Global Change in the Earth System

Edited and augmented for this course by

Olivia Jensen

Professor of Geophysics

McGill University

Montreal, Canada

Updated by:

***Rick Oches**, Professor of Geology & Environmental Sciences*

Bentley University

Waltham, Massachusetts

Based on slides prepared by:

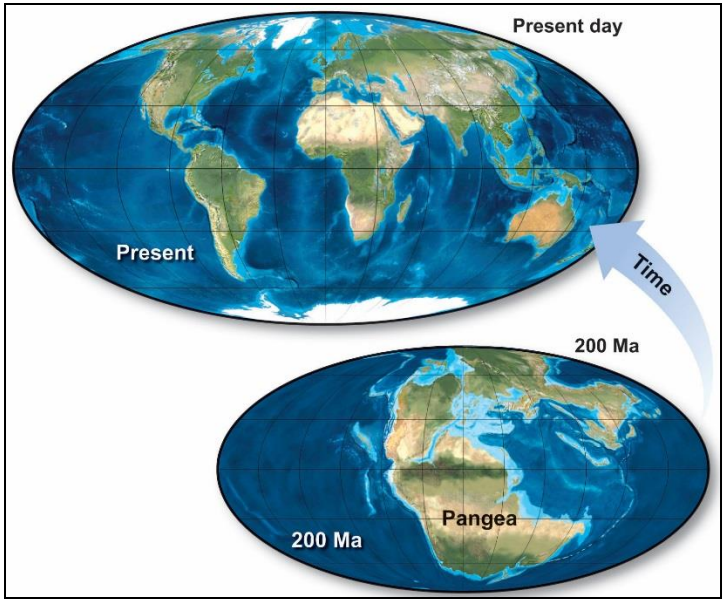
***Ronald L. Parker**, Senior Geologist*

Fronterra Geosciences

Denver, Colorado

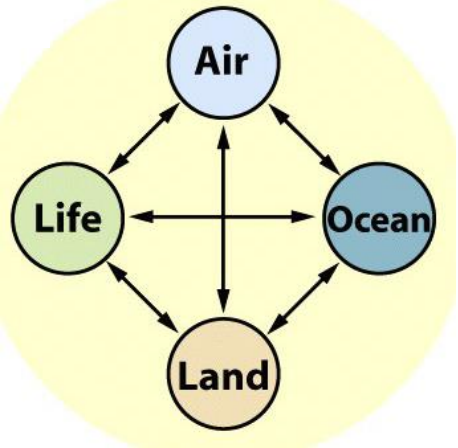
Global Change

- Geology verifies that Earth changes constantly.
- Why does it change constantly?
  - A plastic asthenosphere permits tectonic plate motion.
  - A star is close enough to warm Earth and its atmosphere.
  - Liquid water is possible; thus, weathering and erosion.
  - Biotic evolution continually modifies the biosphere.



The Earth System

- **Life on Earth is due to interactions among the:**
  - **Lithosphere**
  - **Atmosphere**
  - **Hydrosphere**
  - **Biosphere**



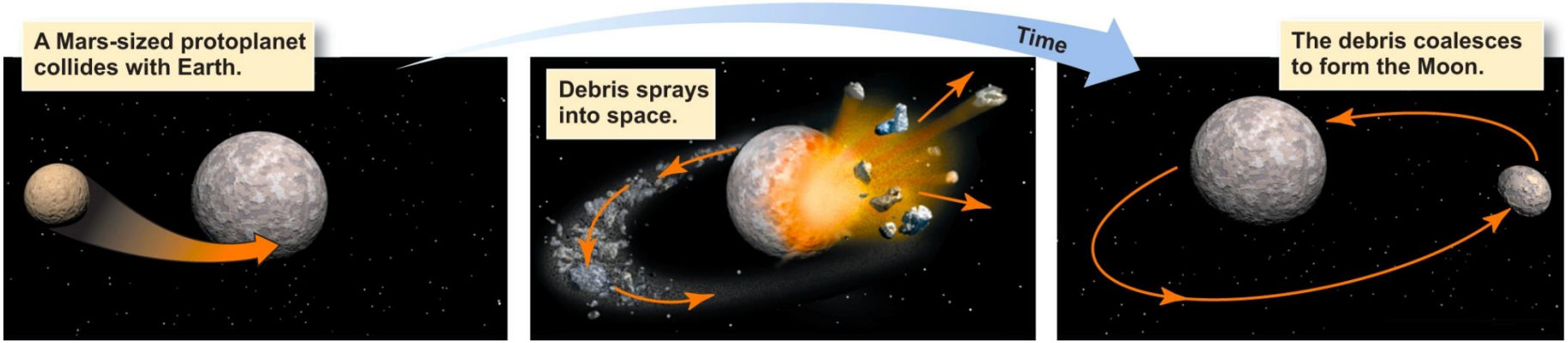
- **The "Earth System" is composed of these physical components interacting with the biosphere.**

The Earth System

- The interlinkage of the physical and the biological:
- Global changes transform or modify both realms.
  - There are many ways to describe changes:
    - Gradual change
    - Catastrophic change
    - Unidirectional change
    - Cyclic change

Unidirectional Changes

- Evolution of the solid Earth:
  - Planetesimal accretion
  - Melting and differentiation
- Formation of the Moon:
  - Mars-sized protoplanet collides
  - Mantle blasted into space
  - Debris coalesced to form the Moon

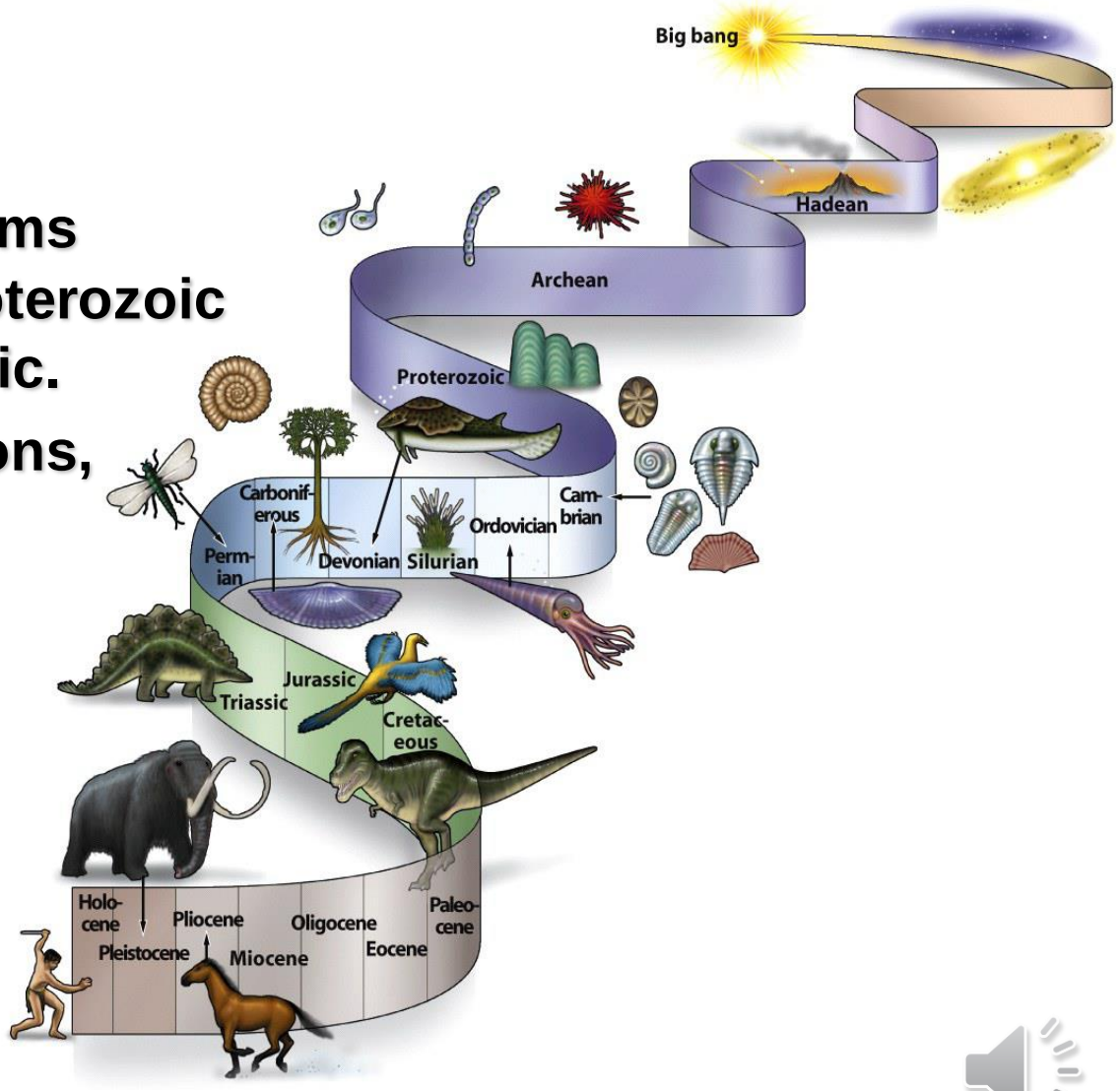


Unidirectional Changes

- **Evolution of the atmosphere and oceans:**
  - **Volcanic gases created an early atmosphere.**
    - **CO_2, H_2O, N_2**
  - **Liquid water condensed to form the oceans.**
  - **Photosynthetic organisms appeared.**
    - **O_2 becomes a significant component of the atmosphere.**

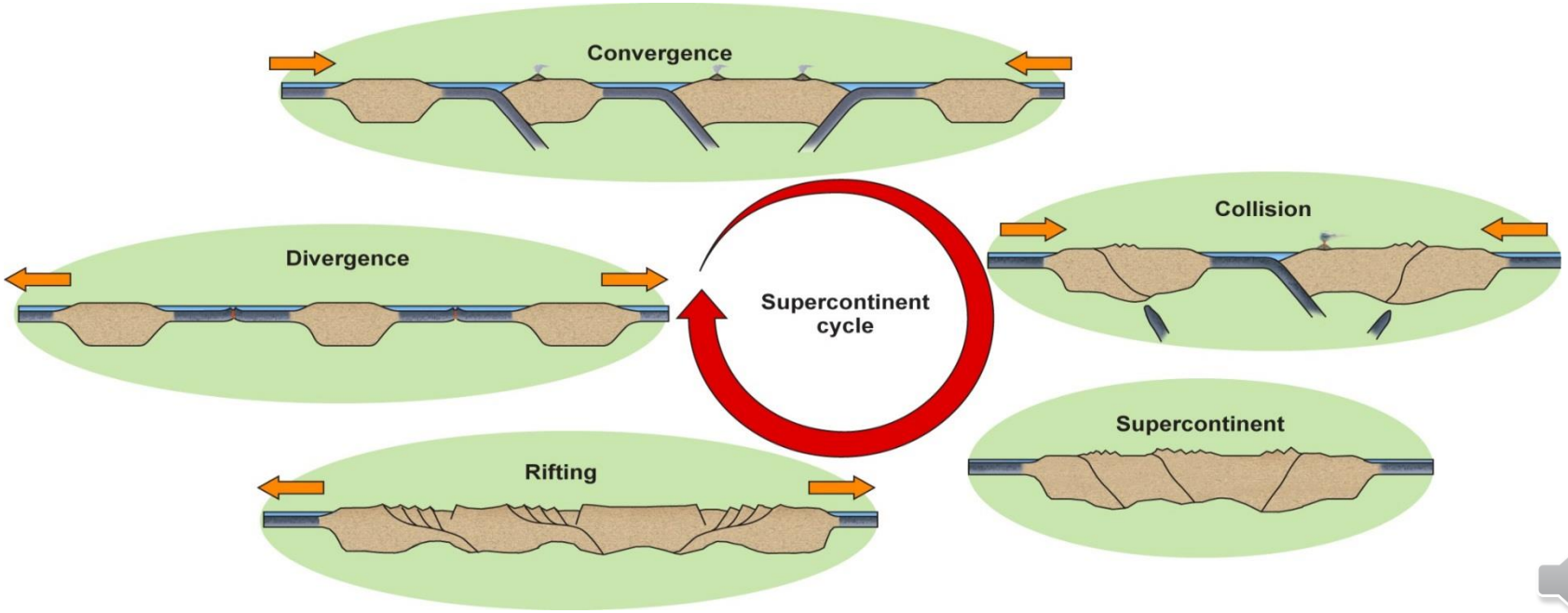
Unidirectional Changes

- **Evolution of Life**
  - **Life appeared on Earth before 3.8 Ga.**
  - **Multicellular organisms appeared in Late Proterozoic and early Phanerozoic.**
  - **Life inhabits all regions, within a few km of Earth's surface.**



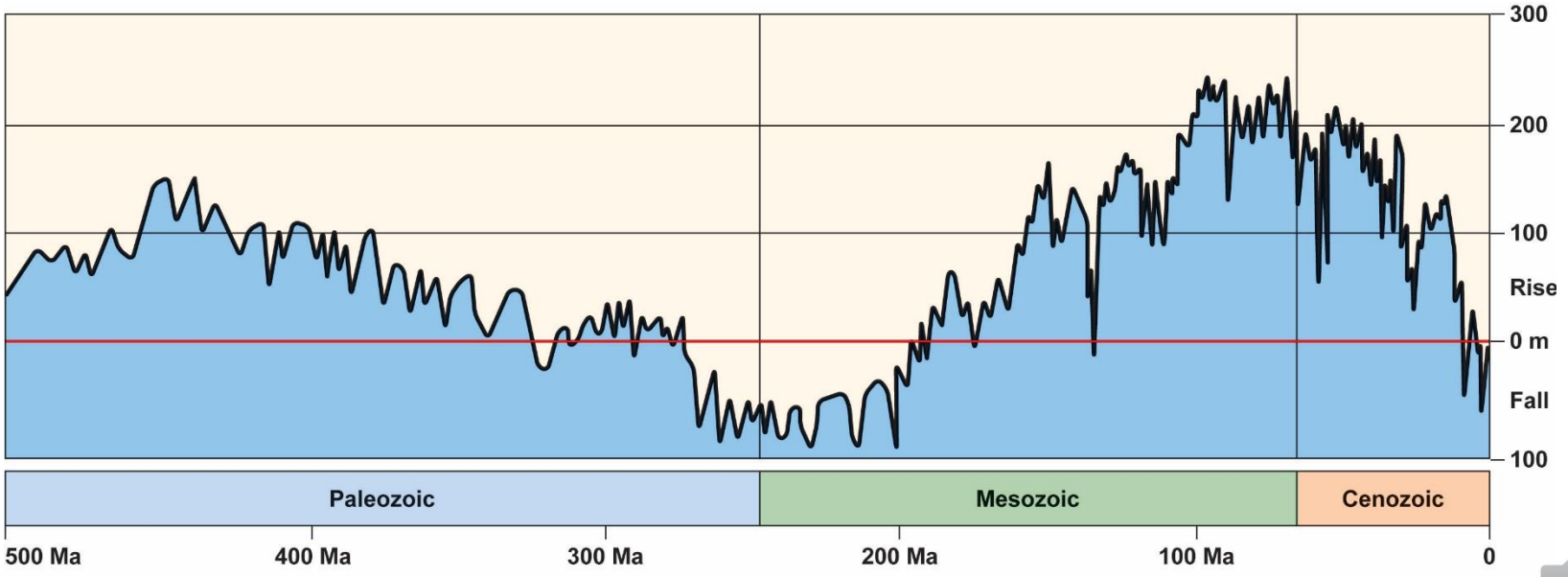
Physical Cycles

- **The supercontinent cycle:**
  - **Plate tectonics drives continental movement.**
  - **Ocean basins open and close.**
  - **Continental landmasses collide and rift apart.**
  - **Supercontinents (like Pangaea) have formed several times.**



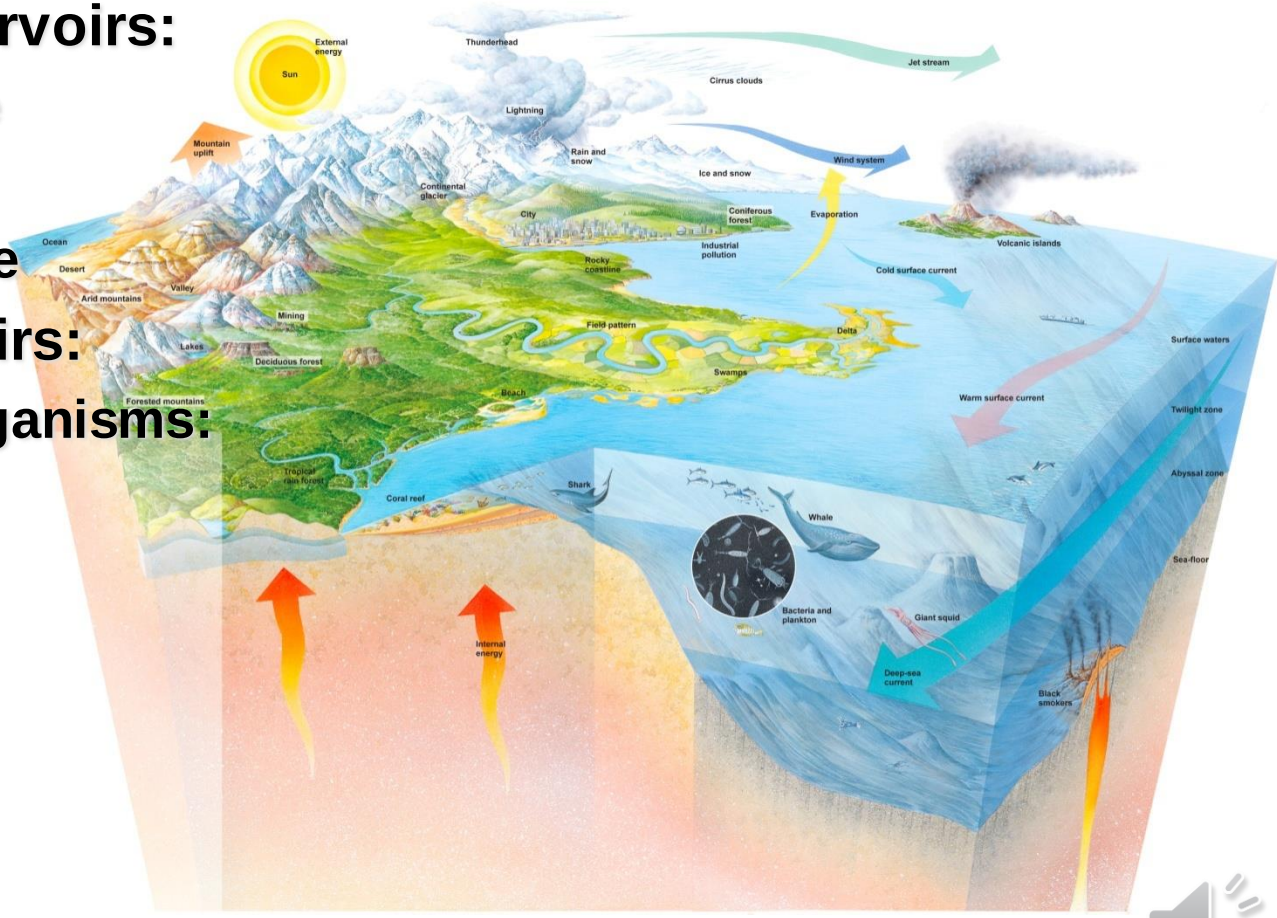
Physical Cycles

- SL has risen and fallen many times over Earth's history.
  - +/- 300 meters during the Phanerozoic
  - Transgression (SL rise): shorelines move landward
  - Regression (SL fall): shorelines move seaward
  - Sedimentary rocks preserve evidence of sea-level change.
  - Sea-level cycles are bounded by unconformities.



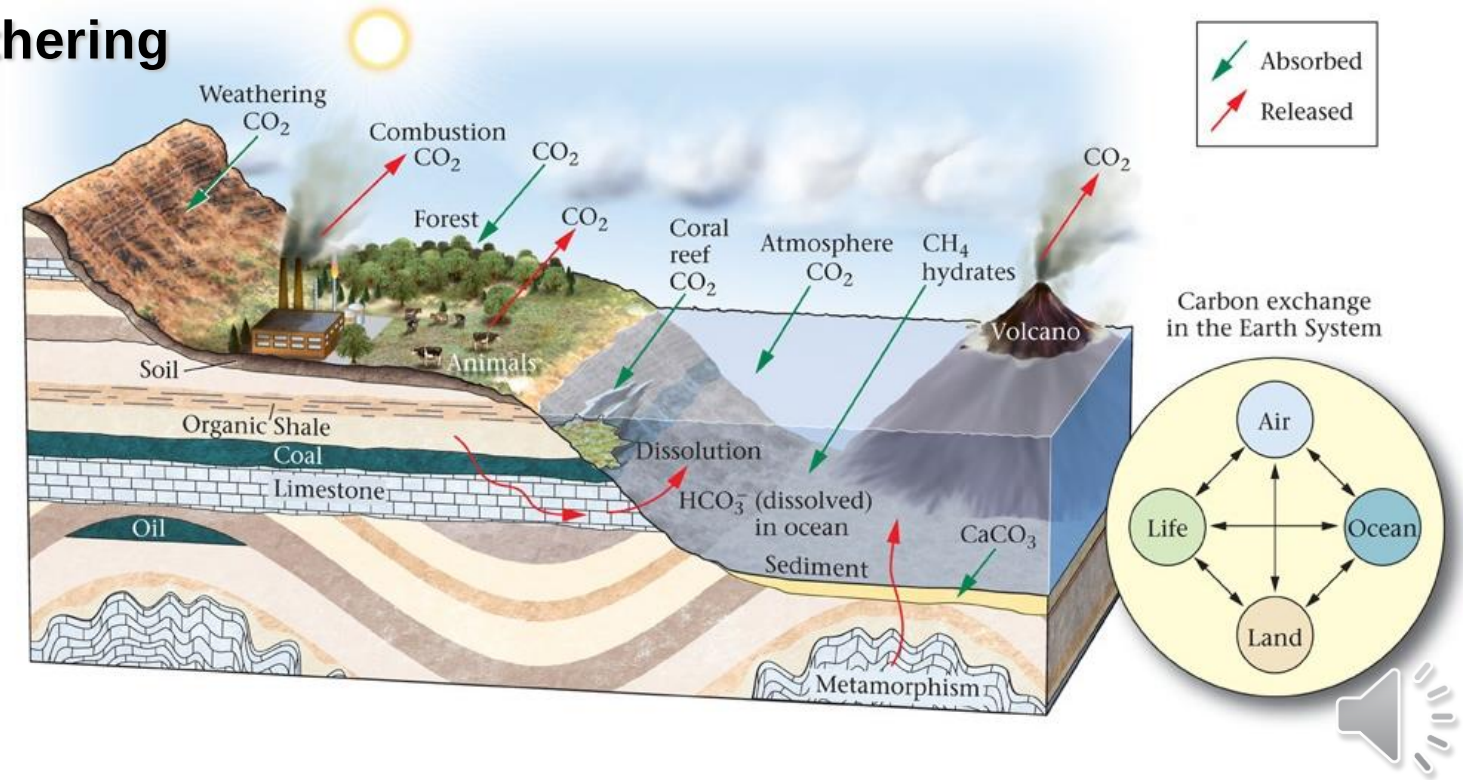
Biogeochemical Cycles

- Chemical fluxes between living and nonliving.
- Involve storage and transfer between reservoirs
  - Nonliving reservoirs:
    - Atmosphere
    - Lithosphere
    - Hydrosphere
  - Living reservoirs:
    - All living organisms:
      - ✔ Microbes
      - ✔ Plants
      - ✔ Animals



The Carbon Cycle

- **A biogeochemical cycle that regulates climate**
  - **Volcanic CO_2 adds carbon to the atmosphere.**
  - **Atmospheric CO_2 is removed in several ways:**
    - **It dissolves in water as carbonic acid and bicarbonate.**
    - **Photosynthesis removes CO_2.**
    - **Weathering**



The Carbon Cycle

- **Carbon may be stored for long periods of time.**
  - **Limestones**
  - **Fossil fuels (coal and oil)**
  - **Organic shales**
  - **Methane hydrates**

The Carbon Cycle

- **Carbon is returned to the atmosphere.**
  - **Biotic respiration creates CO_2 from organic matter.**
  - **Rapid oxidation (burning) of organic matter creates CO_2.**
  - **Metamorphism of carbonate rocks liberates CO_2.**
  - **Degassing removes dissolved CO_2 from water.**

Global Climate Change

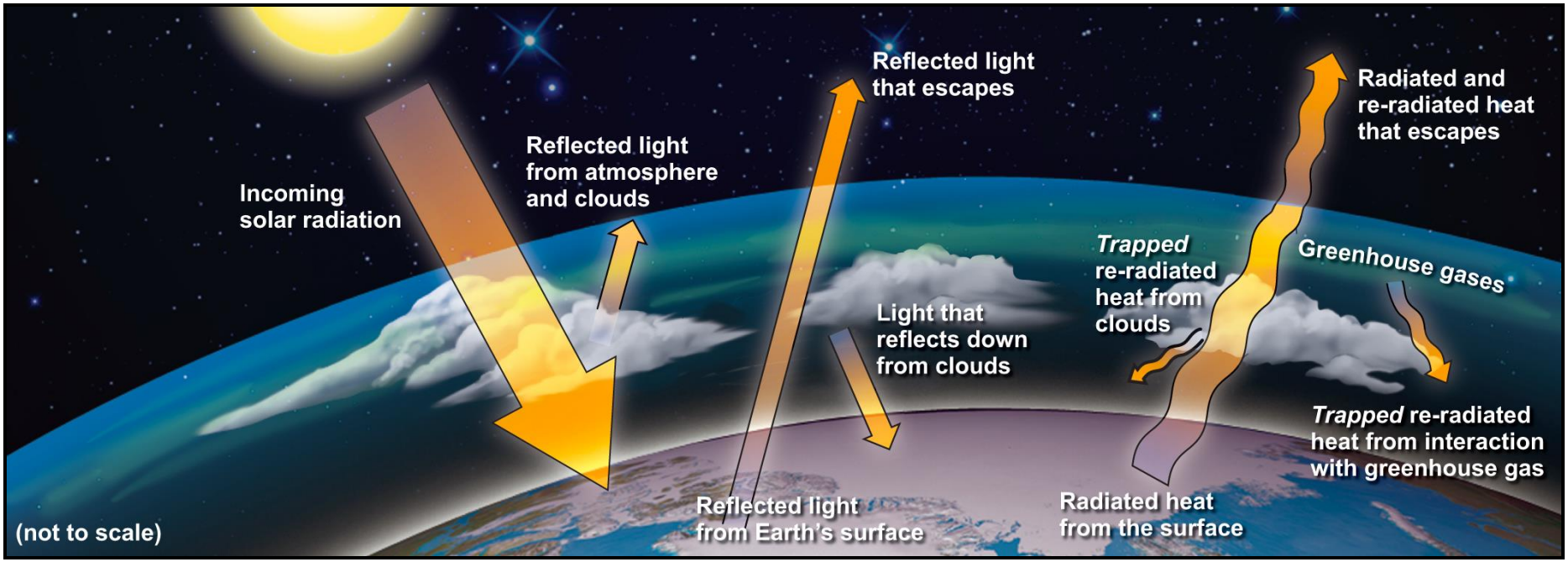
- Earth's climate has changed many times.
  - Long-term climate change
    - Millions to tens of millions of years in scale
  - Short-term climate change
    - Tens to hundreds of thousands of years in scale

Global Climate Change

- Climate studies reveal our past and suggest our future.
  - Distinguish kinds of climate changes
  - Establish rates at which these changes occur
  - Determine the effects on Earth and its inhabitants
- Methods of study:
  - Paleoclimates—investigations of past climatic variation
  - Computer simulations—modeling past and future changes

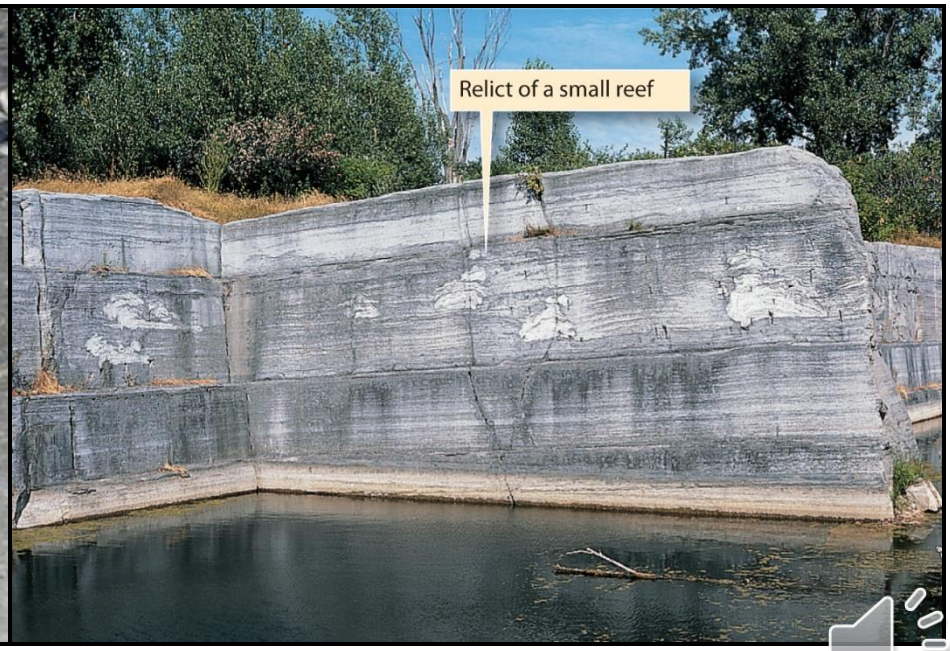
Global Climate Change

- H_2O, CO_2, and CH_4 in Earth's atmosphere absorb thermal energy and reradiate it, warming the lower atmosphere.
  - This is called the greenhouse effect.



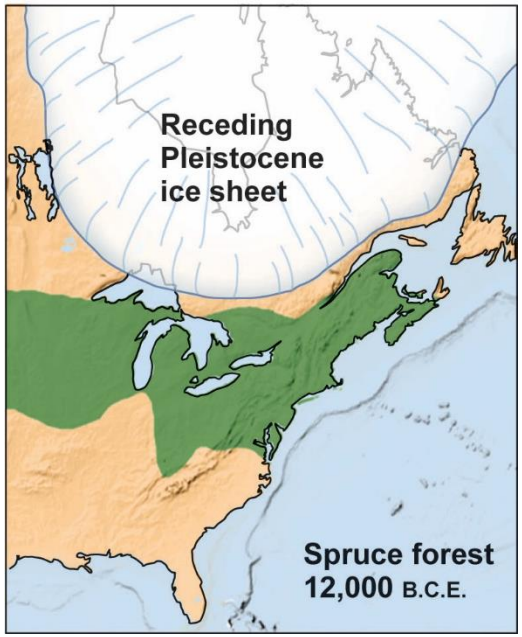
Global Climate Change

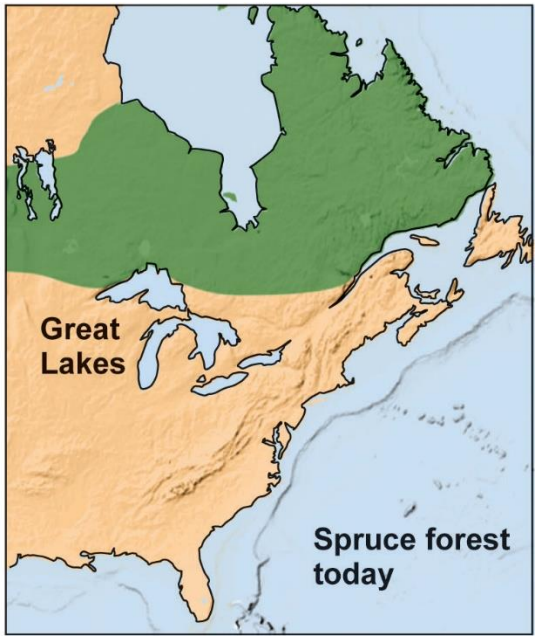
- **Paleoclimates—past climates are interpreted by datable Earth materials that are climate-sensitive.**
  - **Stratigraphic records—sequences of rock strata**
    - **Depositional environments are often climate-sensitive.**
      - **Glacial tills—cold and continental**
      - **Coral reef— tropical marine**

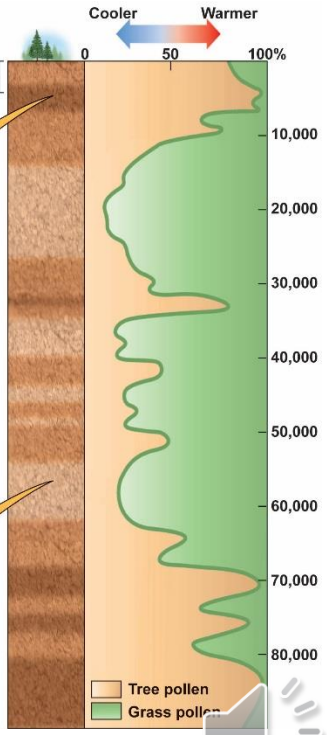


Global Climate Change

- **Paleoclimatic evidence:**
  - **Paleontological—faunal assemblages reflect climate.**
    - **Assemblage changes record climatic shifts.**
      - **Pollen in pond sediments**
        - **Spruce (colder) versus hemlock (warmer)**
        - **Trees (colder, drier) versus grasses (warmer, wetter)**

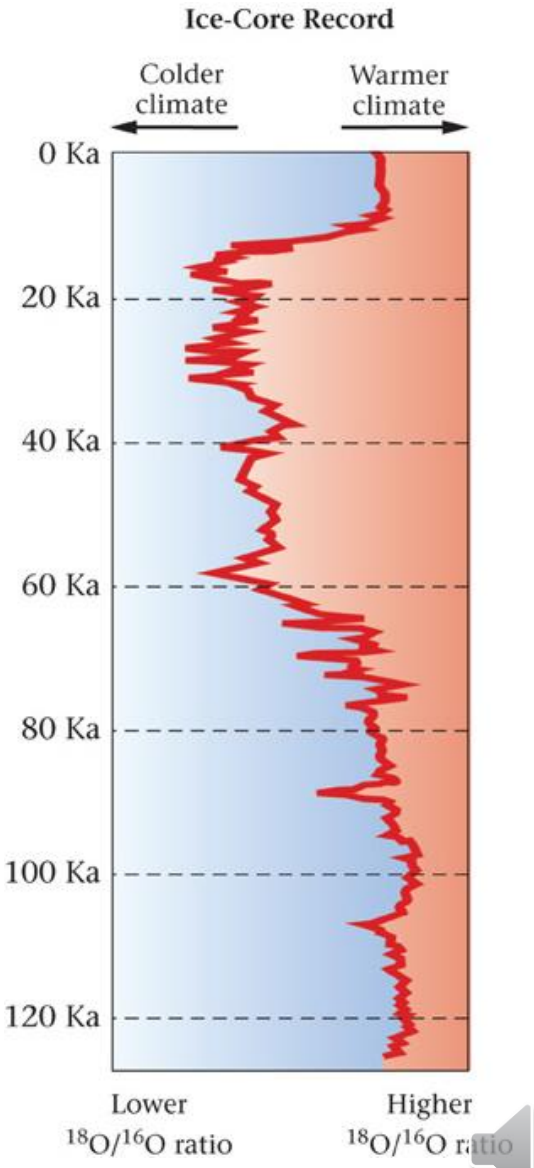






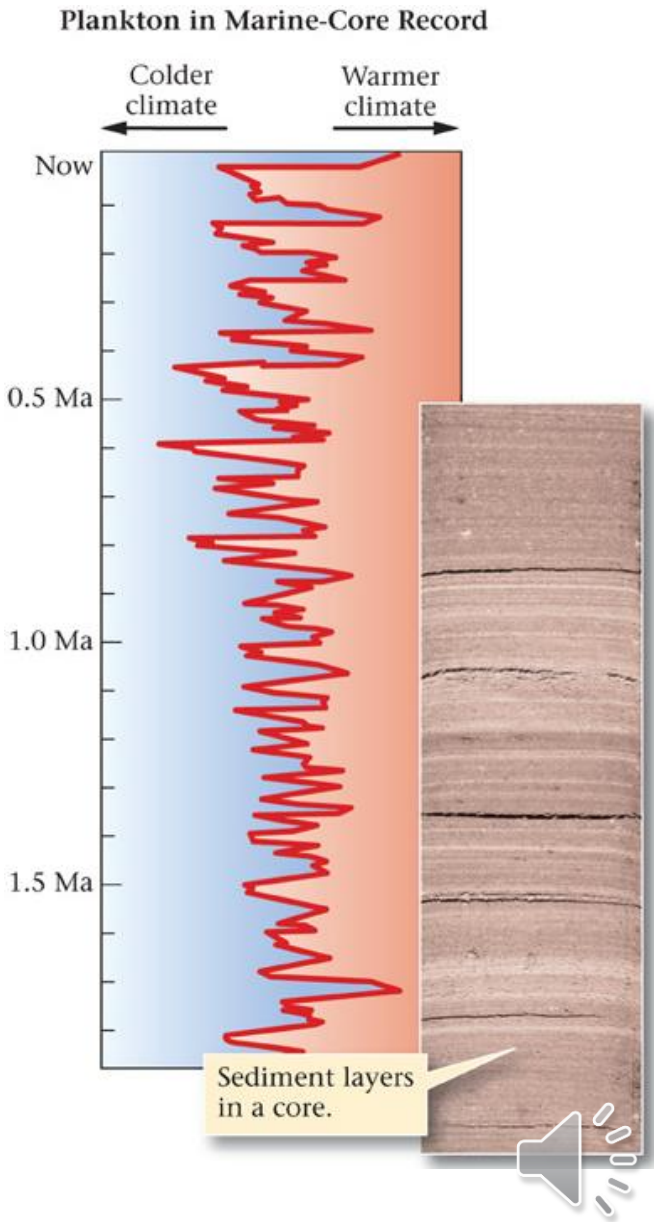
Global Climate Change

- **Paleoclimates:**
  - **Oxygen isotopes—two isotopes: ^{16}O ($8p^+$, $8n^0$) and ^{18}O ($10n^0$)**
    - **^{16}O water evaporates faster than ^{18}O water.**
      - **$^{18}O/^{16}O$ in ice cores reveal the temperature in which the cloud vapours formed.**



Global Climate Change

- **Paleoclimates:**
  - **Oxygen isotope ratios are preserved in carbonate shells of organisms.**
    - **The oxygen in $CaCO_3$ shells mirrors oceanic $^{18}O/^{16}O$.**
    - **Sea-floor sediments preserve ocean chemistry and temperature changes.**



Global Climate Change

- **Paleoclimates:**
  - **Growth rings—tree rings can easily be dated.**
    - **Ring thickness reflects climatic changes.**
      - **Wetter, warmer = thicker; drier, colder = thinner.**
  - **Growth rings in corals and shells provide similar data.**

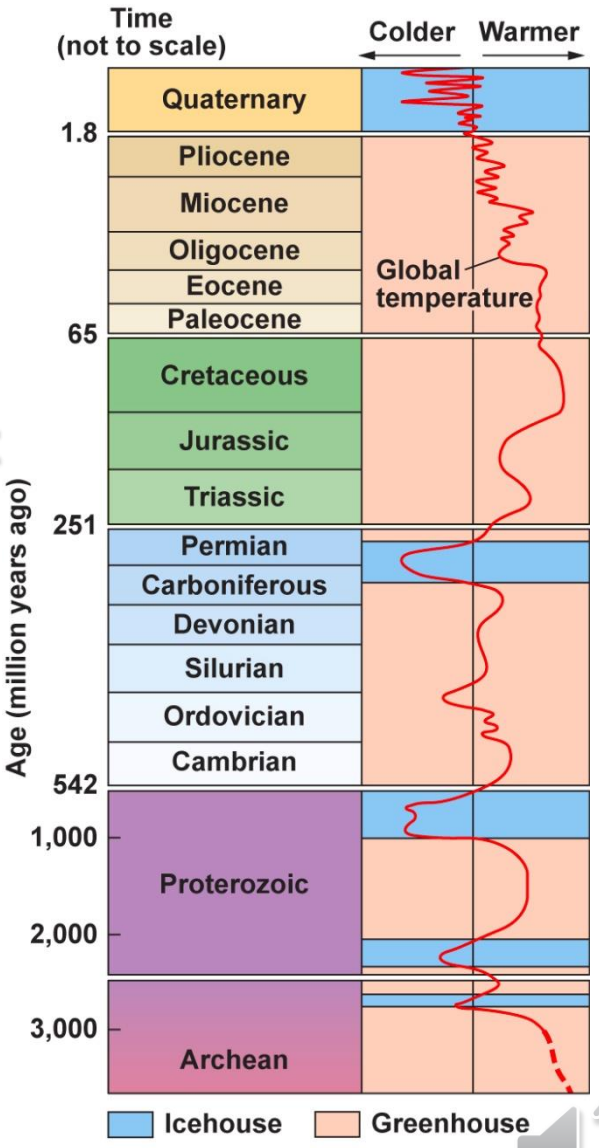
Global Climate Change

- **Paleoclimates:**
  - **Historical records are useful in the reconstruction of past climate change.**
    - **Written documents**
    - **Archaeological evidence**
    - **Paintings**
    - **Crop records**

      (eg. Grape vines in Newfoundland and wheat crops in Greenland circa 1000 -1200.)

Long-Term Climate Change

- Earth's climate history has been largely deciphered.
  - Greenhouse—warmer climates
  - Icehouse—colder climates
- Today, we live in an "Icehouse" but in an *interglacial* period in that icehouse
- There have been at least five major icehouse periods in Earth's geologic history.

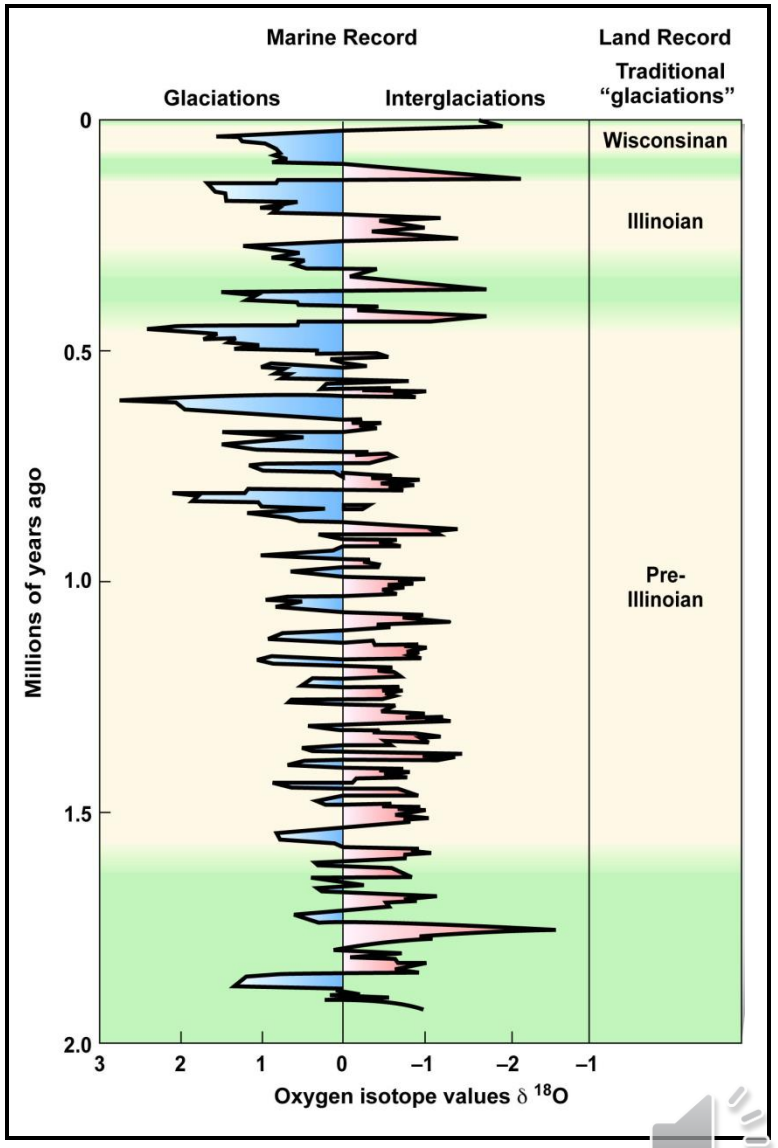


Long-Term Climate Change

- What causes long-term climate changes?
- Complex interactions across the Earth System
  - Plate tectonics modifies the position of continents.
  - Uplift of land surfaces influences atmospheric circulation.
  - Formation of coal and oil removes carbon from atmosphere.
  - Evolution of life affected atmospheric composition.

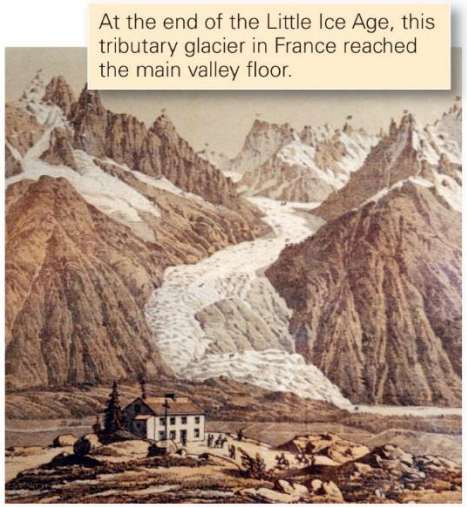
Natural Short-Term Climate Change

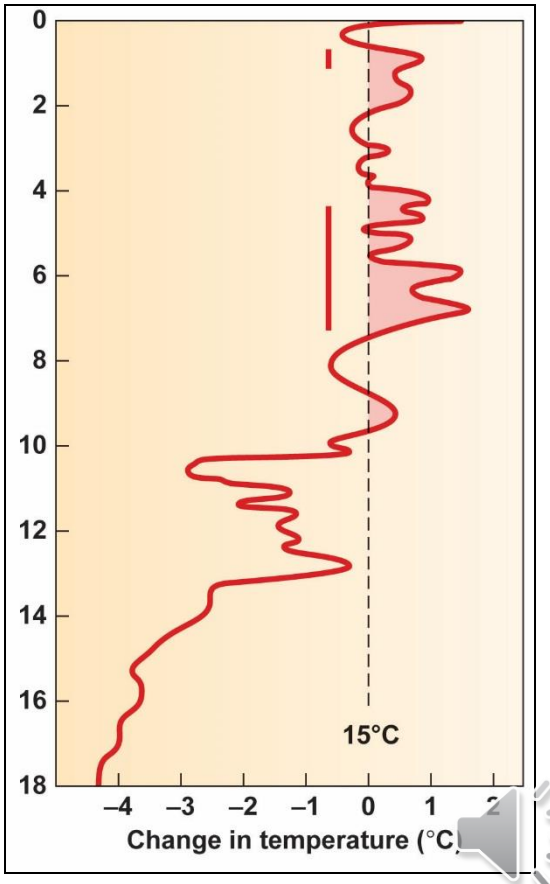
- Warmer or colder climates may last thousands of years.
- The past million years—dramatic climate flux
  - Around 20 to 30 glaciations
  - Separated by interglacials
- Shorter-term climate changes may last decades to centuries.



Short-Term Climate Change

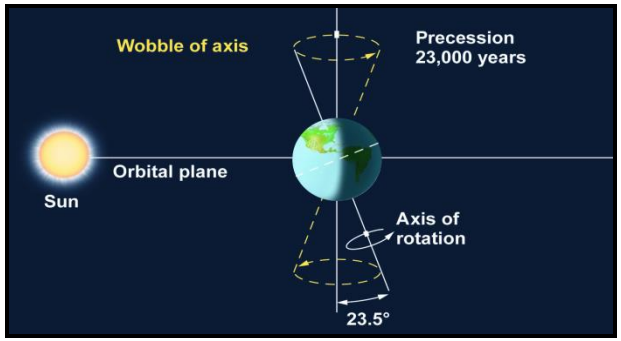
- **The past 15,000 years (the Holocene)**
  - **Warming led to deglaciation; temperatures still fluctuate.**
  - **Several cold periods have punctuated this interglacial:**
    - **Younger Dryas**
    - **Holocene maximum**
    - **Medieval Warm Period**
    - **Little Ice Age**
    - **Modern warming trend (human driven)**

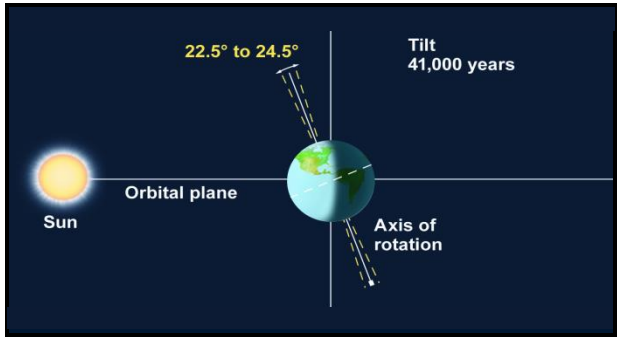


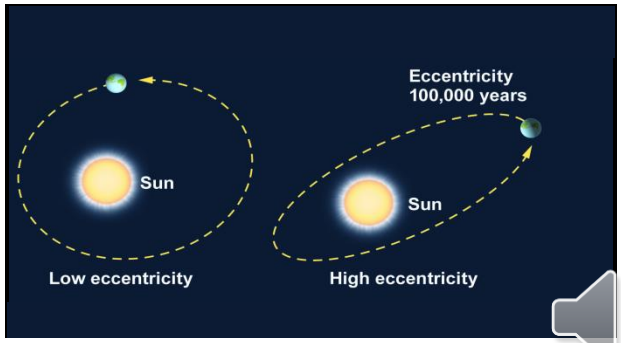


Short-Term Climate Change

- **Short-term climate changes regulated by several factors:**
  - **Fluctuations in solar radiation and cosmic rays**
  - **Changes in Earth's orbit and tilt**
  - **Changes in volcanic emissions**
  - **Changes in ocean currents**
  - **Changes in surface albedo**
  - **Abrupt changes in concentrations of greenhouse gases**

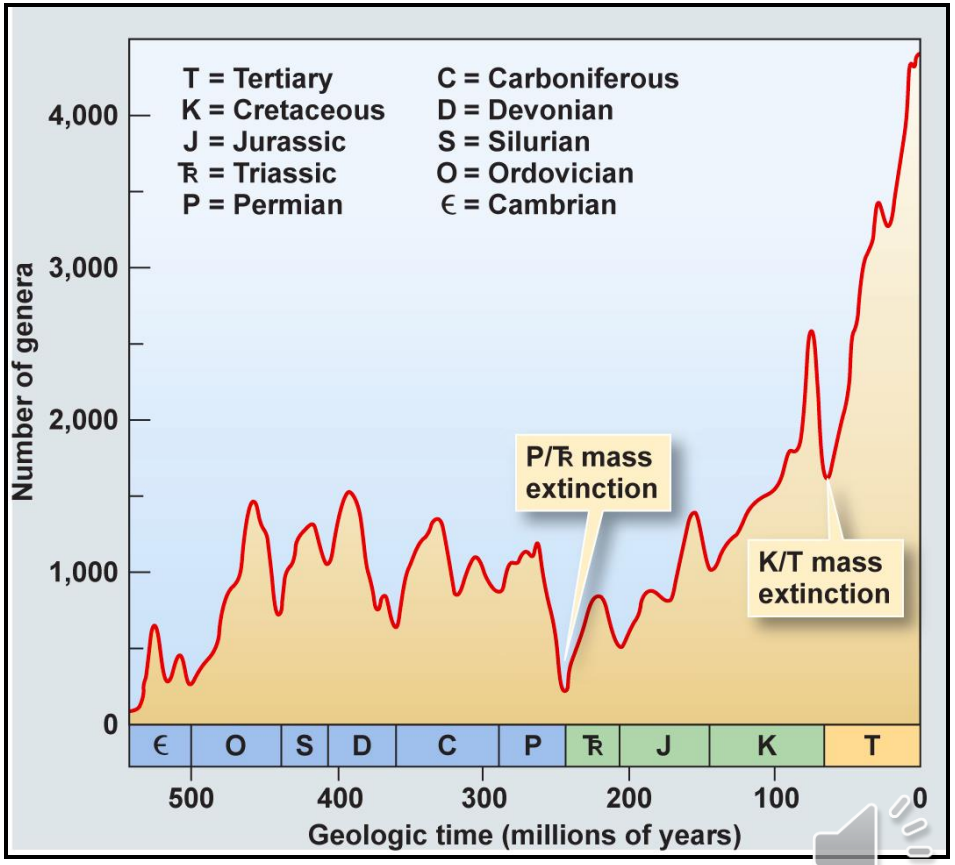






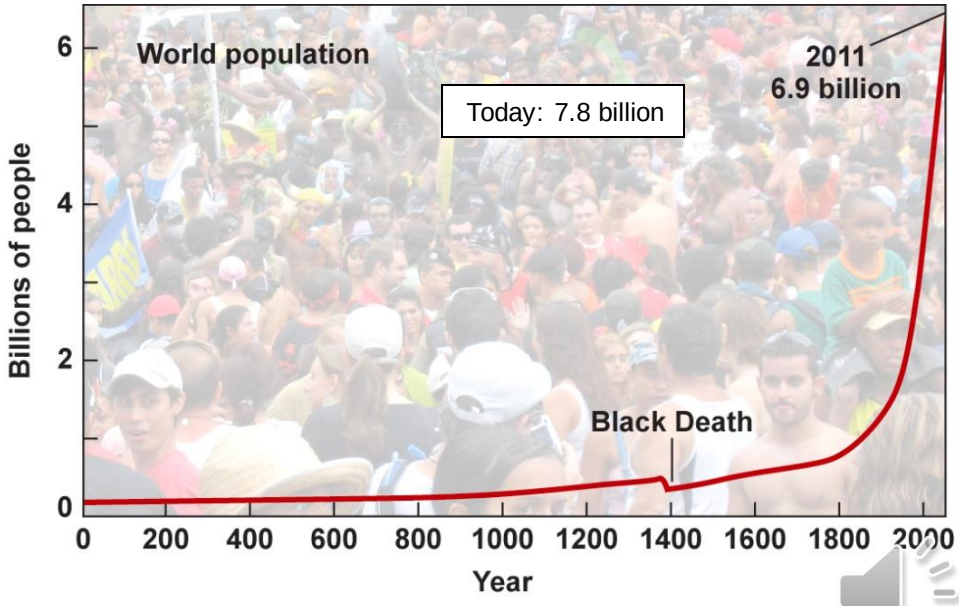
Catastrophic Change and Extinction

- Mass Extinction events: the stratigraphic record contains evidence of dramatic decreases in biodiversity.
- Catastrophic changes
- Large numbers of species disappear forever
- Millions of years needed for biodiversity to recover
- Major extinctions:
  - Late Ordovician
  - Mid-Late Devonian
  - End Permian
  - Late Triassic.
  - End Cretaceous



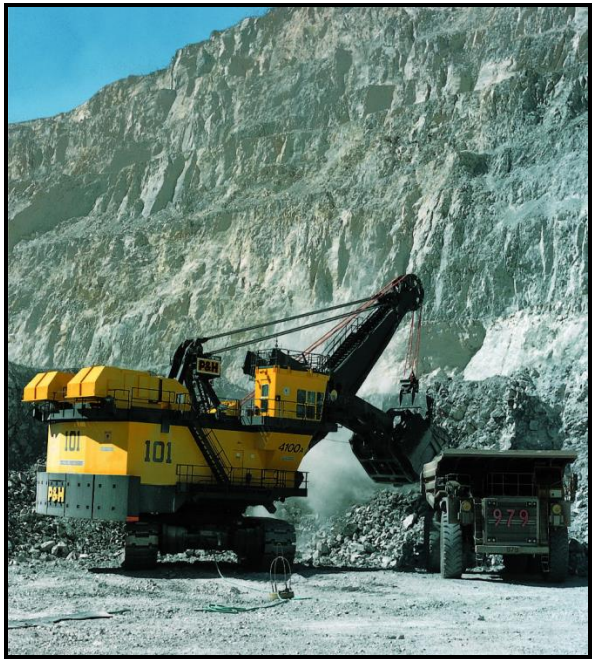
Human Impact on the Earth-System

- Prehistoric humans were few, having a small impact.
- Today, humans are a huge force of planetary change.
  - Exponential population growth aided by advancements in:
    - Industry, agriculture, technology, and medicine
    - Fueled by a suitable supply of natural resources
- Human demands often rival or exceed natural processes of recovery.



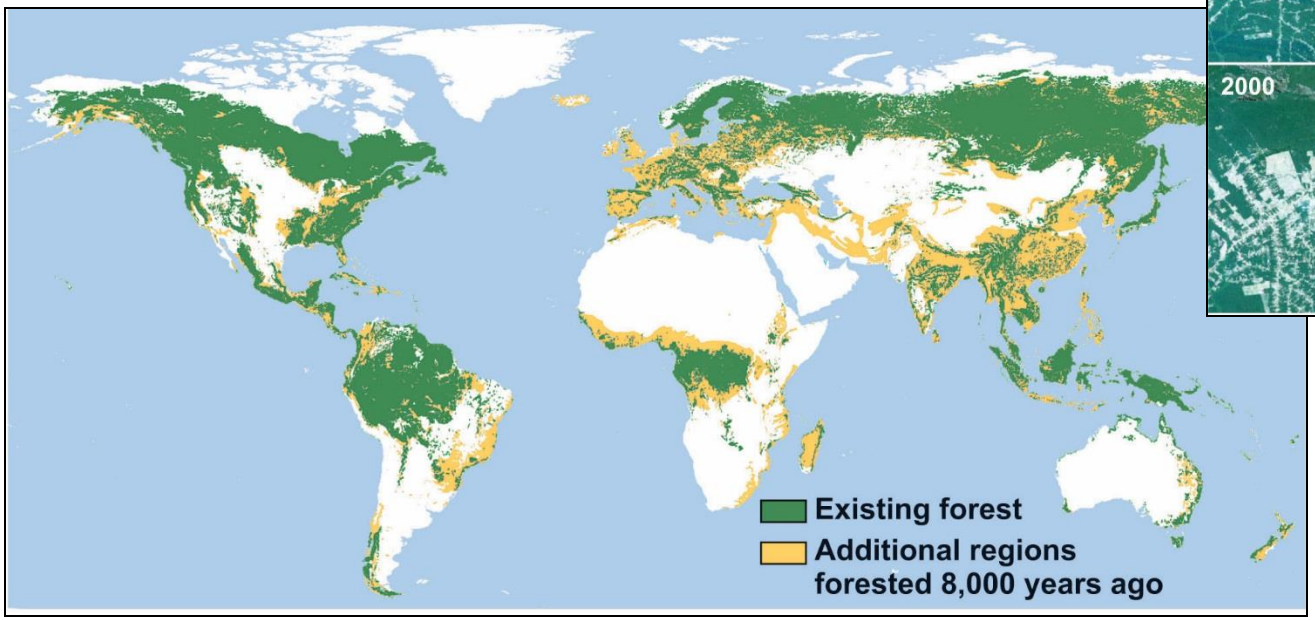
Human Impact on the Earth-System

- **Landscape modifications**
  - **Human-induced erosion may exceed natural processes.**



Human Impact on the Earth System

- **Ecosystem modification—balances are destabilized.**
  - **Human-caused changes occur faster than indigenous organisms can adapt.**
  - **Rainforest decline is largely the result of human activity.**



Human Impact on the Earth-System

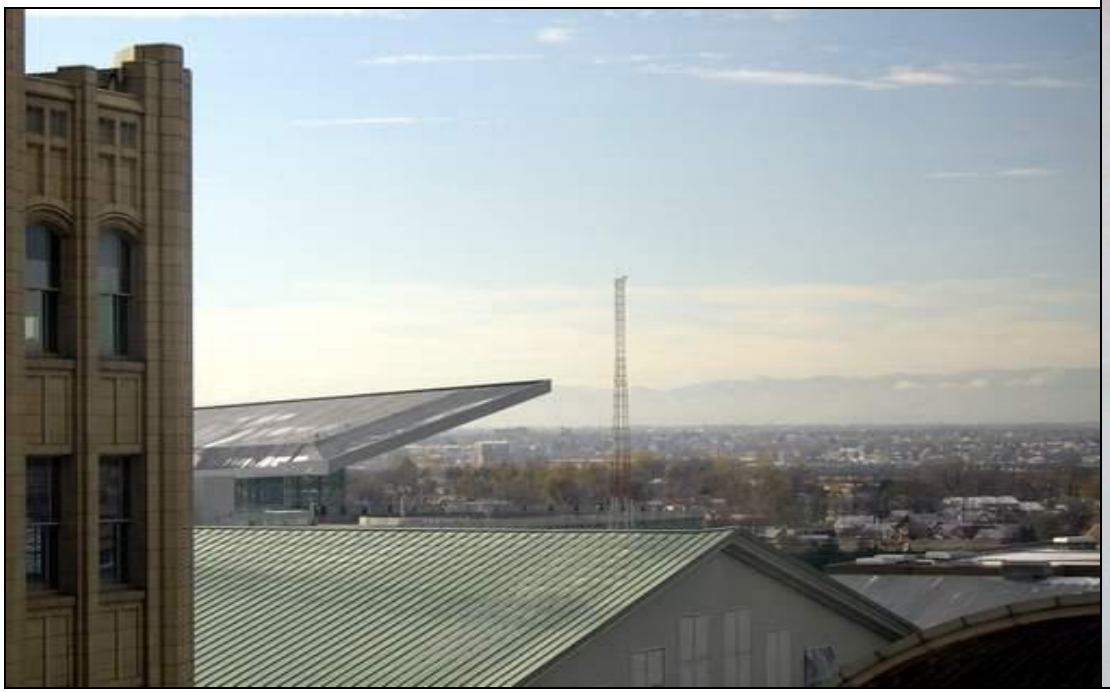
- **Ecosystem modifications—destroy habitats**
  - **Deforestation**
  - **Overgrazing**
  - **Agriculture**
  - **Urbanization**

Human Impact on the Earth System

- Pollution—materials that harm life forms and resources
- Modern human society generates contaminants.
  - Contaminating materials are numerous and diverse.
  - They are produced so fast that the natural environmental systems can't absorb or modify/neutralize them.

Human Impact on the Earth-System

- **Pollution affects air quality.**
  - **Smog (smoke + fog)—urban haze created by reaction of:**
    - **Ground-level ozone, and**
    - **Unburned hydrocarbons.**



Human Impact on the Earth System

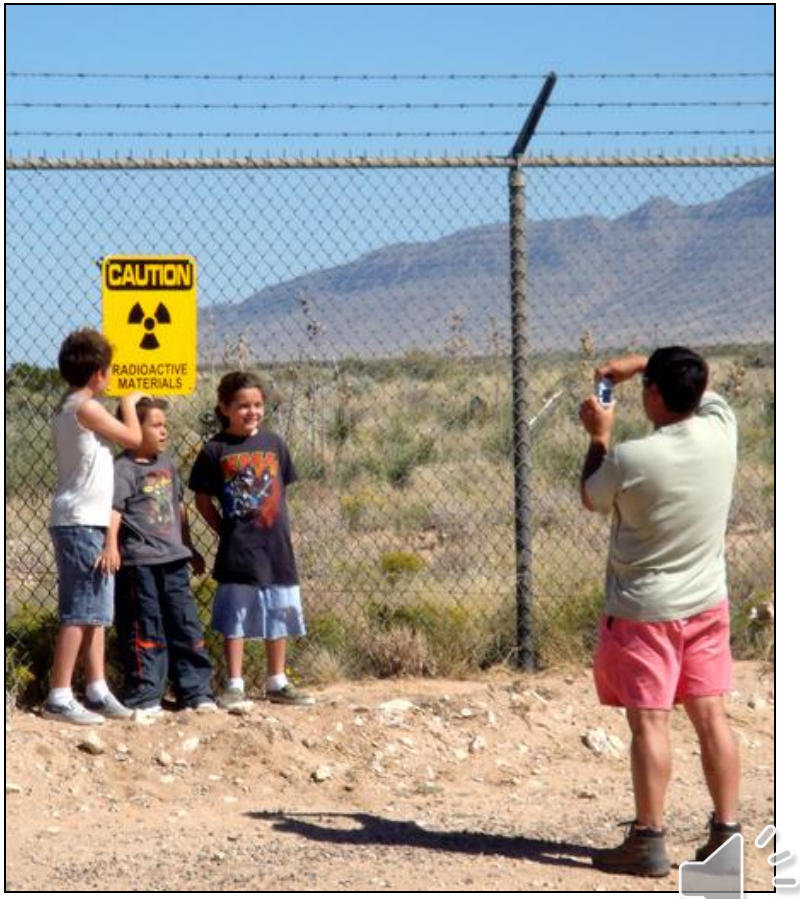
- **Pollution causes water contamination.**
  - **Pollutants frequently enter surface and groundwater.**
    - **Sanitary wastes**
    - **Fuel and oil**
    - **Solvents**
    - **Fertilizers**
    - **Pesticides**

Human Impact on the Earth System

- **Pollution causes acidification.**
  - **Acid runoff—sulfide minerals dissolve and release acid.**
    - **Coal mining**
    - **Metal mining**
  - **Acid precipitation—sulfide-rich aerosols acidify rain.**
    - **Coal-fired power plants**
    - **Ore smelters**

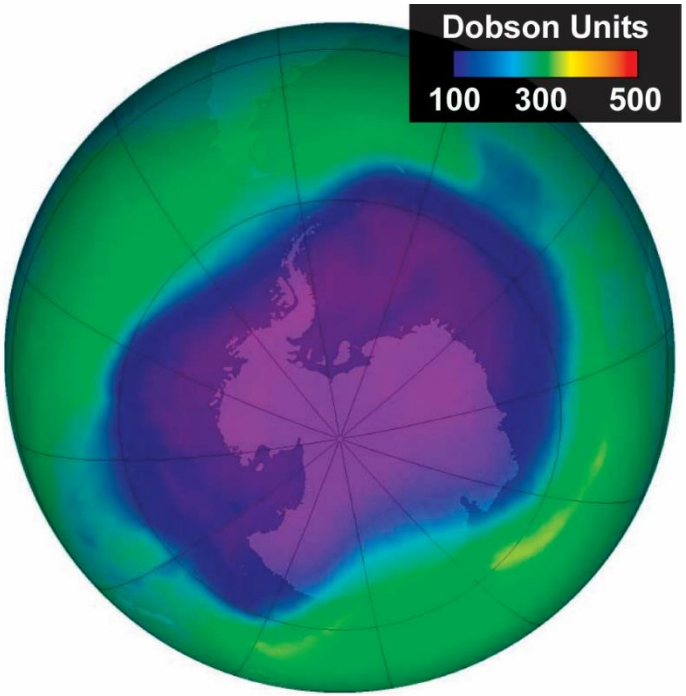
Human Impact on the Earth System

- **Pollution—radioactive waste**
  - **Nuclear materials, mining and processing, generate wastes:**
    - **Mine spoil and mill tailings**
    - **High-level nuclear wastes**
    - **Medical radioactive isotopes**



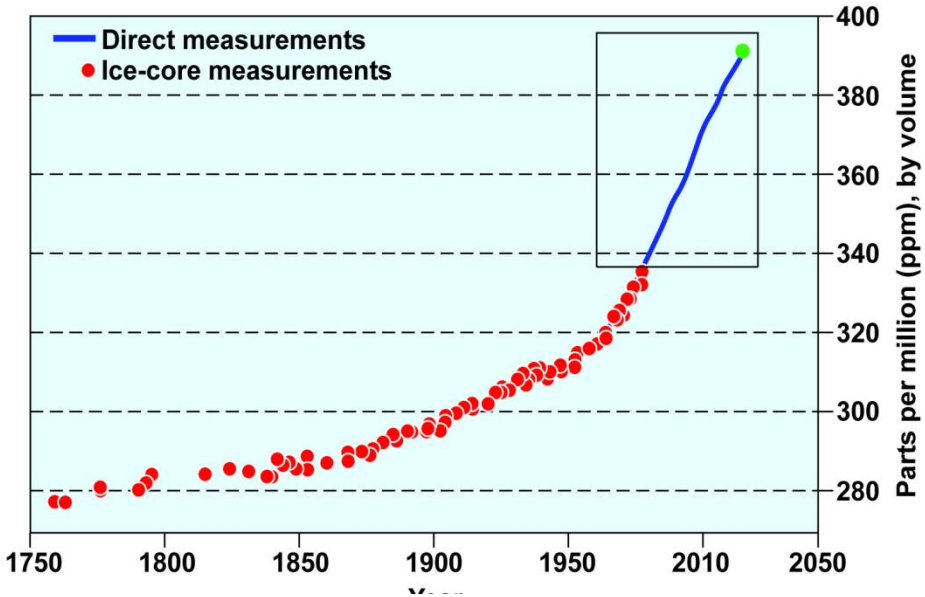
Human Impact on the Earth System

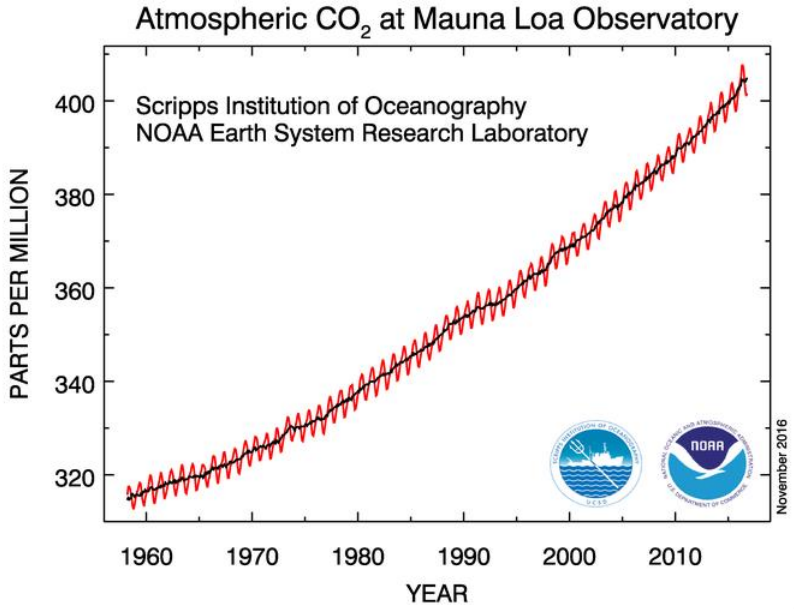
- Pollution causes depletion of stratospheric ozone (O_3).
  - Chlorofluorocarbons (CFCs) catalyze destruction of ozone.
  - Stratospheric ozone protects Earth from UV radiation.
  - Ozone depletion is harmful to many life forms.
  - Note: Ozone depletion is unrelated to CO_2 buildup.



Human Impact on the Earth System

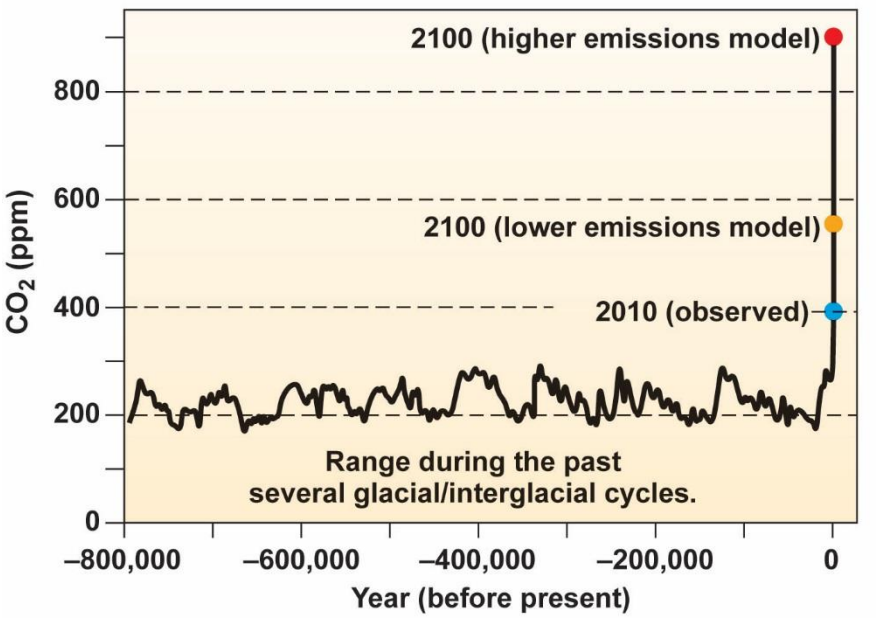
- **Recent global warming—human greenhouse gas additions alter climate.**
  - **CO_2 in the atmosphere has steadily climbed since the industrial revolution began.**
    - **Ice core data show atmospheric CO_2 in 1750 was ~ 280 ppm.**
    - **In 1958, CO_2 was ~315 ppm; in 2010, CO_2 was ~390 ppm; today, it surpasses ~415 ppm and is increasing at >2 ppm/yr.**

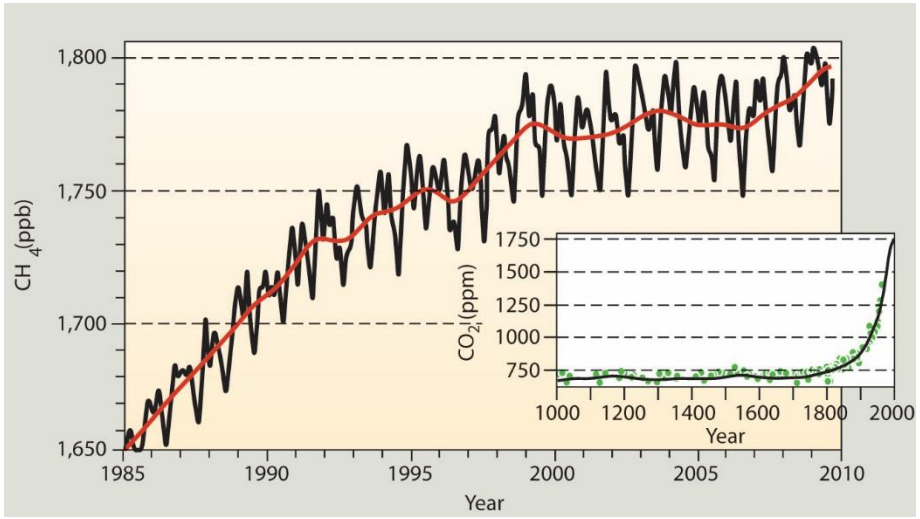




Human Impact on the Earth System

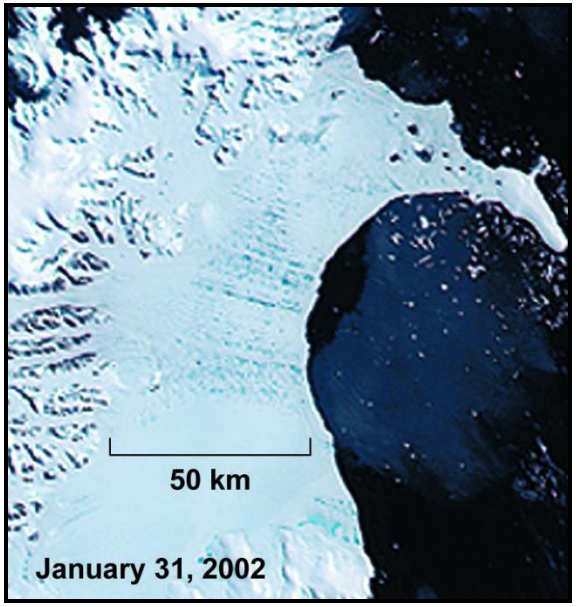
- **Recent global warming—human greenhouse gas additions alter climate.**
  - **Human additions of CO_2 and CH_4 exceed natural removals.**
    - **Fossil fuel combustion (CO_2)**
    - **Rice-paddy decay (CH_4)**
    - **Cow flatulence (CH_4)**

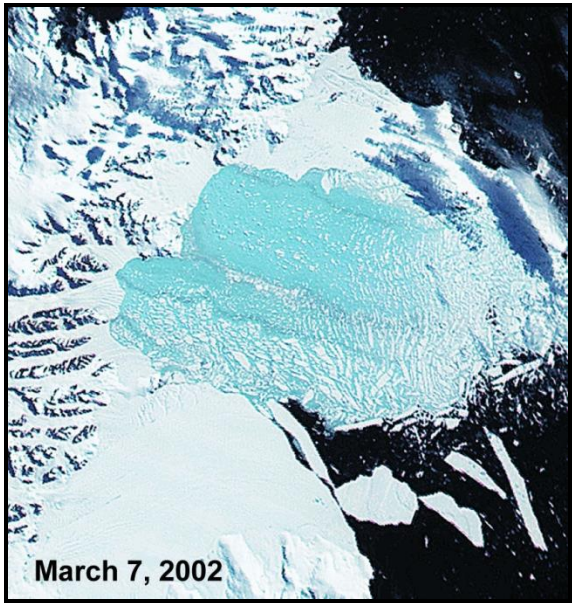


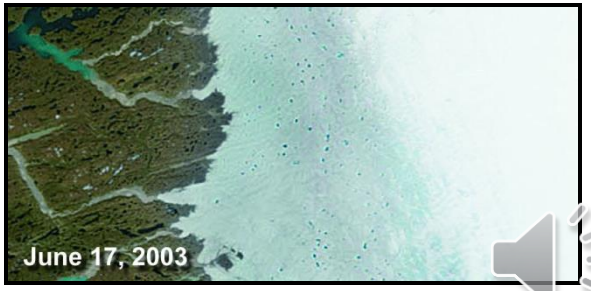


Human Impact on the Earth System

- **Thousands of observations worldwide have documented effects of 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.**

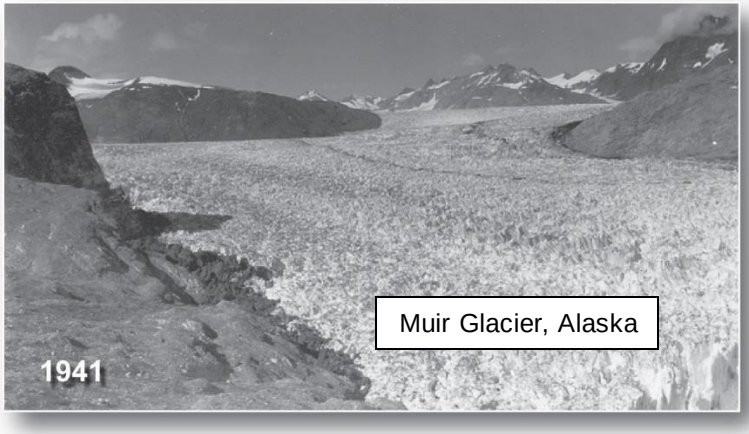






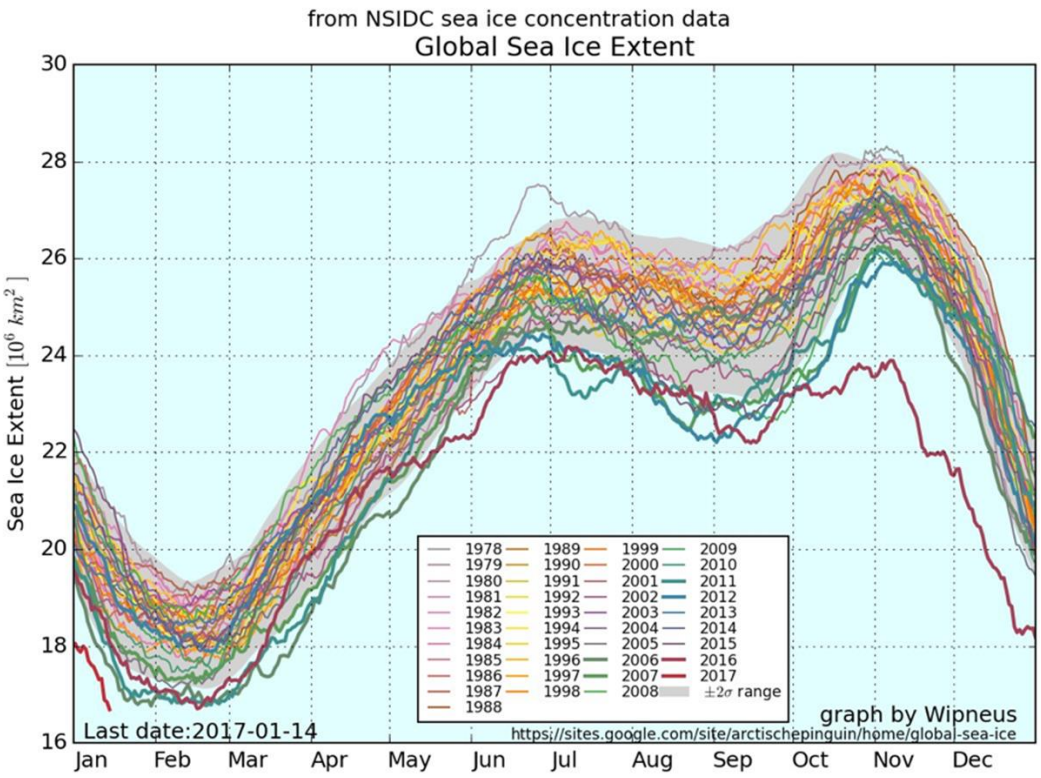
Human Impact on the Earth System

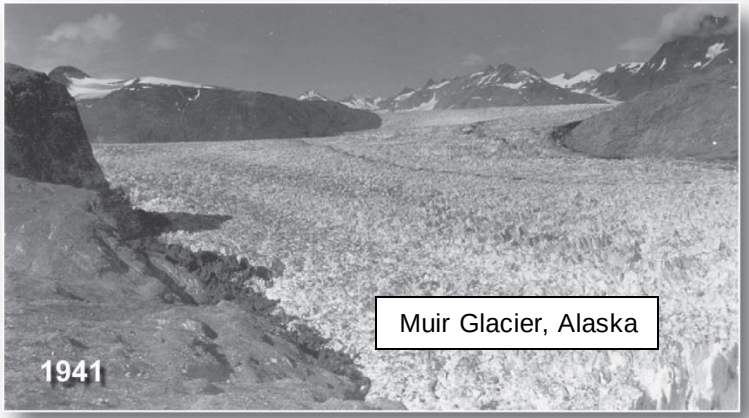
- **Thousands of observations worldwide have documented effects of recent global warming:**
  - **Valley glaciers worldwide are retreating.**
  - **Arctic Ocean sea-ice is reduced.**

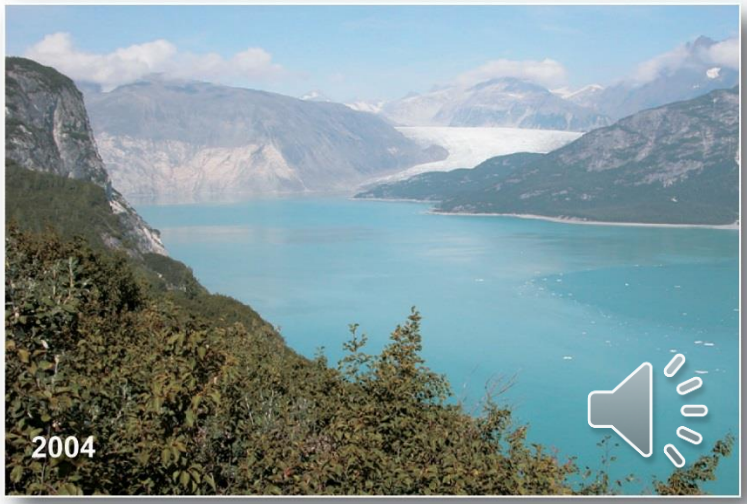


Human Impact on the Earth System

- **Thousands of observations worldwide have documented effects of recent global warming:**
  - **Valley glaciers worldwide are retreating.**
  - **Arctic Ocean sea-ice is reduced.**

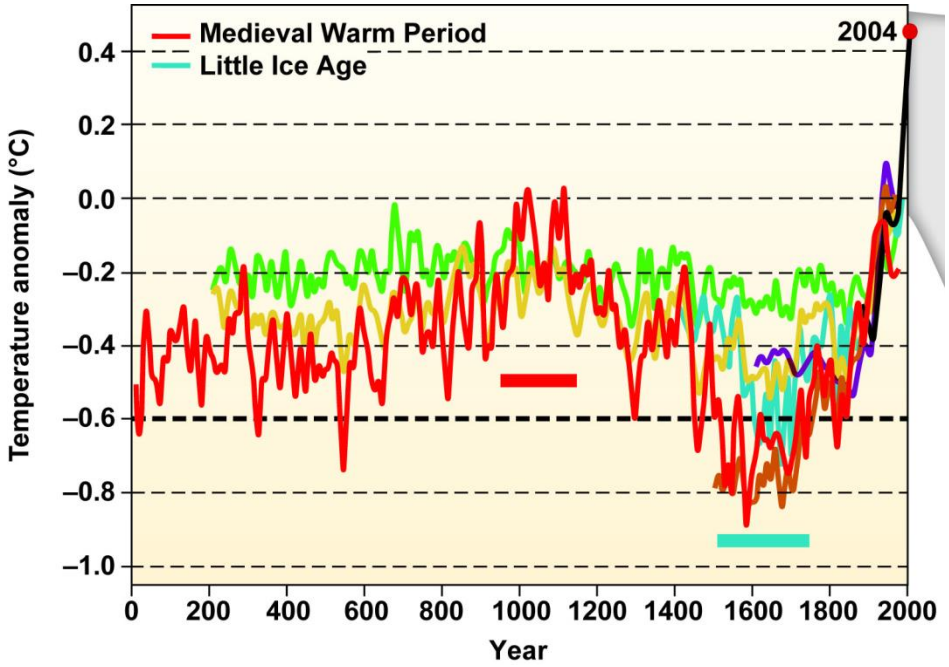


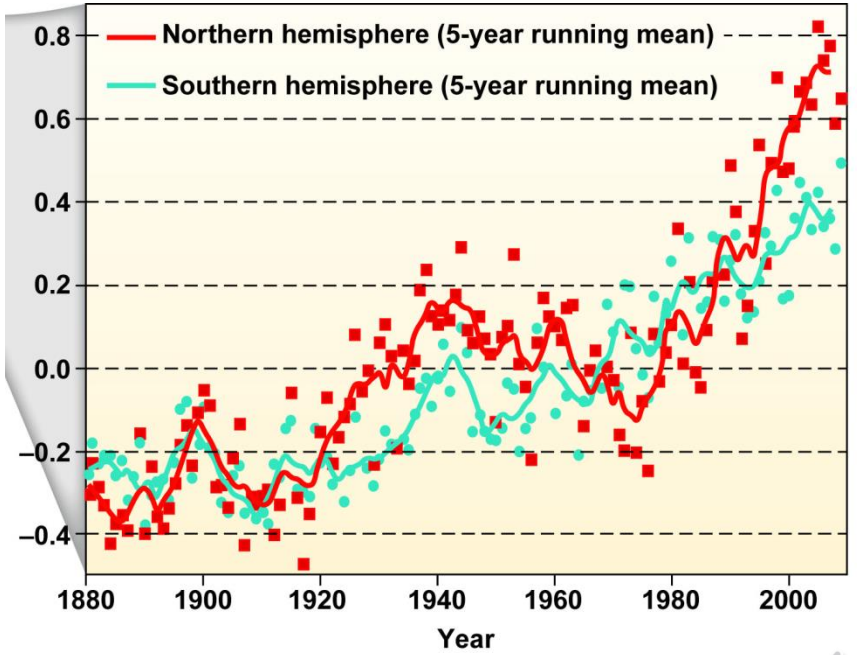




Human Impact on the Earth System

- **Consensus now: global warming is fact.**
  - **Tropospheric temperature has warmed by ~ 1ºC since 1880.**
  - **Global average temperature is higher today than at any time in the last 2,000 years, now even warmer than during the medieval warm period.**





Human Impact on the Earth System

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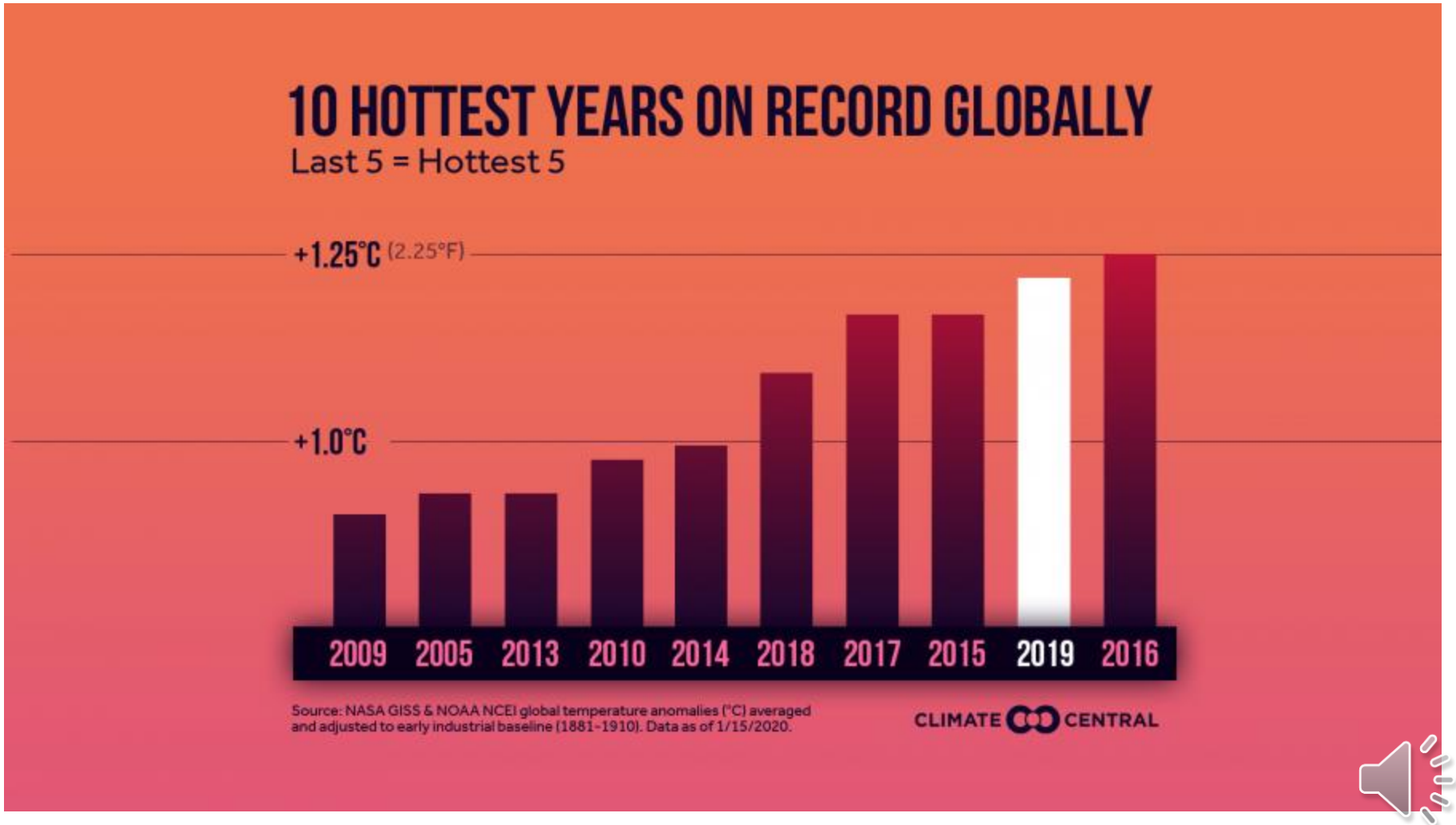
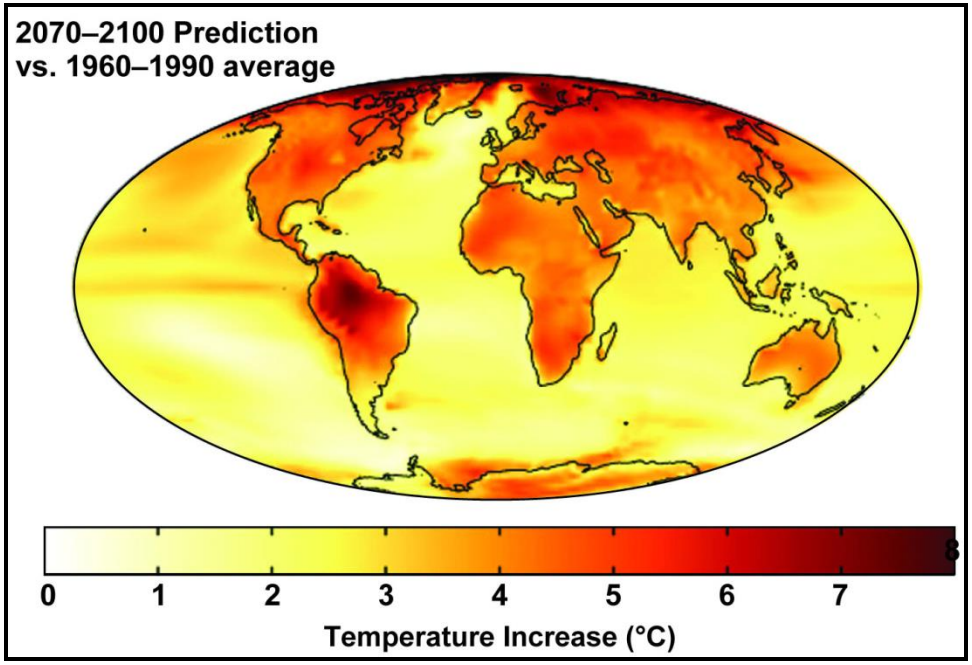
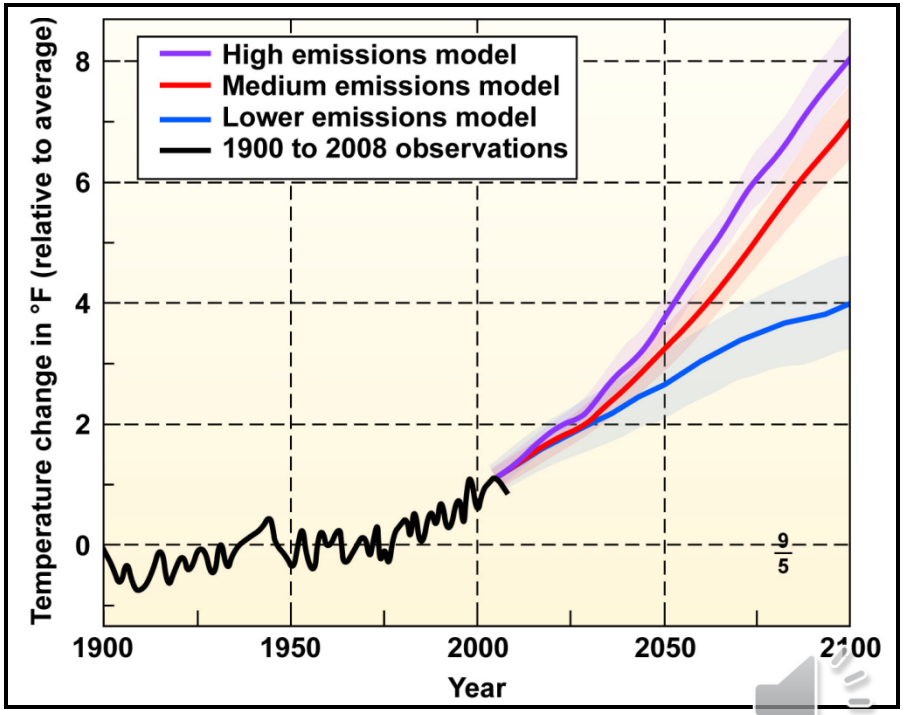


Human Impact on the Earth System

- **Computer models predict climate changes:**
  - **By 2050, average annual T will increase by 1.5ºC to 2.0ºC.**
  - **By 2150, global T could be 5ºC to 11ºC warmer than present.**



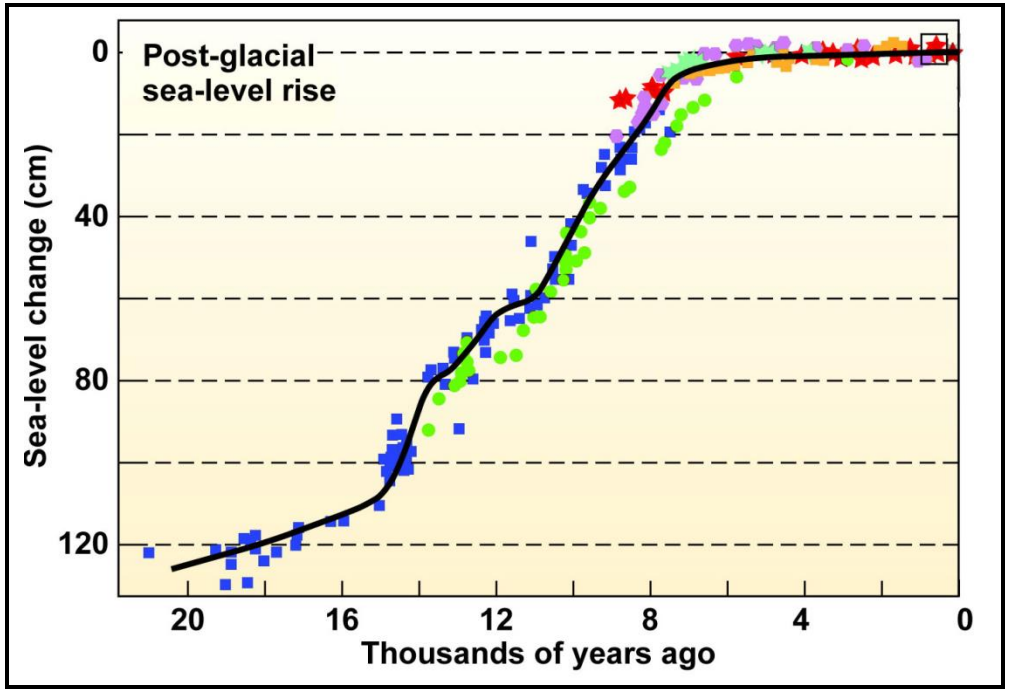


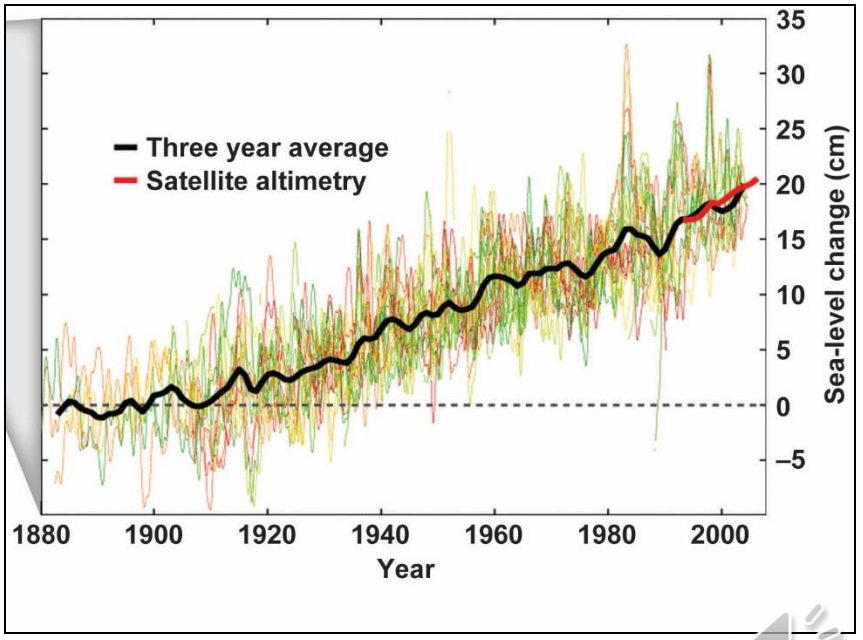
Human Impact on the Earth System

- **What might we expect from global warming:**
  - **Stronger storms due to a more vigorous hydrologic cycle:**
    - **Higher sea-surface temperatures**
    - **Greater evaporation**
    - **Greater differential pressures – so stronger cyclonic winds!**
    - **2005 set a number of storm records but the North Atlantic has been relatively quiet since then? Until 2017-2018!**

Human Impact on the Earth System

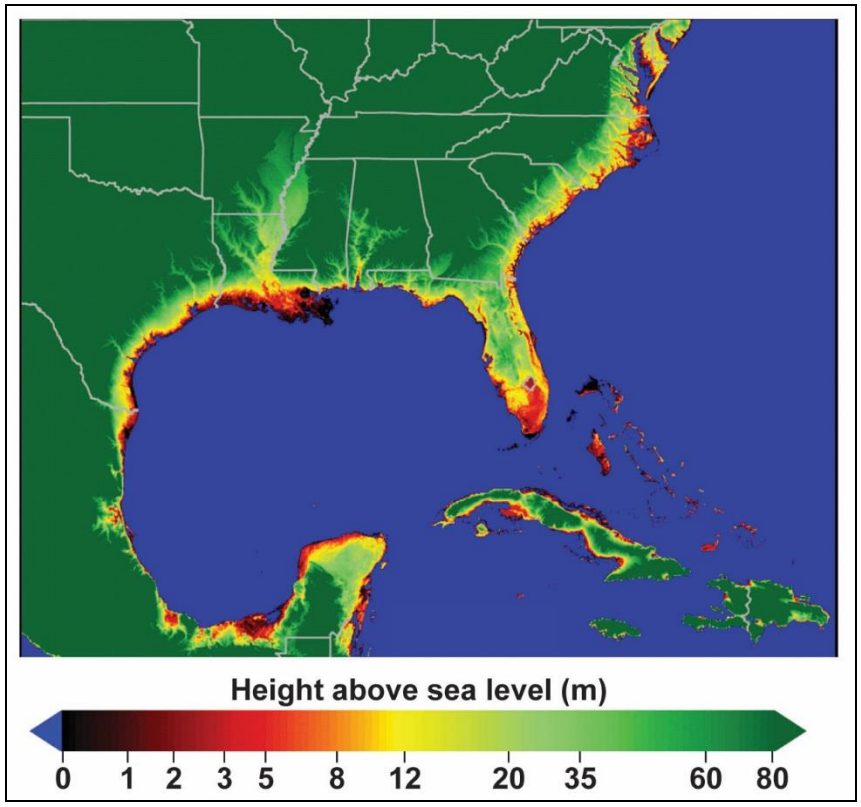
- **The predicted effects of global warming:**
  - **A rise in sea level**
    - **Global sea level is now rising ~ 3.2 mm/year.**
    - **Warming will accelerate this trend by:**
      - **Thermal expansion of seawater**
      - **Melting polar ice**

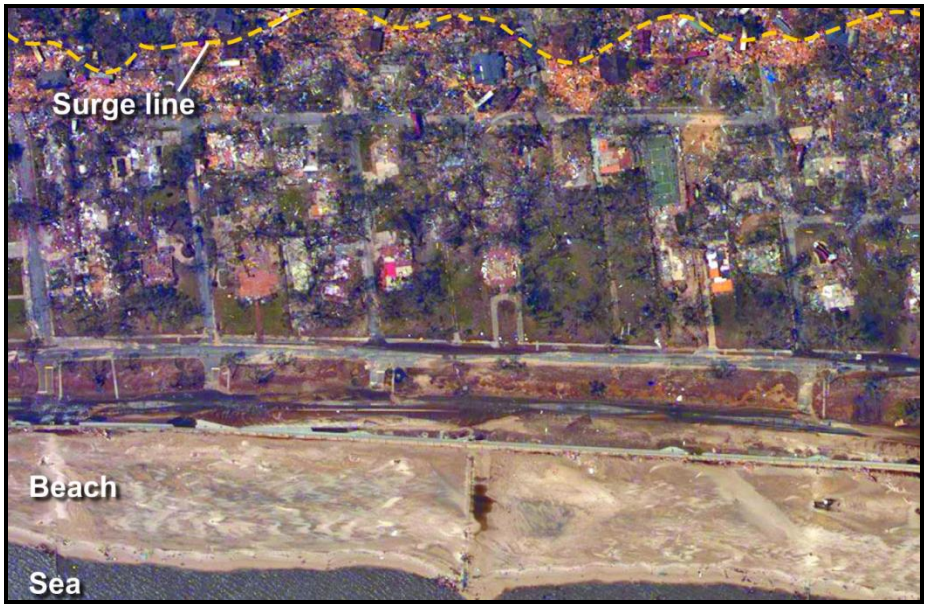




Human Impact on the Earth System

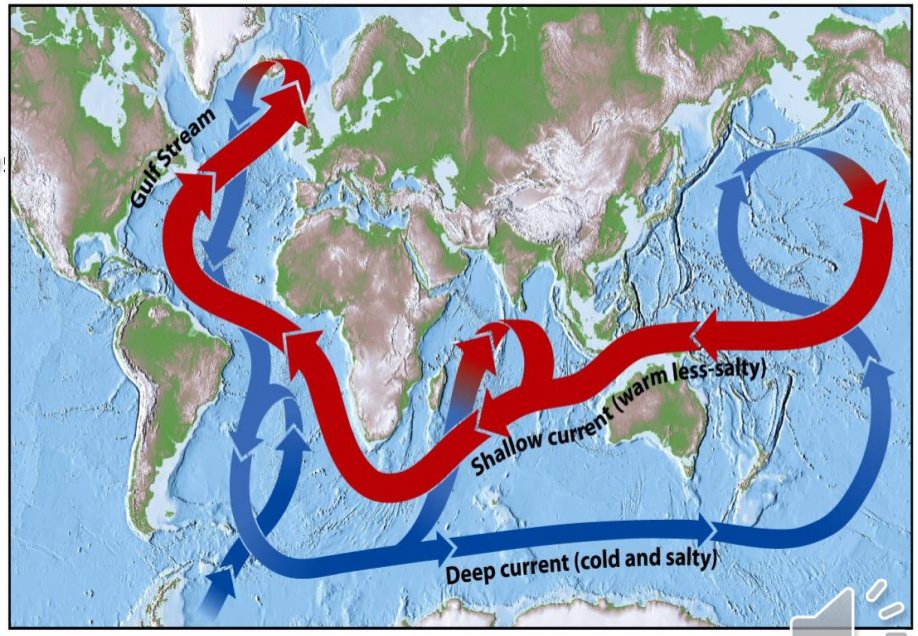
- **The predicted effects of global warming:**
  - **A rise in sea level**
    - **Many people live within as little as 1 meter of sea level.**
    - **Rising sea level will require that millions retreat from coasts.**





Human Impact on the Earth System

- Many scientists think that global warming could lead to:
  - Interruption of the oceanic heat conveyor system.
  - Polar ice meltwater is freshwater.
    - Would dilute surface ocean water near the poles.
    - This freshwater won't sink and move southward.
    - Thermohaline circulation would stop preventing warm water from flowing northward.
    - This might lead to an irreversible "tipping point" and a permanent change to the climate system.



Earth's Future

- Our future on Earth requires a sustainable environment.
  - Prosperity must balance societal and human needs
    - Many (most?) resources are not limitless.
  - Without sustainability, Earth and humans will be in trouble.
    - Earth System disruption will reach a critical point based on:
      - Natural resource limitations (fuels, metals, water)
      - Shrinking land areas
      - Increasing populations
    - Under such a scenario, a new equilibrium will need to be reached. Growth of material prosperity may be impossible.

Earth's Future

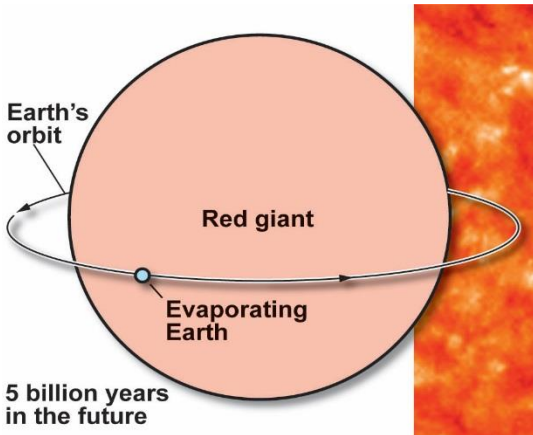
- In millions of years, Earth's surface will be different.
  - Plate tectonics will reshuffle continents.
  - Erosion will reshape the landscape.
  - Seas will invade or expose land.
- Homo sapiens may no longer be present.
  - A new species of hominids might have evolved by then, or perhaps another thread of evolution will master the Earth.

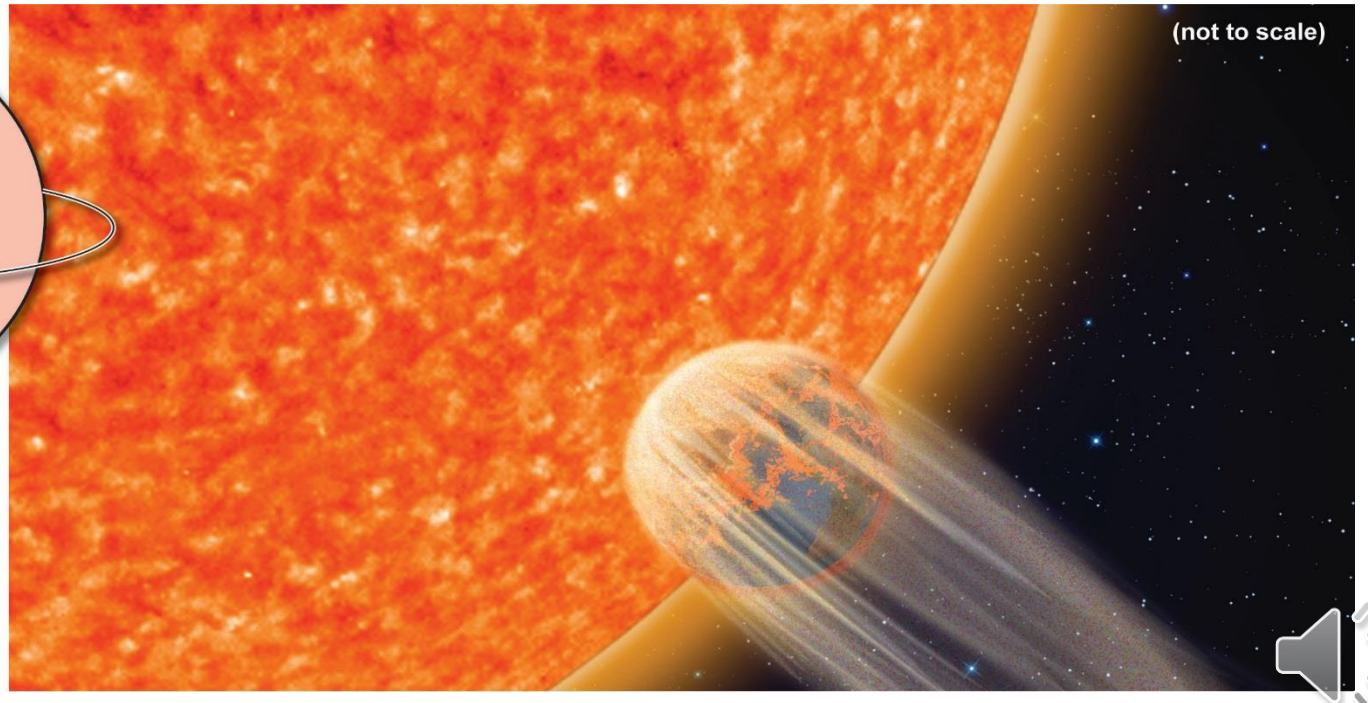
The Anthropocene

When geologists return to the Earth from millions of years hence, they will recognize that an amazing environmental event occurred starting about 6000 years before our present time. Human induced change in the Earth System has been as abrupt as many of the catastrophic changes in the environment of the past that have defined geological periods. Those future geologists might wonder just what events combined to cause what might be then seen as the greatest mass extinction since that of the Dinosaurs – the extinction that ends a geological period that we are now calling the Anthropocene – the Age of the Humans.

Earth's Future

We don't have "forever"… Earth's viability for life will come to an end as the Sun continues to evolve toward its Red Giant phase in about 6 billion years. But even before that..

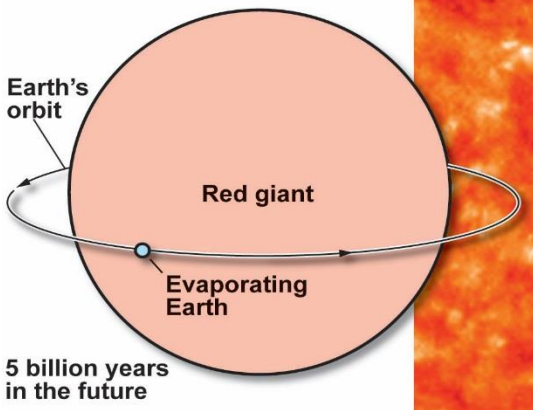


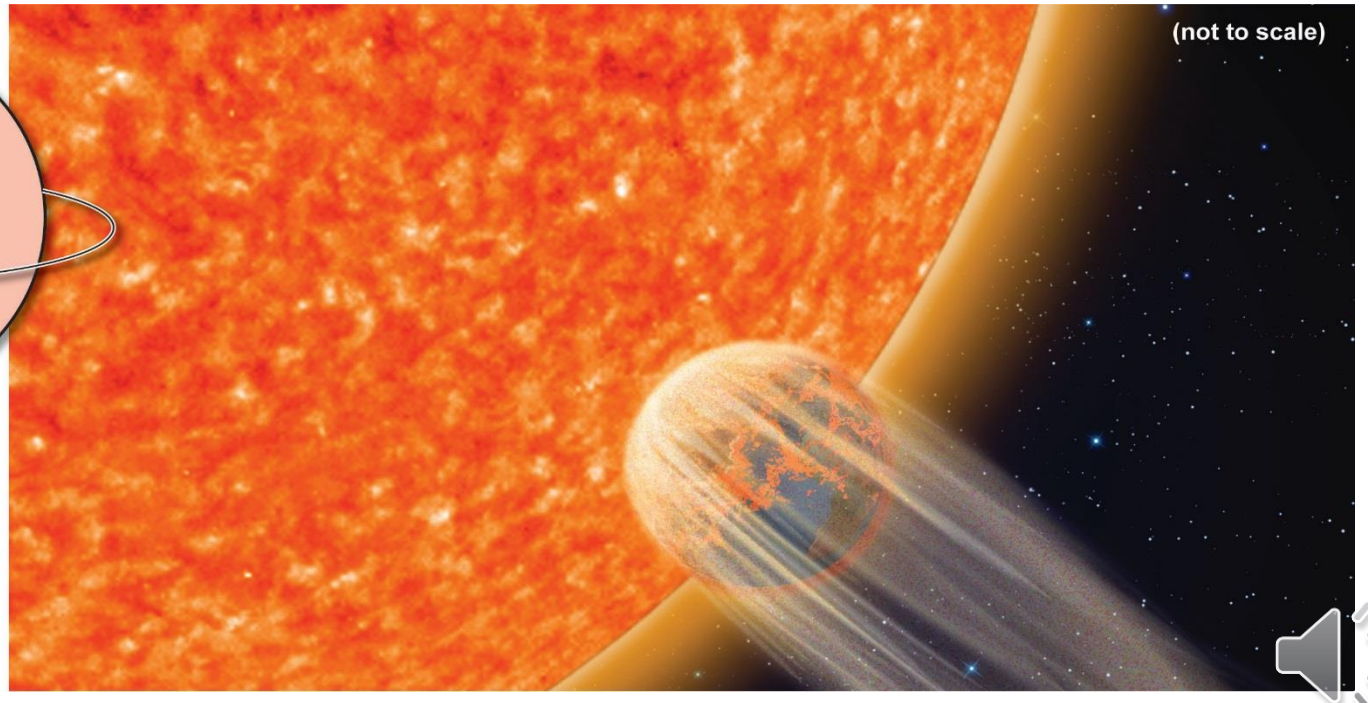


Earth's Future

Earth's oceans will have already evaporated within 800Ma leaving us an uninhabitable hot rocky planet long before that. 800 Ma? Let's not worry about that just yet.

Let us husband the planet that we have so that it may be a viable home for *life* for all of those 800 million years!





Essentials of Geology

by Stephen Marshak

PowerPoint slides prepared by

Ronald L. Parker
Senior Geologist
Fronterra Geosciences
Denver, Colorado

Rick Oches
Professor of Geology
Bentley University
Waltham, Massachusetts

Edited and augmented for this course by

Olivia Jensen
Professor of Geophysics
McGill University
Montreal, Canada