Chapter 14

Global Climate Change

PowerPoint® Slides prepared by
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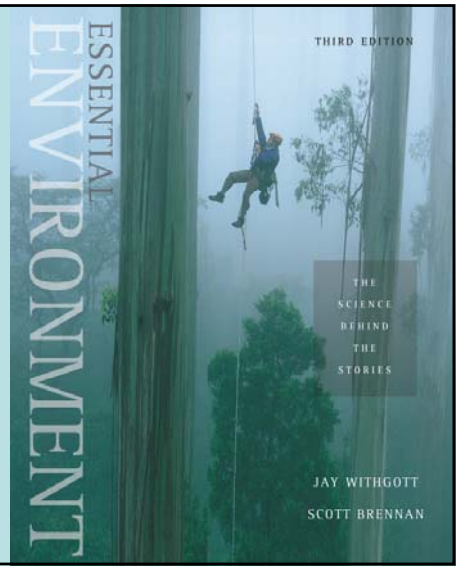


This lecture will help you understand:

- The Earth's climate system
- Human influences on the atmosphere and climate
- Methods of climate research
- Impacts of global climate change
- Ways we can respond to climate change

Central Case: Rising seas may flood the Maldives

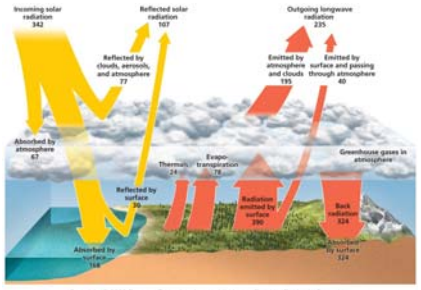
- Visiting tourists think of the Maldives Islands in the Indian Ocean as paradise.
- The islands could be submerged by rising seas accompanying global climate change.
  - 80% of land lies less than 1 m (39 in) above sea level.
  - Higher seas will flood areas and contaminate drinking water.
- The government has already evacuated residents from the lowest-lying islands.
- Other island nations and mainland coastal areas will face similar challenges.

Our dynamic climate

- **Climate**: an area's long-term atmospheric conditions
  - Temperature, moisture content, wind, precipitation, etc.
  - Influences everything around us
- **Weather***:* conditions at localized sites over hours or days
- **Global climate change**: describes trends and variations in Earth's climate
  - Temperature, precipitation, storm frequency
- **Global warming**: an increase in Earth's average temperature
  - Earth's climate has varied naturally through time.
  - The rapid climatic changes taking place now are due to human activity: fossil fuels, combustion, and deforestation.

The sun and atmosphere warm the Earth

- Three factors exert more influence on climate than all others:
  - The sun — without it, the Earth would be dark and frozen
  - The atmosphere — without it, the Earth's temperature would be much colder
  - The oceans — store and transport heat and moisture



Greenhouse gases warm the lower atmosphere

- As Earth's surface absorbs solar radiation, the surface increases in temperature and emits infrared radiation.
- **Greenhouse gases**: atmospheric gases that absorb infrared radiation
  - Water vapor, ozone, carbon dioxide, nitrous oxide, methane, chlorofluorocarbons (CFCs)
  - Greenhouse gases differ in their ability to warm the troposphere and surface.

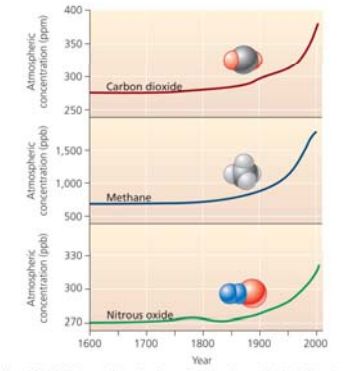
The greenhouse effect

- After absorbing radiation, greenhouse gases re-emit infrared energy.
  - Some energy is lost to space.
  - **Greenhouse effect**: some energy travels back downward, warming the atmosphere and planet's surface
- **Global warming potential**: the relative ability of one molecule of a given greenhouse gas to contribute to warming
  - Expressed in relation to carbon dioxide (potential = 1)
  - Hydrochlorofluorocarbons are 12,000 times as potent as carbon dioxide.

Carbon dioxide is of primary concern

- Not the most potent greenhouse gas, but it is extremely abundant
  - The major contributor to global warming
- Emissions of greenhouse gases from human activities consist mostly of carbon dioxide.

The atmosphere's concentrations of CO_2 are now at their highest level in over 800,000 years.



Greenhouse gases are increasing

- Using fossil fuels in homes, factories, and automobiles
  - Transfers large amounts of carbon dioxide from lithospheric reservoirs into the atmosphere
  - The main reason atmospheric carbon dioxide concentrations have increased so dramatically
- Deforestation has contributed to rising atmospheric CO_2.
  - Forests serve as sinks for recently active carbon.
  - Their removal reduces the biosphere's ability to absorb carbon dioxide from the atmosphere.

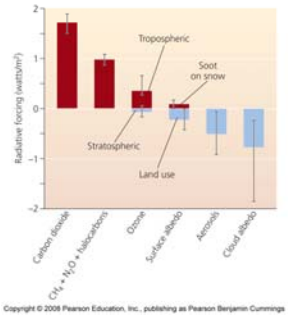
Other greenhouse gases add to warming

- **Methane**: fossil fuel deposits, livestock, landfills, and crops such as rice
- **Nitrous oxide**: feedlots, chemical manufacturing plants, auto emissions, and synthetic nitrogen fertilizers
- **Water vapor**: the most abundant greenhouse gas and contributes most to the greenhouse effect
  - But its global concentration has not changed
  - It's not viewed as driving industrial-age climate change.

Aerosols may exert a cooling effect

- **Aerosols**: microscopic droplets and particles that have either a warming or cooling effect
- Soot, or black carbon aerosols, cause warming by absorbing solar energy.
  - But most tropospheric aerosols cool the atmosphere by reflecting the Sun's rays.
- Sulfate aerosols produced by fossil fuel combustion may slow global warming, at least in the short term.
  - Volcanic eruptions reduce sunlight reaching the earth.

Radiative forcing expresses change in energy

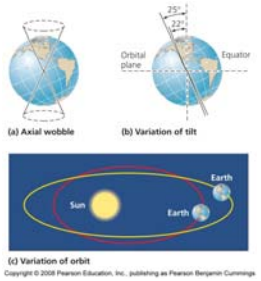


Red — positive forcing (warming)
Blue — negative forcing (cooling)

- Scientists estimate the influence of factors over Earth's energy balance
- **Radiative forcing**: the amount of change in energy that a given factor causes
  - Positive forcing warms the surface; negative forcing cools it.
- Compared with the pre-industrial Earth, today, the Earth is experiencing radiative forcing of 1.6 watts/m^2.
  - Enough to alter the climate

Milankovitch cycles also influence climate

- **Milankovitch cycles**: periodic changes in Earth's rotation and orbit around the Sun
  - Alter the way solar radiation is distributed over Earth's surface
  - By modifying patterns of atmospheric heating, these cycles trigger long-term climate variation such as periodic glaciation.



Solar output and ocean absorption also influence climate

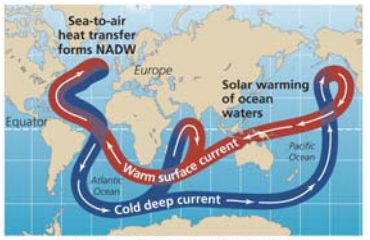
- **Solar output**: the sun varies in the radiation it emits
  - At each peak of its 11-year sunspot cycle, the sun emits flares strong enough to disrupt satellite communications.
  - But variation in solar energy has not been great enough to change Earth's temperature.
- **Ocean absorption**: the ocean holds 50 times more carbon than the atmosphere and absorbs it from the atmosphere
  - Carbon absorption by the oceans is slowing global warming but not preventing it.
  - Warmer oceans absorb less CO_2 because gases are less soluble in warmer water, which accelerates warming.

Ocean circulation also influences climate

- **Ocean circulation**: ocean water exchanges tremendous amounts of heat with the atmosphere
  - Moves energy from place to place
- **Thermohaline circulation**: a worldwide current system
  - Warmer, fresher water moves along the surface and carries heat to Europe
  - **North American Deep Water** (**NADW**): the deep portion of the thermohaline circulation, consisting of denser, saltier, cool water that sinks and moves deep beneath the surface

NADW is vulnerable

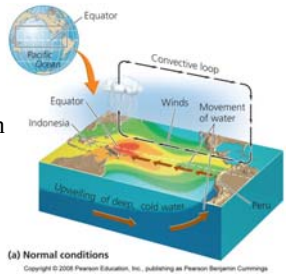
- Interrupting thermohaline circulation could trigger rapid climate change.
- If Greenland's ice melts, freshwater runoff would dilute surface waters, making them less dense, and stopping NADW.
  - Data suggest thermohaline circulation is slowing.



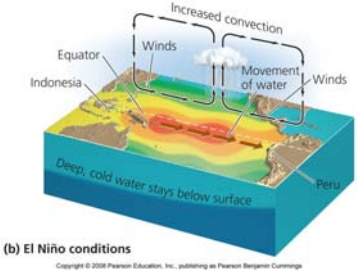
ENSO also influences climate

- **El Niño-southern oscillation (ENSO)**: a systematic shift in atmospheric pressure, sea surface temperature, and ocean circulation in the tropical Pacific Ocean

- Normally, winds blow from east to west along the equator, from high to low pressure.
  - Water "piles up" in the western Pacific.
  - Westward-moving surface waters allow nutrient-rich upwelling along the coast of Peru.



El Niño



- **El Niño**: occurs when air pressure increases in the western Pacific and decreases in the eastern Pacific, weakening the equatorial winds
  - Water flows eastward, suppressing upwellings, shutting down delivery of nutrients to aquatic life
  - Coastal industries are devastated; global weather is changed

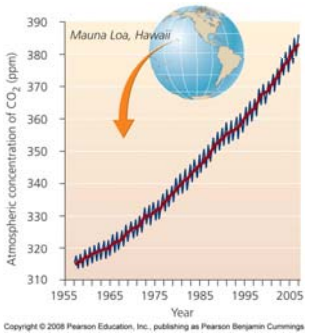
La Niña events

- The opposite of El Niño events
  - Cold surface waters extend far westward in the equatorial Pacific and weather patterns are affected in opposite ways.
- ENSO cycles are periodic, occurring every 2-8 years.
  - Globally warming air and sea temperatures may be increasing their frequency and strength.

Scientists use direct sampling to study climate change

- Scientists measure atmospheric gases directly.

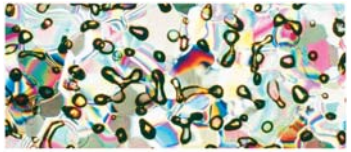
Carbon dioxide concentrations increased from 315 ppm to 383 ppm between 1958 and 2008.



Proxy indicators tell us about the past

- **Proxy indicators**: indirect evidence that serve as substitutes for direct measurements
  - Shed light on past climate
  - Ice caps, ice sheets, and glaciers hold clues to Earth's climate
  - Trapped bubbles in ice cores show atmospheric composition, greenhouse gas concentration, temperature trends, snowfall, solar activity, and frequency of fires.

(a) Ice core

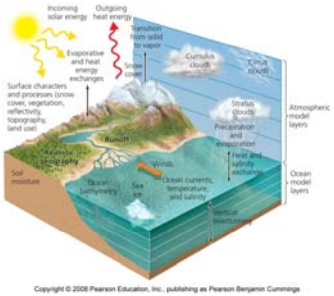


(b) Micrograph of ice core

More proxy indicators

- Sediment beds preserve pollen grains and other plant remnants.
- Tree rings precipitation history and fire occurrence
- Pack rat middens preserve plant parts for centuries
- Coral reefs reveal aspects of ocean chemistry.

Models help us understand and predict climate change



Climate models: programs that combine what is known about atmospheric circulation, ocean circulation, atmosphere-ocean interactions, and feedback mechanisms to simulate climate processes

- These models are becoming more reliable in predicting climate change.

Current and future trends and impacts

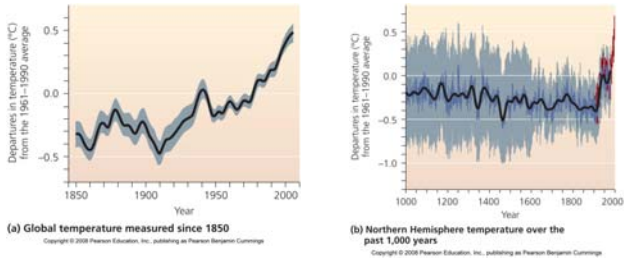
- Scientific evidence that climate has changed since industrialization is now overwhelming and indisputable.
- **Intergovernmental Panel on Climate Change (IPCC)**
  - An international panel of scientists and government officials established in 1988
  - The most thoroughly reviewed and widely accepted synthesis of scientific information on climate change
  - Has issued a series of reports on climate change

The fourth assessment report

- **Fourth Assessment Report (2007)**
  - Consensus of scientific climate research from around the world
  - Summarizes thousands of studies
  - It documents observed trends in surface temperature, precipitation patterns, snow and ice cover, sea levels, storm intensity, etc.
  - Predicts future changes, addressing impacts of climate change on wildlife, ecosystems, and human societies
  - Discusses possible strategies to pursue in response to climate change

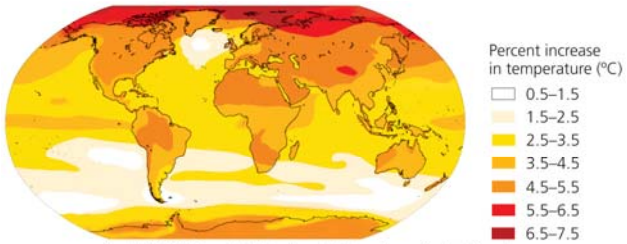
IPCC report: Continued temperature increases

- The IPCC report concludes that average surface temperatures on earth have been rising since 1906, mostly in the last few decades.
- At the end of the 21st century, temperatures will be 1.8-4.0° C (3.2-7.2 ° F) higher than today.

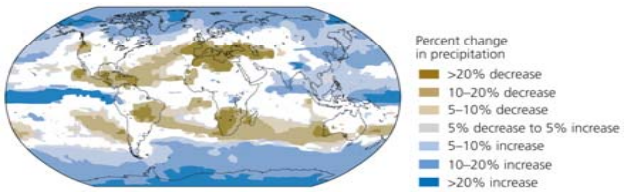


Global temperature change will vary

- Sea surface temperatures will also increase as oceans absorb more heat.
  - May not have more storms, but storms will be stronger and longer



Projected changes in precipitation



•High latitudes = increased precipitation
•Low and middle latitudes = decreased precipitation will worsen water shortages in developing countries

Worldwide, glaciers are melting rapidly

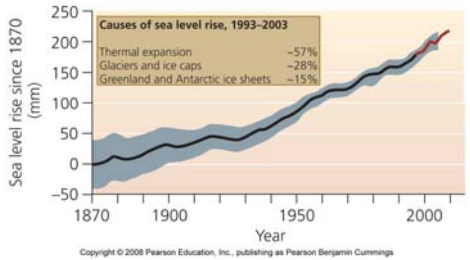
(a) Grinnell Glacier in 1938

- Russia, the U.S., Canada, and other nations are already claiming regions of the Arctic as ice melts.
  - To get underwater oil and mineral reserves

(b) Grinnell Glacier in 2005

Rising sea levels

- As glaciers and ice melt, increased water will flow into the oceans.
- As oceans warm, they expand.
- Leads to beach erosion, coastal floods, and salt water intrusion into aquifers



Climate change affects organisms

- Organisms are adapted to their environments, so they are affected when those environments change.
- Global warming modifies temperature-dependent phenomena.
  - Timing of migration, breeding
- Spatial shifts in the range of organisms
  - Animals and plants will move toward the poles or upward in elevation.
  - 20-30% of all species will be threatened with extinction.
- Plants act as carbon sinks; droughts result in fewer plants, which means more CO_2 in the atmosphere.

Climate change exerts societal impacts

- Human society is beginning to feel the impacts of climate change.
- Forestry:
  - Increased insect and disease outbreaks,
  - Invasive species,
  - Forest fires (especially in rainforests)
- Agriculture:
  - Droughts, floods,
  - Decreased yields, worsened hunger

U.S. Global Change Research Program (2008)

Highlighted past effects and predicted future impacts of climate change

TABLE 18.2 Some Predicted Impacts of Climate Change in the United States

- Average temperatures will rise 3–5° C (5.4–9.0° F) in 100 years.
- Droughts and flooding will worsen.
- Drought and other factors could decrease crop yields, but longer growing seasons and enhanced CO_2 could raise yields.
- Snowpack will decrease; water shortages will worsen.
- Greater temperature extremes will increase health problems and human mortality. Some tropical diseases will spread north.
- Forest growth may increase in the short term, but in the long term, drought, pests, and fire may alter forest ecosystems.
- Alpine ecosystems and barrier islands will begin to disappear.
- Southeastern U.S. forests will break up into savanna/grassland/forest mosaics.
- Northeastern U.S. forests will lose sugar maples.
- Sea level rise will cause loss of coastal wetlands and real estate.
- Melting permafrost will undermine Alaskan buildings and roads.

Are we responsible for climate change?

- The IPCC 2007 report concluded that it is more than 90% likely that most global warming is due to humans.
- In 2005, national academies of 11 nations issued a joint statement urging political leaders to take action.
- Despite broad scientific consensus (not as broad as it was 5 years ago) that climate change is a pressing issue, it remains mired in an outdated debate (is this truly outdated?).
  - Is global warming real? Are humans to blame?
- The debate was fanned and funded by industry skeptics (and recently other scientists).
  - Industry aimed to cast doubt on the scientific consensus
- The media try to present two sides to the story, even with overwhelming scientific evidence that climate is changing (evidence for climate change is not evidence that humans are causing it).

The debate over climate change is over

- Most Americans accept that fossil fuel consumption is changing the planet.
- *An Inconvenient Truth* helped turn the tide.
  - Shifted the public's perception
  - Many corporations offer support for greenhouse gas reductions.

Shall we pursue mitigation or adaptation?

- **Mitigation**: pursue actions that reduce greenhouse gas emissions to lessen severity of future climate change
  - Renewable energy, efficiency, farm practices to protect soil integrity, preventing deforestation
- **Adaptation**: accept climate change is happening and pursue strategies to minimize its impacts
  - Uses technology and engineering, adjusting farming to cope with droughts, etc.
  - Criticized as sidestepping
- Both are necessary

The FCCC

- **UN Framework Convention on Climate Change (FCCC)**: outlines a plan for reducing greenhouse gas emissions to 1990 levels by the year 2000 through a voluntary, nation-by-nation approach
  - By the late 1990s, it was clear that the voluntary approach would not succeed.
  - Most developed nations did not voluntarily cut emissions.
- The **Kyoto Protocol** mandates that, between 2008-2012, signatory nations must reduce emissions of six greenhouse gases to levels below those of 1990.
  - This treaty took effect in 2005, after Russia became the 127th nation to ratify it.

The Kyoto Protocol seeks to limit emissions

- The United States will not ratify the Kyoto Protocol.
  - It requires industrialized nations to reduce emissions, but not rapidly industrializing nations (China and India).
- Governments and businesses in industrialized nations feel they have more to lose economically from restrictions.
  - But they can gain more by inventing, developing, and marketing new technologies.

Others are advancing climate change policy

- U.S. state and local governments are advancing policies to limit greenhouse emissions.
  - Mayors from 850 cities agreed to pursue policies to "meet or beat" Kyoto Protocol guidelines.
- California is determined to cut greenhouse gas emissions 25% by the year 2020.
- 10 northeastern states set up a cap-and-trade program for carbon emissions from power plants.

(a) Greg Nickels

(b) Arnold Schwarzenegger

Top 10 solutions to climate change

TABLE 14.5 Top Solutions to Climate Change, as Voted on by *Focus the Nation* participants

1.	Invest in the clean energy revolution	13%
2.	Cleaner cars, California-style	12%
3.	Create green jobs, save energy	12%
4.	Build green: Carbon neutral by 2030	12%
5.	Get efficient—cut energy, save money	11%
6.	Support stronger forests	11%
7.	Tax global warming pollution	9%
8.	No new coal plants without "capture and sequestration"	7%
9.	Cap CO_2 emissions, share the auction revenues	7%
10.	Jumpstart low polluting biofuel	6%

Data from Eban Goodstein and Focus the Nation, www.focusthenation.org/