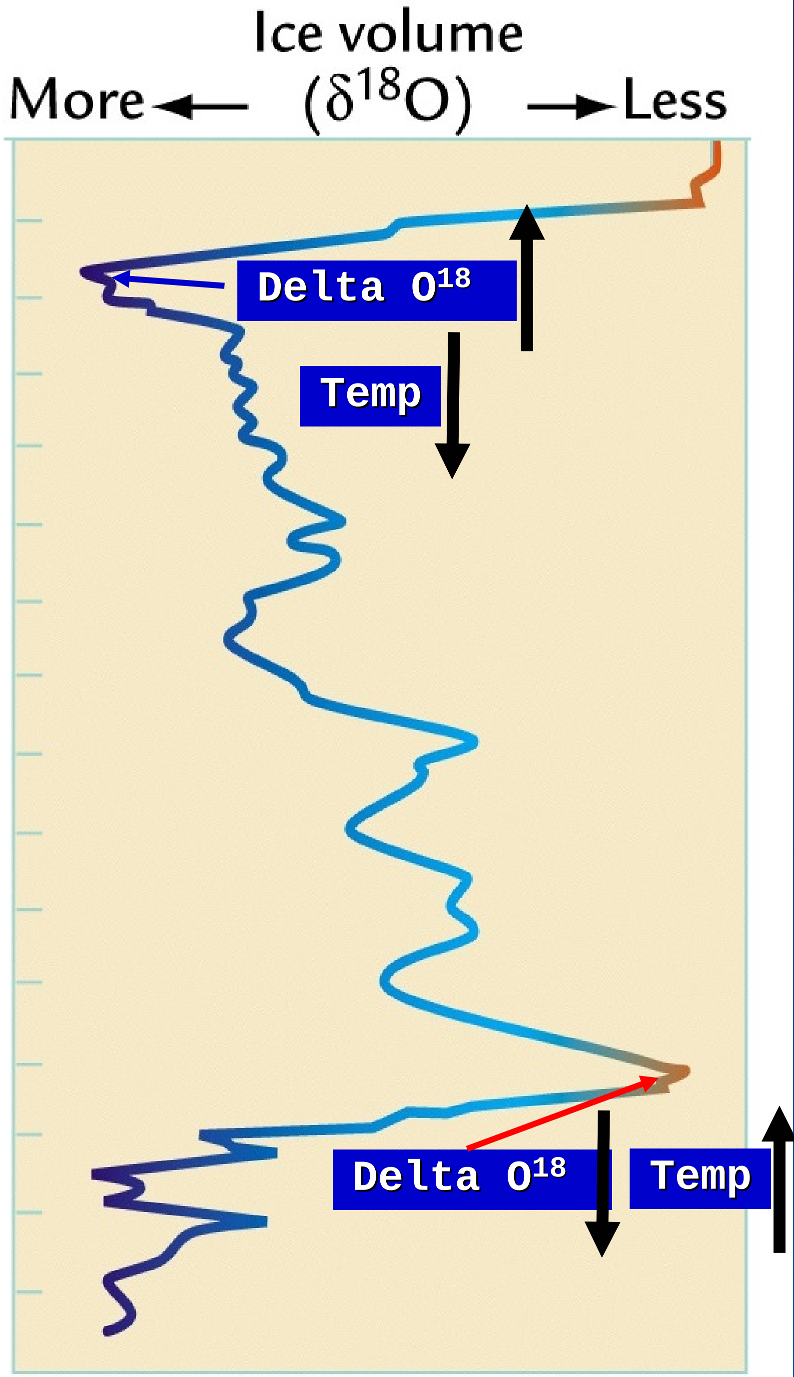




Delta O^{18}

- Delta $O^{18} = \{ (O^{18} / O^{16})_{sample} - (O^{18} / O^{16})_{SMOW} \} / (O^{18} / O^{16})_{SMOW}$
- SMOW = Standard Mean Ocean Water which has the delta O^{18} value of zero.

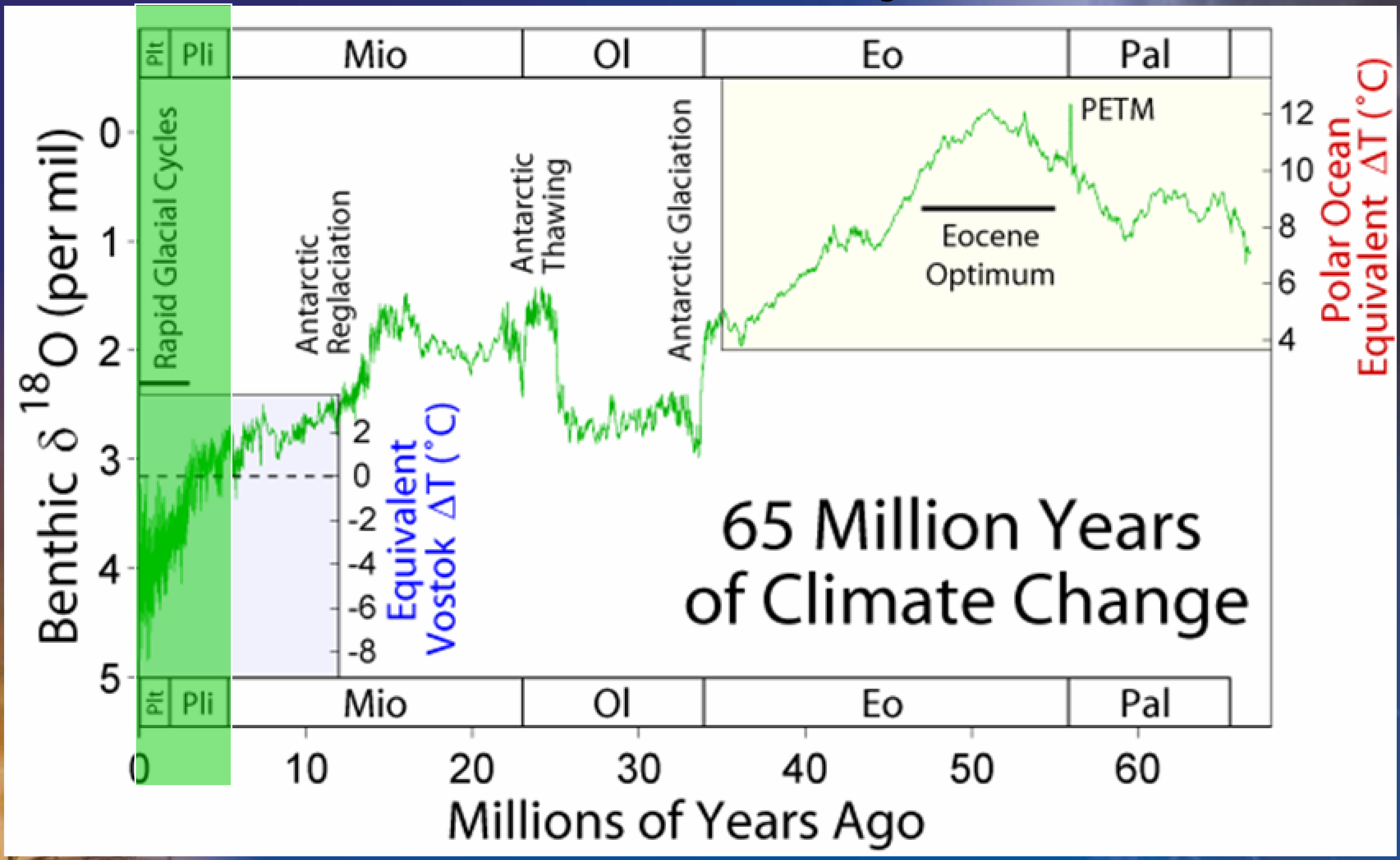




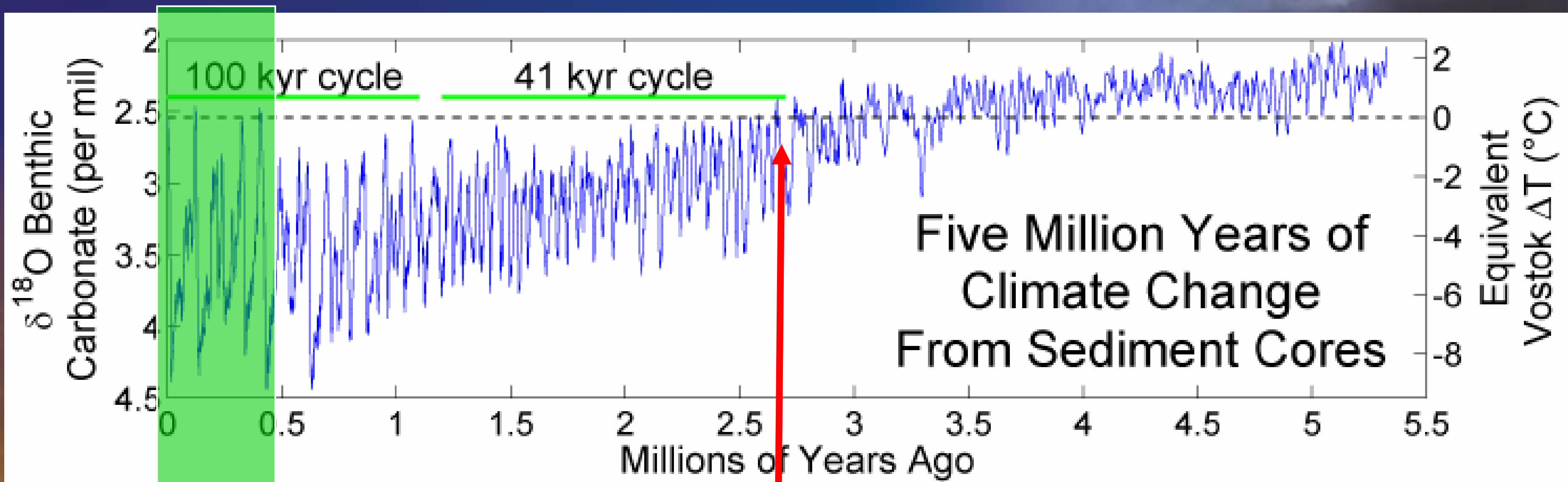
Marine Cores Delta O^{18}

- O^{16} changes phase preferentially versus O^{18}
- Evaporates and condenses more so than O^{18}
- Precipitation has more O^{16}
- When a large percentage of water is locked up in ice sheets, the oceans are depleted in O^{16}
- Temperature signal + volume of ice sheets signal in marine cores.
  - *Warmer ocean more O^{18} changes phase, less O^{18} in ocean.*
- Delta O^{18} decreases when there are large ice sheets
- Delta O^{18} inversely proportional to ice sheet volume and global temperatures

Climate Change- Cenozoic Cooling
Last 60 million years



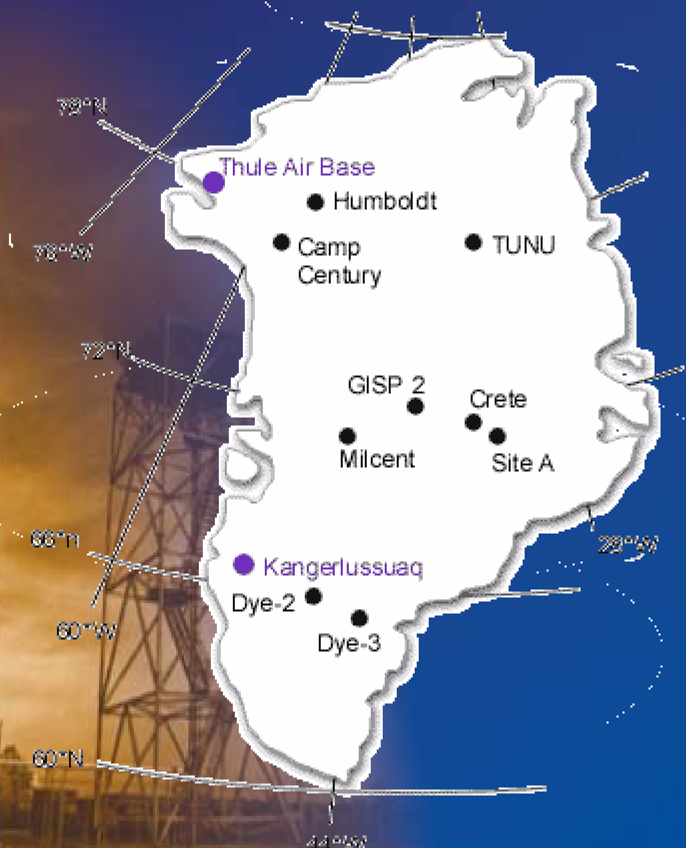
Climate Change

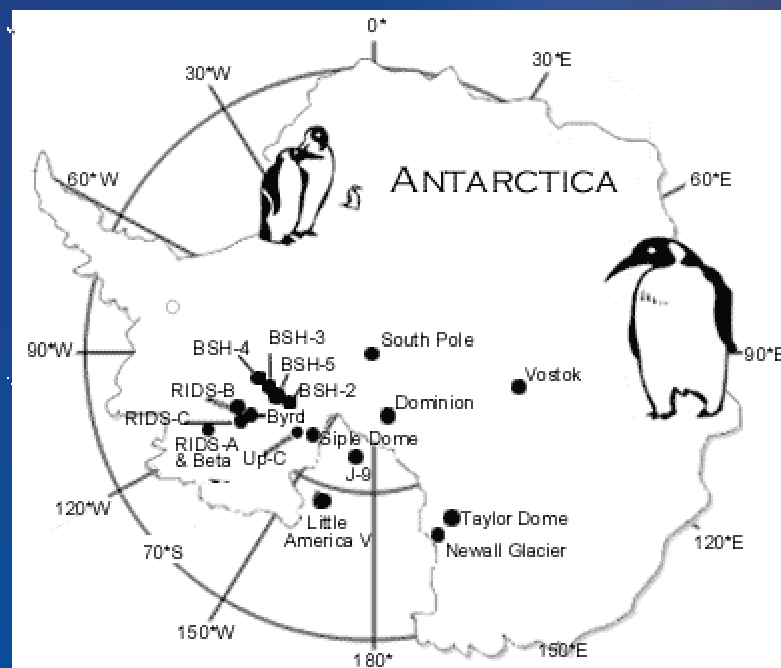


Widespread Northern Hemisphere Glaciations Begin

Ice cores

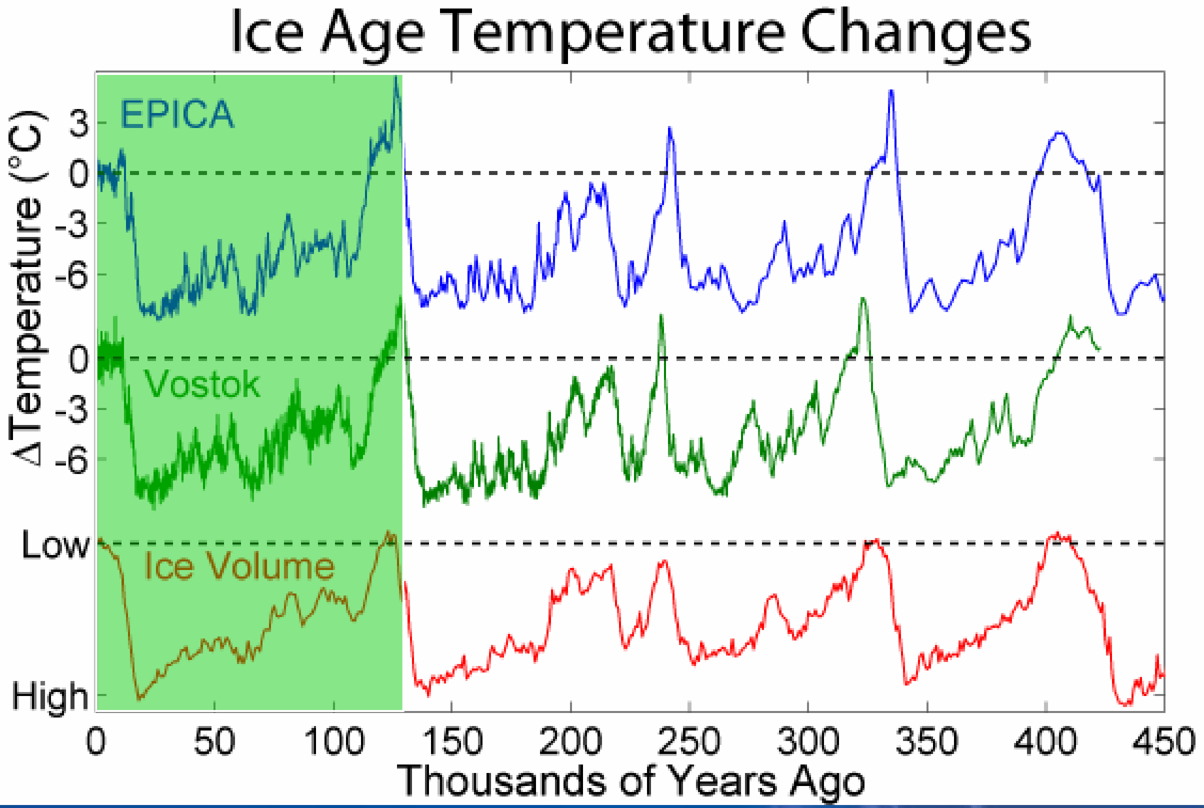
- Ice accumulation rates
- Annual layers
- Delta O^{18} from ice cores
- Atmospheric composition
- Electrical Conductivity Measure (ECM)



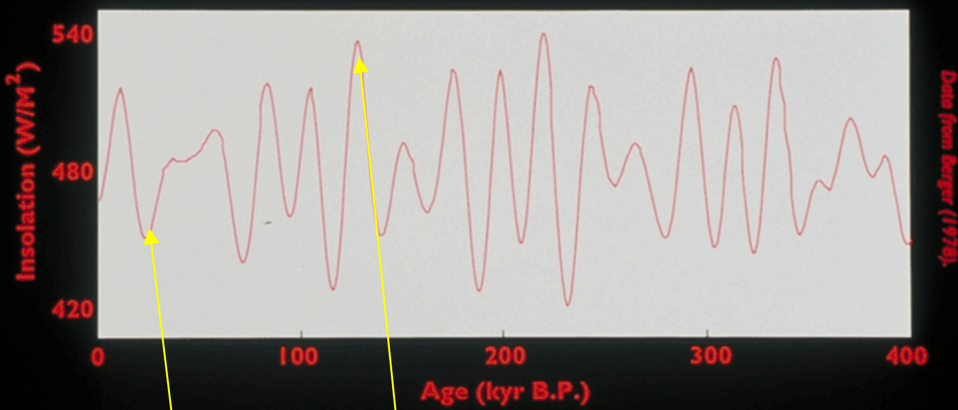


Delta O^{18} in Ice Cores

- Opposite of Marine Cores
- Proportional to temperature
- Warmer temperatures more O^{18} changes phase relative to colder temperatures.
- Ends up in ice sheet as heavier oxygen isotope ratio.

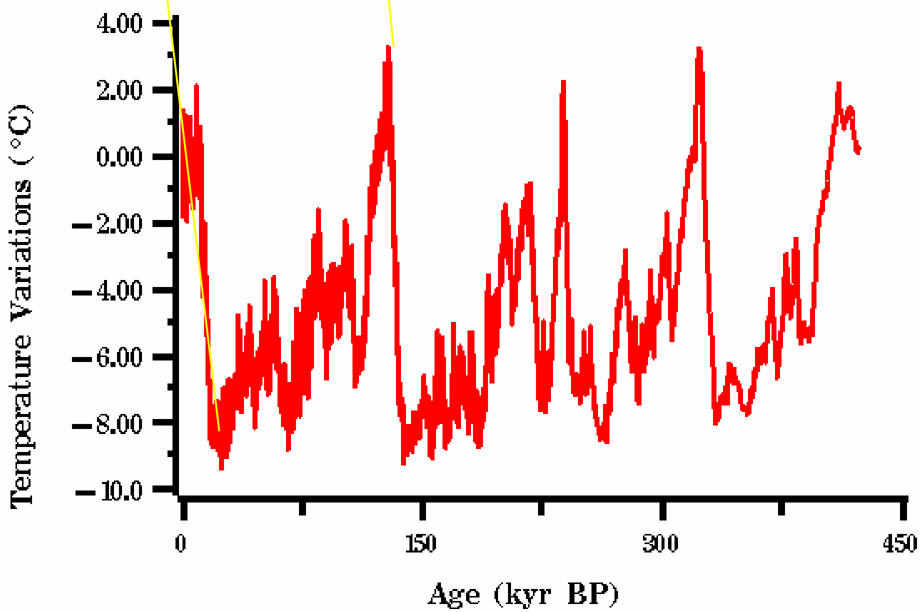


A summer insolation curve for 65 degrees North latitude demonstrates how variations in precession, eccentricity, and tilt have affected the amount of solar radiation reaching Earth's surface.



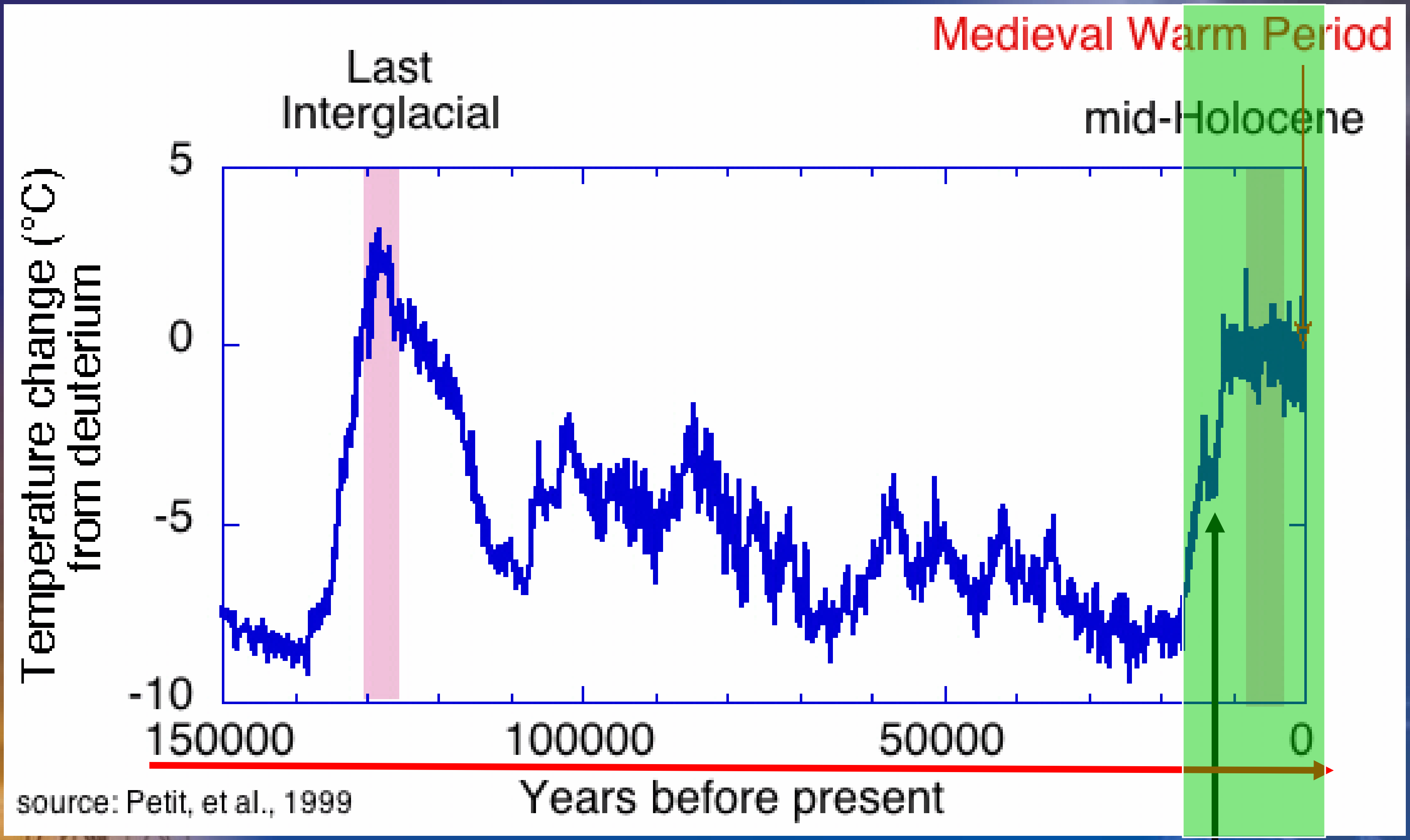
Variations In Insolation

Historical Isotopic Temperature Record from the Vostok Ice Core

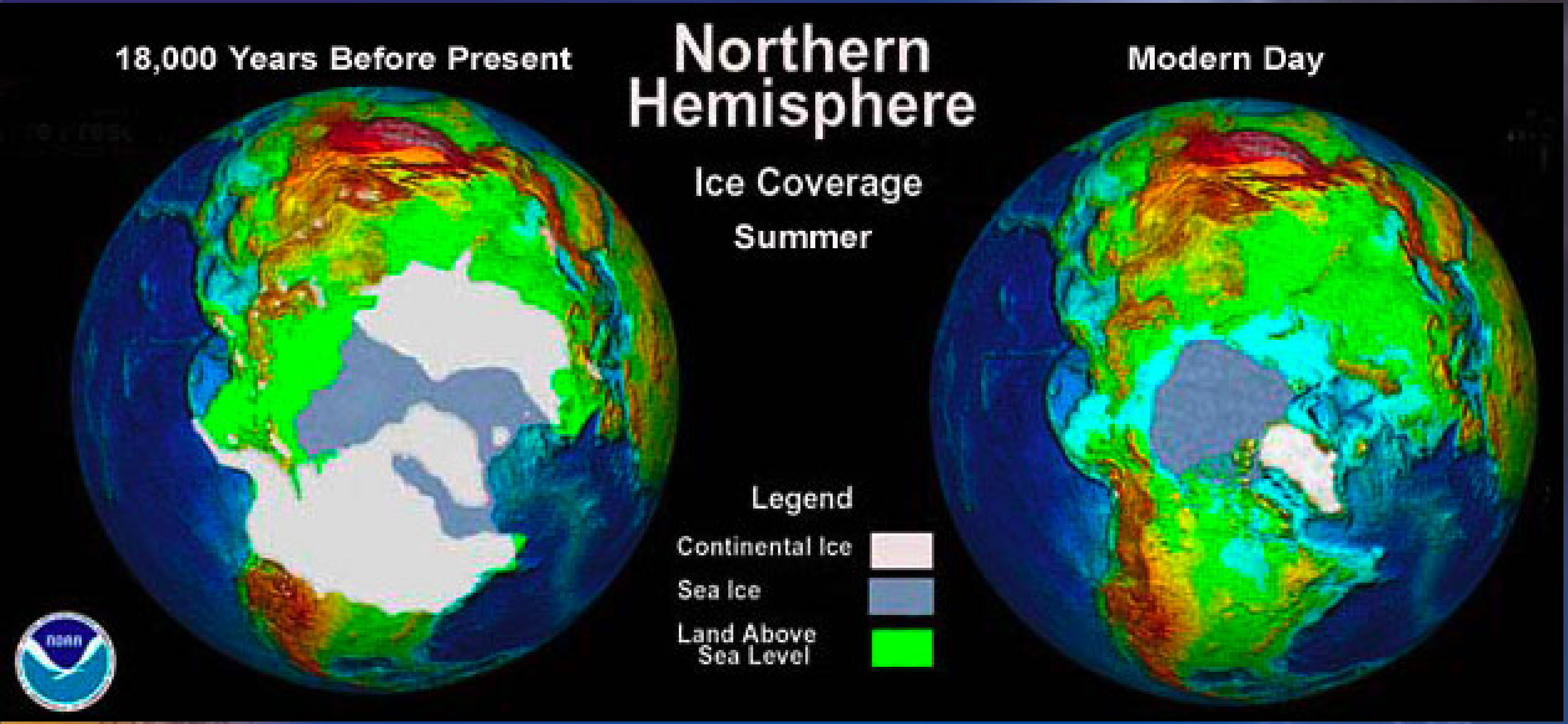


Variation with time of the Vostok isotope temperature record as a difference from the modern surface temperature value of −55.5 °C.

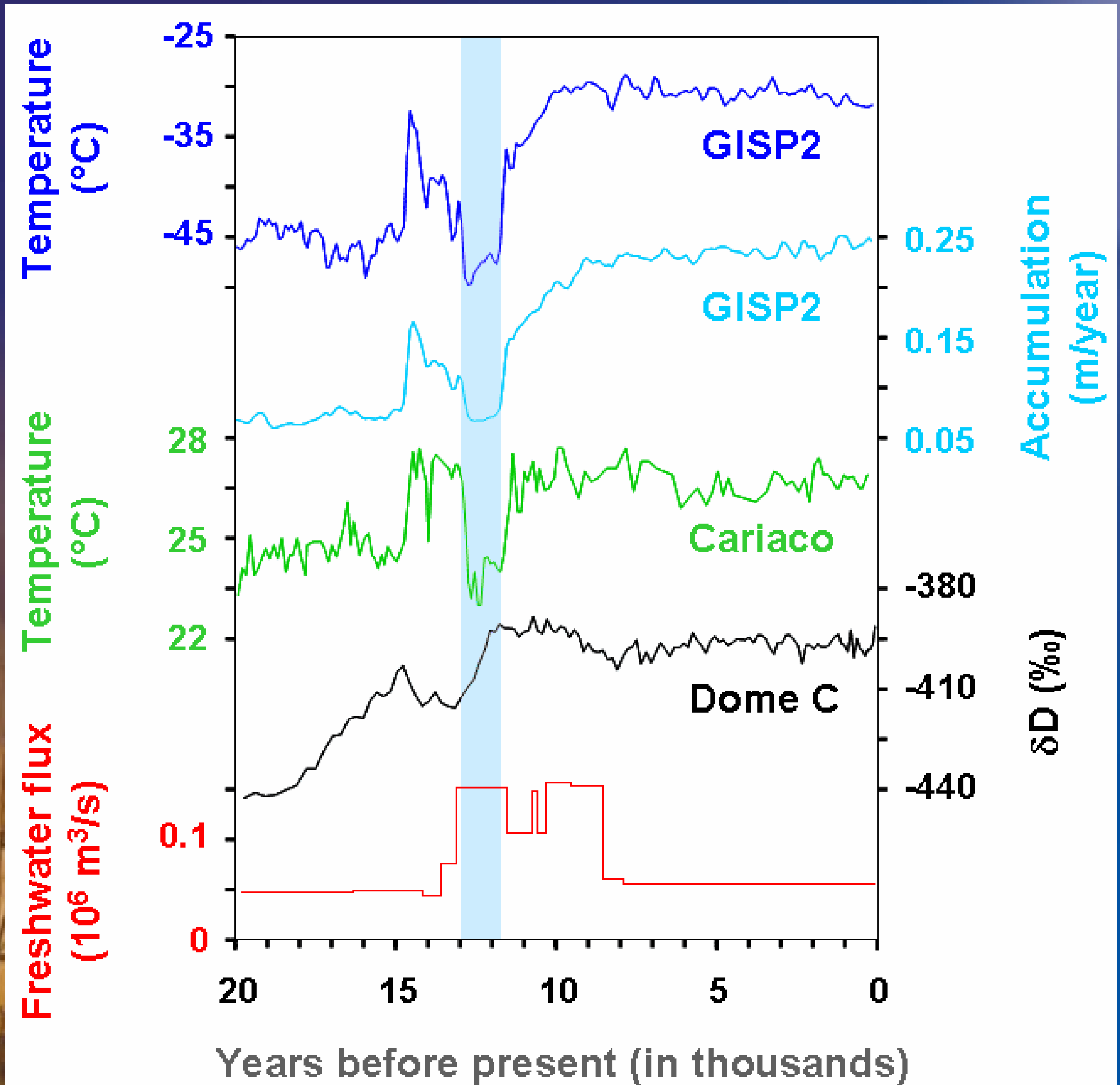
Source: Petit et al.



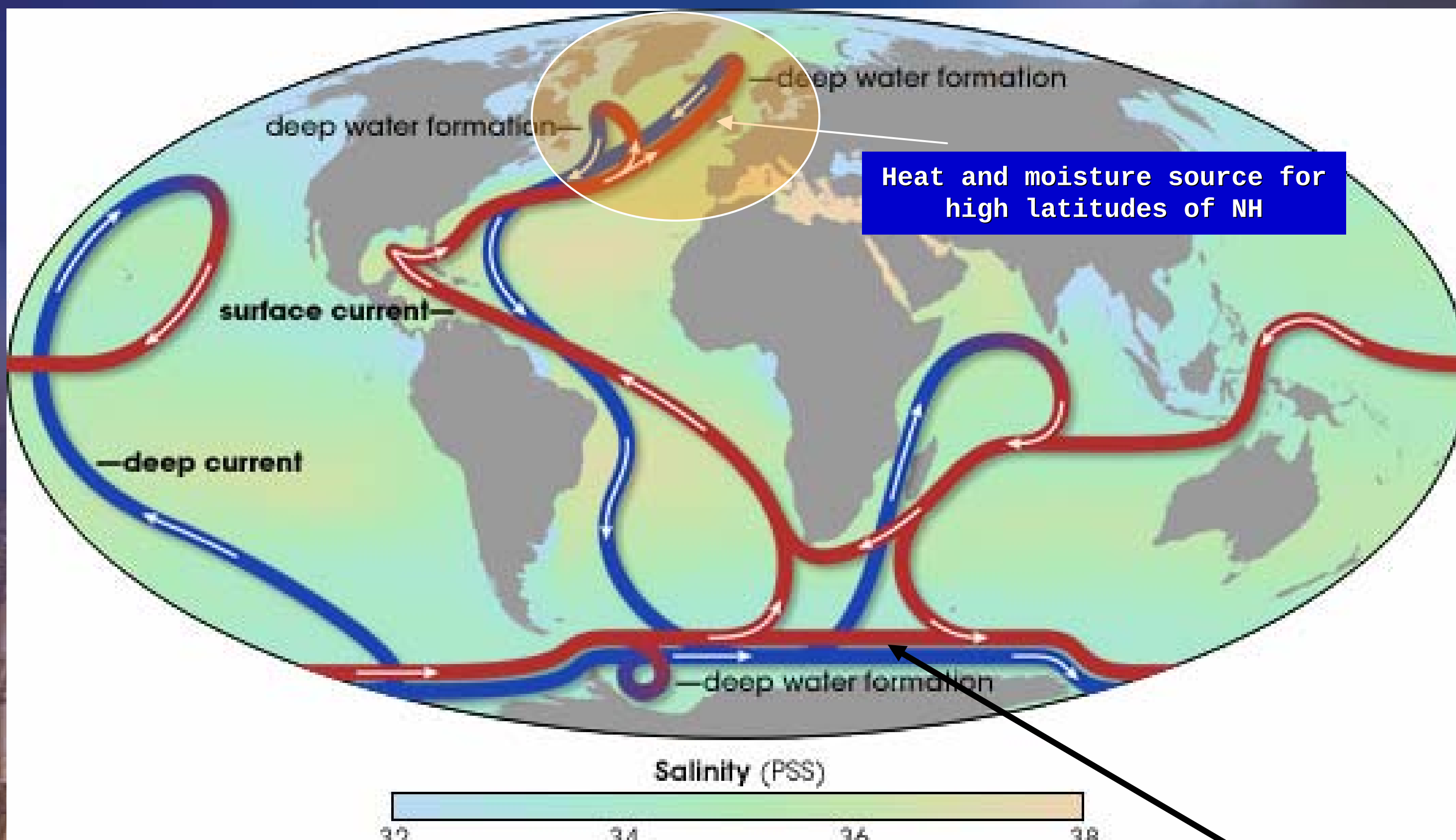
11,000 years ago


18,000 Years Before Present
Northern Hemisphere
Modern Day
Ice Coverage
Summer
Legend
Continental Ice
Sea Ice
Land Above Sea Level

Deglaciation- Turbulent Climate



Abrupt Climate Change: Variations in the Thermohaline Circulation



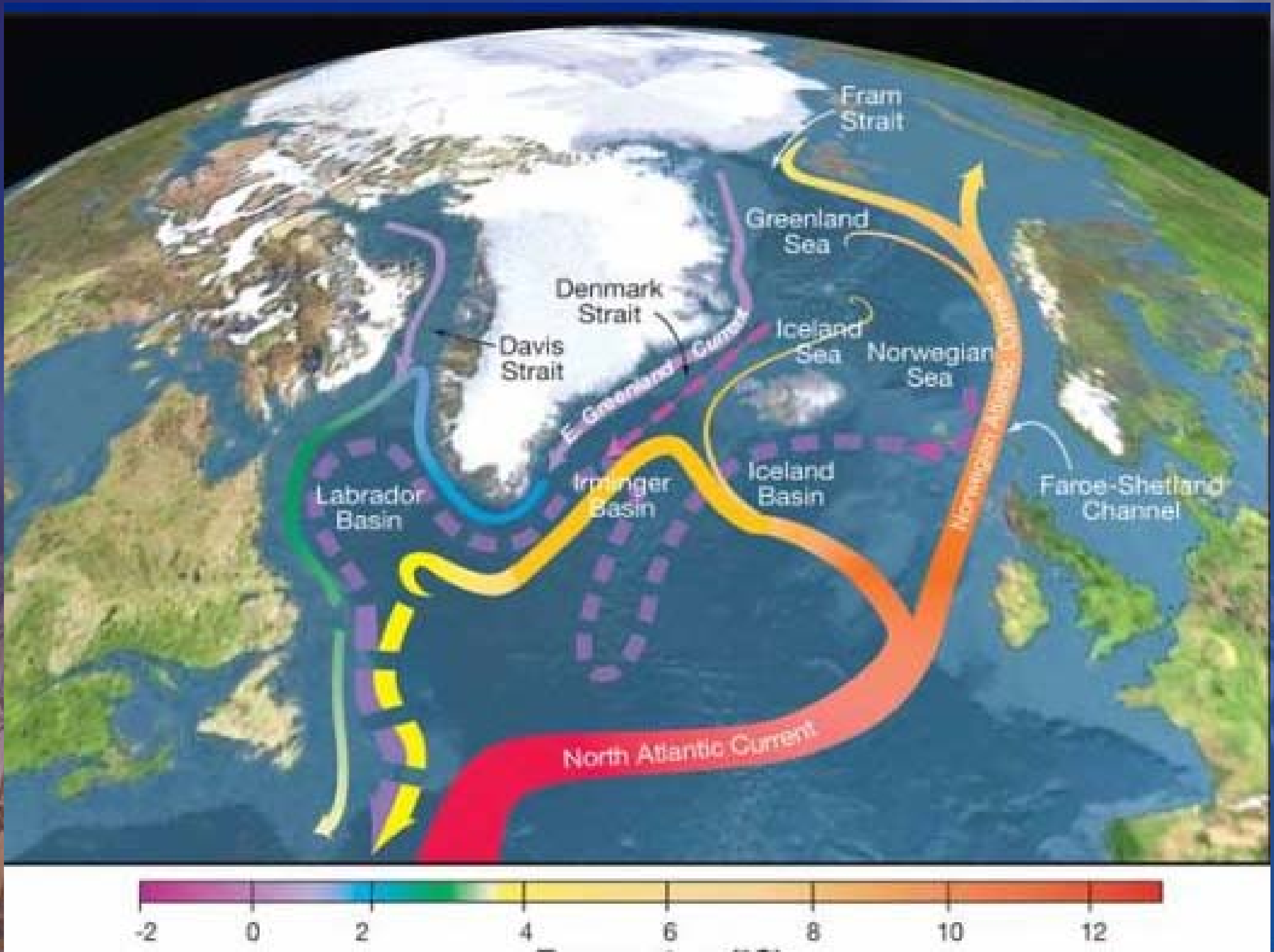
Heat and moisture source for high latitudes of NH

Thermally "Isolated"

North Atlantic Deep Water Circulation: Salt Oscillator

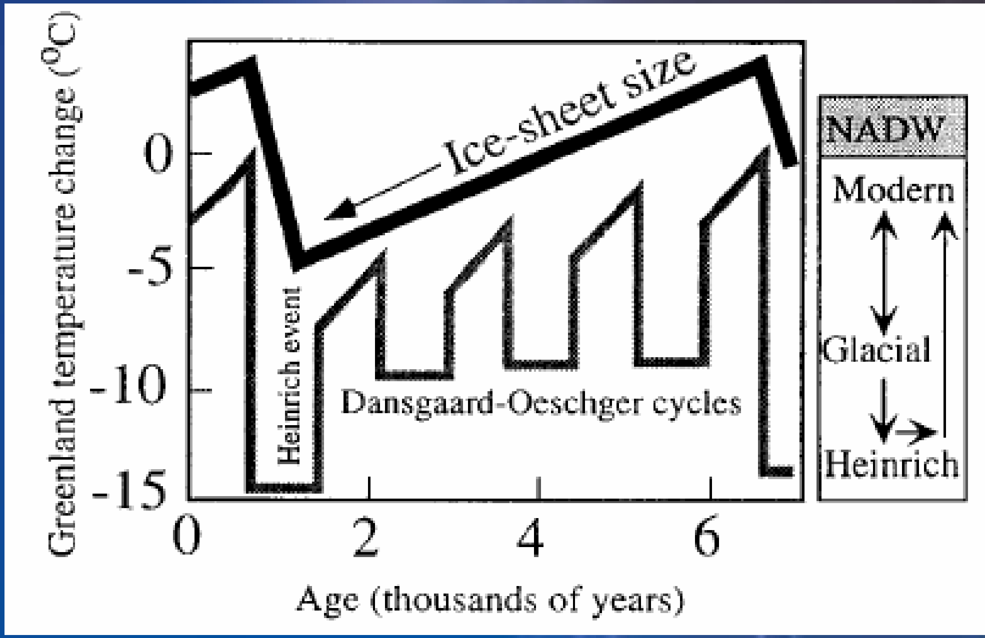
- Increase in salty water, more sinking, more compensation southerly current to complete circuit. More heat transported north. More evaporation from ocean current, increase in salt.
- Eventually warming leads to more melting of glaciers and snows, more fresh water precipitation which in turn lowers salinity.
- Freshening of currents slows the deep water sinking, slows the southerly north Atlantic current, slows transport of heat and moisture north.
- Cooling and drying takes place at high latitudes of NH. Eventually fresh water input declines, and salt gradually builds up in the north Atlantic current and salt water increases again

Variations in the North Atlantic Deep Water Current: Key to Global temperatures



D-O Cycles

- Roughly every 1500 years.
- Caused by variations in solar forcing?
- Cycle of warmer and colder temperatures in NH.
- Related to fluctuations in the thermohaline circulation.
- Extent and magnitude of D-O cycle is related to how much ice is covering the NH landscape.
- The more ice, the higher amplitude of the freshening and the larger climatic response.
- As the ice sheets build, a threshold is crossed and the entire current shuts down.
  - *Heinrich event*



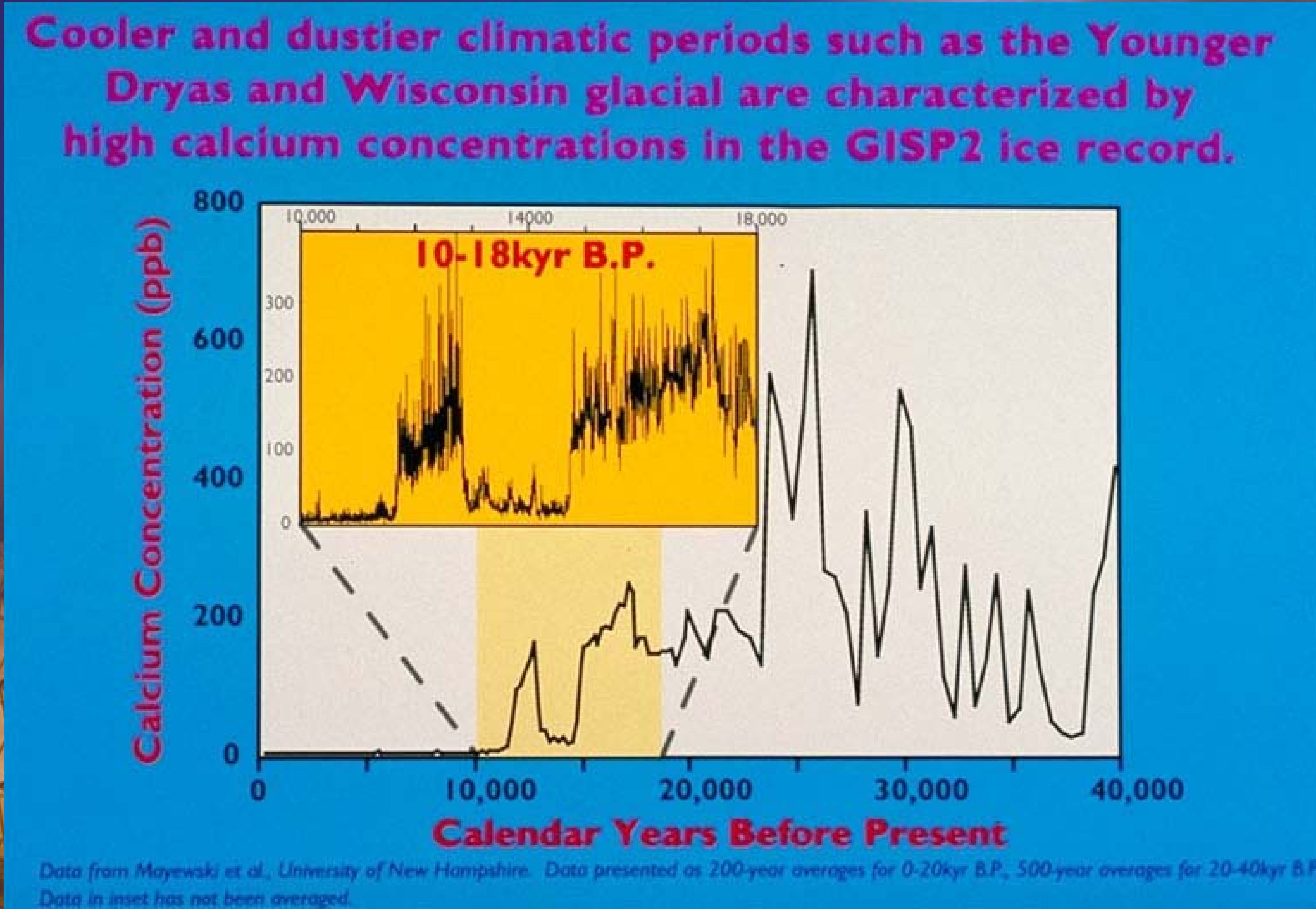
Heinrich Events

- Heinrich event, entire North Atlantic Deep Water current including Gulf Stream shut downs completely.
- Rapid climate change.
- Major cooling ~ 10 degrees C!
- When current switching back on massive warming by 10 C!
- Proxy records suggest this happens over a few years!!

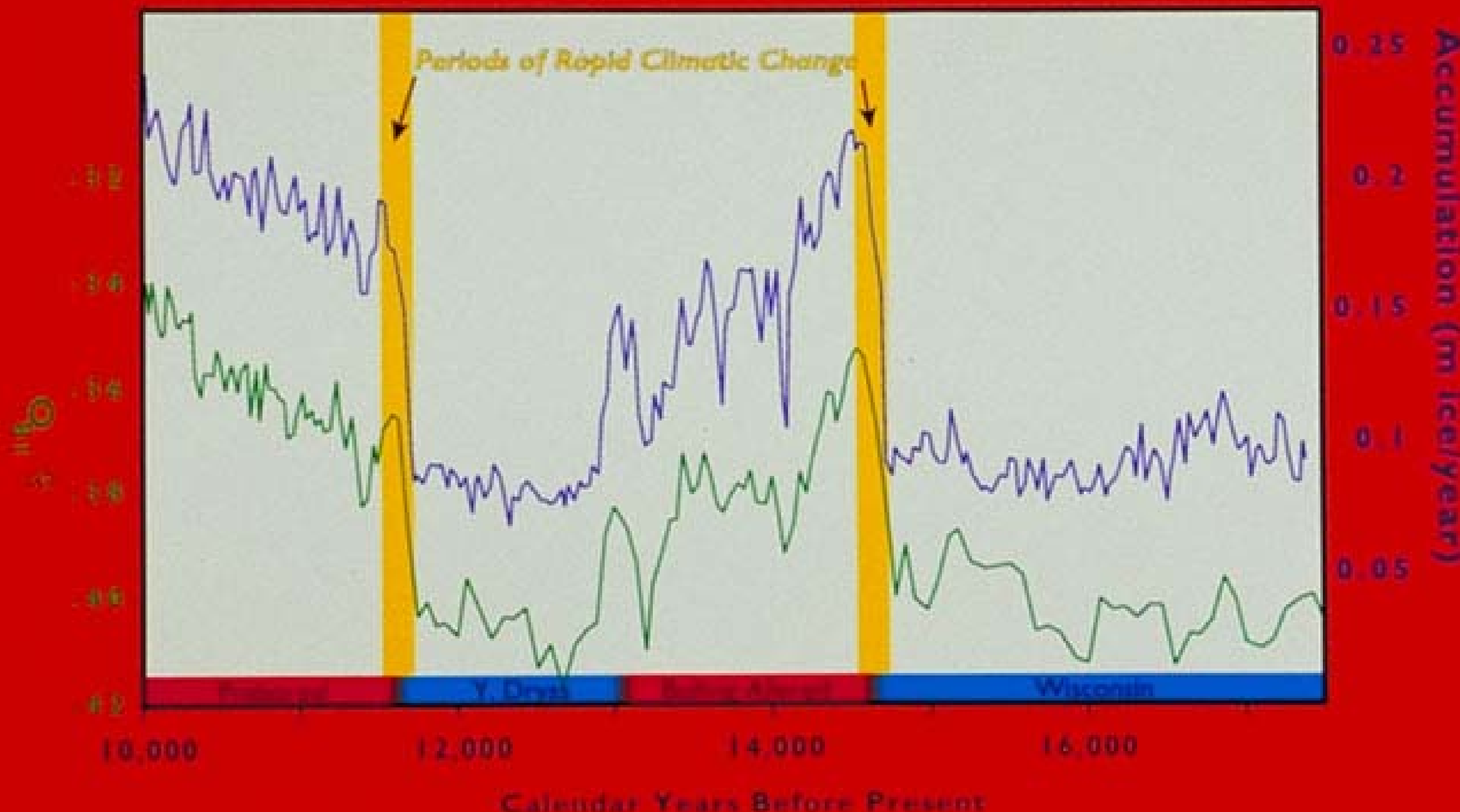
Younger Dryas

- Pronounced cooling around 12,000 to 13,000 years ago.
- Not classified as a Heinrich Event
- Stronger D-O cycle?
- Massive cooling seen in the Delta O18 and ice accumulation rates of the Greenland ice sheet.
- Melt water flood?
  - *Similar effect as Heinrich event*

Calcium Concentrations in Ice Cores

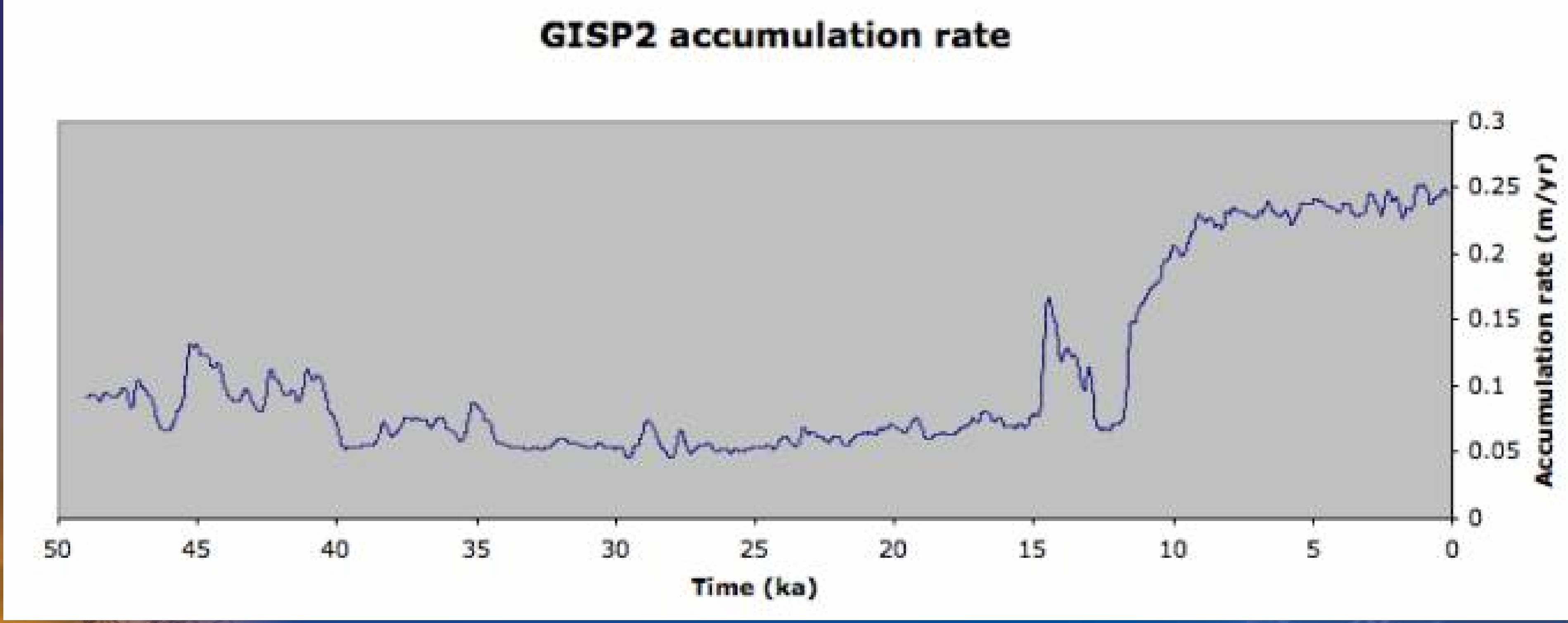


Periods of colder climate are associated with lower accumulation rates in the GISP2 ice record. Note the extremely rapid reorganizations of the climatic system that took place between the Wisconsin and Bolling-Allerød and between the Younger Dryas and Preboreal.

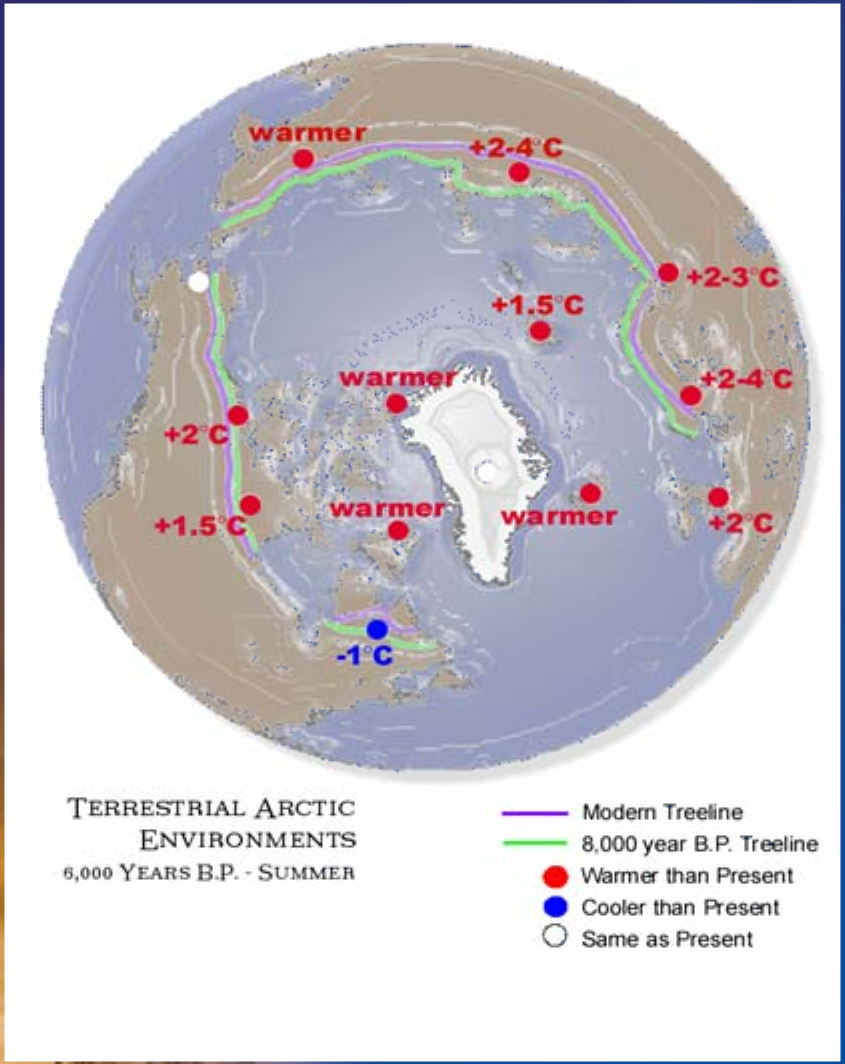


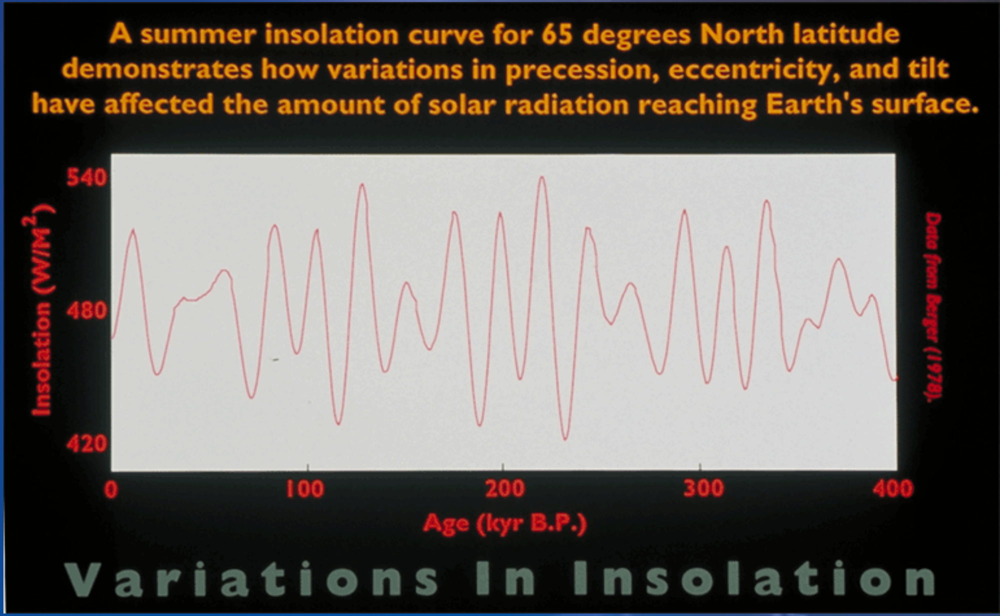
Accumulation data from Alley et al. (Penn State University); oxygen isotope data from Grootes et al. (University of Washington)

Holocene- stable climate!!

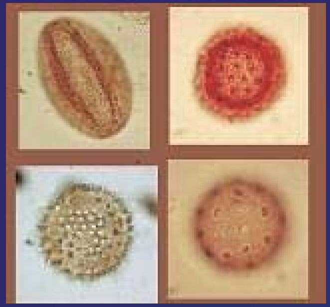


Holocene Warm Period





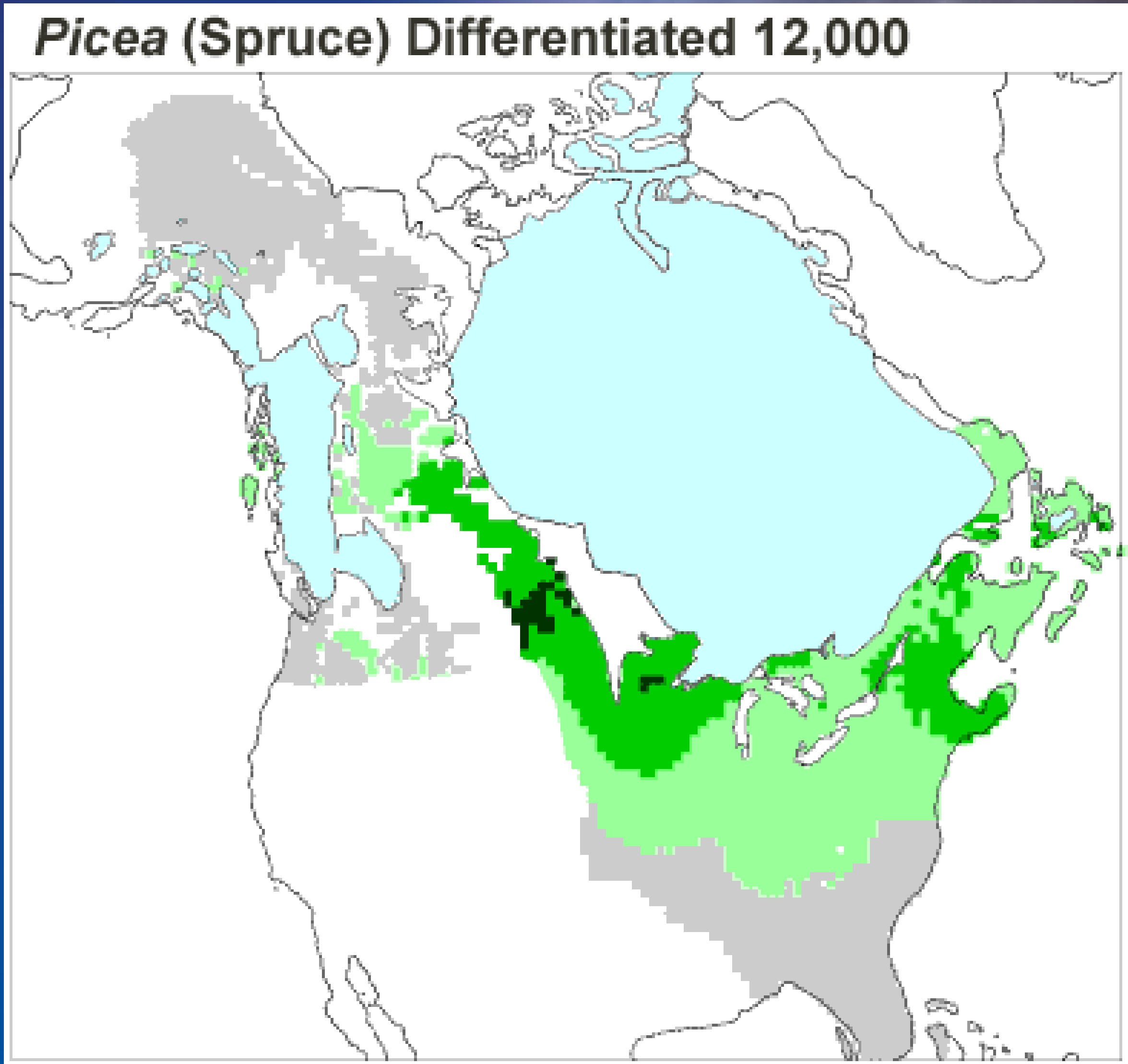
Kerwin, M., J.T. Overpeck, R.S. Webb, A. DeVernal, D.H. Rind and R.J. Healy, "The role of oceanic forcing in mid-Holocene northern hemisphere climatic change." ***Paleoceanography***, 14, pp. 200-210. 1999.



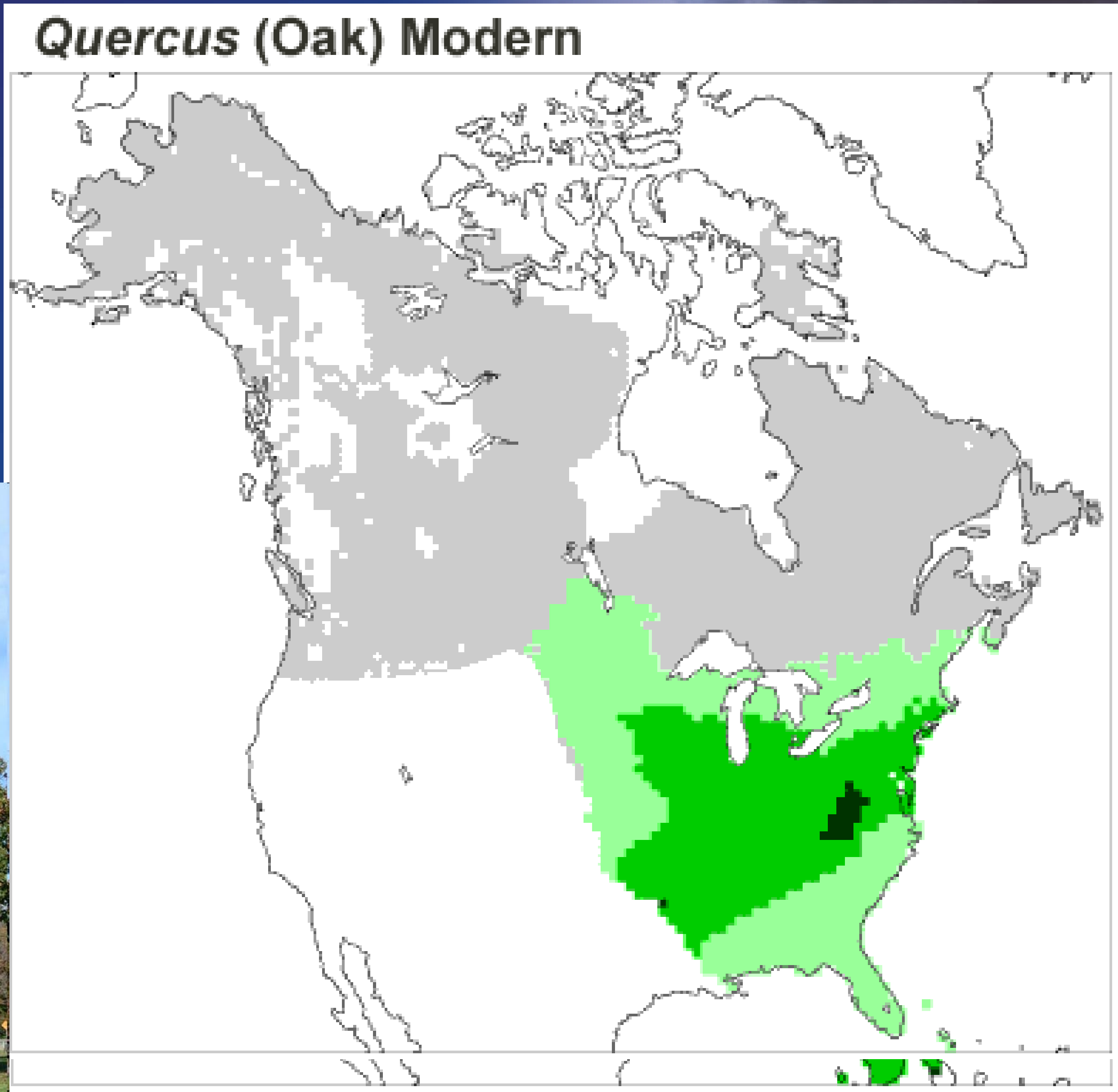
Tree Pollens

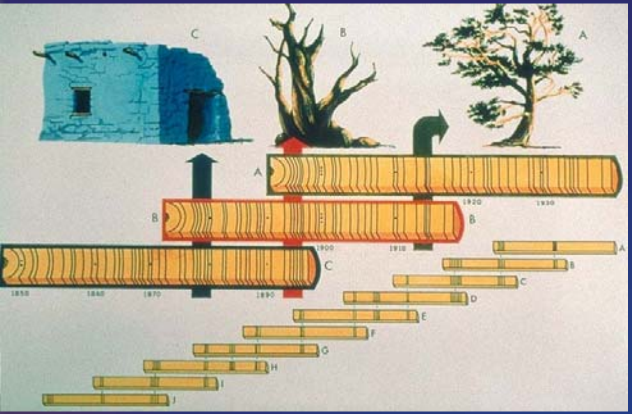
- Use tree pollens from lake and bog cores
- Reconstruct forest specie composition
- Compare with today's forest communities
- Key species
  - *Tundra sedges = high Arctic, northern Canada*
  - *Spruce = southern and central Canada*
  - *Maple, hemlock, beech = northern U.S*
  - *Oak = central and southern U.S*

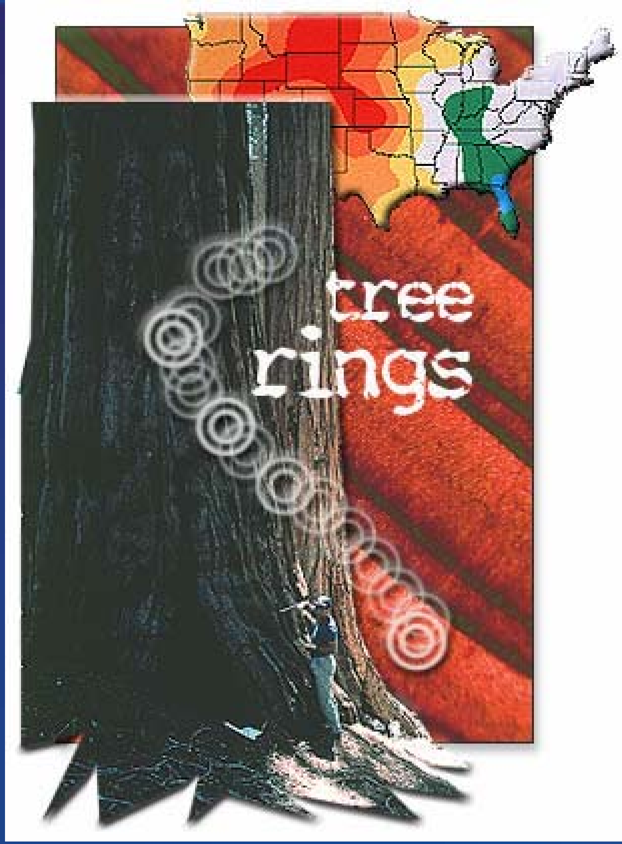
Spruce Pollens



Oak Pollens





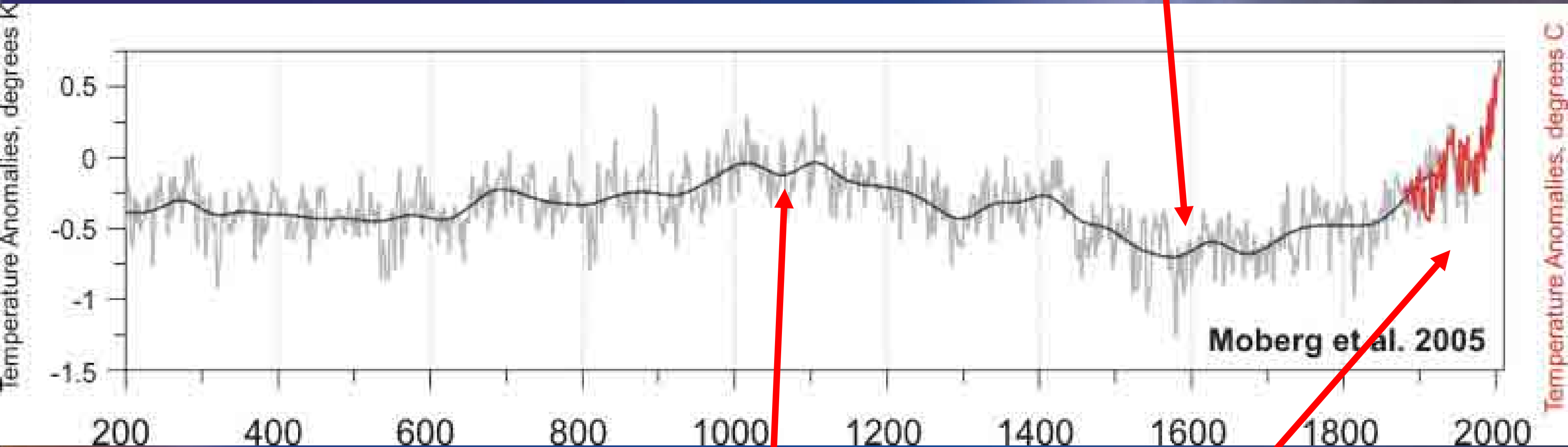


- Ring widths
- Temperature
- Precipitation
- Both.
- Complacent tree vs. stressed tree
- Ragged trees with open canopy near tree-line best for temperature signal.
- Open canopy trees near edge of prairie/grasslands for precipitation signal.

Millennial Climate Change

Tree Ring Reconstructions

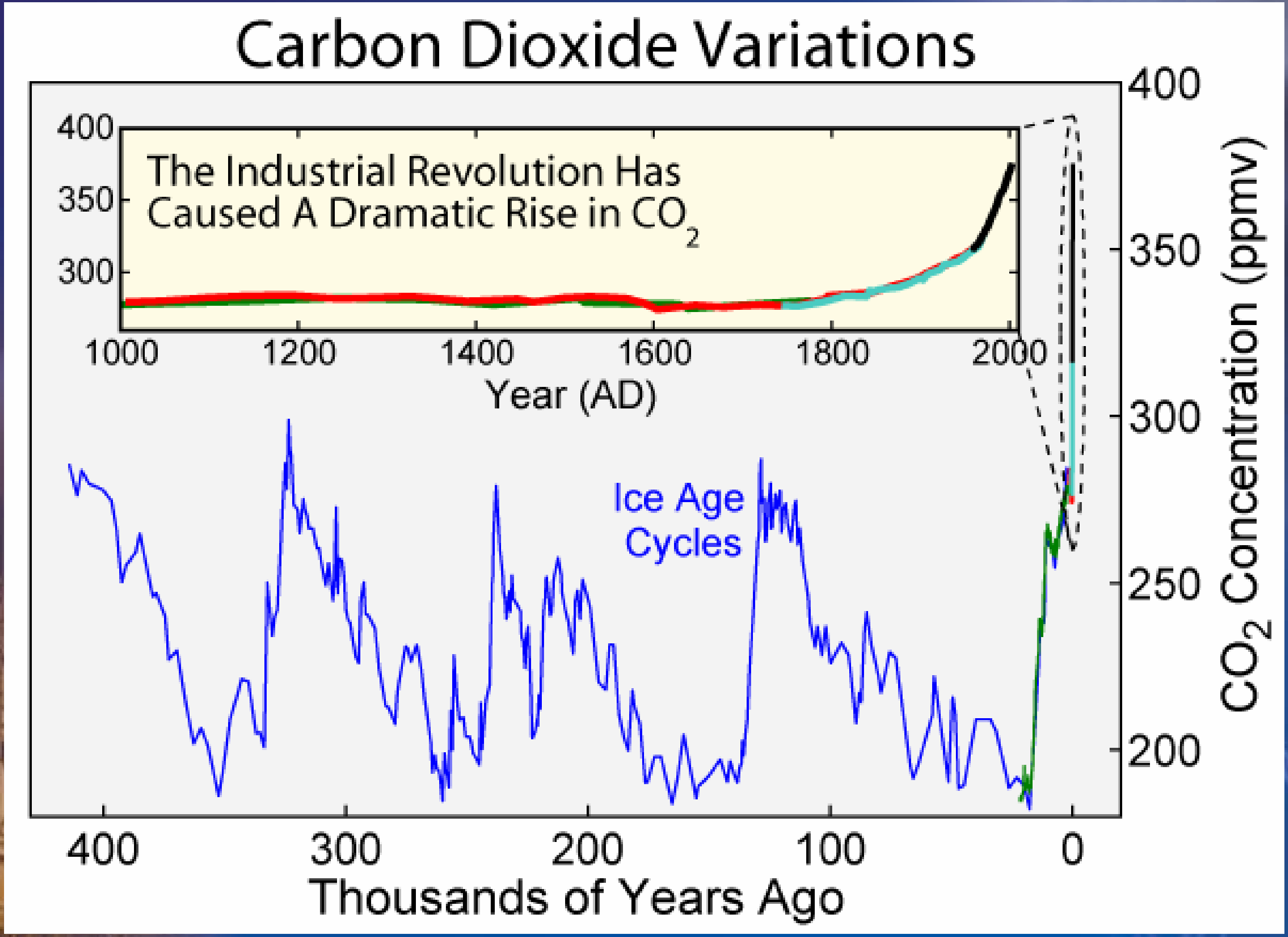
Little Ice Age



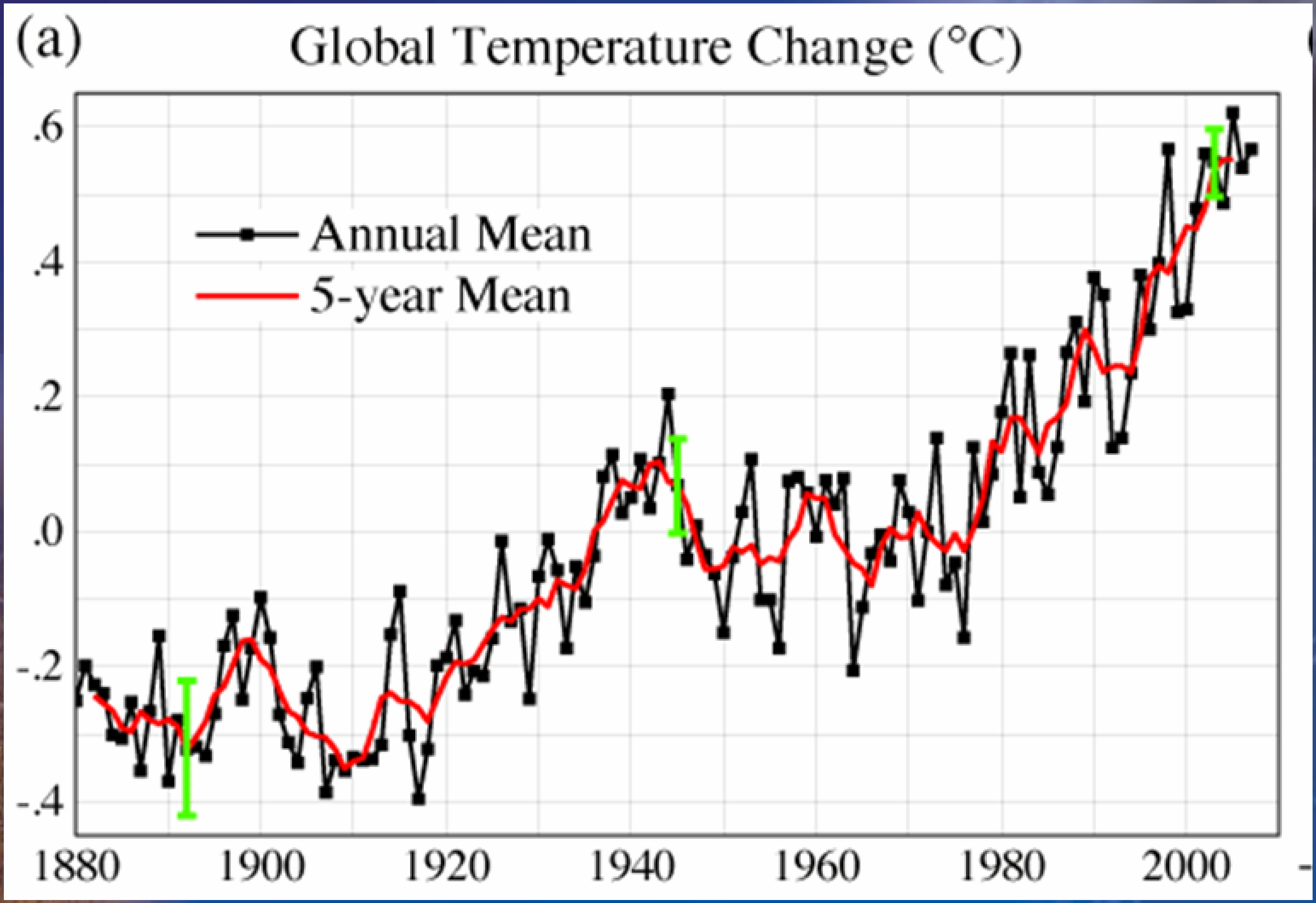
Medieval Warm Period

Surface instrumentation record

Recent Rise in CO2

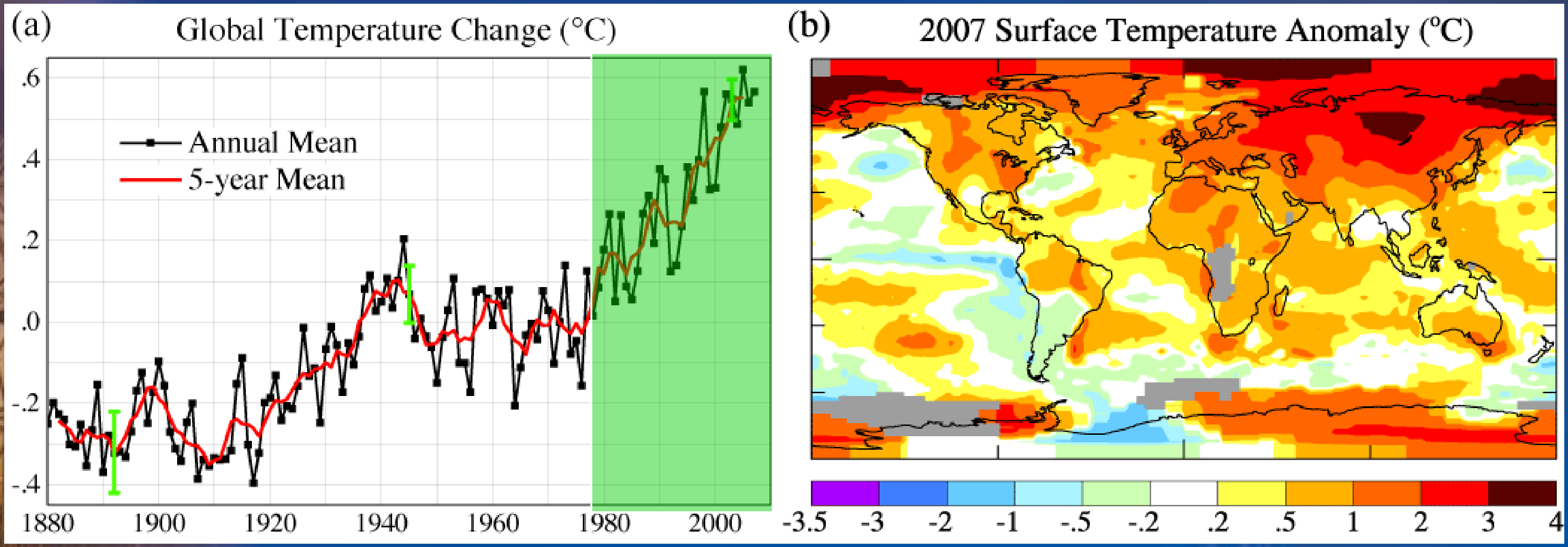


Surface Temperature Record



Global Warming

- Earth's surface temperature has risen by .8C (1.2F) in the past century.
- There is evidence that much of the warming over the last 50 years is attributable to human activities.
- What might the future bring?

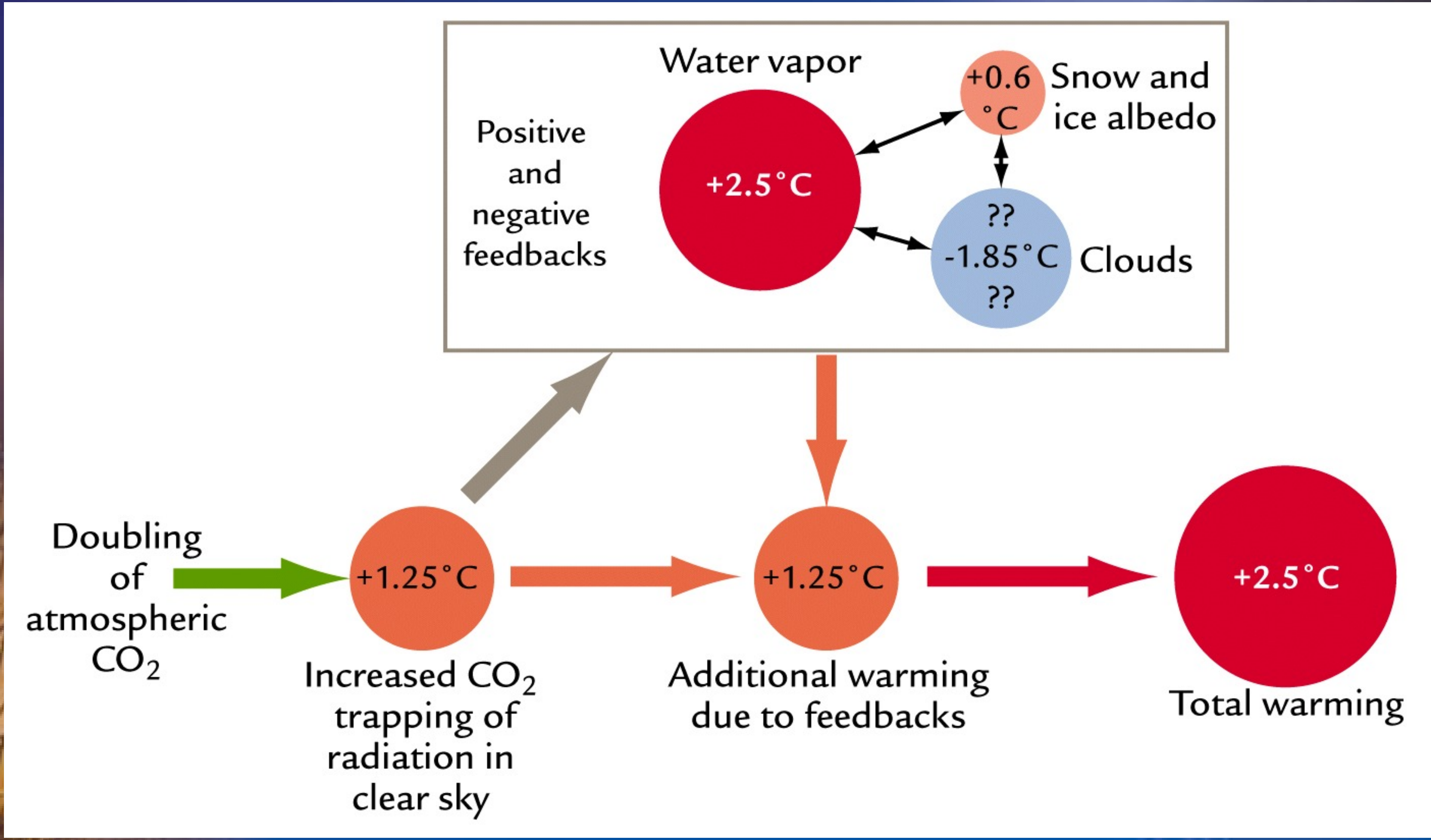


Is the recent warming unusual?

- Paleoclimatic studies: 20th century may not necessarily be the warmest time in the Earth's “recent” history.
- Helps put 20th century in perspective.
- What is unique is that the warmth cannot be explained by natural forcing mechanisms according to the many global climate model runs.

Climate models

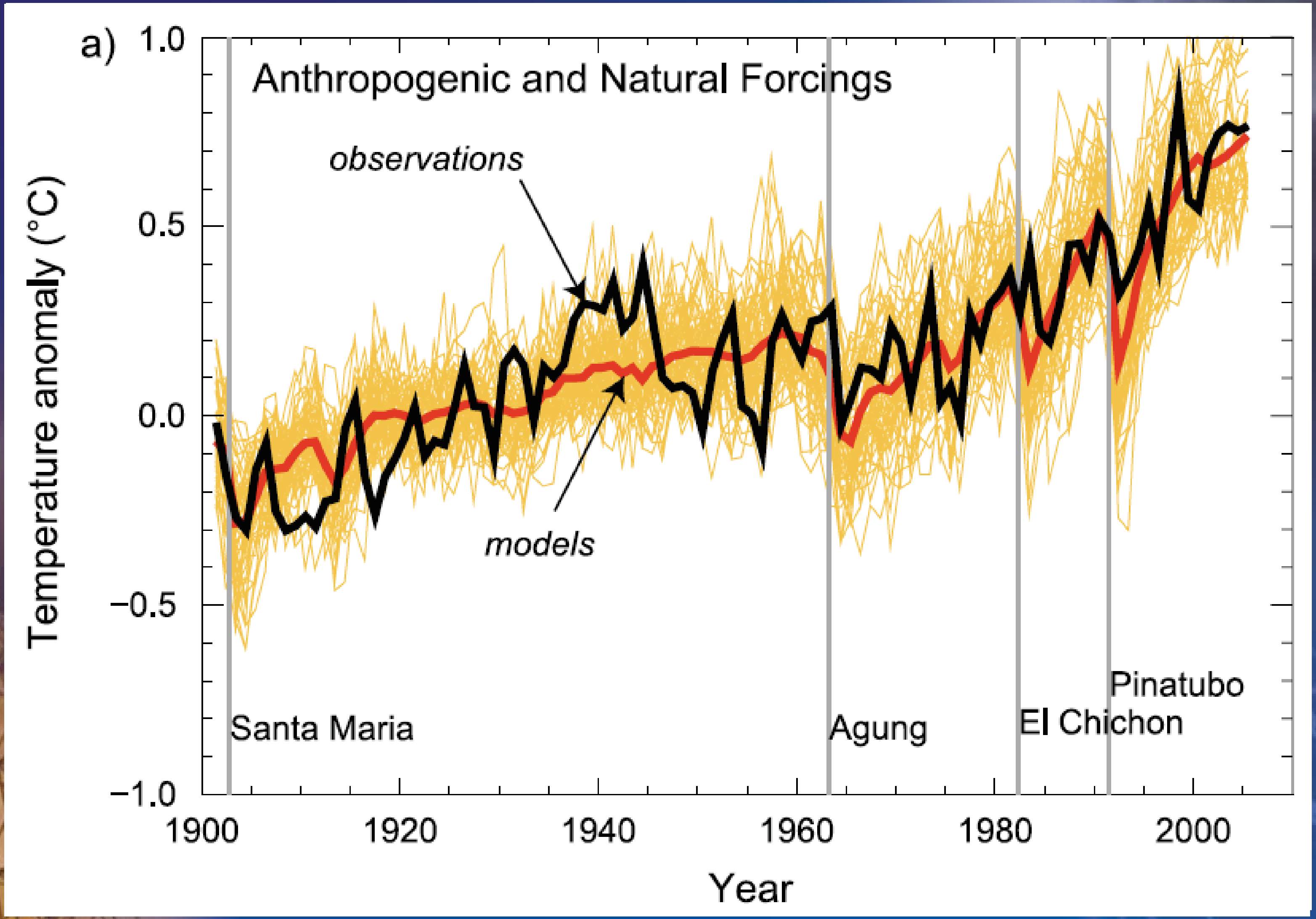
- **Sensitivity analysis**
  - *Doubling of CO_2*



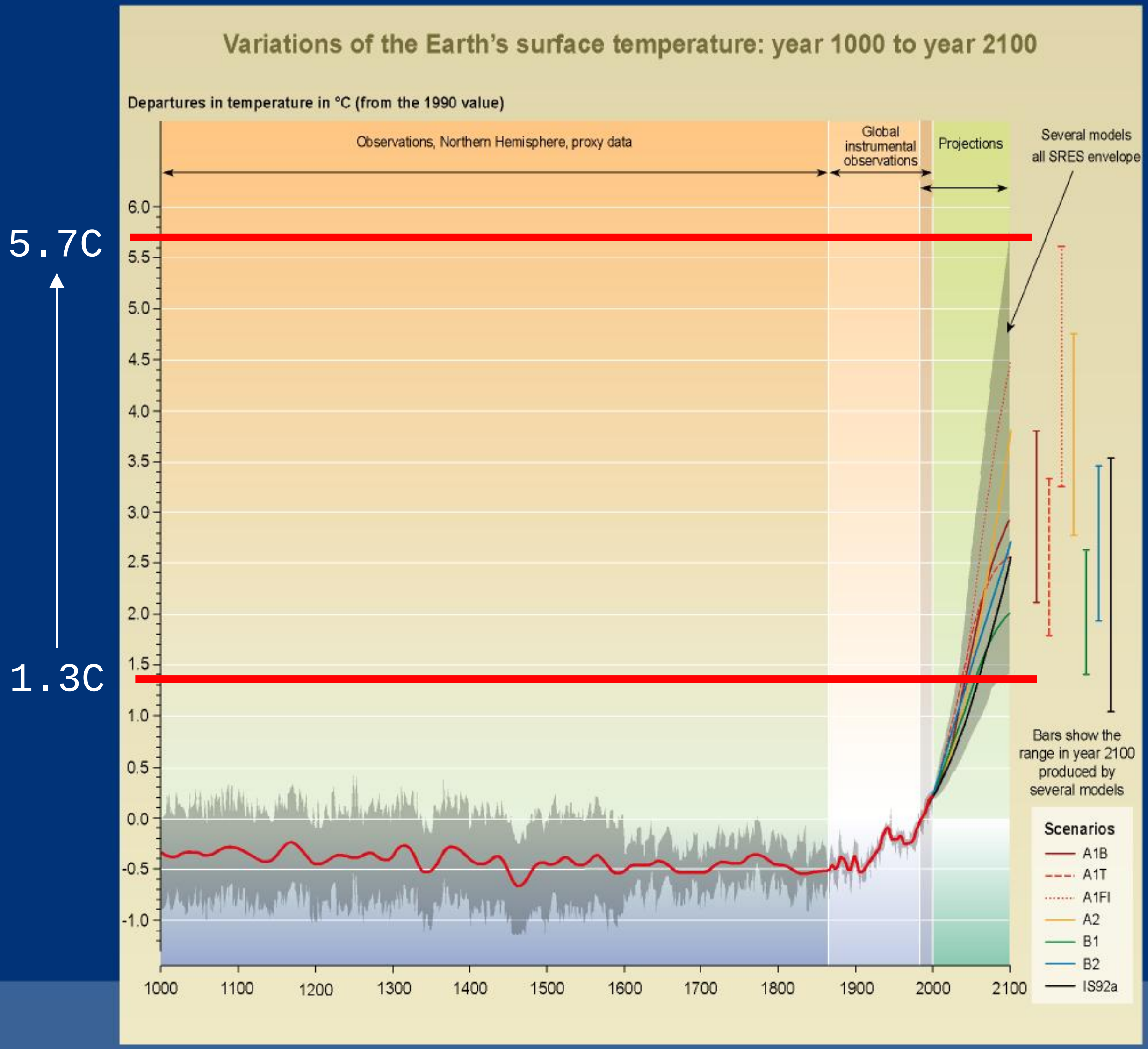
.JPG

Climate models

- **Simulation**



IPCC_AR4_TS_F23b



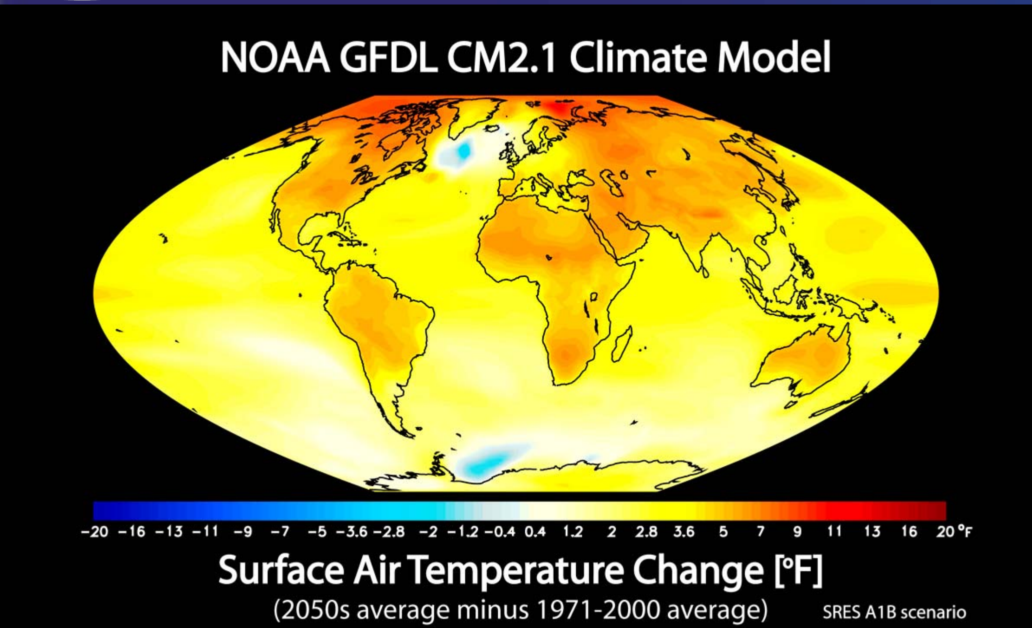
SYR - FIGURE 9-1b

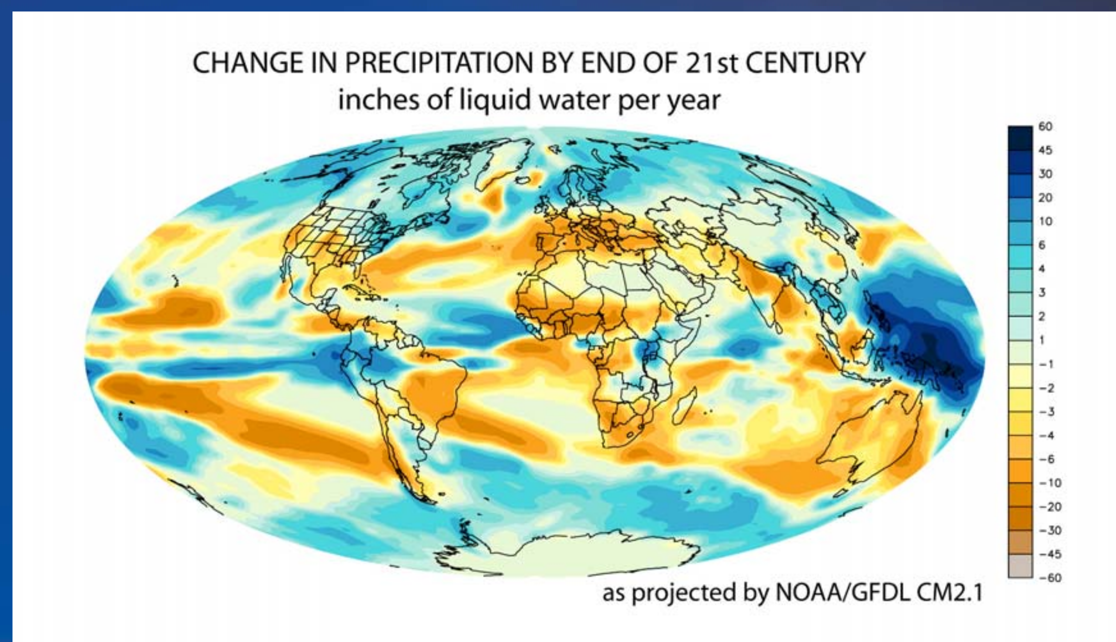
IPCC

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

WMO UNEP

Slide from IPCC


NOAA GFDL CM2.1 Climate Model
−20 −16 −13 −11 −9 −7 −5 −3.6 −2.8 −2 −1.2 −0.4 0.4 1.2 2 2.8 3.6 5 7 9 11 13 16 20 °F
Surface Air Temperature Change [°F]
(2050s average minus 1971-2000 average)
SRES A1B scenario


CHANGE IN PRECIPITATION BY END OF 21st CENTURY
inches of liquid water per year
60 45 30 20 10 6 4 3 2 1 −1 −2 −3 −4 −6 −10 −20 −30 −45 −60
as projected by NOAA/GFDL CM2.1

Uncertainty

- The paleoclimatological record shows rapid swings in climate *only* when large ice sheets are present.
- Climate seems fairly stable without large ice sheets.
- We are entering into new ground since large ice sheets currently absent.
- How does the climate system respond when large ice sheets are not present due to GHG forcing?

Summary

- Climate change historically has had a profound effect on humanity.
- Break up of Pangaea leads to large landmasses at high latitudes
  - *Allows for formation of large ice sheets due to ice-albedo effect.*
- Orbital forcing leads to variations in insolation at 65 degree N latitude during the summer
  - *Determines if ice sheets will form in the northern hemisphere.*

Summary (continued)

- Amount of ice in the NH affects global temperature through:
  - *Ice-albedo affect*
  - *Greenhouse gas concentration*
  - *Larger amplitude variations in the thermohaline circulation.*
    - Bond cycle
  - *Less ice in NH, more stable climate.*
- Variations in solar forcing leads to shorter-term millennial climate changes.
- Concern is that recent increase in greenhouse gases may be pushing the climate system into “unknown” territory.
- Climate models suggest 2 to 6 C warmer with a doubling of CO_2 mainly due to the water-vapor feedback.

Internet and Contact

David J. Nicosia

NOAA National Weather Service
Binghamton NY

http://weather.gov- main NWS site

http://www.noaa.gov- NOAA web site

My email: david.nicosia@noaa.gov

Phone: 607-770-9531 x 223