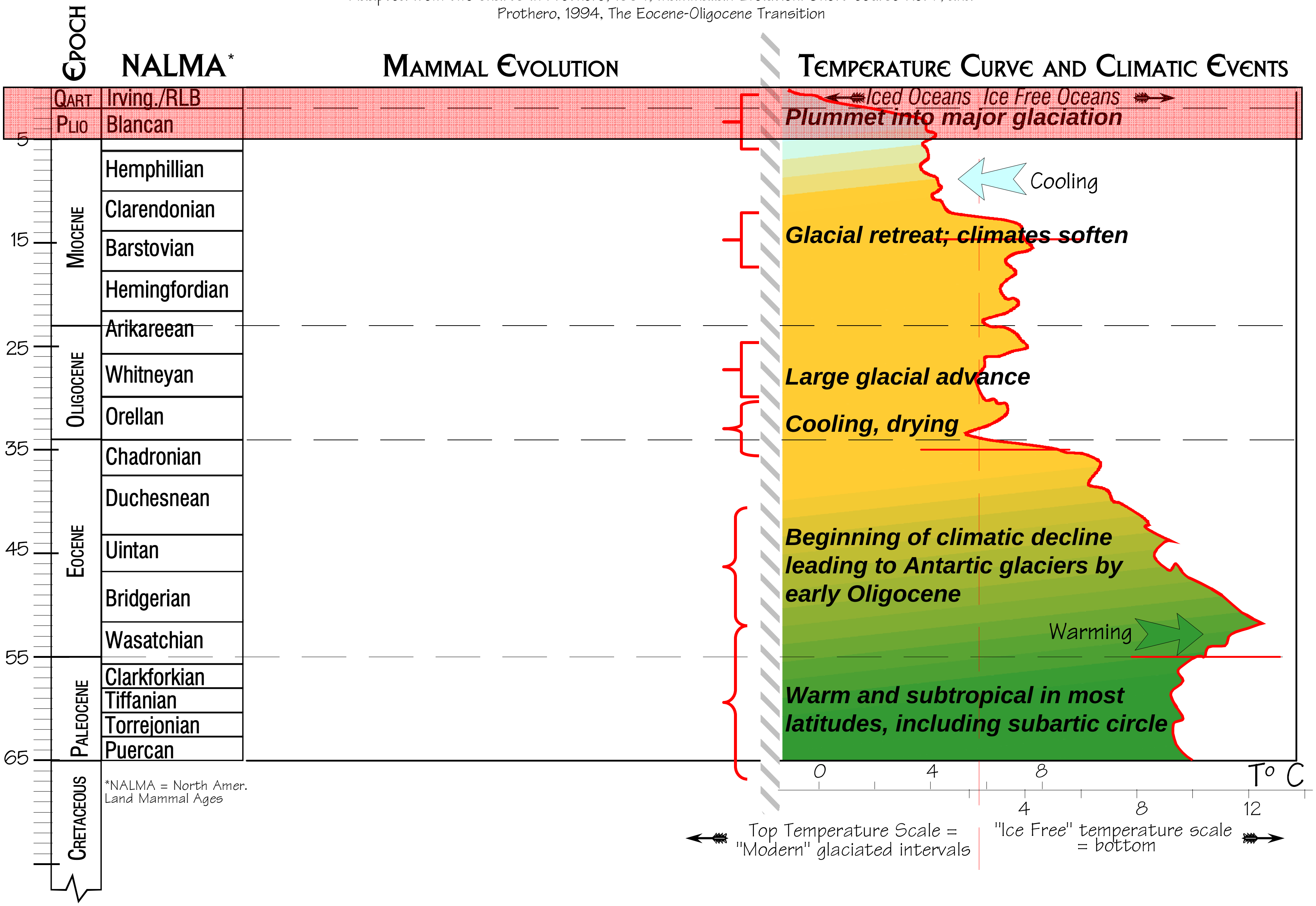
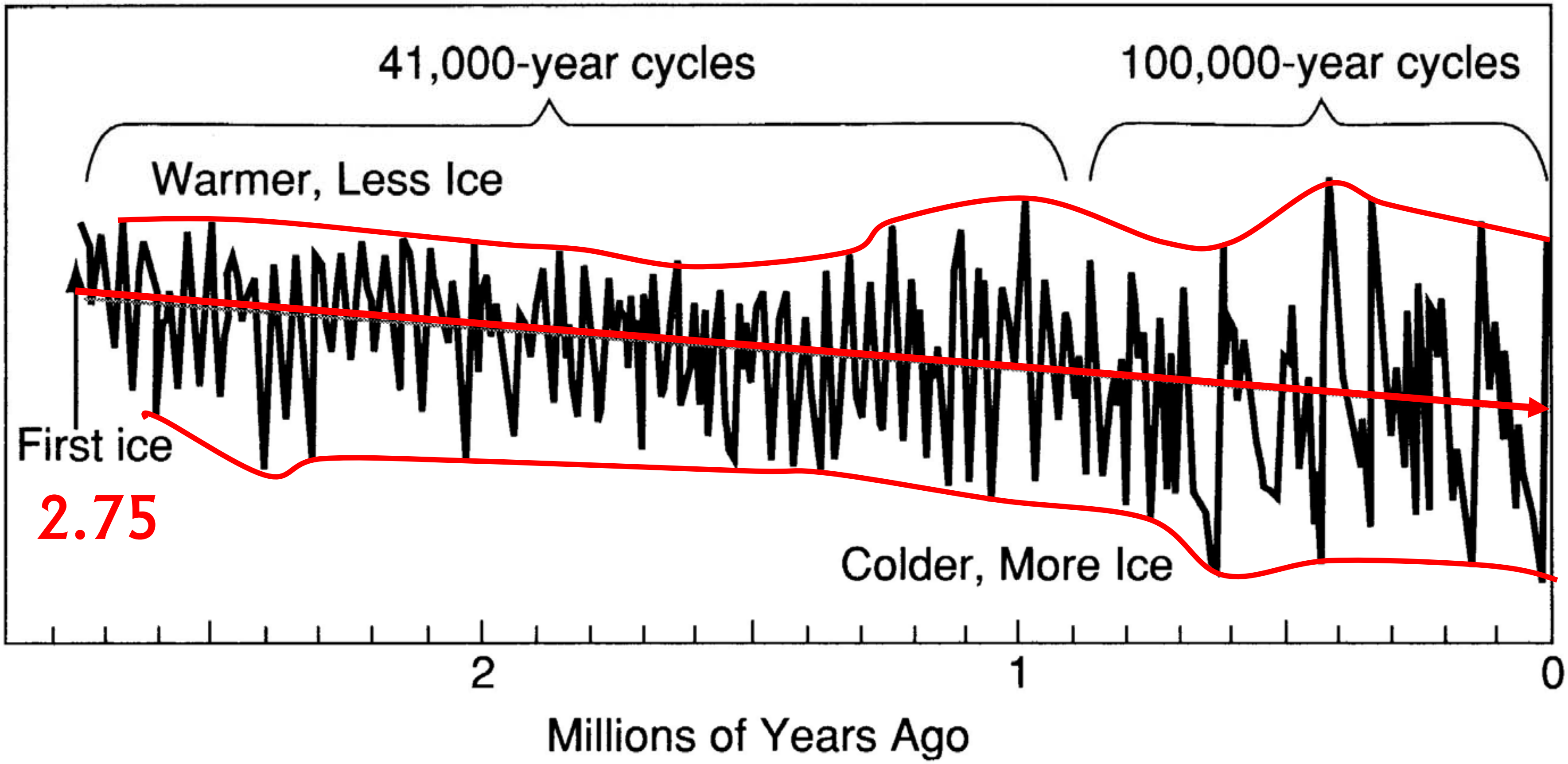
The Pleistocene Ice Ages

CENOZOIC FAUNAL AND CLIMATIC EVOLUTION

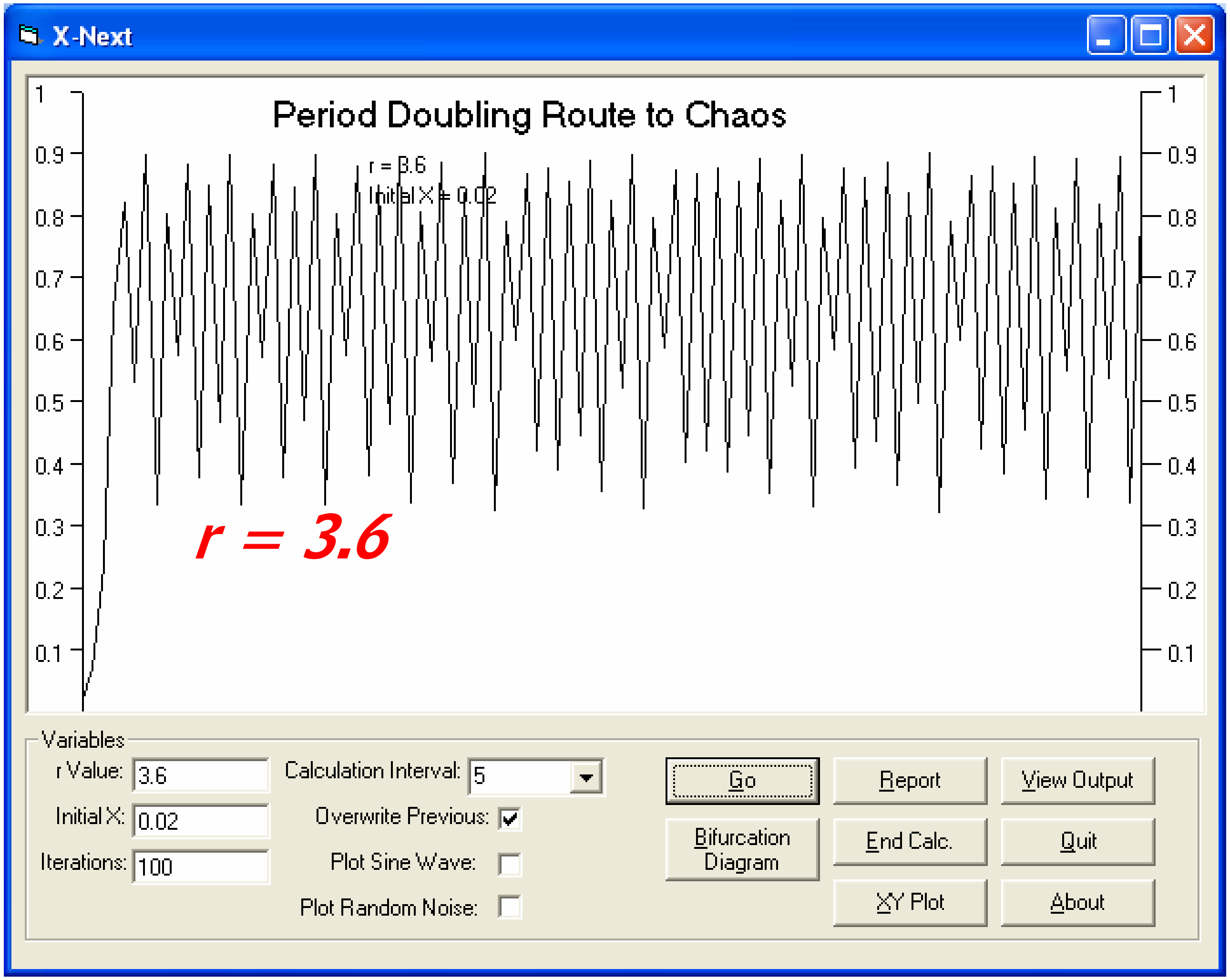
Adapted from two charts in Prothero, 1994, Mammalian Evolution: Short Course No. 7, and
Prothero, 1994, The Eocene-Oligocene Transition



*NALMA = North Amer. Land Mammal Ages



4.2. Large ice sheets first appeared in the Northern Hemisphere nearly 2.75 million years ago and grew and melted at the 41,000-year cycle of orbital tilt until about 0.9 million years ago. Since that time, the major cycle of ice-sheet changes has been at a cycle of 100,000 years.



Variables

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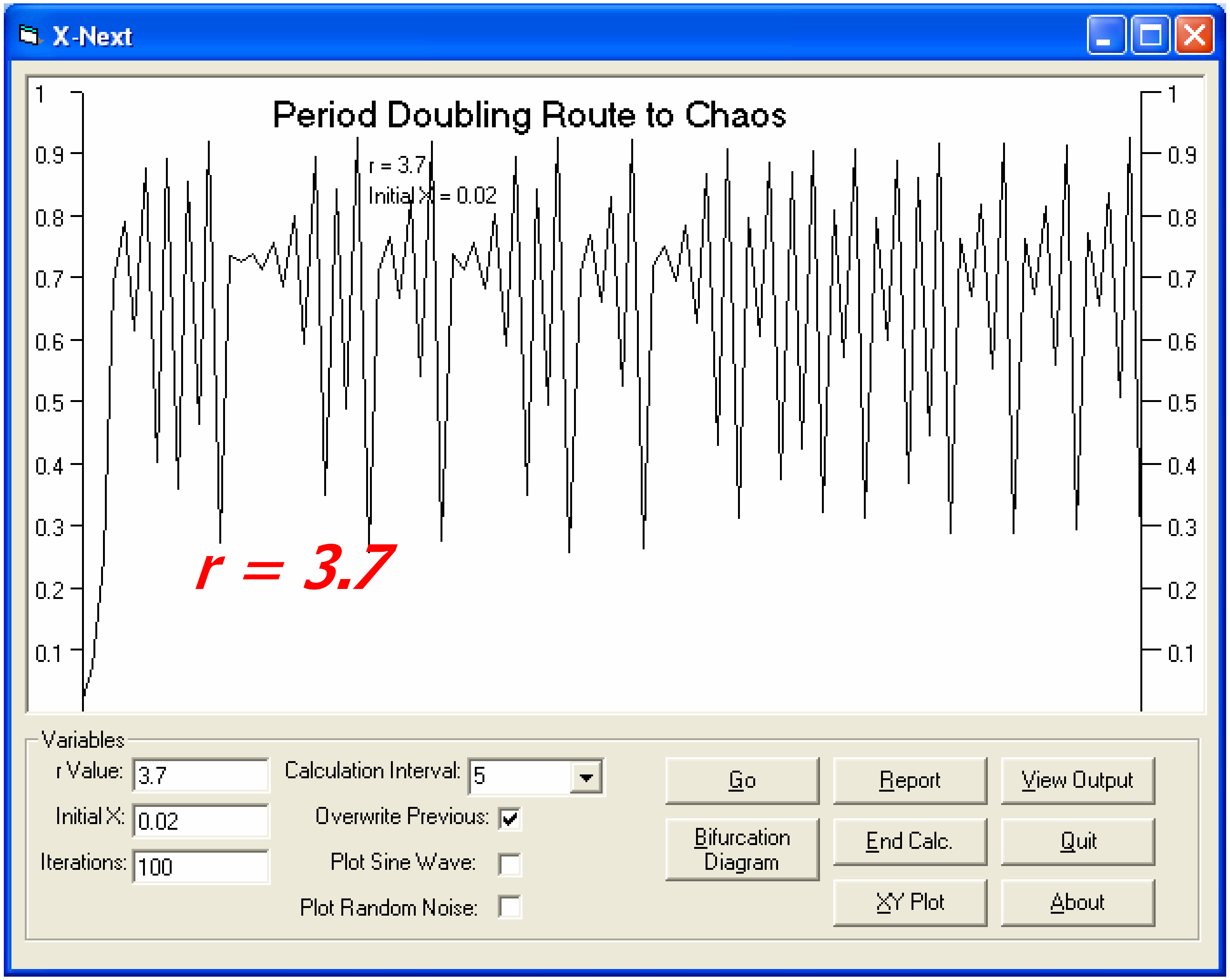
Iterations: 100
Calculation Interval: 5
Overwrite Previous: ☑
Plot Sine Wave: ☐
Plot Random Noise: ☐



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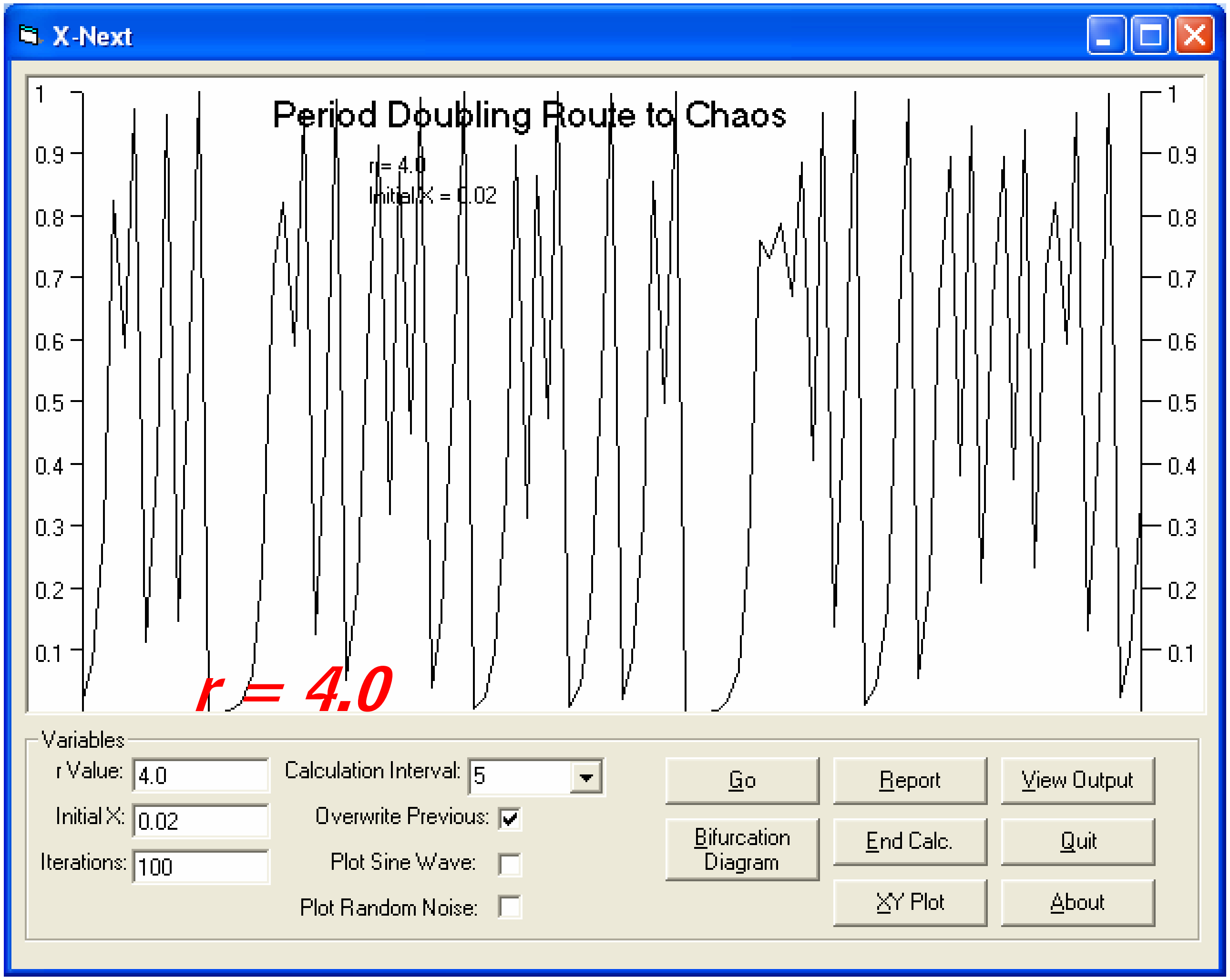
Plot Random Noise: ☐



Variables

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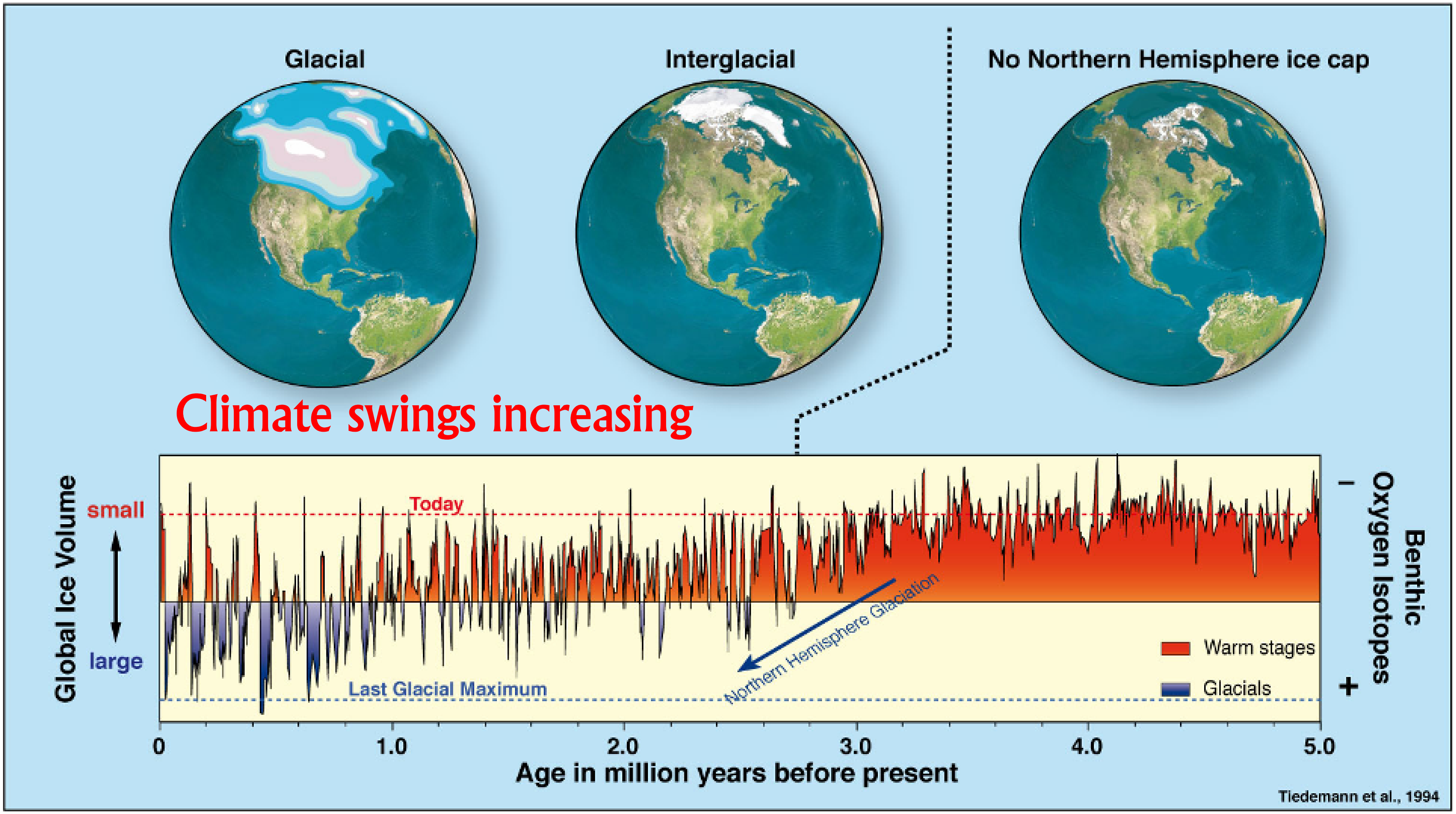
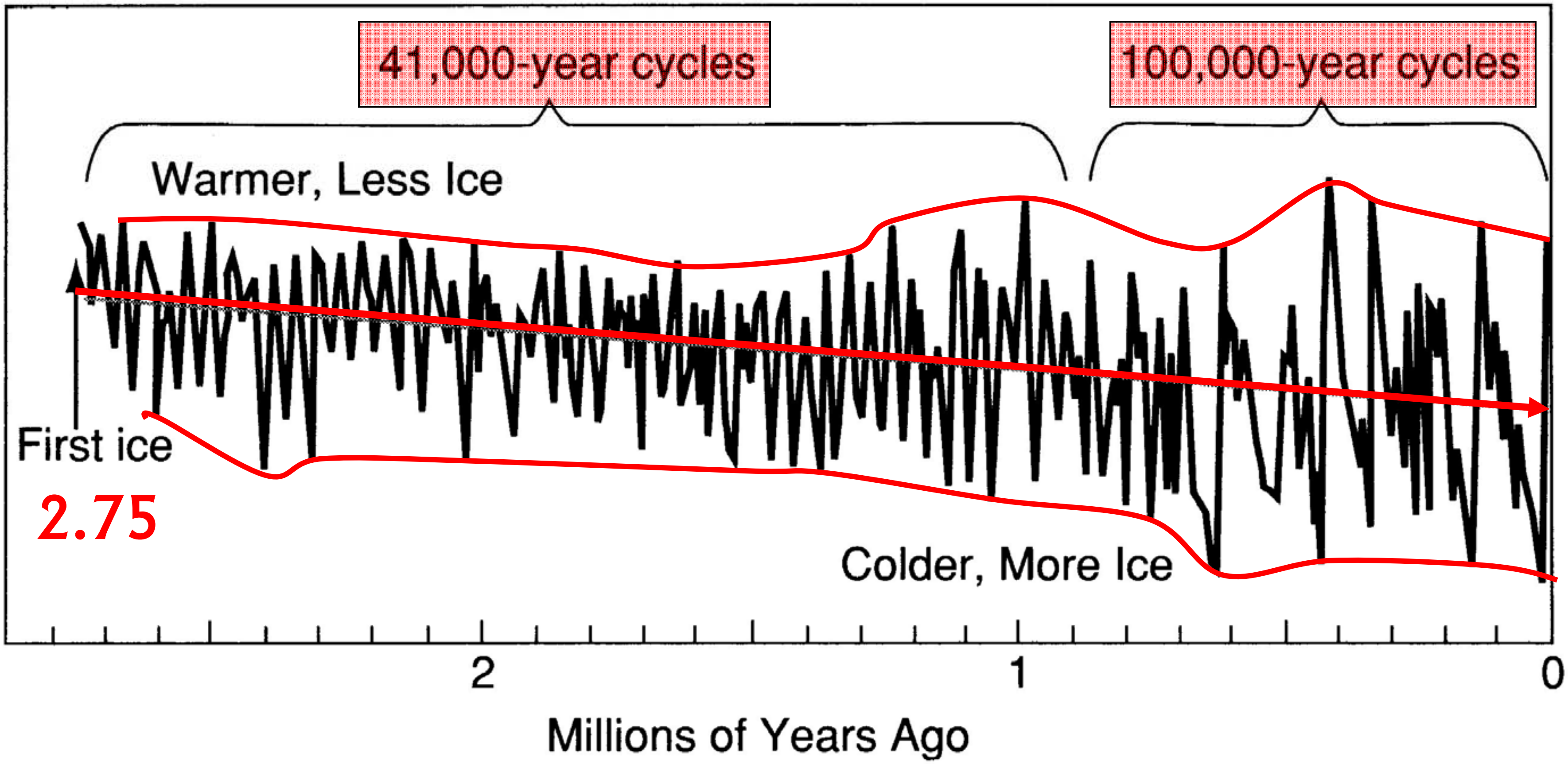


Climate swings increasing

Tiedemann et al., 1994

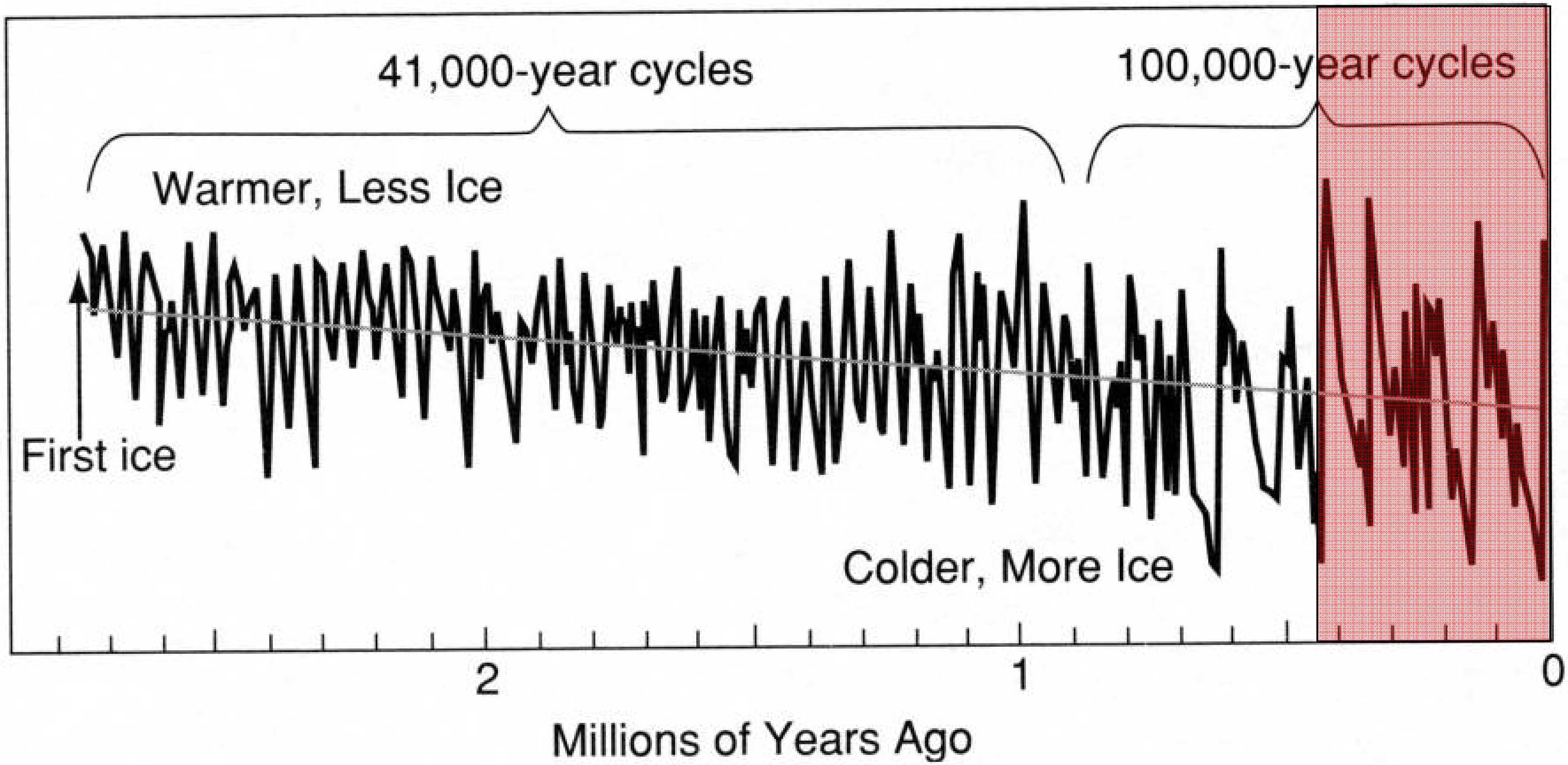
The benthic oxygen isotope curve reflects the global climate evolution of the last 5 million years, as it is a measure of changes in global ice volume and deep-water temperature. The Pliocene warm period from ~5 to ~3 million years ago is believed to hold clues for assessing future climate change. This time interval, with atmospheric CO2-concentrations close to modern ones, was significantly warmer than today. High-latitude sea surface temperatures were up to 7°C higher, the modern Northern Hemisphere ice cap over Greenland was absent, and the sea level was about 30 m higher than today. Hence, it represents a possible future climate scenario predicted by numerical models. The long-term increase in oxygen isotope values from ~3–2.5 million years ago marks the development of a permanent Northern Hemisphere ice cap with varying size. The last 3 million years are characterized by alternating glacial and interglacial climate stages, while glacial ice sheets reached their largest size during the last 700.000 years.

http://www.awi.de/de/forschung/fachbereiche/geowissenschaften/marine_geology_and_paleontology/



4.2. Large ice sheets first appeared in the Northern Hemisphere nearly 2.75 million years ago and grew and melted at the 41,000-year cycle of orbital tilt until about 0.9 million years ago. Since that time, the major cycle of ice-sheet changes has been at a cycle of 100,000 years.

450,000 Record



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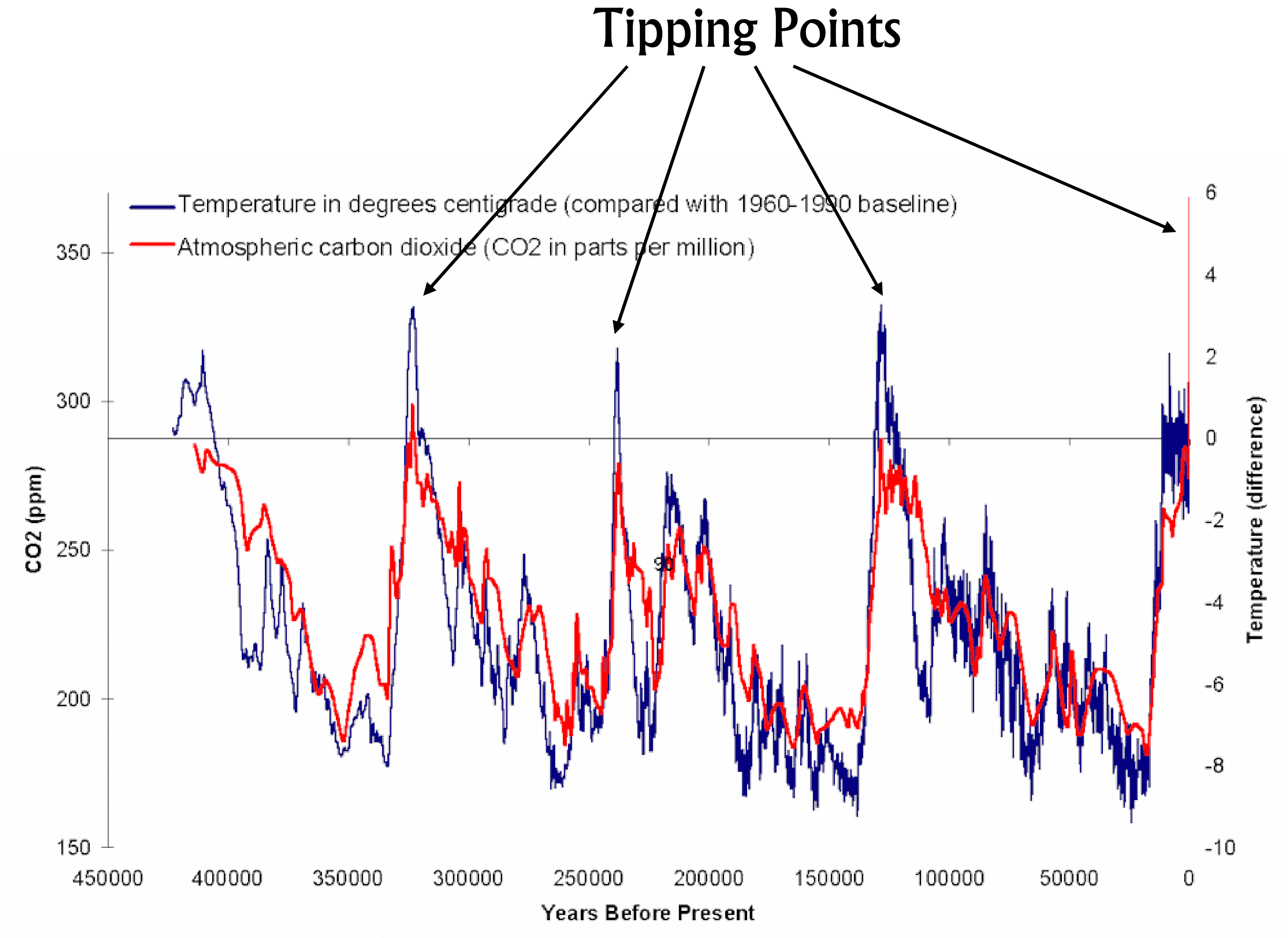
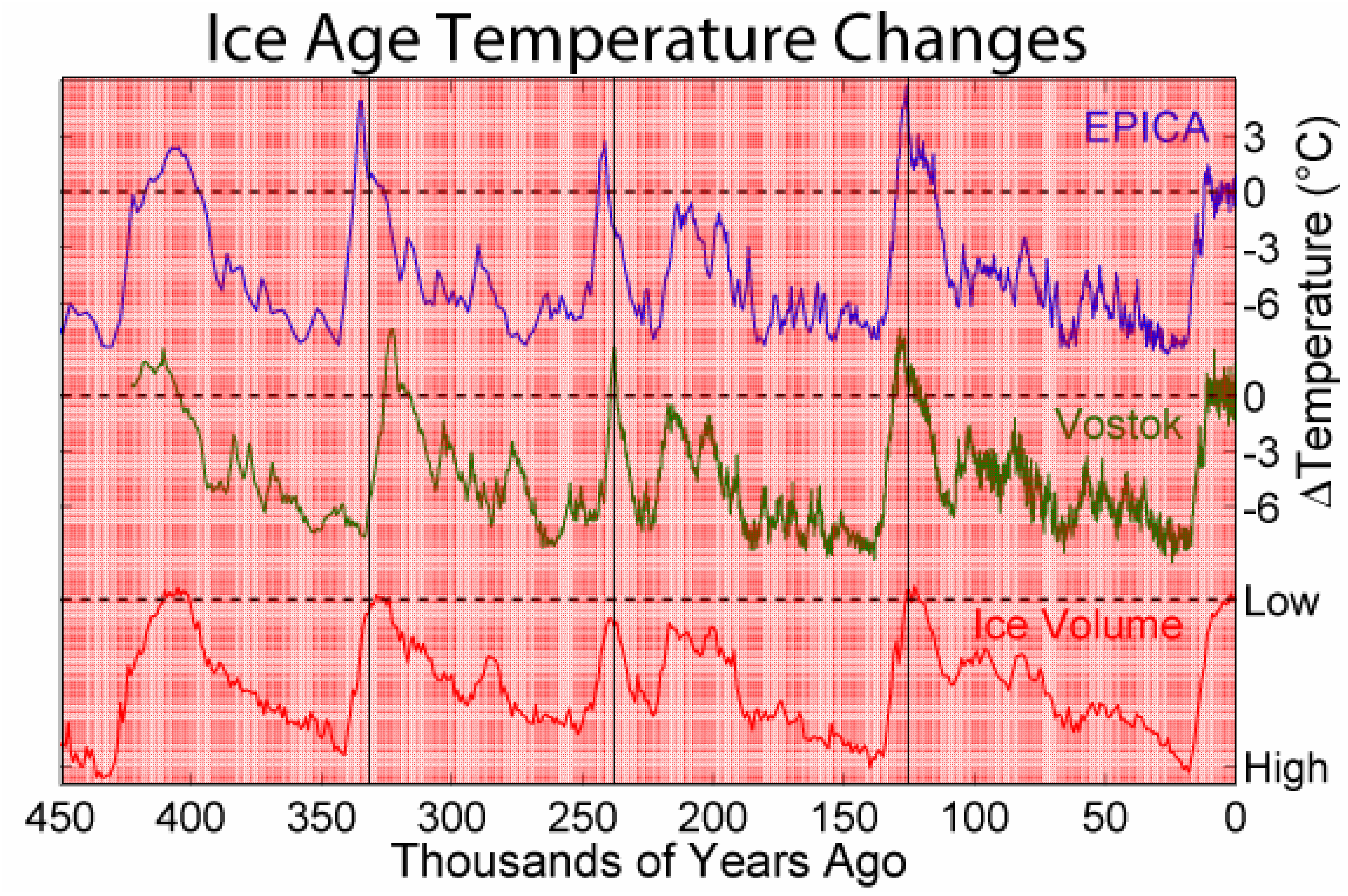
#1 - Temperature Tipping Point

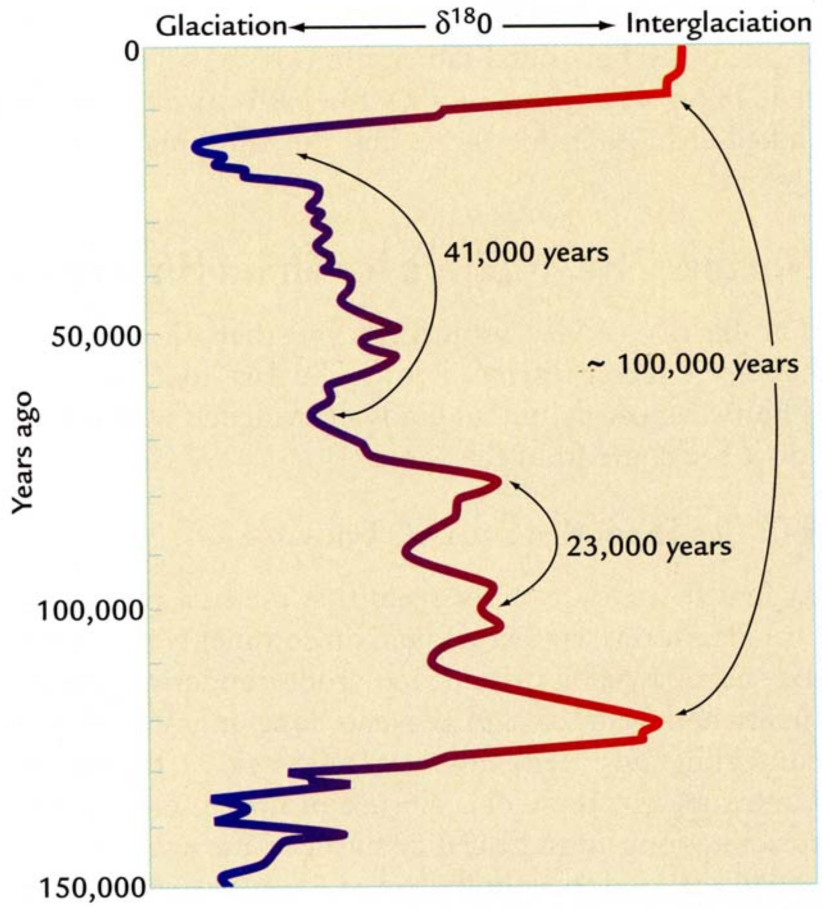

Tipping Points

450,000 Year Record

Four 100,000 long glaciations in the past 450,000 Year Record



And each 100,000 long glaciation has had numerous smaller ice fluctuations



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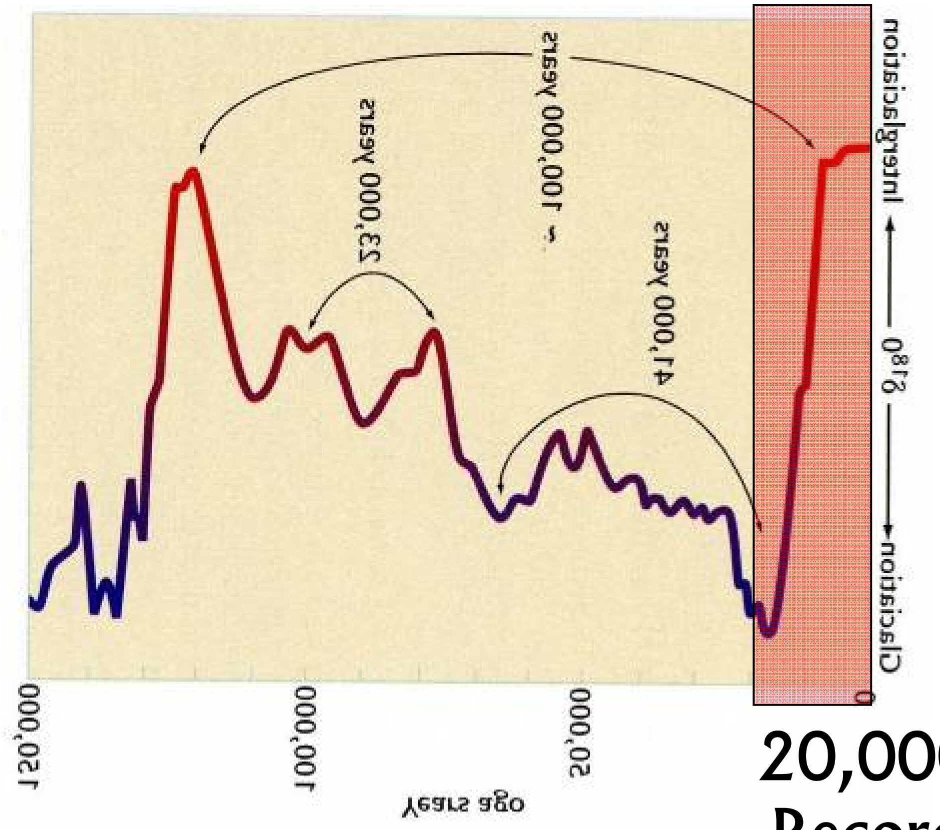
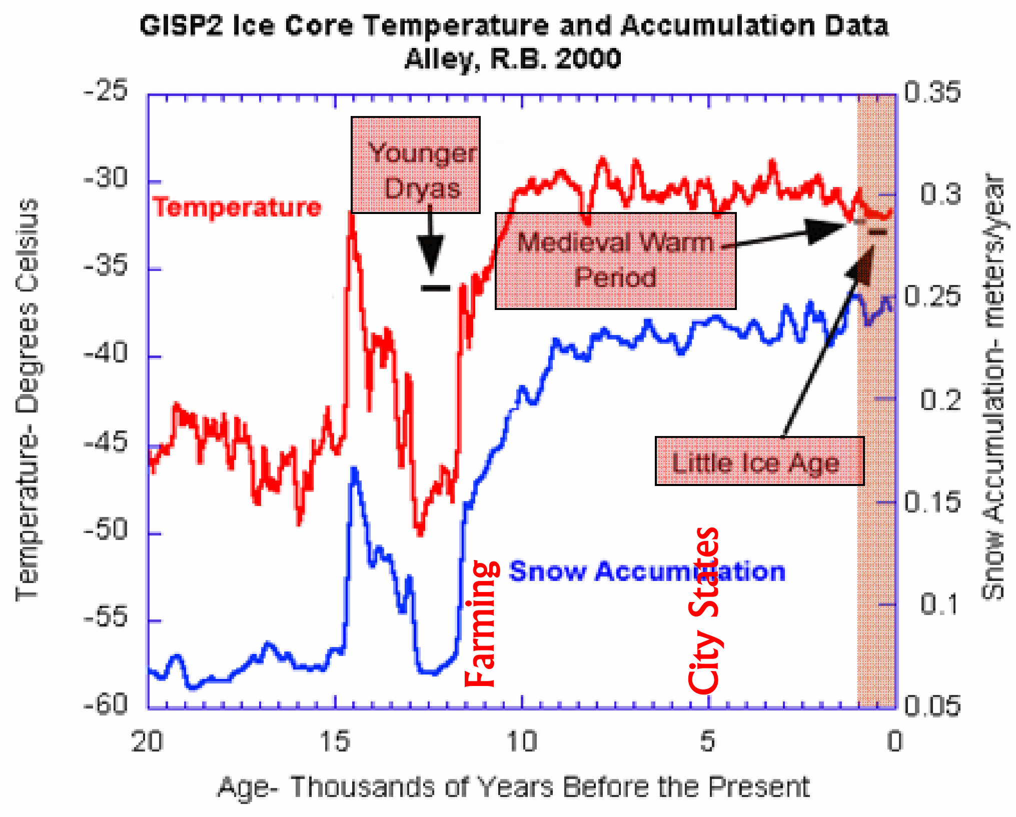


20,000
Record

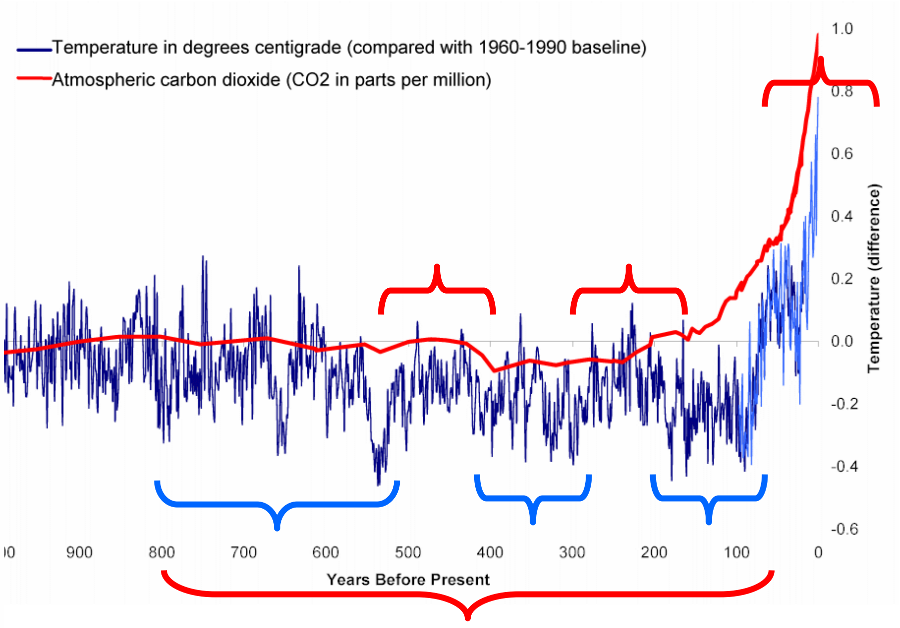
While within the 20,000 and 1,000 year records have been numerous smaller fluctuations

20,000 Year Record



GISP2 Ice Core Temperature and Accumulation Data
Alley, R.B. 2000

1,000 Year Record



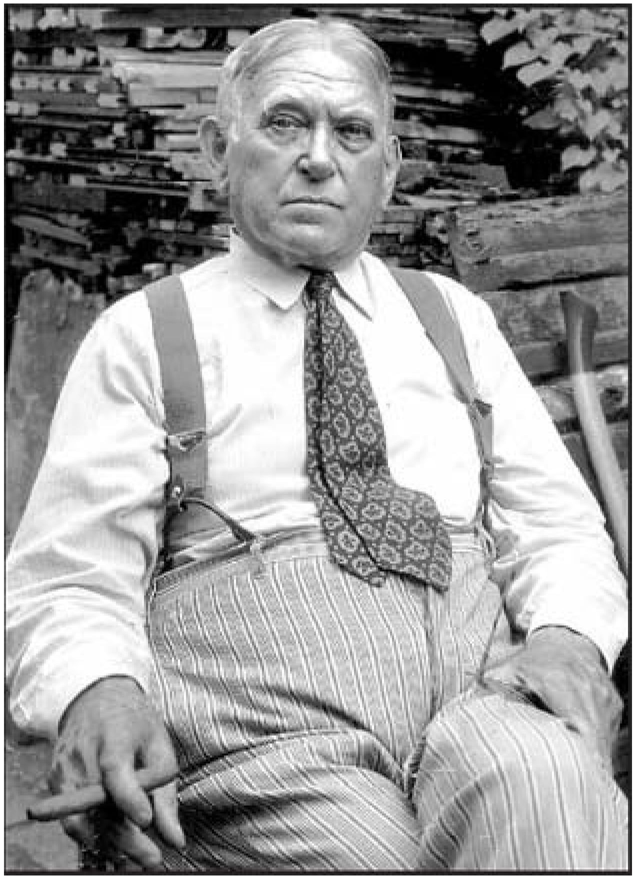
The Little Ice Age
1150-1850?

These fluctuations have produced many records of human suffering in the past several thousand years.

What Caused the Global Cooling that Lead to the Pleistocene Ice Age?

Plausible Explanations

‘For every complex problem there is a solution that is simple, neat, persuasive, and wrong.'

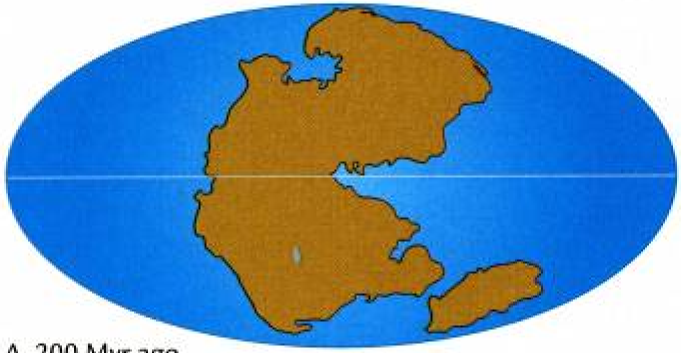


H.L. Mencken: one of the many variations on his original quote "There is always an easy solution to every human problem--neat, plausible, and wrong“

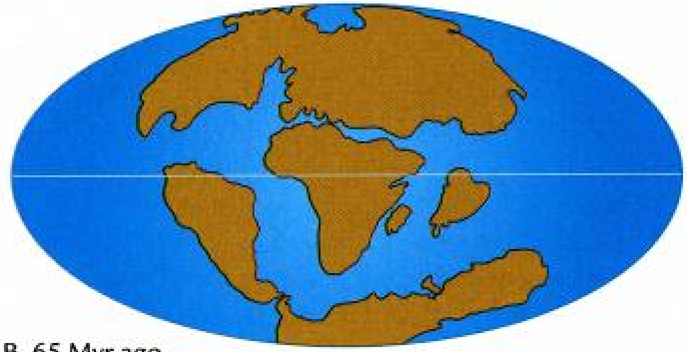
From "The Divine Afflatus," originally published in 1917, and reprinted in 1920 and 1949.

Plate movements since breakup of Pangaea

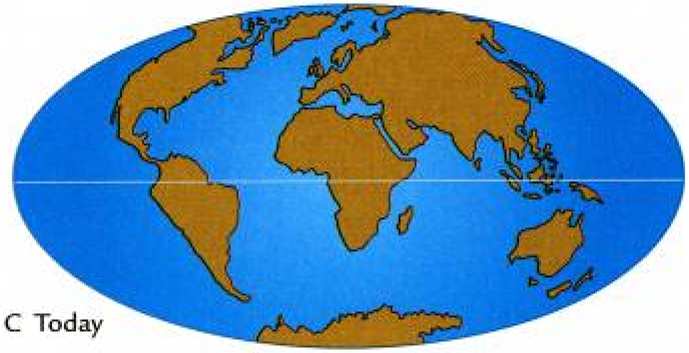
1. Gateway Hypotheses



A 200 Myr ago



B 65 Myr ago



C Today

FIGURE 6-9 Continental movements since 200 Myr ago Since (A) the time of Pangaea, 200 Myr ago, (B, C) the Atlantic Ocean has widened, the Pacific Ocean has narrowed, and India and Australia have separated from Antarctica and moved northward to lower latitudes. (Modified from F. Press and R. Siever, Understanding Earth, 2nd ed., © 1998 by W. H. Freeman and Company.)

Plate movements since breakup of Pangaea

1. Gateway Hypotheses

Case Study 1: Antarctica

FIGURE 6-10 Opening of Drake's Passage Opening of an ocean gap between South America and Antarctica near 25 to 20 Myr ago allowed a strong Antarctic circumpolar current (arrows) to flow uninterrupted around the Antarctic continent. The passageway between Australia and Antarctica had opened 10 Myr earlier. (Adapted from E. J. Barron et al., "Paleogeography: 180 Million Years Ago to the Present," *Ecologae Geologicae Helvatiae* 74 [1981]: 443–70.)

Plate movements since breakup of Pangaea

> *"It seems unlikely that such discontinuous gateway episodes could have driven a progressive climate cooling for 50 Myr."*

1. Gateway Hypotheses

Case Study 2: Central America Seaway

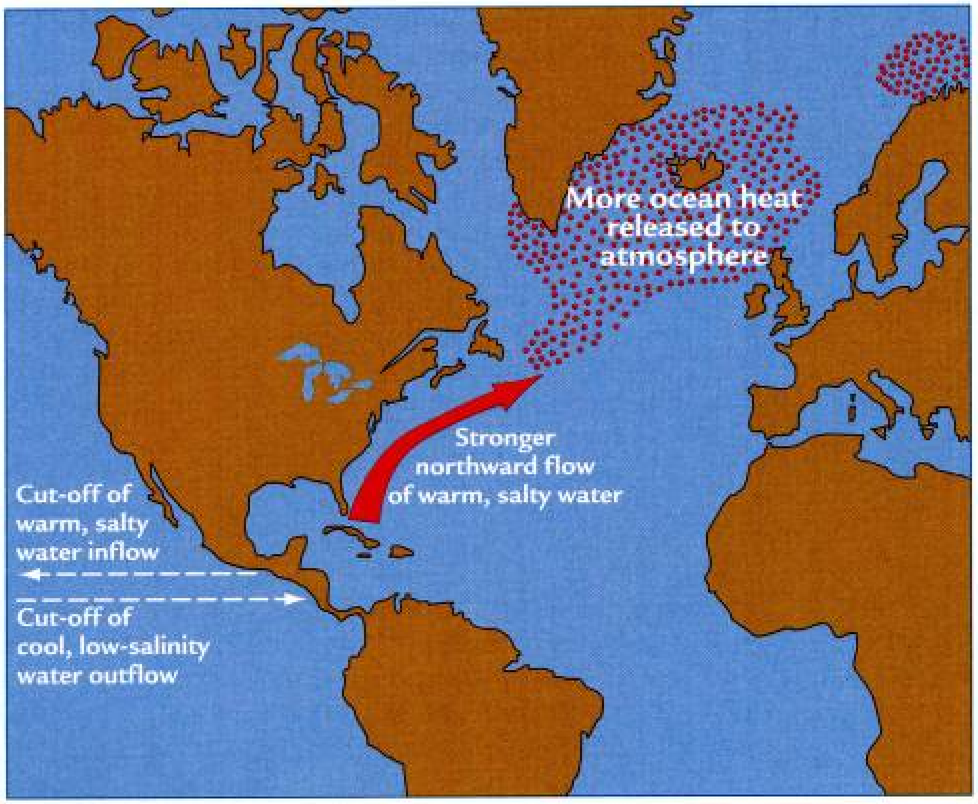


FIGURE 6-11 Closing of the Isthmus of Panama Simulations with ocean models indicate that gradual closing of the Central American isthmus between 10 and 4 Myr ago redirected warm, salty water northward into the Atlantic Ocean, reduced the extent of high-latitude sea ice, and handed off additional heat to the atmosphere. (Adapted from E. Maier-Reimer et al., "Ocean General Circulation Model Sensitivity Experiment with an Open Central American Isthmus," *Paleoceanography* 5 [1990]: 349-66.)

Plate movements since breakup of Pangaea

1. Gateway Hypotheses
2. Changes in ocean spreading rates hypothesis.

More specifically the slowing of sea floor spreading slows the amount of volcanism, that slows the amount of CO_2 *put into the atmosphere, that reduces the greenhouse effect, that causes cooling.*

"The evidence indicates that the spreading rate hypothesis may have explained global cooling before 15 Myr ago, but it predicts a warming during the last 15 Myr, when a major cooling has actually occurred.

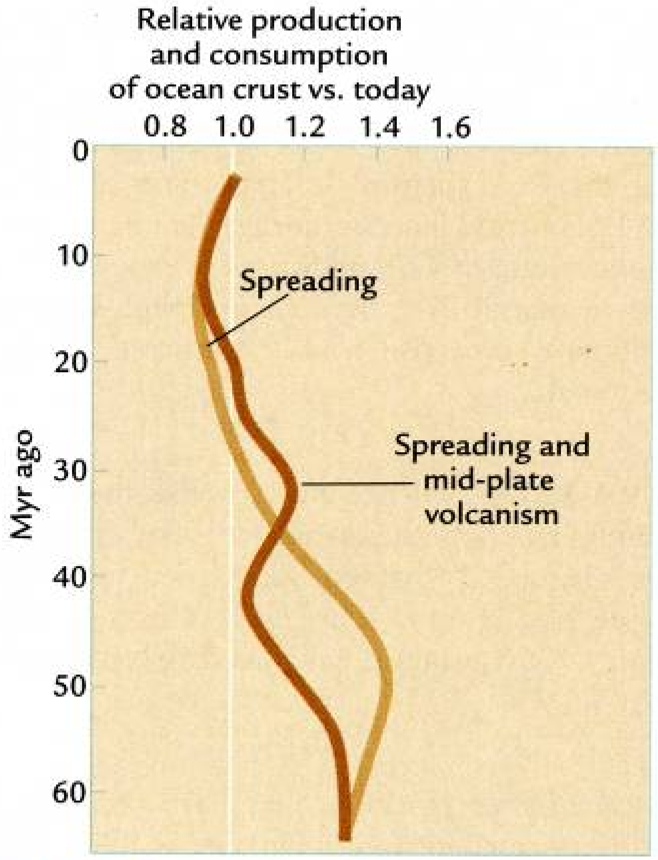


FIGURE 6-12 **Changes in spreading rates** The average rate of seafloor spreading slowed until 15 Myr ago, but it has since increased slightly. Adding the effects of generation of new crust by volcanism at hot spots away from plate margins does not change this basic trend. (Adapted from L. R. Kump and M. A. Arthur, "Global Chemical Erosion During the Cenozoic," in *Tectonic Uplift and Climate Change*, ed. W. F. Ruddiman [New York: Plenum Press, 1997].)

Plate movements since breakup of Pangaea

1. Gateway Hypotheses
2. Changes in ocean spreading rates hypothesis.

Uplift-weathering hypothesis.

Uplift-weathering hypothesis.

Development of extensive high terranes . . .

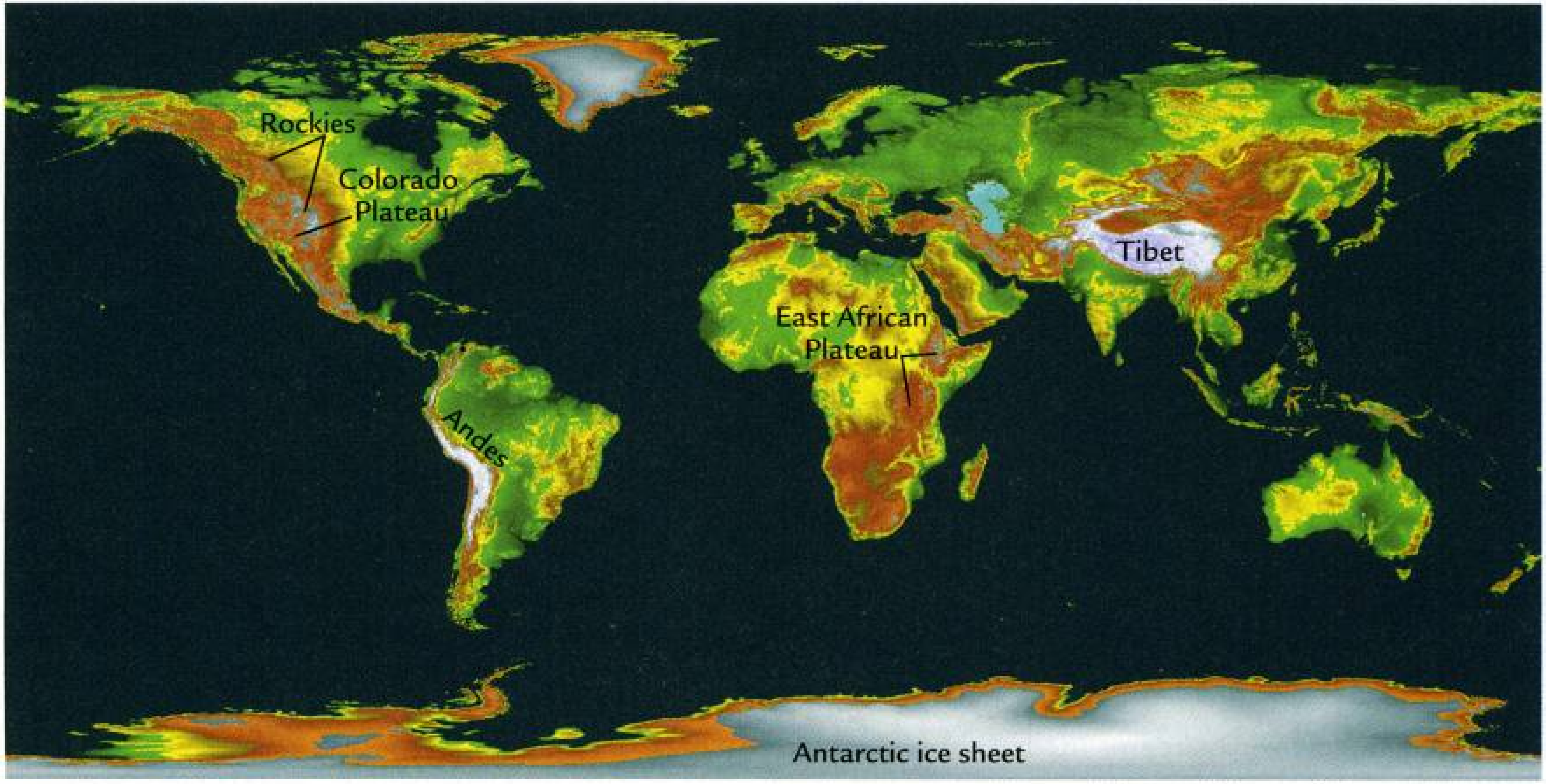


FIGURE 6-13 Earth's high topography Earth today has only a few regions where broad areas of land stand more than 1 km high (shown in brown, blue, and white). Except for the high ice domes on Antarctica and Greenland, the highest bedrock surfaces are the Tibetan Plateau and other high terrain in southern Asia, the Andes of South America, the Rocky Mountains and Colorado Plateau of North America, and the volcanic plateaus of eastern and southern Africa. (Courtesy of Peter Schloss, National Geophysical Data Center, Boulder, CO.)

Uplift-weathering hypothesis.

Which leads to increased monsoonal rains that enhances the intensity of the warm, moist summers . . .

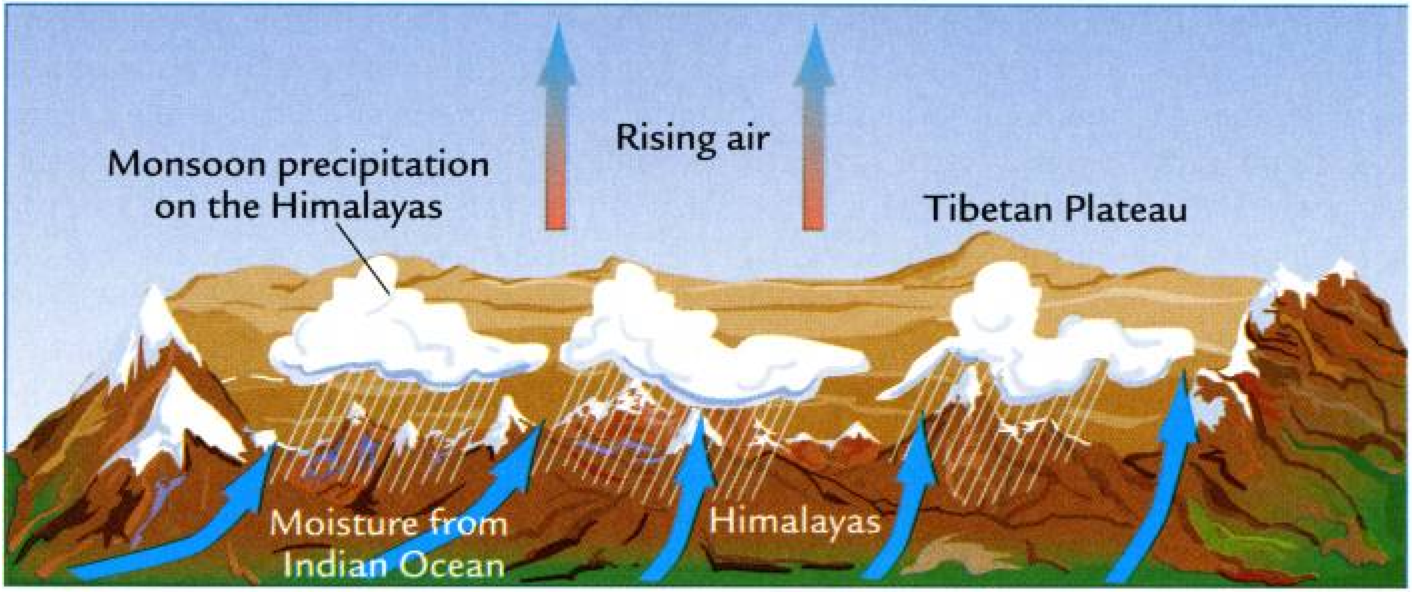


FIGURE 6-17 Tibet and the monsoon Heating of the Tibetan Plateau draws in moisture from the Indian Ocean and enhances the intensity of the warm, moist summer monsoon on its southern (Himalayan) margin

Uplift-weathering hypothesis.

Which leads to increases in physical and chemical weathering . . .

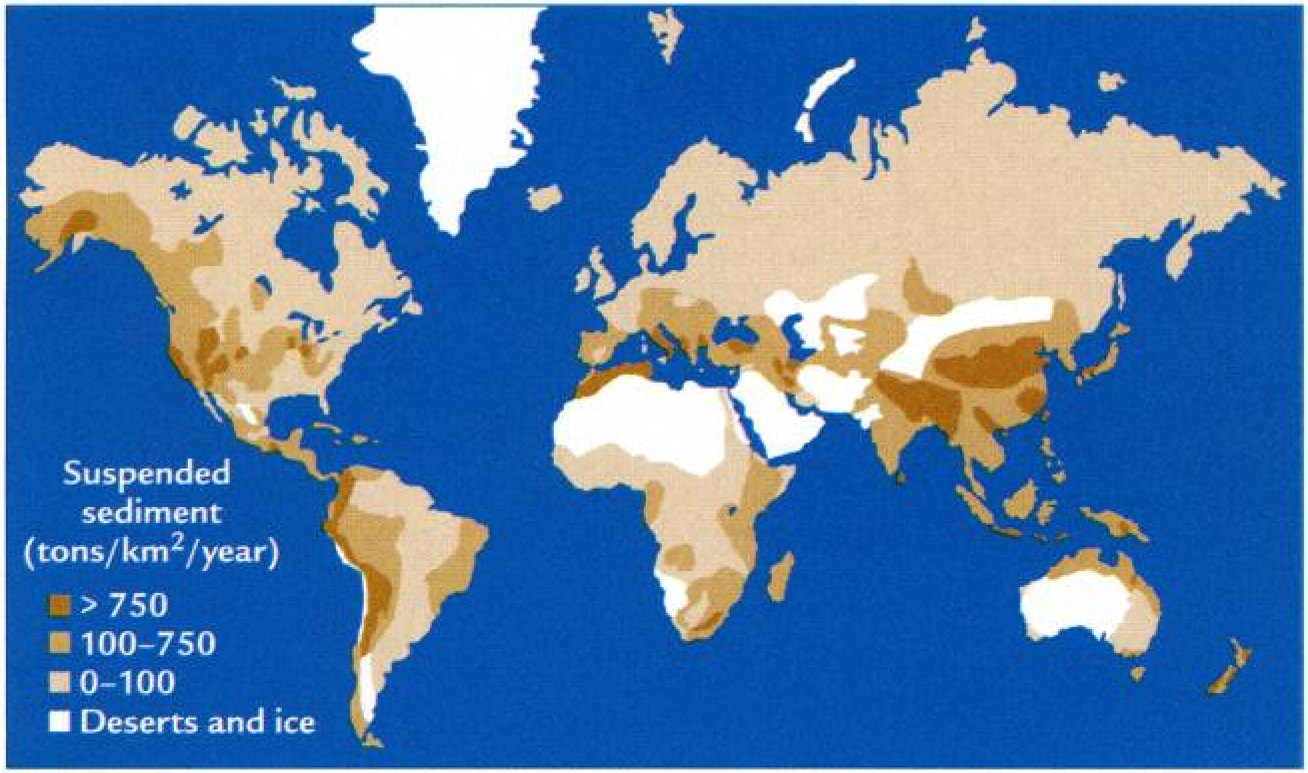


FIGURE 6-15 Sediments suspended in rivers The annual yield of suspended sediments is highest in two regions: the Himalayas of southeast Asia and the Andes of South America. (Adapted from D. E. Walling and B. W. Webb, “Patterns of Sediment Yield,” in *Background to Paleohydrology*, ed. K. J. Gregory [New York: Wiley, 1983].)

Uplift-weathering hypothesis.

Which leads to increases in physical and chemical weathering . . .

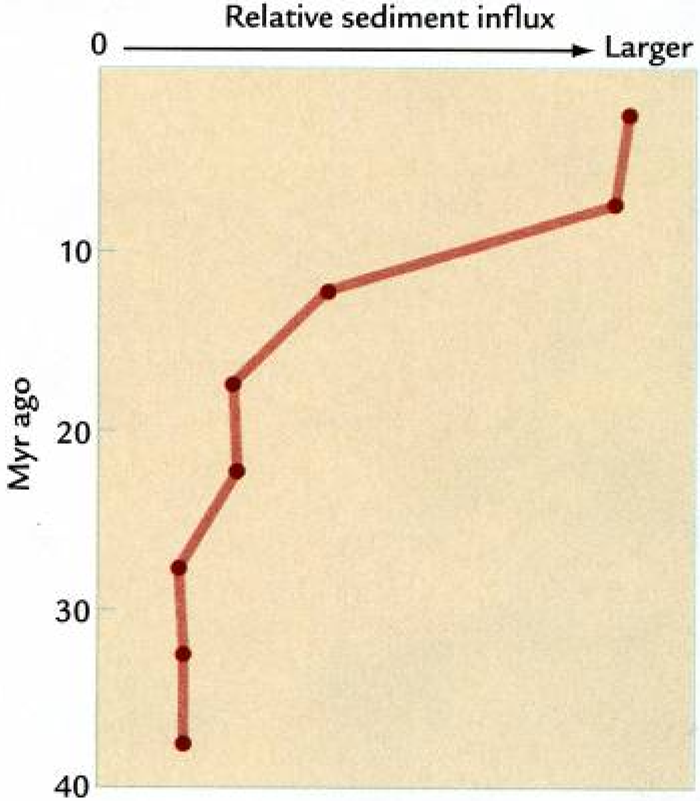
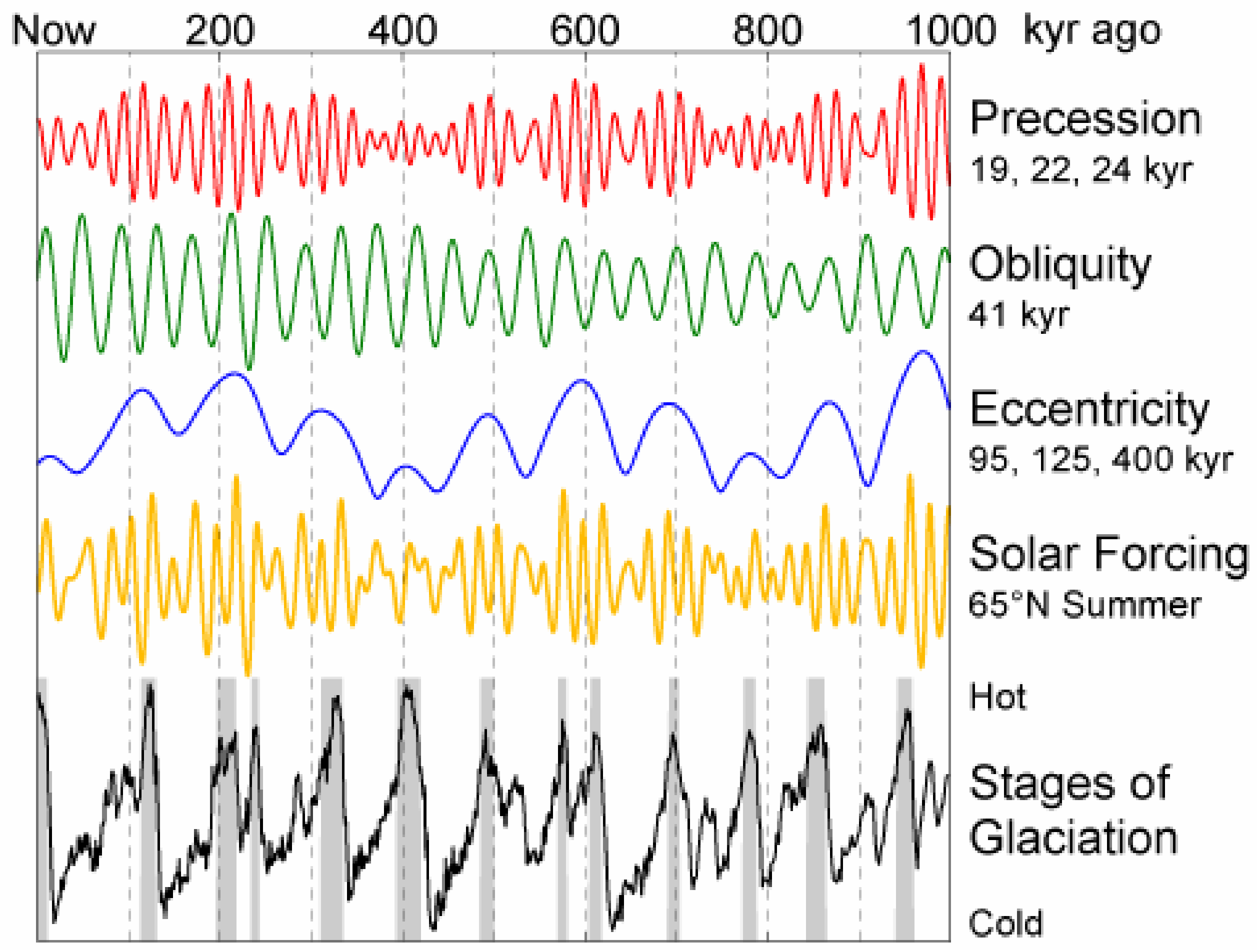


FIGURE 6-16 Himalayan sediments in the Indian Ocean The rate of influx of sediments from the Himalayas and Tibet to the deep Indian Ocean has increased almost tenfold since 40 Myr ago. (Adapted from D. K. Rea, "Delivery of Himalayan Sediment to the Northern Indian Ocean and Its Relation to Global Climate, Sea Level, Uplift, and Seawater Strontium," in *Synthesis of Results from Scientific Drilling of the Indian Ocean,* ed. R. A. Duncan et al. [Washington, DC: American Geophysical Union, 1992].)

Uplift-weathering hypothesis.

Which draws down carbon dioxide leading to cooling . . .

Which along with Milankovitch orbital cycles, leads to cycles of glaciation .

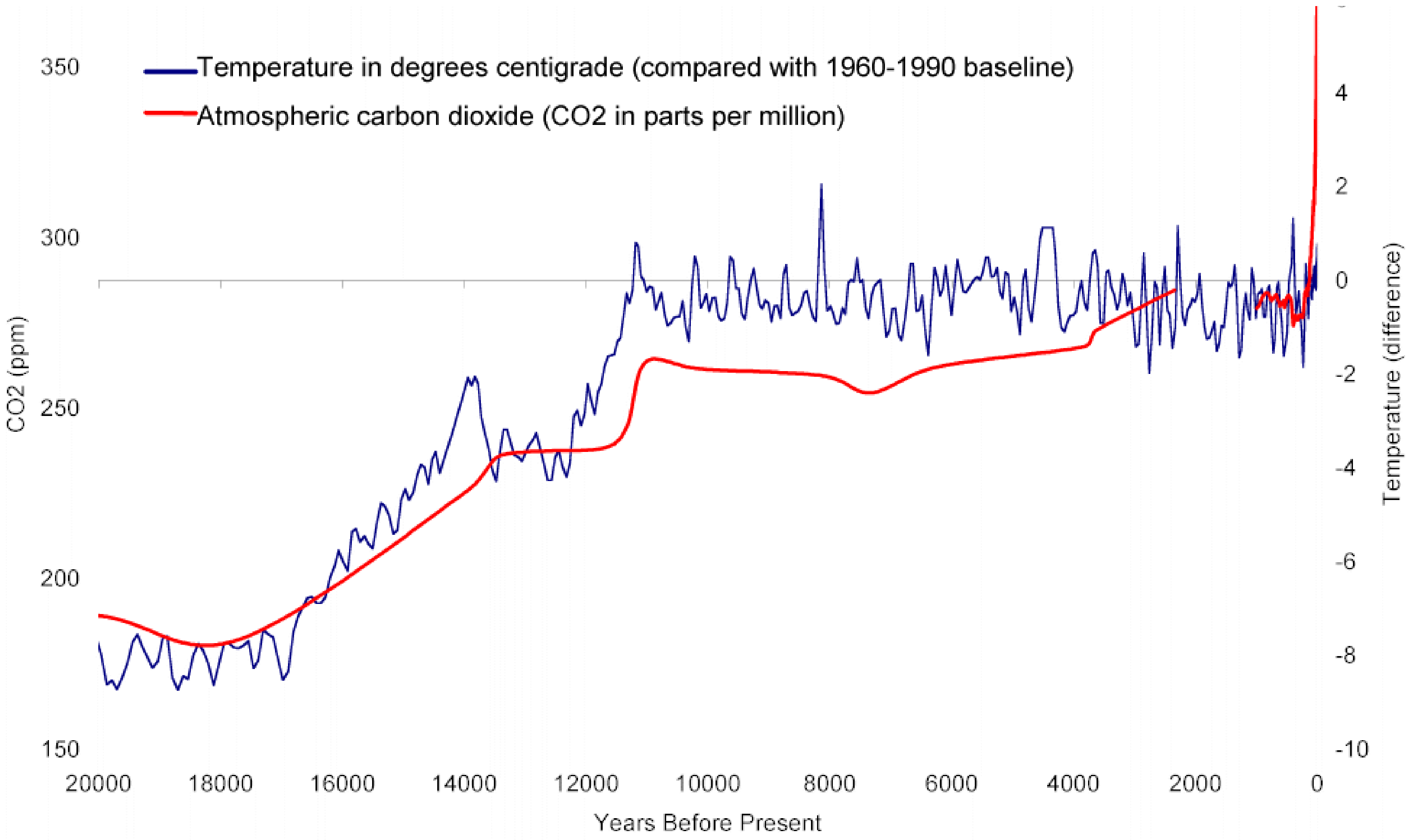


Environmental Effects of Ice Age Climates

Greenhouse Gasses

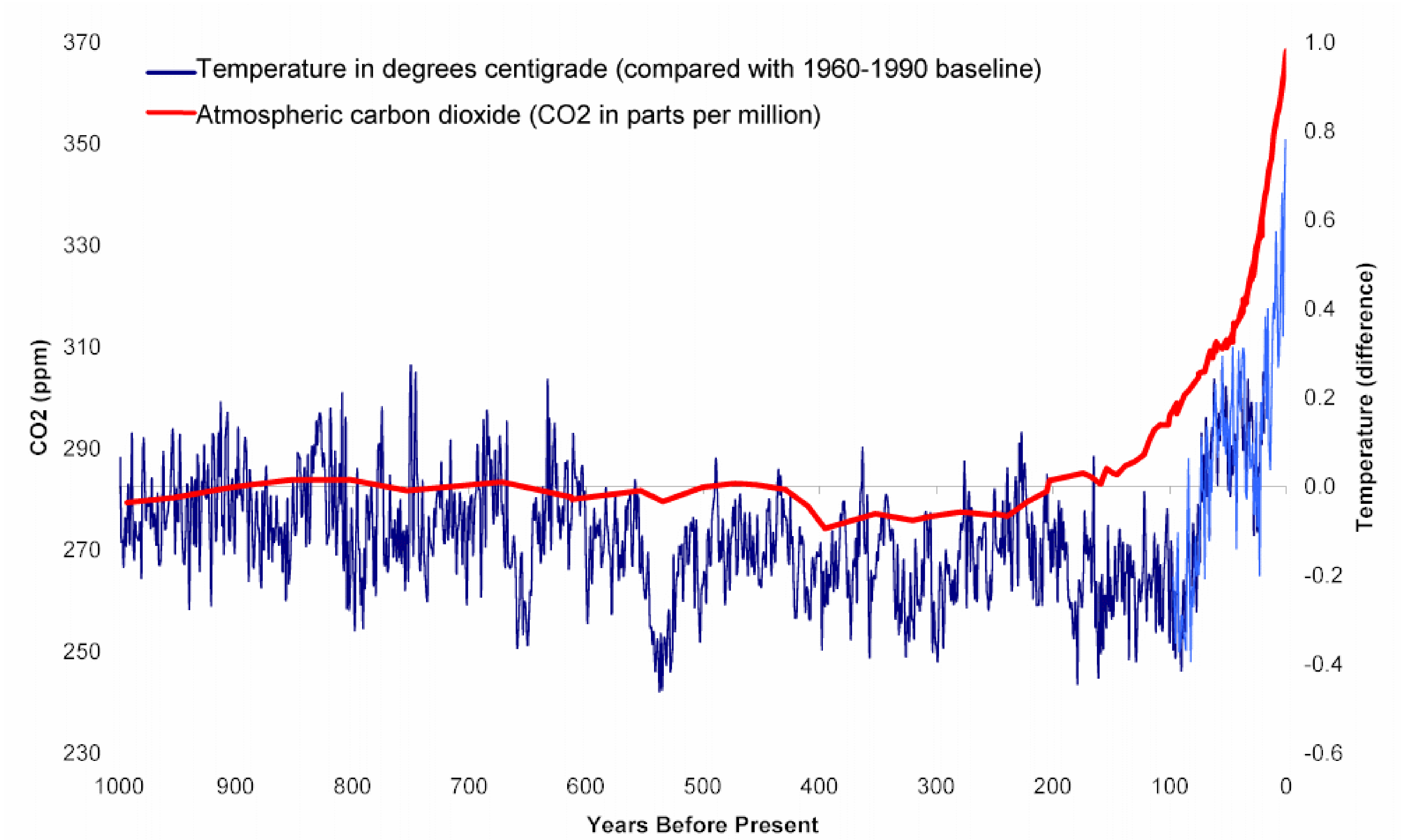
Correlation with glaciation events

Carbon Dioxide/T° 20,000 Year Record



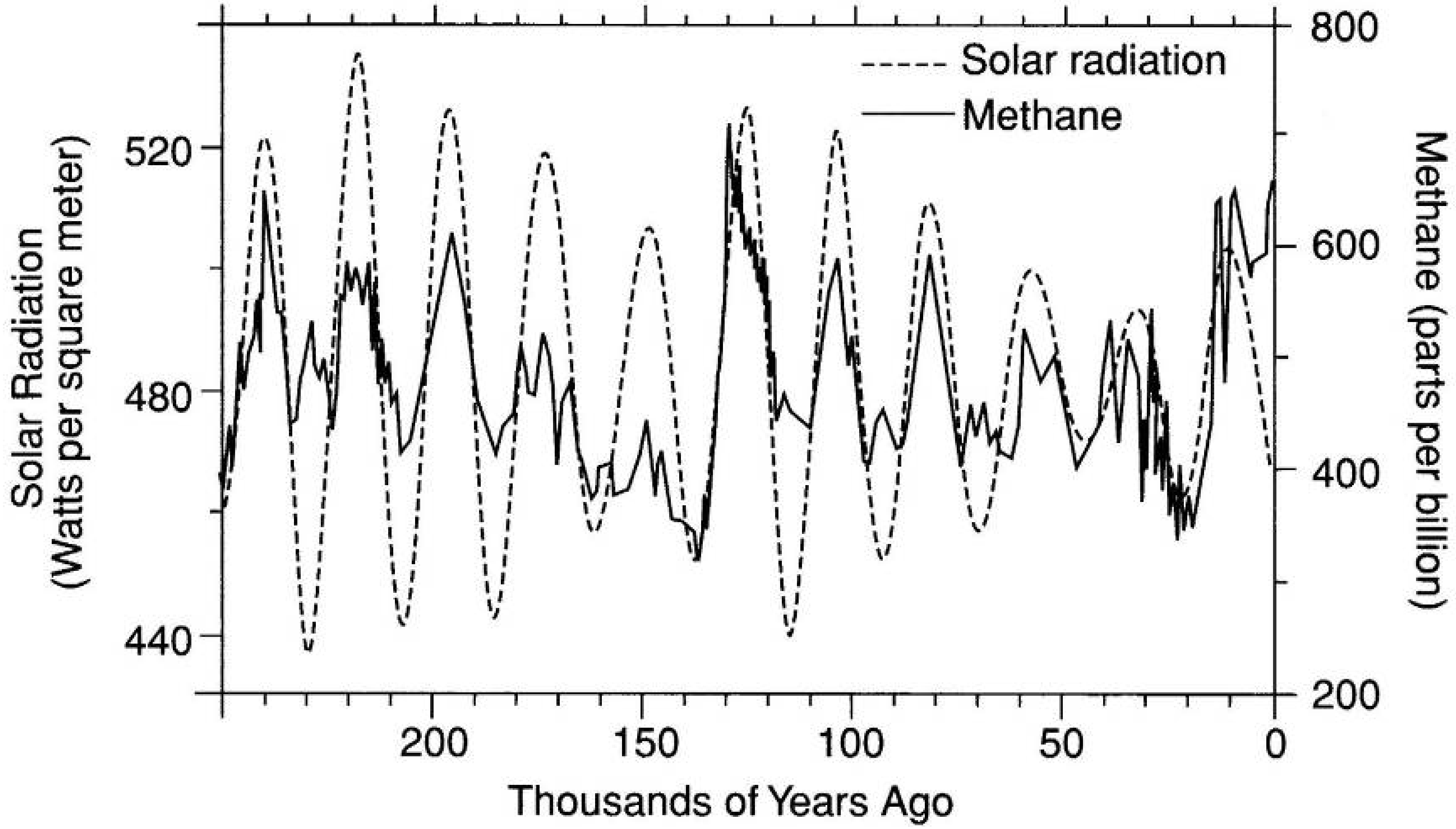
Temperature and carbon dioxide track together

Carbon Dioxide/T° 1,000 Year Record



Temperature and carbon dioxide track together

Methane/T° 250,000 Year Record



Temperature and methane track together

Greenhouse Gasses

Whom is driving whom?

CO_2 and CH_4 clearly track temperature changes . . . But . .

Do the fluctuations in greenhouse gasses lag behind, or respond to the advance and retreat of the glaciers?

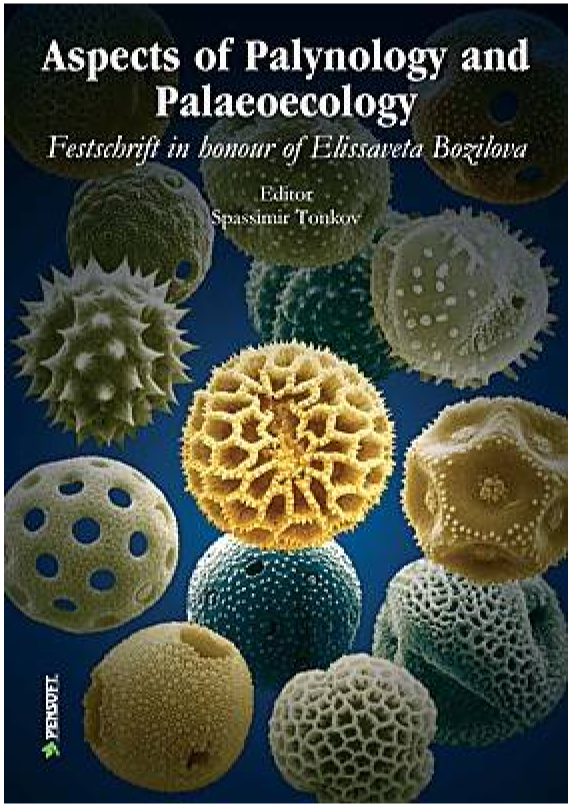
Or, does the advance and retreat of the glaciers respond to the fluctuations in greenhouse gasses?

Or, are they coupled

What is driving the greenhouse fluctuations?

How Well Does Vegetation Track Glacial Ice ?

Palynology

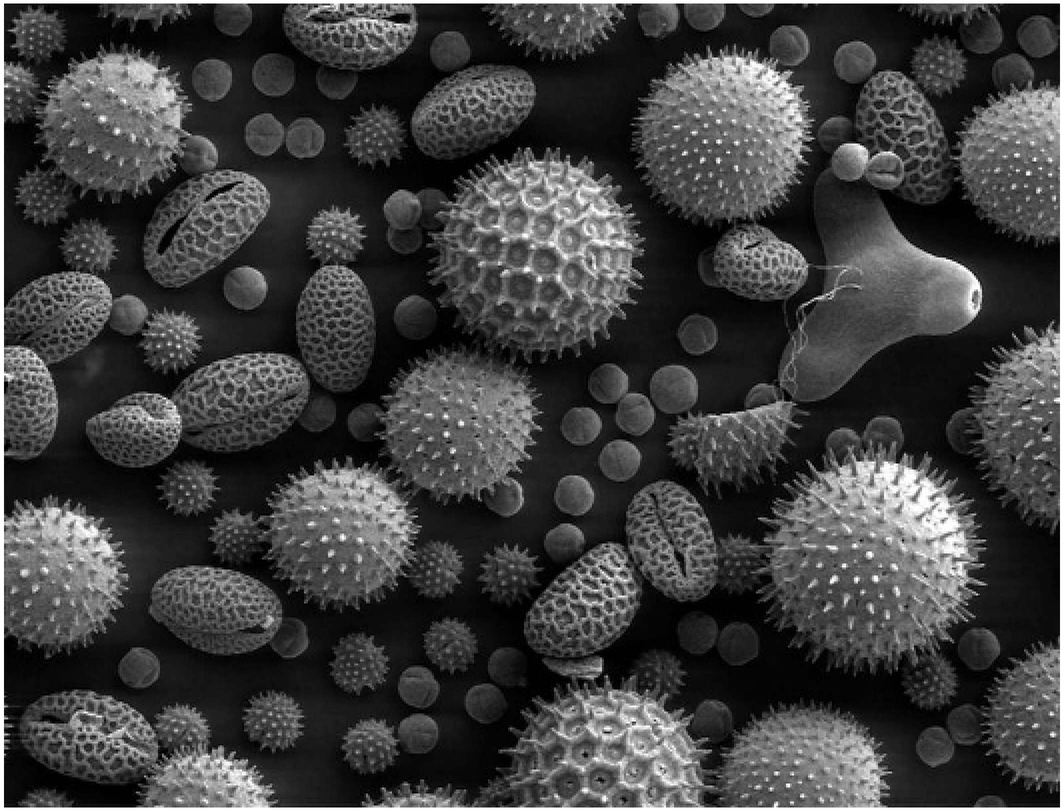


Aspects of Palynology and Palaeoecology

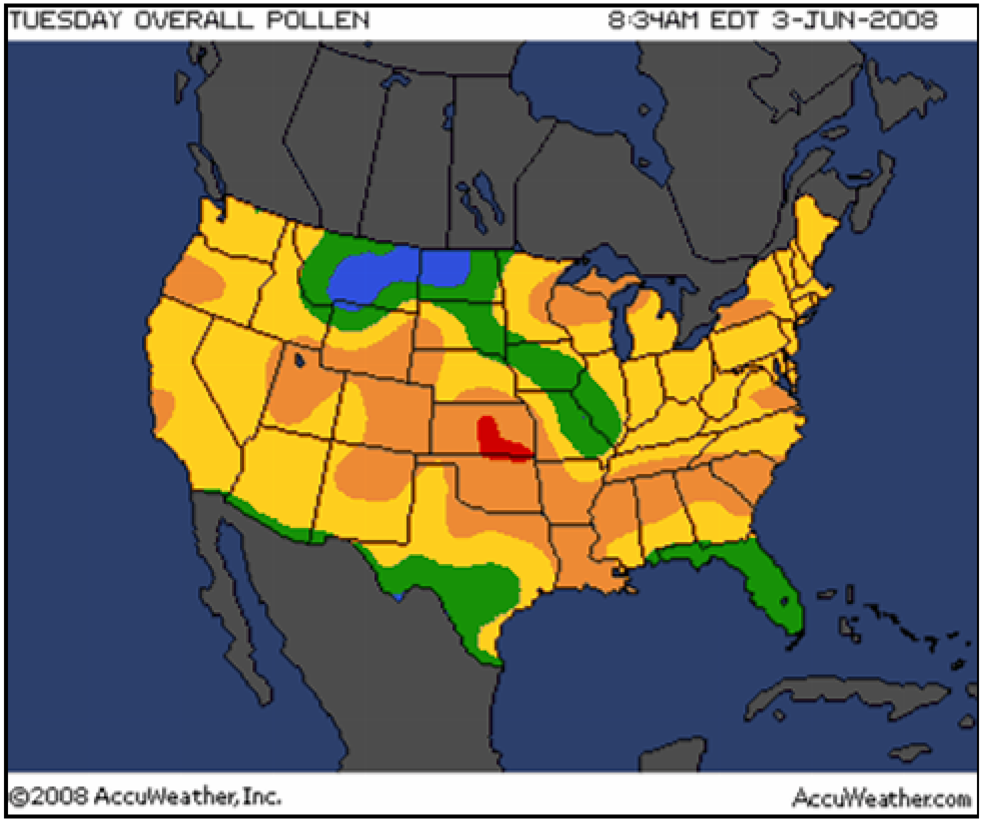
Festschrift in honour of Elissaveta Bozilova

Editor
Spassimir Tonkov

PENSOFT.



Palynology


TUESDAY OVERALL POLLEN
8:34AM EDT 3-JUN-2008
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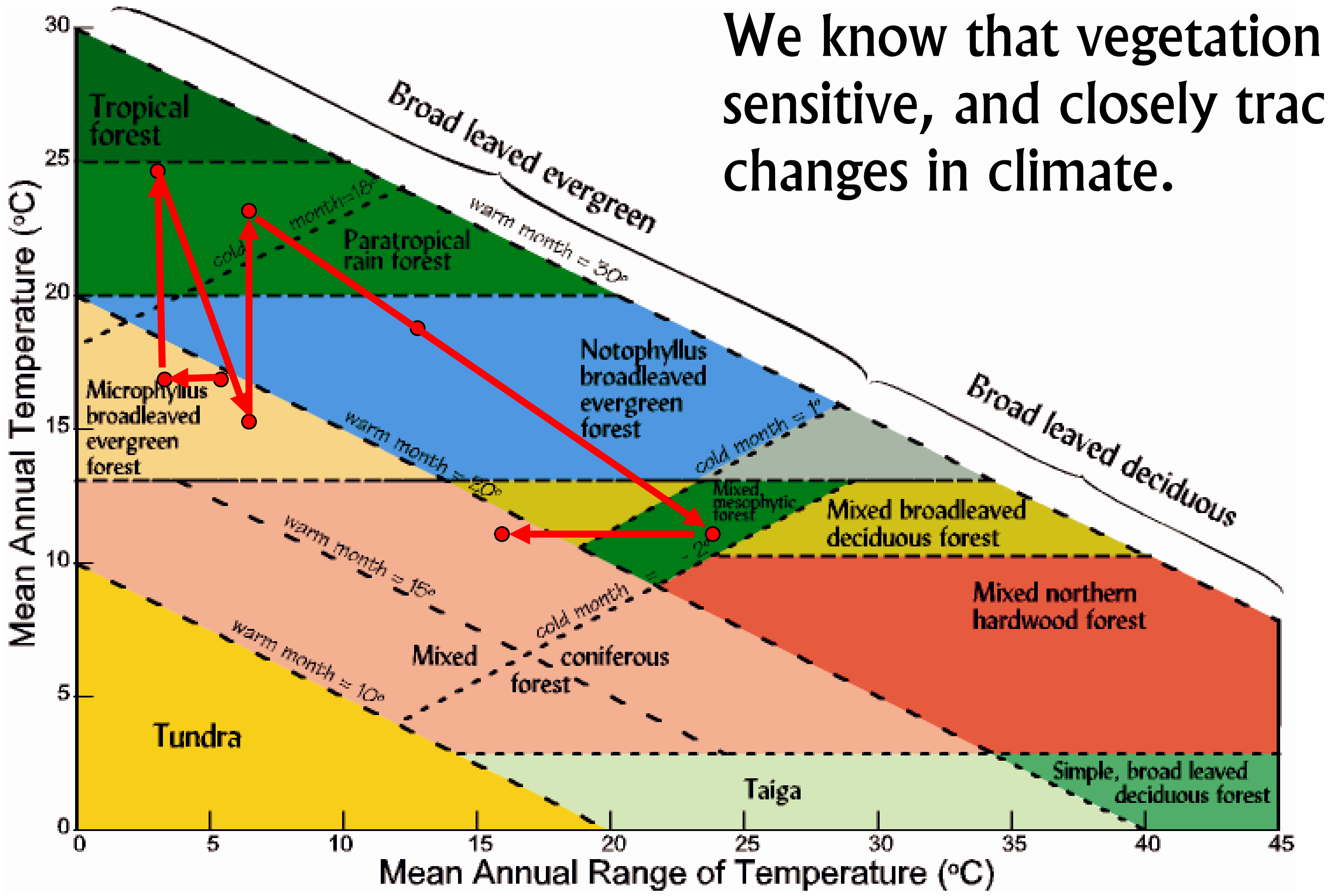
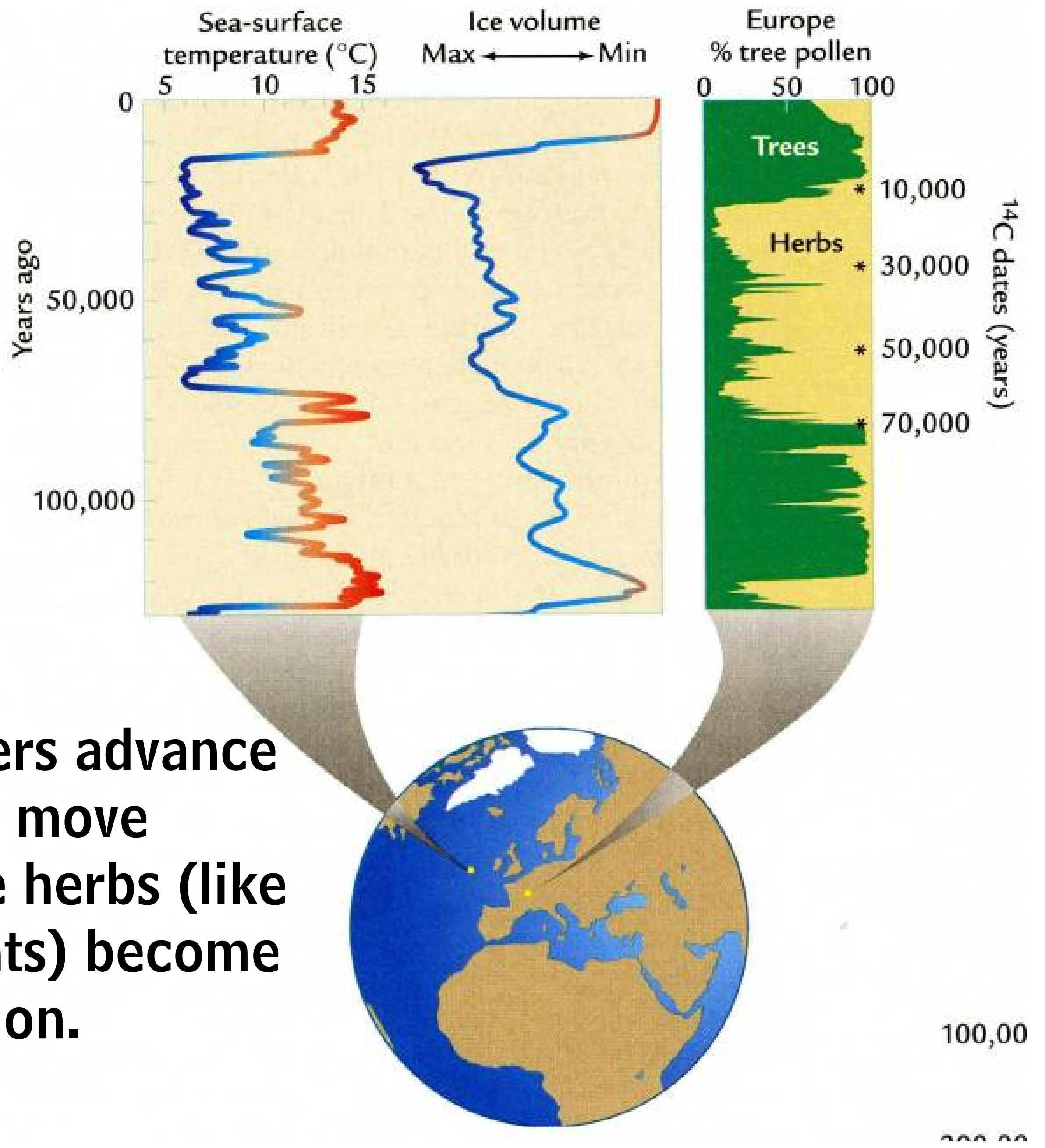
Pacific Northwest

Trajectory of changing climate/vegetation across the middle-late Eocene to Oligocene boundary for the Pacific Northwest. The rapid transition from paratropical forest to mixed mesophytic forest, and then mixed coniferous forest/taiga reflects climatic deterioration at the Oligocene "big chill."



We know that vegetation is very sensitive, and closely tracks changes in climate.

France Vegetation Shifts



When glaciers advance tree biomes move south, while herbs (like Tundra plants) become more common.

South America Vegetation Shifts

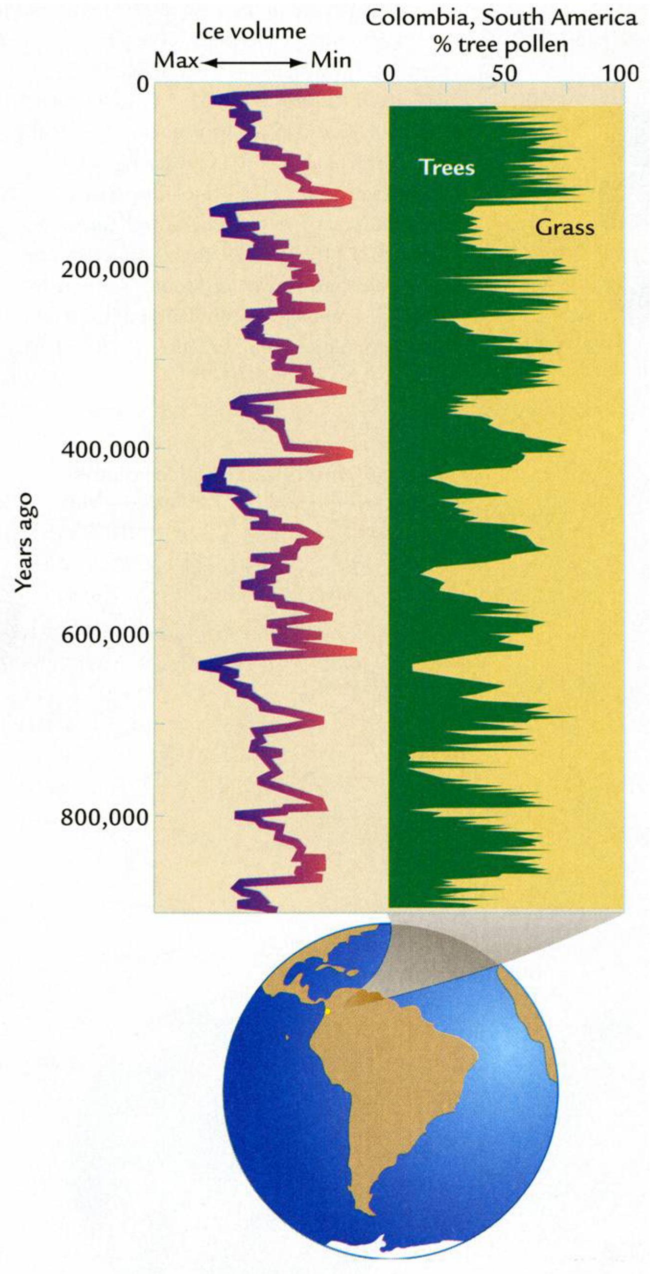


FIGURE 11-11 **Vegetation response in South America** A long lake core from the eastern Andes Mountains in Colombia shows major shifts between forest and grassland pollen that match 100,000-year glacial-interglacial ice volume changes in the northern hemisphere. (Adapted from H. Hooghiemstra et al., "Frequency Spectra and Paleoclimatic Variability of the High-Resolution 30–1450 Kyr Funza I Pollen Record," *Quaternary Science Reviews* 12 [1993]: 141–56.)

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New Zealand Vegetation Shifts

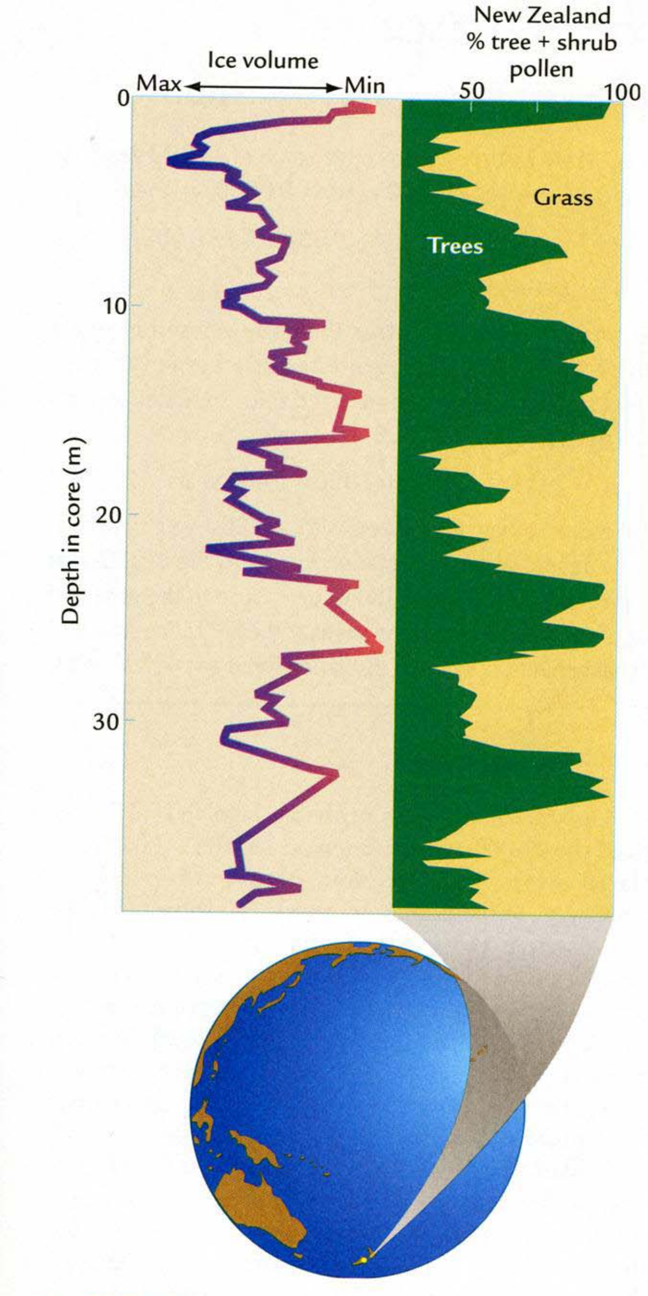

FIGURE 11-12 **Vegetation response in New Zealand** A marine sediment core from the east coast of New Zealand shows major 100,000-year shifts between forest and grassland pollen that match glacial-interglacial ice volume ($\delta^{18}O$) signals. (Adapted from L. E. Heusser and G. van der Geer, "Direct Correlation of Terrestrial and Marine Paleoclimatic Records from Four Glacial-Interglacial Cycles-DSDP Site 594, Southwest Pacific," *Quaternary Science Reviews* 13 [1994]: 275–82.)

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Minnesota Lake Vegetation Shifts

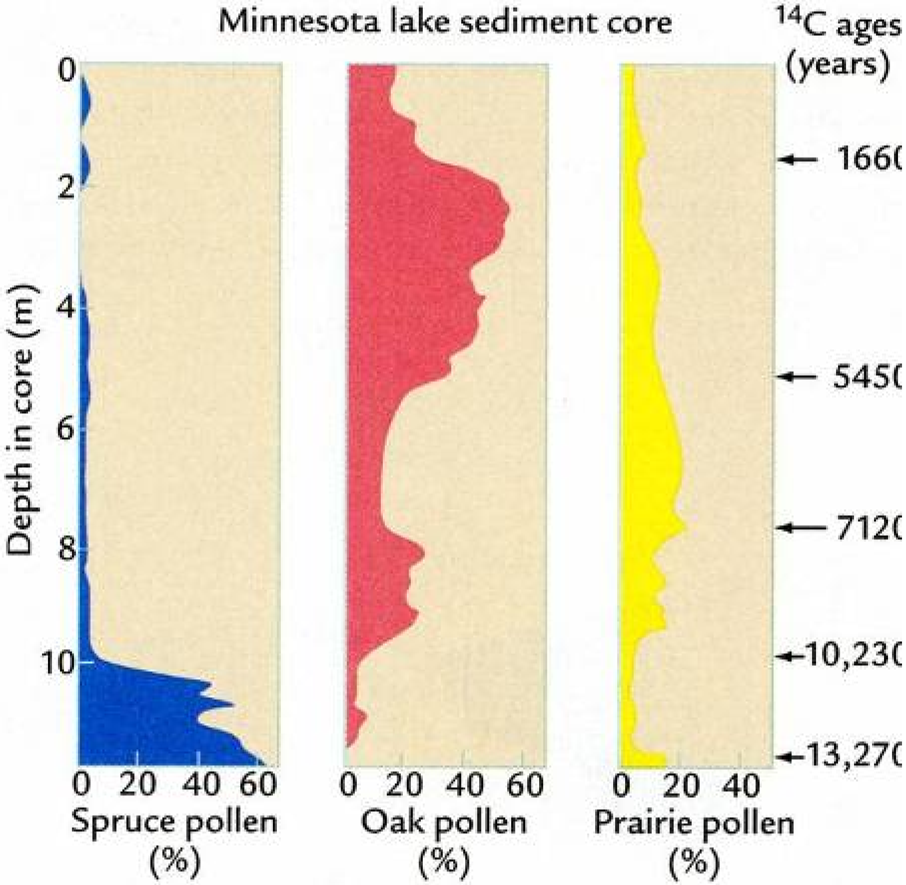

FIGURE 12-9 Pollen in a lake core A ^{14}C-dated sediment core from a Minnesota lake shows a transition in climate near 10,000 years ago from colder conditions (abundant spruce) to a warmer climate (abundant oak). High percentages of prairie grasses near 6000 years ago indicate a drier climate. (Adapted from H. E. Wright et al., "Two Pollen Diagrams from Southeastern Minnesota: Problems in the Late- and Postglacial Vegetation History," *Geological Society of America Bulletin* 74 [1963]: 1371–96.)

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Vegetation Shifts

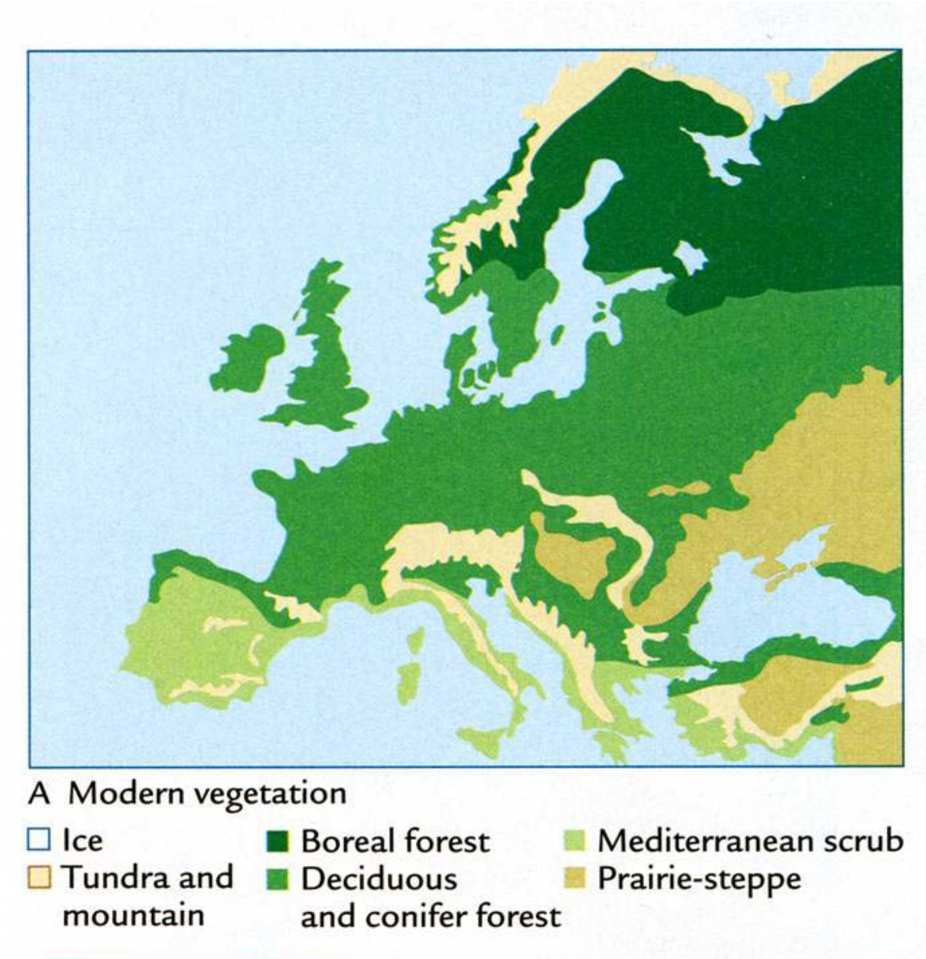


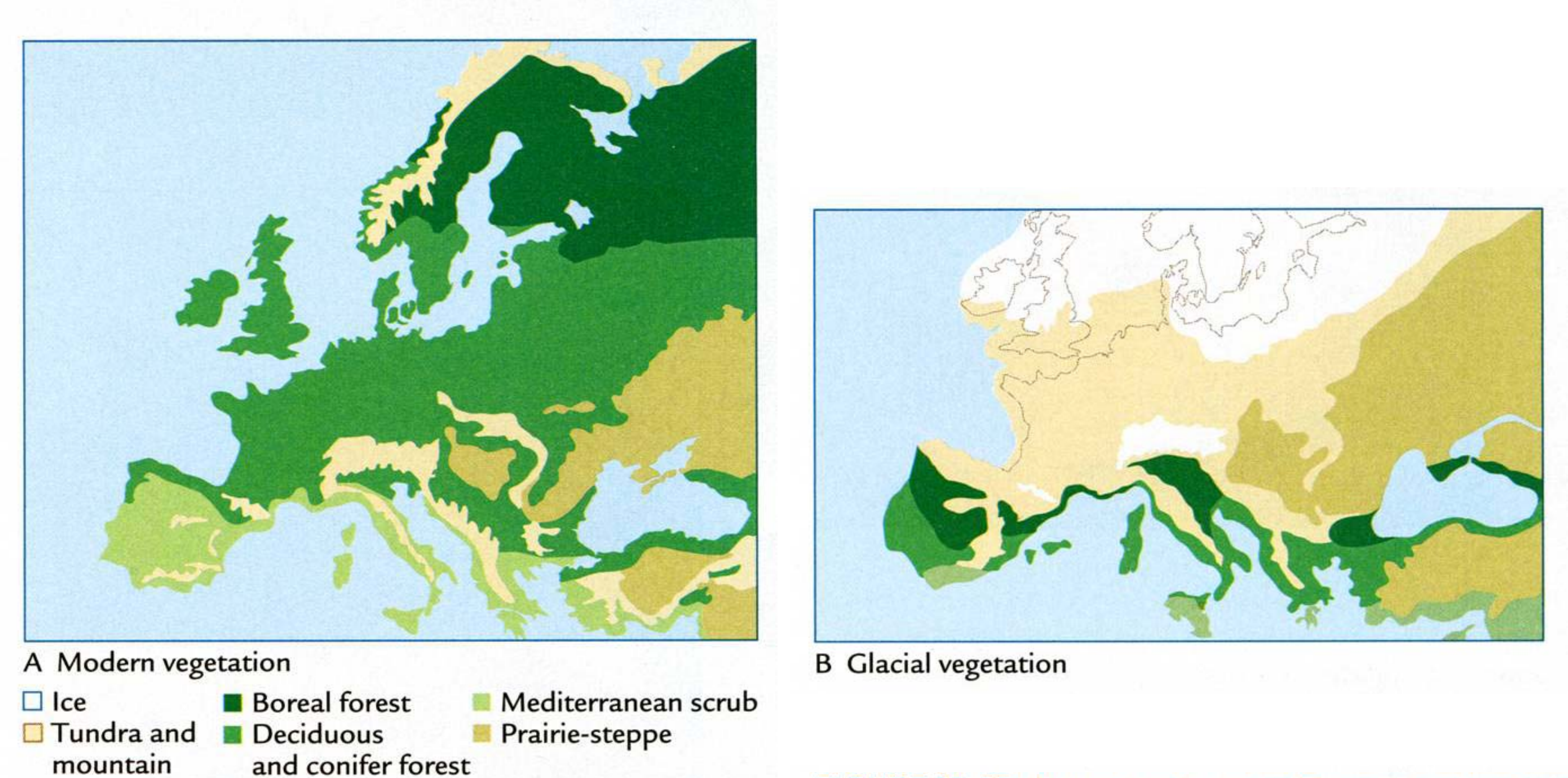
FIGURE 12-15 Glacial north-central Europe was treeless (A) Vegetation in modern Europe is dominated by forest, with conifers in the north and deciduous trees to the south. (B) At the glacial maximum, Arctic tundra covered a large area south of the ice sheet, with grassy steppe farther south and east and patchy forests near the Mediterranean coasts. (Adapted from R. F. Flint, *Glacial and Quaternary Geology* [New York: Wiley, 1971].)

P 222 12-15

Black Forest, Germany (Today)

Ardenne Forest France (Today)

Vegetation Shifts


A Modern vegetation

B Glacial vegetation

FIGURE 12-15 Glacial north-central Europe was treeless (A) Vegetation in modern Europe is dominated by forest, with conifers in the north and deciduous trees to the south. (B) At the glacial maximum, Arctic tundra covered a large area south of the ice sheet, with grassy steppe farther south and east and patchy forests near the Mediterranean coasts. (Adapted from R. F. Flint, *Glacial and Quaternary Geology* [New York: Wiley, 1971].)

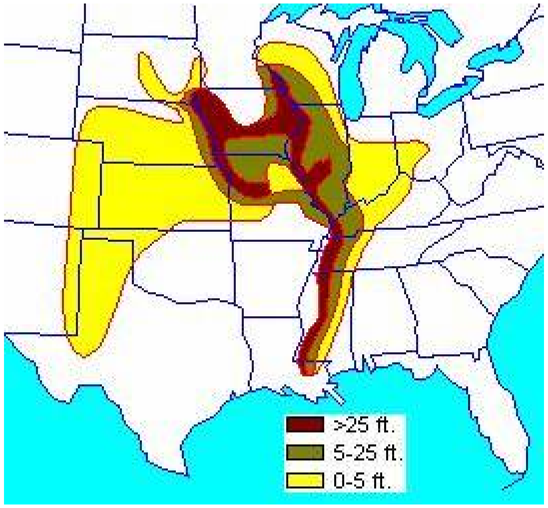
P 222 12-15

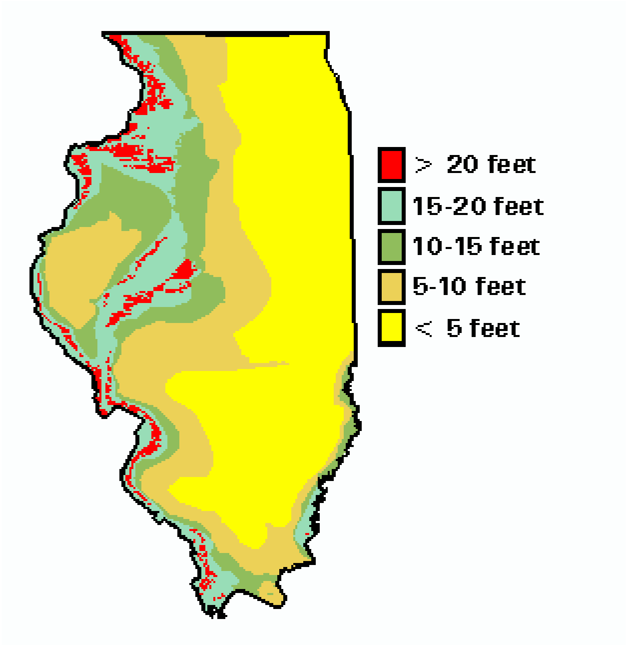
Windblown Debris:

Loess

Dry and Desert
Conditions

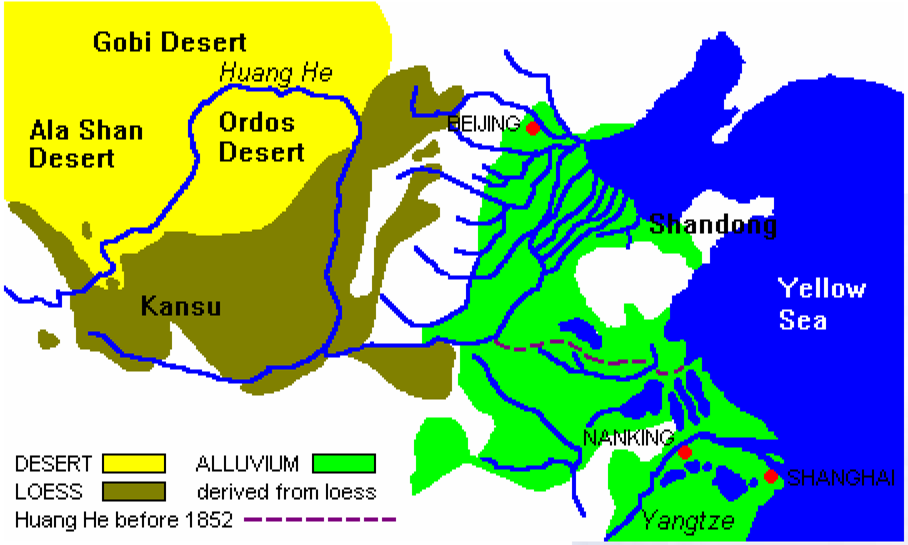
Loess





Nebraska Sand (Loess) Hills

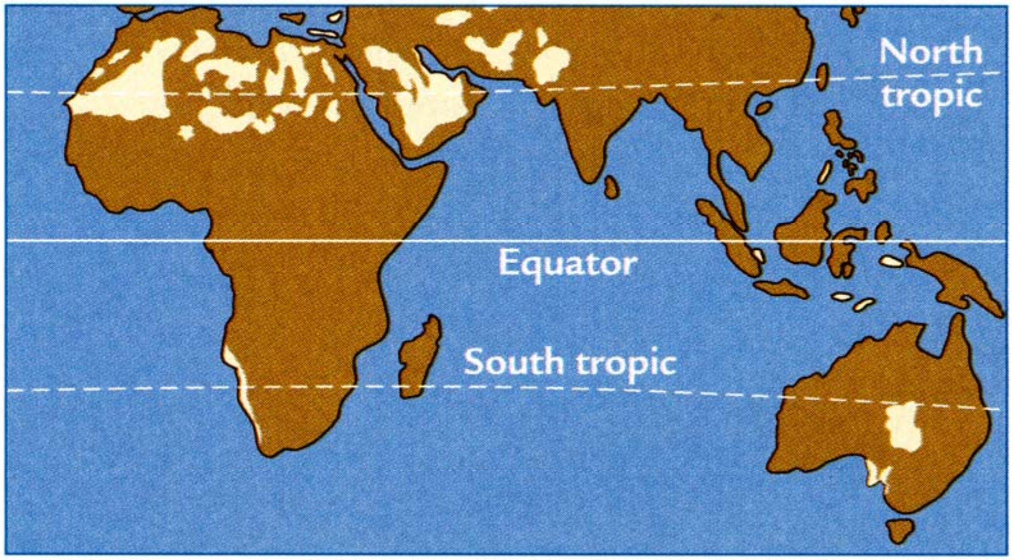
Loess in China



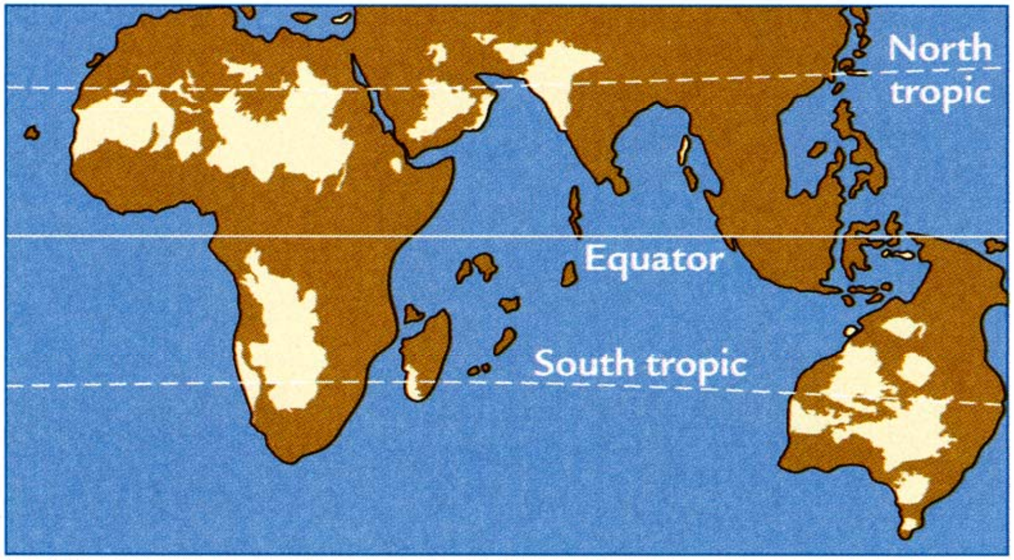
Loess-paleosol sequence, near Xi'an

http://www.geo.vu.nl/~prim/pictures.htm

Loess



A Sand dunes active today

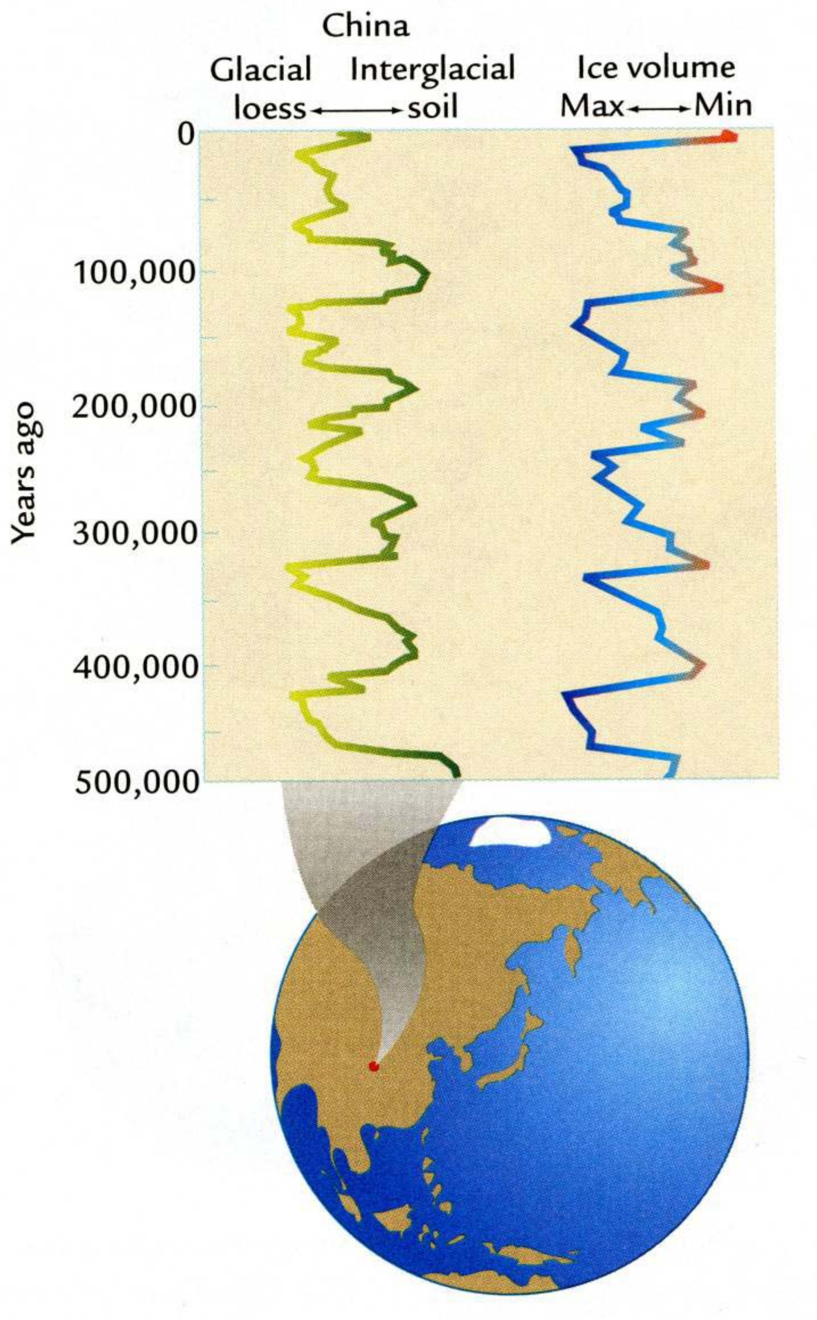


B Sand dunes active at glacial maximum

FIGURE 12-5 Glacial maximum sand dunes (A) Moving sand dunes occur today in Africa, Arabia, and Australia. (B) At the last glacial maximum, drier climates and stronger winds created more extensive sand dunes. (Adapted from M. Sarnthein, "Sand Deserts During Glacial Maximum and Climatic Optimum," *Nature* 272 [1978]: 43–46.)

http://www.geo.vu.nl/~prim/pictures.htm

Windblown Debris



When glaciers advance toward glacial maxima the climate gets dryer, as indicated by the expansion of leoss deposits.

FIGURE 11-10 Responses of windblown debris in East Asi to ice volume Alternating layers of windblown loess and soil in Southeast Asia match variations in δ^{18}O (ice volume). (Adapted from G. Kukla et al., "Pleistocene Climates in China Dated by Magnetic Susceptibility," *Geology* 16 [1988]: 811–14.)

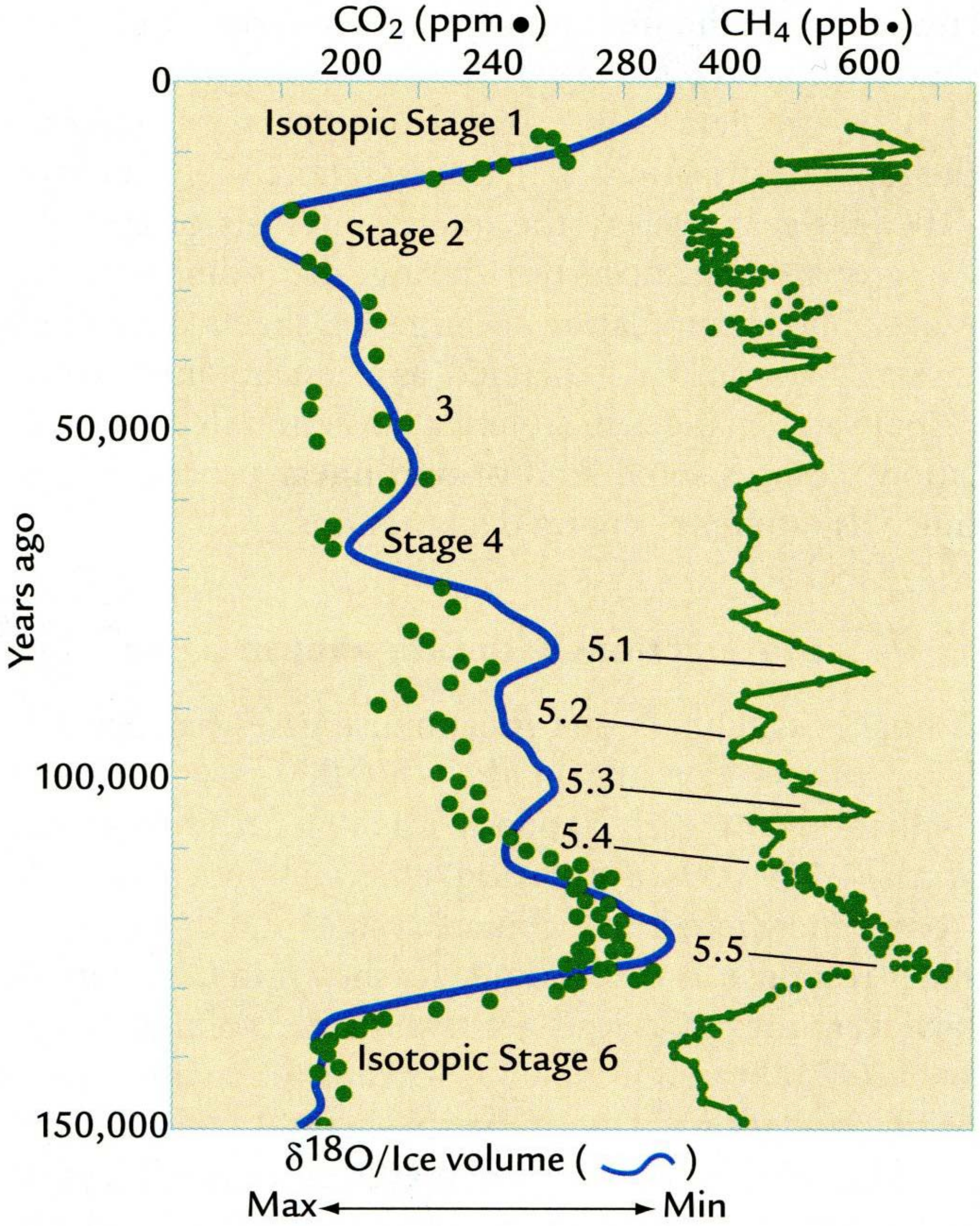
Greenhouse Gasses and Glaciation:

Whom is driving Whom?

Greenhouse Gas Fluctuations

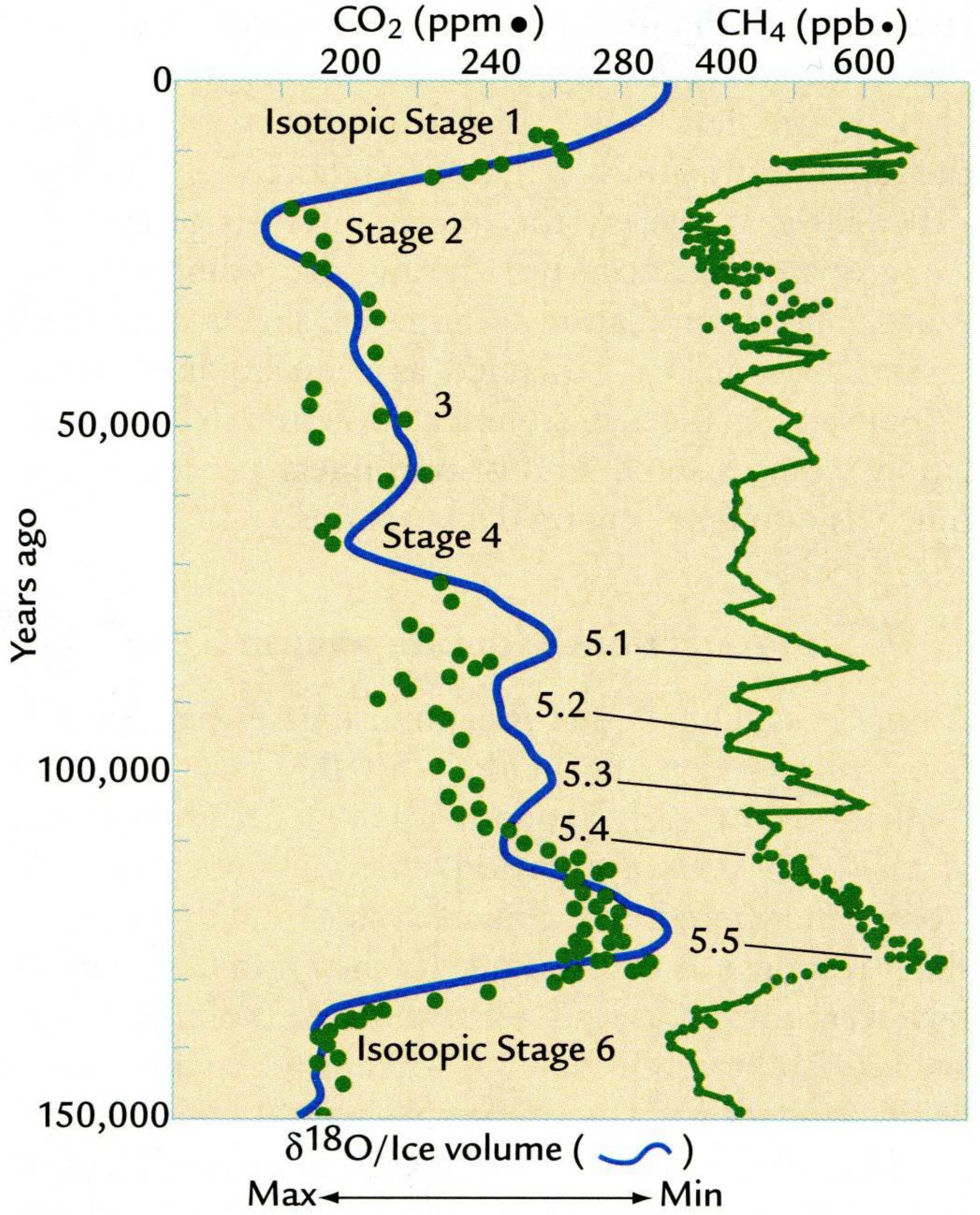
Methane and carbon dioxide track each other, and decrease when ice volume expands

WHY ?



Greenhouse Gas Fluctuations

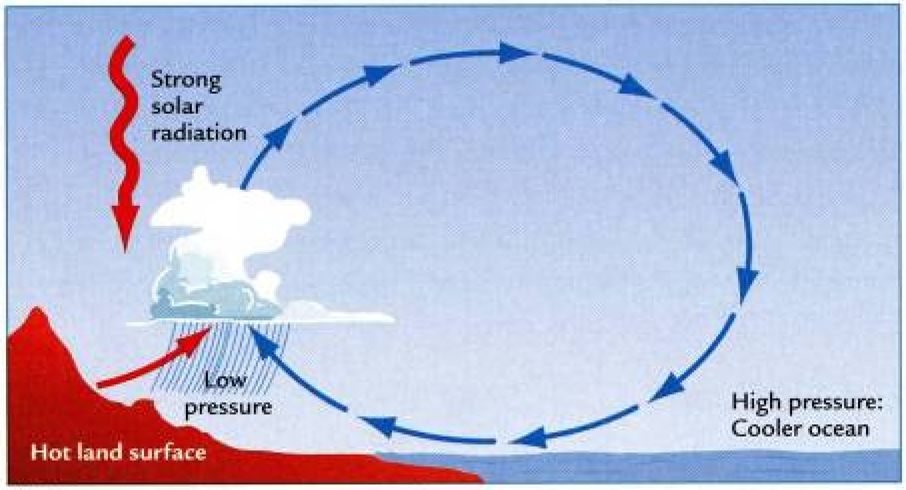
Methane and carbon dioxide are different problems, and fluctuate for different reasons



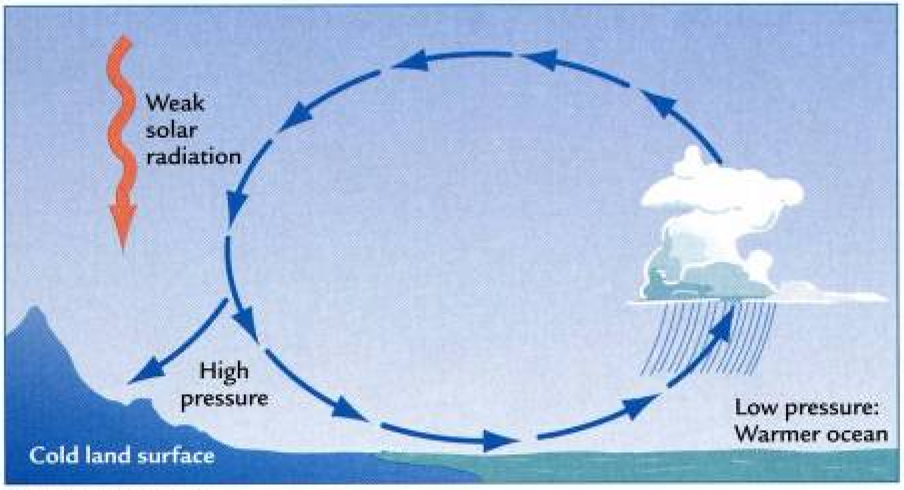
Methane Responds to Moisture . . .

Which Responds to Monsoons

Present Day Monsoons



A Summer monsoon



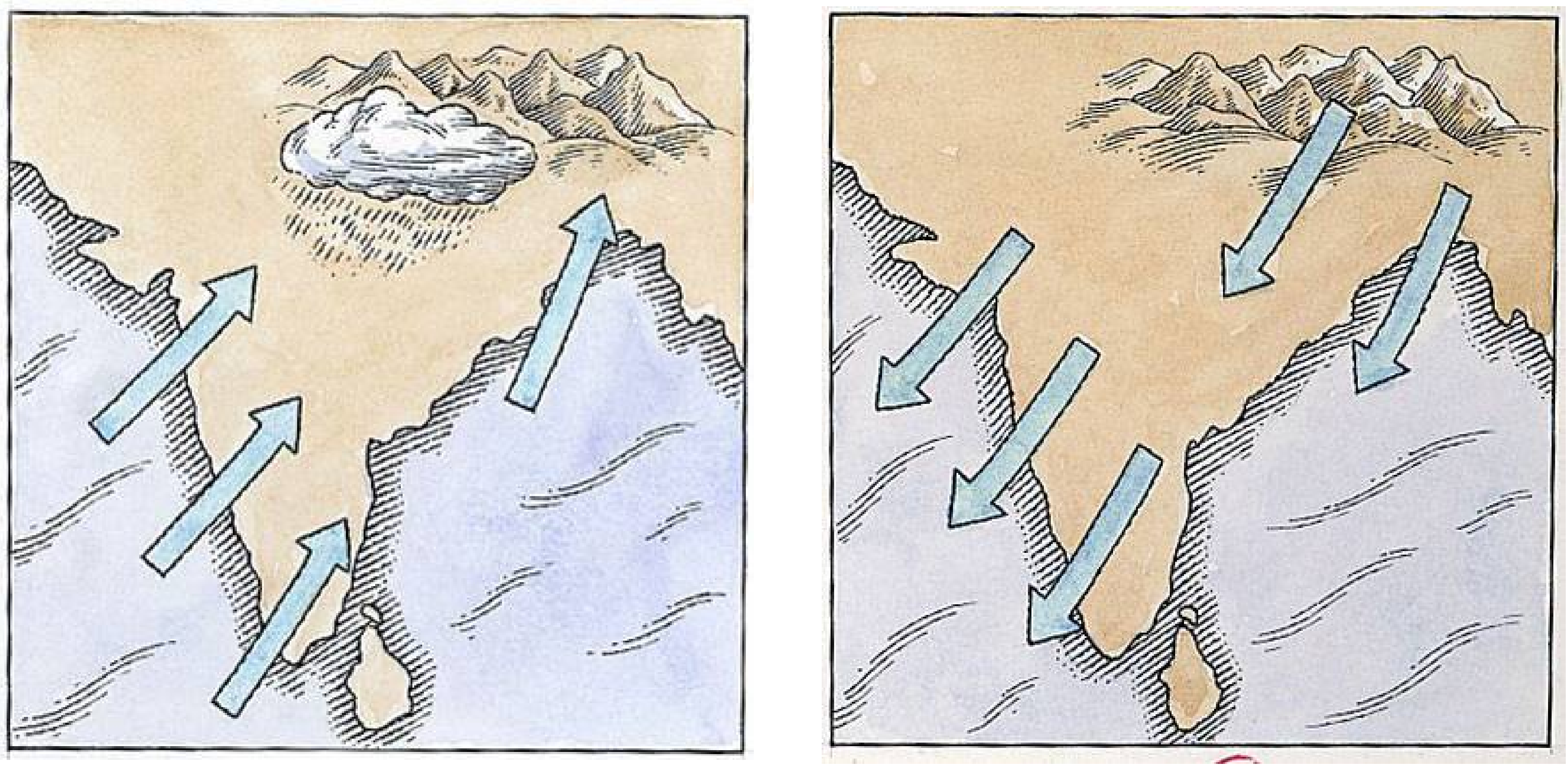
B Winter monsoon

During summer greater insolation heats the land creating low pressure over the land, which causes air to rise, which draws water off the oceans, which falls as rain.

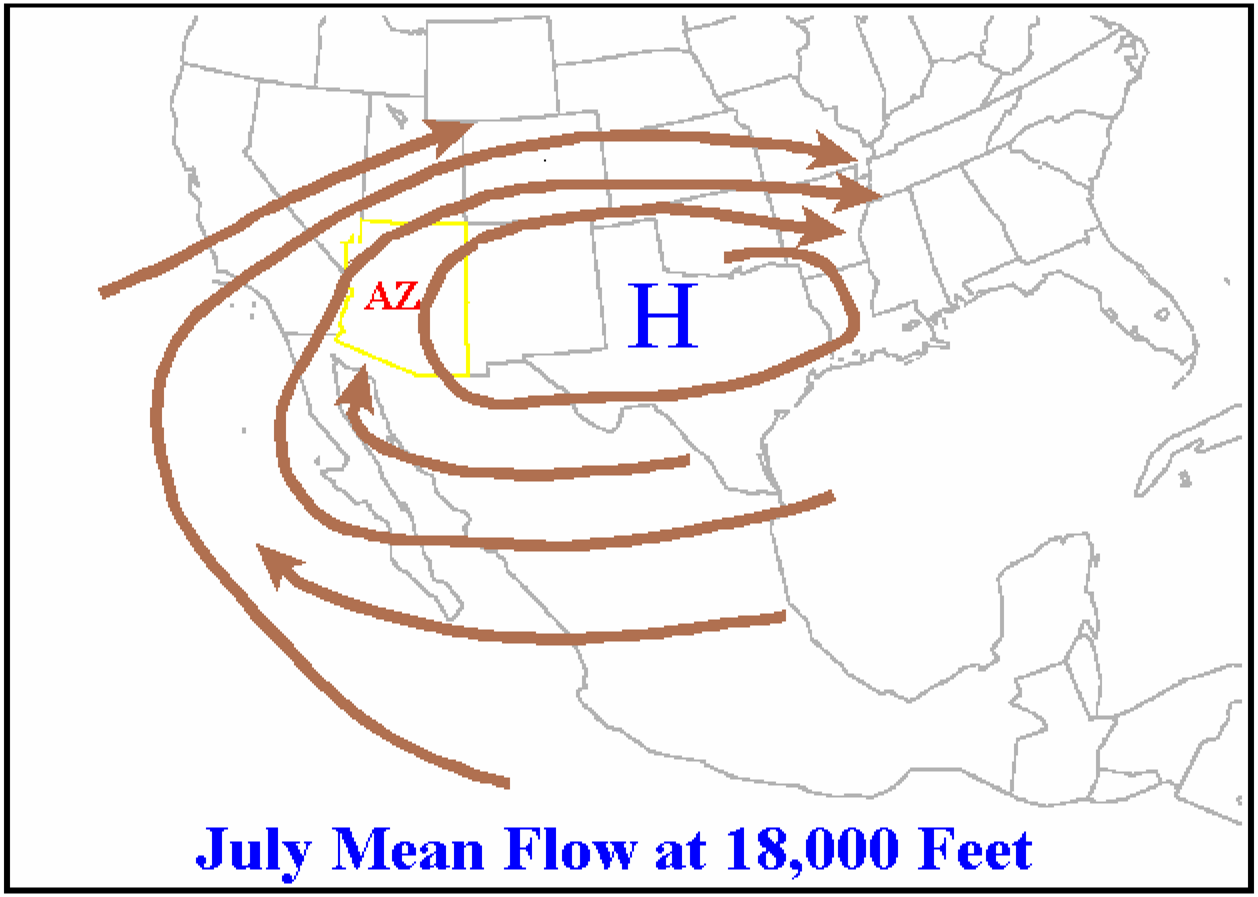
During winter decreased insolation leads to cooling of the land, higher pressures, and air flow heads off shore, leading to dry season.

FIGURE 8-1 Seasonal monsoon circulations Seasonal changes in the strength of solar radiation affect the surface of the land more than the ocean. (A) In summer, intense solar heating of the land causes an in-and-up circulation of moist air from the ocean. (B) In winter, weak solar radiation allows the land to cool off and creates a down-and-out circulation of cold dry air.

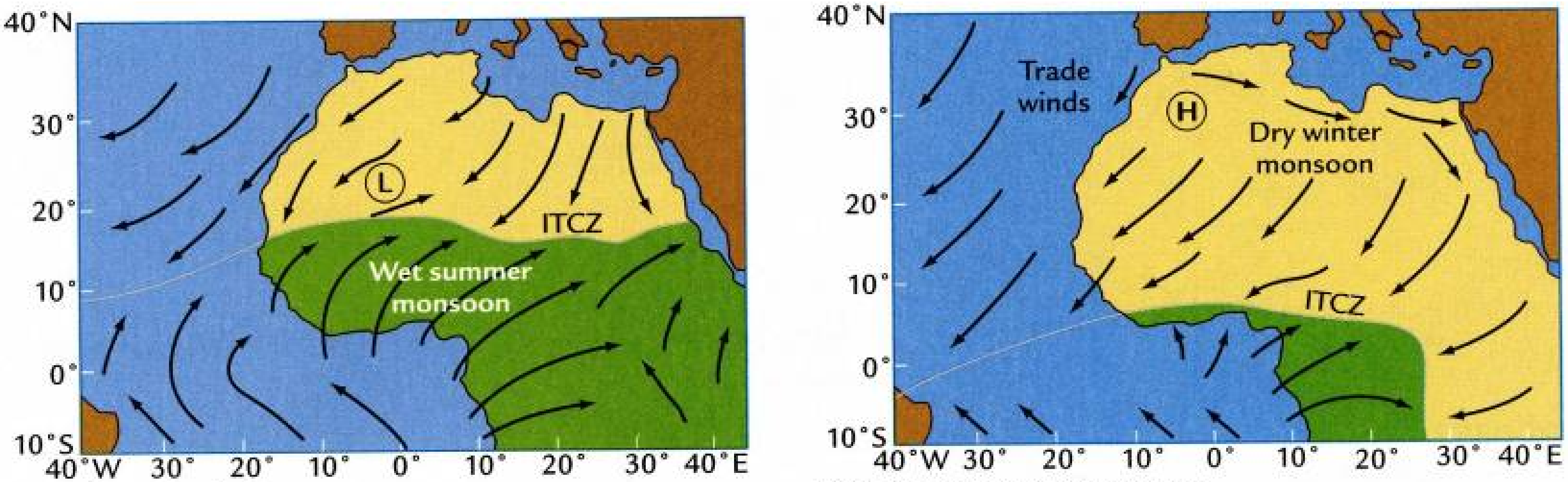
Monsoons



Monsoons



July Mean Flow at 18,000 Feet



A Northern hemisphere summer

B Northern hemisphere winter

FIGURE 8-2 Monsoon circulations over North Africa Seasonal changes cause (A) a moist inflow of monsoonal air toward a low-pressure center over North Africa in summer and (B) a dry monsoonal outflow from a high-pressure center over the land in winter. (Adapted from J. F. Griffiths, *Climates of Africa* [Amsterdam: Elsevier, 1972].)

Long Term Monsoonal Fluctuations

Changes in the precession of the Earth's axis of rotation along with the other Milkanovitch patterns changes the amount of insolation which changes the strength of the monsoons over longer spans of time.

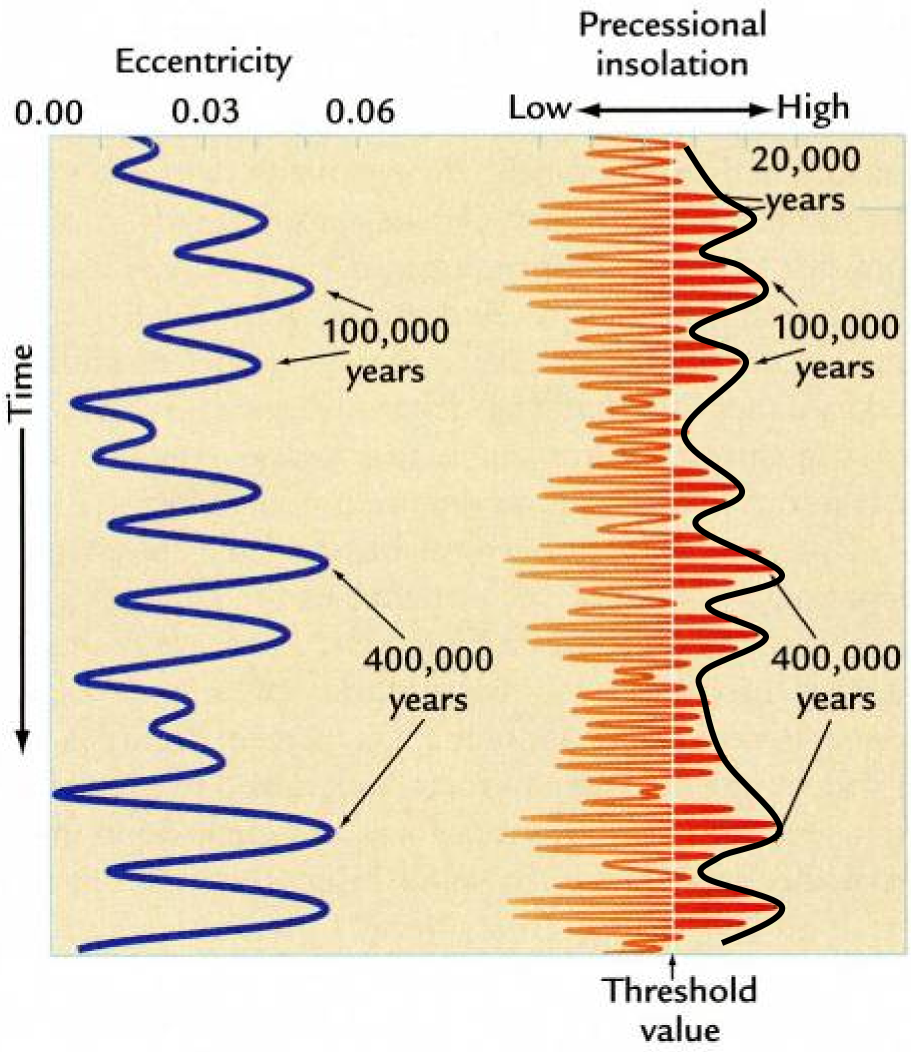
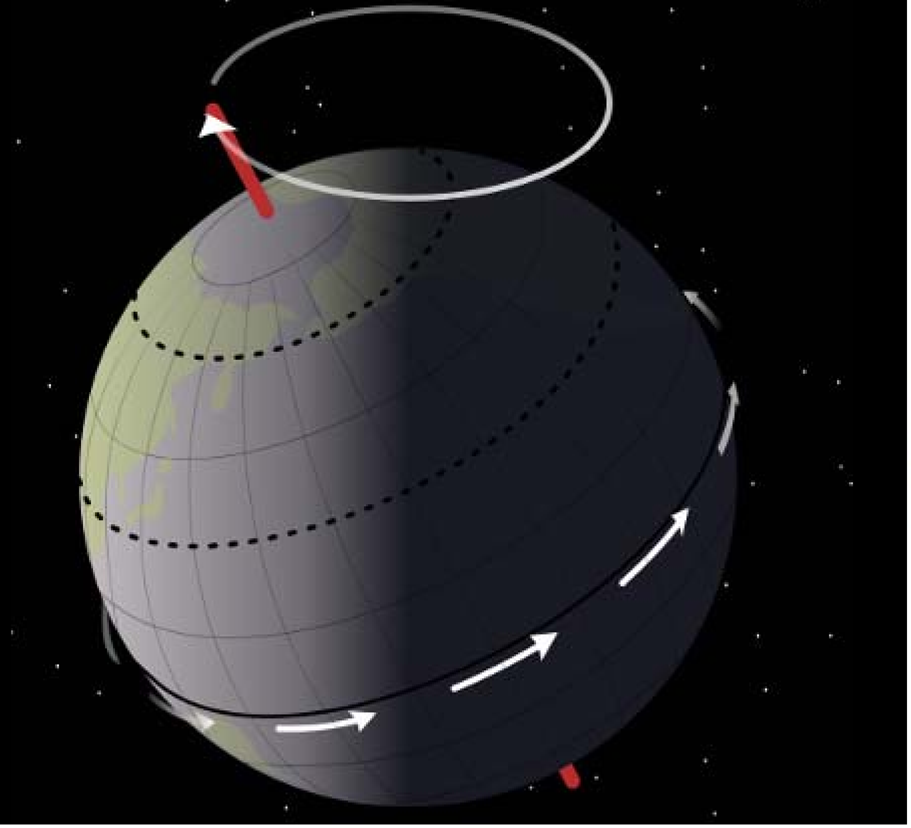
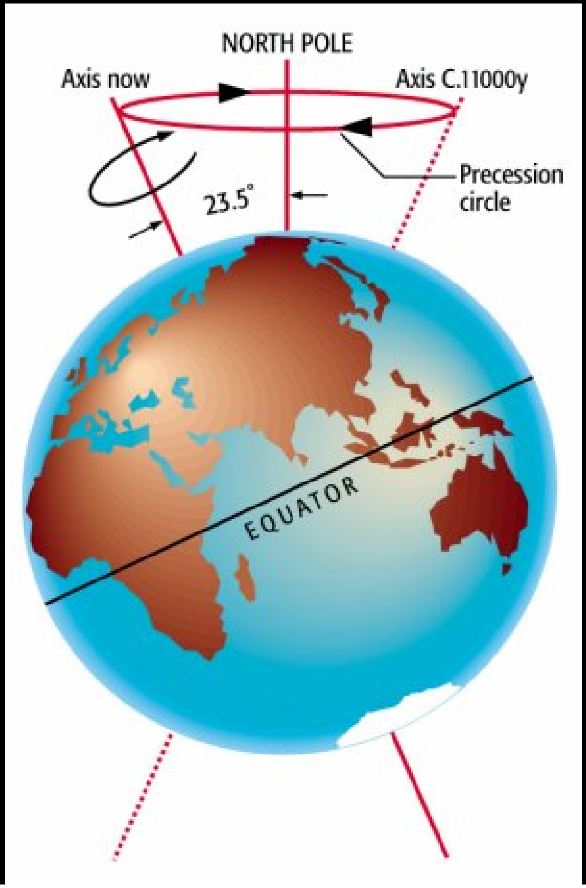


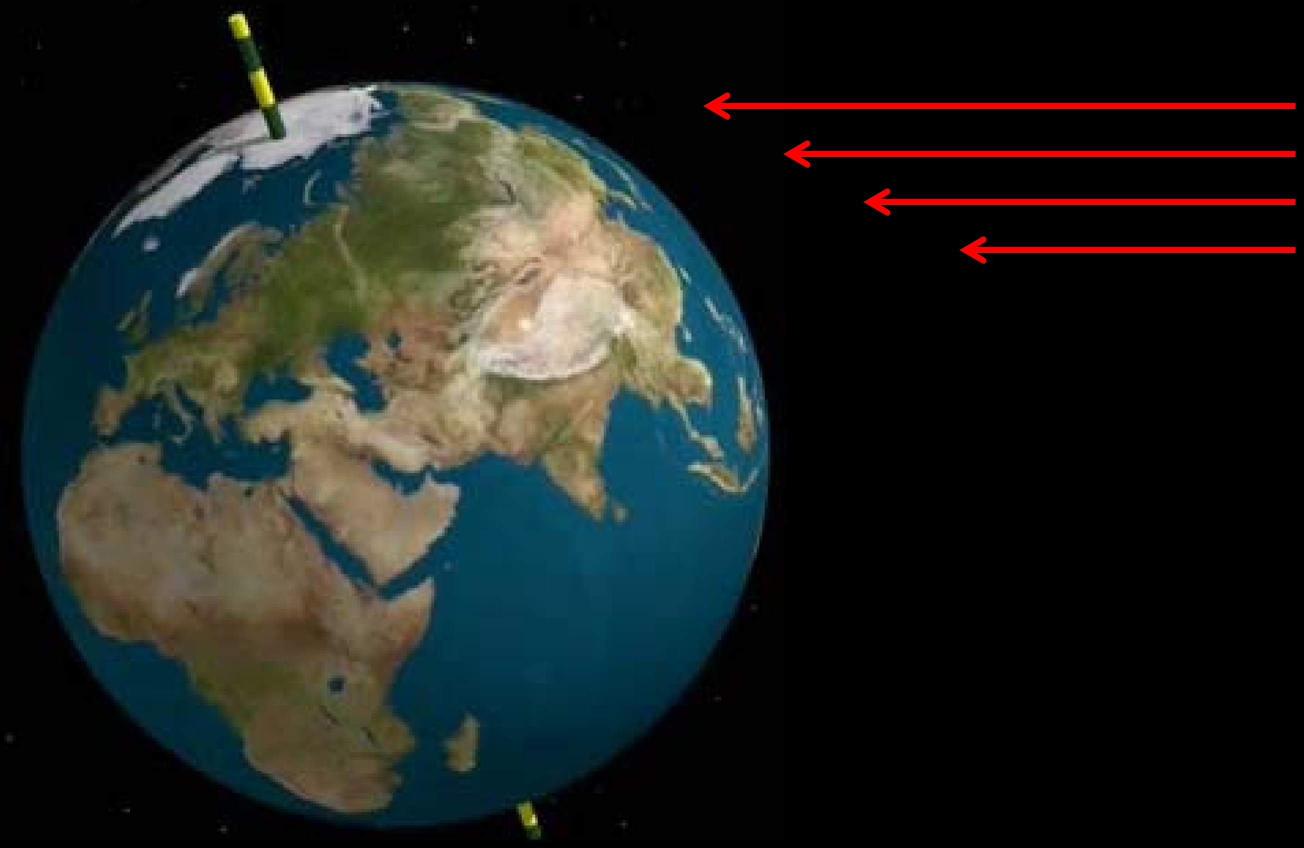
FIGURE 8-13 Monsoon signals recorded in sediments Monsoonal influences can be detected in older sediment sequences. High orbital eccentricity values (left) should amplify individual 23,000-year precession cycles approximately every 100,000 and 400,000 years (right). The monsoon signal in the sediments could resemble the red-shaded area to the right of the threshold insolation value.

Milankovitch Cycles - Precession

Precession is the change in the direction of the Earth's axis of rotation relative to the fixed stars, with a period of roughly 26,000 years. This gyroscopic motion is due to the tidal forces exerted by the sun and the moon on the solid Earth, associated with the fact that the Earth is not a perfect sphere but has an equatorial bulge



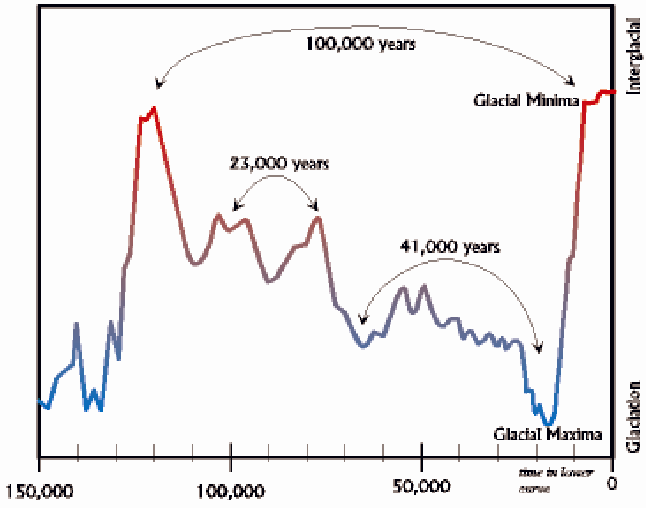




Climate Change Over the Past 20,000 Years and Its Influences

Based on Precessional Positions in Different Parts of Climate Cycle

Ice Sheet Changes
Over the Past 150,000 Years Based on Oxygen Isotopes



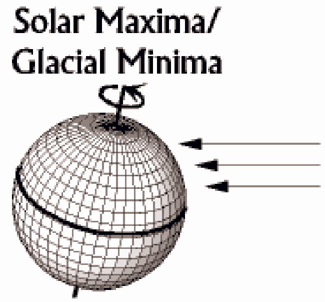
Warming part of cycle

CH_4 CO_2 increasing

Melting of glaciers

Increasing monsoons

Forests migrate north



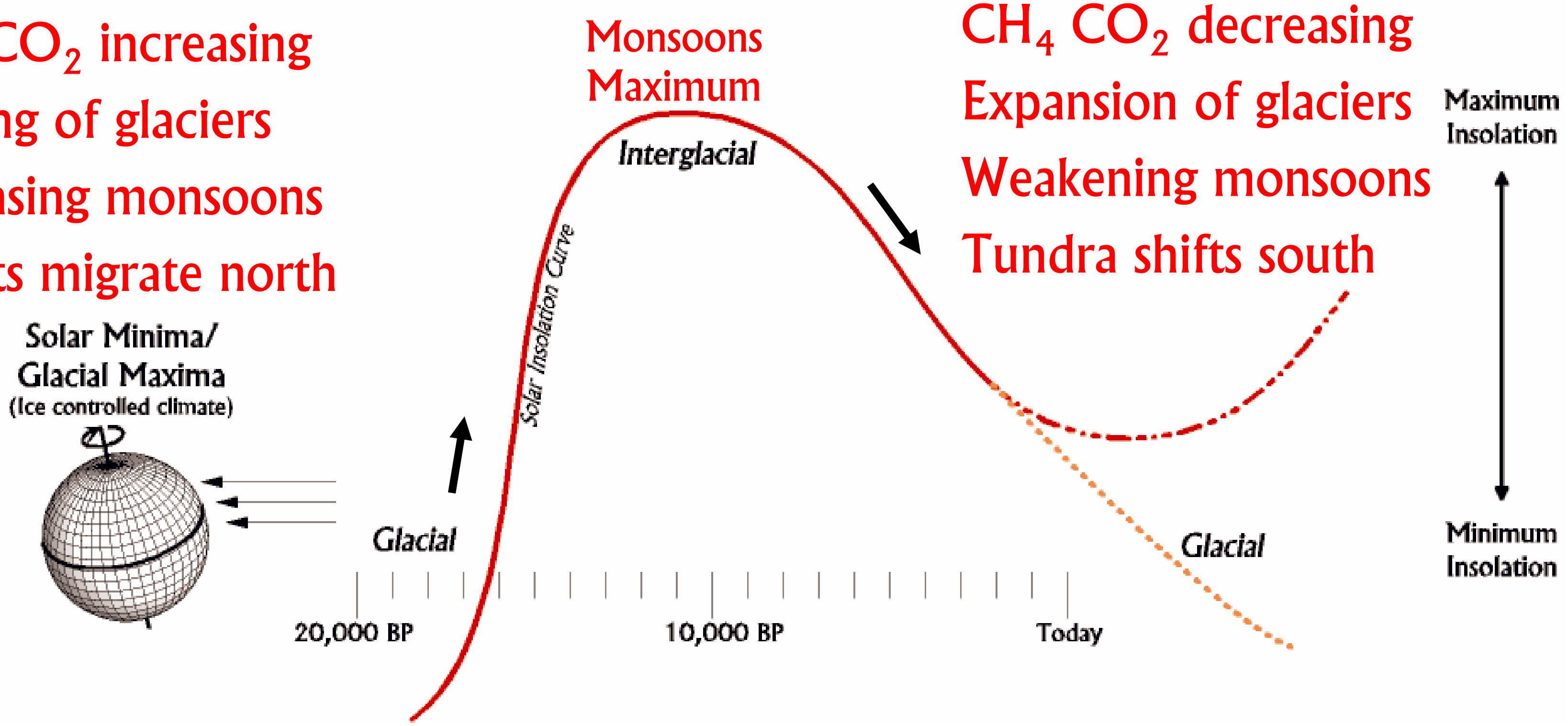
Cooling part of cycle

CH_4 CO_2 decreasing

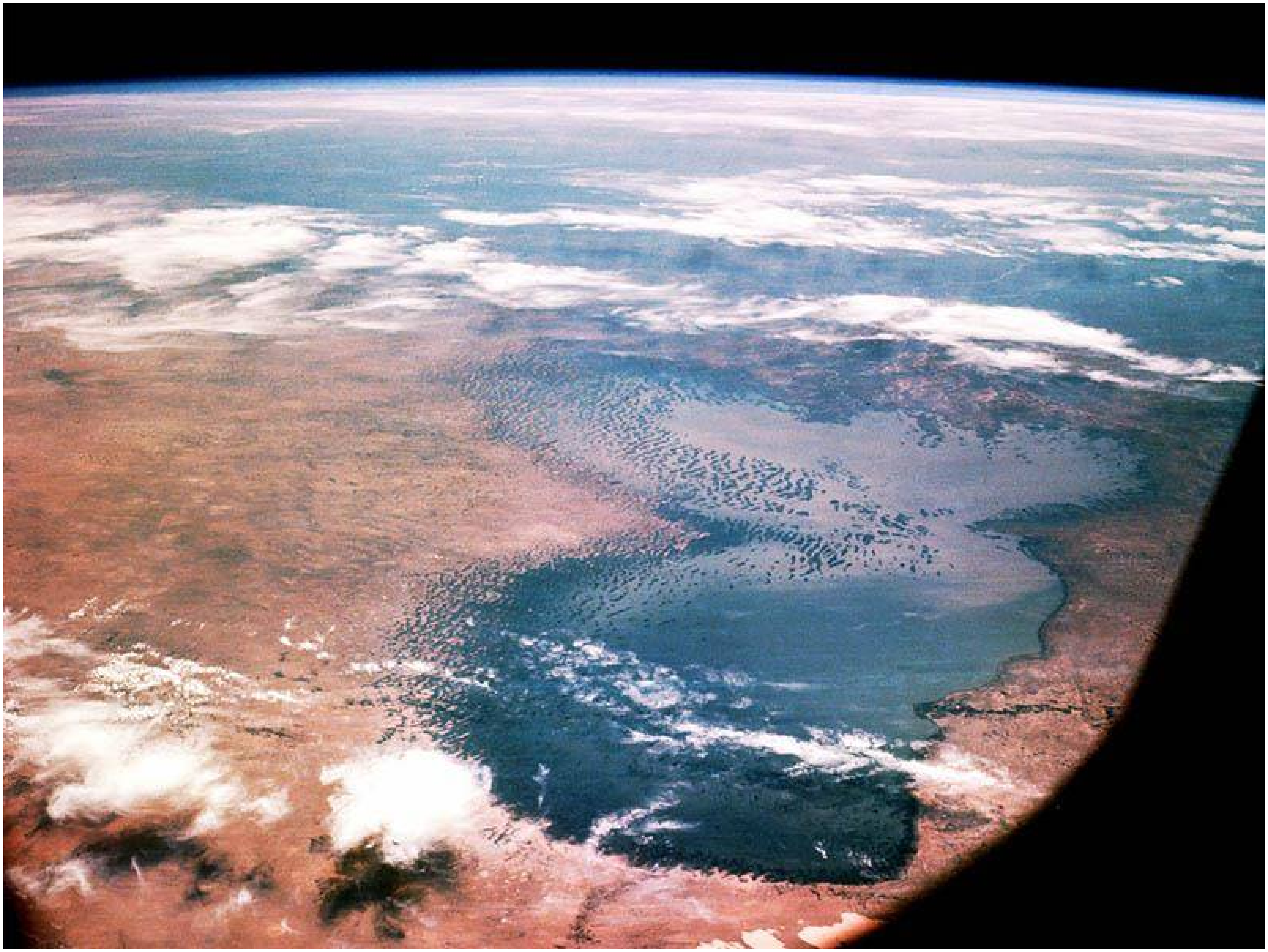
Expansion of glaciers

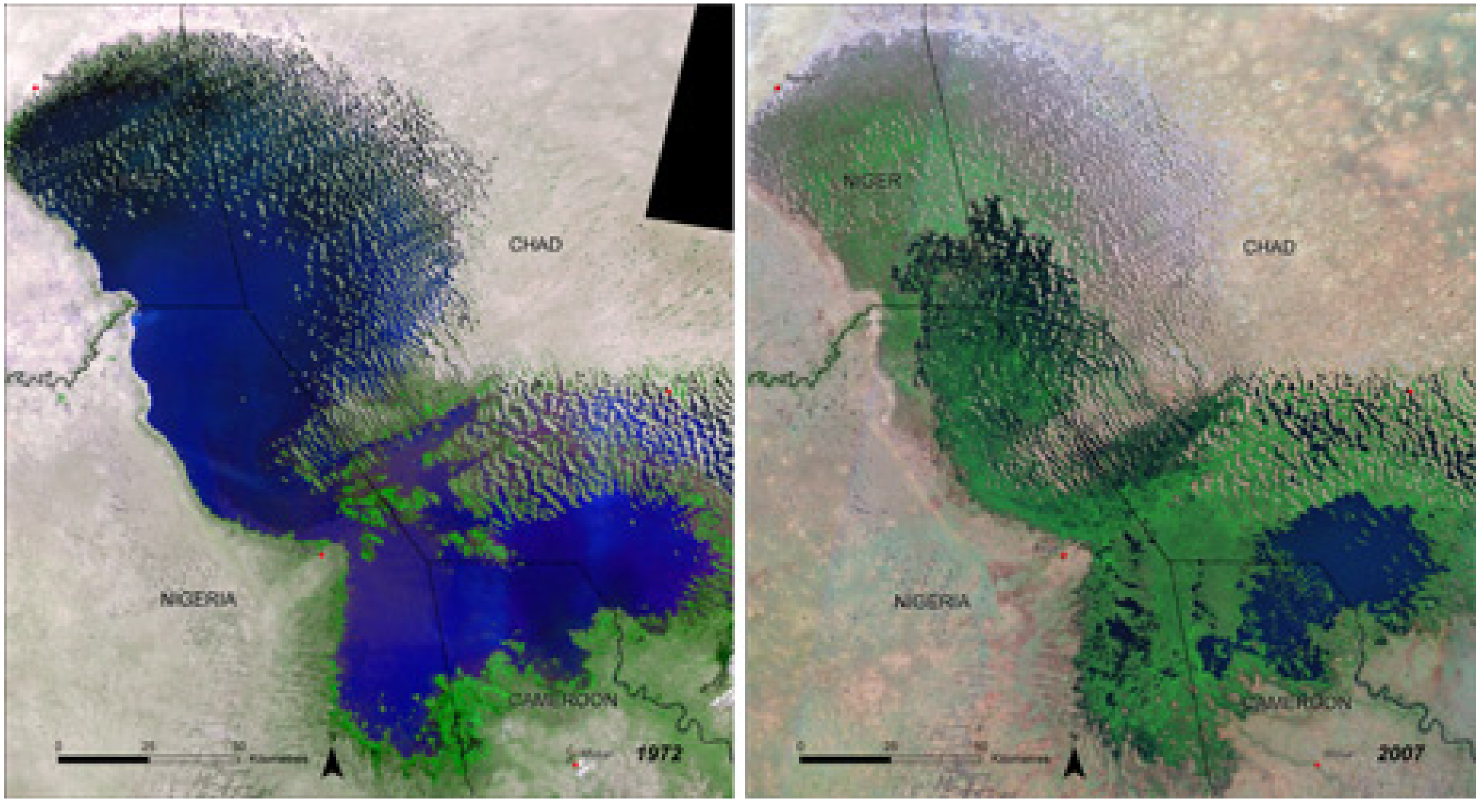
Weakening monsoons

Tundra shifts south



Lake Chad

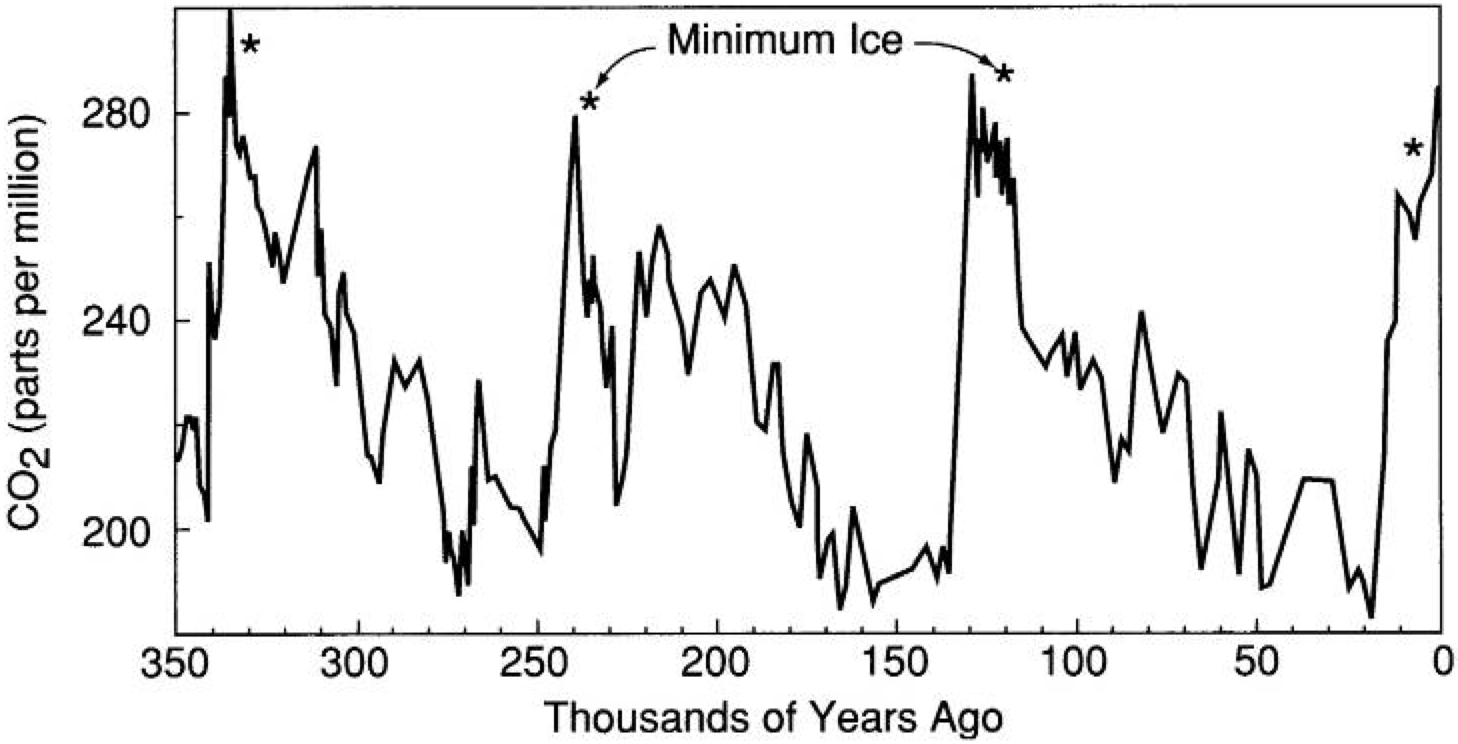




June 11, 2008—Satellite images from 1972 (left) and 2007 (right) show water-level decline in Lake Chad, once the world's sixth largest.

http://news.nationalgeographic.com/news/2008/06/photogalleries/Africaatlas-photos/index.html

20,000 Year Monsoonal Fluctuations

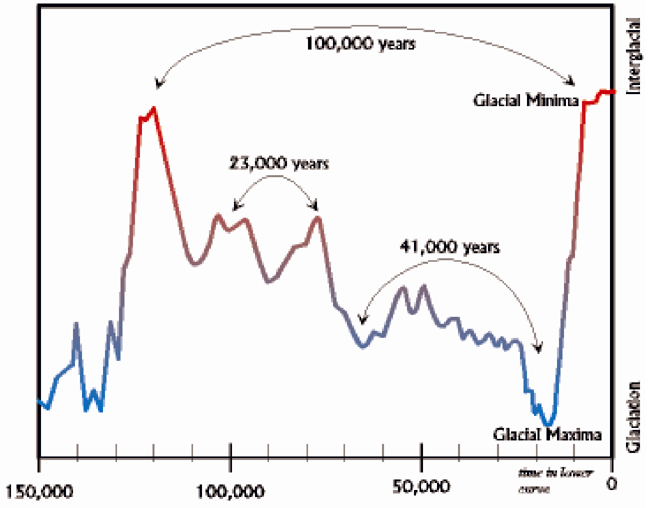


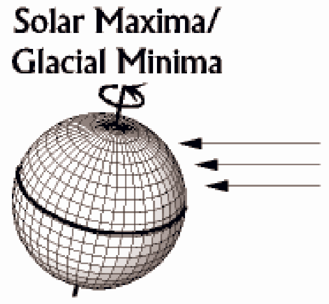
9.1. CO_2 concentrations in the atmosphere vary naturally at a cycle of 100,000 years, with peak values occurring a few thousand years before the ice sheets reach minimum (interglacial) size.

Climate Change Over the Past 20,000 Years and Its Influences

Based on Precessional Positions in Different Parts of Climate Cycle

Ice Sheet Changes
Over the Past 150,000 Years Based on Oxygen Isotopes





Warming part of cycle

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Melting of glaciers

Increasing monsoons

Forests migrate north

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Expansion of glaciers

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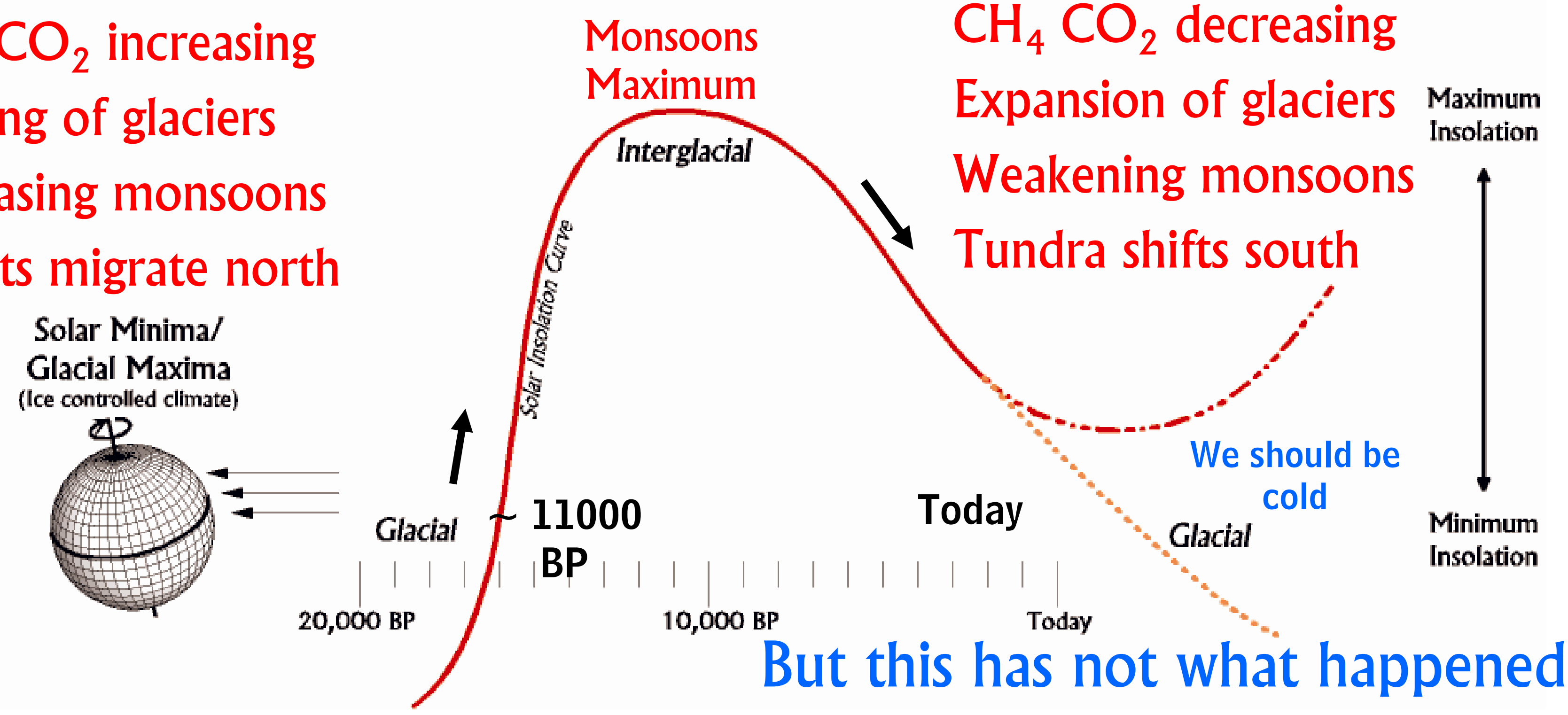
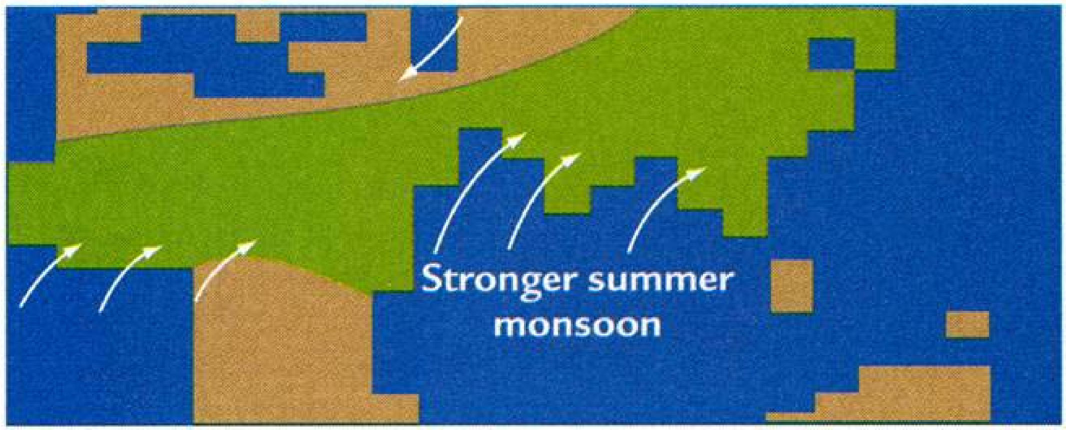
Tundra shifts south

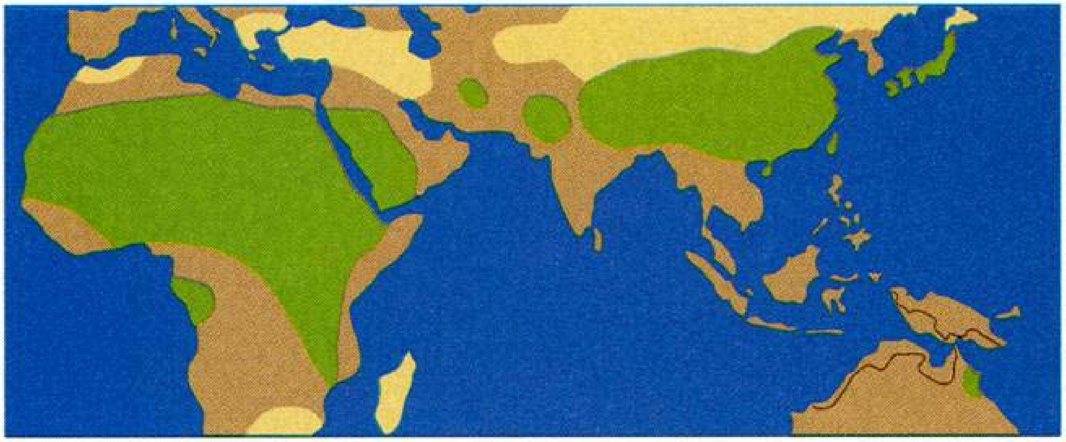


We should be cold

But this has not what happened !



A Model simulation



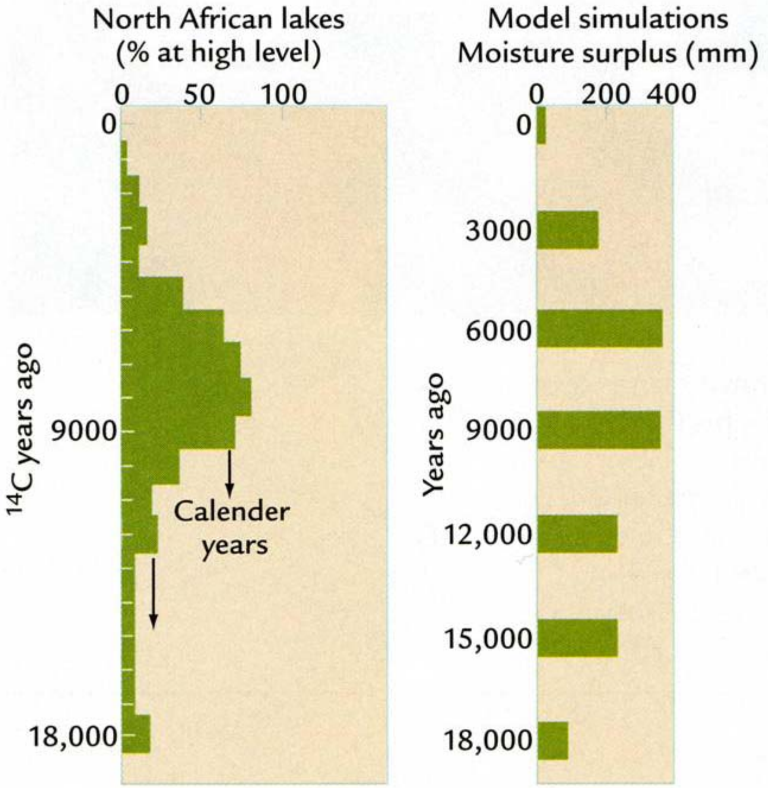
B Observations

Effective moisture (9000 years ago versus today)

🟩 Greater 🟨 Less 🟫 Same

North African lakes
(% at high level)

Model simulations
Moisture surplus (mm)

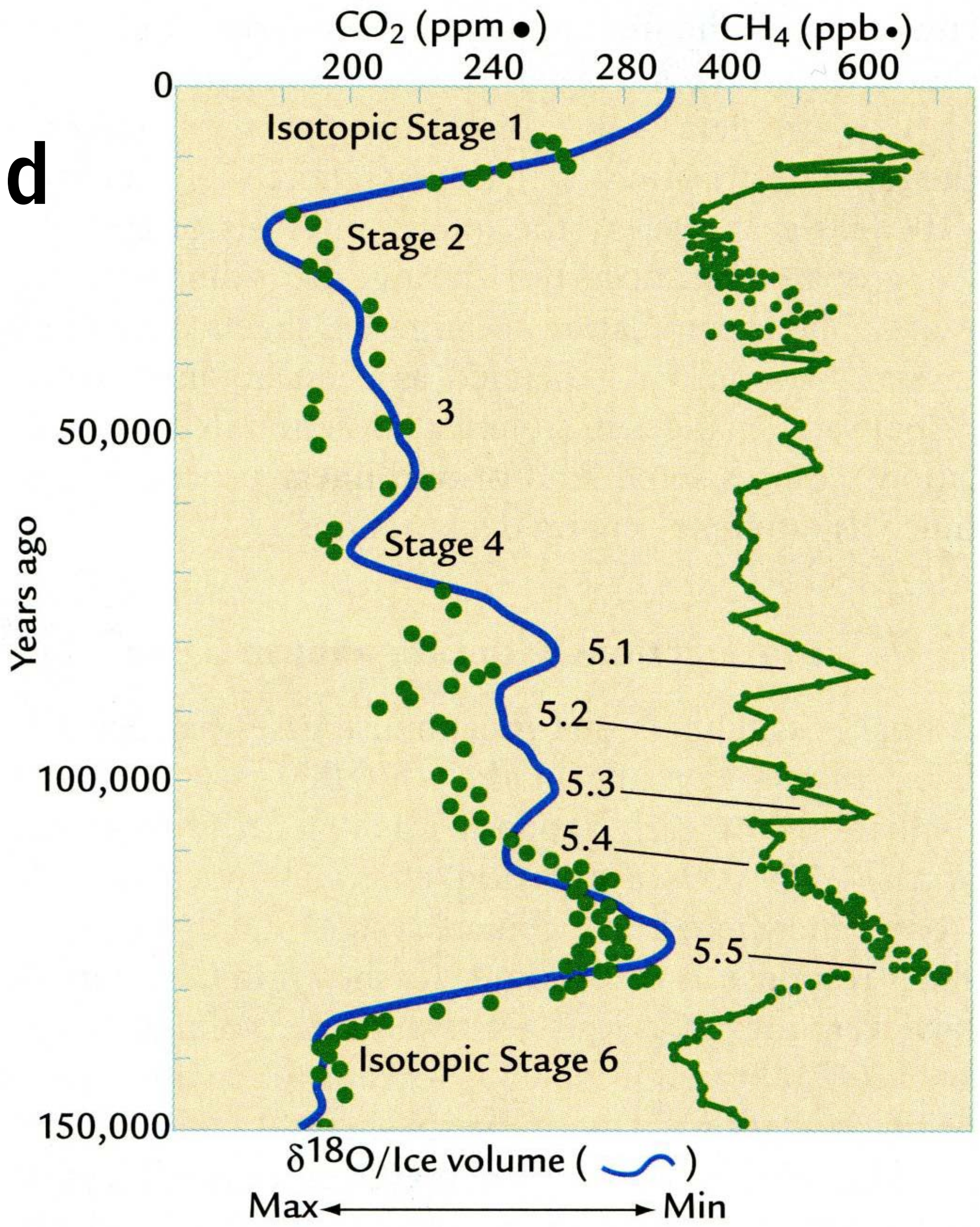


C Data-model comparison versus time

FIGURE 13-13 Tropical monsoon maximum Climate model simulations of stronger summer monsoons in the north tropics near 9,000 years ago agree with evidence in the climate record, such as higher lake levels. (A and B: Adapted from COHMAP Members, "Climatic Changes of the Last 18,000 Years: Observations and Model Simulation," *Science* 241 [1988]: 1043–52. C: Adapted from J. E. Kutzbach and F. A. Street-Perrott, "Milankovitch Forcing of Fluctuations in the Level of Tropical Lakes," *Nature* 317 [1985]: 130–34.)

Greenhouse Gas Fluctuations

Carbon dioxide tracks methane and the monsoon patterns, . . .



But, CO_2 is more complex than CH_4

More feedbacks

We do not know clearly by what mechanisms CO_2 oscillates with ice volume changes.

Last
(most recent)
Glacial Retreat

Last Glacial Retreat

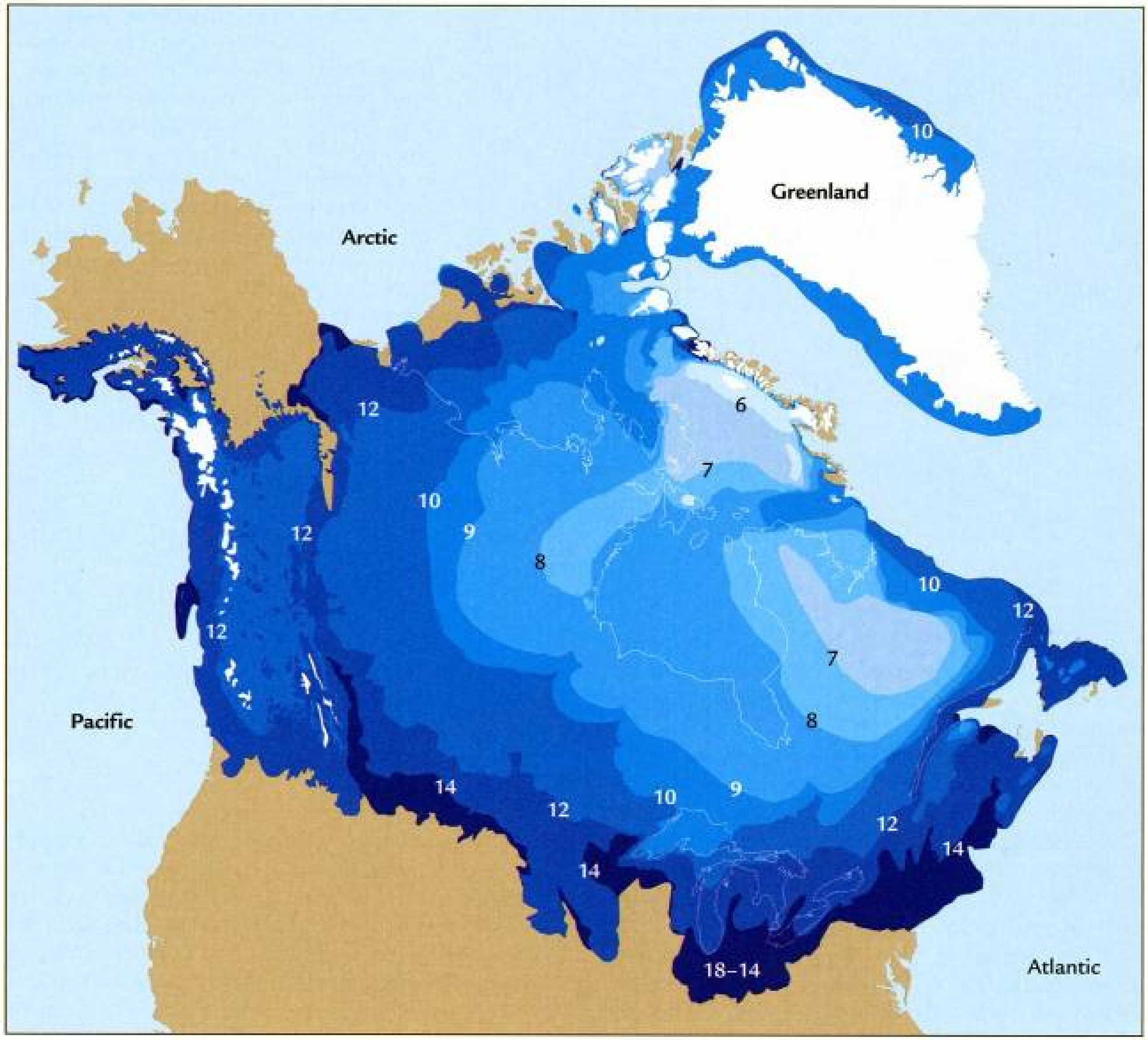


FIGURE 13-2 Retreat of the North American ice sheets Radiocarbon dating of organic remains shows that the margins of ice sheets in North America began to retreat near 14,000 ^{14}C years ago, and the ice disappeared completely shortly after 6000 years ago. The numbers indicate ^{14}C-dated ice limits in thousands of years. (Courtesy of Arthur Dyke, Geological Survey of Canada, Ottawa.)

P 231 13-2

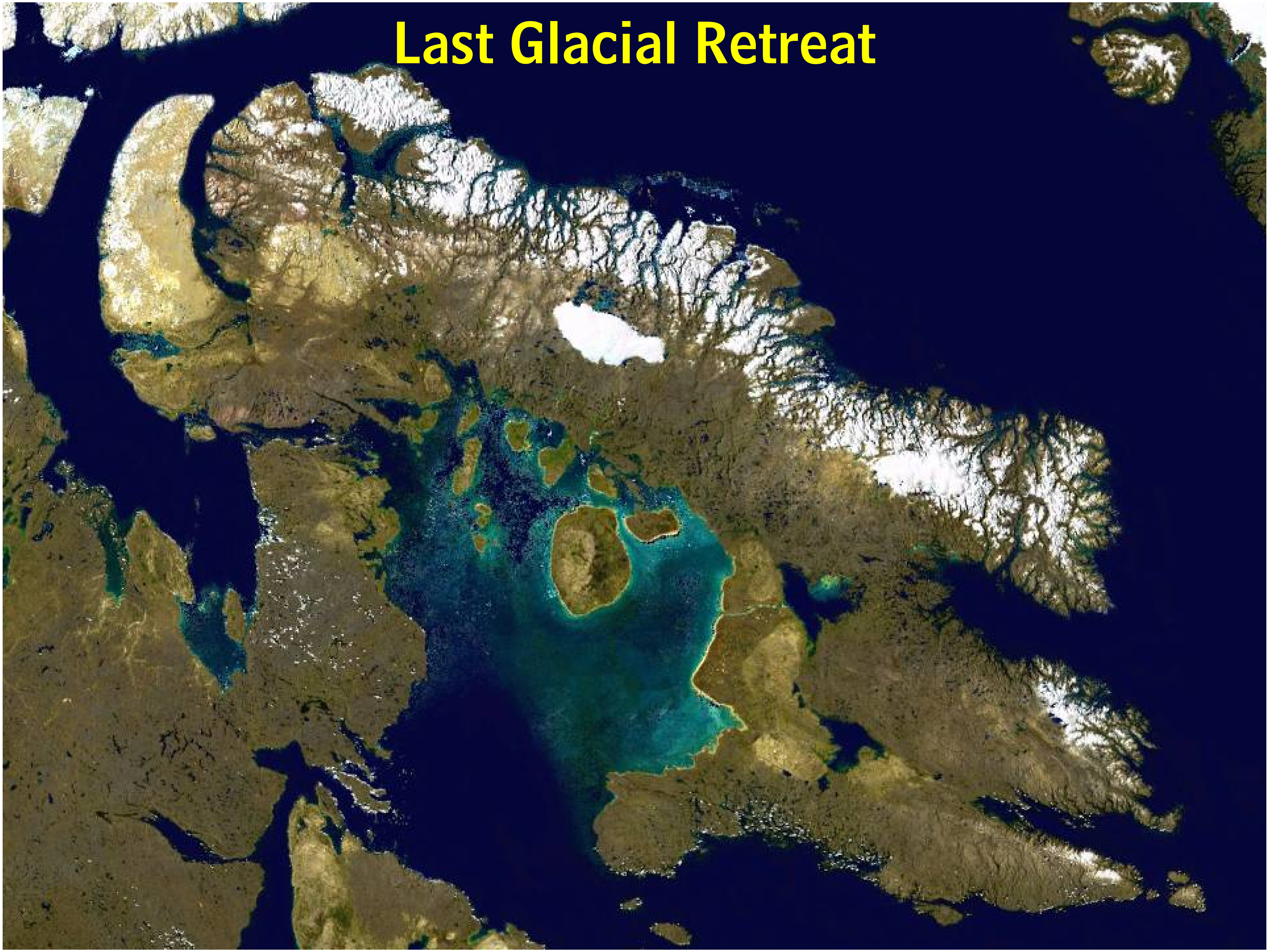
Last Glacial Retreat

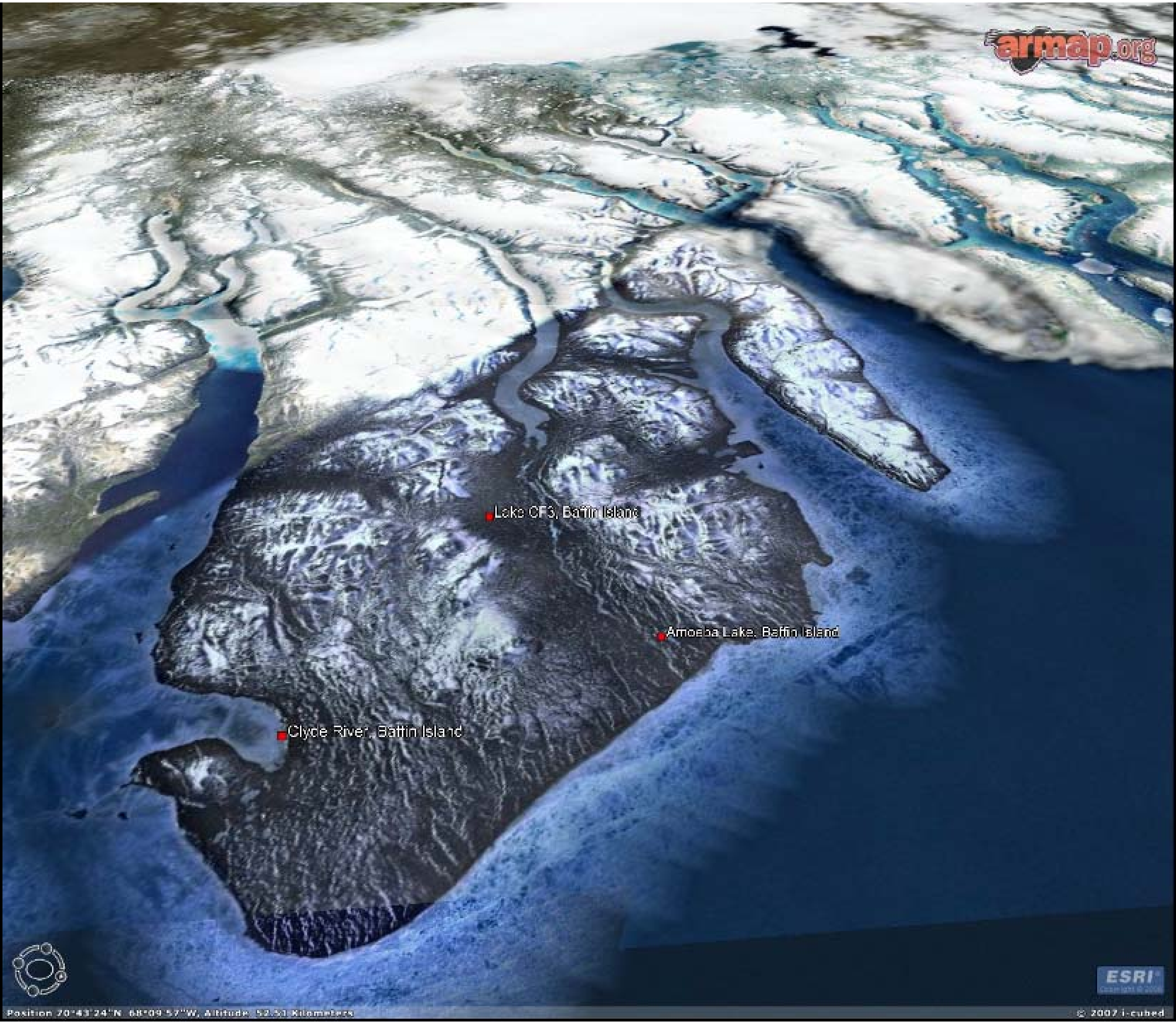
18

kya

Last Glacial Retreat

Last Glacial Retreat




armap.org
Lake CF3, Baffin Island
Amoeba Lake, Baffin Island
Clyde River, Baffin Island
ESRI
Position 70°43'24"N 68°09'57"W, Altitude 52.51 Kilometers
© 2007 i-cubed

Last Glacial Retreat

Last Glacial Retreat

Last Glacial Retreat

HTTP://GSC.NRCAN.GC.CA/LANDSCAPES/DETAILS_E.PHP?PHOTOID=228

Last Glacial Retreat

HTTP://ADAPTATION.NRCAN.GC.CA/ASSESS/2007/CH4/IMAGES/FIG3_F.JPG