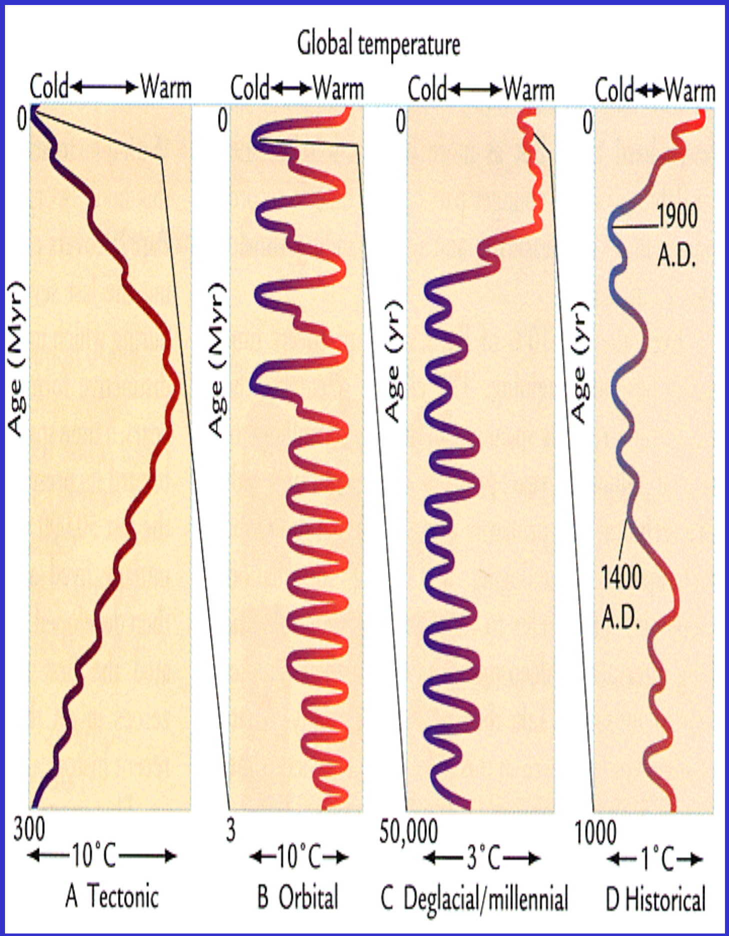
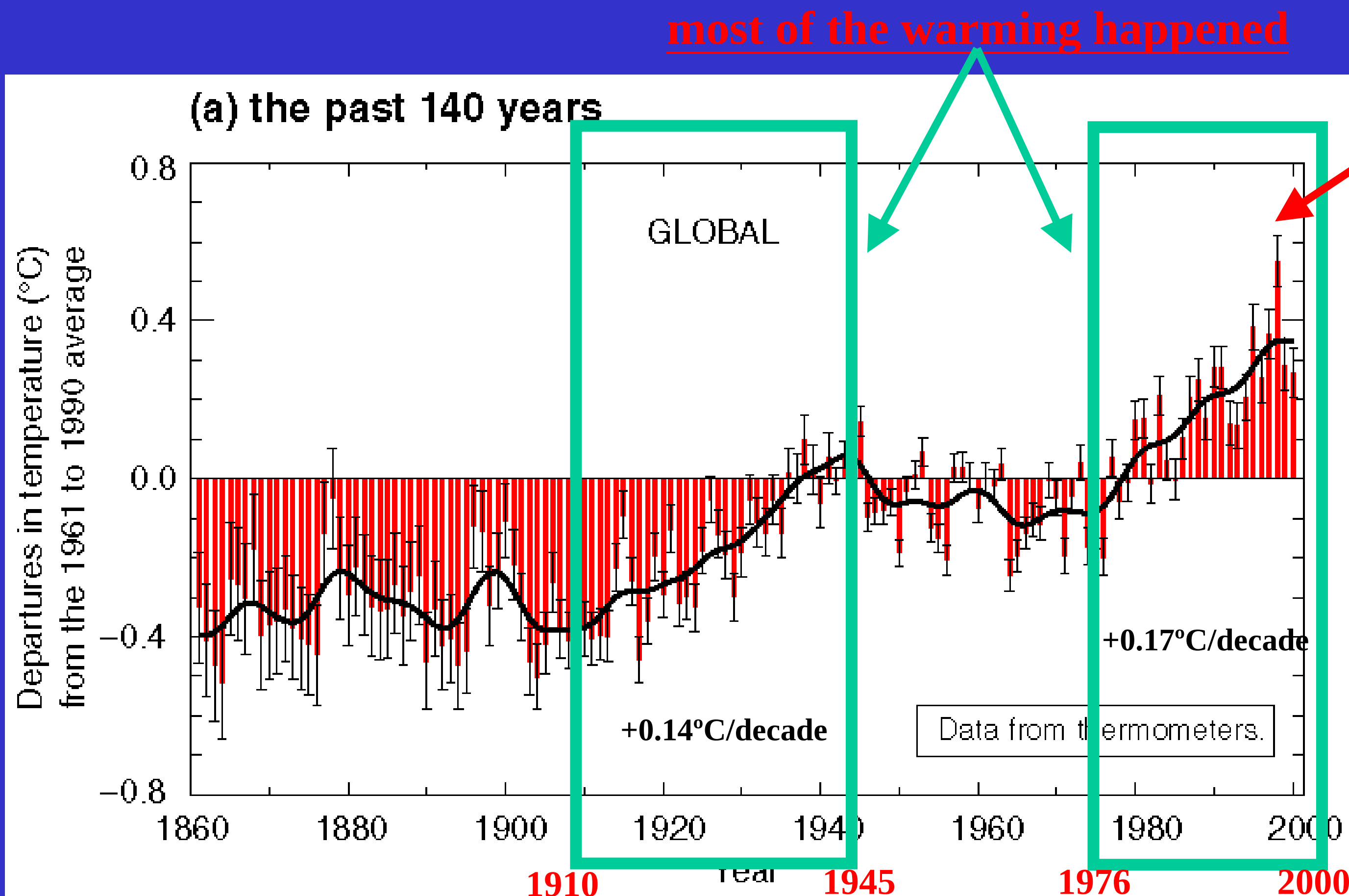
Chapter 16: Climate Changes



(from *Earth's Climate: Past and Future*)

- ❑ Global Warming
- ❑ Tectonic-Scale Climate Changes
- ❑ Orbital-Scale Climate Changes
- ❑ Deglacial and Millennial Climate Changes
- ❑ Historical Climate Changes

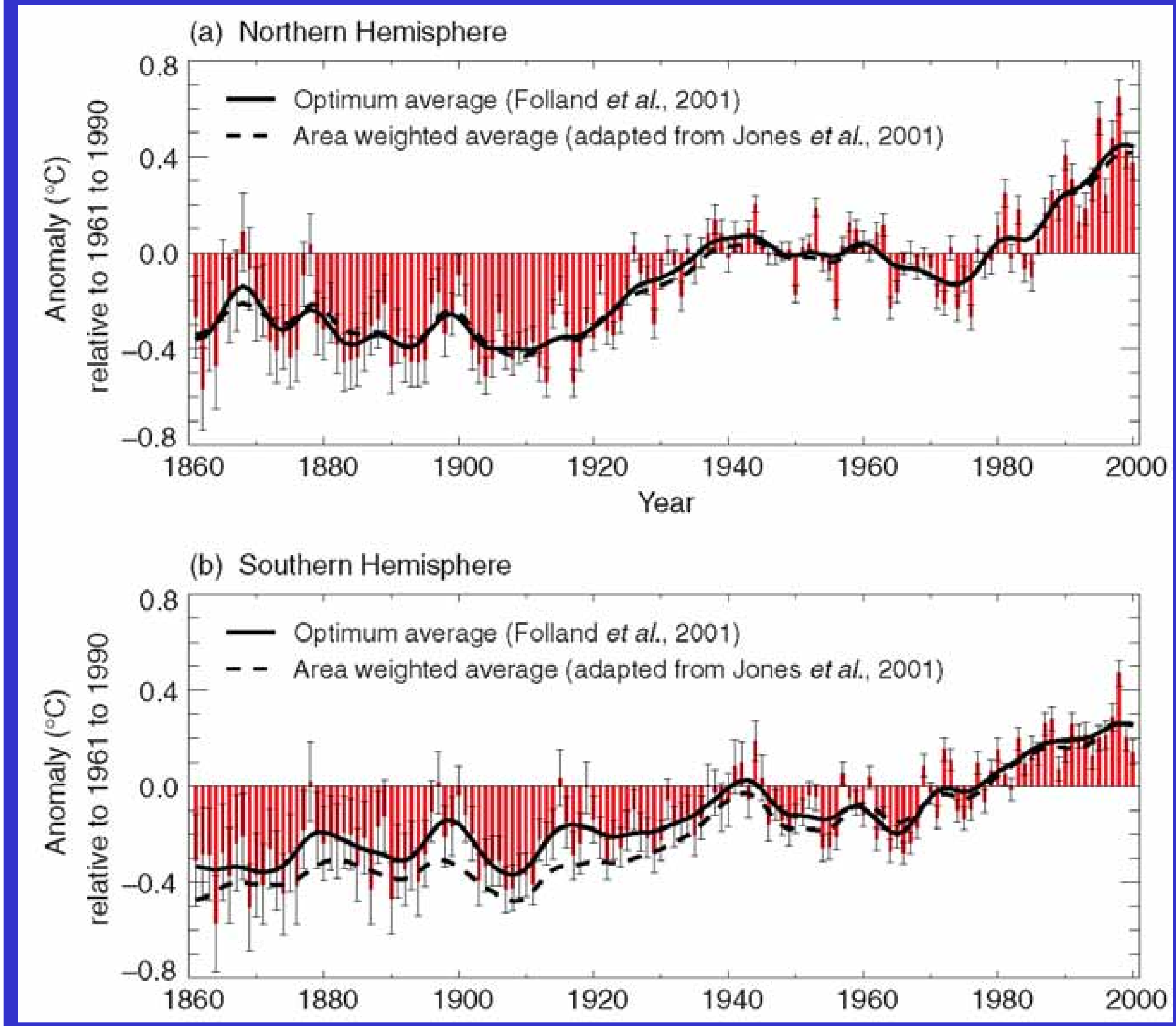
Global Surface Temperature



Warmest years
(1) 1998 – 0.63ºC
(2) 2005 – 0.58ºC
(3) 2002 – 0.56ºC
2003
(4) 2004 – 0.54ºC
(5) 2001 – 0.51ºC

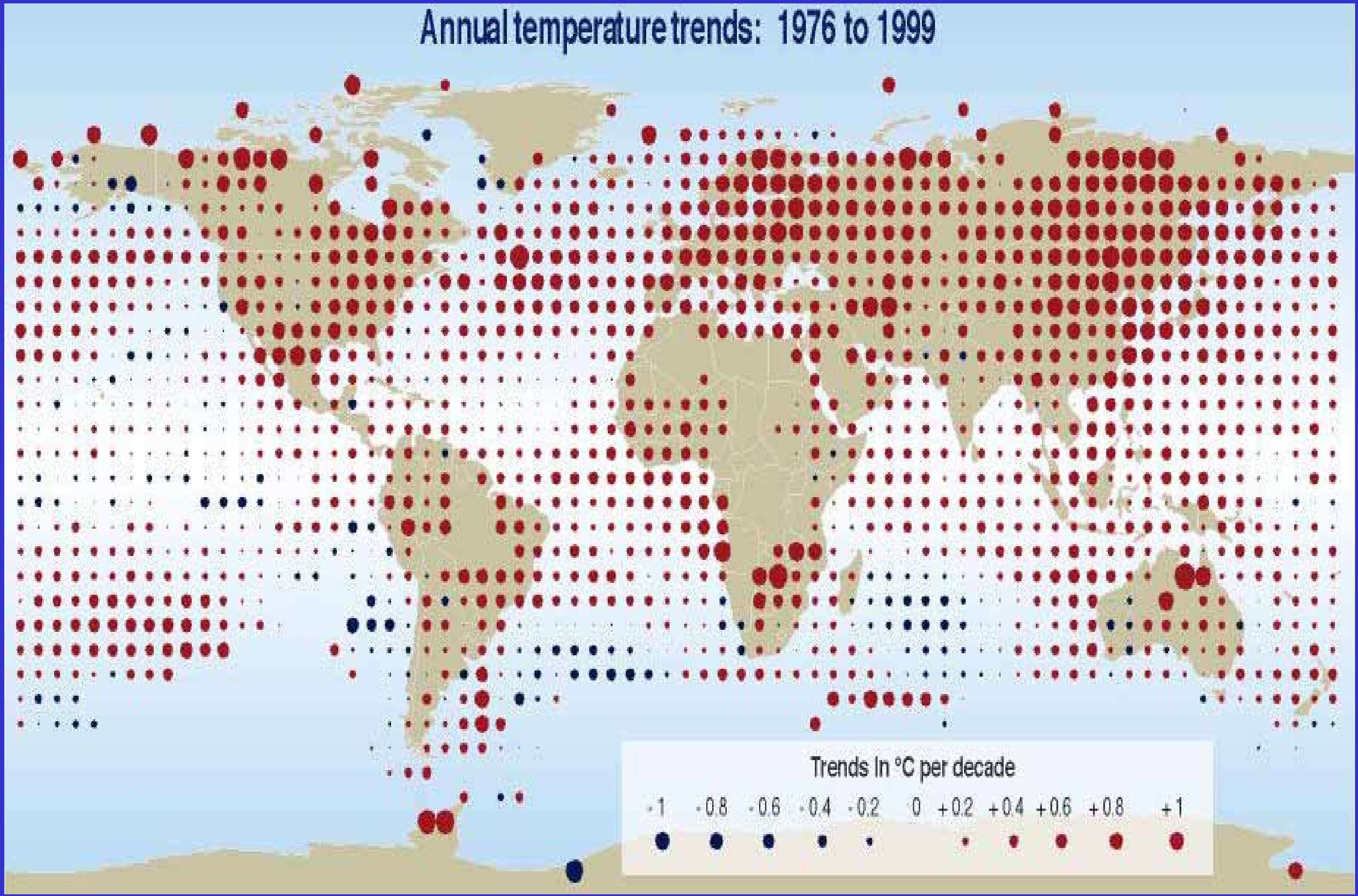
The global average surface temperature has increased over the 20th century by about 0.6°C.

More Warming in the N.H.



Both the earlier period of warming (1910 to 1945) and the more recent one (1976 to 1999) saw rates of warming about twice as great in the Northern Hemisphere than in the Southern Hemisphere.

Faster Warming Trend Over Lands



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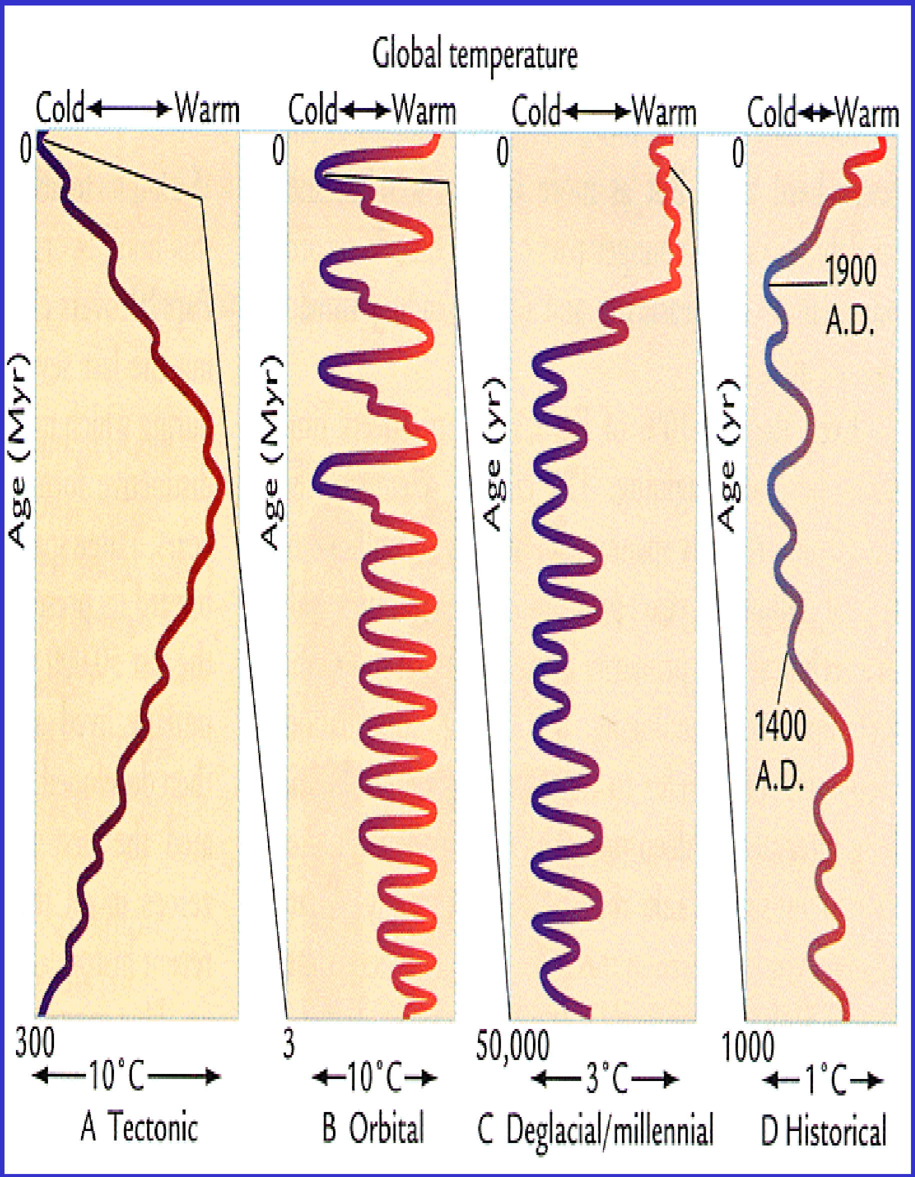
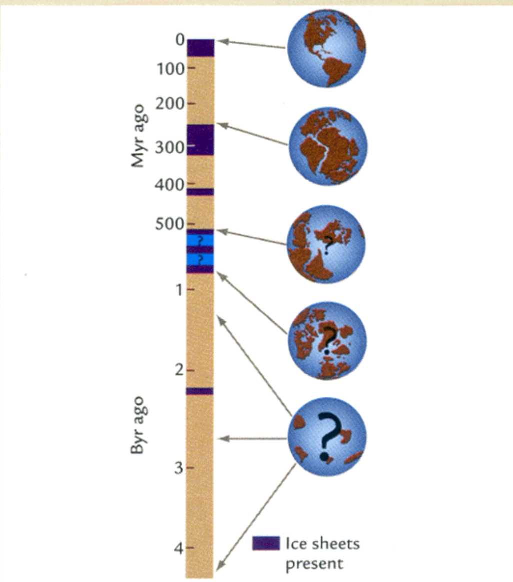
Climate Change on Various Time Scales



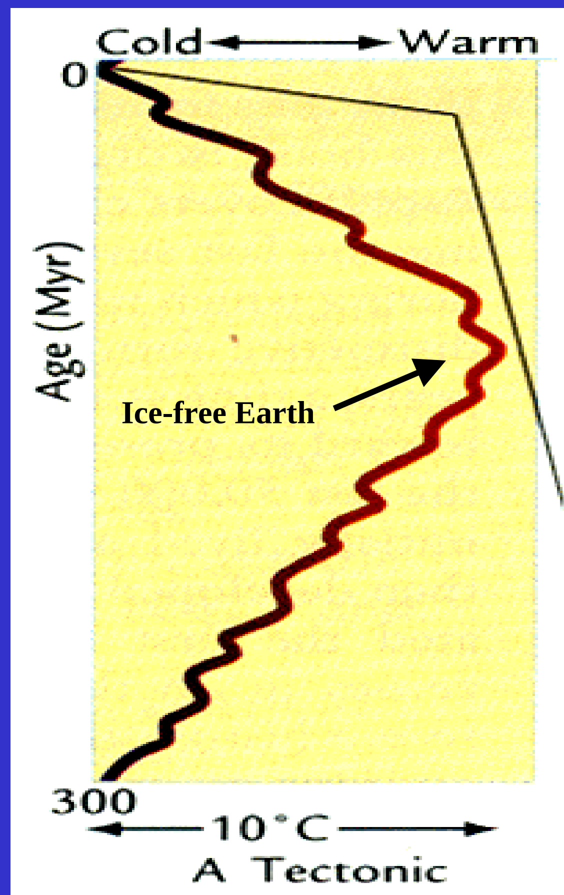
(from *Earth's Climate: Past and Future*)

- ❑ Tectonic-Scale Climate Changes
- ❑ Orbital-Scale Climate Changes
- ❑ Millennial Climate Changes
- ❑ Historical Climate Change
- ❑ Anthropogenic Climate Changes

Tectonic-Scale Climate Change



Past glaciations and continental positions. During Earth's 4.55-billion-year history, intervals when large continental ice sheets were present alternated with times when they were not (left). The earliest history of these changes is poorly defined because few ancient records are preserved. The movements of continents in relation to ocean basins are well known only for the last several hundred million years (right). (Globes adapted from D. Merritts et al., *Environmental Geology*, © 1997 by W. H. Freeman and Company.)

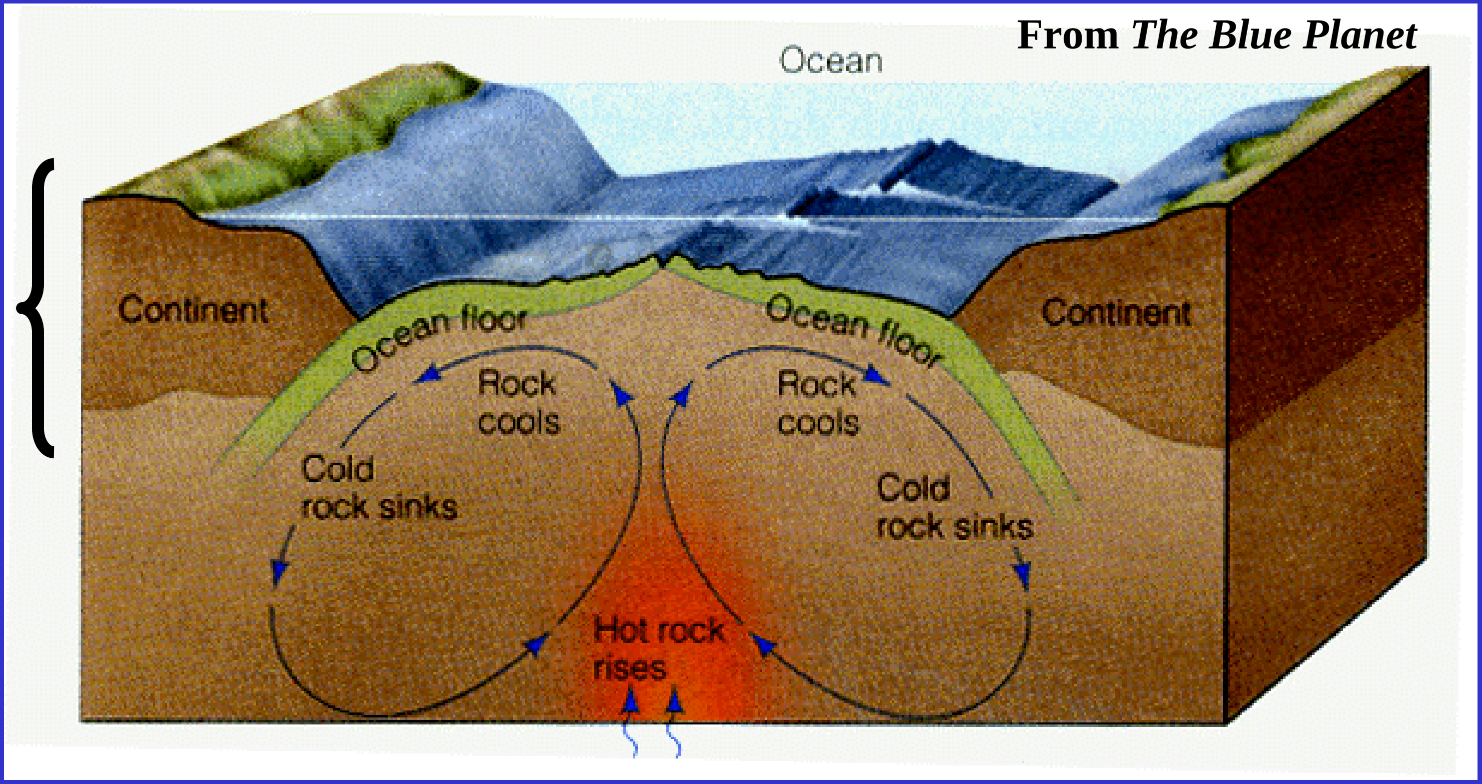


(from *Earth's Climate: Past and Future*)

- The faint young Sun paradox and its possible explanation.
- Why was Earth ice-free even at the poles 100 Myr ago (the Mesozoic Era)?
- What are the causes and climate effects of changes in sea level through time?
- What caused Earth's climate to cool over the last 55 Myr (the Cenozoic Era)?

Circulation of the Solid Earth

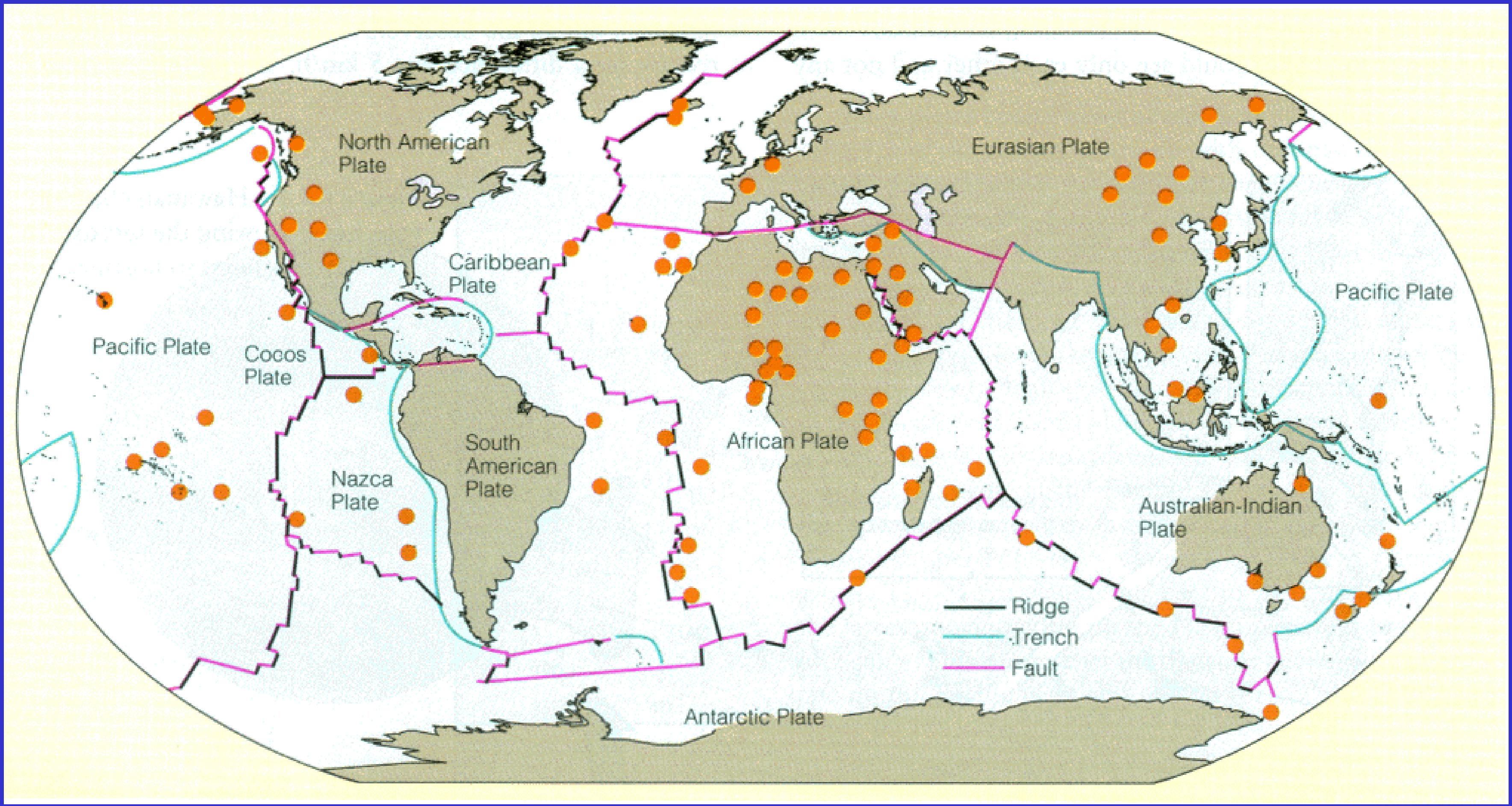
Cold
Lithosphere



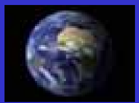
❑ The rising hot rocks and slid-away flows are thought to be the factor that cont5rol the positions of ocean basins and continents.

➔ The convection determines the shape of the Earth.

Twenty Rigid Plates



From *The Blue Planet*



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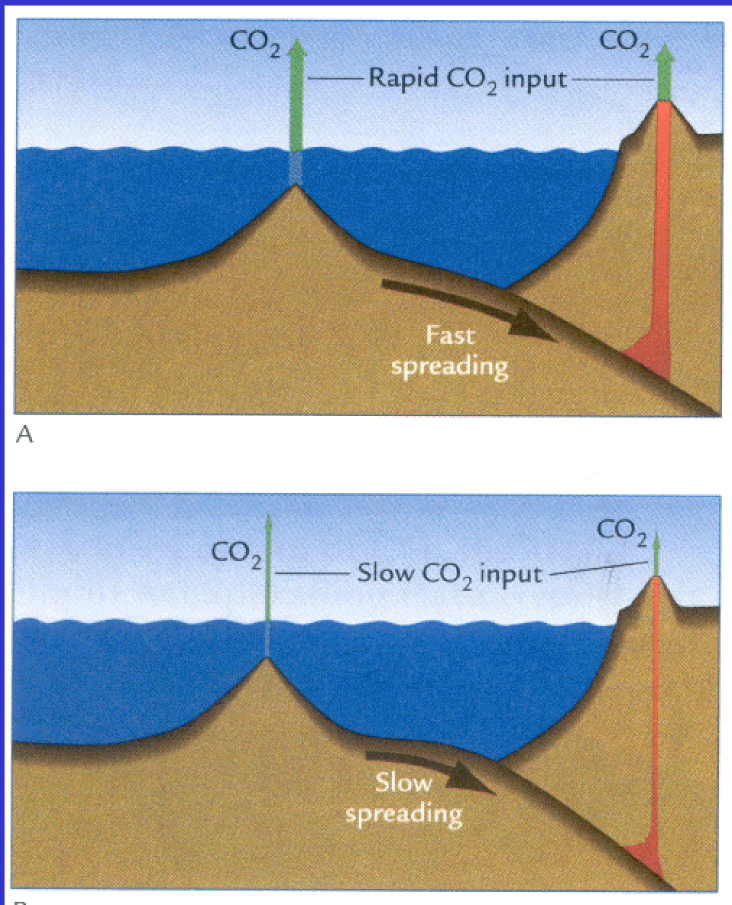
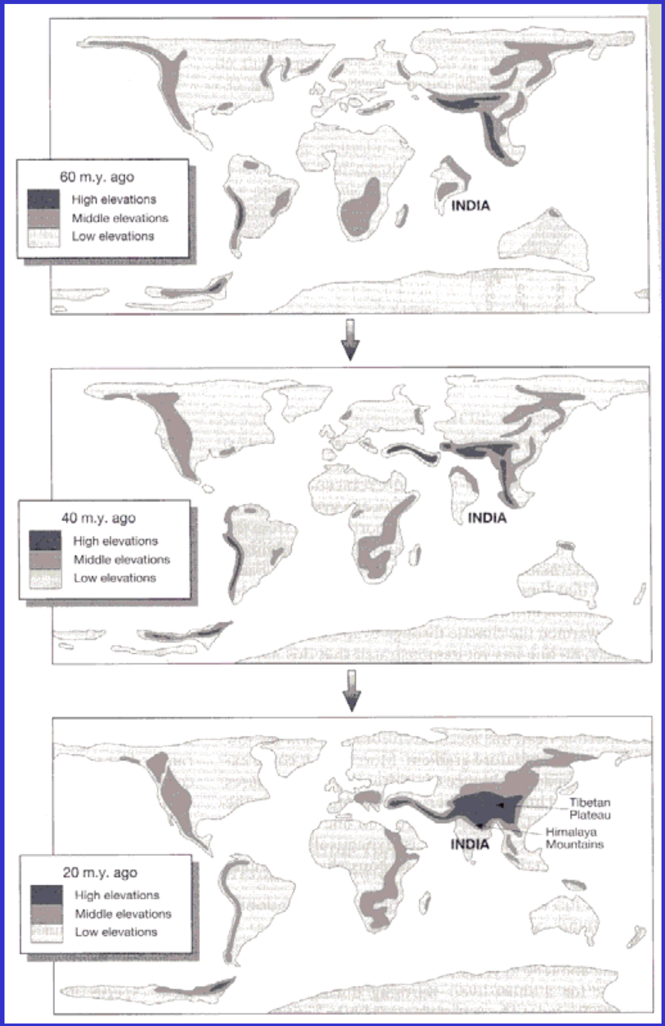
Tectonic Control of CO_2 *Input* – The Seafloor Spreading Rate Hypothesis



(from *Earth's Climate: Past and Future*)

- During active plate tectonic processes, carbon cycles constantly between Earth's interior and its surface.
- The carbon moves from deep rock reservoirs to the surface mainly as CO_2 gas associated with volcanic activity along the margins of Earth's tectonic plates.
- The centerpiece of the seafloor spreading hypothesis is the concept that changes in the rate of seafloor spreading over millions of years control the rate of delivery of CO_2 to the atmosphere from the large rock reservoir of carbon, with the resulting changes in atmospheric CO_2 concentrations controlling Earth's climate.

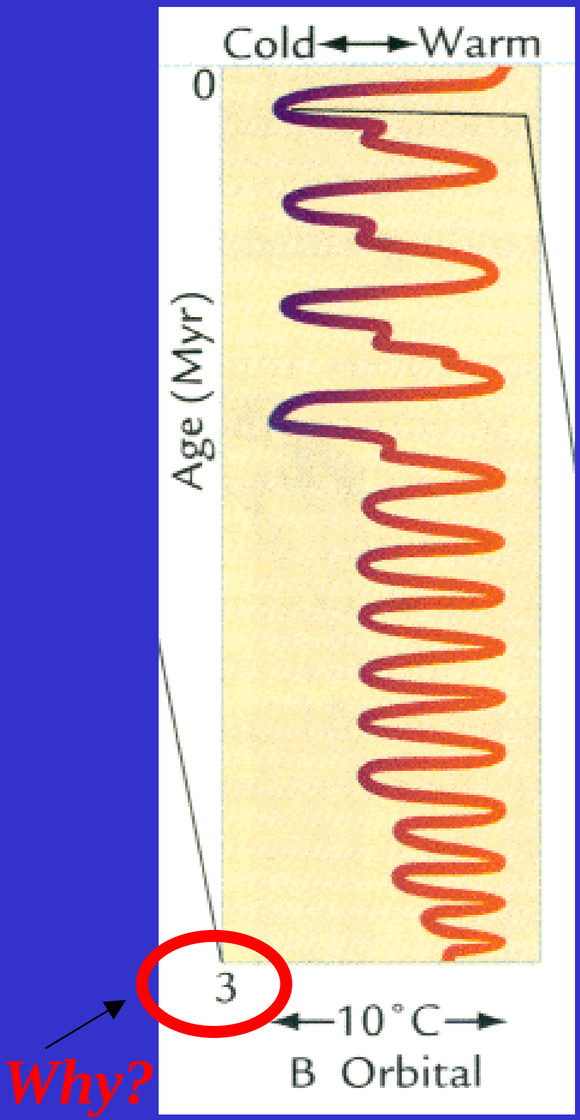
Why the Cooling over the Last 50 Myr?



(from *The Earth System*)

- The collision of Indian and Asia happened around 40 Myr ago.
- The collision produced the Himalayas and a huge area of uplifted terrain called the Tibetan Plateau.
- The Himalayas Mountains provided fresh, readily erodable surfaces on which chemical weathering could proceed rapidly.
- At the same time, the uplifting of the Tibetan Plateau create seasonal monsoon rainfalls, which provided the water needed for chemical weathering.
- Therefore, the collision of India and Asia enhanced the chemical weathering process and brought down the atmospheric CO2 level to the relatively low values that prevail today.
- This reduced the greenhouse effect and cooled down the climate over the last 50 Myr.

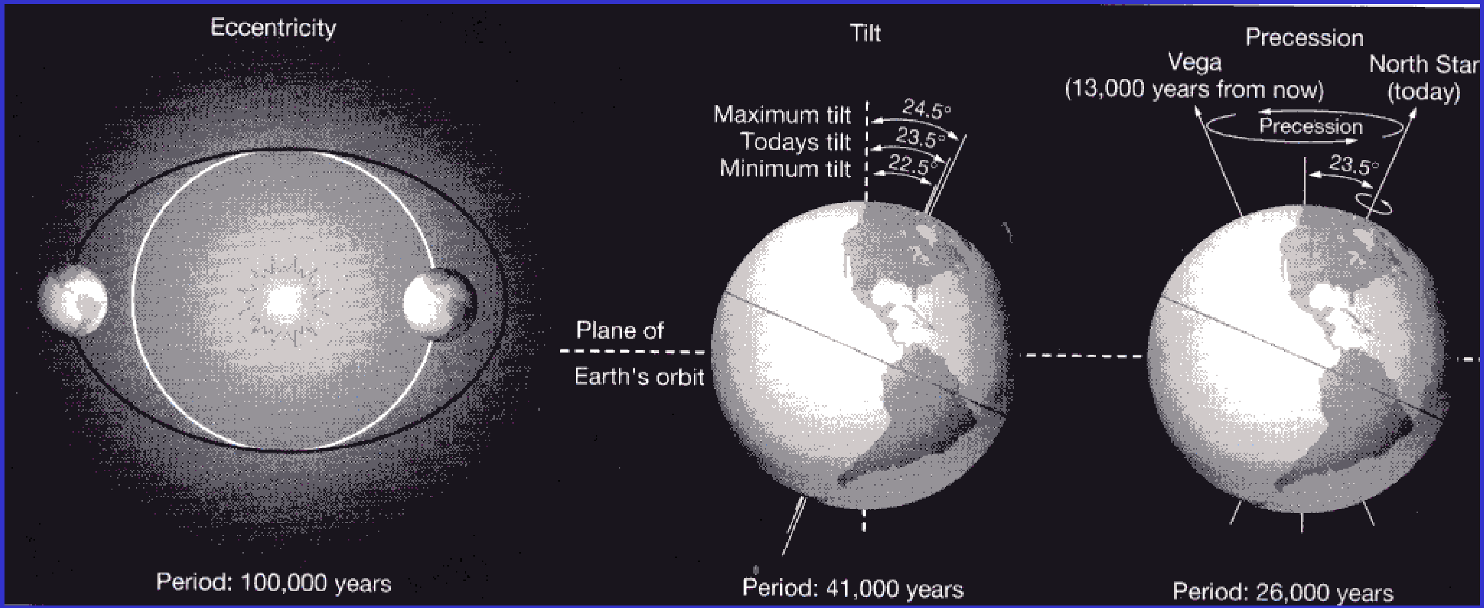
Orbital-Scale Climate Change



- **Changes in solar heating driven by changes in Earth's orbit are the major cause of cyclic climate changes over time scales of tens to hundreds of thousands of years (23k years, 41k years, and 100k years) .**
- Earth's orbit and its cyclic variations: tilt variations, eccentricity variations, and precession of the orbit.
- How do orbital variations drive the strength of tropical monsoons?
- How do orbital variations control the size of northern hemisphere ice sheets?
- What controls orbital-scale fluctuations of atmospheric greenhouse gases?
- What is the origin of the 100,000-year climate cycle of the last 0.9 Myr (ice sheets melt rapidly every 100,000 years)?

(from *Earth's Climate: Past and Future*)

Earth's Orbit and Its Variations



(from *The Earth System*)

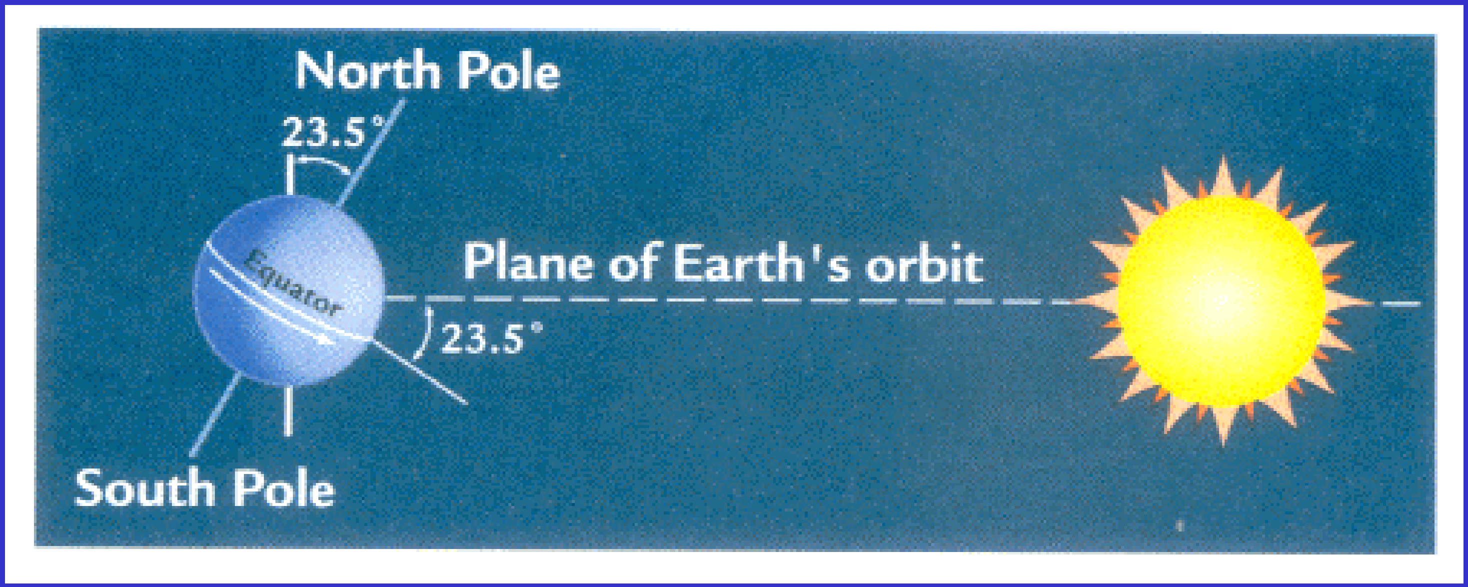
- First, Earth spins around on its axis once every day ➔ The ***Tilt.***
- Second, Earth revolves around the Sun once a year ➔ The shape of the ***Orbit***.
- Both the tilt and the shape of the orbit have changed over time and produce three types of orbital variations:

  (1) obliquity variations

  (2) eccentricity variations

  (3) precession of the spin axis.

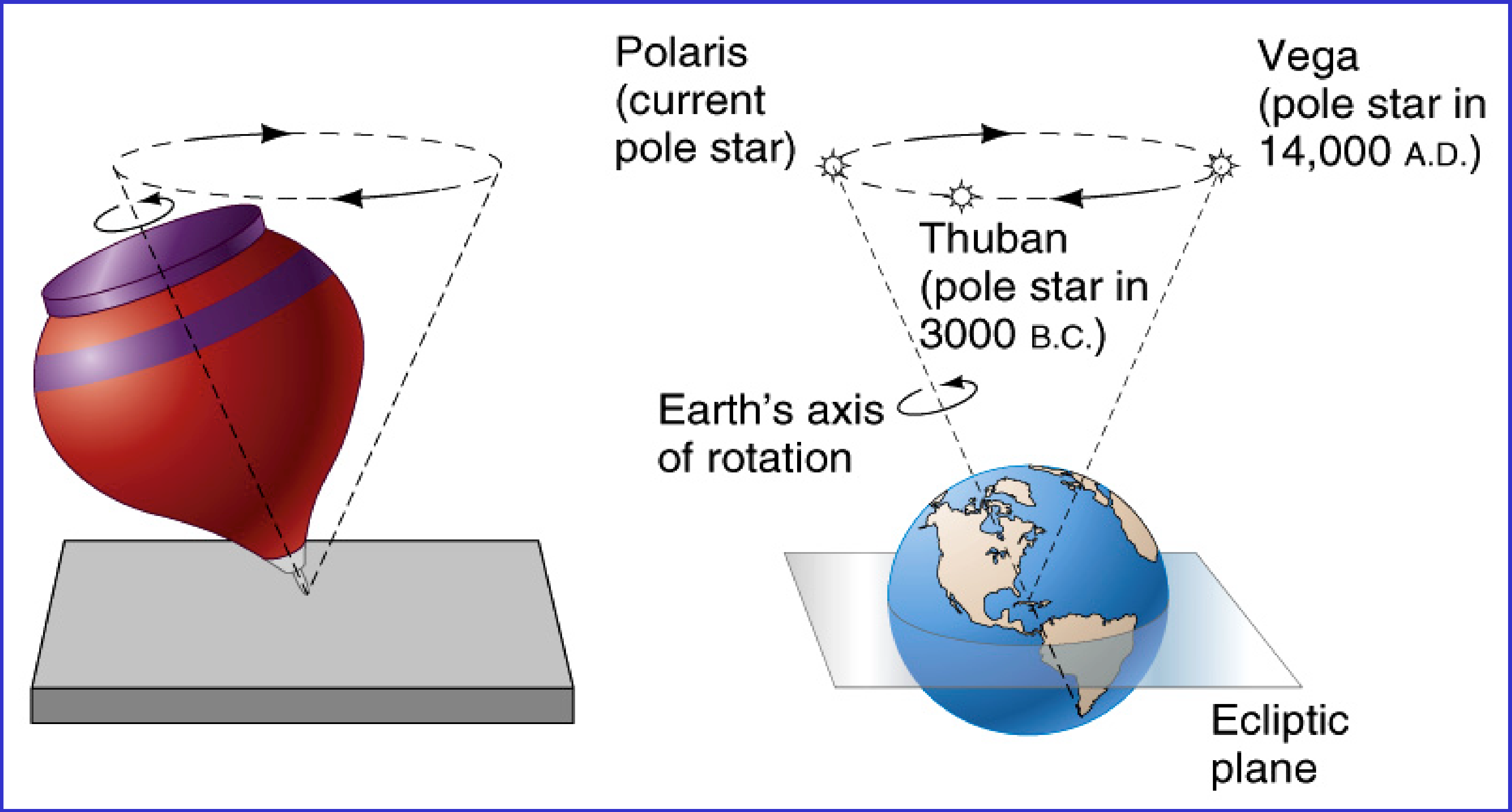
How Does the Tilt Affect Climate?



(from *Earth's Climate: Past and Future*)

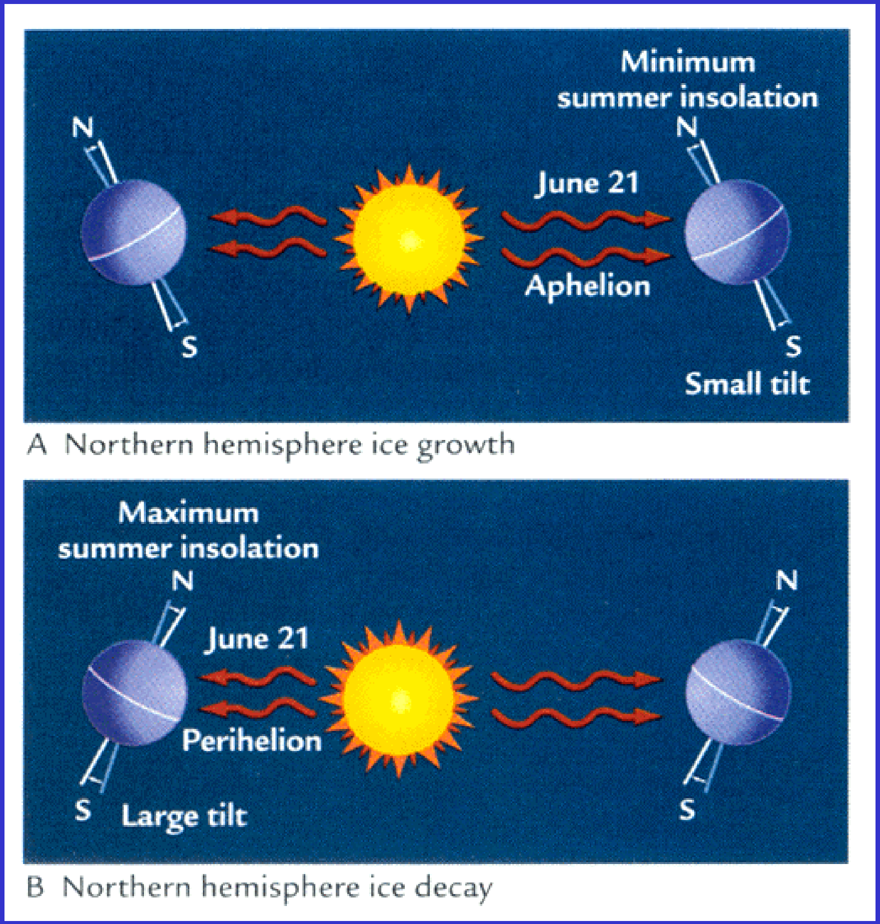
- At present-day, the axis is tilted at an angle of 23.5°, referred to as Earth's "obliquity", or "tilt".
- The Sun moves back and forth through the year between 23.5°N and 23.5°S.
- Earth's 23.5° tilt also defines the 66.5° latitude of the Artic and Antarctic circles. No sunlight reaches latitudes higher than this in winter day.
- The tilt produces ***seasons***!!

Precession



Polaris
(current
pole star)
Vega
(pole star in
14,000 A.D.)
Thuban
(pole star in
3000 B.C.)
Earth's axis
of rotation
Ecliptic
plane

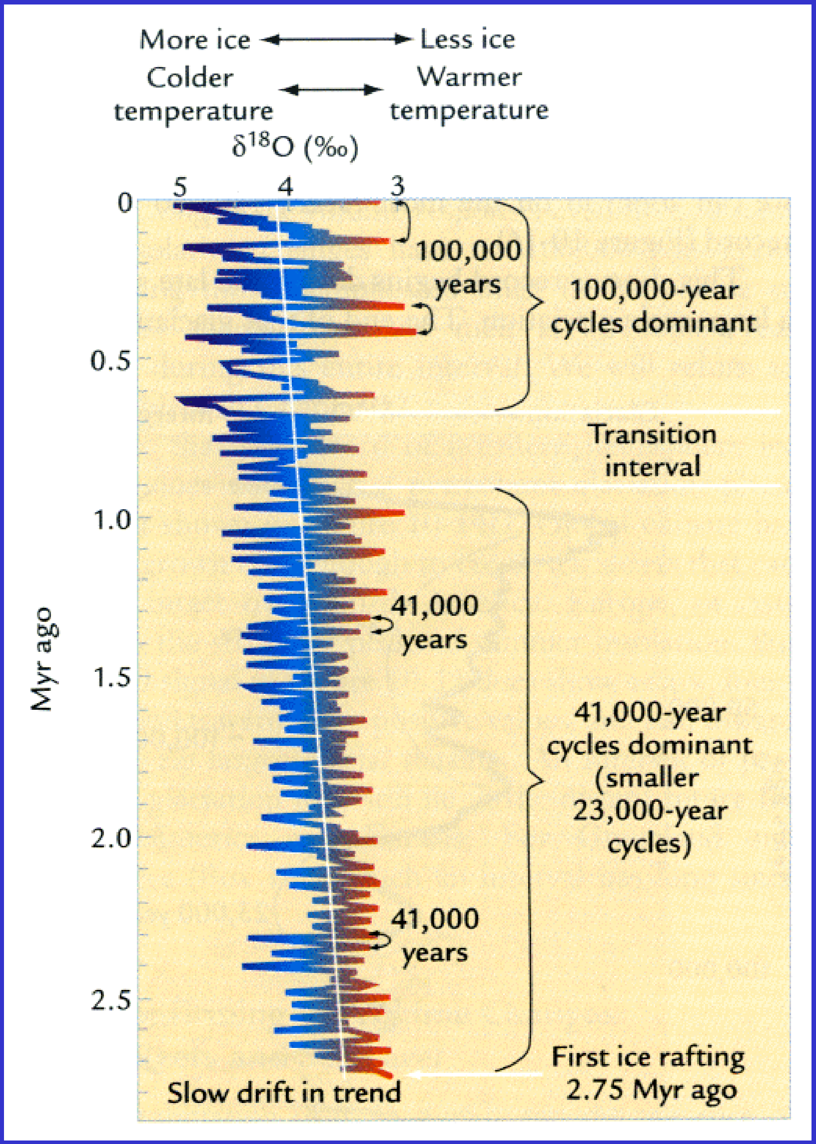
Milankovitch Theory



(from Earth's Climate: Past and Future)

- Milankovitch suggested that the critical factor for Northern Hemisphere continental glaciation was the amount of summertime insolation at high northern latitudes.
- Low summer insolation occurs during times when Earth's orbital tilt is small.
- Low summer insolation also results from the fact that the northern hemisphere's summer solstice occurs when Earth is farthest from the Sun and when the orbit is highly eccentric.

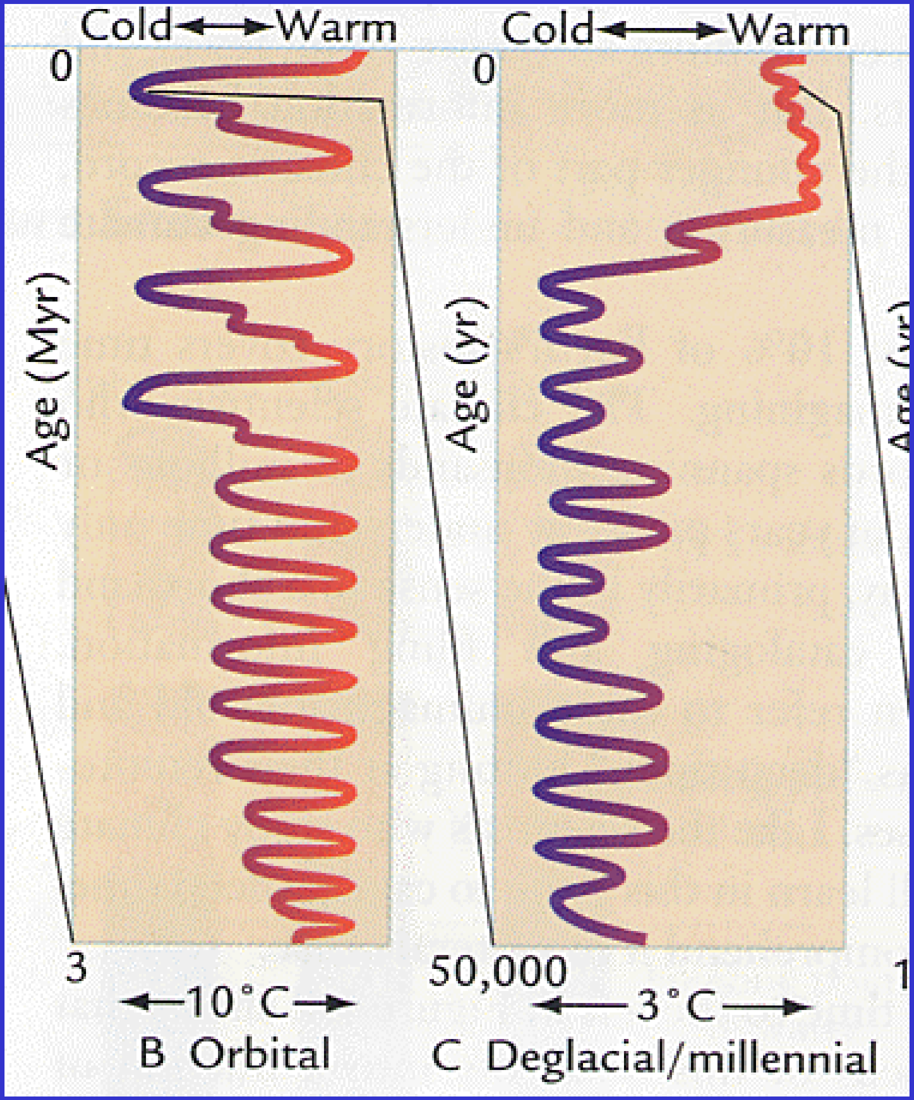
Evidence of Ice Sheet Evolution



(from Earth's Climate: Past and Future)

- This figures shows a North Atlantic Ocean sediment core holds a 3 Myr $\delta^{18}O$ record of ice volume and deep-water temperature changes.
- There were no major ice sheets before 2.75 Myr ago.
- After that, small ice sheets grew and melted at cycles of 41,000 and 23,000 years until 0.9 Myr ago.
- After 0.9 Myr ago, large ice sheet grew and melted at a cycle of 100,000 years.

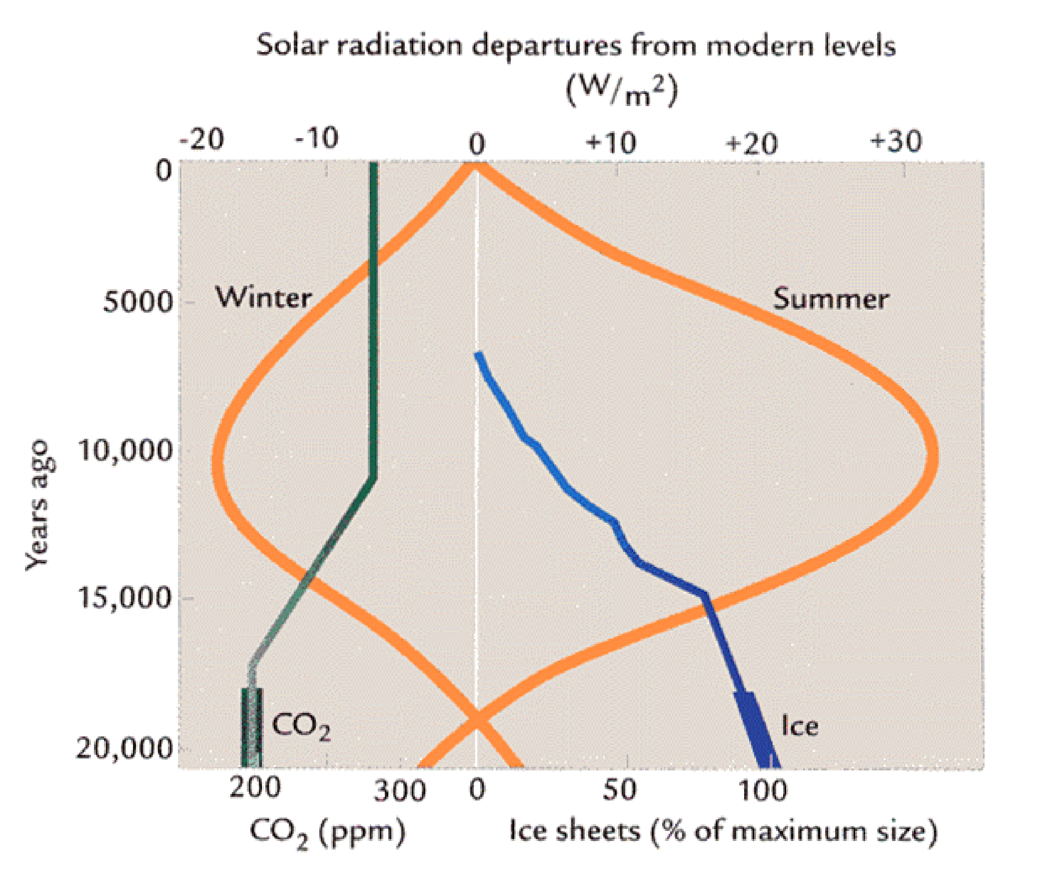
Deglacial and Millennial Scales



(from *Earth's Climate: Past and Future*)

- ❑ Climate changes of these scales in the past several tens of thousands of years occurred within the time span of recorded human civilization.

The Last Glacial Maximum (21,000 Years Ago)



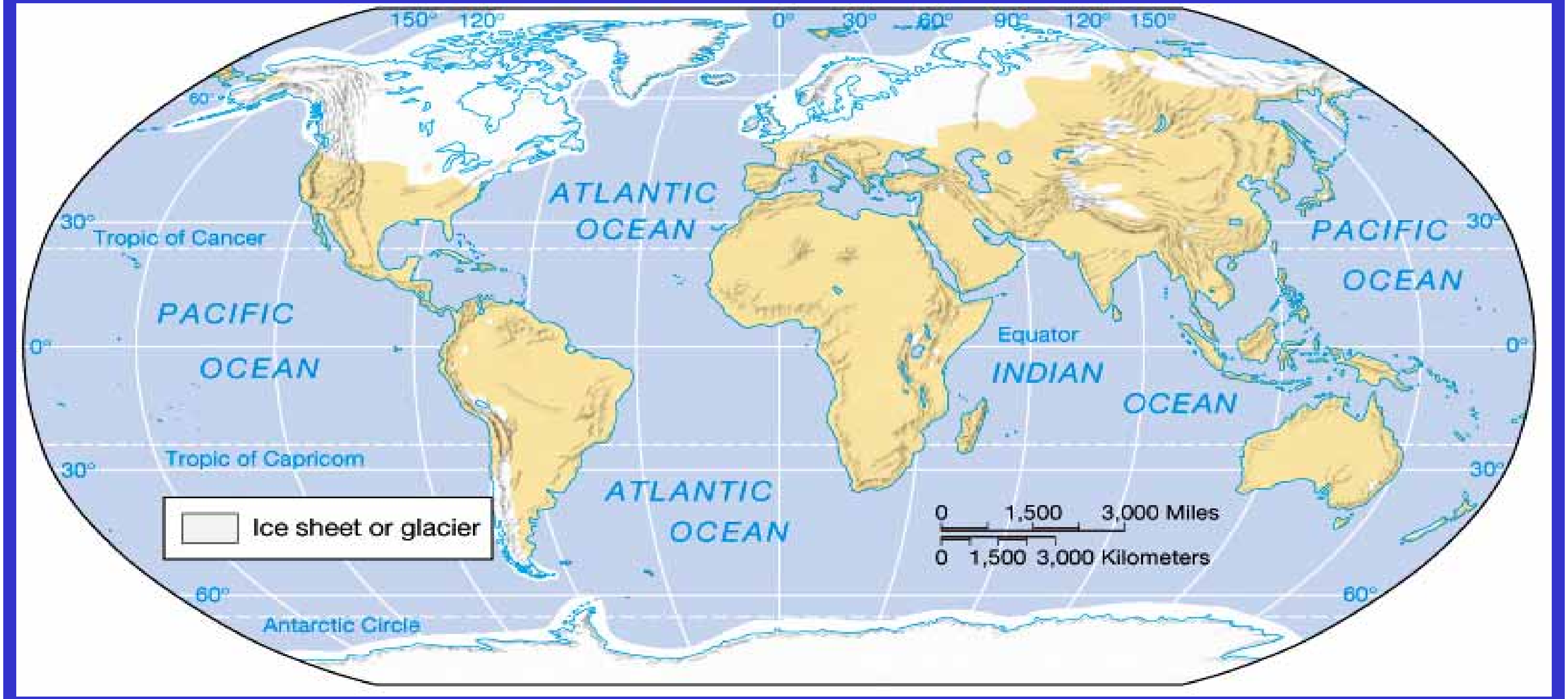
(from *Earth's Climate: Past and Future*)

- Seasonal insolation levels 21,000 years ago were nearly identical to those today.
- The only factors that can explain the colder and drier glacial maximum climate 21,000 years ago are:

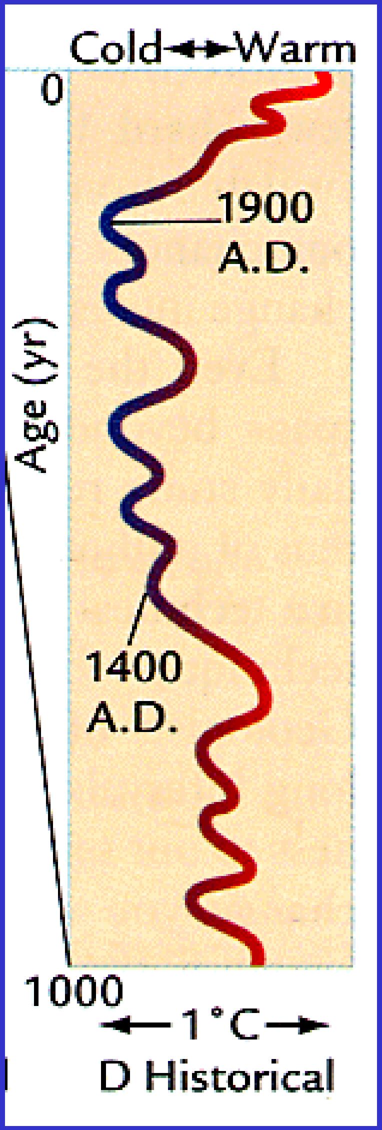
  (1) the large ice sheets

  (2) the lower values of greenhouse gases.

Ice extent during the last glacial



Historical Climate Changes

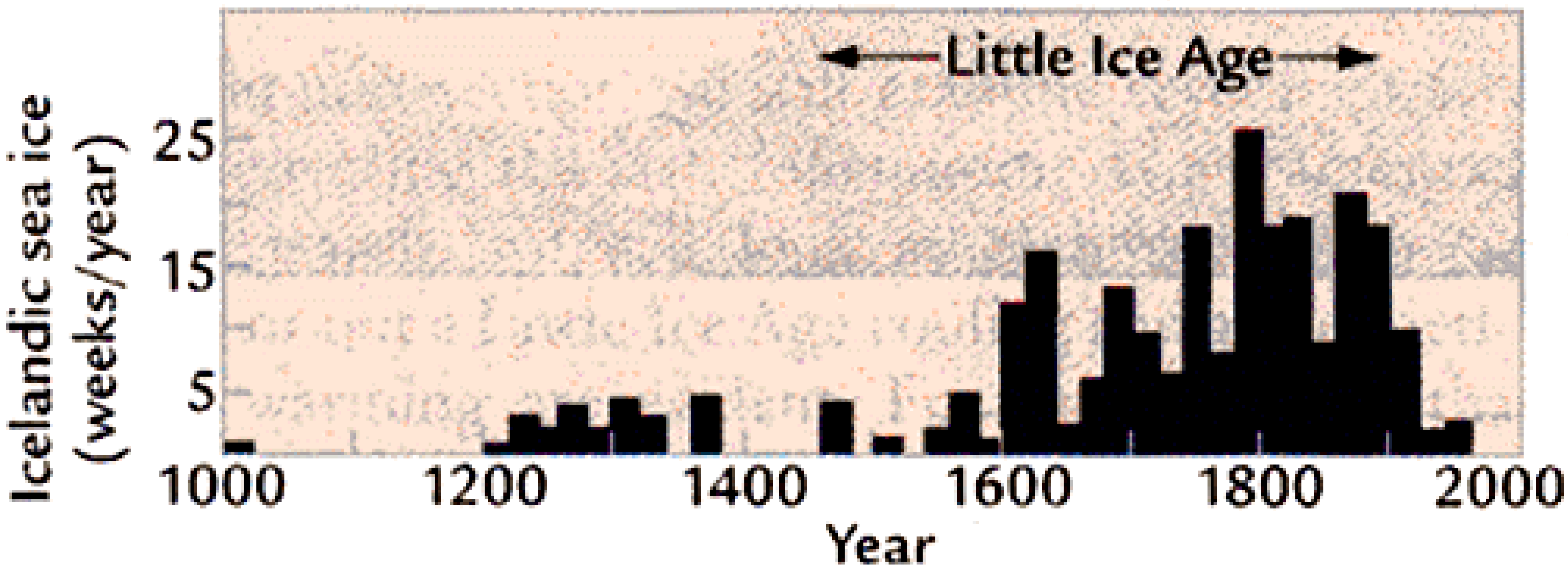


(from *Earth's Climate: Past and Future*)

- Climate changes over the last 1000 years have been smaller than those over tectonic, orbital, and glacial-age millennial time scales, never exceeding 1°C on a global basis.
- Climate changes over the last several thousand years have been highly variable in pattern from region to region.

The Little Ice Age

(from *Earth's Climate: Past and Future*)



- **Medieval Warming**: A relatively warm climate near 1000 to 1300.
- **Little Ice Age**: The cooling during 1400-1900 that seriously affect Europe.
- **Twentieth-Century Warming**