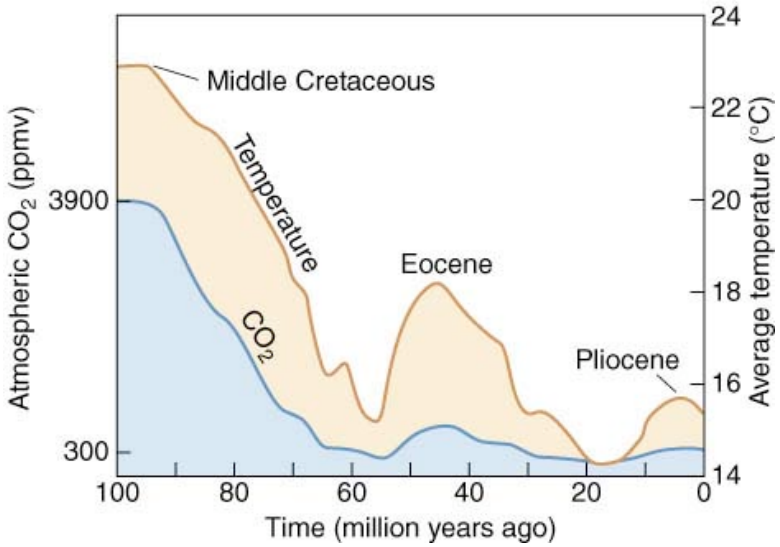
Paleoclimate, GCMs, Tectonics

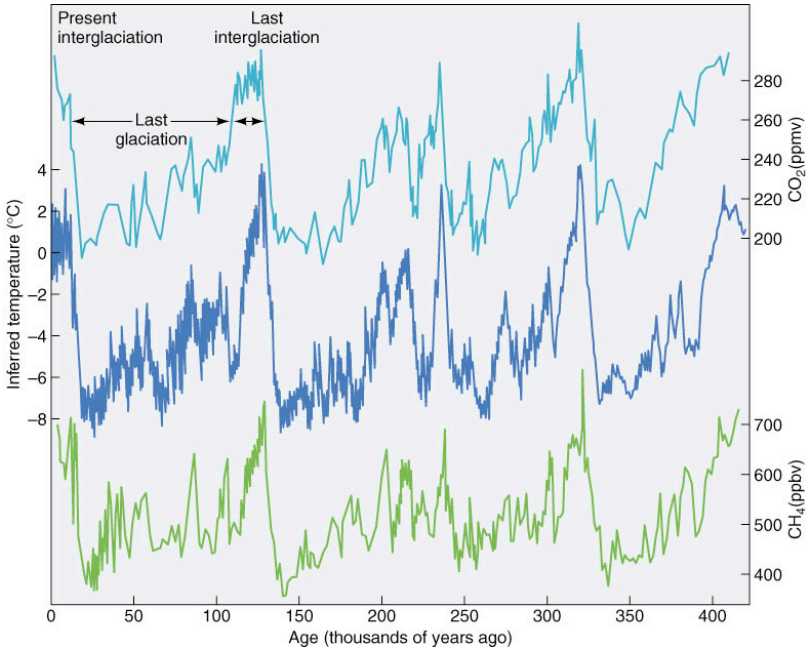
Climate Proxies

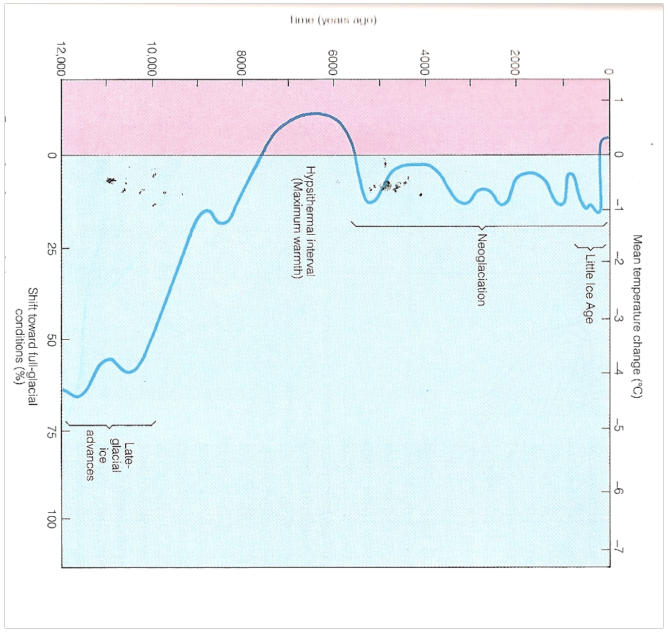
- $^{18}O/^{16}O$ ratio in sediments or ice
- Pollen
- Tree rings
- Lake levels
- Loess-soil record
- Terminal location of glaciers
- Human records

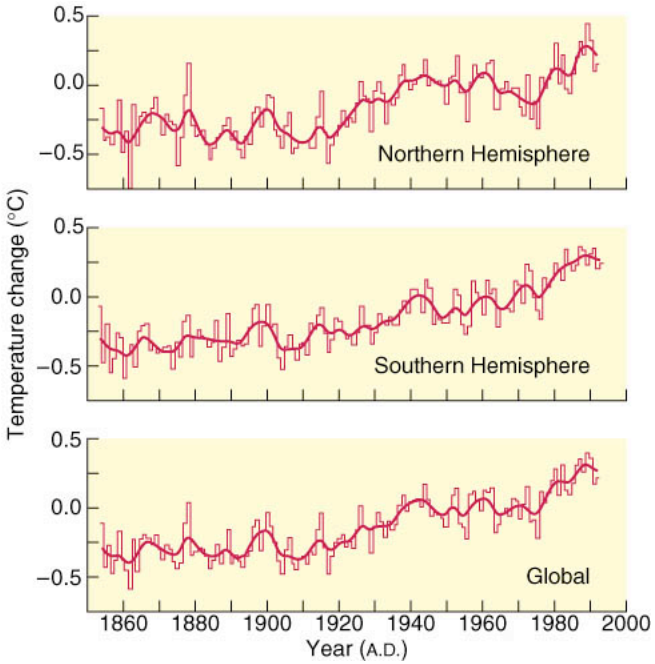
The Climate Record

- 50 million years
  - Collapse of Mesozoic climate
- 2.5 million years
  - Repeated continental glaciation (more than 20 times)
- 100,000 years
  - Last full continental glaciation cycle
- 10,000 years
  - Recovery from most recent continental glaciation
- 700 years
  - The “Little Ice Age”
- 100 years
  - Anthropogenic era









Causes?

- Shifting Plates
  - Change in ocean currents
  - Change in continental position relative to poles
  - Change in atmosphere due to volcanic activity & weathering
  - Change in atmospheric circulation due to mountains
- Biologic activity
- Solar activity
- The “Milankovitch” cycles and Northern Hemisphere insolation
  - Eccentricity (100,000 years)
  - Tilt (41,000 years)
  - Precession (23,000 years)
- Anthropogenic

Cause of "Little Ice Age"?

(and other Holocene variability)

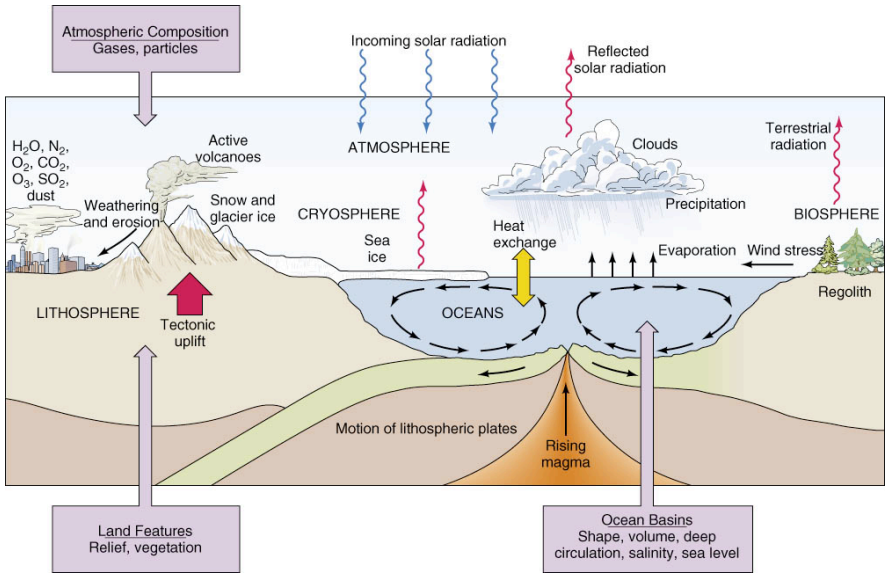
- Hypothesis: energy output of the Sun fluctuates over time
  - Correlation between sunspot cycle and weather patterns?
    - Fewer sunspots during 17th century?
    - Not yet convincing argument
- Volcanic emissions produce detectable changes of climate
  - Dust blocks sun – few year time scale
    - 1816 the "year without a summer" (Mt Tambora eruption)
  - SO_2 scatters light - decade time scale

Current Trends

- Warming of 3°C by end of century
- Snowline up by 500 m
- All but a few glaciers in Alps, Cascades, Himalayas will disappear

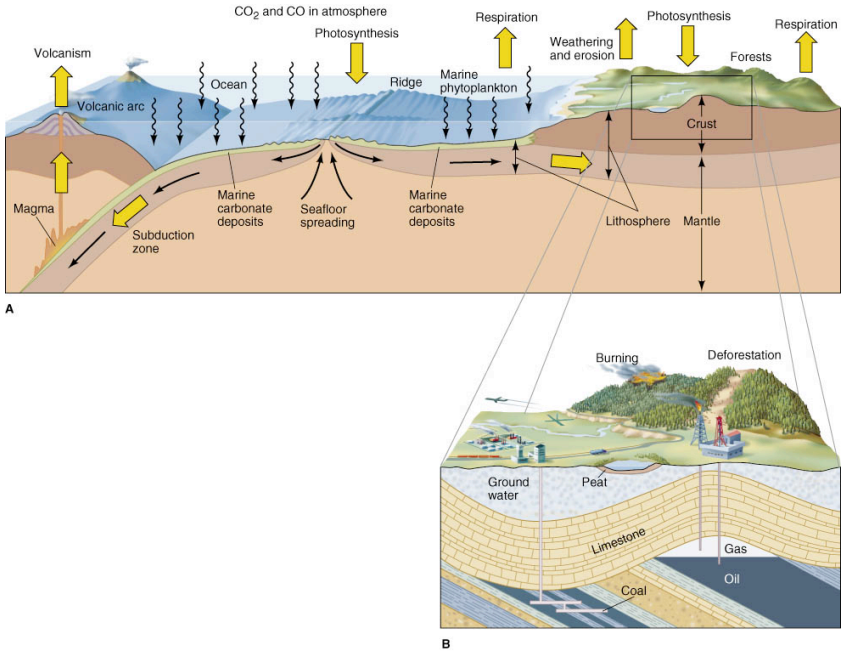
Earth Climate System

- Interacting components:
  - **The atmosphere.**
  - **The hydrosphere.**
  - **The solid Earth.**
  - **The biosphere.**



The Carbon Cycle

- **Carbon: five reservoirs**:
  - **In the atmosphere, it occurs in carbon dioxide.**
  - **In the biosphere, it occurs in organic compounds.**
  - **In the hydrosphere, it occurs as carbonic acid.**
  - **In the crust, it occurs both in the calcium carbonate of limestone and in decaying and buried organic matter such as peat, coal, and petroleum.**
  - **In the mantle, carbon has been present since the Earth first formed. Some is recycled by subduction, some released by volcanism**

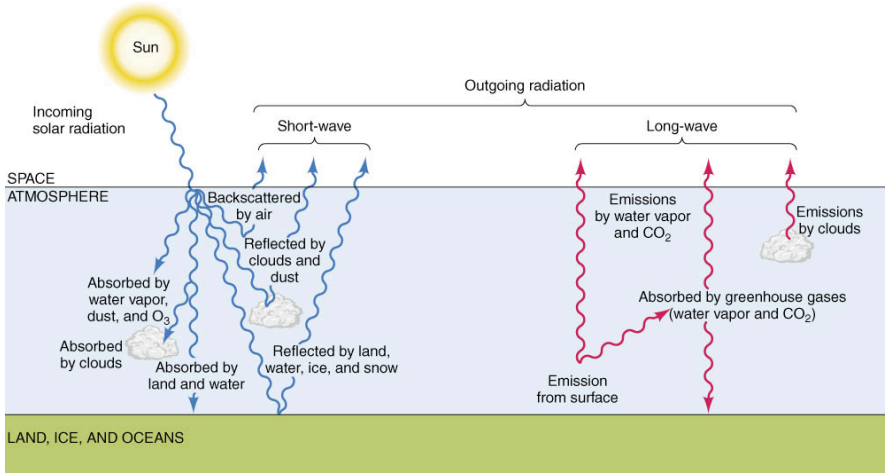


Biosphere<->atmosphere

- **Plants extract CO_2 from the atmosphere**
  - **photosynthesis to form organic compounds.**
  - **Decay returns CO_2 to atmosphere**
  - **Rapid cycle every 4.5 years**
- **Not all returned**
  - **Some dissolved in water**
    - **Extracted in shells**
    - **Precipiated as limestone**
  - **Some cycled into mantle in subduction**
- **Human activity accelerates release into atmosphere**

Greenhouse Effect

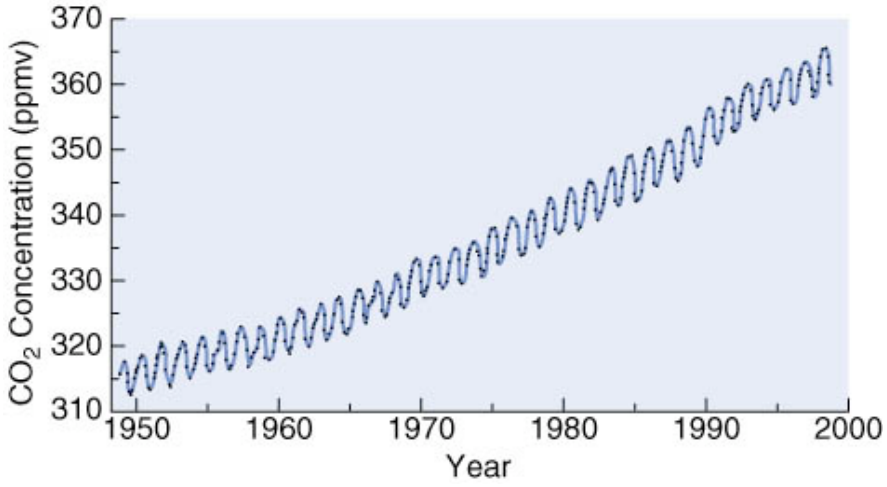
- Radiation balance
  - Earth receives energy from sun
  - Earth radiates energy into space
  - Balance required if temperature constant
- Solar radiation:
  - Some is absorbed by land and oceans
  - Some is reflected by
    - Water
    - Snow
    - Ice
    - Reflective surfaces
- Atmospheric gases
  - Transparent to visible light
  - Absorb infrared light

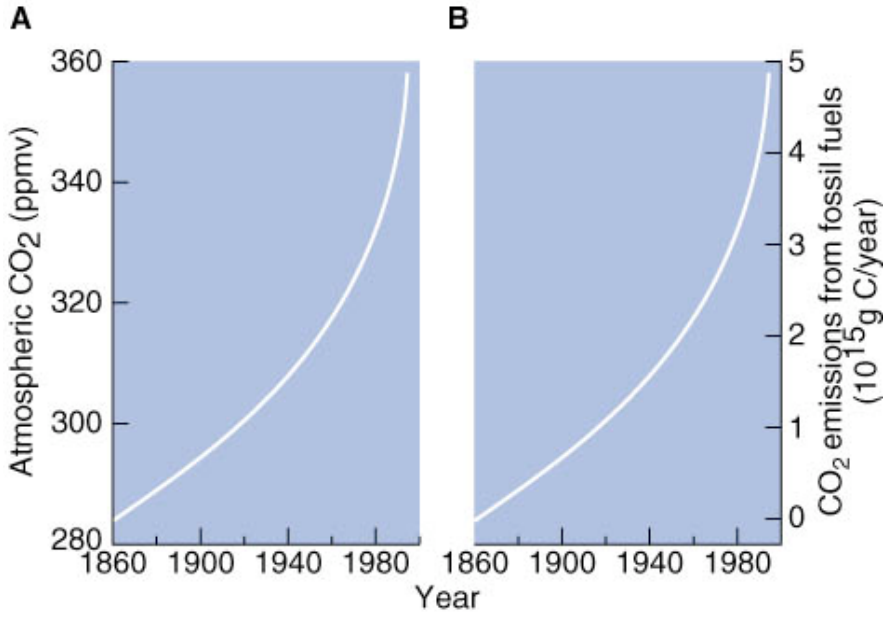


Greenhouse Gases

- **Dry air consists mainly of three gases:**
  - **Nitrogen (79%).**
  - **Oxygen (20%).**
  - **Argon (1%).**
- **Water vapor is usually present in the Earth's atmosphere in concentrations of up to several percentage points, and accounts for about 80 percent of the natural greenhouse effect.**

- **The remaining 20 percent is due to other gases present in very small amounts:**
  - **Carbon dioxide.**
  - **Methane.**
  - **Nitrous dioxide.**
  - **Ozone.**





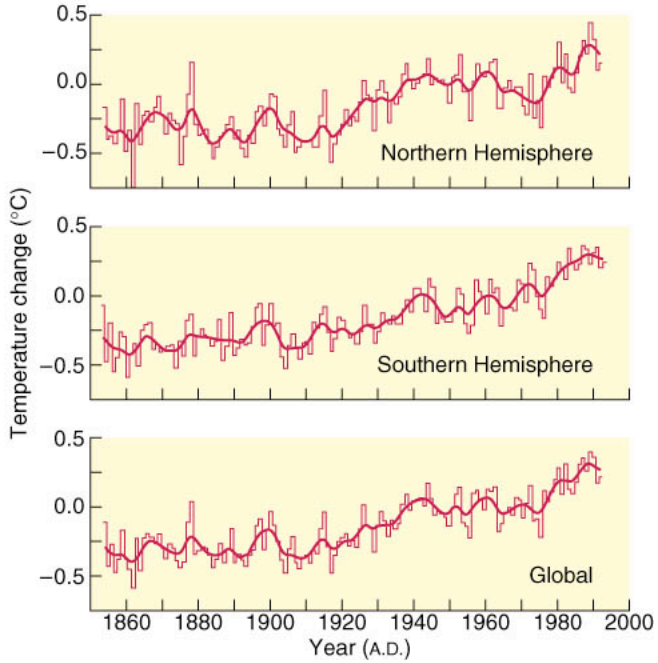
- **Inescapable conclusion: anthropogenic (human-generated) burning of fossil fuels is primary factor in the observed increase in atmospheric CO_2.**
- **Additional contributing factors are:**
  - **Widespread deforestation.**
  - **Use of wood as a primary fuel.**
- **Largest yearly increases on CO_2 in the 1990s occurred in years with maximum El Niño conditions**
  - **warmer water holds less dissolved CO_2**
  - **CO_2 is less likely to be absorbed by the ocean in an El Niño years.**

Methane

- **Methane (CH_4) absorbs infrared radiation 25 times more effectively than CO_2.**
- **Methane levels show increases that parallel the rise in the human population.**
- **It is generated by:**
  - **Biological activity related to rice cultivation.**
  - **Leaks in domestic and industrial petrochemical use.**
  - **The digestive processes of domestic livestock.**

Global Climate Change

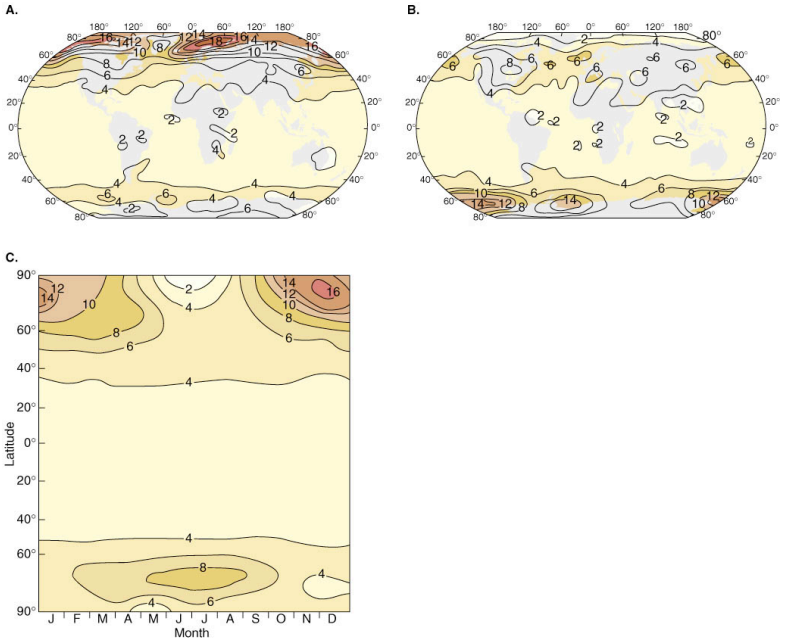
- **Correctly assessing recent global changes in temperature is a very complicated task.**
  - **Few instrumental measurements were made before 1850.**
  - **Vast regions have no weather data before World War II.**
  - **The earliest records are from western Europe and eastern North America.**
  - **Records from oceanic areas (70 percent of the globe) are sparse.**



General Circulation Models (GCMs)

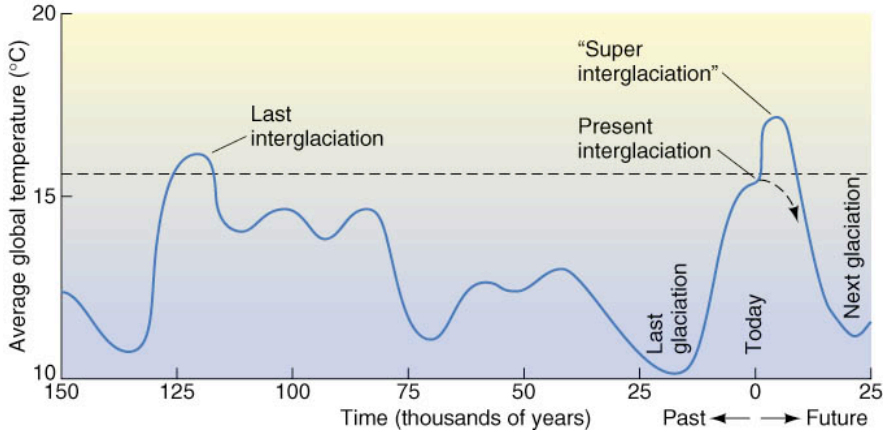
- Three dimensional mathematical model of Earth's climate system -
  - predict weather (short term)
  - Predict future climate
  - Explain past climate trends
- Can link atmosphere, hydrosphere, biosphere, and geosphere

- Successful in simulating current general climate patterns (although may incorrectly predict tomorrow's weather)
- Require input boundary conditions:
  - **The solar radiation reaching Earth.**
  - **The geographic distribution of land and ocean.**
  - **The position and heights of mountains and plateaus.**
  - **The concentrations of atmospheric trace gases.**
  - **Sea-surface temperatures.**
  - **The limit of sea ice.**
  - **The snow and ice cover on the land.**
  - **The albedo (reflectivity) of land ice and water surfaces.**
  - **The effective soil moisture.**



Some unknows

- **The rate at which the projected warming will occur depends on a number of uncertainties:**
  - **How rapidly will concentrations of the greenhouse gases increase?**
  - **How rapidly will the oceans respond to changing climate?**
  - **How will changing climate affect ice sheets and cloud cover?**

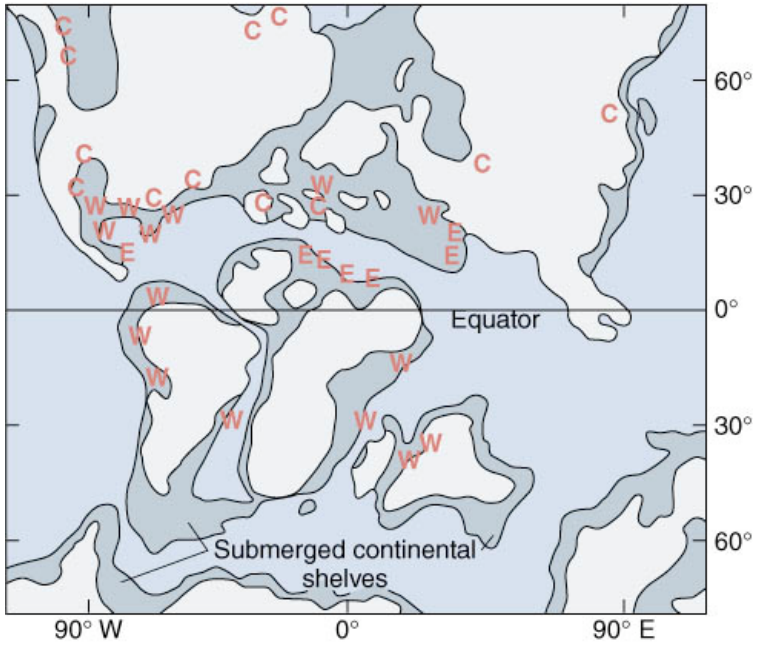


Expected Environmental Changes

- **Global precipitation changes because of**
  - **Increased or decreased evaporation.**
  - **Changes in vegetation.**
  - **Increased storminess (warmer, wetter atmospheres favor an increase in tropical storm activity).**
  - **Melting or growing glaciers.**
    - **Warmer summers favor increased ablation.**
    - **Warmer air in high-latitudes could evaporate and transport more moisture causing glaciers to grow larger.**
  - **Reduction of sea ice.**
  - **Thawing of frozen ground.**
  - **Rise of sea level.**
  - **Changes in the hydrologic cycle.**
  - **Decomposition of soil organic matter.**
  - **Breakdown of gas hydrates.**
    - **Ice-like solids in which gas molecules mainly methane, are locked in the structure of solid H_2O,**
    - **Found in some ocean sediments and beneath frozen ground.**

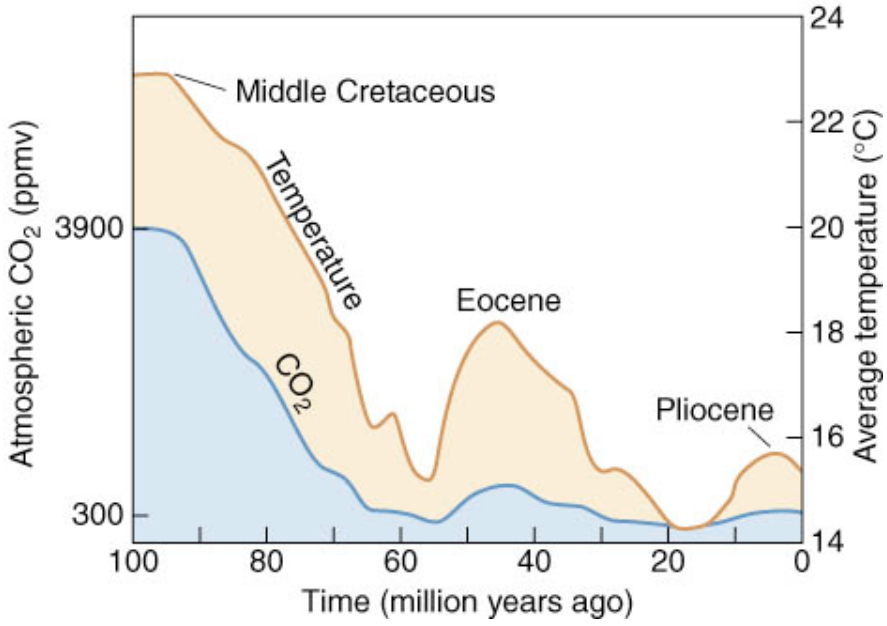
The Past As A Key To The Future

- **Geologic record: past climate has paralleled today's climate only occasionally.**
- **Interglacial interval approximately 12,000 years old**
  - **close to the age where a return to glacial conditions can be expected.**
- **Climate in the last million years has occasionally been warmer than today's climate.**
  - **In the early Holocene, from 10,000 to about 6000 years ago, average temperatures were 0.5 to 1^0C warmer than today.**
  - **About 120,000 years ago, global temperatures were 1 to 2^0C higher than today.**

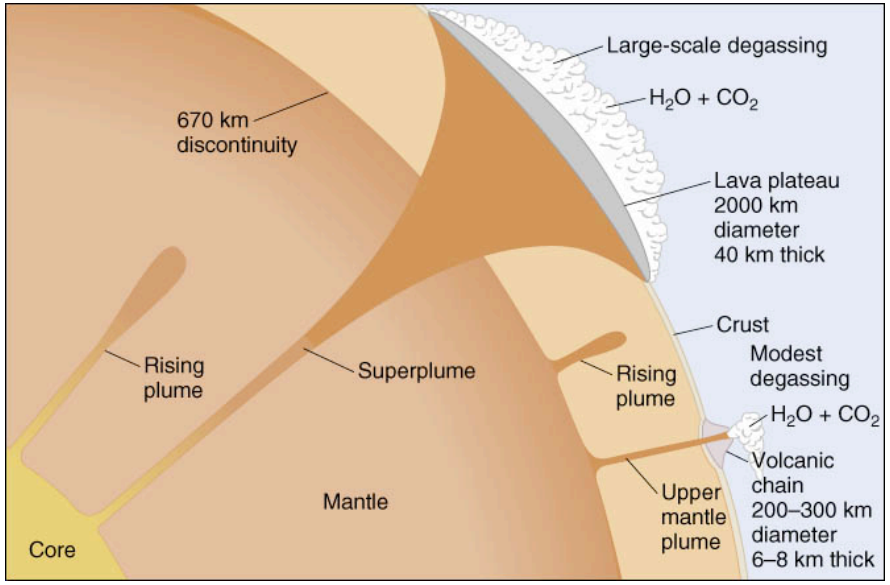


Why Was the Middle Cretaceous Climate 8°C Warmer?

- The world was inhabited by huge carnivorous dinosaurs.
- Coral reefs grew 5 to 15^0 closer to the poles than they do now.
- Vegetation zones were displaced about 15° poleward of their present positions.
- Sea level was 100 to 200 m higher, indicating the absence of polar ice sheets.



- **Several factors could be involved in producing Middle Cretaceous globally warm conditions:**
  - **Geography.**
  - **Ocean circulation.**
  - **Atmospheric composition.**
- **The most likely source CO_2 entering the atmosphere is volcanic activity.**
- **Geologic evidence points to an unusually high rate of volcanic activity in the Middle Cretaceous.**



- **Vast outpourings of lava created a succession of great undersea plateaus across the central Pacific Ocean between 135 and 115 million years ago.**
  - **The Ontong-Java plateau (twice the area of Alaska and 40 km thick).**
- **The eruptions could have released enough CO_2 to raise the atmospheric concentration to 20 times the preindustrial value.**

Modeling past Global Changes

- **Paleoclimatic reconstructions offer a means of testing the accuracy of climate models.**
- **We can test, or "validate," these climate simulations by comparing the model results against independent geologic evidence.**
- **The results of the model simulation are generally consistent with the paleoclimatic data assembled by geologists.**

Link Between GCM and Tectonics

- New discovery in last decade
- Erosion enhances uplift
  - Not just case of wearing down mountain
  - Mountains respond to climate
- Isostatic adjustment due to erosion
  - Valleys get deeper, ridges rise
  - Explains Himalaya on edge of Tibetan Plateau
- Mountain ranges change atmospheric circulation