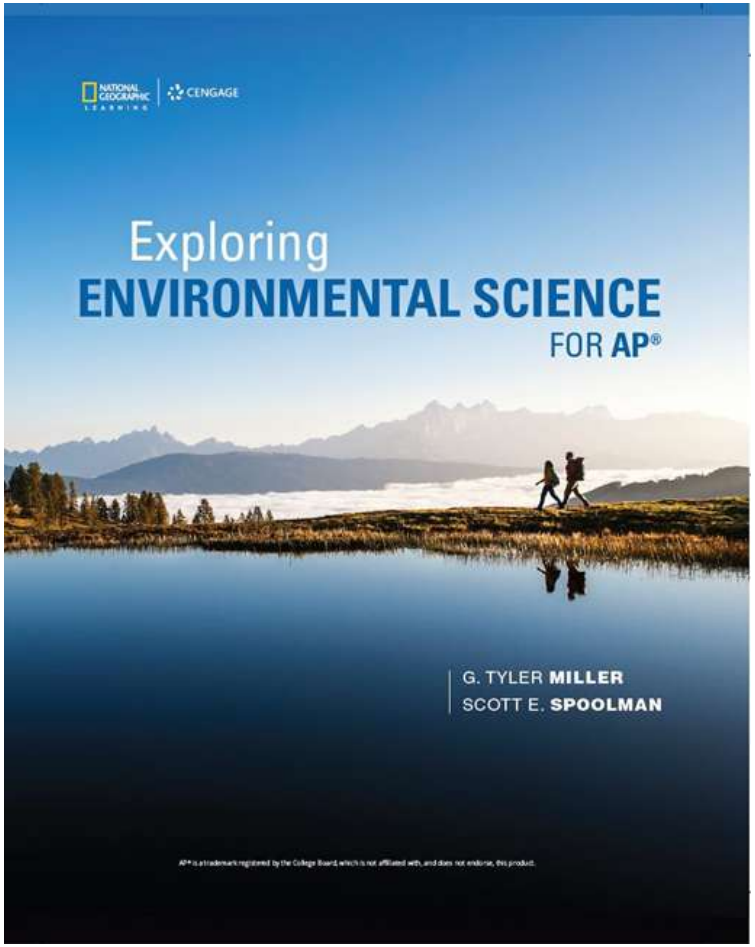
Exploring Environmental Science for AP®

1st Edition

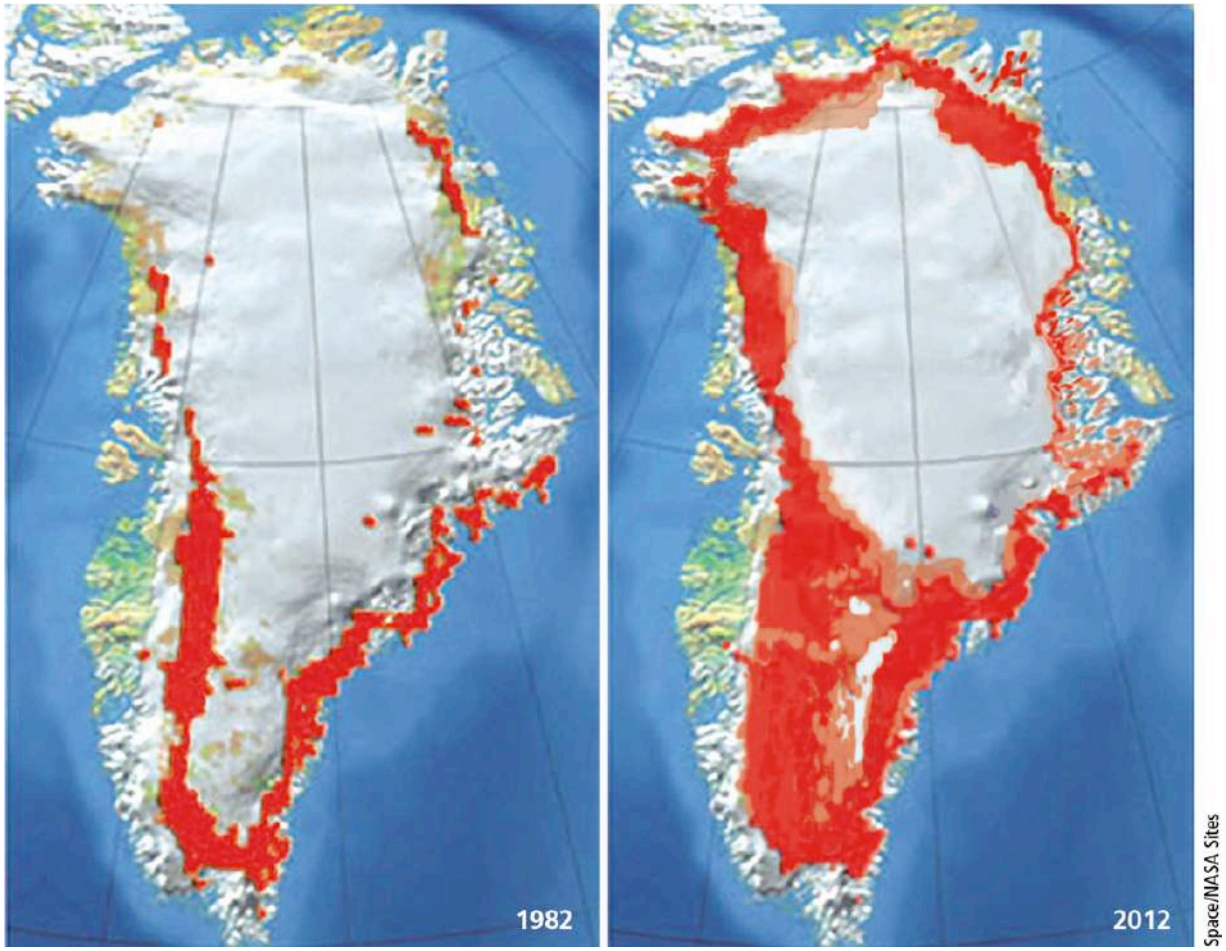


Chapter 20
Climate Change

Core Case Study: Melting Ice in Greenland (1 of 2)

- World's largest island
  - Mostly covered by ice glaciers
- Glaciers melting at an accelerating rate in summers
  - Atmospheric warming a key factor
- Greenland's ice loss
  - Responsible for nearly one-sixth of the global sea-level rise over the past 20 years

Core Case Study: Melting Ice in Greenland (2 of 2)



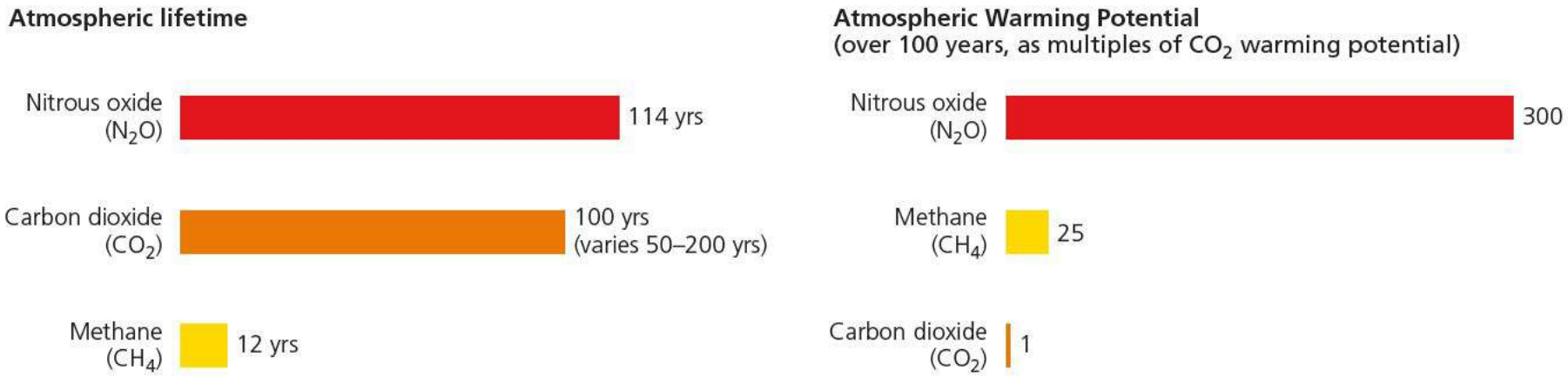
20.1 How and Why Is the Earth's Climate Changing?

- Scientific evidence strongly indicates that the earth's atmosphere is warming at a rate that is likely to lead to significant climate change
- Weather
  - Short-term changes
- Climate
  - Average weather conditions of a particular area over 30 years or more

Climate and the Natural Greenhouse Effect (1 of 2)

- The greenhouse effect is a natural process
  - Heat-holding gases absorb heat
  - CO_2, CH_4, N_2O
  - Historical changes in the amount of carbon dioxide in the atmosphere correlate to changed in global temperatures

Climate and the Natural Greenhouse Effect (2 of 2)

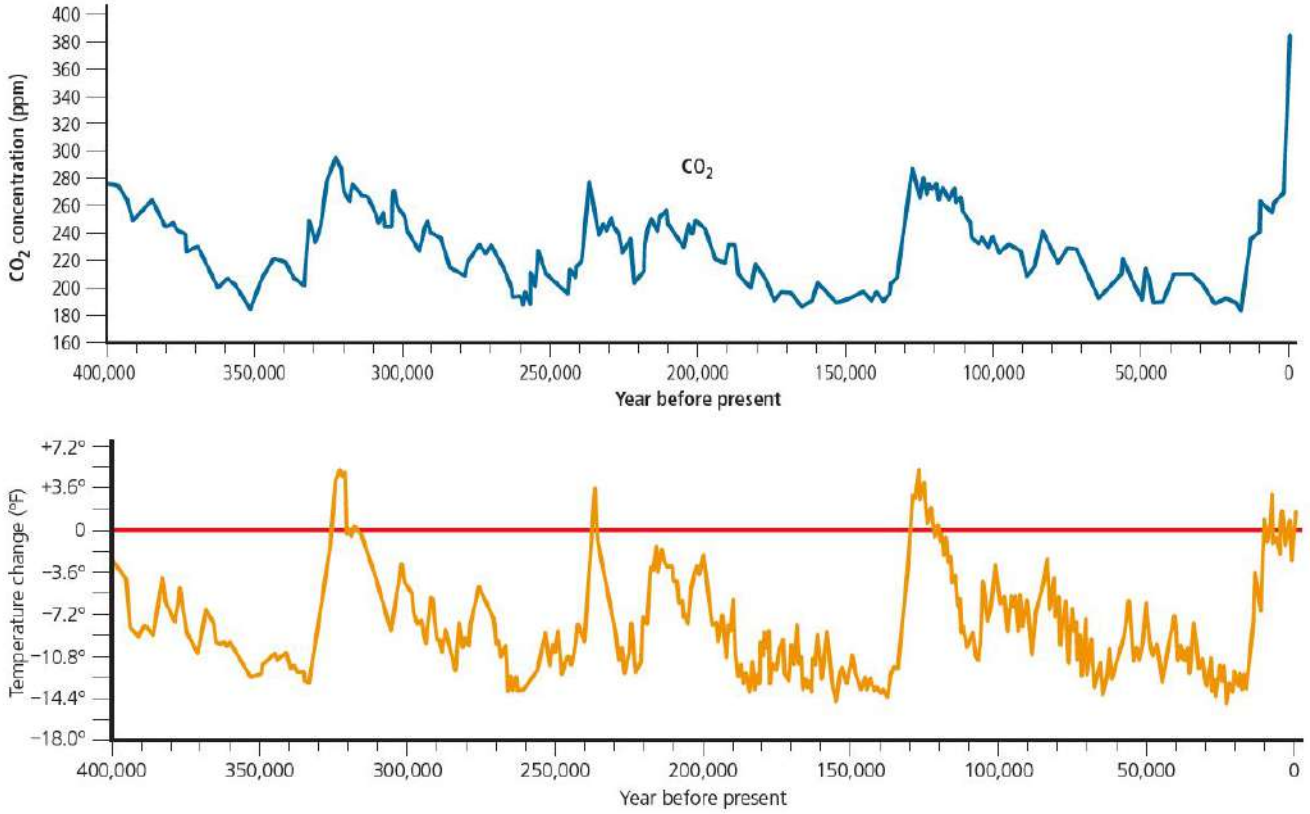


Atmospheric lifetimes and warming potentials for three major greenhouse gases.

Climate Change in the Past (1 of 2)

- Natural factors cause climate to change
  - Massive volcanic eruptions
  - Changes in solar input
  - Changes in earth's orbit
  - Changes in tilt of earth
  - Milankovitch cycles
  - global air circulation patterns
  - Changes in amount of reflective ice (albedo)
  - Changes in greenhouse gases
  - Changes in ocean currents

Climate Change in the Past (2 of 2)



Atmospheric levels of carbon dioxide (CO2) and changes in average global temperature of the atmosphere near the earth's surface over the past 400,000 years. These data were obtained by analysis of ice cores removed at Russia's Vostok Research Station in Antarctica.

Current Atmospheric Warming and Climate Change

- Climate change is happening now
  - Between 1906 and 2016, earth's temperature rose by 0.94°C
  - 10 warmest years on record since 1861 have taken place since 2005
  - Arctic ice has been shrinking since 1979
  - Glaciers are melting
  - Permafrost is melting, rising sea levels reducing coast
  - Carbon dioxide and methane levels have risen sharply
  - Terrestrial organisms have migrated towards poles and up mountains where it is cooler

Role of Human Activities in Current Atmospheric Warming (1 of 3)

- Burning of fossil fuels, deforestation, and agriculture led to significant increases in greenhouse gases
- Increase of methane (more potent than CO_2) from livestock, rice production, natural gas production
- U.S. has largest per capita carbon footprint
- Carbon added to the atmosphere faster than the carbon cycle can remove it

Role of Human Activities in Current Atmospheric Warming (2 of 3)

- Humans have also cut down forests, a sink for carbon
- Change in climate is much faster than change induced by natural factors
- Climate scientists agree that
  - Climate change is happening now
  - Human activities play a significant role in climate change
  - Average atmospheric temperatures are likely to increase
  - Immediate action is possible and affordable and would bring major benefits

Role of Human Activities in Current Atmospheric Warming (3 of 3)

- Fossil fuel lifestyle has led to serious problems
  - Air pollution
  - Climate change
  - Ocean acidification
- Scientists use models to make projections about future trends

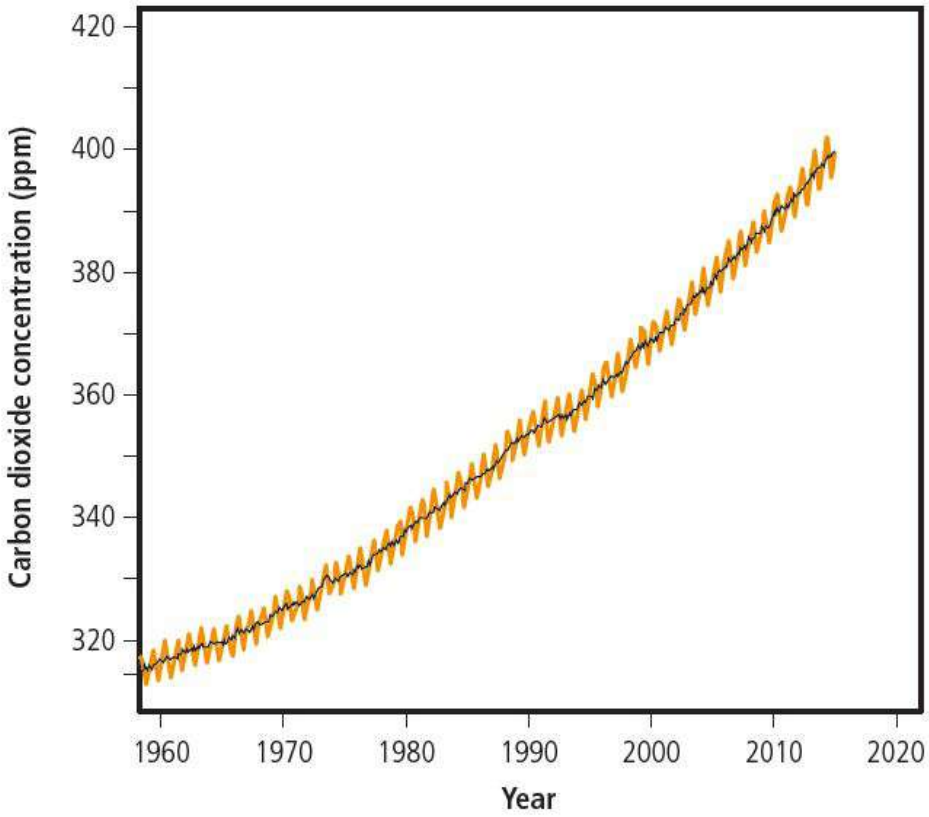
Role of the Sun in Current Atmospheric Warming

- Cause of warming cannot be increased solar output
  - Output has dropped slightly during last few decades
  - Troposphere has warmed while stratosphere has cooled
  - Atmosphere is heating from the bottom up

Effects of the Oceans on Current Atmospheric Warming (1 of 2)

- Sink for carbon, most stored as carbon in marine algae and vegetation, in coral reefs and bottom sediments
- Also absorb heat from troposphere
- Has resulted in ocean acidification

Effects of the Oceans on Current Atmospheric Warming (2 of 2)



Rising global atmospheric levels of CO_2,1880–2015.

Effects of Cloud Cover on Atmospheric Warming (1 of 2)

- Net effect of cloud cover change is likely to increase warming
- Cumulus clouds reflect light back into space
- Cirrus clouds insulate earth, increasing cooling

Effects of Cloud Cover on Atmospheric Warming (2 of 2)

Tatiana Grozetskaya/Shutterstock.com

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Cumulus clouds (left) are thick, relatively low-lying clouds that tend to decrease surface warming by reflecting some incoming solar radiation back into space. Cirrus clouds (right) are thin and float at high altitudes; they tend to warm the earth's surface by preventing some heat from flowing into space.

Effects of Outdoor Air Pollution on Atmospheric Warming

- Light colored aerosols reflect incoming sunlight
- Dark particles like soot absorb heat
- Most likely will not affect climate change

20.2 What are the Likely Effects of a Warmer Atmosphere?

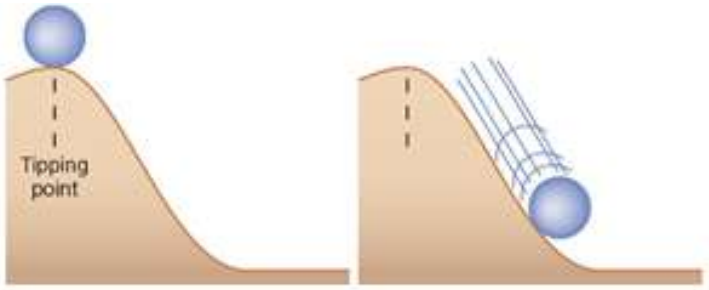
- Projected change in temperature could have severe and long-lasting consequences
  - Flooding
  - Rising sea levels
  - Shifts in location of croplands and wildlife habitats
  - More extreme weather

Rapid Atmospheric Warming Could Have Serious Consequences (1 of 3)

- Temperatures rising rapidly
- Climate change tipping points
  - Thresholds beyond which natural systems will not recover
    - Global temperature rise of 2°C
    - CO_2 concentration above 450 ppm
- Harmful effects will be unevenly distribute
  - Reduce food security, increase poverty and social conflict

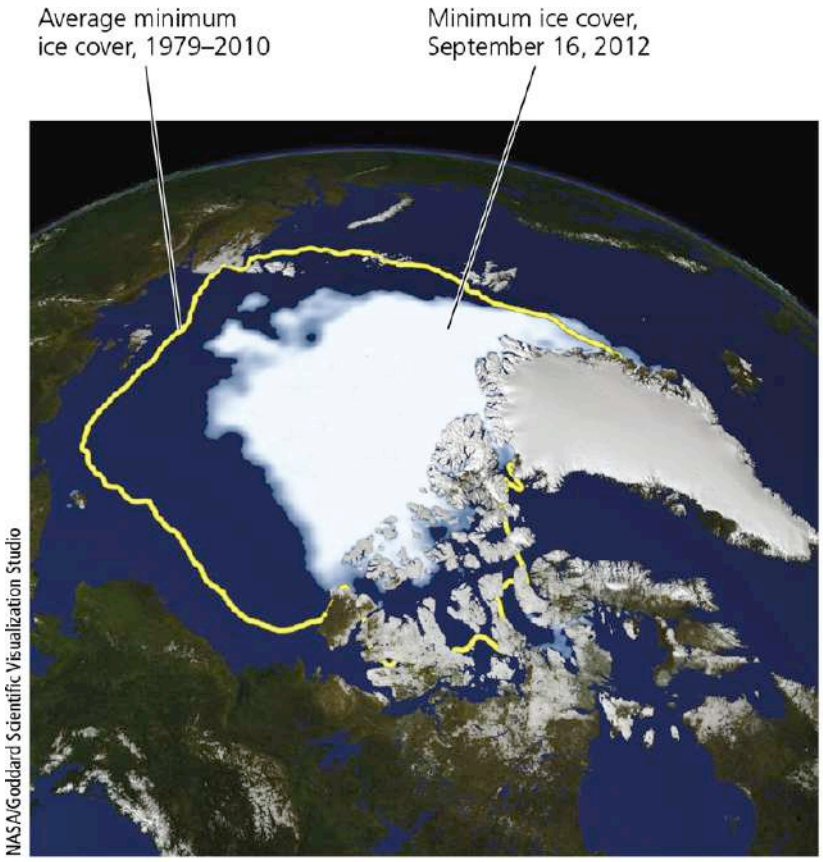
Rapid Atmospheric Warming Could Have Serious Consequences (2 of 3)

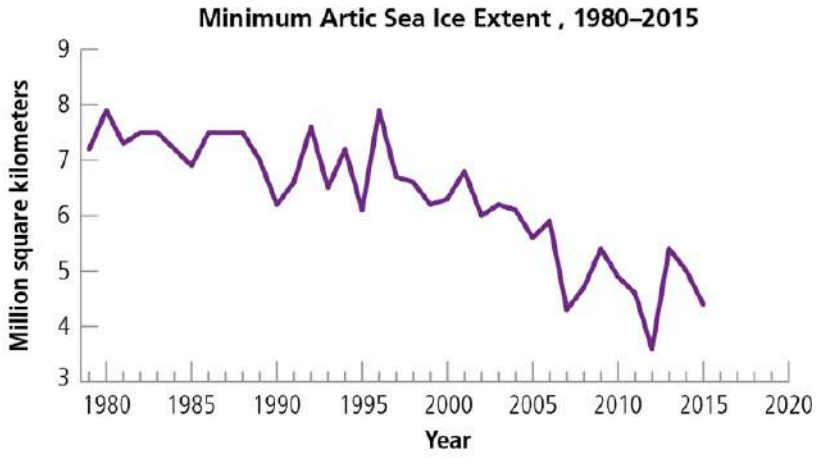
- Atmospheric carbon level of 450 ppm
- Melting of all arctic summer sea ice
- Collapse and melting of the Greenland ice sheet
- Severe ocean acidification, collapse of phytoplankton populations, and a sharp drop in the ability of the oceans to absorb CO_2
- Massive release of methane from thawing arctic permafrost and from the Arctic seafloor
- Collapse and melting of most of the western Antarctic ice sheet
- Severe shrinkage or collapse of Amazon rainforest

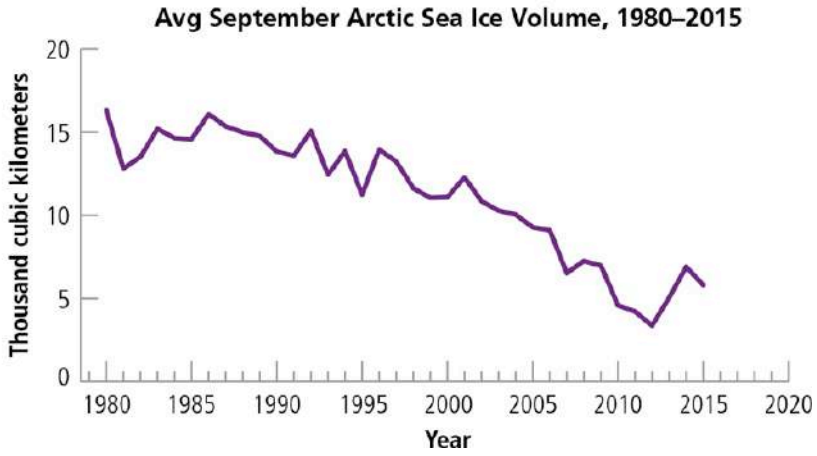


Tipping point

Rapid Atmospheric Warming Could Have Serious Consequences (3 of 3)







Increased Melting of Ice and Snow

- Less light-colored ice and snow to reflect solar energy (albedo reduced)
  - Accelerated polar ice melting
  - Positive feedback loop
- Climate tipping point
  - Complete melting of summer arctic sea ice
    - May happen by 2050
  - Changes in arctic seawater temperatures influence the jet stream
- Mountain glaciers are shrinking
  - Play a vital role in the water cycle

Methane Emissions from Thawing Permafrost

- Permafrost: frozen soil in northern hemisphere
- Climate change is projected to thaw significant amounts of permafrost
  - Already happening in Alaska and Siberia
  - Releases methane and CO_2
    - Release accelerates projected warming
- Methane in permafrost on Arctic Sea floor

Rising Sea Levels (1 of 3)

- Projected sea level rise
  - 40–60 cm by the end of the century
  - More than half of the rise from melting of Greenland's ice
- Serious effects of sea level rise
  - Degradation and loss of one-third of coastal estuaries, wetlands, and coral reefs
  - Disruption of coastal fisheries
  - Flooding barrier islands and coastal areas

Sea Levels Are Rising (2 of 3)

- Serious effects (cont'd.)
  - Contamination of freshwater coastal aquifers
  - Submergence of low-lying islands in the Pacific and Indian Oceans and the Caribbean
  - Flooding of coastal cities could displace 150 million people

Sea Levels Are Rising (3 of 3)

Ocean Acidification: The Other CO_2 Problem

- Surface waters have increased acidity by 30% since 1800
  - Could reach dangerous levels before 2050
- CO_2 combines with water to become carbonic acid (H_2CO_3)
  - Threatens corals, snails, and other organisms with shells
  - Threatens phytoplankton
    - Primary producer species of ocean food webs

More Severe Drought

- Extra heat in the atmosphere depletes soil moisture
  - Prolongs droughts and makes them more severe
- Higher temperatures intensify the water cycle
  - Additional water vapor warms the atmosphere
- Increased wildfires
- Reduced growth of plants and trees

More Extreme Weather

- Intensified water cycle will bring more flooding to some areas
- Annual days of extreme heat in parts of the United States will rise dramatically by the end of the century
- Some areas may experience colder winter weather
  - Due to changes in global air circulation patterns

Threats to Biodiversity

- Amazon rainforest
  - Up to 85% could be lost due to warming
- Extinctions due to loss of habitat
  - Polar bears and penguins
  - Species that live at high elevations
  - Corals
  - Species with limited ranges
- Increase in mountain pine beetle destroying forests

Case Study: Alaska – A Preview of the Effects of Climate Change (1 of 2)

- Warming at twice the average rate of the rest of the U.S.
  - All but five glaciers melting
  - Sea ice melting sooner and refreezing later, shortening the hunting season for walruses, polar bears, and humans
  - Coastal villages not protected by sea ice and damaged by storms
  - Melting permafrost damages roads and buildings
  - Population explosion of beetles that attack white spruce forests

Case Study: Alaska – A Preview of the Effects of Climate Change (2 of 2)

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With warmer winters, populations of mountain pine beetles have exploded and killed large numbers of trees (orange areas). in the Canadian province of British Columbia.

Threats to Food Production (1 of 2)

- Regions of farming will shift
  - Decrease in tropical and subtropical areas
  - Increase in northern latitudes
    - Less productivity–soil not as fertile
- Flooding will reduce crop production
- Several hundred million people could face starvation and malnutrition

Threats to Food Production (2 of 2)

Palash Khan/Age Fotostock

An elderly woman seeks a bag of rice in Dhaka, Bangladesh, after a 2007 flood that killed at least 198 people and drove 19 million people from their homes.

Threats to Human Health, National Security, and Economies (1 of 2)

- Increase in heat-related deaths
- Conditions favorable for:
  - Disease-transmitting mosquitos and ticks
  - Microbes, molds, and fungi
- Increase in photochemical smog
- National security and economic effects
  - Food and water scarcity, poverty, mass migrations, political instability, and increased unemployment

20.3 How Can We Slow Climate Change?

- We can reduce greenhouse gas emissions and the threat of climate change while saving money and improving human health
  - Reduce energy waste
  - Rely more on cleaner renewable energy resources

Dealing with Climate Is Difficult (1 of 2)

- Global problem
  - Requires unprecedented and prolonged international cooperation
- Long-term political issue
  - Most people who will suffer most serious harm have not been born yet
- Harmful and beneficial impacts of climate change not spread evenly worldwide

Dealing with Climate Is Difficult (2 of 2)

- Proposed solutions are controversial
  - Economic disruption
- Projected effects are uncertain
  - Difficult to plan for avoiding or managing risk
  - Urgent need for more research to reduce uncertainty

What Are Our Options?

- Mitigation
  - Slow climate change to avoid its most harmful effects
- Adaptation
  - Recognize climate change is inevitable because we have waited too long to act
  - Adapt to some of its harmful effects
- Most urgent priority: avoid climate change tipping points

Reducing Greenhouse Gas Emissions (1 of 2)

- Most of the world's economies depend on using fossil fuel reserves
  - Shift is difficult but humans have done it before
- Good starting points
  - Decrease black carbon and methane emissions
    - Technology exists to accomplish this quickly
  - Make the switch to hybrid and electric cars

Reducing Greenhouse Gas Emissions (2 of 2)

Solutions

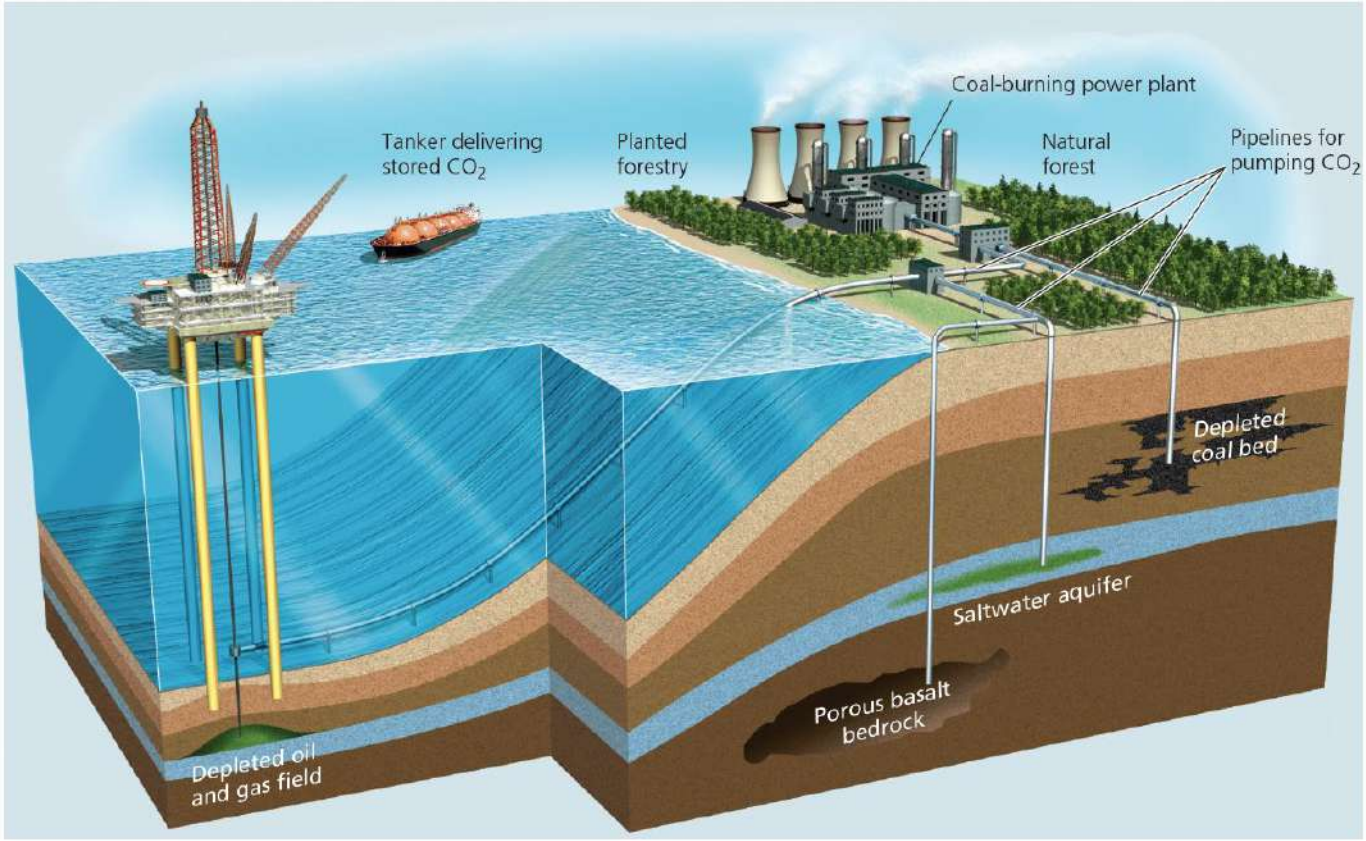
Slowing Climate Change

Prevention		Cleanup
Cut fossil fuel use (especially coal)		Sequester CO_2 by planting trees and preserving forests and wetlands
Shift from coal to natural gas		
Repair leaky natural gas pipelines and facilities		Sequester carbon in soil using biochar
Improve energy efficiency		Sequester CO_2 deep underground (with no leaks allowed)
Shift to renewable energy resources		
Reduce deforestation		Sequester CO_2 in the deep ocean (with no leaks allowed)
Use more sustainable agriculture and forestry		
Put a price on greenhouse gas emissions		Remove CO_2 from smokestack and vehicle emissions

Removing CO_2 from the Atmosphere (1 of 2)

- Solution strategies
  - Massive, global tree-planting and forest restoration program
  - Restore wetlands drained for farming
  - Plant fast-growing perennials on degraded land
  - Produce and bury biochar in the soil
  - Capture and store carbon from coal-burning plants

Removing CO_2 from the Atmosphere (2 of 2)



Some proposed carbon capture and storage (CCS) schemes for removing some of the carbon dioxide from smokestack emissions and from the atmosphere and storing (sequestering) it in soil, plants, deep underground reservoirs, and sediments beneath the ocean floor.

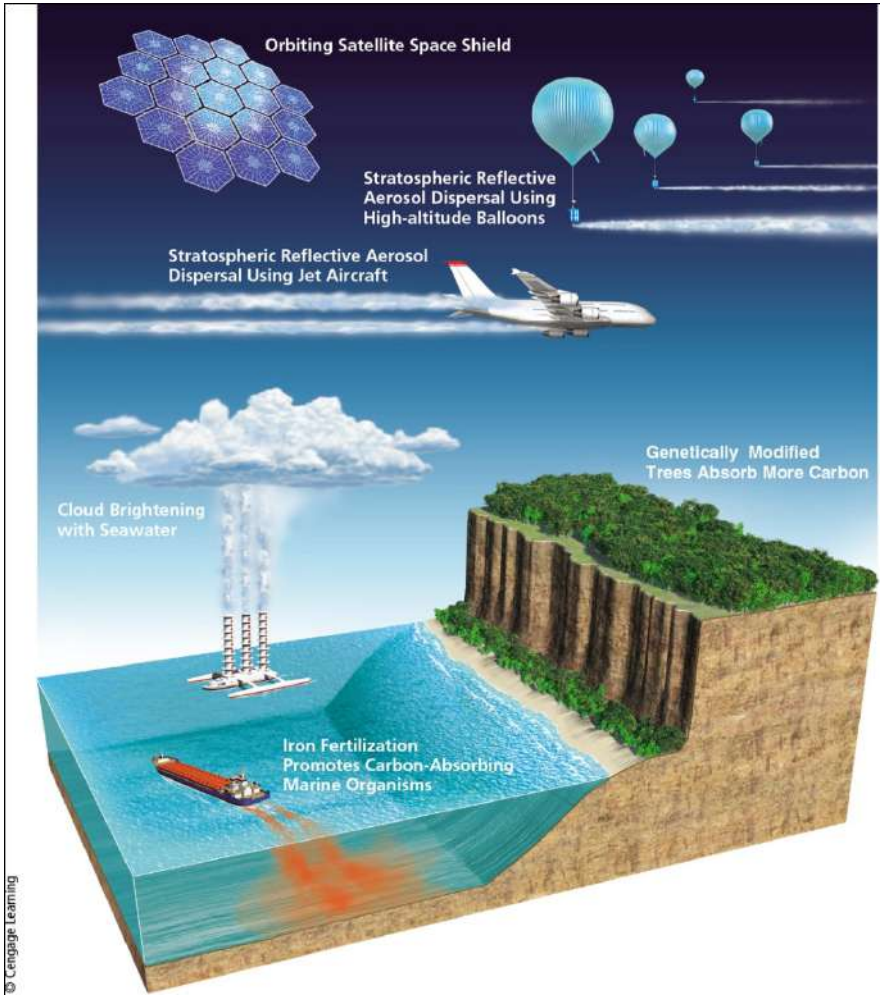
Geoengineering Solutions? (1 of 3)

- Geoengineering
  - Manipulating natural conditions to counter the human-enhanced greenhouse effect
- Concepts
  - Inject sulfate particles into the stratosphere
  - Spray saltwater into sky to make clouds more reflective
  - Pump nutrient-rich water from deep ocean to feed algae blooms to absorb CO_2

Can Geoengineering Provide Solutions? (2 of 3)

- Problems
  - Unknown side effects
  - Huge investments of energy and materials
  - Could justify continued use of fossil fuels
  - Political and ethical aspects

Can Geoengineering Provide Solutions? (3 of 3)



Government Actions to Reduce Greenhouse Gases Emissions (1 of 3)

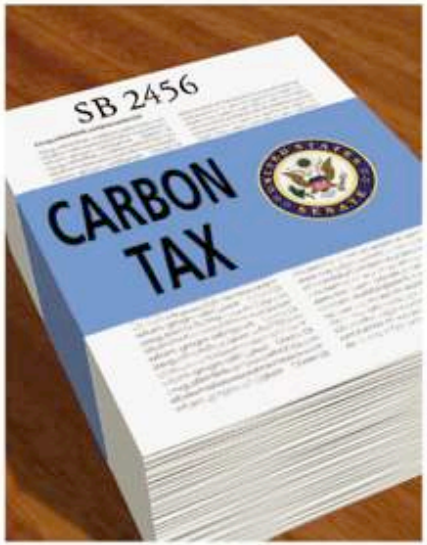
- Strategies to promote solutions
  - regulate CO_2 and methane as air pollutants
  - Phase out coal burning plants
  - Tax CO_2 and methane emissions
  - Use cap-and-trade system
  - Phase out government subsidies and tax breaks for fossil fuel industry
  - Reduce deforestation

Government Actions to Reduce Greenhouse Gases Emissions (2 of 3)

Trade-Offs

Carbon and Energy Taxes

Advantages	Disadvantages
Simple to administer	Tax laws can get complex
Clear price on carbon	Vulnerable to loopholes
Covers all emitters	Doesn't guarantee lower emissions
Predictable revenues	Politically unpopular



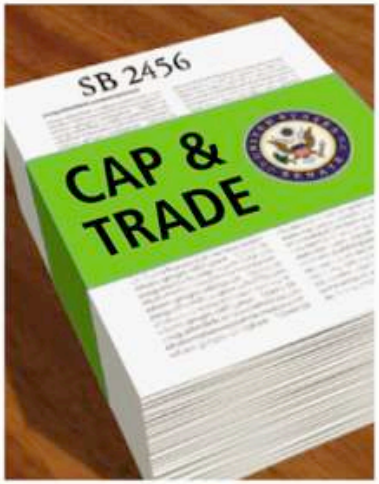
Government Actions to Reduce Greenhouse Gases Emissions (3 of 3)

Trade-Offs

Cap-and-Trade Policies

Advantages

- Clear legal limit on emissions
- Rewards cuts in emissions
- Record of success
- Low expense for consumers



Disadvantages

- Revenues not predictable
- Vulnerable to cheating
- Rich polluters can keep polluting
- Puts variable price on carbon

International Climate Change Treaties (1 of 2)

- The Kyoto Protocol
  - 1997 treaty to slow climate change
  - Not signed by the United States
- 2014: the United States and China agreed to cap carbon emissions within 15–20 years
- 2015: Paris meeting
  - Countries pledged to meet certain goals
  - No provision of money to assist poorer countries in reaching goals

International Cooperation (2 of 2)

- Countries not legally bound to comply
- Wealthier countries must help poorer countries in meeting their goals
- Benefits of slowing climate change outweigh long-term economic and environmental risks of not doing it

Some Countries, States, and Localities Are Leading the Way

- Costa Rica goal: carbon neutral by 2030
- China and India must change energy habits
- U.S. cities and states taking initiatives to reduce carbon emissions
  - California

Critical Concept: Government Incentives to Reduce Carbon Emissions

- Cap-and-trade
  - Tradable pollution or resource-use permits
- Carbon tax
  - Fee levied on units of carbons dioxide or methane produced

Colleges and Universities Are Reducing Their Carbon Footprints

- Arizona State University
  - Solar panels
  - Established School of Sustainability
- College of the Atlantic
  - Carbon neutral since 2007
- EARTH University, Costa Rica
  - Sustainable agriculture degree program

Every Individual Can Make a Difference (1 of 2)

- Two-thirds of average American's carbon footprint is embedded carbon
  - Energy used in manufacture
- Diet choices
  - Processed foods require more energy than fresh fruits and vegetables
  - Beef requires more energy than chicken
- Political involvement

Every Individual Can Make a Difference (2 of 2)

What Can You Do?

Reducing CO_2 Emissions

- Calculate your carbon footprint (there are several helpful websites)
- Drive a fuel-efficient car, walk, bike, carpool, and use mass transit
- Reduce garbage by reducing consumption, recycling, and reusing more items
- Use energy-efficient appliances and LED lightbulbs
- Wash clothes in warm or cold water and hang them up to dry
- Close window curtains to keep heat in or out
- Use a low-flow showerhead
- Eat less meat or no meat
- Heavily insulate your house and seal all air leaks
- Use energy-efficient windows
- Set your hot-water heater to 49°C (120°F)
- Plant trees
- Buy from businesses working to reduce their emissions

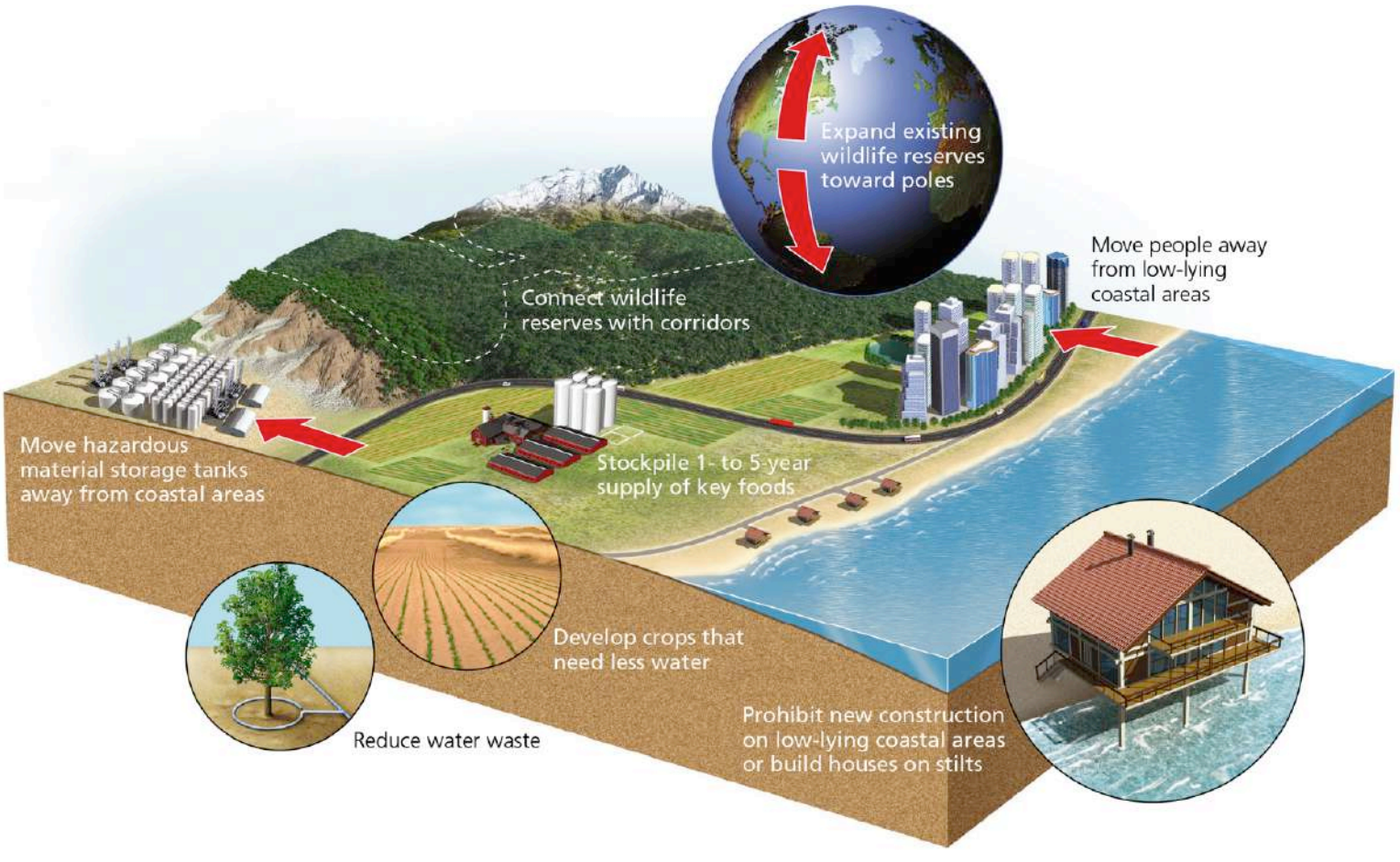
20.4 How Can We Adapt to Climate Change?

- Realize important economic, ecological, and health benefits by drastically reducing greenhouse gas emissions
  - Goal: slow projected climate change

We Can Prepare for Climate Change (1 of 2)

- Cut greenhouse gas emissions by 50–85% by 2050 to stabilize concentrations
- Plan for environmental refugees from coastal areas
  - Take measures against storm surges at coast
- Prepare for more intense wildfires
- Conserve water and build desalination plants

We Can Prepare for Climate Change (2 of 2)



A No-Regrets Strategy

- What if climate models are wrong and there is no serious threat of climate change?
- No-regrets strategy
  - Actions against climate change will benefit environments, health, and economies