CE/SC 10110-20110: Planet Earth

Global Change

Earth

Portrait of a Planet
Fifth Edition

Chapter 23

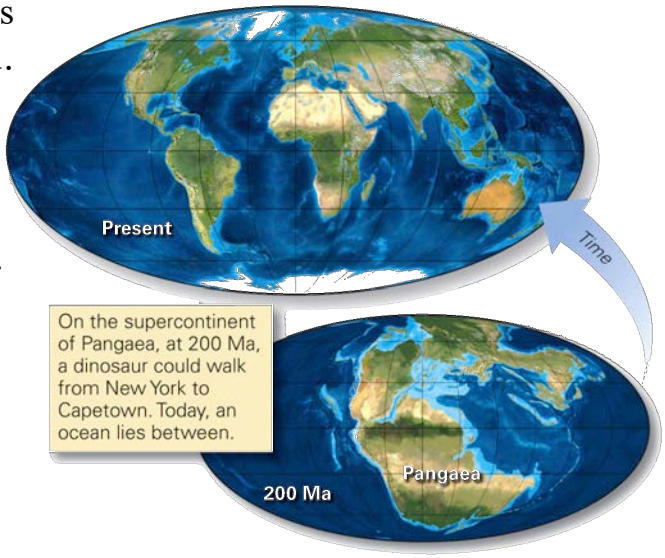
Global Change

The Earth has changed over geologic time as the planet has cooled and plates have drifted.

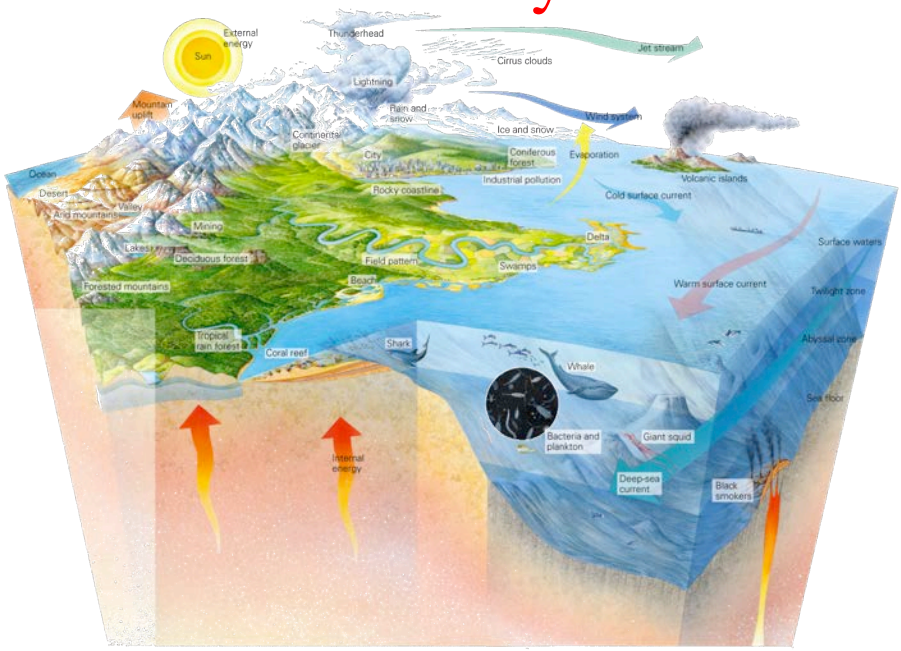
At the start of the course we looked at how the solid Earth evolved through magma generation and plate tectonics.

Earth is just in the right place in the Solar System for life to develop.

Ocean development was critical for removing CO_2 and preventing a runaway green-house effect, as on Venus.



The Earth System



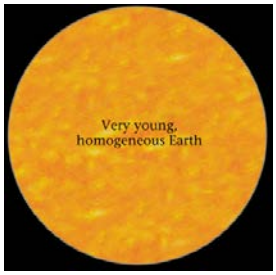
Life on Earth is due to interaction between the lithosphere, the atmosphere, and the hydrosphere.

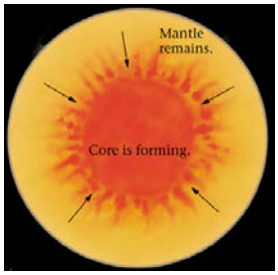
The Changing Earth

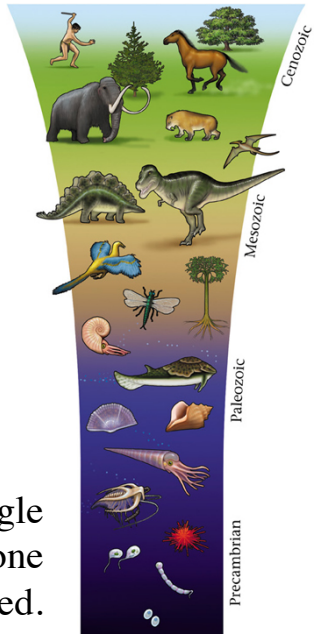
Rate—gradual vs. catastrophic. Frequency—unidirectional vs. cyclic Agency—geogenic vs. anthropogenic

Global Change

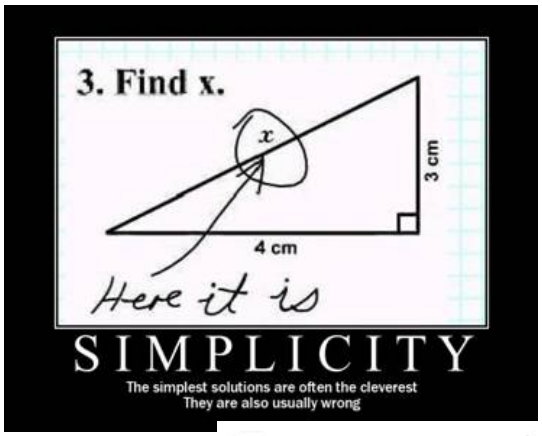
Formation of the Moon has also been critical for the development of life and produces tides.







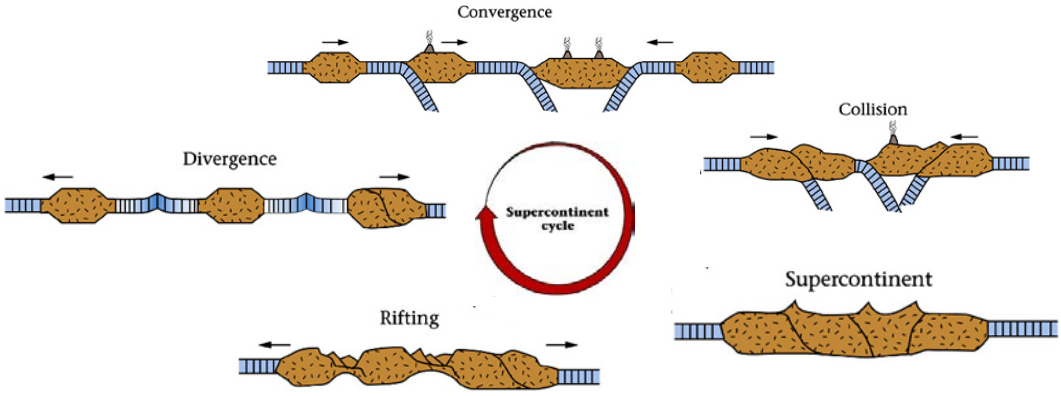
Life began slowly - single cells. Needed O and Ozone to be developed.



Quiz Time!

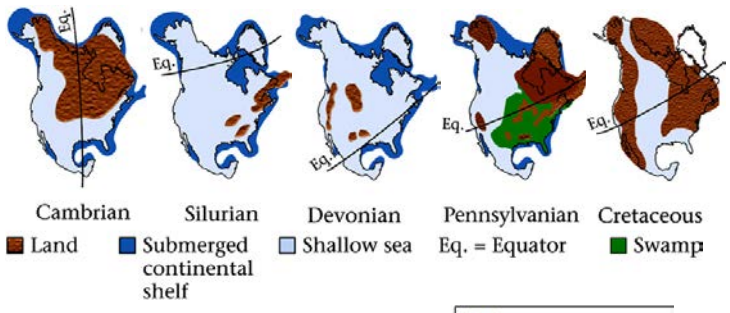
Physical Cycles

All continents are joined in one land mass. Has happened ~4 times over the last 3 b.y. **Supercontinent Cycle**.

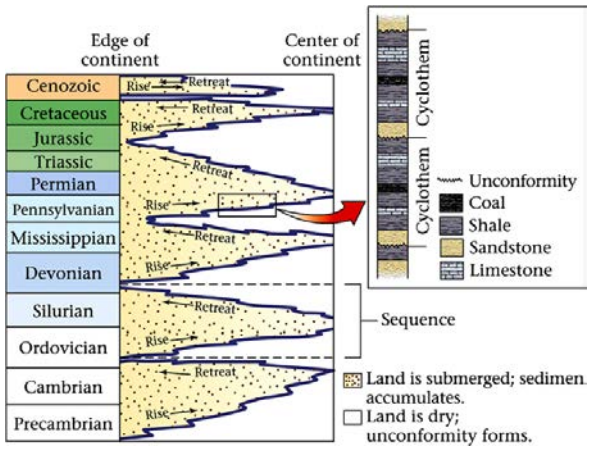


As plates only move at 1-15 cm per year, this cycle takes a few hundred million years to complete and the land never rearranges exactly the same through two cycles.

Physical Cycles



Sea-level cycles: sea level has fallen ~300 m during Phanerozoic. When sea level rises over 50% of continental landmass is inundated and a sedimentary sequence develops.

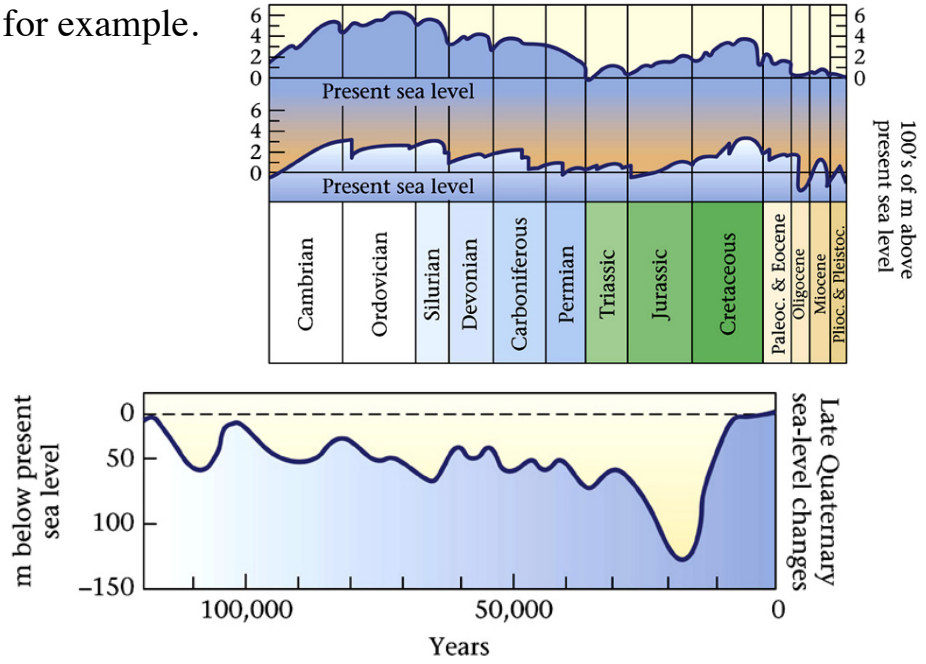


When sea level falls, unconformities develop.

Pennsylvanian important - it records >30 shorter cycles ("cyclotherms") that contain the coal measures - submergence-emergence.

Physical Cycles

The global sedimentary cycle chart largely reflects eustatic sea-level change, although the sedimentary sequence also reflects sediment supply, for example.

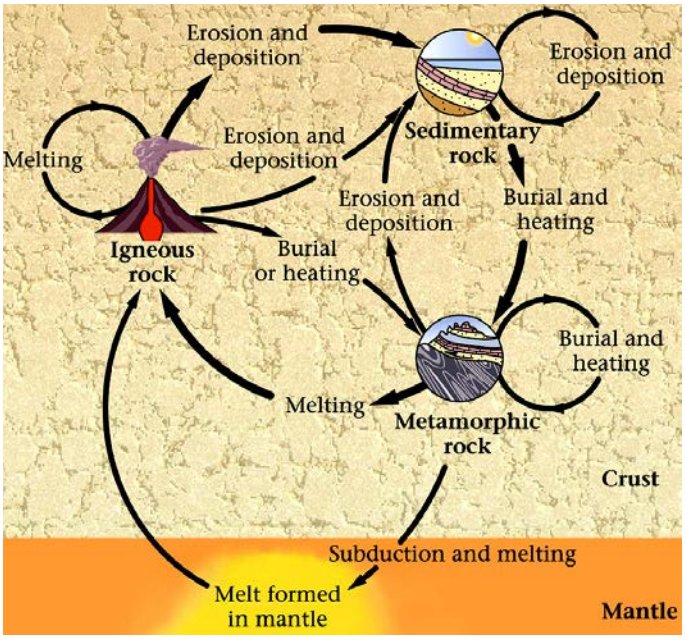


Physical Cycles

The Rock Cycle

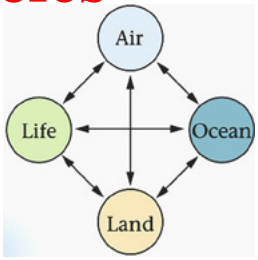
ROCK: Naturally occurring aggregate of two or more minerals.

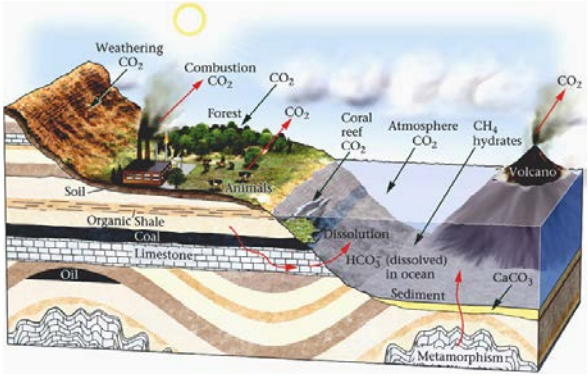
Rock-Types:
IGNEOUS
SEDIMENTARY
METAMORPHIC



Biogeochemical Cycles

Movement of chemicals among living and non-living reservoirs.
Non-living: atmosphere, crust, oceans;
Living: plants, animals, microbes.





Cycles can take hours or millions of years. For intervals of time, they can reach a steady state condition (proportions in various reservoirs are constant although there is a constant flux among reservoirs).

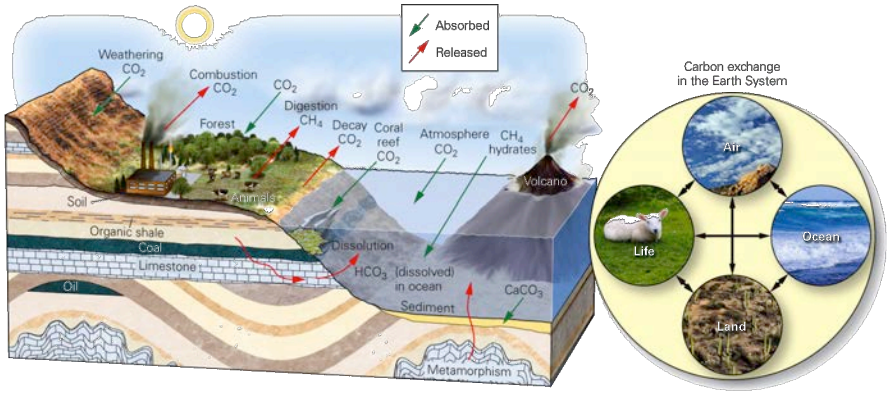
Global Change: change in the steady states situation (i.e., relative proportions of a chemical held in a reservoir at a given time).

Biogeochemical Cycles

Hydrologic Cycle

Biogeochemical Cycles

Carbon cycle: starts with CO_2 bubbling out of the Earth from volcanoes where it can be removed by:
Dissolving in oceans (eventually) as HCO_3^- ions:
Absorption by organisms for food;
Dissolving in rain and being used in chemical weathering reactions.
Precipitation as $CaCO_3$.
Burial and removal as fossil fuels.

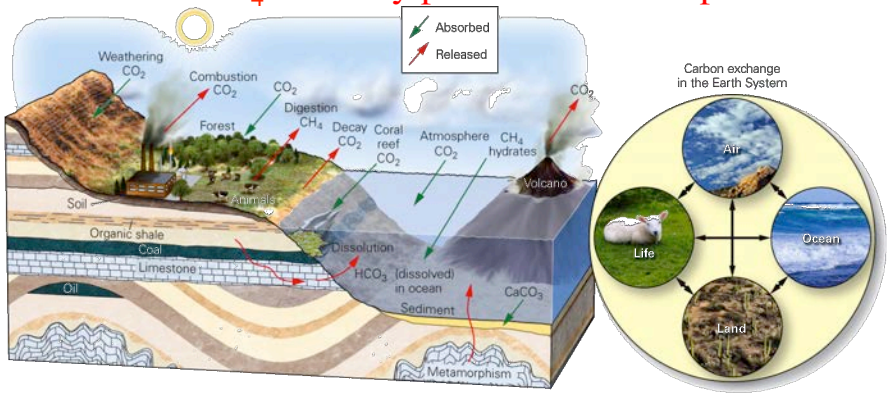


Biogeochemical Cycles

Carbon cycle:

Put back into the atmosphere by:
Oxidation after death of organic matter;
Anoxic decay of organic matter and flatulence! (CH_4)
Burning of fossil fuels.
CO_2 and CH_4 = important greenhouse gases - CH_4 is a more efficient greenhouse gas than CO_2.

How is CH_4 naturally put into the atmosphere?



The Carbon Cycle

Carbon is removed from the cycle for long periods of time when stored in limestones, fossil fuels (coal and oil), organic shales, and methane hydrates.

The Carbon Cycle

Carbon is removed for short periods of time when stored in organic matter (trees, animals).

Carbon is returned to the atmosphere by biotic respiration, burning organic matter, metamorphism of carbonate rocks, and degassing from the oceans.

Global Climate Change

A rise in the average surface temperature of just a few degrees is enough to melt the polar ice caps and cause a dramatic sea-level rise - ***Global Warming***.

Remember: >60% of the worlds population lives at or near coasts.

If global temperatures fall = ***Global Cooling***.

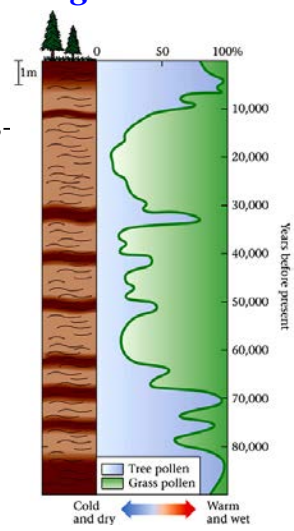
Long-term global climate change: millions-tens of millions of years;

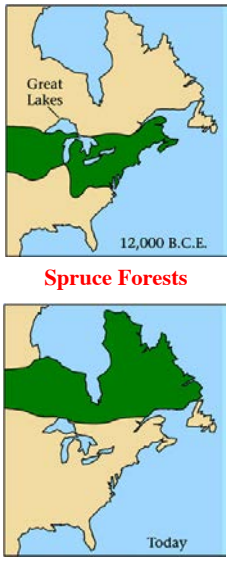
Short-term global climate change: tens-thousands of years – even decades.

Study of paleoclimate conducted by:

1) **The Stratigraphic Record** - nature of sediments (continental, marine, coal, cross-bedded sandstones);

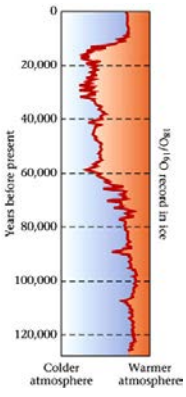
2) **Paleontological Evidence**: different species live in different climates, including plankton and pollen.



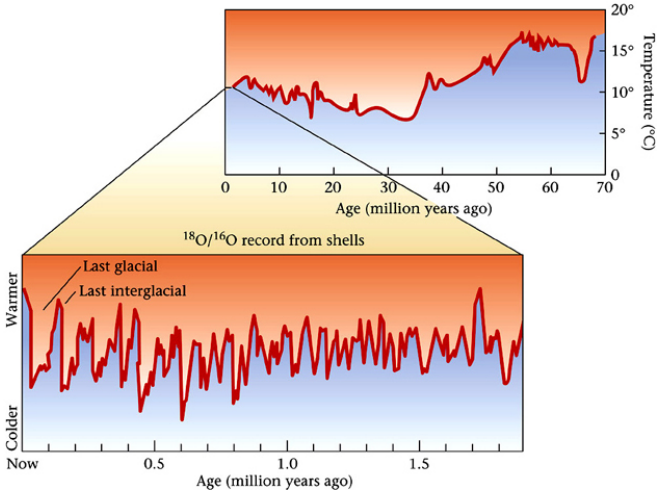


Global Climate Change

3) **Oxygen Isotopes**: Ratio of ^{18}O to ^{16}O is larger in snow that forms in warmer air and smaller in snow formed in colder air.



Greenland ice gives a record back 400,000 years.

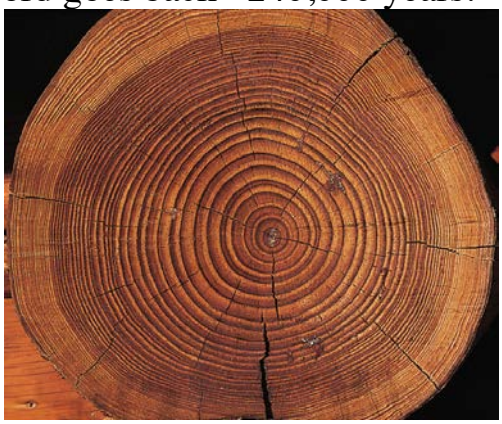


$CaCO_3$ of plankton shells in marine sediments gives a record of millions of years.

Global Climate Change

4) Bubbles in Ice: Can measure directly the CO_2 content of atmosphere at various times. This record goes back ~240,000 years.

5) Growth Rings: Trees, corals, stalagtites/stalagmites. Bristlecone pines extend the record back 4,000 years. Go back further by logs dated by radiocarbon that overlap with live trees.



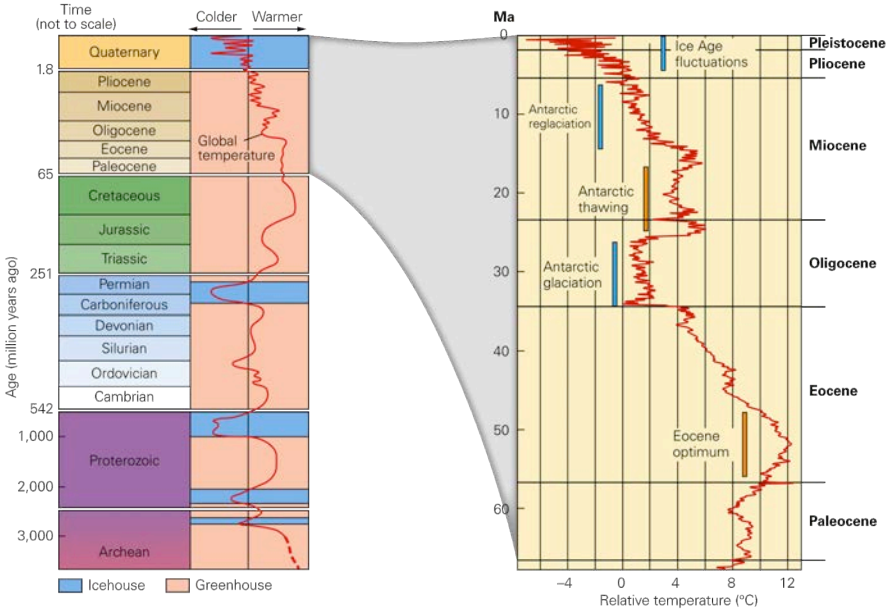
6) Human History: Written record, art, etc.

Record of medieval flood in England.

Global Climate Change

Long-Term Climate Change

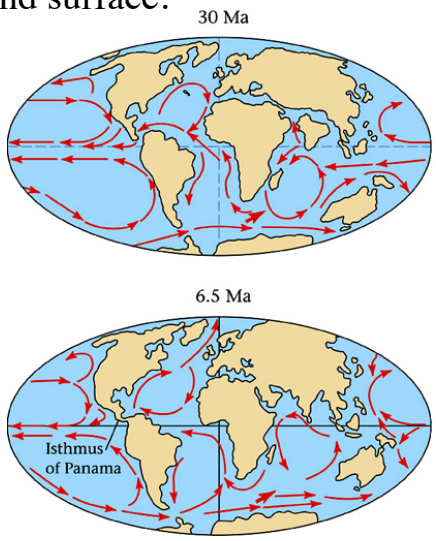
Ice-house and greenhouse effects. There have been at least 5 major ice-house periods during Earth history.

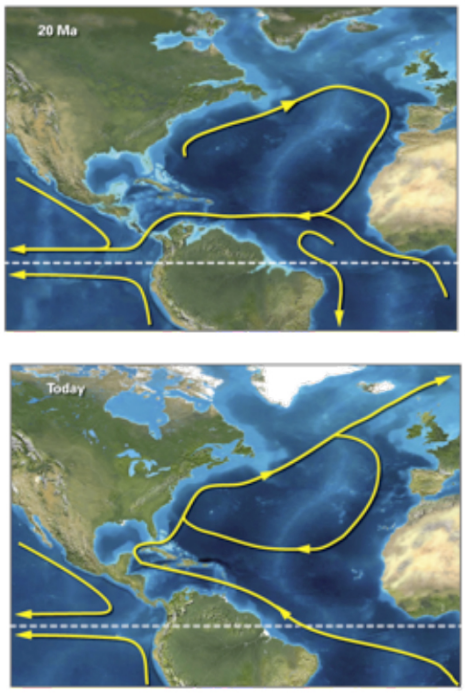


Global Climate Change

Long-Term Climate Change

Positions of the Continents:
Controls the ocean currents and amount of solar radiation reaching the land surface.

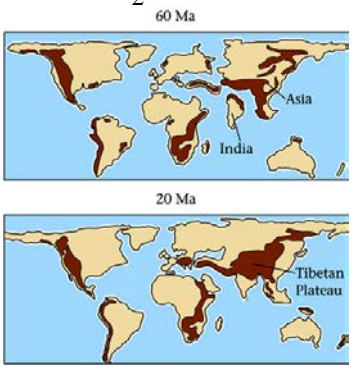




Global Climate Change

Volcanic Activity: Increased volcanic activity can contribute to overall global warming. During the Cretaceous, LIP formation occurred in the Pacific and Indian oceans. CO_2 content of the atmosphere increased - no ice caps.

Uplift of Land Surface: Exposes more land to chemical weathering. This absorbs CO_2 and can reduce the atmospheric concentration. This may have triggered the Cenozoic cooling that led to the Pleistocene ice age.



Brown = land at high elevations.

Formation of Fossil Fuels: This can remove C from the system over time. However, if it is put back all at once……!

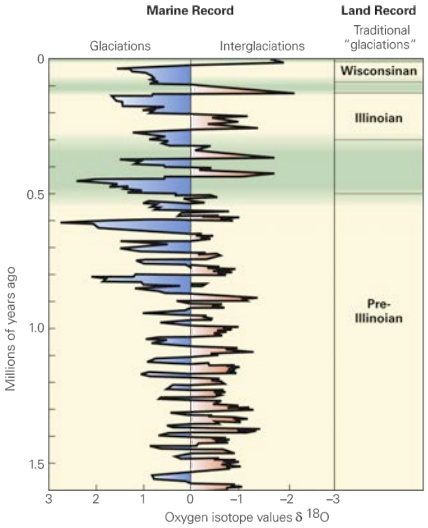
Evolution of Life: Life initiation changed the atmosphere through CO_2 removal. Could have promoted the "snowball Earth" during the Proterozoic.

Global Climate Change

Negative Feedback - slows a process down or reverses it (e.g., increase of CO_2 increases global temperature, but also increases chemical weathering due to more precipitation, which removes CO_2).
Positive Feedback - makes a process continue or accelerate (e.g., runaway greenhouse effect on Venus).

Short-Term Climate Change

Climate changes lasting centuries to hundreds of thousands of years are considered to be short term. The climate variability of the Pleistocene, as indicated from fossils, sediments, and isotopes, indicates that continental glaciers have advanced and retreated 20 to 30 times in the northern hemisphere.



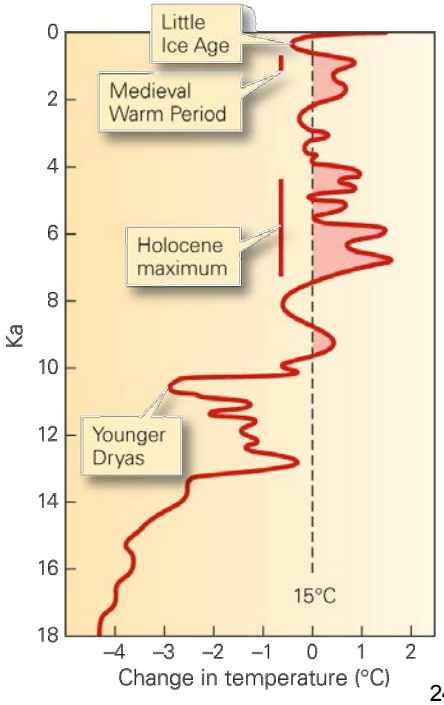
Global Climate Change

Short-Term Climate Change – The Holocene

Over the last 15,000 years global temperature has increased, but there have been notable departures that can occur over just 10 years.

Younger Dryas: cooling event named after expansion of arctic plant.
Climate warming reached a peak at 5,000 to 6,000 years ago called the Holocene Maximum.
Medieval Warm period - increased evaporation - middle east was fertile area. Vikings able to live in Greenland.

Little Ice Age: Middle ages - Thames froze over, as did the dikes in Netherlands.
Climate has warmed since 1800 C.E.



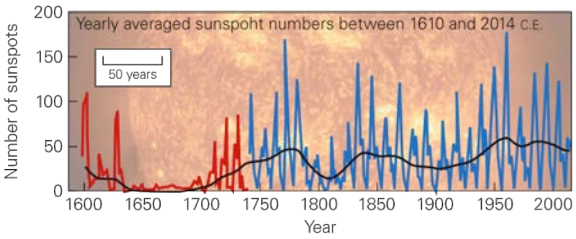
Global Climate Change

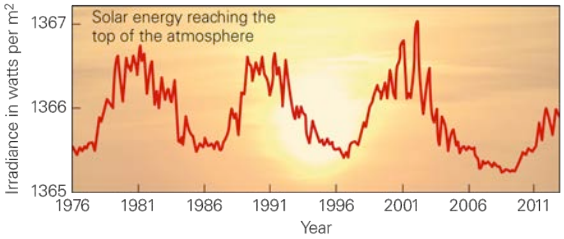
Six factors used to explain short-term climate change:

Fluctuation in Solar Radiation: Sunspot Cycle - magnetic storms on the Sun's surface every 9-11.5 years.

Hypothesized that changes in the rate of influx of cosmic radiation. This strikes the upper atmosphere that produces ions that act as condensation nucleii. High-elevation clouds reflect incoming radiation, but low-level clouds could trap infra-red radiation and promote heating.

Measurements of the solar energy reaching the top of the atmosphere fluctuates periodically.



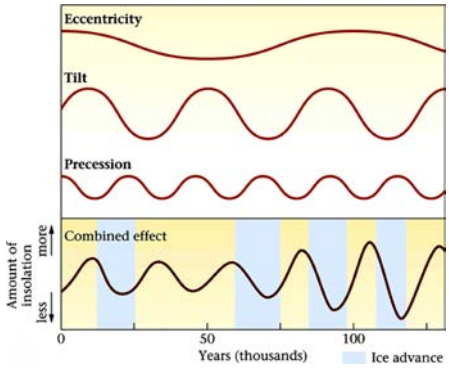


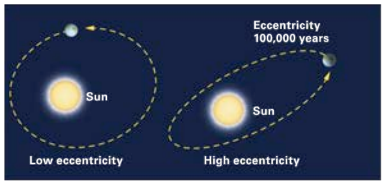
Global Climate Change

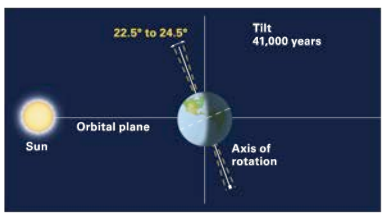
Six factors used to explain short-term climate change:

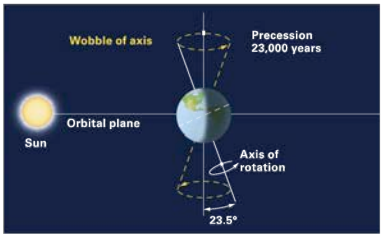
Changes in Earth's Orbit and Tilt: Milankovitch Theory.

Cycles recorded in tills and from oceanic cores suggest wobbles every 21,000, 41,000, and 100,000 years.









Global Climate Change

Changes in Volcanic Emissions: Increased volcanic emissions in the atmosphere change Earth's albedo resulting in a diminishing of solar radiation reaching the surface.

Changes in Ocean Currents: The ***Younger Dryas*** may have occurred because a layer of freshwater from melting glaciers spread out over the North Atlantic and prevented thermohaline circulation, shutting off the Gulf Stream.

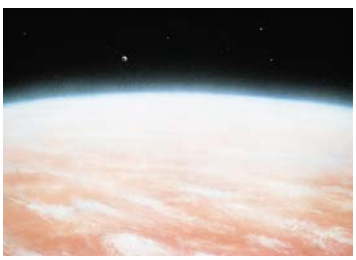
Changes in Surface Albedo: Ice caps reflect more radiation, promoting cooling. As glaciers melt, the land surface absorbs more heat and more melting occurs. Both are positive feedback mechanisms.

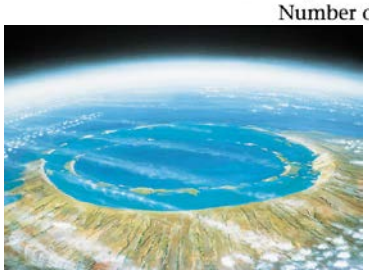
Abrupt Changes in Greenhouse Gas Concentration: Sea level drop could expose gas hydrates that put CH_4 into the atmosphere quickly. Dropping sea level exposes continental shelves and releases methane hydrates.

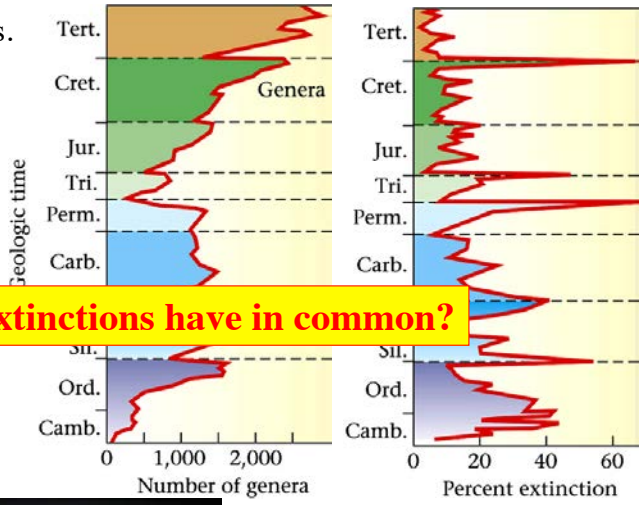
Catastrophic Changes

Occur because of catastrophic events. Whole species go extinct worldwide and reduces biodiversity.

Cretaceous-Tertiary Extinction: Chicxulub impact into evaporite sequence.



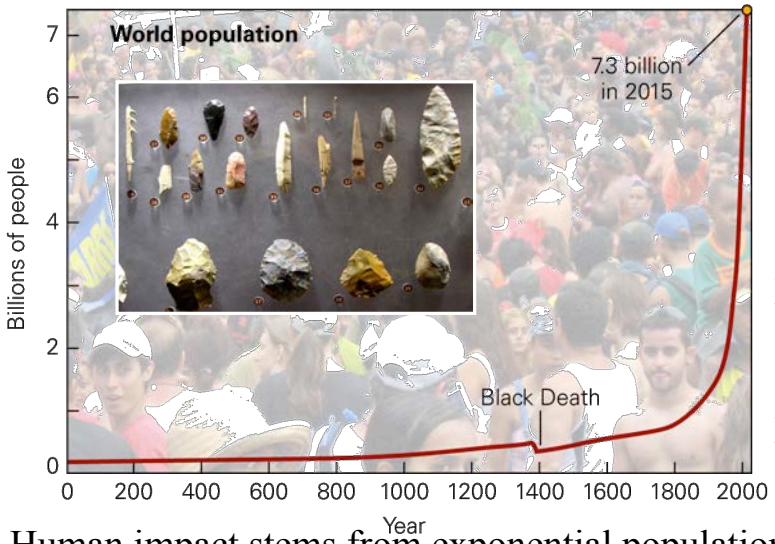




What do all mass extinctions have in common?

Permo-Trias Extinction: Siberian Traps LIP occurred at the same time, although some think an impact structure off the NW coast of Australia represents a mass-extinction-causing impact.

Human Impact on the Earth System



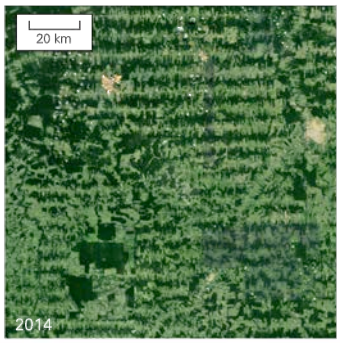
Prehistoric humans had a very a small impact. Today, however, humans are a powerful force of planetary change, rivaling or exceeding some natural processes.

Human impact stems from exponential population growth aided by revolutions in industry, agriculture, technology, and medicine, fueled by accessible natural resources. Population growth has increased dramatically in the last two centuries. This increases pressure on and use of natural resources.

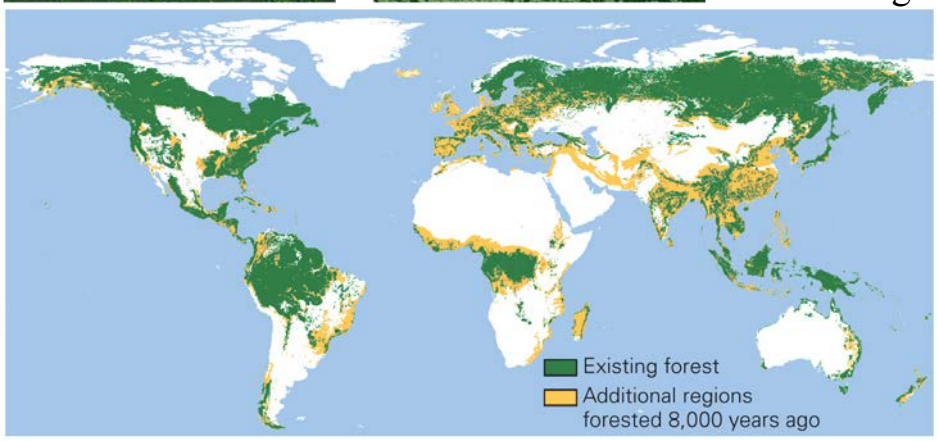
Landscape Modification

Excavation, agriculture, and construction modify the topography, drainage, infiltration, and ecology. Increased mass wasting.

Ecosystem Modification



Human changes occur faster than organisms can adapt, destabilizing established ecological balances. Rainforest decline is largely the result of human agency.

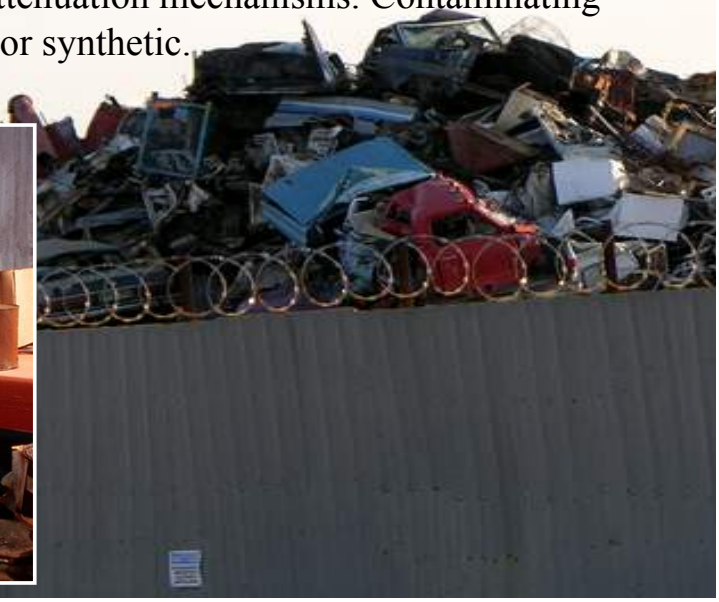


Ecosystem Modification

Excavation, agriculture, and construction modify the topography, drainage, infiltration, and ecology.

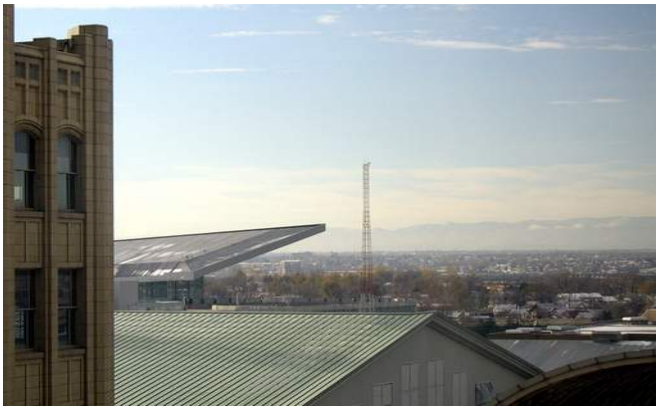
Pollution

Pollution is material that contaminates air, water, or soil. Modern society generates a vast array of solid, liquid, and gaseous contaminants that overwhelm natural attenuation mechanisms. Contaminating materials may be natural or synthetic.



Smog

Smog (smoke + fog) is urban haze created by the reaction of ground-level ozone and unburned hydrocarbons catalyzed by sunlight.

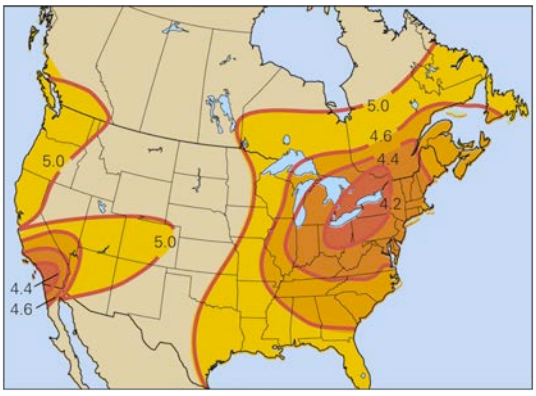


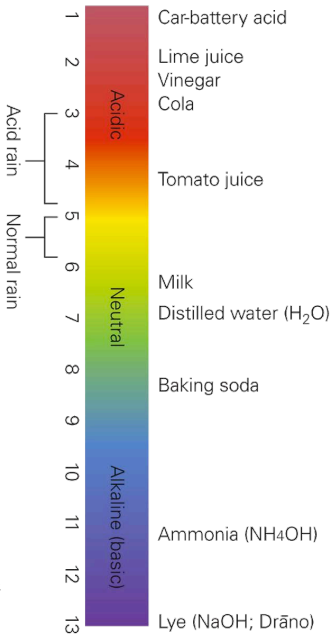
Water Contamination

Contaminating substances frequently enter surface and groundwater.

Common water contaminants include excess sediment, sanitary and agricultural wastes, refined petroleum products, detergents, solvents, fertilizers, pesticides.

Acidification





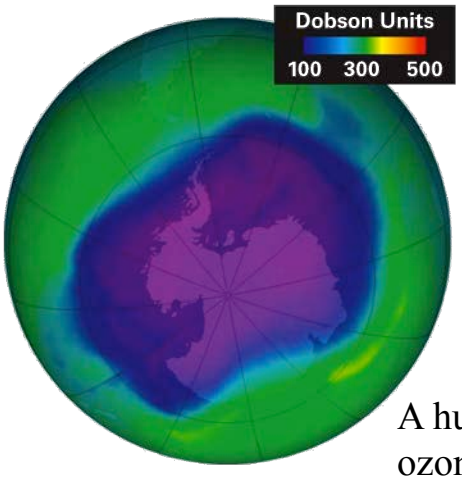
Acid rain is generated from sulfate-rich aerosols from coal-fired power plants. Acid rain occurs downwind of major industrial cities. Acid runoff is pollution from coal and base metal mining. Sulfide minerals in mined rock oxidizes to form sulfuric acid, which dissolves toxic metals and poisons waterways.

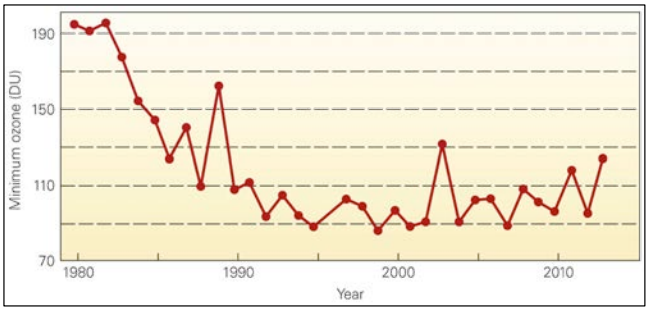
Radioactive Materials

Nuclear weapons, nuclear energy, and medical waste transfer radioactive materials from rock to Earth's surface environment. Nuclear materials from mining and processing generate waste mine spoil and mill tailings; power plants generate high-level nuclear wastes.

Stratospheric Ozone Depletion

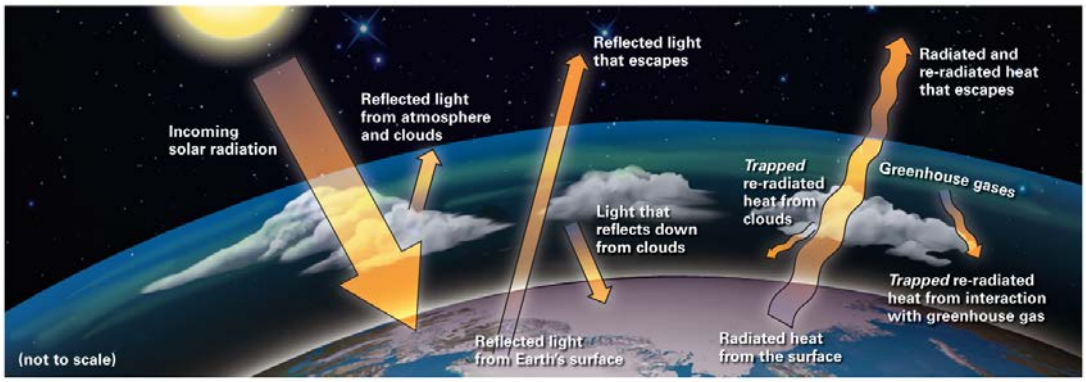
Ozone (O_3) is an important component of the stratosphere because it blocks harmful ultraviolet (UV) radiation. Chlorofluorocarbons (CFCs) catalyze destruction of ozone.





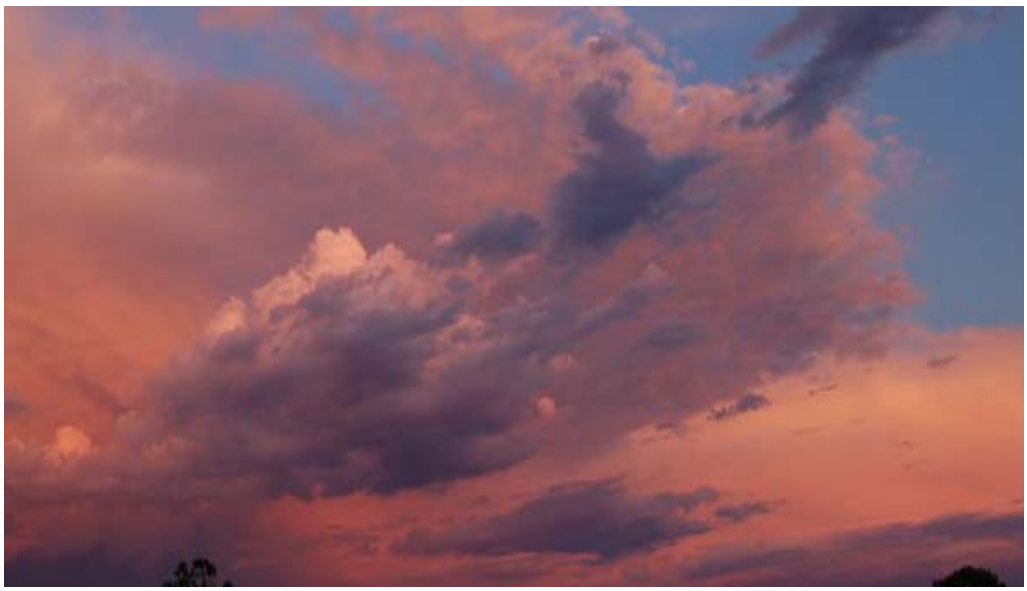
A huge area of depleted ozone (termed an ozone hole although ozone is still present) has been measured in polar regions. Note: Ozone depletion is unrelated to CO_2 buildup.

The Role of Greenhouse Gases



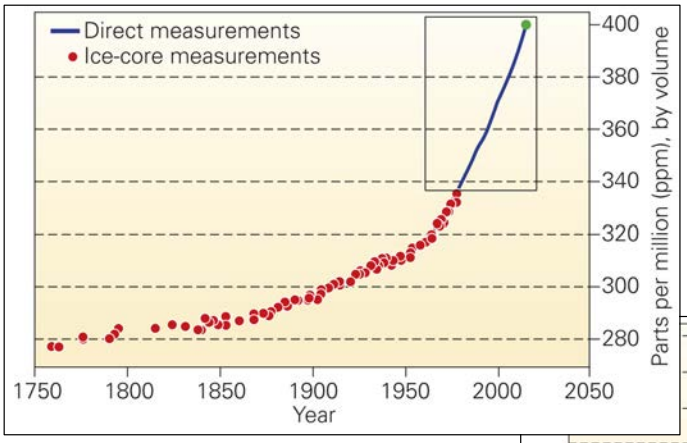
- Most of the incoming visible light from the Sun penetrates the atmosphere and warms Earth's surface.
- This absorbed energy is released from the surface as infrared (thermal) energy.
- Certain gases (H_2O, CO_2, CH_4, NO_2, and O_3) in Earth's atmosphere absorb thermal energy and re-radiate it, warming the lower atmosphere.
- This is the greenhouse effect because it operates in a manner similar to the way glass traps heat in a horticultural greenhouse.

The Role of Greenhouse Gases

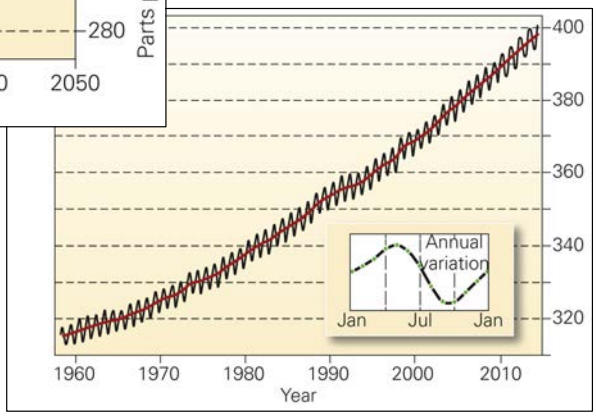


Without greenhouse gases, Earth would be a dead, frozen world. Water (H_2O) is the most important greenhouse gas, followed by carbon dioxide (CO_2). Any process that increases the amount of greenhouse gases warms the atmosphere. Any process that removes greenhouse gases cools the atmosphere.

Recent Global Warming

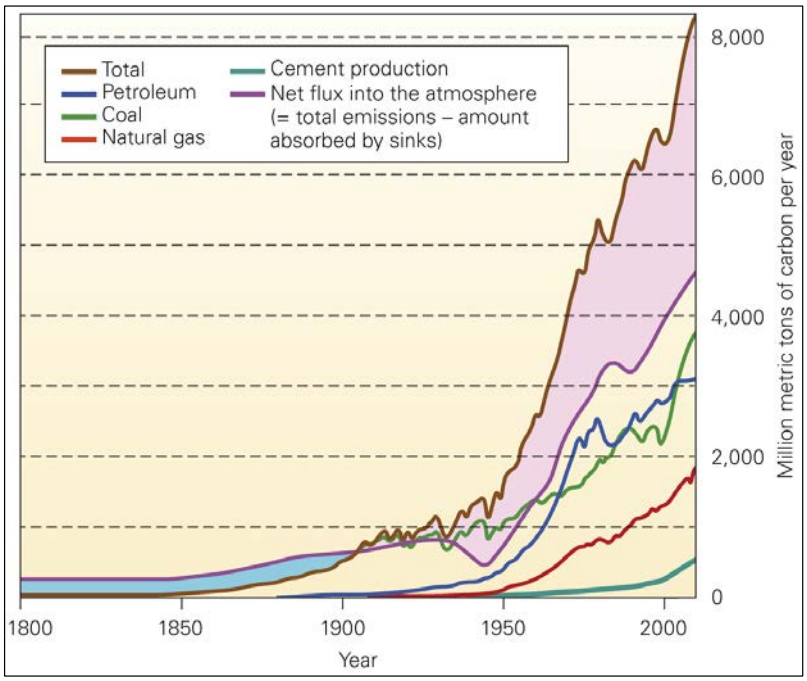


Human greenhouse gas emissions have steadily increased since the start of the industrial revolution. CO_2 in the atmosphere has steadily climbed since the first direct measurements in 1958.



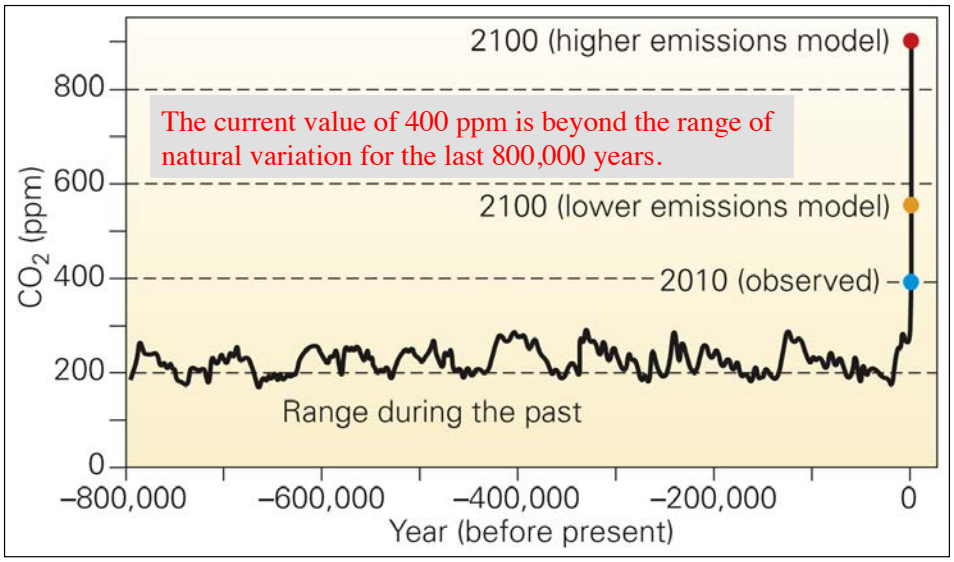
The annual oscillation reflects CO_2 removal by plants in the northern hemisphere summer. In 1958, CO_2 was ~315 ppm; in 2010, it had risen to ~390 ppm. Measuring CO_2 in glacial ice, researchers have discovered that CO_2 in 1750 was only 280 ppm.

Recent Global Warming



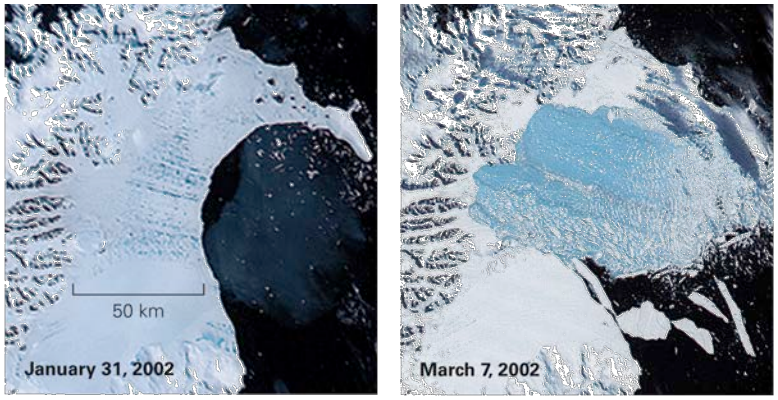
Anthropogenic CO_2 enters the atmosphere from many sources. Natural sinks that remove CO_2 have been overwhelmed by anthropogenic additions since ~1900.

Recent Global Warming



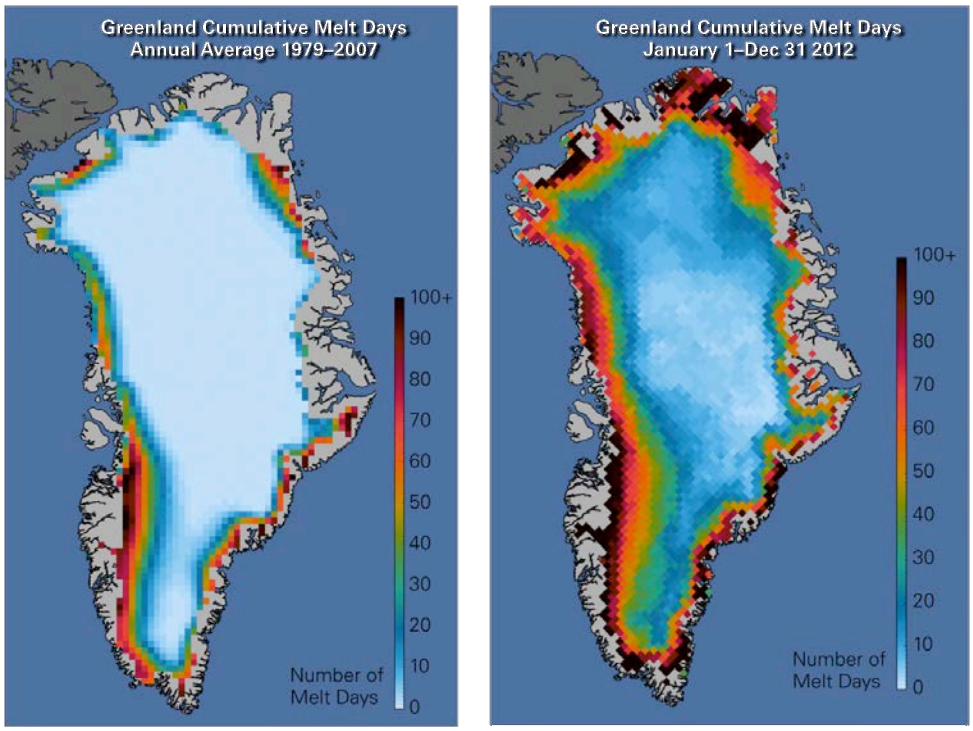
From ice core studies, CO_2 concentration varied from 180 to 280 ppm throughout glacial advances and retreats.

Recent Global Warming

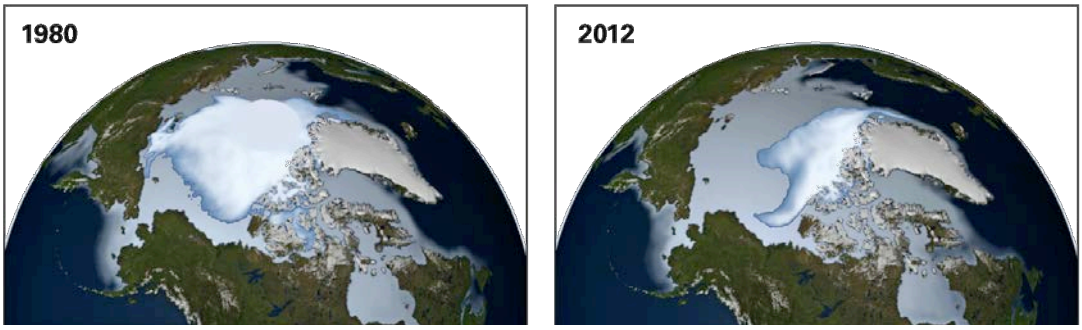


Large ice shelves, like the Larsen B along the Antarctic Peninsula, are breaking up. The summer melt line indicates that melting of the Greenland ice sheet is accelerating.

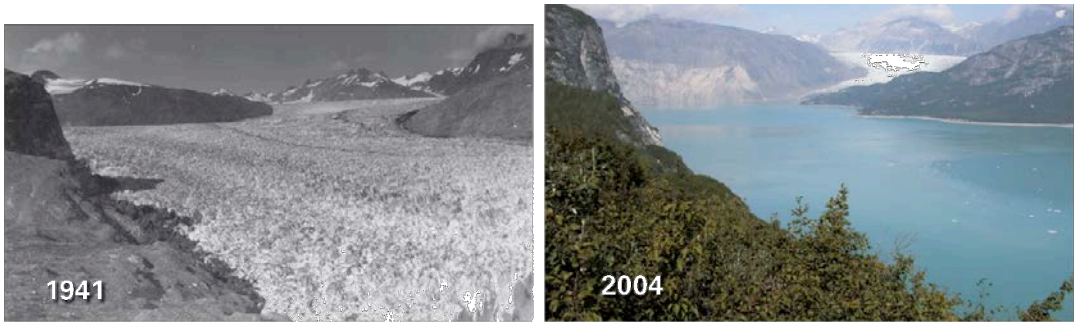
Recent Global Warming



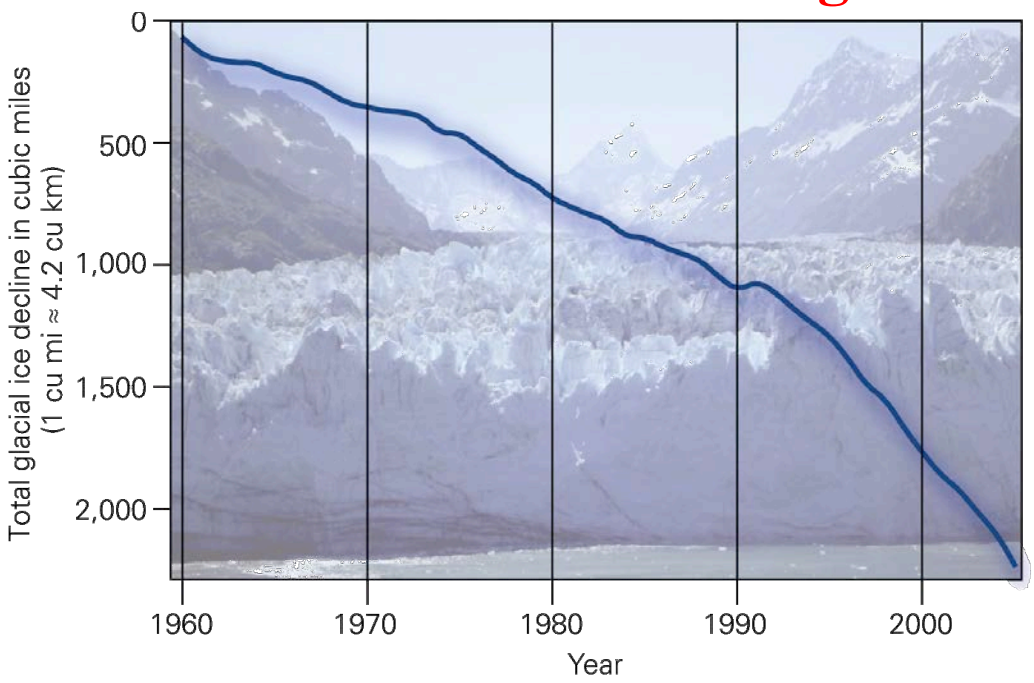
Recent Global Warming



The Muir Glacier, Alaska, retreated 12 km between 1941 and 2004.

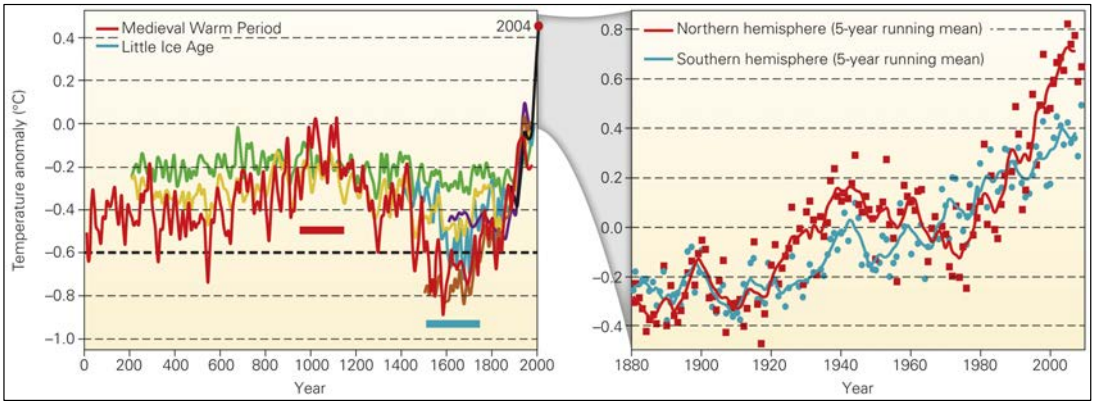


Recent Global Warming



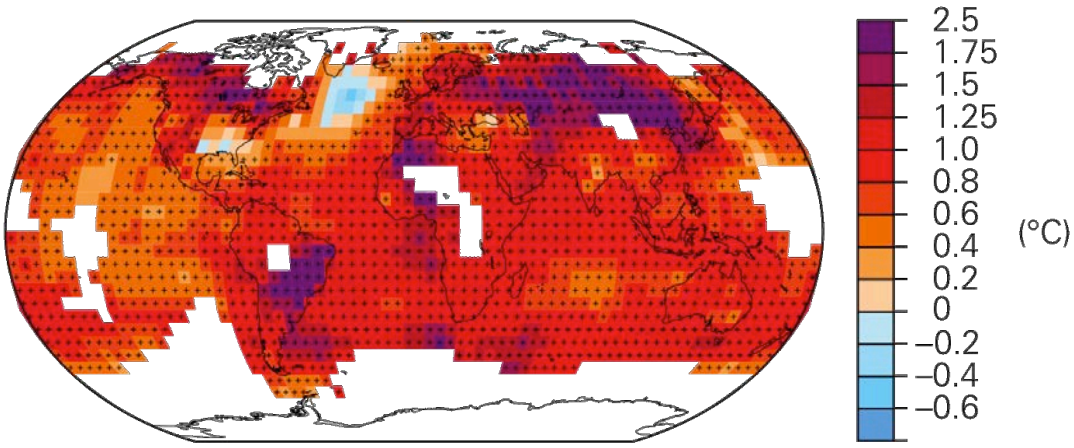
On a global basis, about 100 cubic miles (400 km^3) of glacial ice melts every year. This cumulative decrease in glaciers is highly visible.

Recent Global Warming



Temperature reconstructions during the past 2,000 years: each color represents the results of a study from a different location.
Graph of the change in global average temperature since 1880: both the southern and the northern hemispheres show warming.

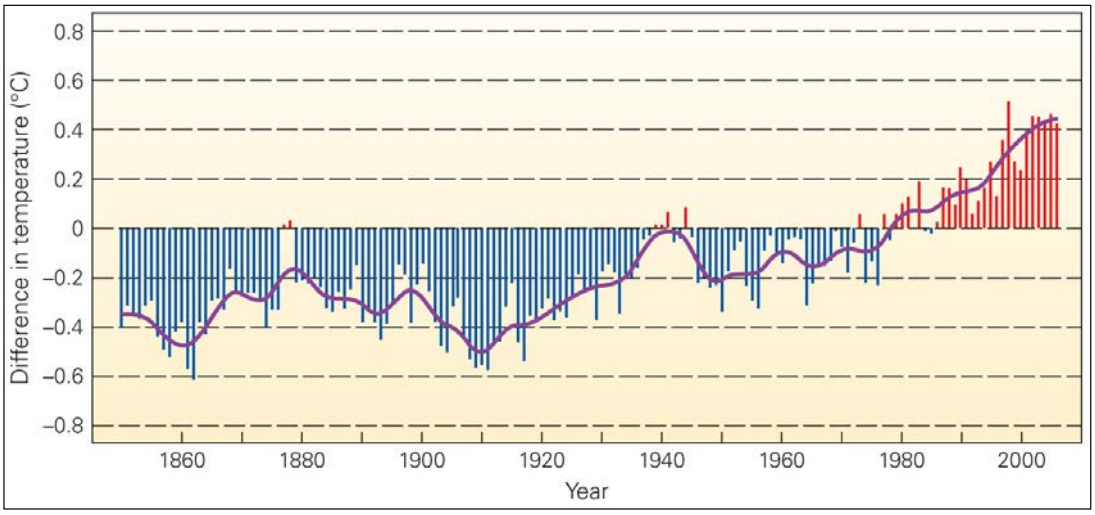
Recent Global Warming



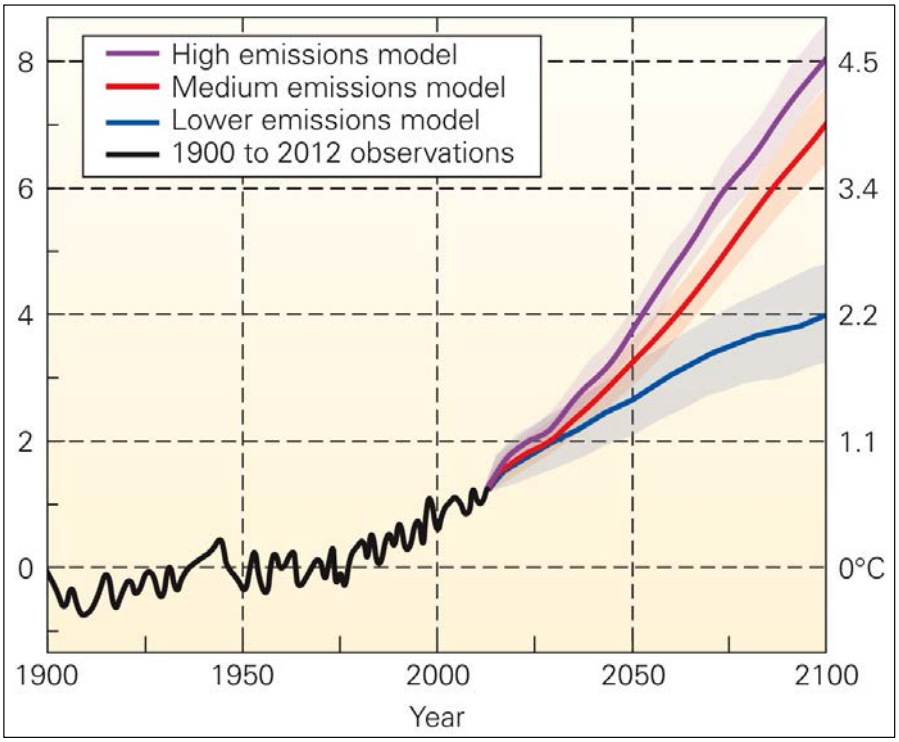
Temperature change (1901–2012)

The position of anomalies changes over time. It is interesting to note that not all change is warming, although warming dominates.

Recent Global Warming

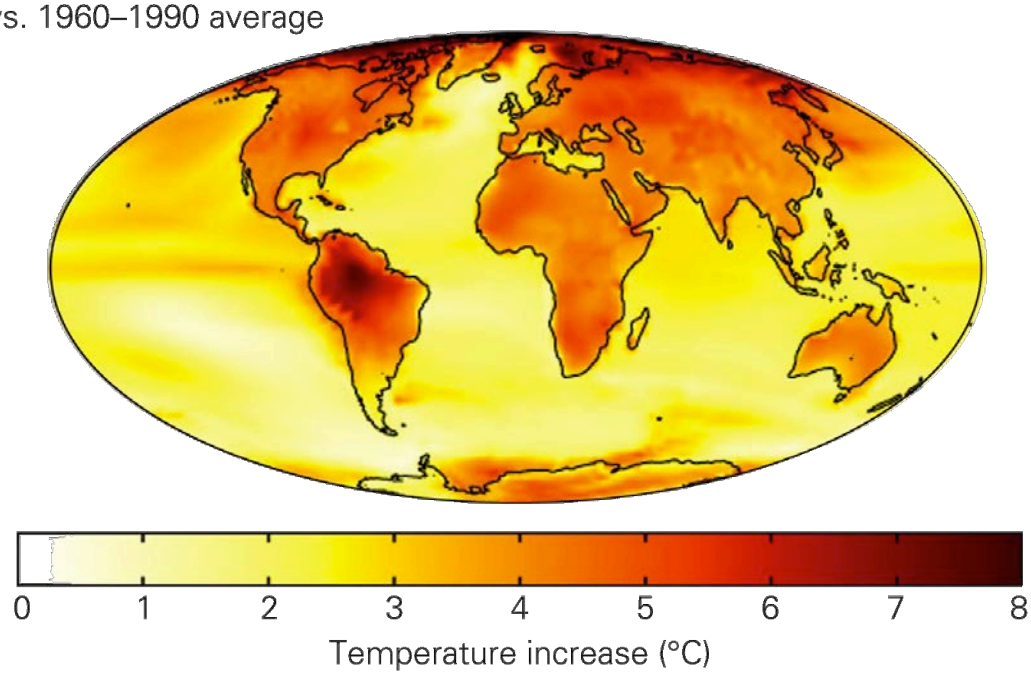


Recent Global Warming

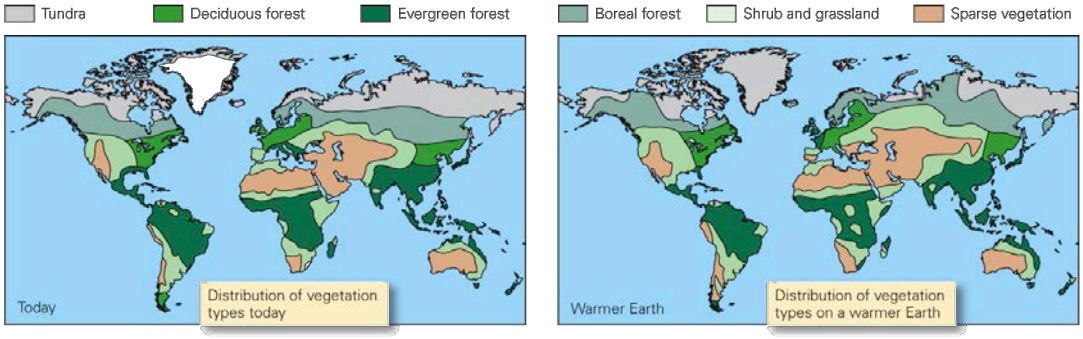


Recent Global Warming

2070–2100 prediction
vs. 1960–1990 average

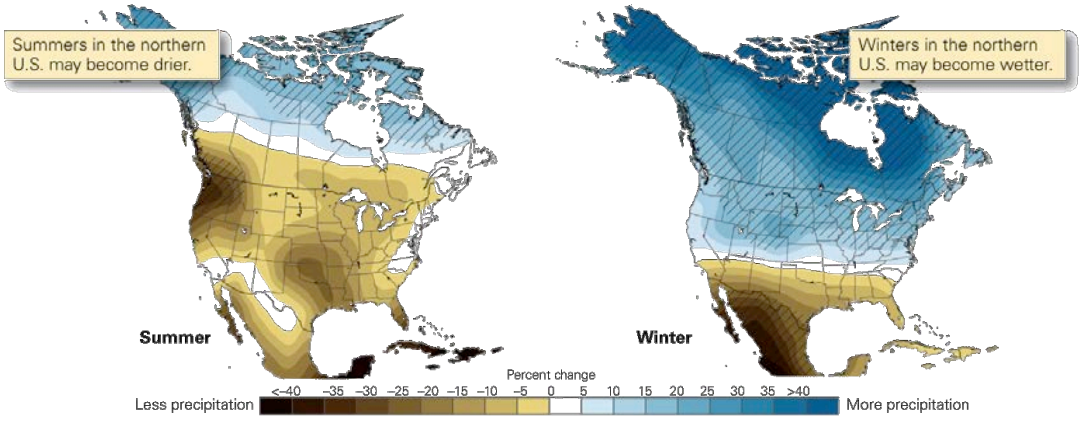


Recent Global Warming



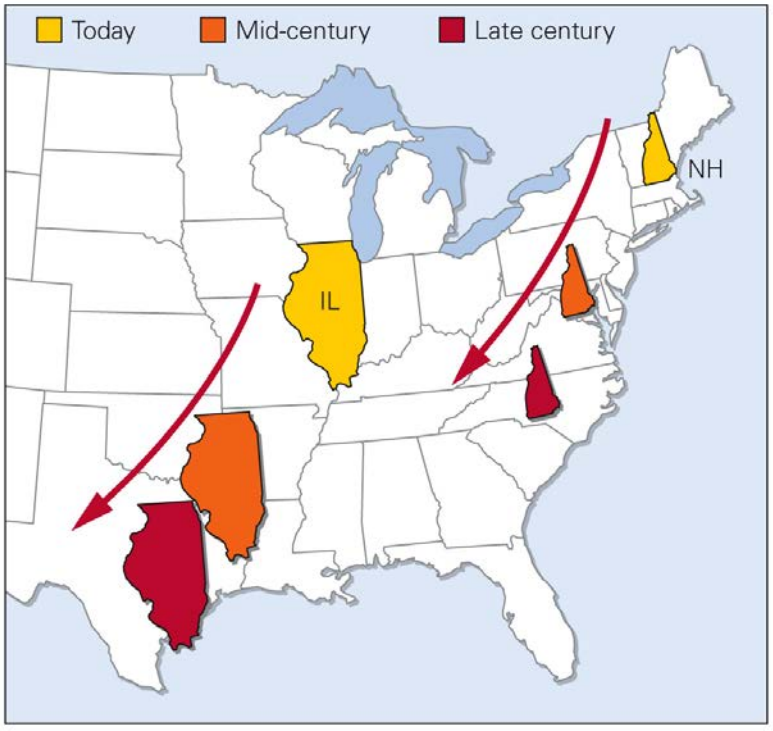
The predicted effects of global warming include a shift in climate belts and vegetation zones.

Recent Global Warming



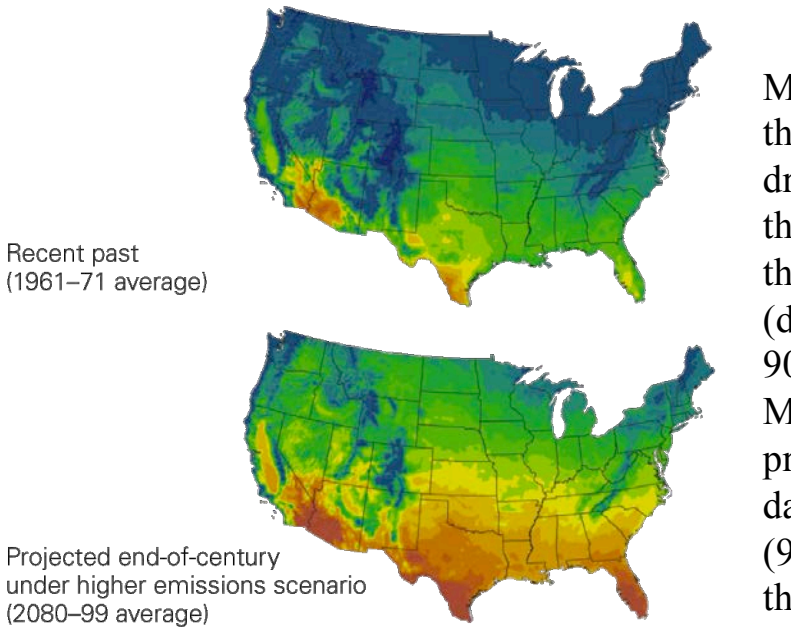
Models predict that the amount of precipitation across North America will be different a hundred years from now.

Recent Global Warming



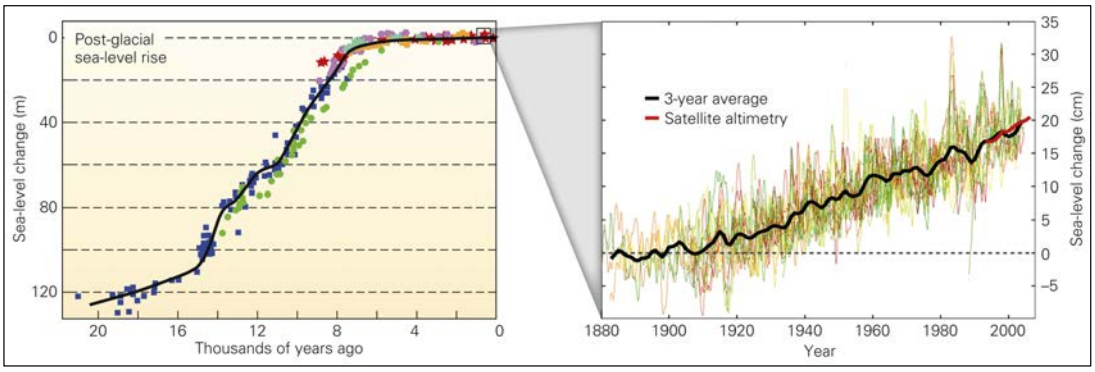
Models predict that warming will modify the climate latitude of states. If current rates of warming continue, Illinois would have the climate of Texas; New Hampshire the climate of North Carolina.

Recent Global Warming



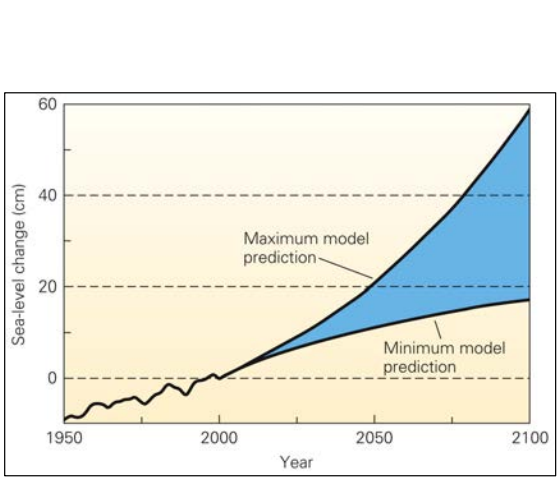
Models also predict that warming will dramatically increase the number of health-threatening heat waves (days above 32°C or 90°F).
Map showing the projected number of days above 32°C (90°F) compared to the recent past.

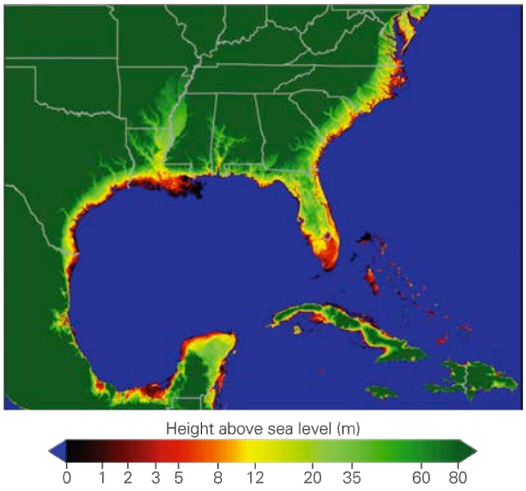
Recent Global Warming



Global warming is predicted to cause a rise in sea level due to water added from melting glaciers, ice shelves, and ice caps. Additionally, warming causes water to expand.
Sea level has risen by about 120 m (400 ft) since the last glaciation, primarily from melting of continental ice sheets. Tide gauges document a steady rise in sea level over the last 130 years.

Recent Global Warming



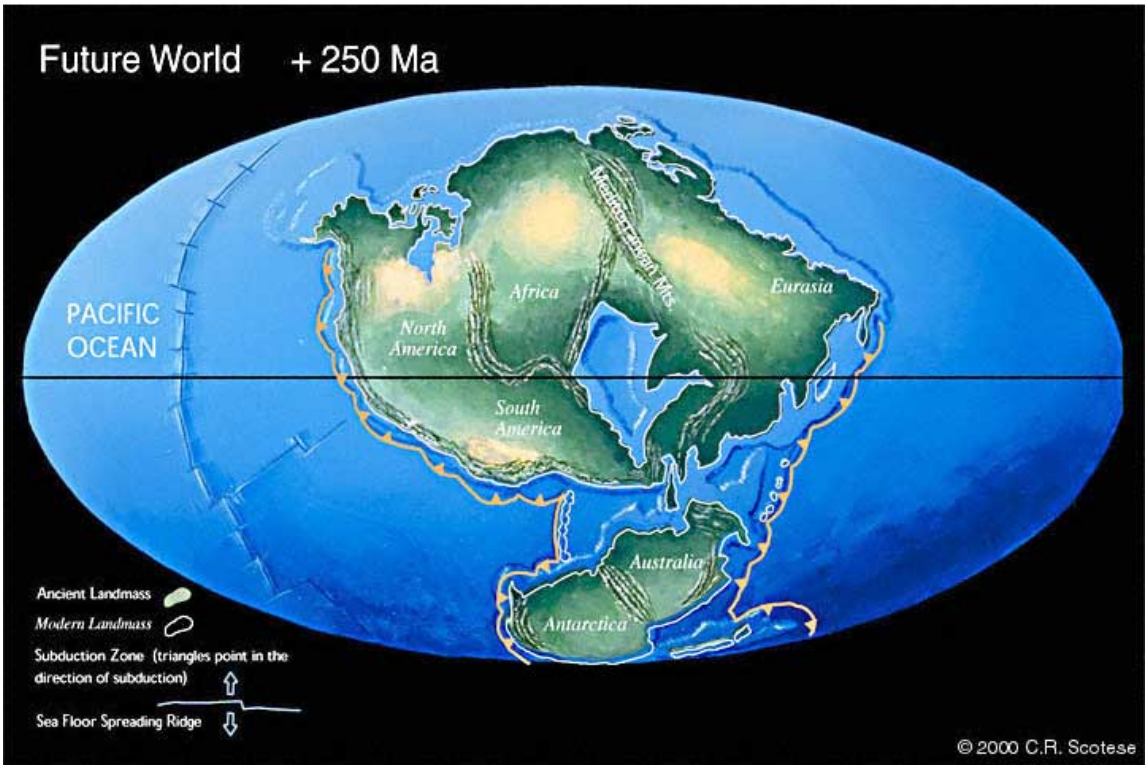


If global warming continues, sea level will continue to rise. Many people live within a meter of sea level. A sea level rise of 1 or 2 m could inundate portions of the world where 20% of the human population lives.

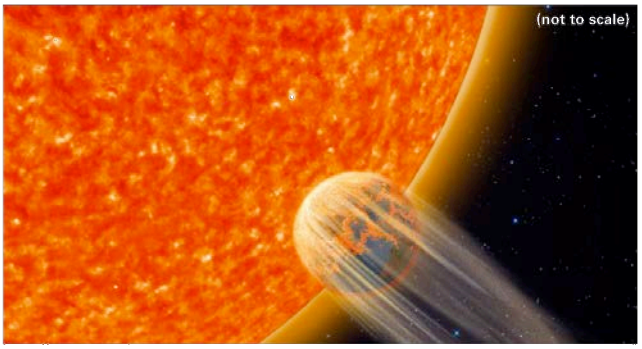
Recent Global Warming

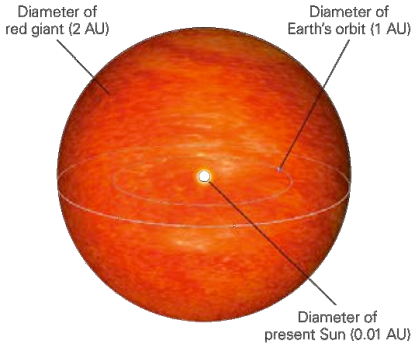
Global warming may generate stronger storms. Higher sea surface temperatures lead to greater evaporation, greater differential pressures, and a more vigorous hydrologic cycle.

The Future of Earth



The Ultimate Fate of Earth



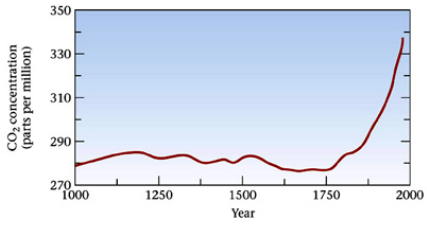


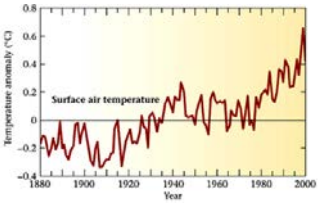
In billions of years, Earth will be vaporized. The Sun will run out of hydrogen, and it will collapse inward. The collapse will heat it causing it to re-expand outward to form a red giant. The red giant phase will expand the remnant Sun past the orbit of Earth. Earth will vaporize, another in a long series of cycles.

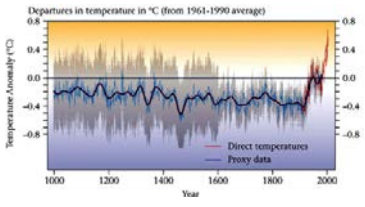
Anthropogenic Changes

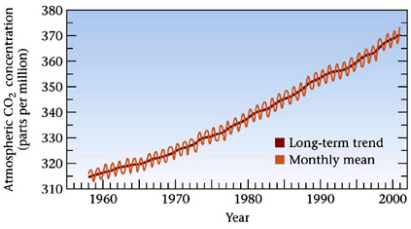
The Evidence

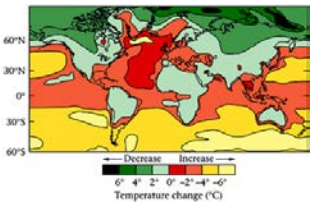
Is this enough to cause "global warming"?



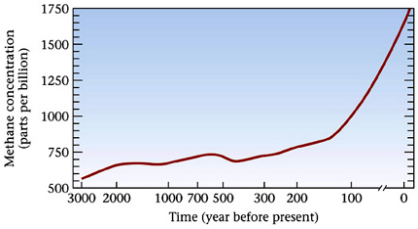




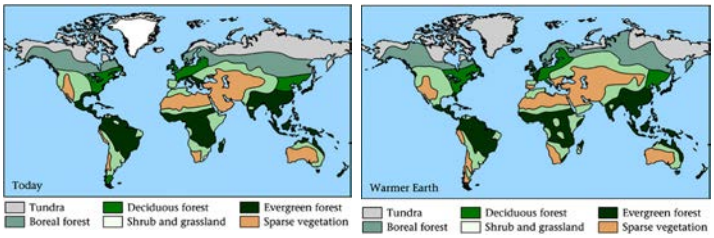




If the trend continues, what will happen?



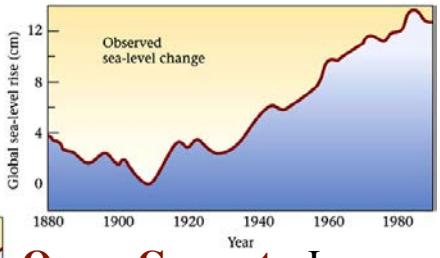
A shift in climatic belts:

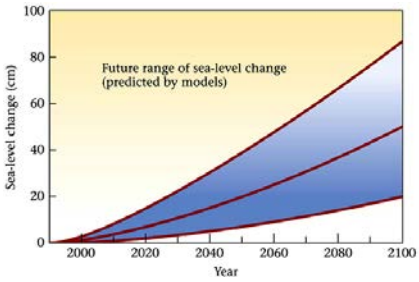


Anthropogenic Changes

Stronger Storms: More hurricanes of higher intensity (greater evaporation and higher sea temperatures.

Rise in Sea Level: Evidence that sea level has risen 112 cm in the last 100 years.





Ocean Currents: Increased glacial melt could shut down thermohaline circulation and produce glacial advance.

Humans need to be more environmentally aware.

Summary

Global Change: Development of Life, Origin of the Moon.

Physical Cycles: Supercontinent Cycle; Sea-Level Cycles (cyclotherms); Rock Cycle.

Biogeochemical Cycles: Hydrologic Cycles; Carbon Cycle.

Global Climate Change: Global Warming & Cooling; Long-term & Short-term; Stratigraphic Record; Paleontological Evidence; Oxygen Isotopes; Bubbles in Ice; Growth Rings; Human History.

Long-Term Climate Change: Positions of the Continents; Volcanic Activity; Uplift of Land Surface; Formation of Fossil Fuels; Evolution of Life; Negative & Positive Feedback.

Short-Term Climate Change: Fluctutation in Solar Radiation; Changes in Earth's Orbit & Tilt; Changes in Volcanic Emissions; Changes in Ocean Currents; Changes in Surface Albedo; Abrupt Changes in Greenhouse Gas Concentrations.

Mass Extinctions.

Anthropogenic Changes: Modification of Landscapes; Modification of Ecosystems; Pollution (Smog, Water Contamination; Acid Runoff; Acid Rain; Radioactive Materials; Ozone Depletion.

Recent Evidence: Warmer Temps., High CO2, Deglaciation, Stronger Hurricanes.