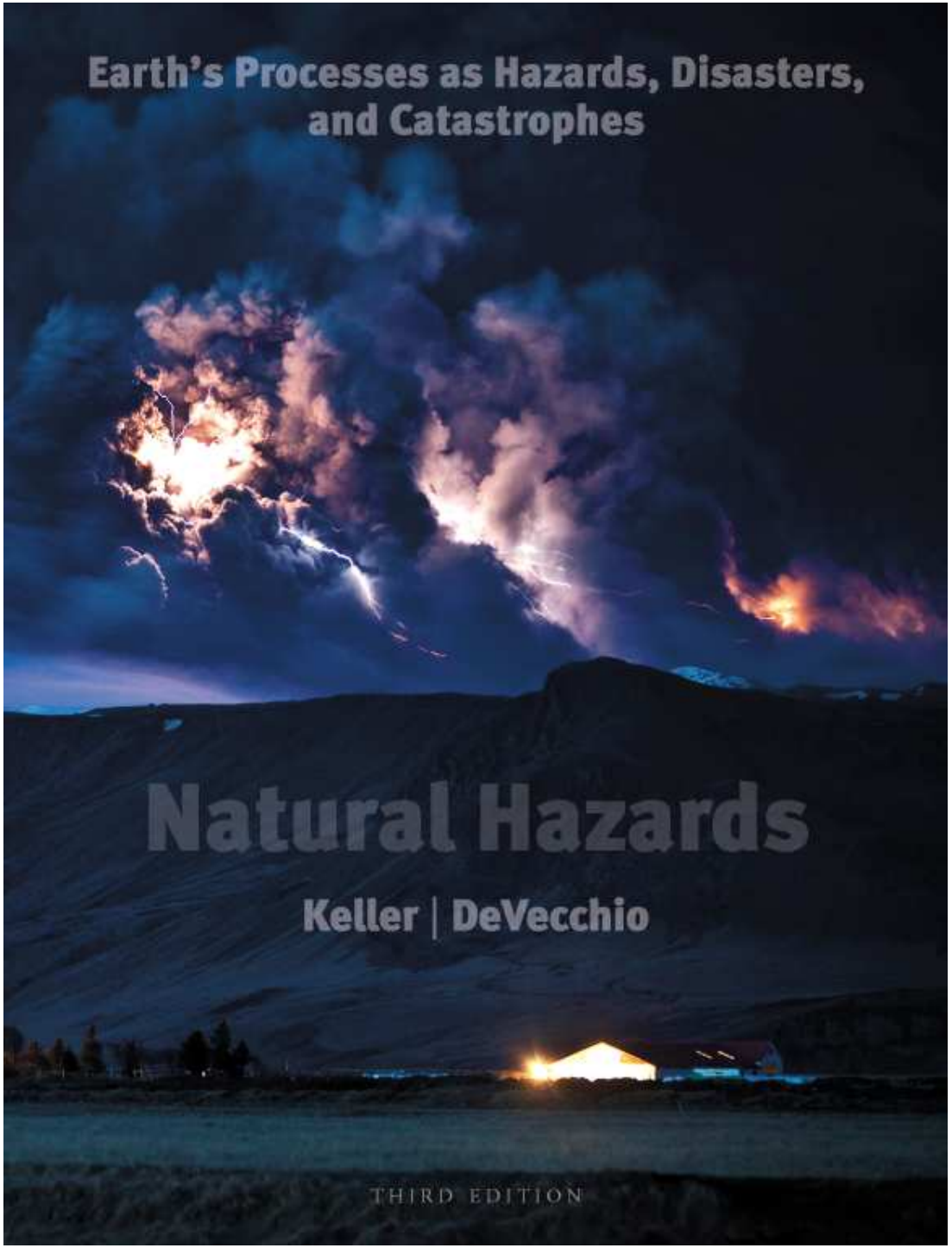

Lecture Presentation

Chapter 12

Climate and Climate Change

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Learning Objectives

- Understand the difference between climate and weather, and how their variability is related to natural hazards

- Know the basic concepts of atmospheric science such as structure, composition, and dynamics of the atmosphere

- Understand how climate has changed during the last million years, through glacial and interglacial conditions, and how human activity is altering our current climate

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Learning Objectives, cont.

- Understand the potential causes of climate change
- Know how climate change is related to natural hazards
- Know the ways we may mitigate climate change and associated hazards

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Global Change and Earth System Science: An Overview

- Earth system science
  - Study of how systems are linked to affect life on Earth
    - The atmosphere
    - The oceans
    - The land
    - The biosphere

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Climate and Weather

- Weather refers to atmospheric conditions over short periods of time
- Climate refers to characteristic atmospheric conditions over a long period of time
  - Average temperatures and precipitation
- Climate zones
  - Defined using **Köppen System**
    - Uses monthly average temperature and precipitation associated with different types of vegetation

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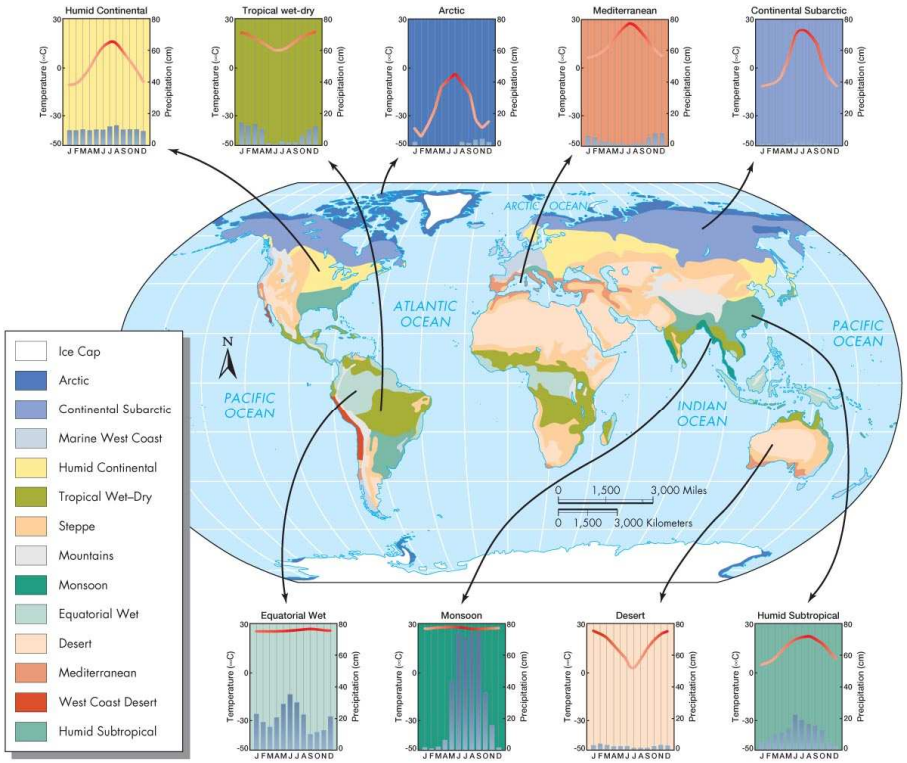

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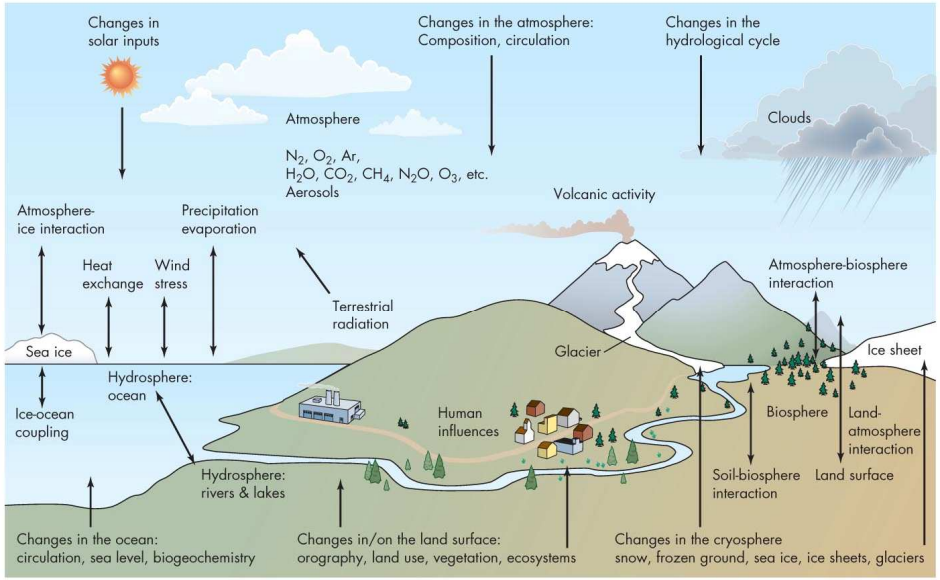

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Figure 12.1

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Earth's Climate System and Natural Processes

- Many hazards and climate are linked
  - Flooding is related to rainfall amount and intensity
  - Landslides are linked to rainy climates
- Wildfires are linked to dry areas
- Knowing the climate can indicate things about the hazards to expect

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The Atmosphere

- Permanent gasses
  - Gasses whose proportions stay constant
  - Nitrogen and oxygen
  - Have little effect atmospherically
- Variable gasses
  - Gasses whose proportions vary with time and space
  - Play important roles in atmospheric dynamics
  - Carbon dioxide, water vapor, ozone, methane, nitrous oxide, and halocarbons.
- Aerosols
  - Particles whose proportions vary with time and space

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TABLE 12.1

Composition of the Atmosphere

Permanent Gases		Variable Gases	
Nitrogen	78.08%	Water Vapor	0.2–4%
Oxygen	20.95%	Carbon Dioxide	0.038%
Argon	0.93%	Methane	0.00017%
Neon	0.0018%	Nitrous Oxides	0.000032%
Helium	0.00052%	Ozone	0.000004%
Krypton	0.00011%	Halocarbons	0.00000002%
Xenon	0.00009%		
Hydrogen	0.00005%		

Percentage by volume. Data in part from Bryant, E. 1997. **Climate process & change.** *New York: Cambridge University Press.*

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Table 12.1

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Glaciations

- Cryosphere
  - The part of the hydrosphere where water stays frozen year-round
  - Permafrost, sea ice, ice caps, glaciers, and ice sheets

- Glaciers flow from high areas to low areas under the weight of accumulated ice
  - Have budgets with inputs and outputs
    - New snow forms ice at high elevations
    - Ice melts, evaporates, and breaks off at lower elevations
    - Glaciers retreat and advance

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Glaciations, cont.

- Glacial intervals
  - Periods with major continental glaciations
- Interglacial intervals
  - Warmer periods with less glaciations
- Multiple advances and retreats of glaciers
  - Rare during Earth's 4.6 billion year history
  - Several in the last 1 billion years
  - We are now living during one of those events that began 2.5 million years ago

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Pleistocene Epoch

- The last series of glacial and interglacial periods
- Multiple ice ages
- Glaciers covered 30 percent of earth (today 10 percent)
- Maximum extent 21,000 years ago
- Global sea level >100 m (330 ft.) lower than today

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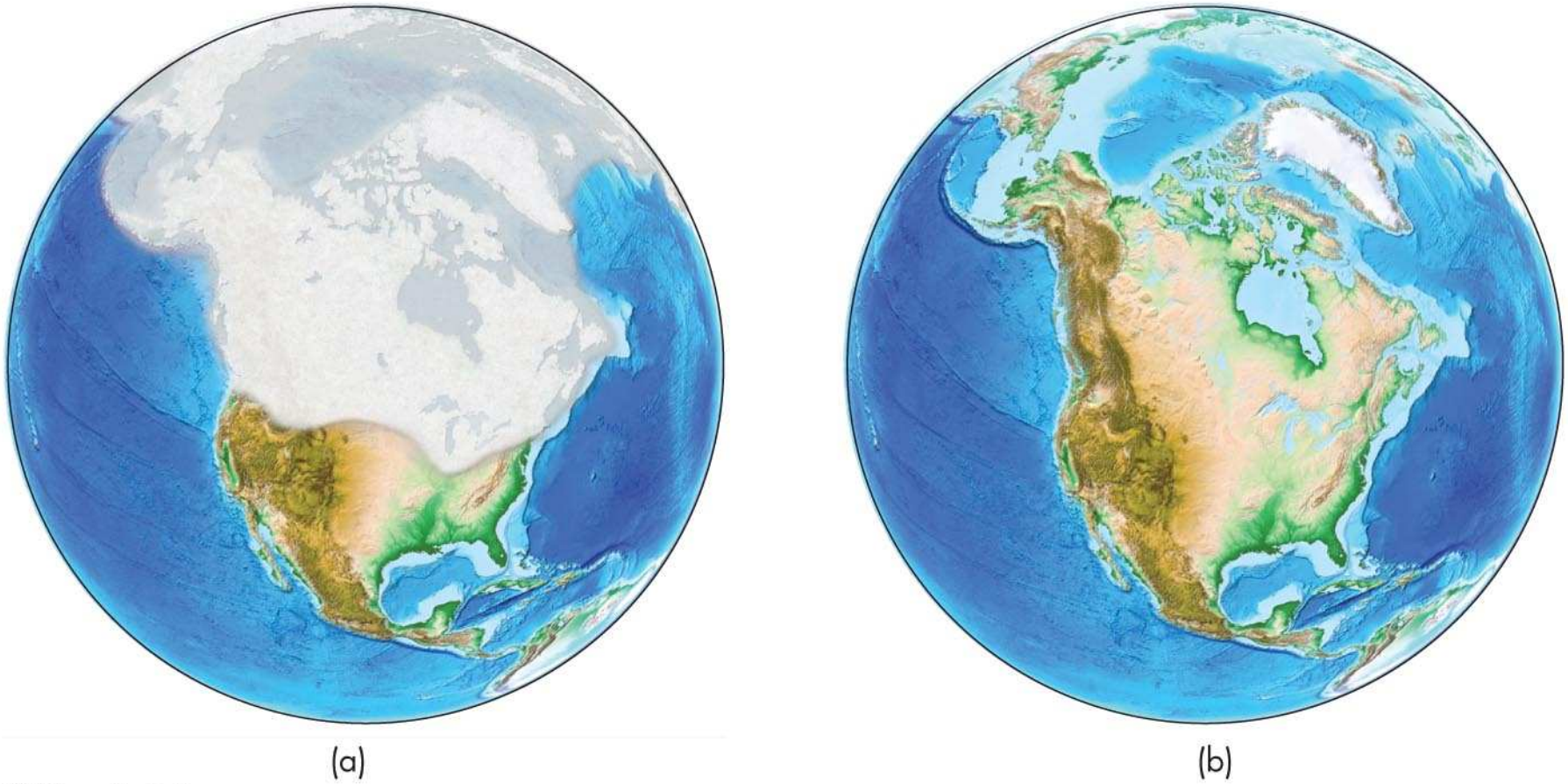

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Figure 12.2

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Glacial Hazards

- Glacier movement and melting have been responsible for property damage, injuries, and deaths

- Hazards include:
  - People can fall into deep crevasses
  - Glacial Ice can fall from above
  - Can expand to overrun villages, etc
  - Produce an ice jam to cause flooding
  - Blocks of ice may fall off in avalanches
  - Calving produces icebergs in ocean

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How We Study Past Climate Change and Make Predictions

- Instrumental Record
  - Measurements of temperature made directly since 1860
  - Carbon dioxide measurements from 1960
  - Solar energy is from past several decades
- Historical Record
  - Includes written recollections (books, newspapers, journal articles, personal journals, etc.)
- Paleo-Proxy Record
  - Proxy data can be correlated with climate
  - Data are not a direct measurement of temperature
  - Provide the best evidence that predates the historical and instrumental records

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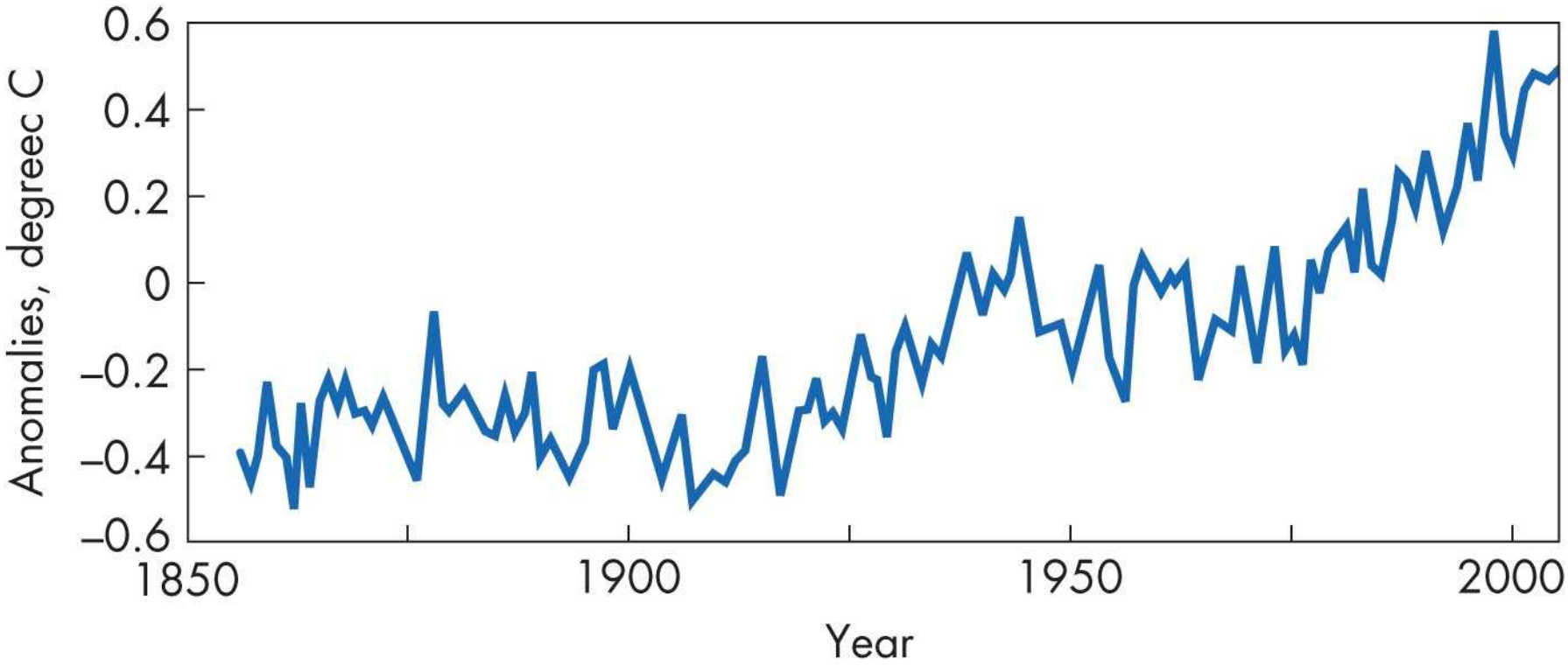

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Paleo-Proxy Data Sources

- Tree rings: Growth of trees depends on rainfall and temperature variability
  - Dendroclimatology: climate data provided by tree rings
  - Extends back more than 10,000 years
- Sediments: Are recovered by drilling into ocean or lake
  - Chemicals are interpreted to provide data on climate change
- Ice cores: Are obtained by drilling into the ice
  - Often contain small bubbles of air deposited at the time of the snow
  - Composition and ratio of past atmospheric gases are studied
  - Ice is studied to determine the composition of the water,
    - Provides information about the volume of ice on the land and about processes occurring in the paleo-oceans.

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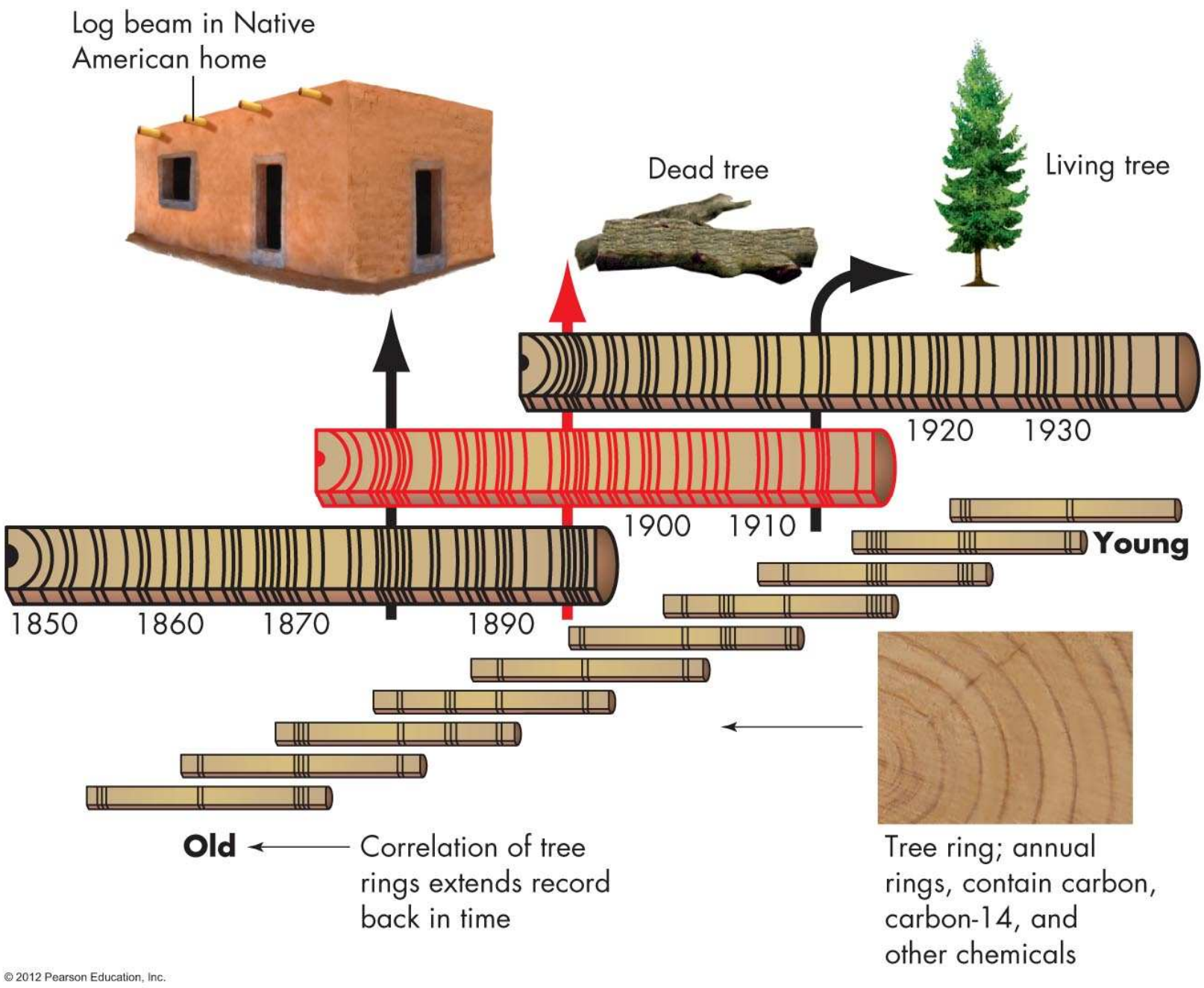

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Paleo-Proxy Data Sources, cont.

- Pollen: Collects in environments
  - Types of pollens found reflect climate
  - Can also be preserved in sedimentary layers to form a chronology
- Corals: Calcium carbonate in corals contains isotopes of oxygen and trace metals that can be analyzed for temperature
- Carbon-14: Can give information about solar activity (sunspot activity)
  - Can be found in tree ring data
  - Can explain some of the warming during the Medieval Warming Period and cooling during Little Ice Age, cannot explain current warming
- Carbon dioxide: Most important proxy for temperature change
  - Data come from instrumental record and ice core samples

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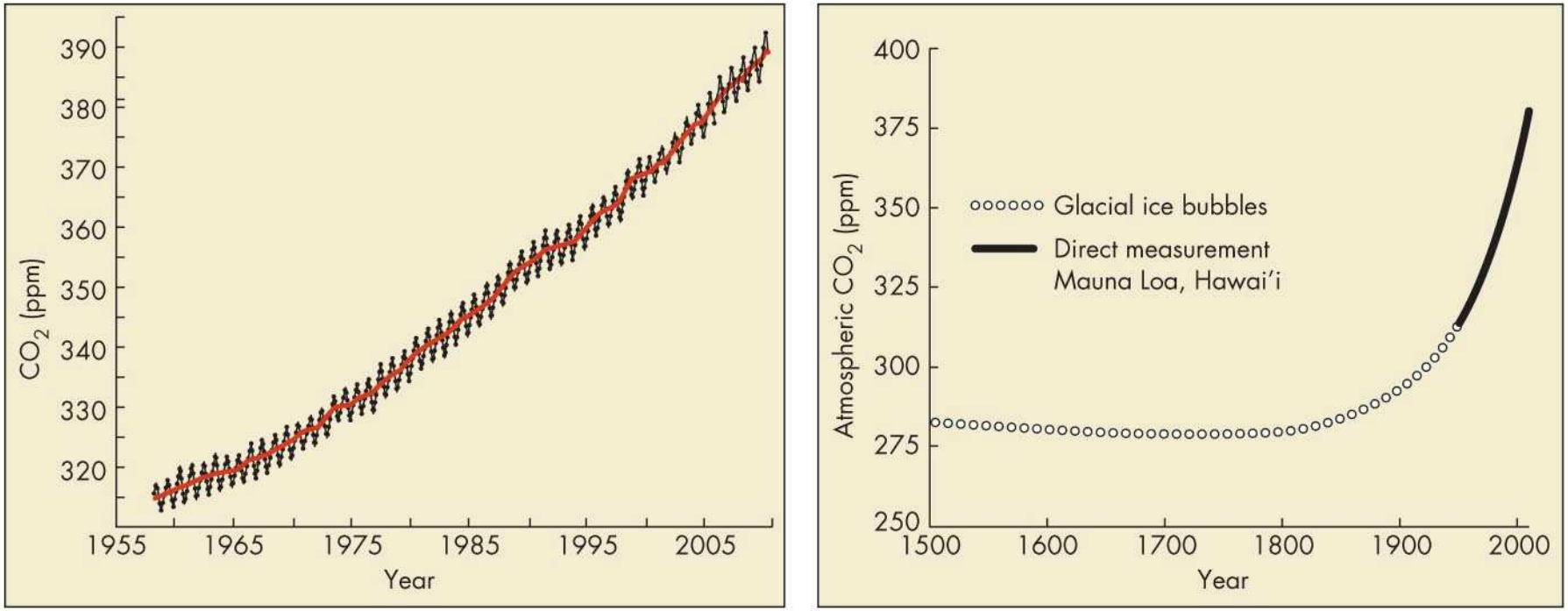

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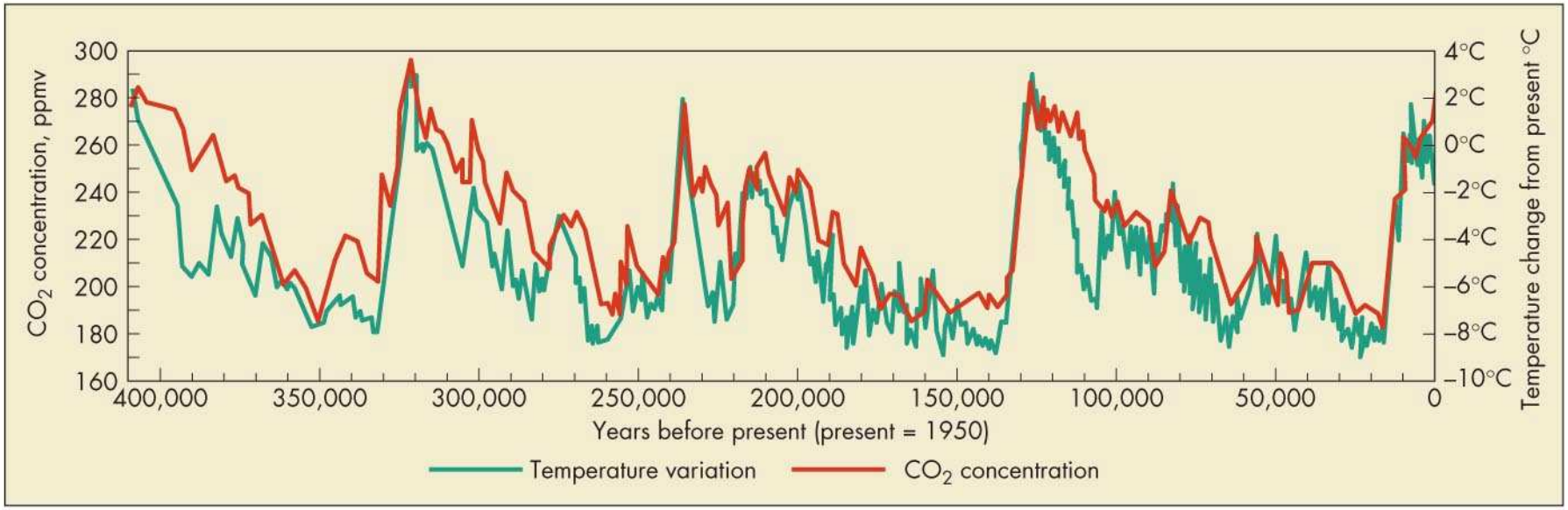

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Global Climate Models

- Mathematical Models used to describe natural events
- General Circulation Model: Used to forecast weather
  - Framework is a large stack of boxes which are 3-dimensional cells
  - Each cell varies in height, models use 6 to 20 layers of cells
  - Data are arranged into each of the cells and mathematical equations are used to describe the atmospheric processes that interact between the cells
- Global Climate Models: Similar to above to describe climate
  - Models are run backwards to describe historic climate changes
  - Are reasonably consistent with global temperature change from 1900 to the present
  - Models do not produce data, use mathematical equations linked to data

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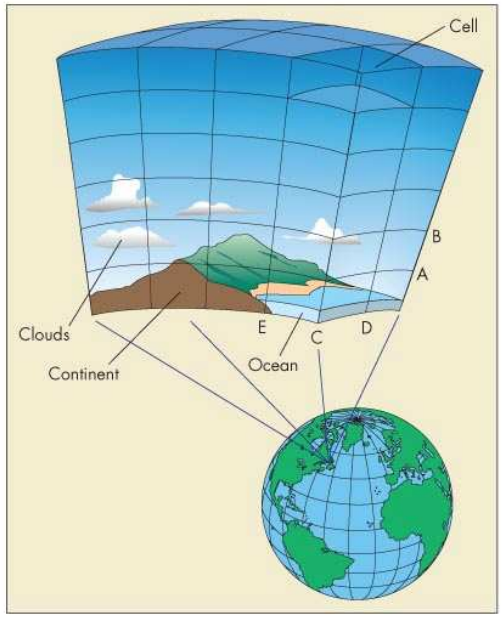

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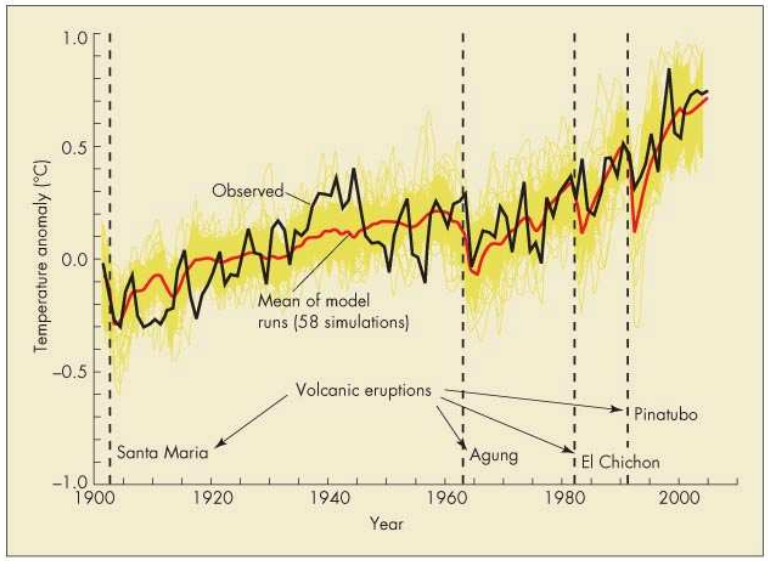

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Global Warming

- Observed increase in average temperature of land and ocean during the last 50 years
- Probably resulting from burning of fossil fuels
- Both human and natural processes are contributing to warming

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The Greenhouse Effect

- Earth's temperature depends on:
  - Amount of sunlight received
  - Amount of sunlight reflected
  - Amount of reradiated heat that is retained
- Earth's energy balance
  - Currently, more energy is coming from sun that is lost to space
    - 1 Watt/square meter
- Sunlight received is short wave and visible
- Reradiated radiation from Earth is mostly long-wave infrared

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The Greenhouse Effect, cont. 1

- Sun's short-wave radiation is absorbed by Earth and atmosphere
- Earth and atmosphere reradiate infrared radiation into space
- Greenhouse gases – Water vapor carbon dioxide (CO_2), methane (CH_4), and chlorofluorocarbons absorb infrared and are warmed
- Lower atmosphere is much warmer than if all this radiation escaped into space

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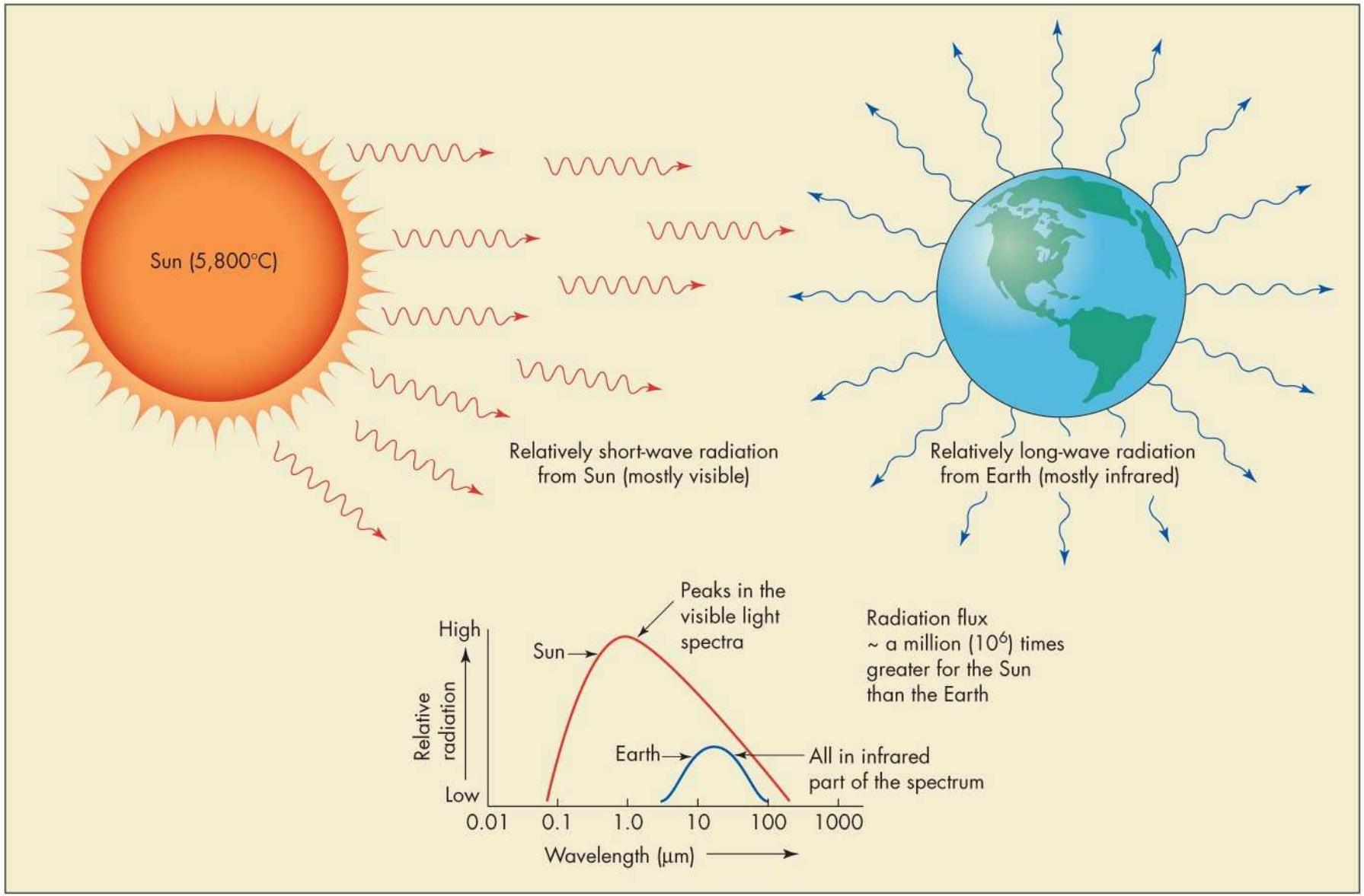

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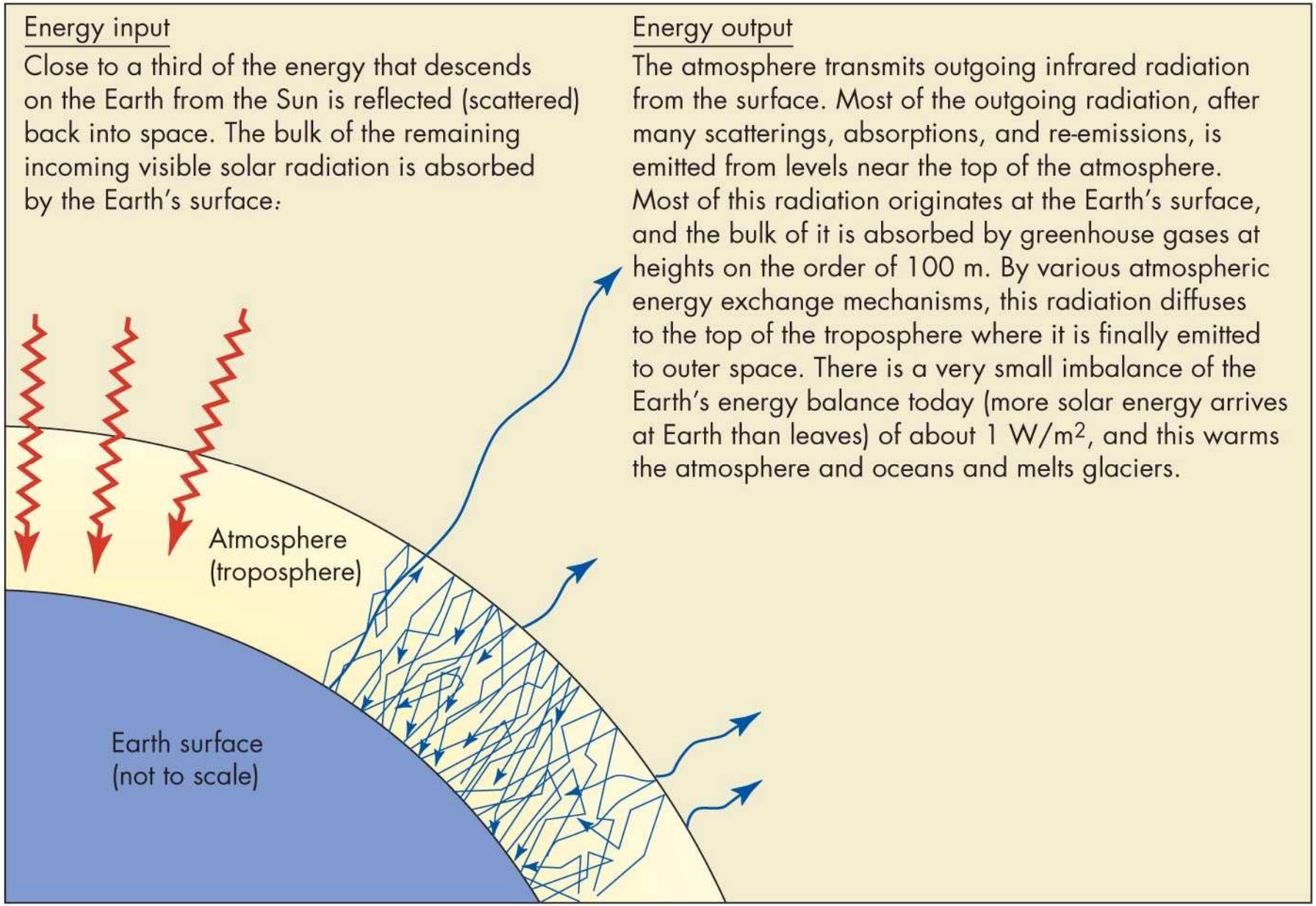

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The Greenhouse Effect, cont. 2

- Greenhouse effect is a natural and necessary process
  - Earth would be 33°colder without it
  - All surface water would be frozen
  - Little life would exist
- Most of the natural effect is from water vapor
- Human activities have increased amounts of greenhouse gasses
  - Antropogenic (human caused) component of warming

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Carbon Dioxide and the Greenhouse Effect

- Carbon dioxide accounts for most of the anthropogenic greenhouse effect
- In past concentrations have varied between 200 ppm to about 300 ppm
- The concentration of carbon dioxide today is 390 ppm, and it is predicted to reach at least 450 ppm by the year 2050

TABLE 12.2

Rate of Increase and Relative Contribution of Several Gases to the Anthropogenic Greenhouse Effect

	Rate of Increase (% per year)	Relative Contribution (%)
CO_2	0.5	60
CH_4	<1	15
N_2O	0.2	5
O_3[a]	0.5	8
CFC-11[b]	4	4
CFC-12[b]	4	8

[a] In the troposphere.

[b] CFC—chlorofluorocarbon (human made chemical)

Source: Data from Rodhe, H. 1990. A comparison of the contribution of various gases to the greenhouse effect. Science *248:1218, table 2. Copyright 1990 by the AAAS.*

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Table 12.2

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Global Temperature Change—Last 800,000 Years

- Low temperatures coincide with major continental glaciations, High temperatures with interglacial periods

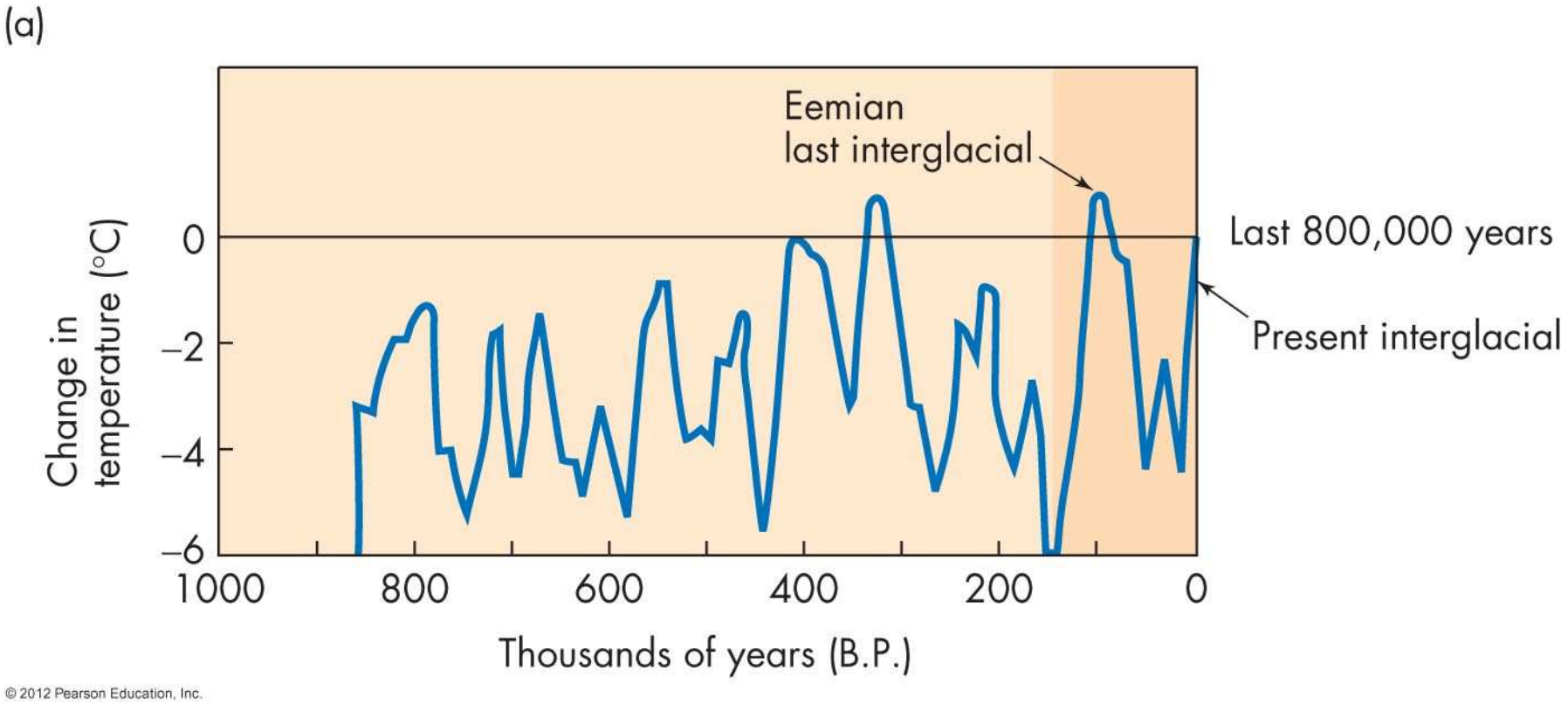

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Figure 12.13a

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Global Temperature Change—Last 150,000 Years

- Last major interglacial period, Eemian, sea level was 4–6 feet higher than today

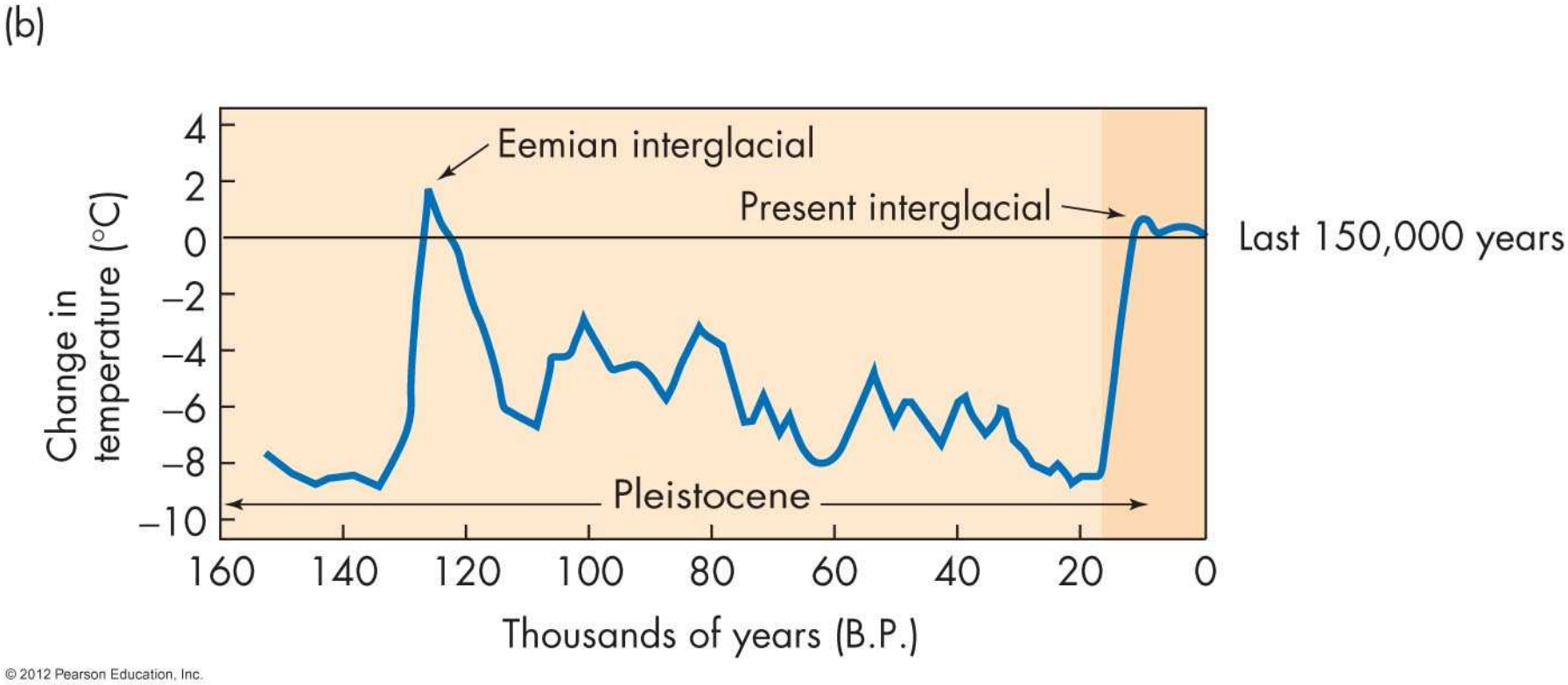

Figure 12.13b

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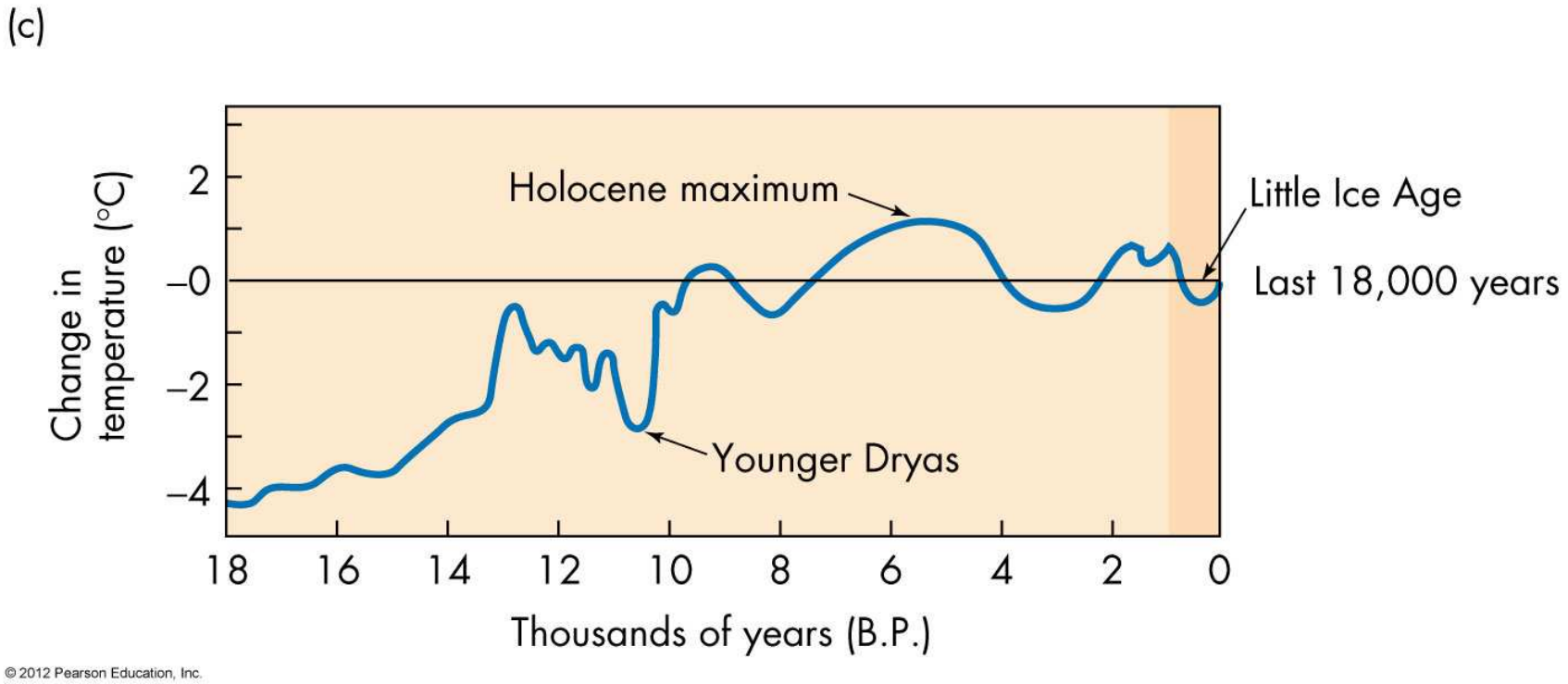
Global Temperature Change—Last 18,000 Years

- Cold interval, Younger Dryas, occurred 11,500 years ago, followed by warming to Holocene maximum
- Recent cooling, called Little Ice Age, 15th–19th centuries



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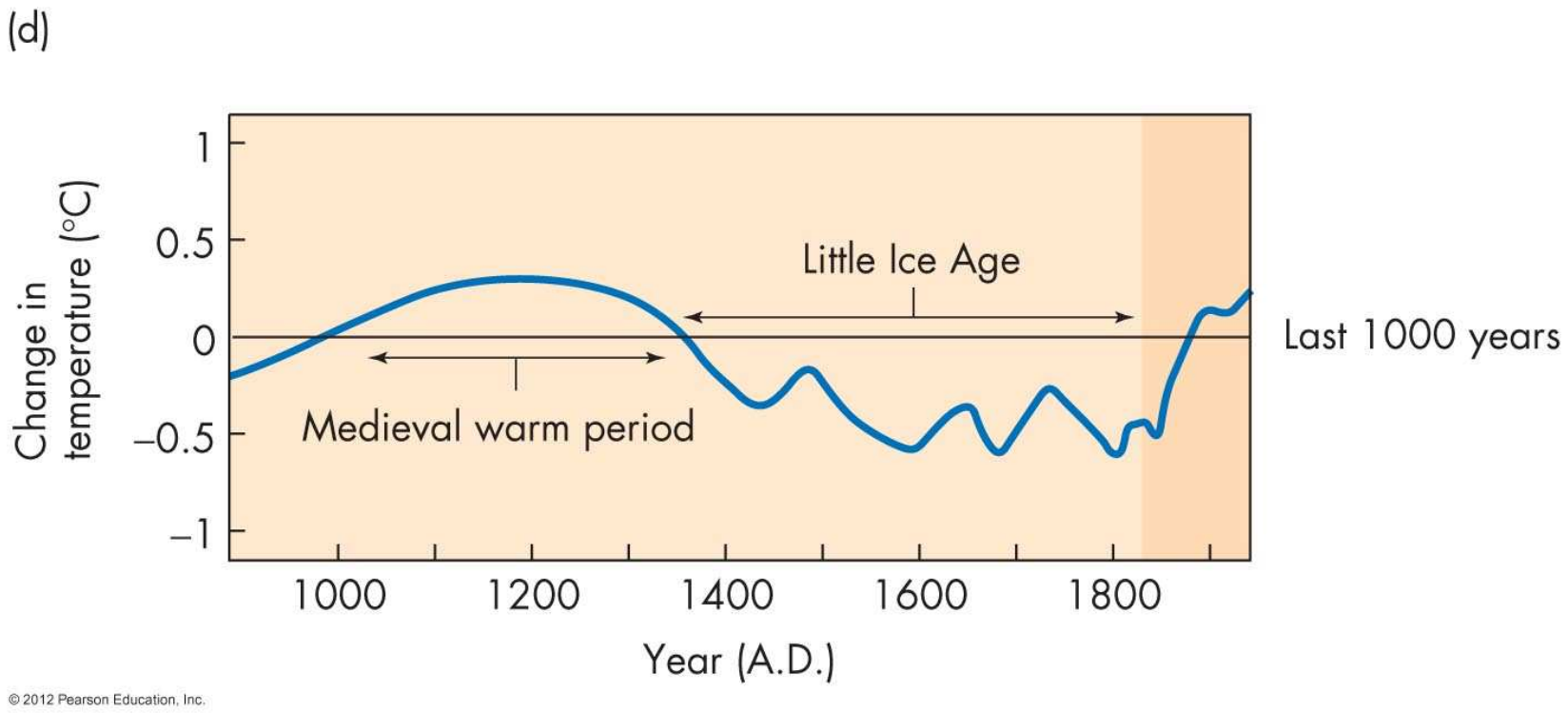
Global Temperature Change—Last 1000 Years

- Several warming and cooling trends
- Warming in A.D.1100–1300 allowed Vikings into Iceland, Greenland, and North America



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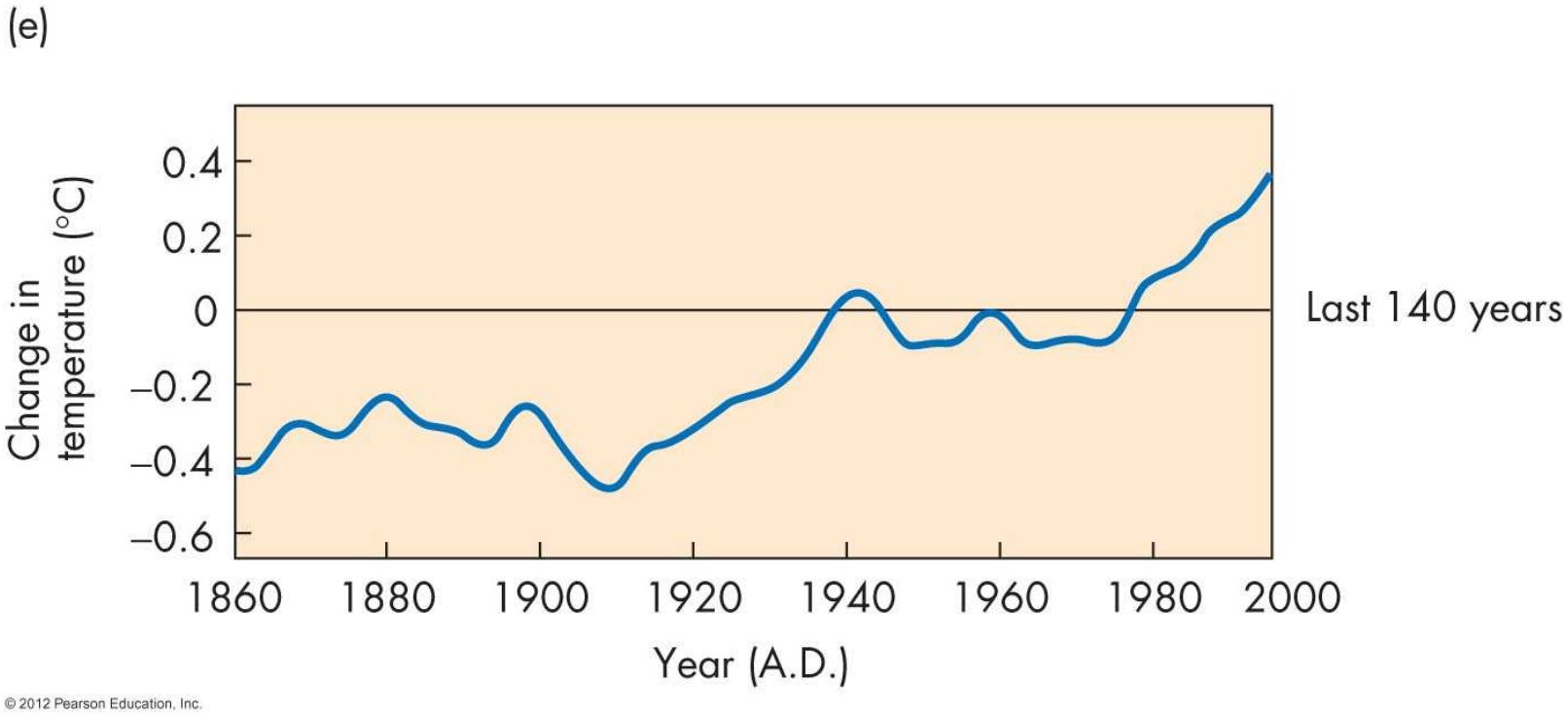
Global Temperature Change—Last 140 Years

- 1750, warming trend begins until 1940s
- 1910 to 1998, global temperatures rise
- Temperatures in past 30 years are warmest since monitoring began



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Why Does Climate Change?

- Milankovitch cycles
  - Natural changes in Earth's orbit, tilt and precession
  - Explain some changes, but not the observed large scale changes
- Climate forcing
  - An imposed change of Earth's energy balance
  - Units are $W/m^{2,}$ positive if it increases temperature or negative if decreased
- Climate sensitivity
  - Response of climate after a new equilibrium has been established
- Climate response time
  - Time required for the response to a forcing to occur

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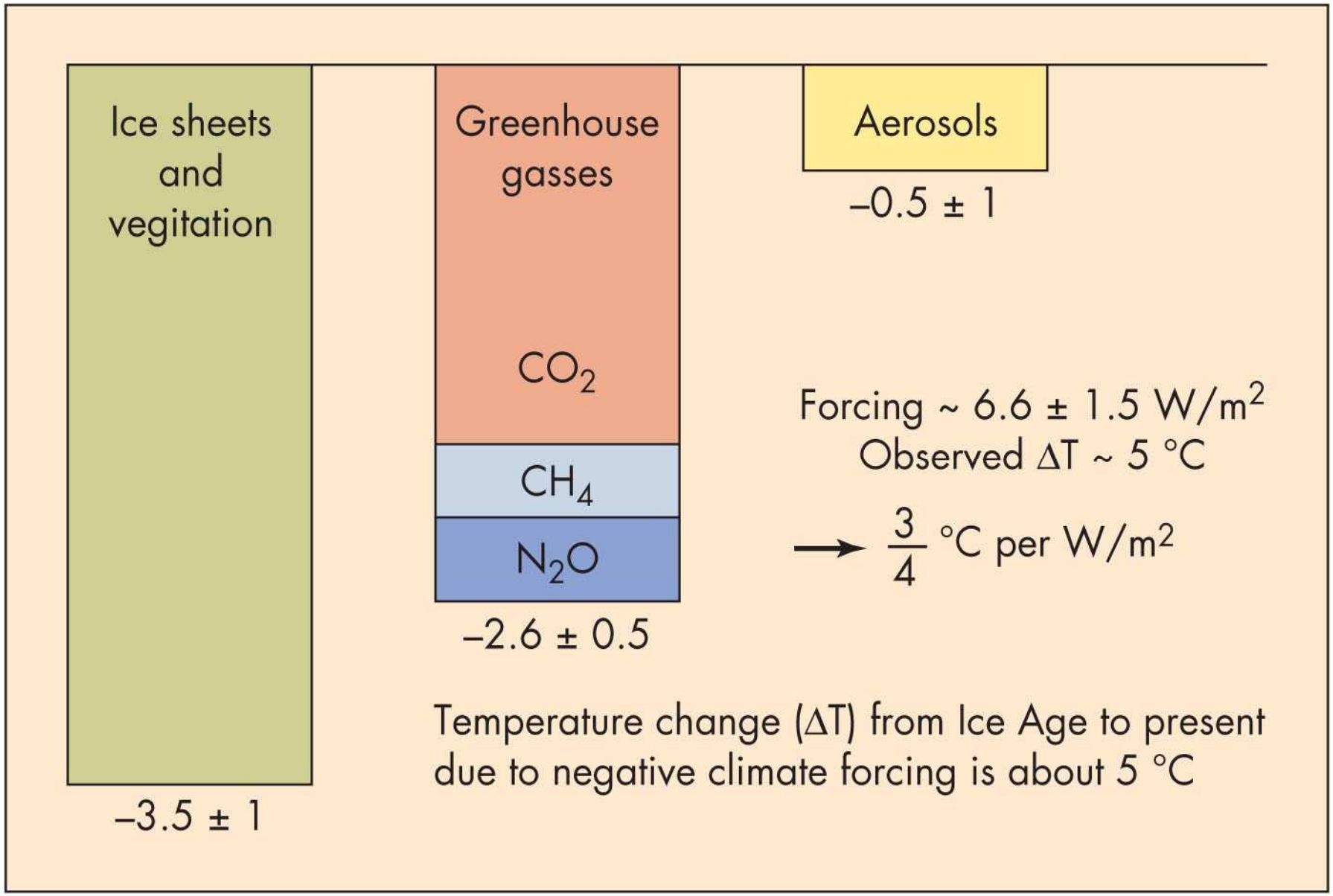

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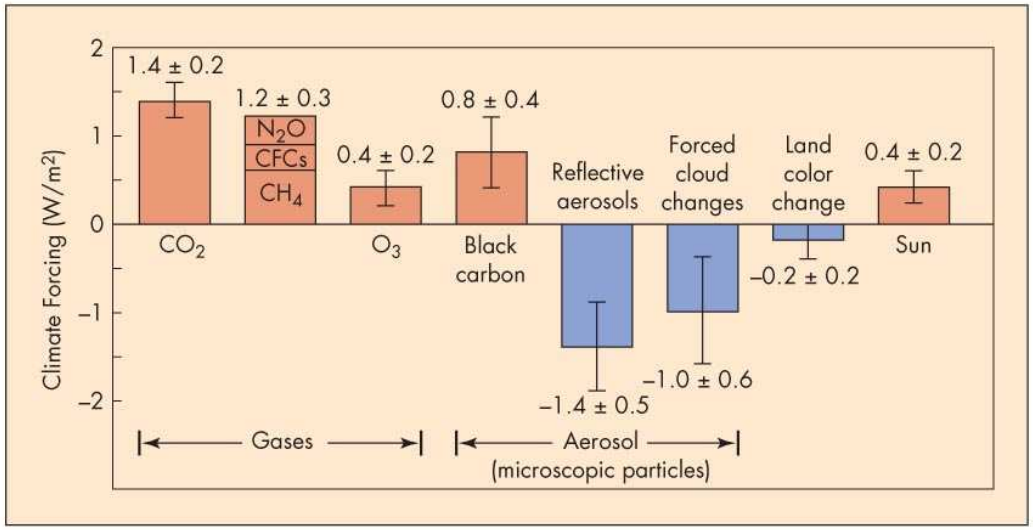

- Increases of greenhouse gases (except O_3) are known from observations and bubbles of air trapped in ice sheets. The increase of CO_2 from 285 parts per million (ppm) in 1850 to 368 ppm in 2000 is accurate to about 5 ppm. The conversion of this gas change to a climate forcing (1.4 W/m^2), from calculation of the infrared opacity, adds about 10% to the uncertainty.

- Increase of CH_4 since 1850, including its effect on stratospheric H_2O and tropospheric O_3, causes a climate forcing about half as large as that by CO_2. Main sources of CH_4 include landfills, coal mining, leaky natural gas lines, increasing ruminant (cow) population, rice cultivation, and waste management. Growth rate of CH_4 has slowed in recent years.

- Tropospheric O_3 is increasing. The U.S. and Europe have reduced O_3 precursor emissions (hydrocarbons) in recent years, but increased emissions are occurring in the developing world.

- Black carbon ("soot"), a product of incomplete combustion, is visible in the exhaust of diesel-fueled trucks. It is also produced by biofuels and outdoor biomass burning. Black carbon aerosols are not well measured, and their climate forcing is estimated from measurements of total aerosol absorption. The forcing includes the effect of soot in reducing the reflectance of snow and ice.

- Human-made reflective aerosols include sulfates, nitrates, organic carbon, and soil dust. Sources include burning fossil fuel and agricultural activities. Uncertainty in the forcing by reflective aerosols is at least 35%.

- Indirect effects of aerosols on cloud properties are difficult to compute, but satellite measurements of the correlation of aerosol and cloud properties are consistent with the estimated net forcing of −1 W/m^2, with uncertainty of at least 50%.

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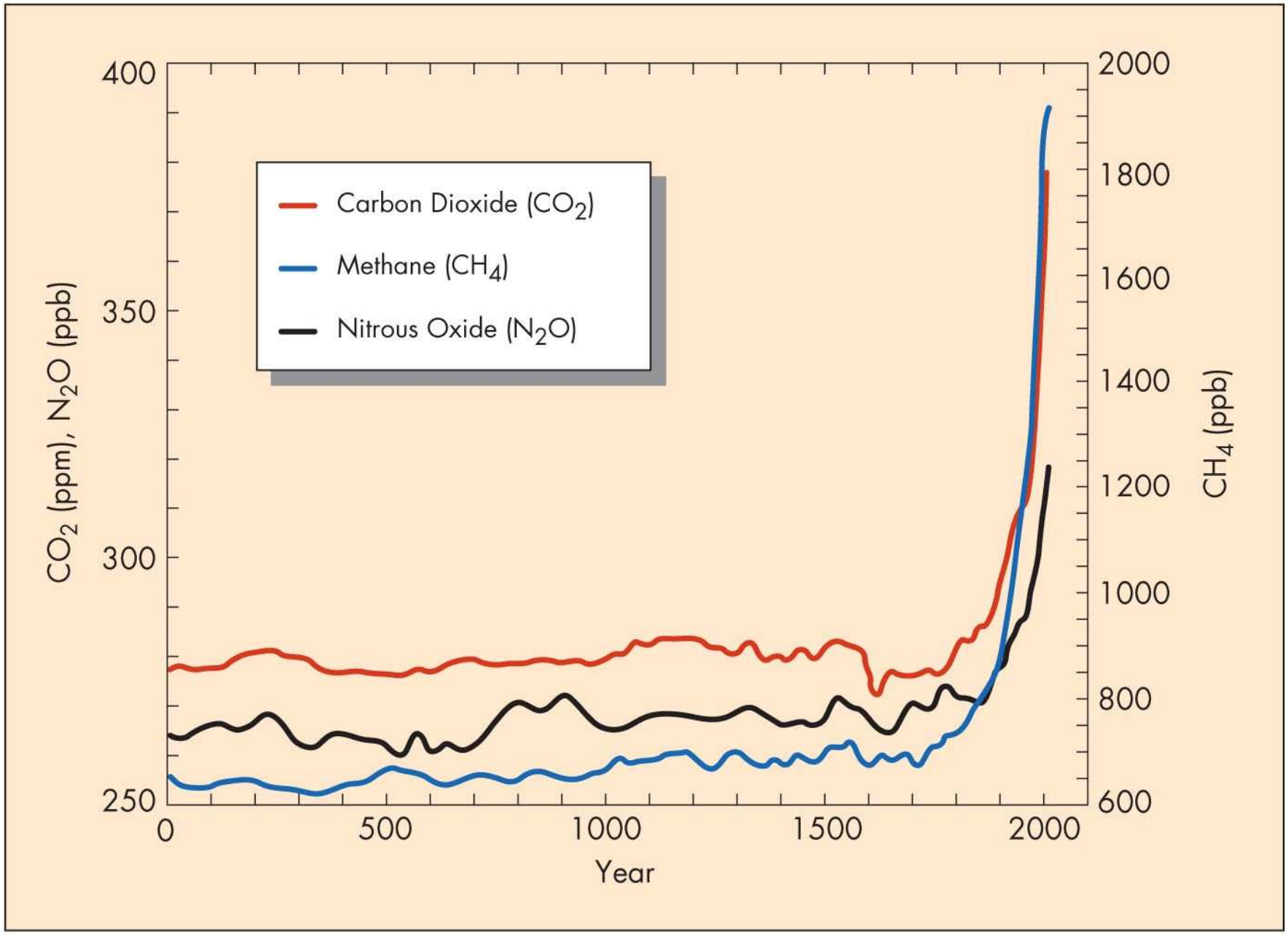

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Ocean Conveyor Belt—Atlantic Ocean

- Ocean Conveyor Belt
  - Circulation of ocean water in oceans
  - Can cause fast changes in climate

- In Atlantic Ocean
  - Strong northward movement of near-surface waters are cooled when they arrive near Greenland
  - The water cools, becomes saltier and denser, and it sinks to the bottom
  - Current then flows southward around Africa
  - Huge amounts of warm water keep Europe warmer than it would be otherwise

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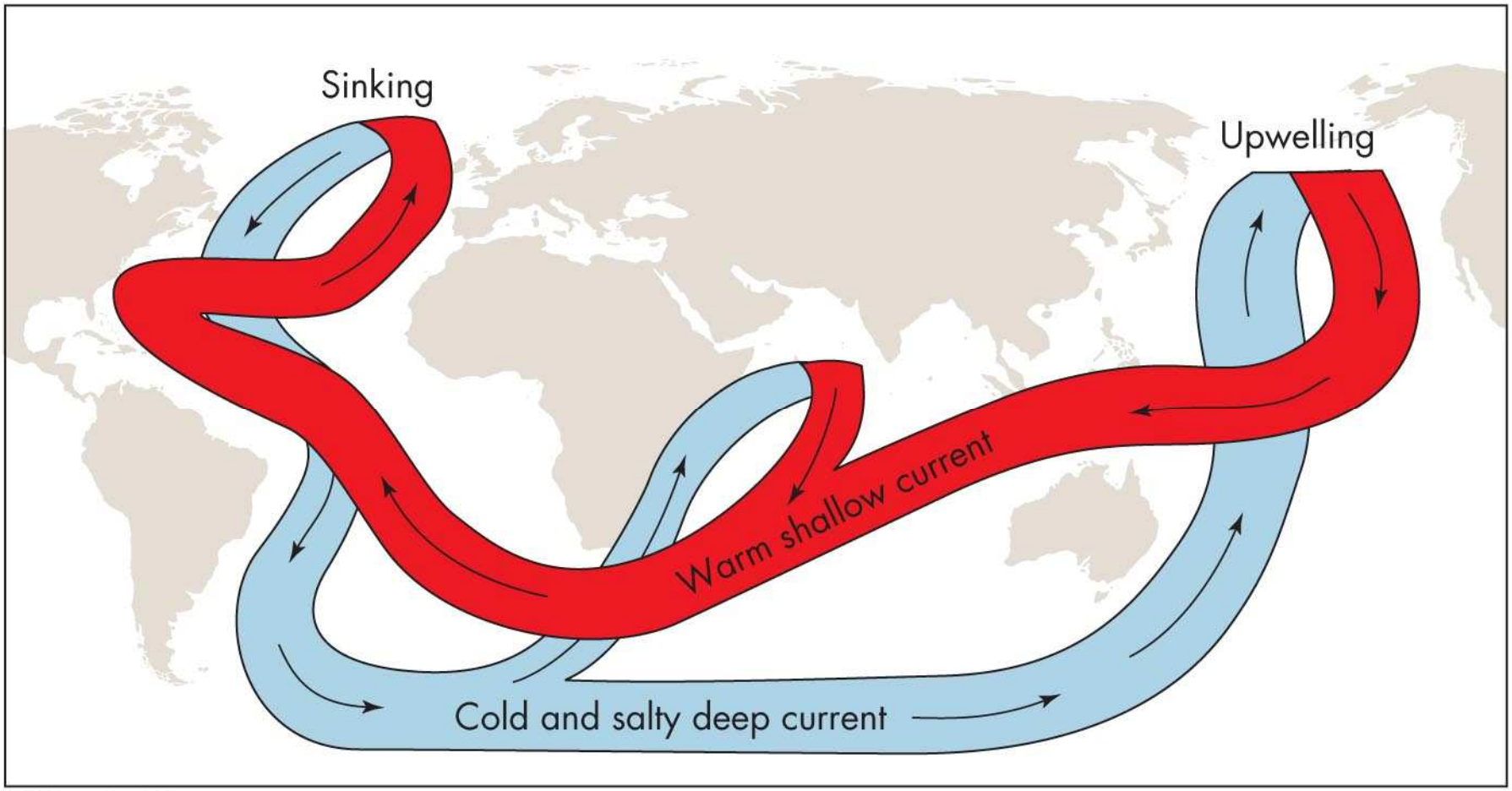

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Climate Change, Review

- Scientific uncertainties exist, but there is sufficient evidence to state:
  1. There is discernable human influence on global climate
  2. Warming is now occurring
  3. Mean surface temperature of Earth will likely increase between 1.5° and 4.5°C (2.6° to 7.8°F) during this ce ntury

- Human-induced global warming from increased emissions of greenhouse gases
  - Increases in gases relate to an increase in mean global temperature of Earth
  - There has been a strong correlation between the concentration of atmospheric CO^2 and global temperatures

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Solar Forcing

- There is a relationship between changes in solar energy and climate change
- Medieval Warm Period (A.D. 1000–1300) corresponds to increased solar radiation
- Little Ice Age corresponds to decreased solar radiation
- Partially explains climate change, but effect is very small

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Volcanic Forcing

- Ash from eruptions becomes suspended in the atmosphere, reflects sunlight having a cooling effect
- Mount Tambora, 1815 eruption contributed to cooling in North America and Europe
- Mount Pinatubo in 1991 counterbalanced global warming during 1991 and 1992
- Volcanic forcing is believed to have contributed to the cooling of the Little Ice Age

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Anthropogenic Forcing

- Evidence of anthropogenic climate forcing, resulting in a warmer world, is based, in part, on the following:
  - Recent warming of 0.2°C (0.4°F) per decade cannot b e explained by natural variability of the climate over recent geologic history
  - Industrial age forcing of 1.6 W/m^2 is mostly due to emissions of carbon dioxide
  - Climate models suggest that natural forcings cannot be responsible for a nearly 1°C (1.8°F) rise in global land temperature. When natural and anthropogenic forcing are combined, the observed changes can be explained.
- Human processes are also causing a slight cooling called global dimming

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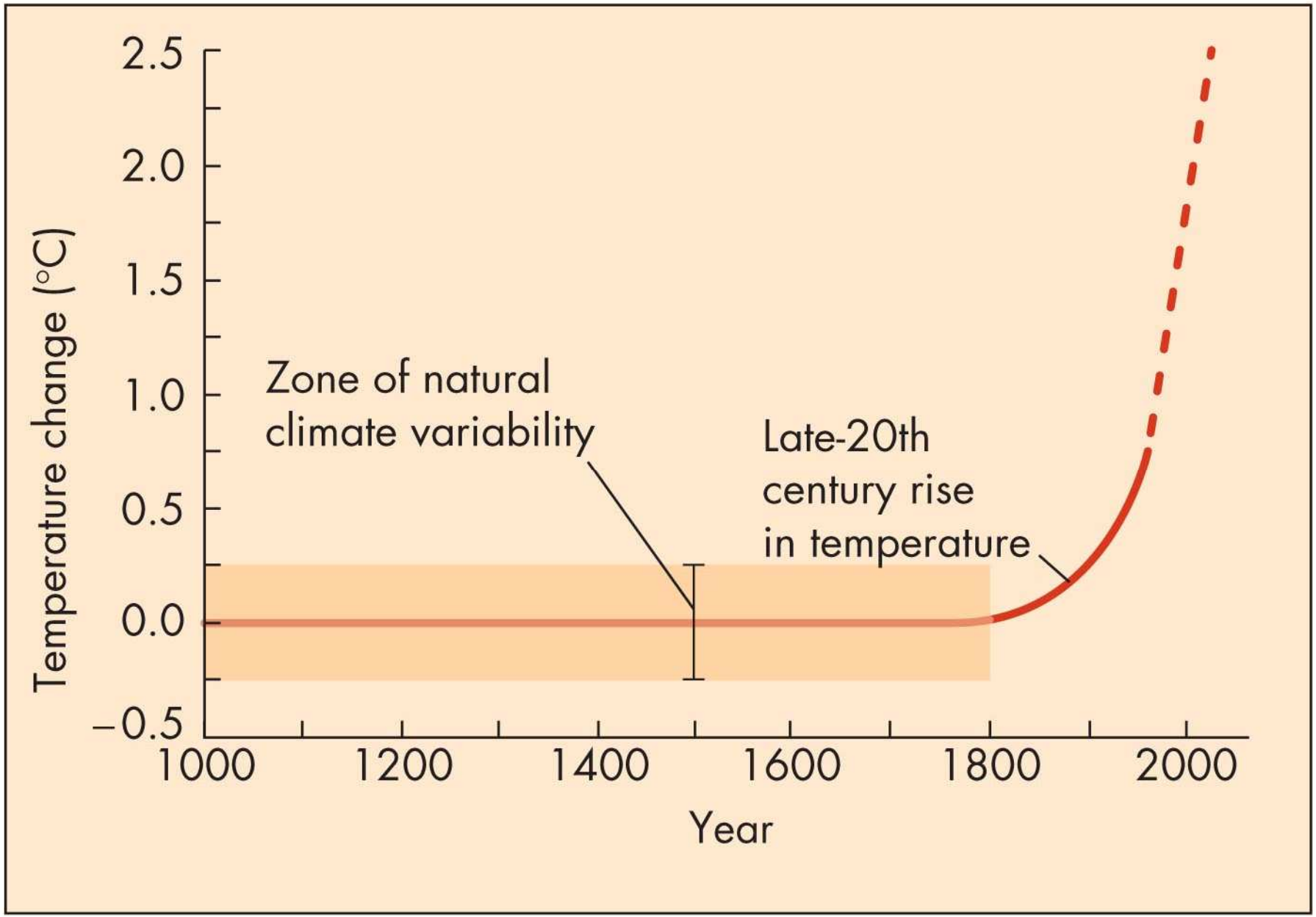

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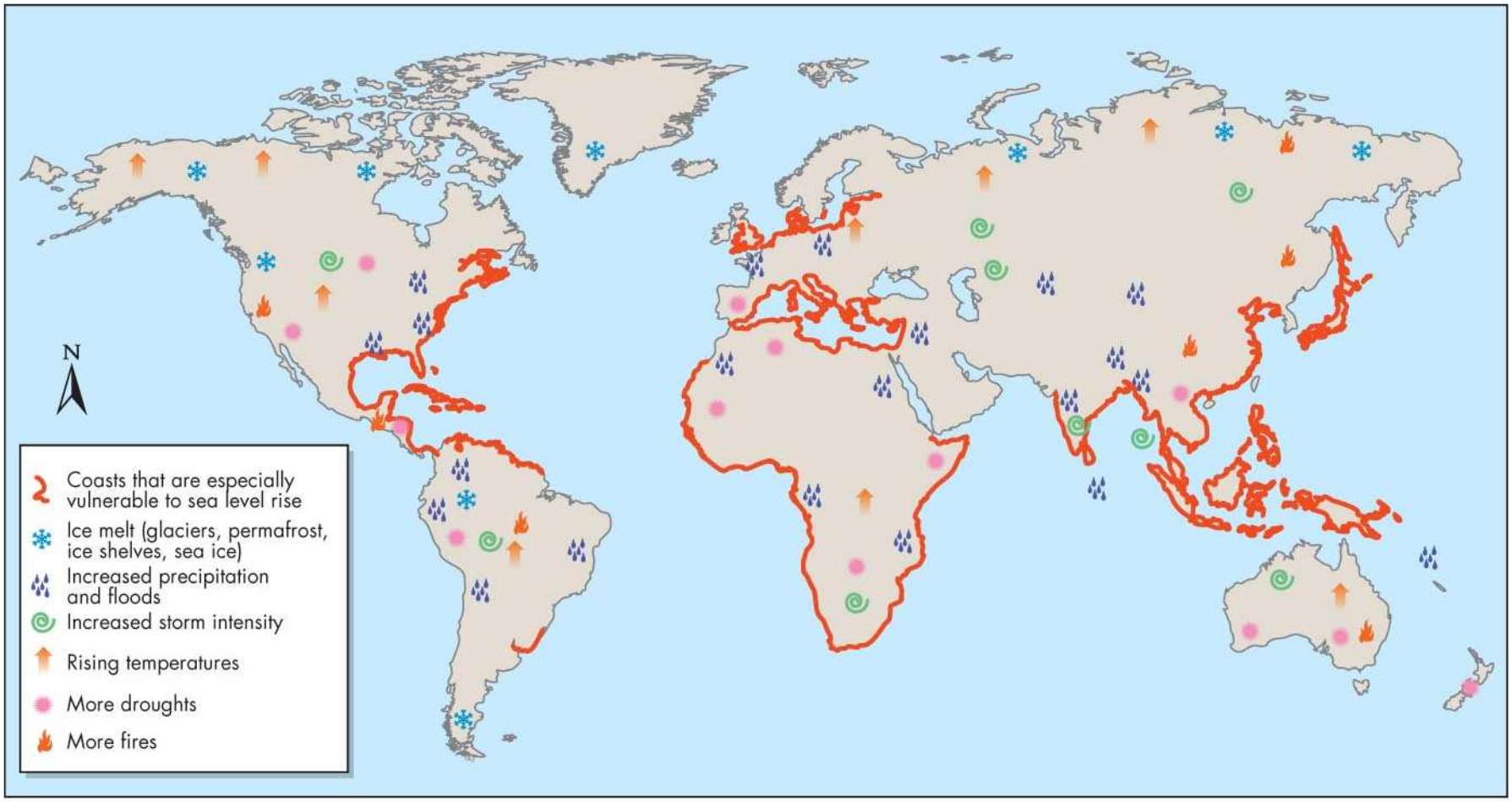

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Glaciers and Sea Ice

- Decreased Arctic ice cap, ice sheets, and glaciers
  - Affects communities dependent on snowmelt for water supply
- Positive feedback cycle
  - Snow and ice reflects radiation, keeping temperatures low
  - Melting exposes darker ground, absorbs radiation increasing temperature increases

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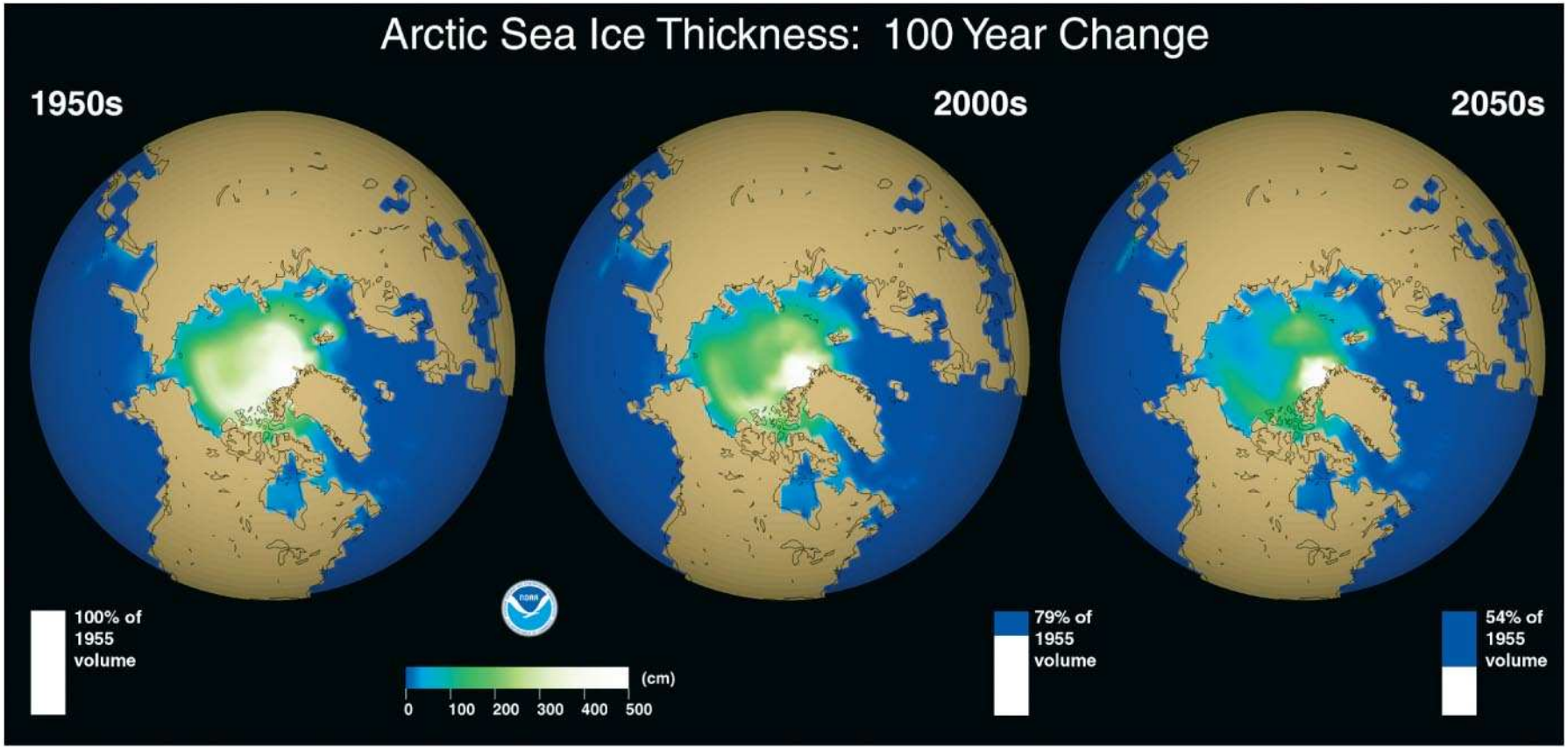

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Climate Patterns

- Warming may increase frequency and intensity of storms
  - Increasing landslides, coastal erosion, etc.
- El Nino
  - Natural climatic event that changes climate patterns
    - Involves high surface temperatures in the eastern equatorial Pacific Ocean and droughts and high-intensity rainstorms in various places on Earth
  - Oscillations like this influence climate more than human-caused global change.
- May change climate important to agriculture
  - Rainfall patterns, soil moisture, etc.
  - Northern Canada and Eastern Europe may be more productive
  - Lands closer to equator become more arid

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Sea-Level Rise

- Near surface ocean temperatures have increased
  - Warming causes ocean water to expand, raising sea level
- Some conclusions:
  - Thermal expansion and melting glacial ice contribute significantly to the observed sea-level rise since 1961
  - Difference between observed and estimated sea level rise is considerable, suggesting that additional research is needed
  - Rates of thermal expansion and melting glacial ice are accelerating
  - The Greenland ice sheet's contribution to sea-level rise has increased about 4 times in recent decades

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Sea-Level Rise, cont.

- Could cause significant environmental impacts
  - May Increase coastline erosion, making structures more vulnerable to waves
  - May cause a landward migration of existing estuaries, requiring beach maintenance or abandonment of human structures
  - Already a threat to some small islands in the tropical Pacific Ocean
  - Already a threat in Alaska
    - Rapid erosion of coastline
    - Melting, permafrost soils
    - Loss of protective summer sea ice

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Wildfires

- Wildfires are related to climate in complex way
- Warming may lead to more drought and El Niño events
  - Both are related to wildfire events
- Wildfire events will increase due to global warming
  - Both in frequency and intensity

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Changes in Biosphere

- Warming changes ecosystems which may lead to:
  - Risk of regional extinction of species
  - Shifts in the range of plants and animals
    - Mosquitoes are moving to higher elevations
    - Northward movement of butterflies in Europe and birds in U.K.
    - Expansion of subalpine forests in Cascades
    - Sea Ice melting stresses seabirds, walruses, and polar bears
    - Warming in Florida Keys bleaching coral reefs
    - Seawater increasing in acidity, threatening coral animals and algae

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Warming Effects in North America

- Climate change may be accelerating
- Warming is expected to be 2°to 4℃ (3.6°to 7.2℉)
- Precipitation in some regions is projected to be less frequent but more intense
- The temperature of streams and rivers will likely increase
- Wildfires will be more frequent

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Warming Effects in North America, cont.

- Growing seasons will be lengthened, with earlier spring and greater primary productivity
- Rainfall and wind speed from hurricanes and other storms are likely to increase
- Many species will migrate toward higher altitudes
- The oceans are warming and becoming more acidic
  - Some species will experience stress. Most vulnerable will be those that are not mobile, such as some vegetation on land and shellfish in the ocean

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Adaptation of Species to Global Warming

- Plants and animals have shifted their ranges 6 km (3.8 mi.) per decade towards the poles
- Spring is arriving earlier (about 2.3 days per decade)
  - Plants are blooming earlier, frogs are breeding earlier, and migrating birds are arriving earlier
- Tropical pathogens have moved up in latitude and elevation, affecting species that may not be adapted to them
  - Extinctions due to warming may have already taken place

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Predicting the Future Climate

- Can attempt to apply the Principle of Uniformitarianism to climate
  - Problem is that we don't have direct temperature data from time period of interest
- Hadley Meteorological Center in Great Britain is attempting to reconstruct temperature data from mid-nineteenth century
  - Emerging from the data is that warming over the past few decades exceeds that in the past 400 years
- Less confidence in temperature reconstructions from about A.D. 950 to A.D. 1250 (Includes Medieval Warming Period (MWP))
  - Limited data suggest that some specific locations may have been as warm as warm or warmer than today
  - Data available for most specific locations suggest that today is warmer than the MWP

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Strategies for Reducing the Impact of Global Warming

- Two important questions: (1) What changes have occurred? (2) What changes could occur in the future?

- We now know that warming is due in part to increased concentration of greenhouse gases
  - Reduction of gases is a primary strategy

- 1997 United Nations Framework Convention on Climate Change in Kyoto, Japan
  - An international agreement to reduce emissions
  - United States has not honored the agreement
  - European Union has become a leader on climate change issues

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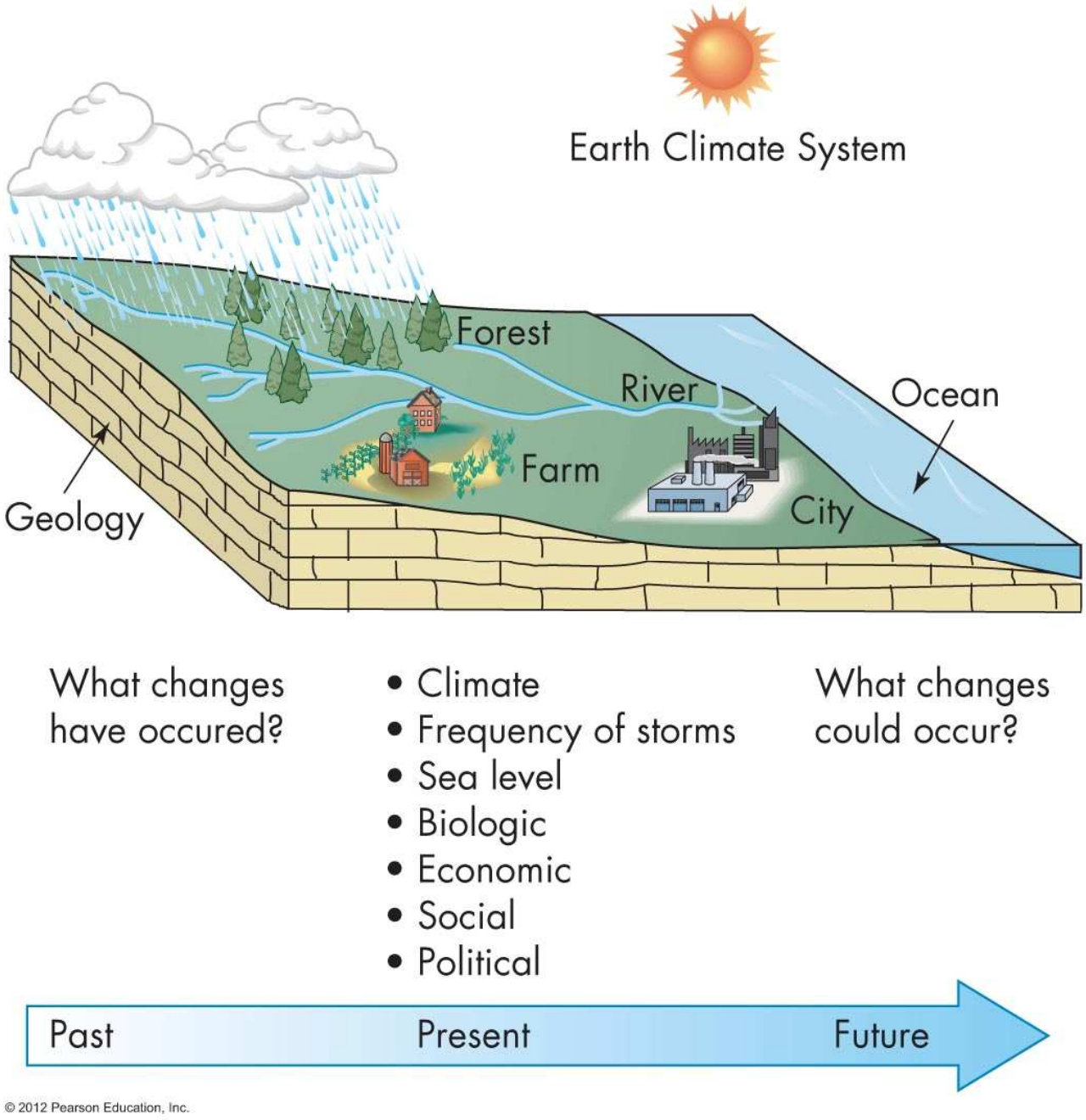

Figure 12.27

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Strategies, cont.

- If temperature increase is on the low side, we can adapt; if it is on the high side, then consequences will be more severe
- One way to estimate is to examine the geologic record for past change
  - These estimates suggest that upper estimates are not improbable
- It will take time for the climate to stabilize when emissions are scaled back

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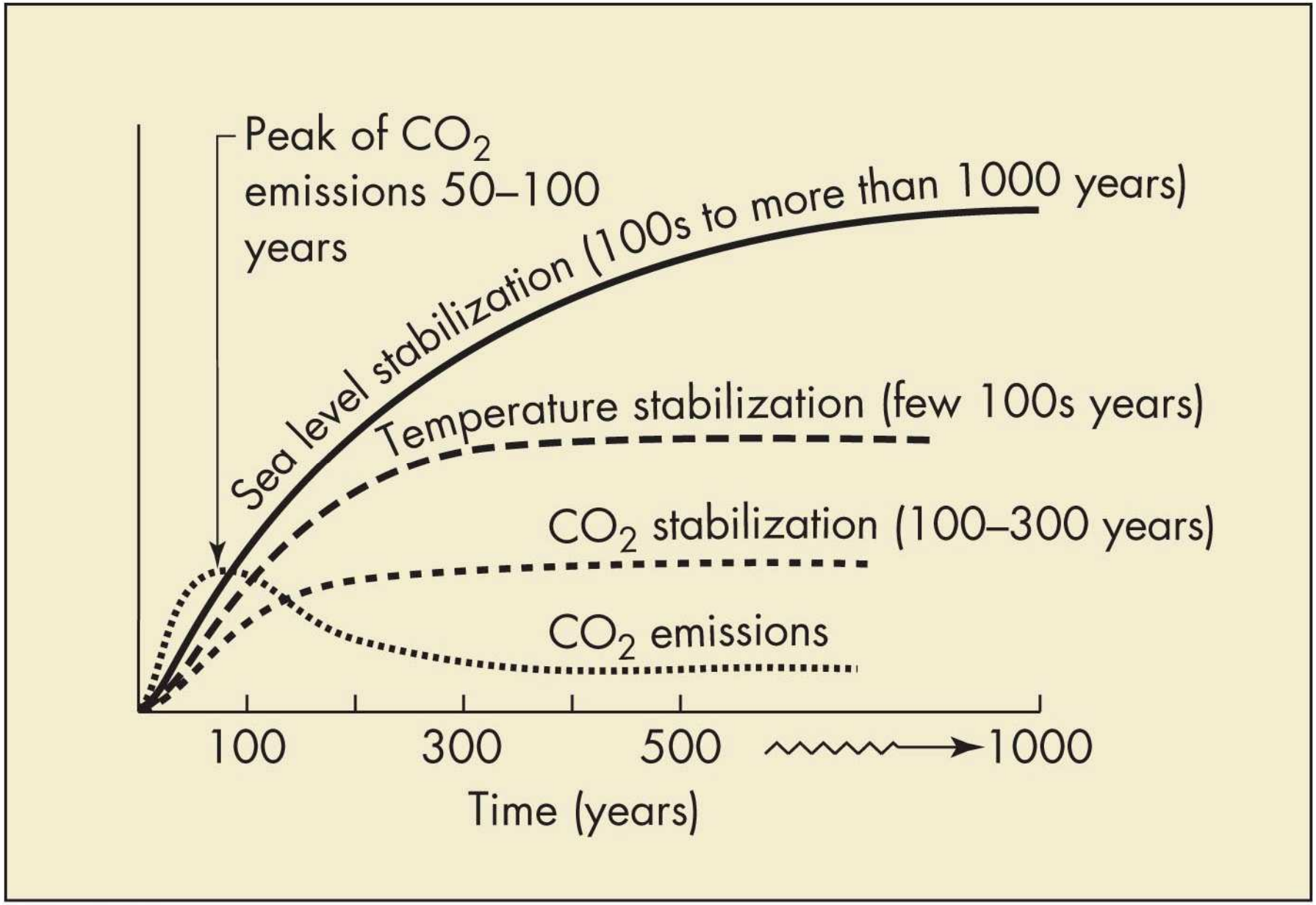

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Figure 12.28

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Reducing Emissions

- Improved engineering of fossil fuel–burning power plants
- Use those fossil fuels that release less carbon into the atmosphere, such as natural gas
- Conserve energy to reduce dependence on fossil fuels
- Use more alternative energy sources
- Store carbon in Earth's systems, such as forests, soils, and rocks below the surface of Earth

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TABLE 12.4

Comparison of Common Fossil Fuels in Terms of Percentage of Total Carbon Released

Fossil Fuel	Carbon Emitted as % of Total Carbon from Fossil Fuels	Comparisons
Coal	36	Releases much more carbon per unit of energy than oil or gas.
Oil	43	Releases 23% less carbon per unit of energy than coal.
Natural Gas	21	Releases 28% less carbon per unit of energy than oil or gas.

Source: Data from Dunn, J. 2001. Decarbonizing the energy economy. World Watch Institute State of the World 2001. *New York: W. W. Norton and Company. Chapters IV, V.*

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Table 12.4

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End

Climate and Climate Change

Chapter 12

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