



PHYS 3800 Physical Geology Chapter 19: Global Change in the Earth System



1

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.

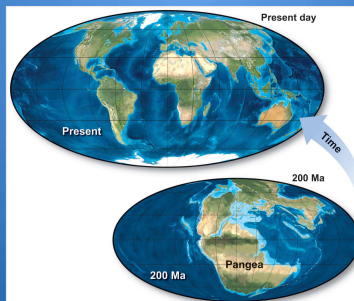


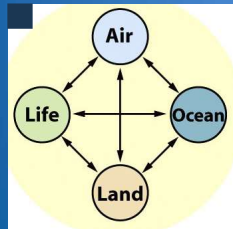
Fig. 19.1



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.

3

The Earth System

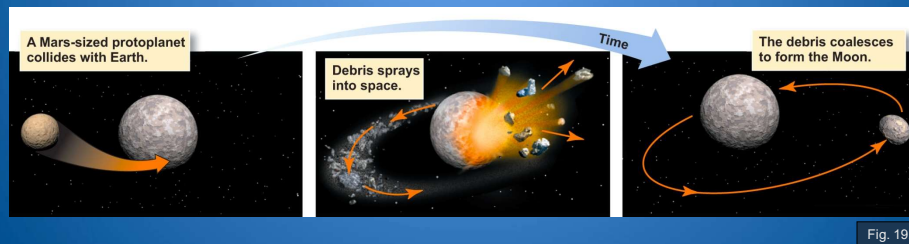
- The interlinkage of the physical and the biological:
- Global changes transform or modify both realms.
 - There are many ways to describe changes:
 - Gradual change
 - Catastrophic change
 - Unidirectional change
 - Cyclic change





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



5

Unidirectional Changes

- Evolution of the atmosphere and oceans:
 - Volcanic gases created an early atmosphere.
 - CO₂, H₂O, N₂
 - Liquid water condensed to form the oceans.
 - Photosynthetic organisms appeared.
 - O₂ becomes a significant component of the atmosphere.

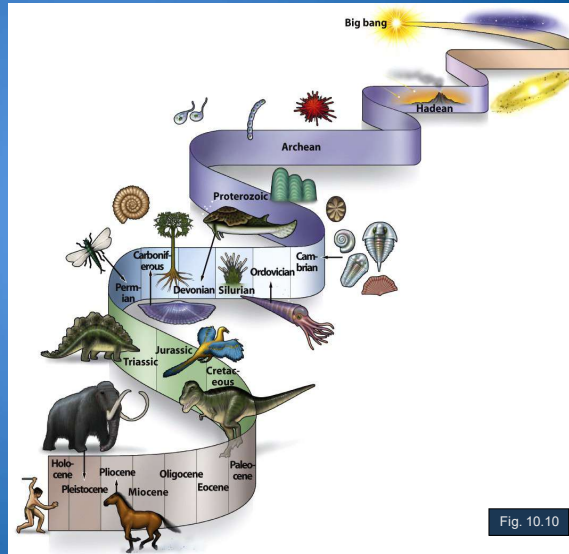




Unidirectional Changes

■ Evolution of Life

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

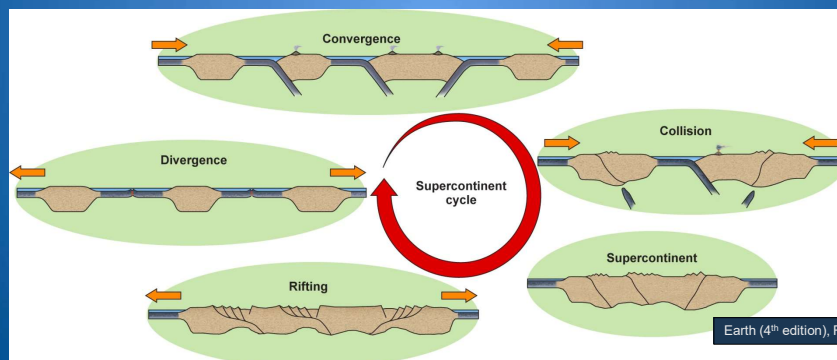


7

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.

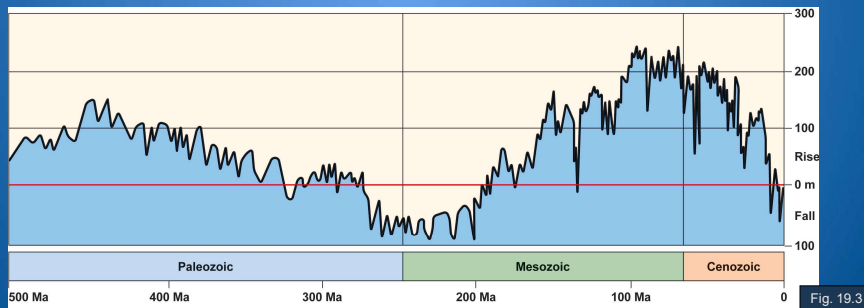


Fig. 19.3

9

Physical Cycles

- The rock cycle—there are three types of rock:
 - Igneous—cooled from a mel.
 - Sedimentary—made of weathered and eroded materials
 - Metamorphic—rocks altered by heat and pressure
- One rock type may transform into any other type.
 - The atoms in rocks are constantly being rearranged.

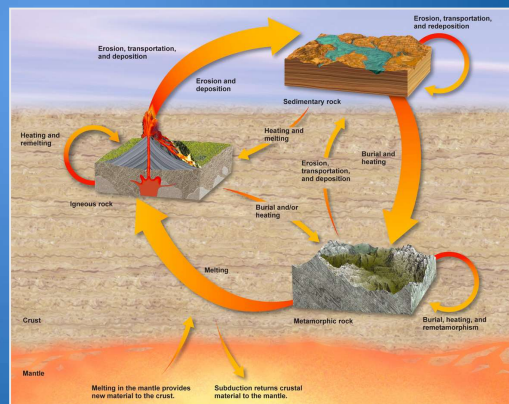
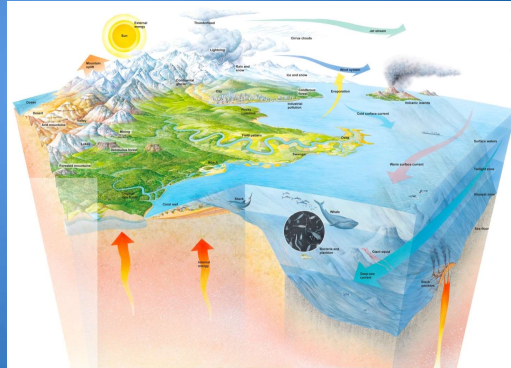


Fig. C.1



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

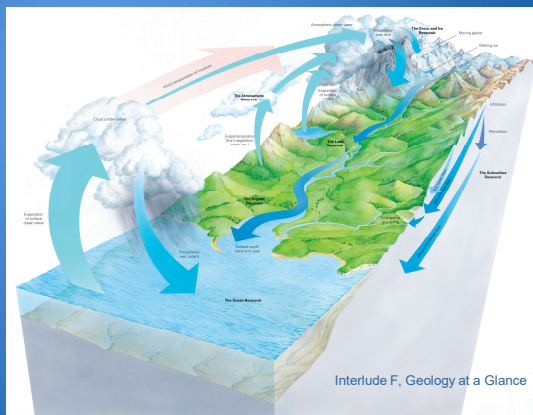


Geology at a Glance

11

Biogeochemical Cycles

- The hydrologic cycle:
 - Water moves between reservoirs on or near Earth's surface.
 - Biological:
 - ✓ All living organisms
 - Physical:
 - ✓ Oceans
 - ✓ Atmosphere
 - ✓ Surface water
 - ✓ Ground water
 - ✓ Glaciers
 - ✓ Soil moisture

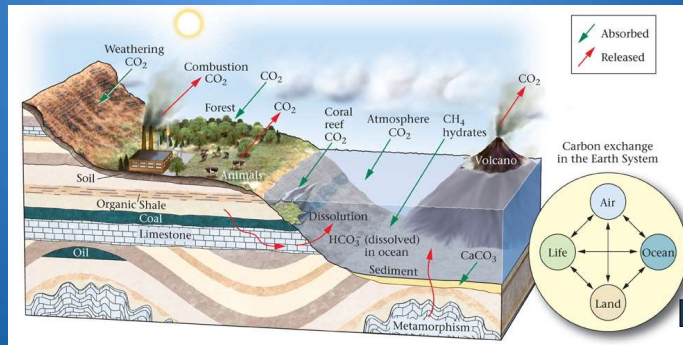


Interlude F, Geology at a Glance



The Carbon Cycle

- A biogeochemical cycle that regulates climate
 - Volcanic CO₂ adds carbon to the atmosphere.
 - Atmospheric CO₂ is removed in several ways:
 - It dissolves in water as carbonic acid and bicarbonate.
 - Photosynthesis removes CO₂.
 - Weathering



13

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 CO₂ from organic matter.
 - Rapid oxidation (burning) of organic matter creates CO₂.
 - Metamorphism of carbonate rocks liberates CO₂.
 - Degassing removes dissolved CO₂ from water.



15

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



17

Global Climate Change

- H₂O, CO₂, and CH₄ in Earth's atmosphere absorb thermal energy and reradiate it, warming the lower atmosphere.
 - This is called the **greenhouse effect**.

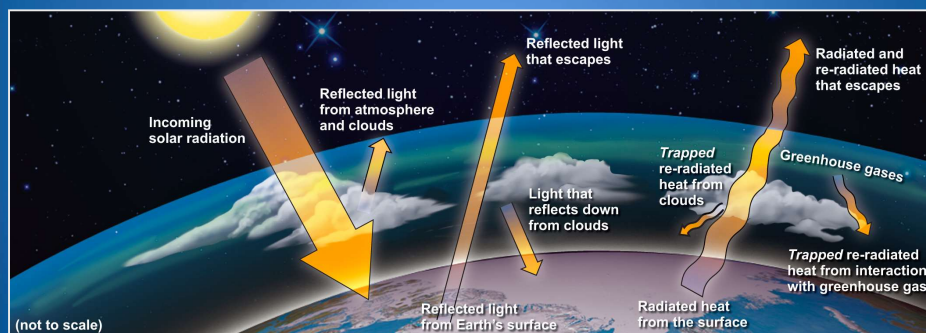


Fig. Bx.19.1



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



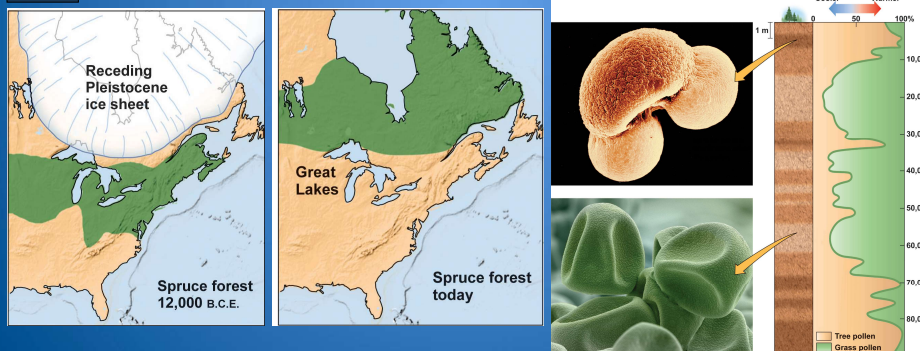
Fig. 6.5c

19

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)

Fig. 19.5





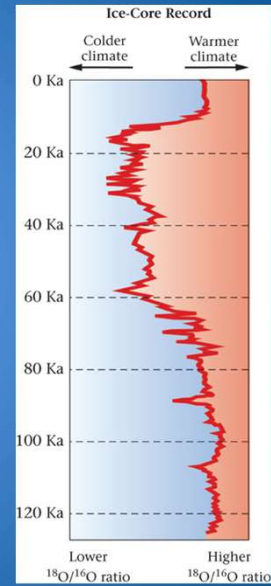
Global Climate Change

■ Paleoclimates:

- Oxygen isotopes—two isotopes: ^{16}O and ^{18}O
 - ^{16}O water evaporates faster than ^{18}O water.
 - ✓ $^{18}\text{O}/^{16}\text{O}$ in ice cores reveal the temperature in which snow formed.



Fig. 19.6a, b



21

Global Climate Change

■ Paleoclimates:

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

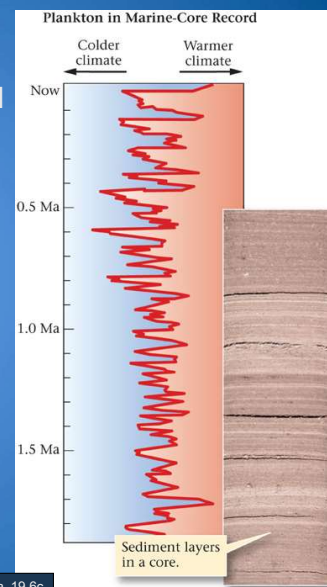


Fig. 6.20a, 19.6c



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.



Fig. 10.14b

23

Global Climate Change

■ Paleoclimates:

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



Fig. 19.8b



Long-Term Climate Change

- Earth's climate history has been largely deciphered.
 - Greenhouse—warmer climates
 - Icehouse—colder climates
- There have been at least five major icehouse periods in Earth's geologic history.

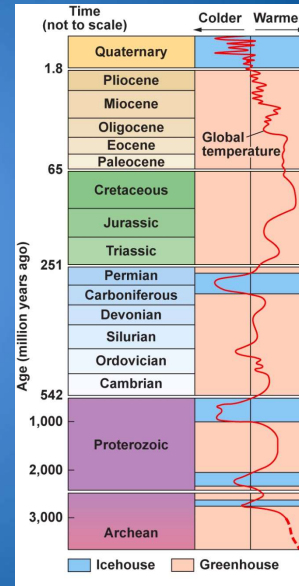


Fig. 19.7

25

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.

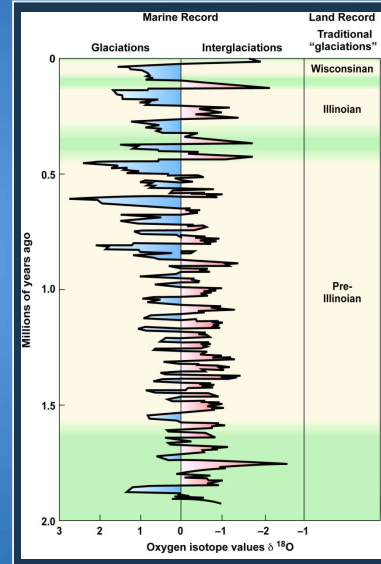


Fig.18.26a

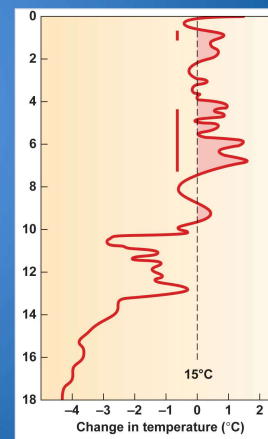
27

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



Fig. 19.8a, c





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

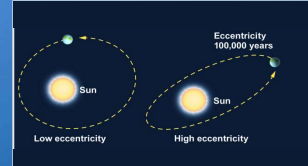
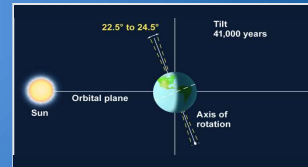
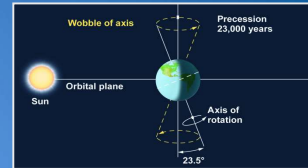


Fig. 18.27a-c

29

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

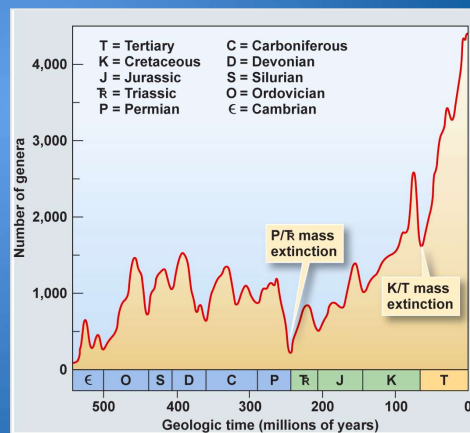
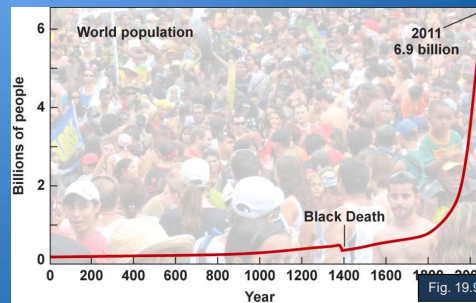


Fig. E.8



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 some natural processes.



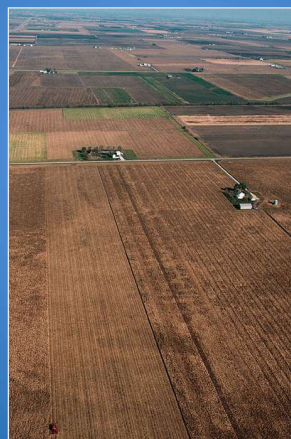
31

Human Impact on the Earth-System

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



Fig. 19.10





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.

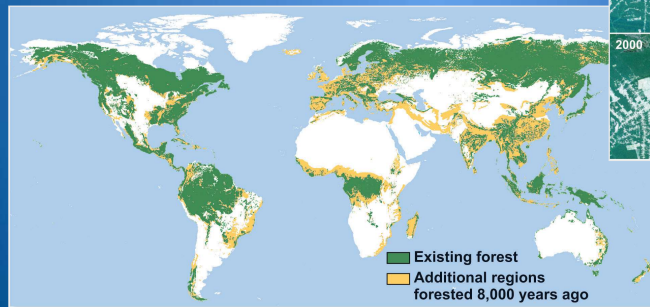


Fig. 19.11a, b

33

Human Impact on the Earth-System

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



Fig. 19.11c



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.



35

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



37

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



Fig. 12.21b



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



39

Human Impact on the Earth System

■ Pollution causes depletion of stratospheric ozone (O₃).

- 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 CO₂ buildup.

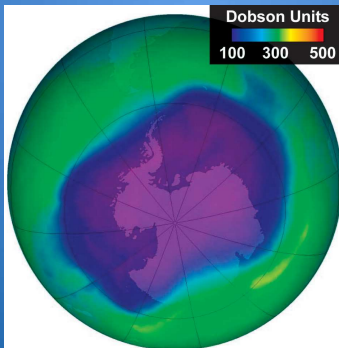


Fig. 19.12



Human Impact on the Earth System

- Recent global warming—human greenhouse gas additions alter climate.
 - CO₂ in the atmosphere has steadily climbed since the industrial revolution began.
 - Ice core data show atmospheric CO₂ in 1750 was ~ 280 ppm.
 - In 1958, CO₂ was ~315 ppm; in 2010, CO₂ was ~390 ppm.

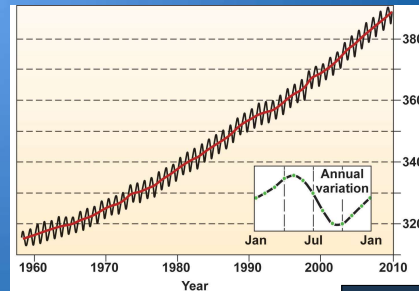
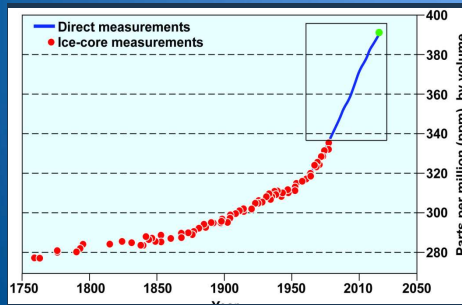


Fig. 19.13a, b

41

Human Impact on the Earth System

- Recent global warming—human greenhouse gas additions alter climate.
 - Human additions of CO₂ and CH₄ exceed natural removals.
 - Fossil fuel combustion (CO₂)
 - Rice-paddy decay (CH₄)
 - Cow flatulence (CH₄)

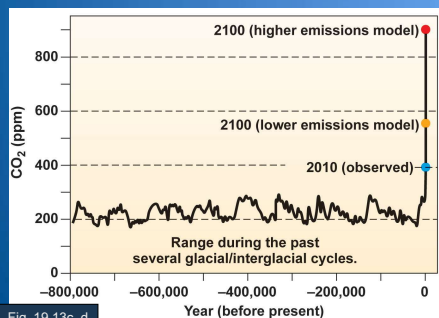
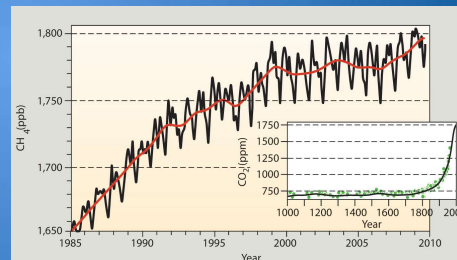


Fig. 19.13c, d





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.

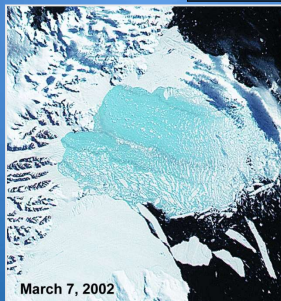
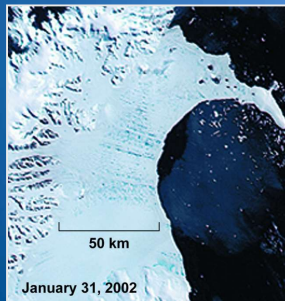


Fig. 19.14a, c



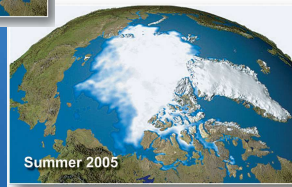
43

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.

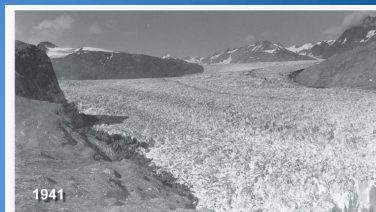


Summer 1979

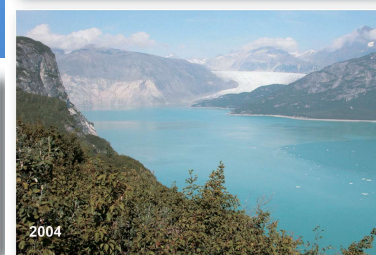


Summer 2005

Fig. 19.14b, d



1941



2004



Human Impact on the Earth System

- Most scientists accept global warming as fact.
 - Surface air temperatures have warmed by $\sim 1^{\circ}\text{C}$ since 1880.
 - Global average temperature is higher today than in the last 2,000 years.

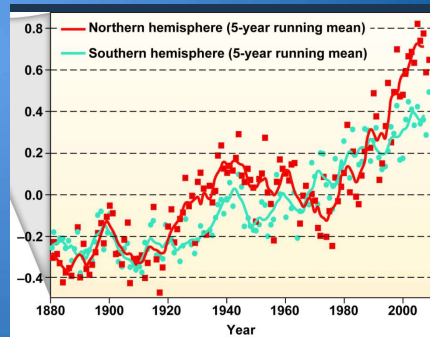
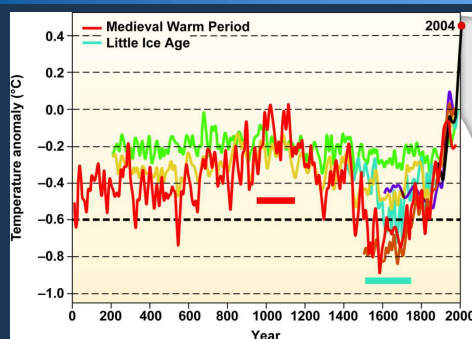


Fig. 19.15a, b

45

Human Impact on the Earth System

- Computer models are used to predict climate changes.
 - By 2050, average annual T will increase by 1.5°C to 2.0°C .
 - By 2150, global T may be 5°C to 11°C warmer than present.

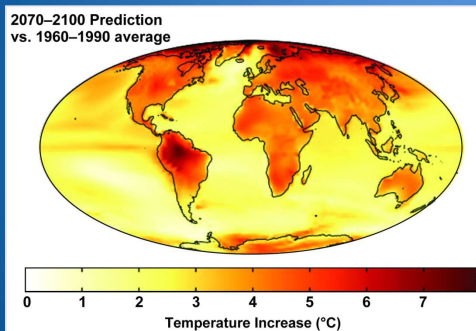
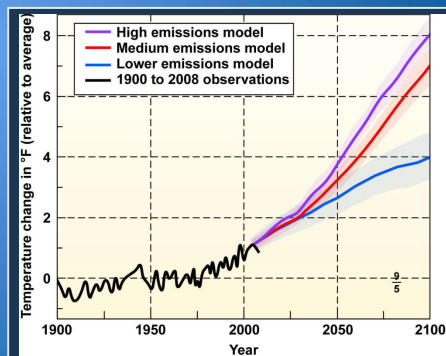


Fig. 19.17





Human Impact on the Earth System

- The predicted effects of global warming:
 - Stronger storms due to a more vigorous hydrologic cycle:
 - Higher sea-surface temperatures
 - Greater evaporation
 - Greater differential pressures
 - 2005 set a number of storm records



47

Human Impact on the Earth System

- The predicted effects of global warming:
 - A rise in sea level
 - Sea level is now rising 1–2 mm/year.
 - Warming will accelerate this trend by:
 - ✓ Thermal expansion of seawater
 - ✓ Melting polar ice

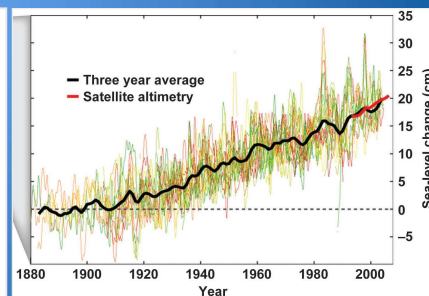
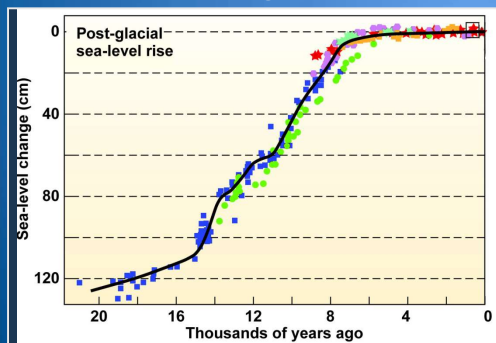


Fig. 19.18a, b



Human Impact on the Earth System

■ The predicted effects of global warming:

- A rise in sea level
 - Many people live within 1 meter of sea level.
 - Rising sea level will displace millions.

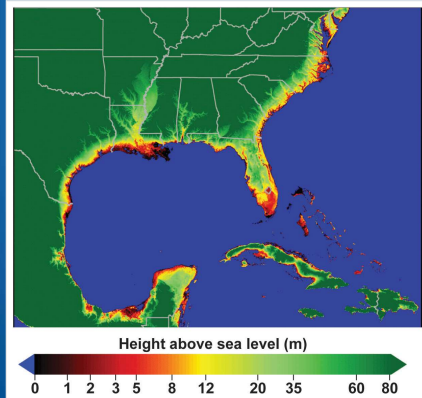


Fig. 19.18c, 15.22a

49

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.

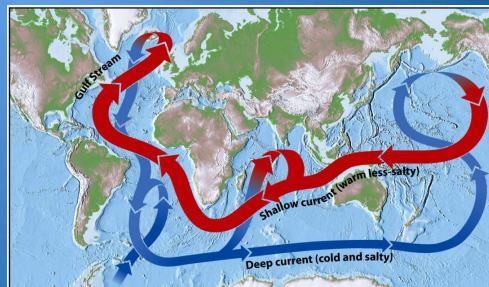


Fig. 15.6b



Earth's Future

- Our future on Earth requires sustainable growth.
 - Prosperity based on balancing societal and human needs
 - Our limitations are Earth's finite resources.
 - 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.



51

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.





Earth's Future

- In about 5 billion years, the Sun will run out of fuel and become a red giant.
 - Earth will dry out.
 - It will become vaporized.

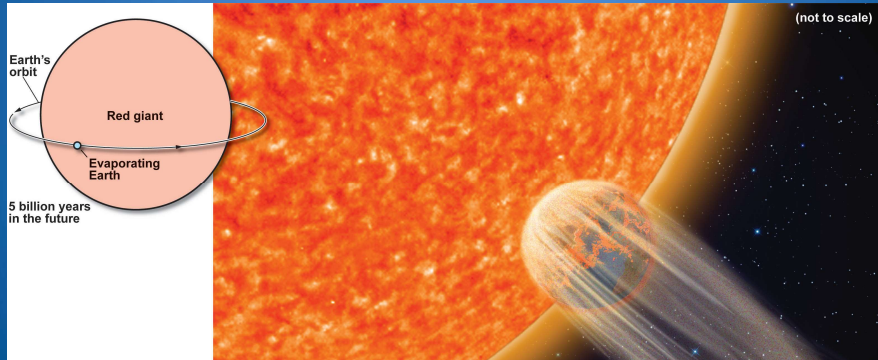


Fig. 19.19

53

Useful Web Resources

USGS Human Impacts

<http://www.usgs.gov/science/science.php?term=548>

The Global Carbon Project

<http://www.globalcarbonproject.org/>

GRID-Arendal United Nations Environment Programme

<http://www.grida.no/>

Intergovernmental Panel on Climate Change (IPCC)

<http://www.ipcc.ch/index.htm>

National Center for Atmospheric Research

<http://ncar.ucar.edu/>

NOAA Earth System Research Laboratory, Global Monitoring Division

<http://www.esrl.noaa.gov/gmd/ccgg/index.html>

Gateway to the United Nations System's Work on Climate Change

<http://www.un.org/wcm/content/site/climatechange/gateway>

Real Climate.org

<http://www.realclimate.org/>

New York Times Global Warming Compendium

<http://topics.nytimes.com/top/news/science/topics/globalwarming/index.html>



Useful Web Resources

- NOAA Weather and Atmosphere
 - http://www.education.noaa.gov/Weather_and_Atmosphere/
- University of California Museum of Paleontology
 - <http://www.ucmp.berkeley.edu/>
- United States Geological Survey
 - <http://www.usgs.gov/>
- The Environmental Protection Agency
 - <http://www.epa.gov/>
- Global Warming
 - <http://www.globalwarming.org/>

55