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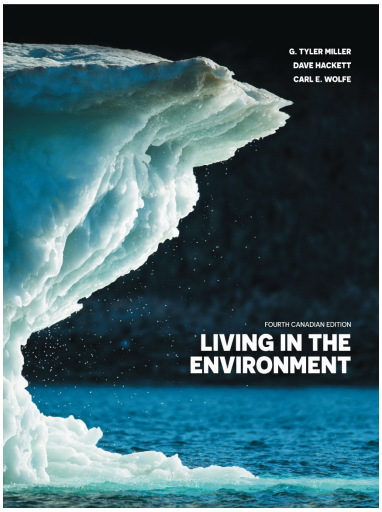

prepared by
Ian Dawe

Chapter 21

Climate Change and Ozone Loss

Key Concepts

- Changes in Earth's climate over time
- Factors affecting climate
- Possible effects of global warming
- Policies to control human impacts on climate
- Adapting to climate change
- Ozone depletion and its effects

Case Study: Heating Up the Arctic

- Temperature is increasing significantly.
  - 2 to 3°C during past century
  - 5 to 7°C during next century (projected)
- Sea ice thinner and less extensive
- Opens up Northwest Passage to shipping
- Impact on wildlife (polar bears, caribou)
- Warming in the Arctic can affect whole world
  - Release of CH_4 and CO_2 from permafrost
  - Increasing meltwater

How Have the Earth's Temperature and Cimate Changed in the Past?

- Past global temperatures
  - Prolonged periods of global cooling and warming
- Recent trends in global temperatures
  - Stable over past 12 000 years
  - Regional climate changes
  - In past 1000 years, temperatures dropped slightly, then started to rise 200 years ago with the Industrial Revolution

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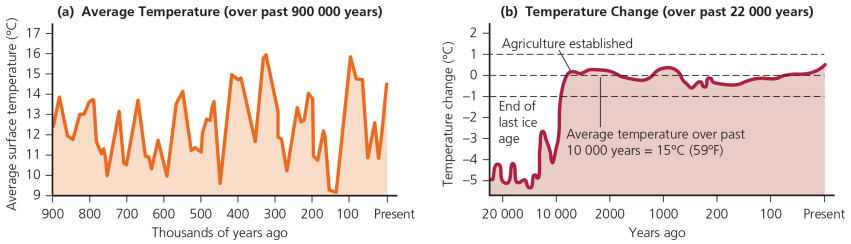
Changes in Temperature Over Time



Source: Data from Goddard Institute for Space Studies, Intergovernmental Panel on Climate Change, National Academy of Sciences, National Aeronautics and Space Agency, National Center for Atmospheric Research, and National Oceanic and Atmospheric Administration.

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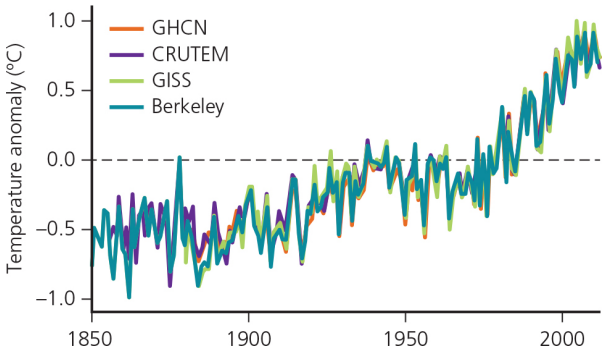
Temperature Changes in Past 160 Years

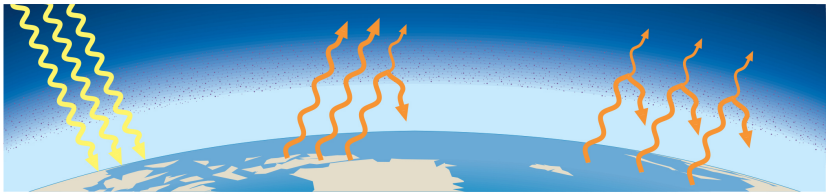


Source: Data from IPCC 2013

How Do Scientists Study Climate Change?

- **Geologic Records**
  - Ice cores (bubbles of trapped air)
  - Sediment cores
- **Atmospheric Measurements**
  - Temperature measurements back to 1861
  - Chemical composition of air

The Earth's Natural Greenhouse Effect



(a) Rays of sunlight penetrate the lower atmosphere and warm the Earth's surface.

(b) The Earth's surface absorbs much of the incoming solar radiation and degrades it to longer-wavelength infrared (IR) radiation, which rises into the lower atmosphere. Some of this IR radiation escapes into space as heat and some is absorbed by molecules of greenhouse gases and emitted as even longer-wavelength IR radiation, which warms the lower atmosphere.

(c) As concentrations of greenhouse gases rise, their molecules absorb and emit more infrared radiation, which adds more heat to the lower atmosphere.

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What Are the Major Greenhouse Gases?

- Carbon dioxide
- Methane
- Nitrous oxide
- Chlorofluorocarbons
- Hydrochlorofluorocarbons
- Hydrofluorocarbons
- Halons
- Carbon tetrachloride

Activities Contributing to Increased Greenhouse Gases

- Increased use of fossil fuels
- Deforestation and clearing
- Raising large number of cattle
- Planting rice
- Using inorganic fertilizers

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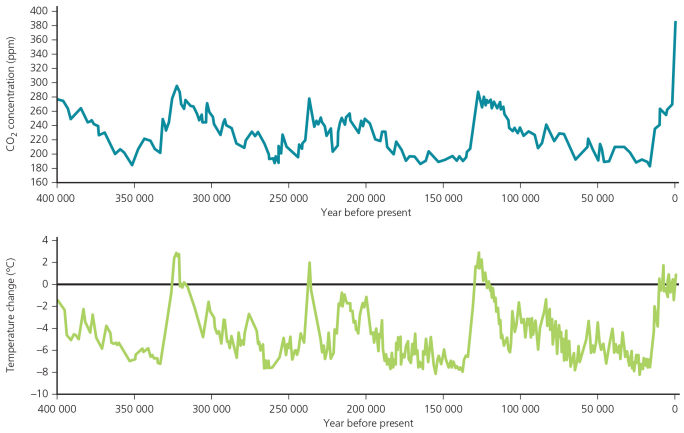
Carbon Dioxide and Global Temperature



Source: Data from Intergovernmental Panel on Climate Change and National Center for Atmospheric Research.

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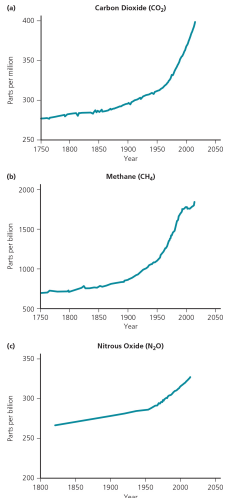
Increasing Greenhouse Gases



Source: Data from EPA, Climate Change Indicators, 2015.

Which Country Is the Largest Greenhouse Gas Emitter?

- **United States** - Highest annual emissions until 2006
  - Largest cumulative emitter (25%)
- **China** - Outpaced the U.S. starting in 2006
  - 5% cumulative emission
  - Only 25% of U.S. emissions/capita
- **Canada** - 2% per year
  - 4 times global average per capita

Is the Troposphere Warming?

2013 IPCC findings

- 90 to 99% probability that troposphere is warming
  - 1983-2012 were likely warmest in past 800 years
  - From 1880-2012, average global temperature raised 0.85ºC
  - Upper 700 metres of ocean warmed between 1971 and 2010
  - Glaciers and sea ice are melting and shrinking.
  - During past century, average sea level rose 0.1 to 0.2m

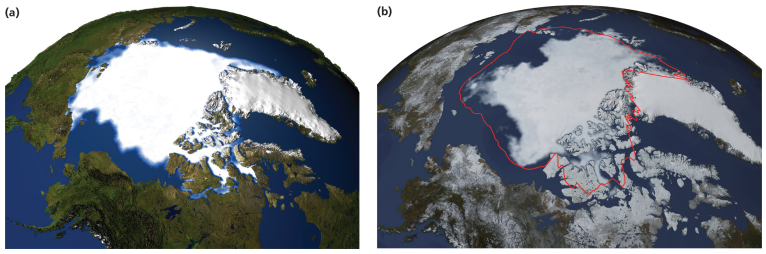
Global warming *vs.* global climate change

Case Study: Warning Signals from the Earth's Ice and Snow

- Why is the Arctic an early warning system?
  - Temperature increases are greater in polar regions due to convection.
- Floating ice and land-based glaciers are melting.
  - Reflects less sunlight back to space
- Many glaciers have disappeared.
- Loss of frozen water reserves

Case Study: Warning Signals from the Earth's Ice and Snow continued

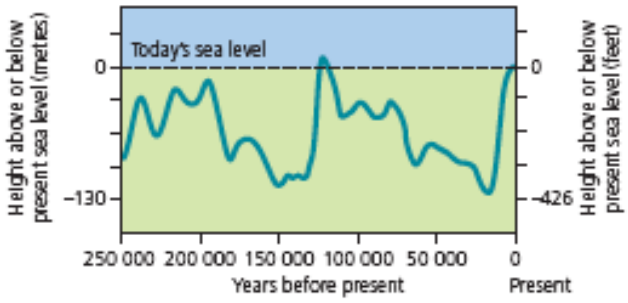
1979 2012



U.S. Goddard Space Flight Center, and NASA, and National Snow and Ice Data Center

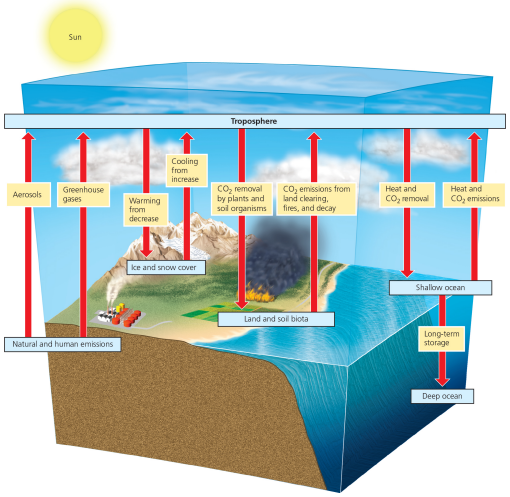
NASA/Goddard Space Flight Center Scientific Visualization Studio. The Blue Marble data is courtesy of Reto Stockli (NASA/GSFC).

Case Study: Warning Signals from the Earth's Ice and Snow continued 2



Source: Adapted from Tom Garrison, *Oceanography: An Invitation to Marine Science,* 3/E, © 1998. Brooks/Cole.

Major Processes That Determine Atmospheric Greenhouse Gas



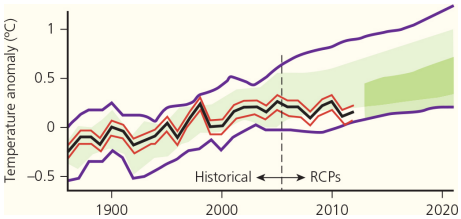
Projecting Future Changes in the Earth's Climate

- Climate models to project future changes

  Models closely match past global temperature changes since 1850.

  New, stronger evidence that most of warming of past 50 years is anthropogenic

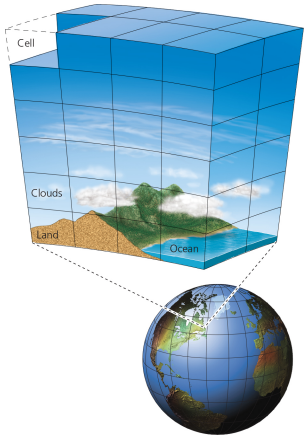
– Models (between two grey lines) have been shown to reflect reality (black line).



Source: IPCC Assessment Report 5 (2013).

Projecting Future Changes in the Earth's Climate continued

- **Global circulation model**
  - Moderating effects of oceans
  - Clouds and water vapour
  - Air pollution
  - Changes in solar output



Factors Affecting the Earth's Temperature: Can the Oceans Store More CO_2 and Heat?

- Oceans remove ~29% of excess CO_2 from atmosphere
- Absorb heat and transfer to deep ocean for storage
- We don't fully understand the impacts of ocean currents.
  - How quickly can they transfer heat?
  - How long will that heat be stored?

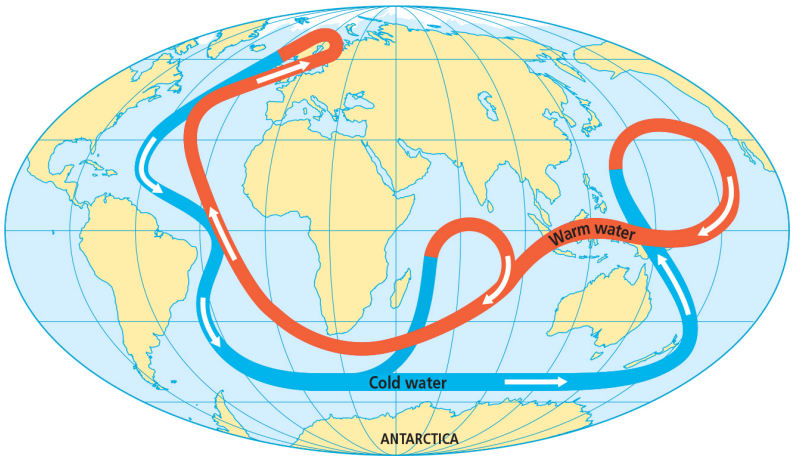
Factors Affecting the Earth's Temperature: Can the Oceans Store More CO_2 and Heat?

continued

- Will the ocean release the stored CO_2 in the near future?
- Does global warming accelerate the water cycle?
- Will this mean some areas will become cooler while others will become warmer?

- Ocean acidification
  - Absorption of CO_2 forms carbonic acid – pH dropping up to 0.5 units
  - Many effects on marine life – dissolve many shelled organisms

Factors Affecting the Earth's Temperature: Shallow and Deep Ocean Currents



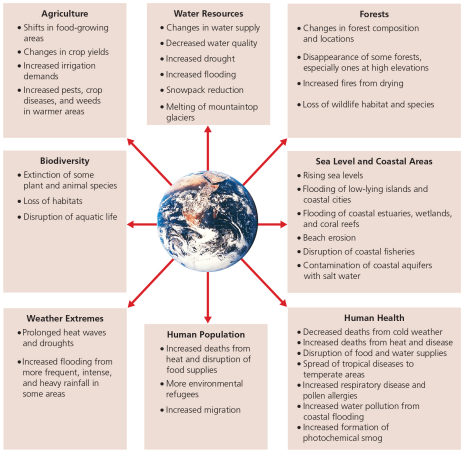
Factors Affecting the Earth's Temperature: Cloud Cover and Outdoor Air Pollution

- **Increased cloud cover**
  - Causes
    - Increased temperature
    - Aerosol and particulate pollution
  - Results
    - Warming? Absorb and release heat
    - Cooling? Reflecting sunlight into space
    - Solar dimming?

Factors Affecting the Earth's Temperature: Increased Photosynthesis

- **Photosynthesis** may increase if plants are not limited by water or nutrients.
  - Removes CO_2 from atmosphere but only *temporarily* until the plant dies
- Changes in Amazon tree species composition affects rate of CO_2 uptake

Possible Effects of a Warmer World



Source: Data from Intergovernmental Panel on Climate Change, U.S. Global Climate Change Research Program, U.S. National Academy of Sciences.

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Possible Effects of a Warmer World: Benefits

- Less severe winters
- More precipitation in some dry areas
- Less precipitation in some wet areas
- Increased food production in some areas
- Expanded population and ranges of some species

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How Might a Warmer Troposphere Affect Canada?

- Longer growing season
- Warmer in both summer and winter
- Higher seas in British Columbia and Eastern Canada
- More droughts in Prairies
- Arctic and Subarctic subject to widespread changes
- Great Lakes—more heat waves and lower lake levels

Dealing With the Threat of Global Warming: Where Do We Disagree?

- **Which is higher if greenhouse gases are reduced?**
  - Economic costs or economic benefits
- **Who should take responsibility for reducing greenhouse gas emissions?**
  - Developed or developing nations or both
- **Should we regulate the reduction of emissions?**
  - Voluntary or legislated

Dealing With the Threat of Global Warming: What Are Our Options?

- **Wait and see**
  - Do more research before we act.
- **Act now**
  - Follow the precautionary principles.
  - We pay to insure our homes and lives against far less certain events.
- **Act now with no regrets**
  - Strategies have benefit regardless of the extent of global warming.

Solutions to Global Warming I

Prevention

- Cut fossil fuel use (especially coal).
- Shift from coal to natural gas.
- Improve energy efficiency.
- Shift to renewable energy resources.
- Transfer energy efficiency and renewable energy technologies to developing countries.

Cleanup

- Remove CO_2 from smokestack and vehicle emissions.
- Store (sequester) CO_2 by planting trees.
- Sequester CO_2 deep underground.
- Sequester CO_2 in soil by using no-till cultivation and taking crop land out of production.

Solutions to Global Warming II

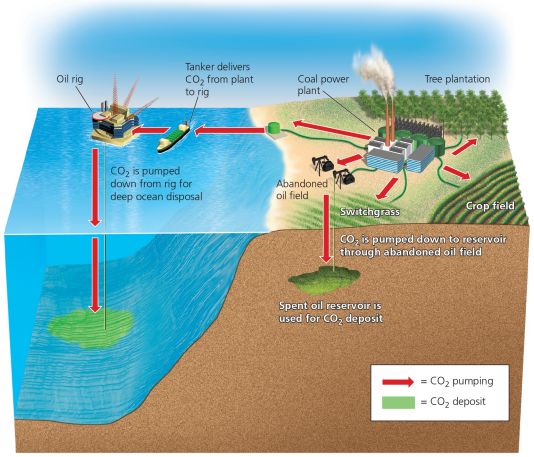
Prevention

- Reduce deforestation.
- Use more sustainable agriculture.
- Limit urban sprawl.
- Reduce poverty.
- Slow population growth.

Cleanup

- Sequester CO_2 in the deep ocean.
- Repair leaky natural gas pipelines and facilities.
- Use feeds that reduce CH4 emissions by belching cows.

Carbon Sequestration



Carbon and Energy Taxes

Advantages

- Simple to administer
- Clear price on carbon
- Covers all emitters
- Predictable revenues

Disadvantages

- Tax laws can get complex.
- Vulnerable to loopholes
- Doesn't guarantee lower emissions
- Politically unpopular

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

What Is Being Done to Reduce Greenhouse Gas Emissions?

Kyoto Protocol (1997)

2012 target:

- Directed at 39 worst CO_2-emitting nations
- Reduce CO_2, CH_4, N_2O emissions by 5% from 1990 levels
- Emissions trading permitted between nations

What Is Canada's Position on Kyoto?

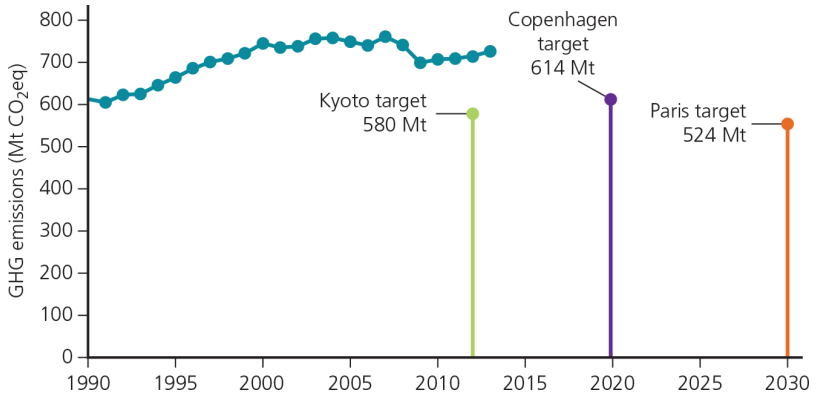
- **2001**: The United States withdraws from Kyoto
- **2002**: Canada ratifies Kyoto, commits to 6% reduction
- **2006**: Canadian government no longer in favour
  - National **Clean Air Act** introduced instead

    Cut emissions to 65% by 2050

What Is Canada's Position on Kyoto?
continued

- **2009**: Canada signs **Copenhagen Accord**
  - Commit to reduce emissions by 17% below 2005 levels by 2020 (607 Mt)
  - Less ambitious that Kyoto goal of 558 Mt
- **2011**: Canada withdraws from Kyoto Protocol
  - Argues that without the United States and China included, Kyoto will fail
- **2014:** Canada issues U.S.-style regulations, aiming to reduce to 2008 levels by 2025

Canadian Greenhouse Gas Emissions



Source: National Inventory Report, http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=5B59470C-1.
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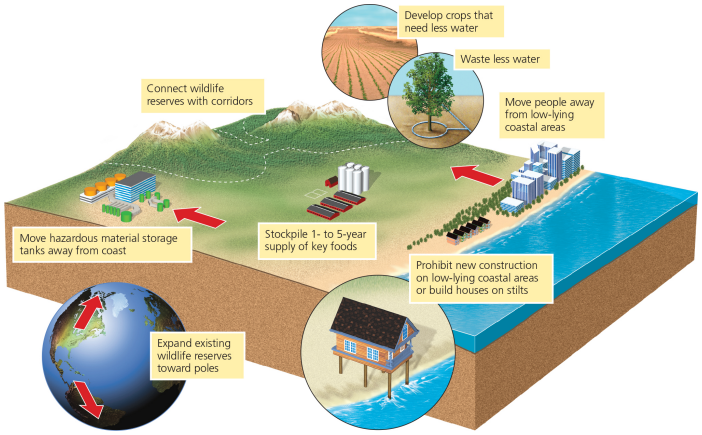
How Can We Prepare for Global Warming?



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Ozone Depletion in the Stratosphere: Causes

- Numerous persistent chemicals
  - Chlorofluorocarbons (CFCs)
  - Halons
  - Methyl bromide
  - Carbon tetrachloride
  - Methyl chloroform
  - Hydrogen chloride

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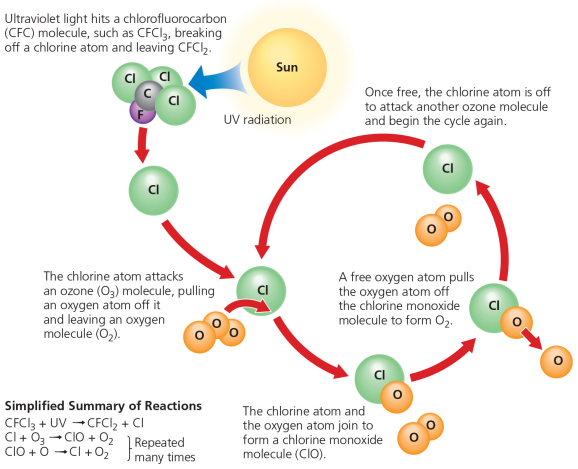
How CFCs React with Ozone

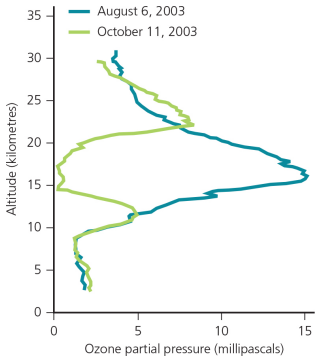


Former Uses of CFCs

- Air conditioners
- Refrigerators
- Spray cans
- Cleaners for electronic parts
- Sterilizing medical instruments
- Fumigants for granaries and cargo ships

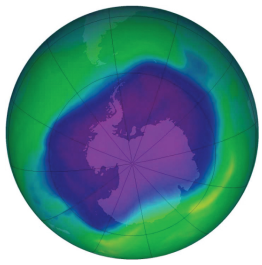
Seasonal Ozone Layer Thinning at the Poles

Polar vortex winds collect ozone-depleting chemicals in ice crystals in winter, setting up ClO formation + ozone depletion in spring.



Source: Data from National Oceanic and Atmospheric Administration

Antarctic ozone



Source: NASA, 2006

Why Should We Be Worried About Ozone Depletion?

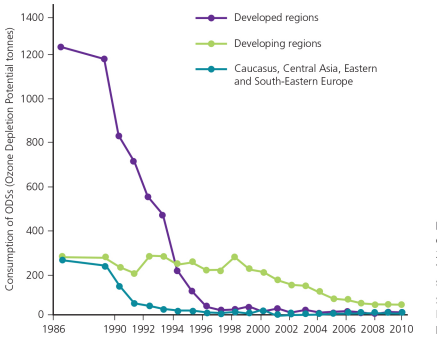
- **Stratospheric ozone blocks 95% of UV radiation to prevent**
  - Increased incidence and severity of sunburn
  - Increase in eye cataracts
  - Increased incidence of skin cancer
  - Immune system suppression
  - Increase in acid deposition
  - Lower crop yields and decline in productivity
  - Accelerated global warming

UV Light in Your Life

- UV Index 8-10
  - Burn in 10-20 minutes
- UV Index 6-7
  - Burn in 20-30 minutes
- UV Index 3-5
  - Burn in 30-60 minutes
- UV Index 0-2
  - Burn in >60 minutes

Protecting the Ozone Layer

- Switch to CFC alternatives
- **Montreal Protocol 1987**
  Successful phase-out of 98% of ozone-depleting substances listed
  Atmospheric levels expected to return to pre-1980 state by 2050
- **Copenhagen Protocol 1992**
  Amendment accelerating the phase-out



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Conclusion

- Climate change is thought to be our biggest single challenge.
- Solutions require acknowledgement of science and international intervention.
- Effects are and will be wide-ranging and global in scope.