ENVIRONMENT

THE SCIENCE BEHIND THE STORIES

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Ch 17

Atmospheric Science and Air Pollution

Part 2: Environmental Issues the Search for Solutions

PowerPoint® Slides prepared by
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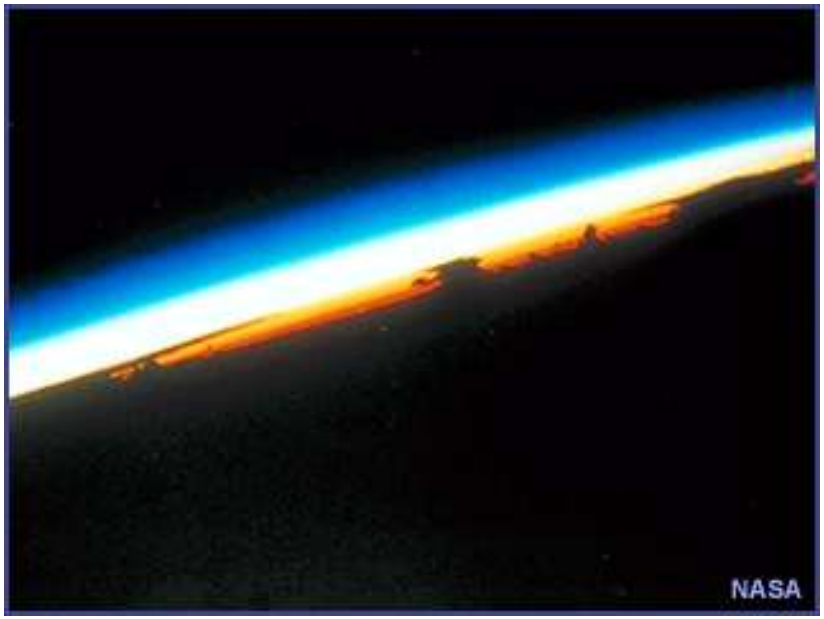
The Atmosphere

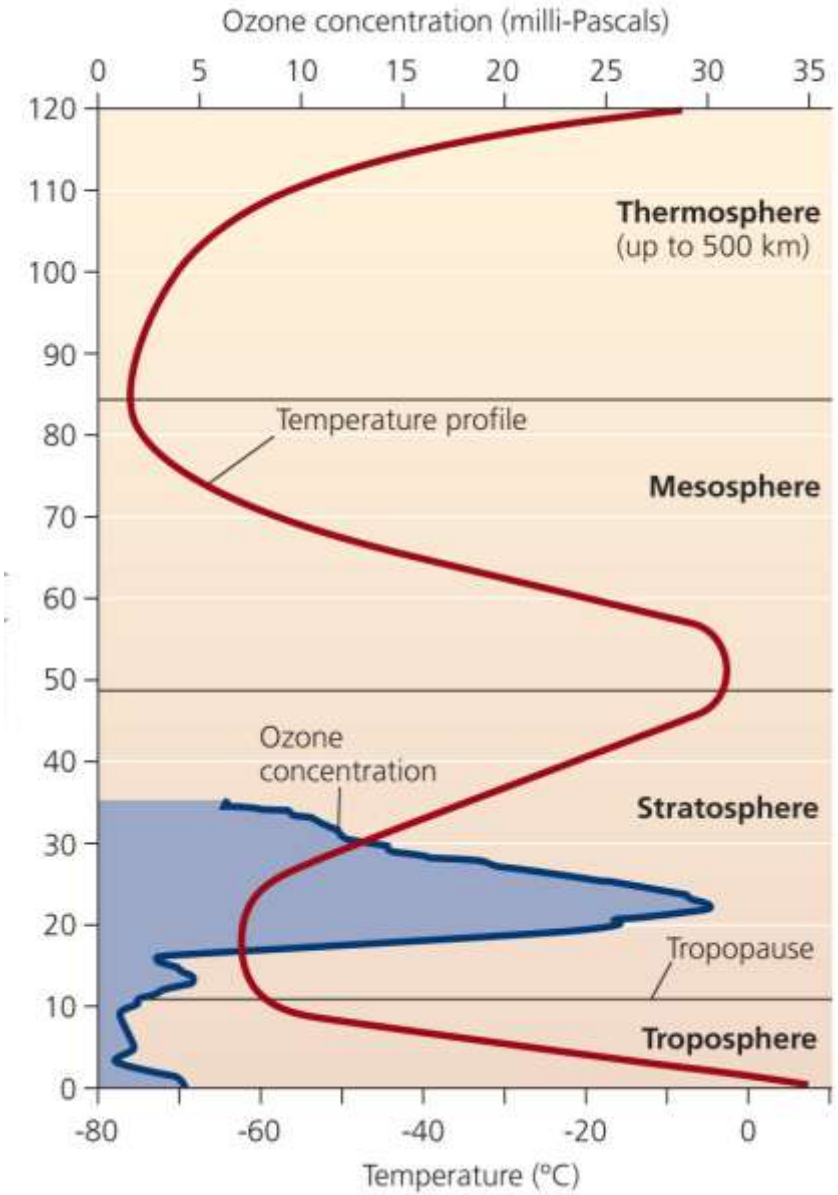
- **Atmosphere** = the thin layer (*1/100th of Earth's diameter*) of gases that surrounds Earth
  - Absorbs radiation and moderates climate
  - Transports and recycles water and nutrients
  - *78% nitrogen gas, 21% oxygen gas, 1% other gases*
  - Its four layers differ in temperature, density and composition



The layers of the atmosphere

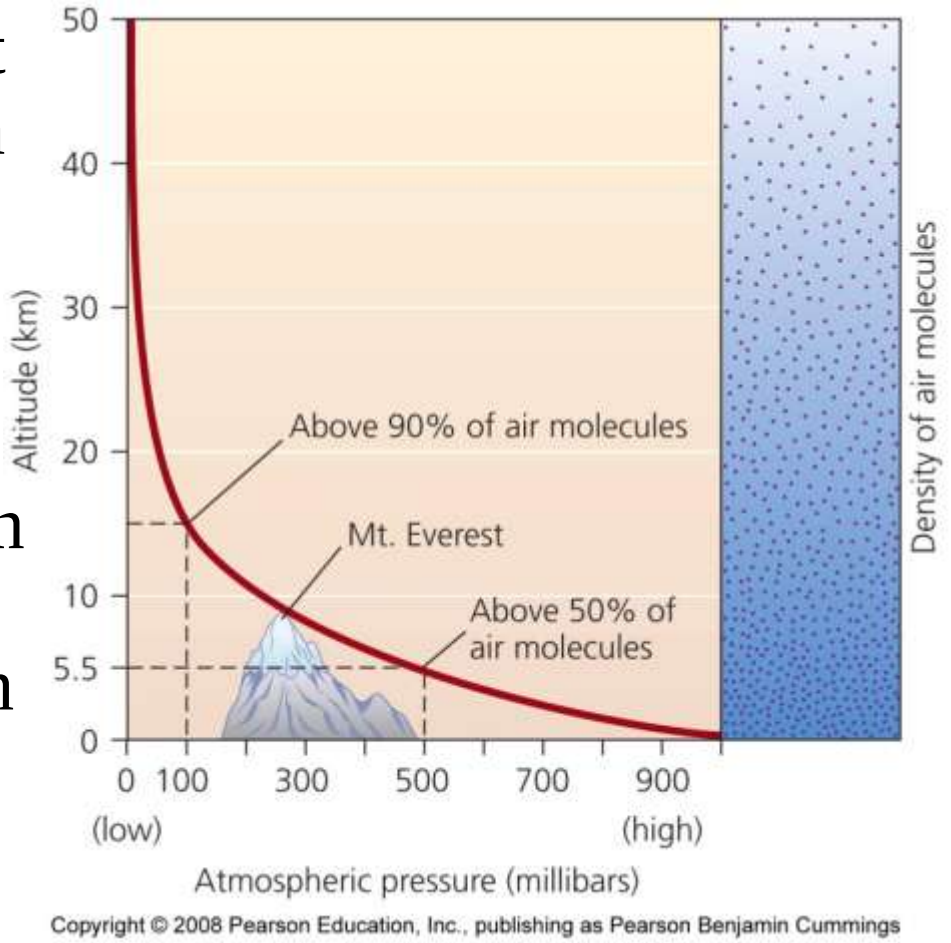
- **Troposphere** = bottommost layer
  - Air for breathing, weather
  - Temperature declines with altitude
  - **Tropopause** = limits mixing between troposphere and the layer above it
- **Stratosphere** = 11-50 km (7-31 mi) above sea level
  - Drier and less dense, with little vertical mixing
  - Contains UV radiation-blocking ozone, 17-30 km (10-19 mi) above sea level
- **Mesosphere** = 50-80 km (31-56 mi) above sea level
  - Extremely low air pressure
- **Thermosphere** = atmosphere's top layer
  - Extends upward to 500 m (300 mi)

The atmosphere's four layers



Atmospheric properties

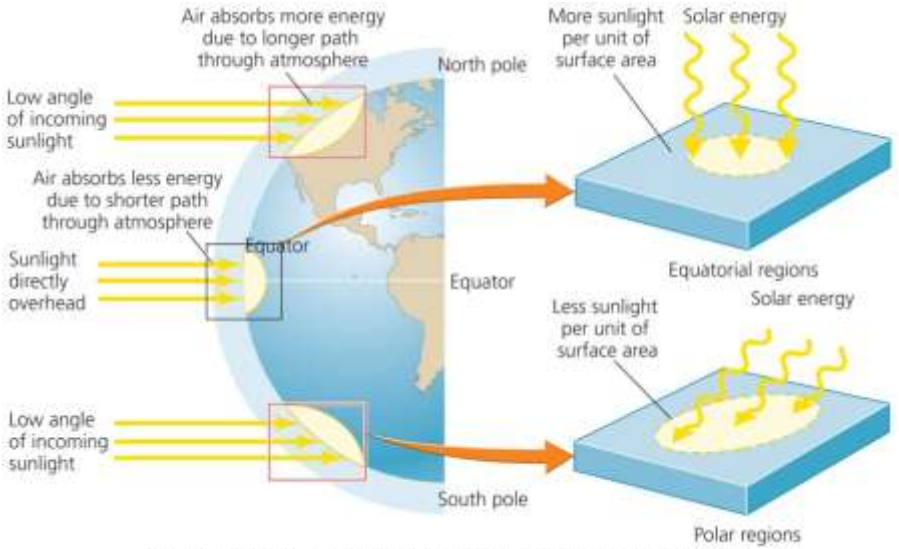
- **Atmospheric pressure** = measures the force per unit area produced by a column of air
  - Decreases with altitude
- **Relative humidity** = the ratio of water vapor a given volume of air contains to the amount it could contain at a given temperature
- **Temperature** = varies with location and time



Solar energy heats the atmosphere

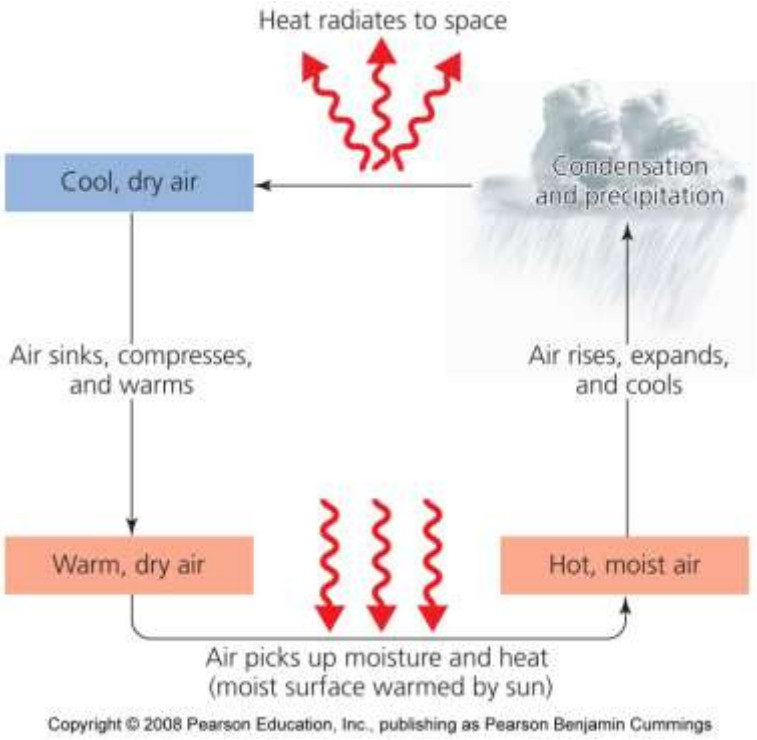
The spatial relationship between the Earth and sun determines the amount of solar energy striking the Earth

- Energy from the sun
  - *Heats air*
  - *Moves air*
  - *Creates seasons*
  - Influences weather and climate
- Solar radiation is highest near the equator



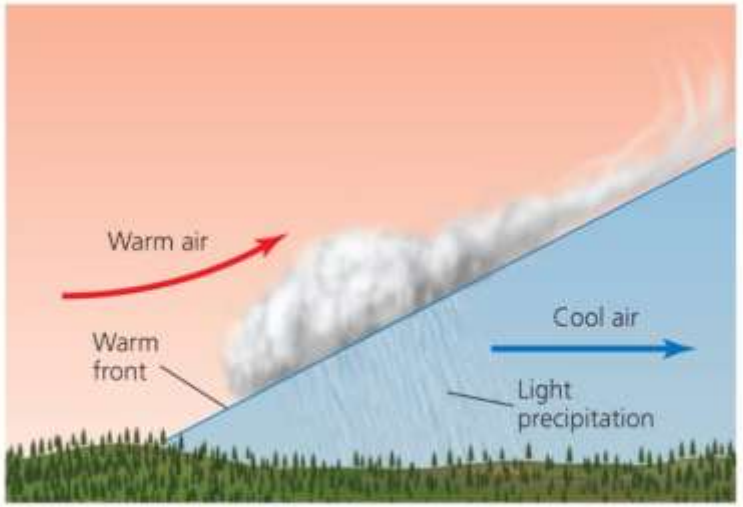
Solar energy causes air to circulate

- Air near Earth's surface is warmer and moister than air at higher latitudes
- **Convective circulation** = less dense, warmer air rises and creates vertical currents
  - Rising air expands and cools
  - Cool air descends and becomes denser, replacing warm air
  - Influences both weather (short term) and climate (long term)

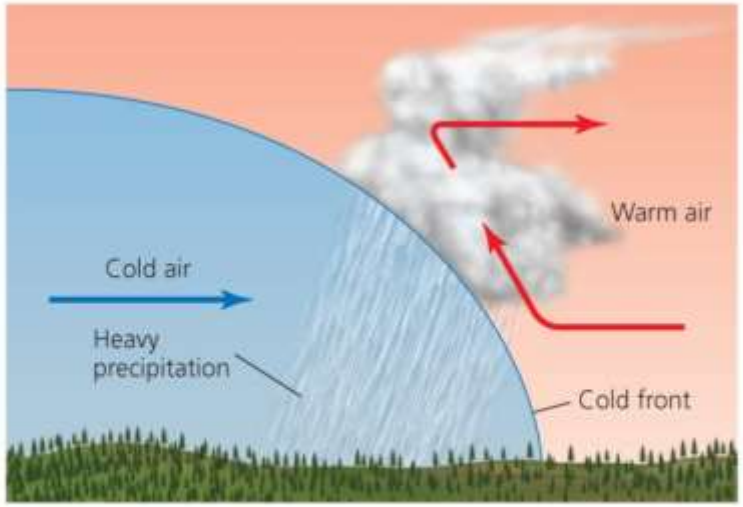


Air masses produce weather

- **Front** = the boundary between air masses that differ in temperature, moisture, and density
- **Warm Front =** the boundary where warm moist air replaces colder, drier air
- **Cold Front =** the boundary where colder, drier air displaces warmer, moister air



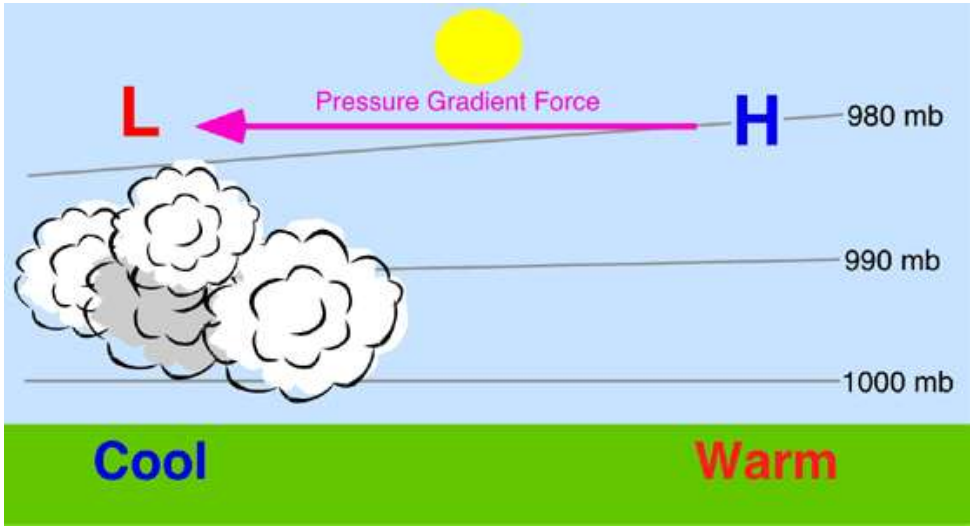
(a) Warm front



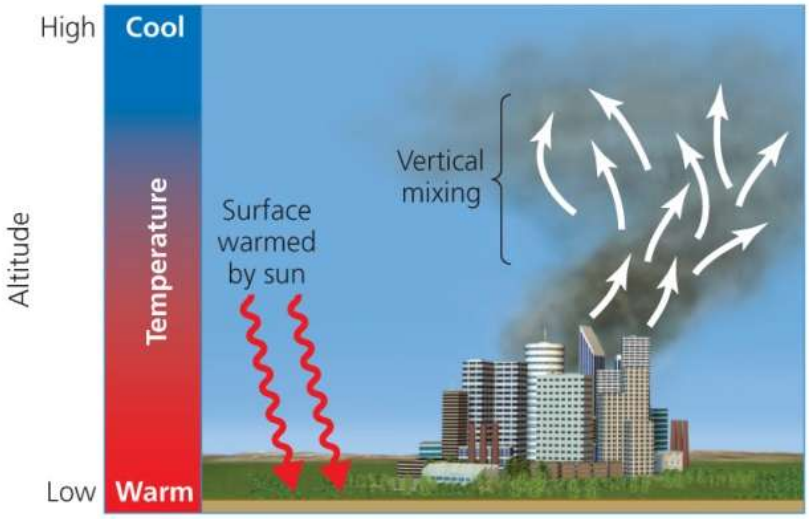
(b) Cold front

Air masses have different atmospheric pressures

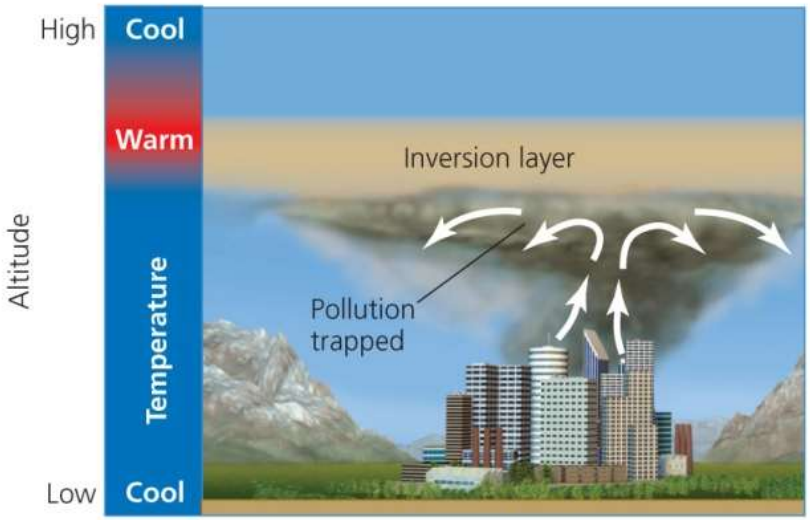
- **High-pressure system** = air that moves away from a center of high pressure as it descends
  - Brings fair weather
- **Low-pressure system** = air moves toward the low atmospheric pressure at the center of the system and spirals upward
  - Clouds and precipitation



Thermal inversion



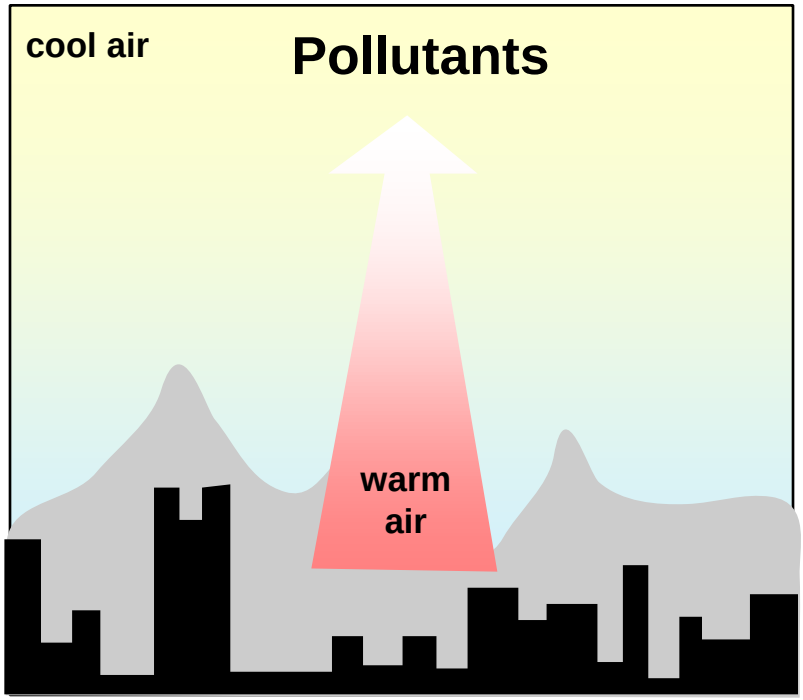
(a) Normal conditions



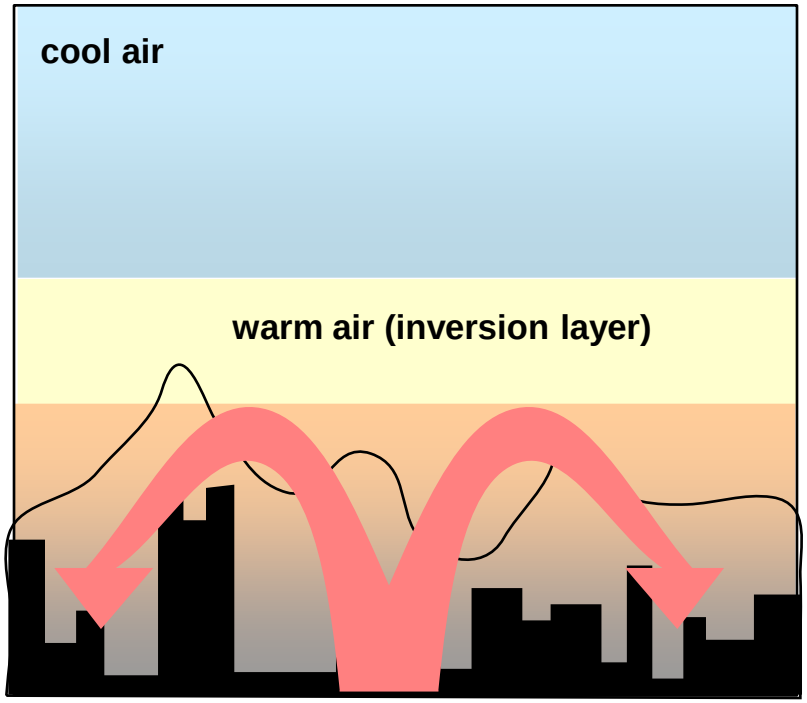
(b) Thermal inversion

- Usually, tropospheric air temperature decreases as altitude increases
  - *Warm air rises, causing vertical mixing*
- **Thermal inversion** = a layer of cool air occurs beneath a layer of warmer air
  - **Inversion layer** = the band of air in which temperature rises with altitude
  - Denser, cooler air at the bottom of the layer *resists mixing*

Thermal Inversion

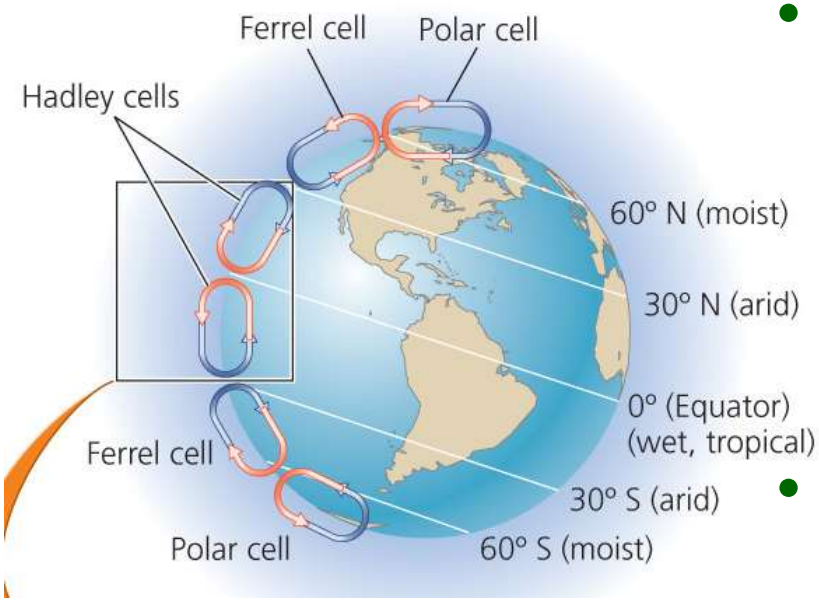


- surface heated by sun
- warm air rises (incl. pollutants)
- cools off, mixes with air of equal density & disperses



- surface cools rapidly (night)
- a layer of warm air overlays surface
- polluted surface air rises but cannot disperse

The atmosphere



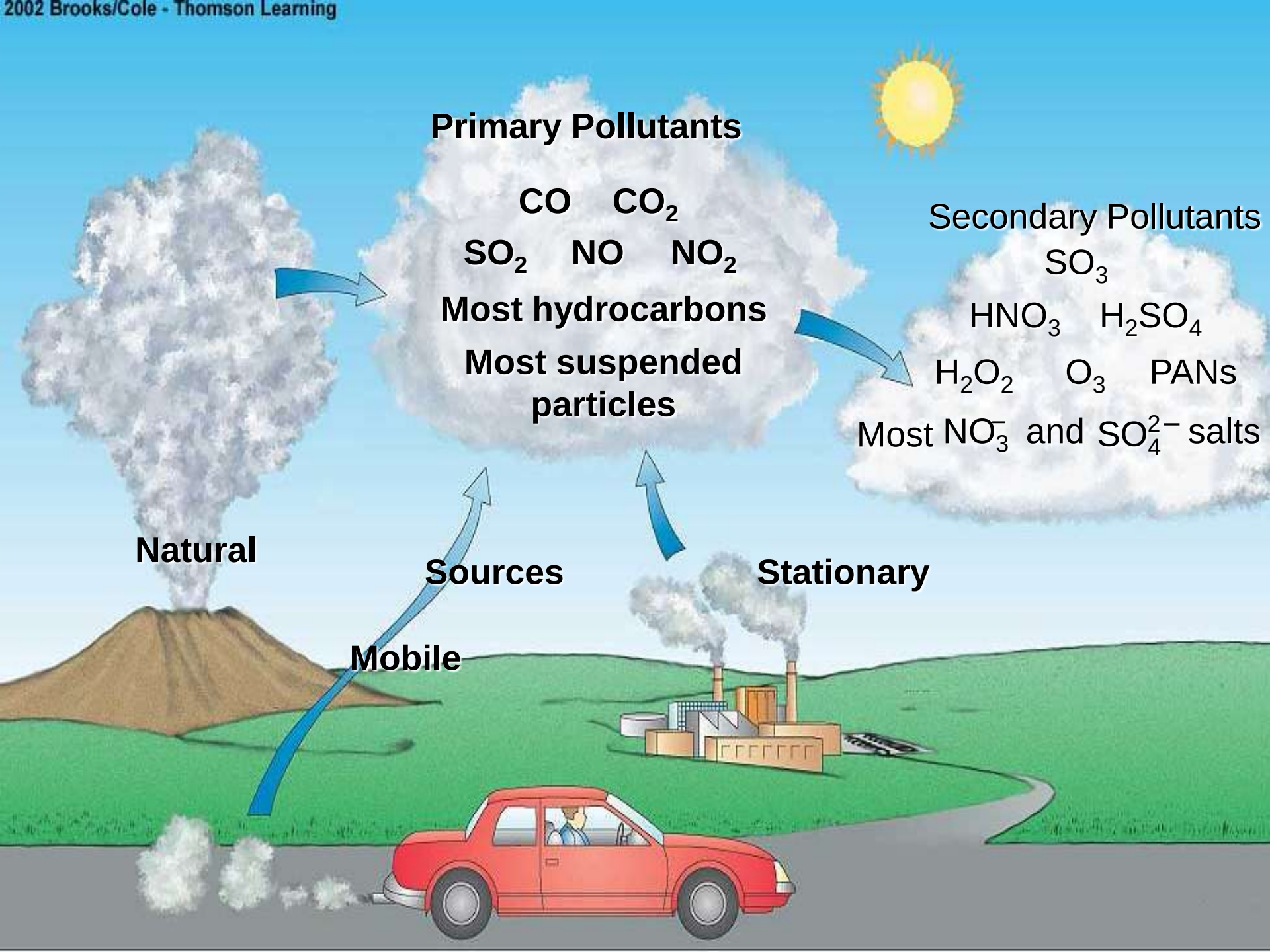
- Convective currents contribute to climatic patterns and affect moisture distribution
- **Hadley cells** = near the equator, surface air warms, rises, and expands
  - Releases moisture and heavy rainfall near the equator
- **Ferrel cells and polar cells** = lift air
  - Creates precipitation at 60 degrees latitude north and south
  - Causes air to descend at 30 degrees latitude

Outdoor air pollution

- **Air pollutants** = gases and particulate material added to the atmosphere
  - Can affect climate or harm people
- **Air pollution** = the release of pollutants
- **Outdoor (ambient) air pollution** = pollution outside
  - Has recently decreased due to government policy and improved technologies in developed countries
  - Developing countries and urban areas still have significant problems

Types of outdoor air pollution

- Air pollution can come from natural, mobile or stationary sources
- **Point Sources** = specific spots where large quantities of pollutants are discharged (power plants and factories)
- **Nonpoint Sources** = more diffuse, consisting of many small sources (automobiles)
- **Primary Pollutants** = *directly harmful and can react to form harmful substances (soot and carbon dioxide)*
- **Secondary Pollutants** = *form when primary pollutants interact or react with constituents or components of the atmosphere (tropospheric ozone and sulfuric acid)*



Legislation addresses pollution

- Congress passed a series of laws starting in 1955
- The Clean Air Act of 1970
  - Sets standards for air quality, limits on emissions
  - Provides funds for pollution-control research
  - Allows citizens to sue parties violating the standards
- The Clean Air Act of 1990
  - Strengthens standards for auto emissions, toxic air pollutants, acidic deposition, stratospheric ozone depletion
  - Introduced emissions trading

The EPA sets standards

- Environmental Protection Agency (EPA) sets nationwide standards for emissions of toxic pollutants
- States monitor air quality and develop, implement, and enforce regulations within their borders
  - If a state's plans for implementation are not adequate, the EPA can take over enforcement

Criteria Air Pollutants

EPA uses six + one "criteria pollutants" as indicators of air quality

1. Nitrogen Dioxide: NO_2
2. Ozone: ground level O_3
3. Carbon monoxide: *CO*
4. Lead: *Pb*
5. Particulate Matter: PM_{10} *(PM 2.5)*
6. Sulfur Dioxide: SO_2

+1 Volatile Organic Compounds: *(VOCs)*

EPA established for each concentrations above which adverse effects on health may occur

Nitrogen Dioxide (NO_2)

- *Properties*: reddish brown gas, formed as fuel burnt in car, strong oxidizing agent, forms Nitric acid in air
- *Effects*: **acid rain, lung and heart problems, decreased visibility (yellow haze), suppresses plant growth**
- *Sources*: fossil fuels combustion, power plants, forest fires, volcanoes, bacteria in soil
- *Class*: Nitrogen oxides (NO_x)
- *EPA Standard*: 0.053 ppm

Ozone (O_3)

- *Properties*: colorless, unpleasant odor, major part of photochemical smog
- *Effects*: lung irritant, damages plants, rubber, fabric, eyes, 0.1 ppm can lower PSN by 50%,
- *Sources*: **Created by sunlight acting on NO_x and VOC , photocopiers, cars, industry, gas vapors, chemical solvents, incomplete fuel combustion products**
- *Class*: photochemical oxidants

Carbon Monoxide (CO)

- *Properties*: colorless, odorless, heavier than air, 0.0036% of atmosphere
- *Effects*: binds tighter to Hb than O_2, mental functions and visual acuity, even at low levels
- *Sources:* **incomplete combustion of fossil fuels 60 - 95% from auto exhaust**
- *Class*: carbon oxides (CO_2, CO)
- *EPA Standard*: 9 ppm

5.5 billion tons enter atmosphere/year

Lead (Pb)

- *Properties*: grayish metal
- *Effects*: accumulates in tissue; affects kidneys, liver and nervous system (children most susceptible); mental retardation; possible carcinogen; 20% of inner city kids have [high]
- *Sources*: **particulates, smelters, batteries**
- *Class*: toxic or heavy metals
- *EPA Standard*: 1.5 ug/m^3

  2 million tons enter atmosphere/year

Suspended Particulate Matter (PM_{10})

- *Properties*: particles suspended in air (<10 um)
- *Effects*: **lung damage, mutagenic, carcinogenic, teratogenic**
- *Sources:* burning coal or diesel, volcanoes, factories, unpaved roads, plowing, lint, pollen, spores, burning fields
- *Class*: SPM: dust, soot, asbestos, lead, PCBs, dioxins, pesticides
- *EPA Standard*: 50 ug/m^3 (annual mean)

Sulfur Dioxide (SO_2)

- *Properties*: colorless gas with irritating odor
- *Effects*: produces acid rain (H_2SO_4), breathing difficulties, eutrophication due to sulfate formation, lichen and moss are indicators
- *Sources*: **burning high sulfur coal or oil, smelting or metals, paper manufacture**
- *Class*: sulfur oxides
- *EPA Standard*: 0.3 ppm (annual mean)

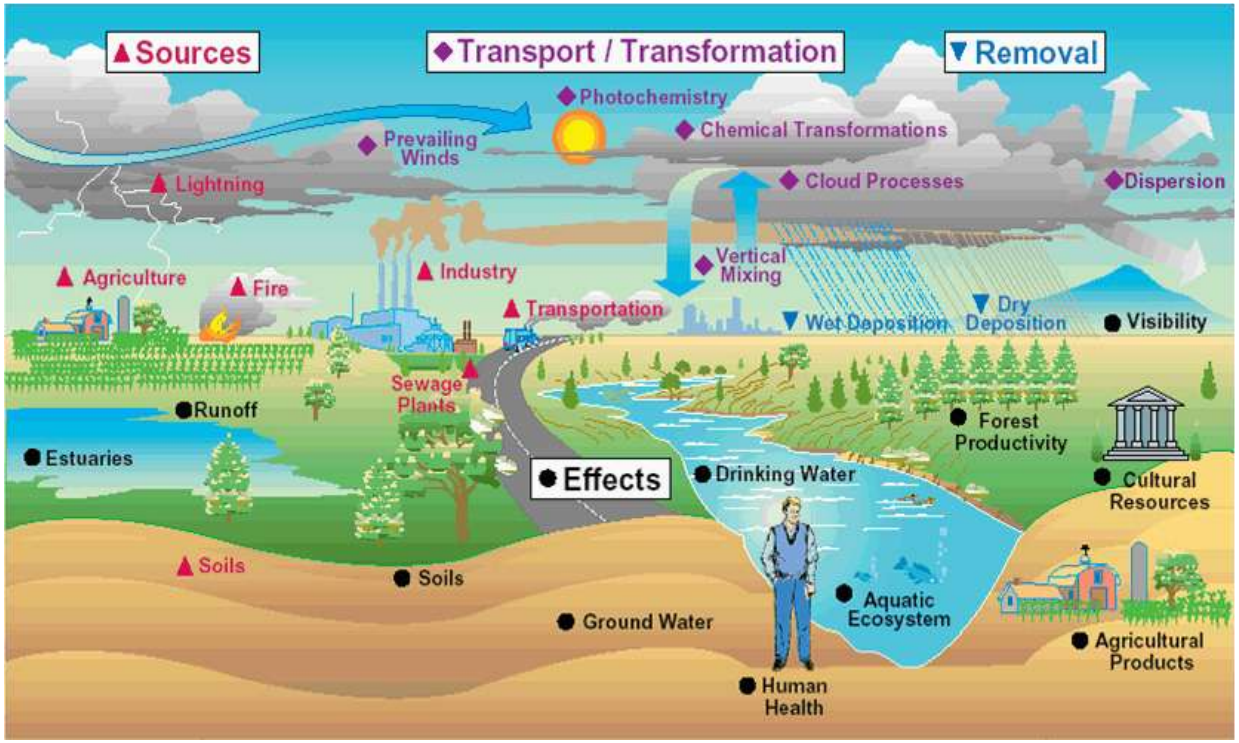
  Combines with water and NH_4 to increase soil fertility

VOCs (Volatile Organic Compounds)

- *Properties*: organic compounds (hydrocarbons) that evaporate easily, usually aromatic
- *Effects*: eye and respiratory irritants; carcinogenic; liver, CNS, or kidney damage; damages plants; lowered visibility due to brown haze; global warming
- *Sources:* **vehicles (largest source), evaporation of solvents or fossil fuels, aerosols, paint thinners, dry cleaning**
- *Class*: HAPs (Hazardous Air Pollutants)

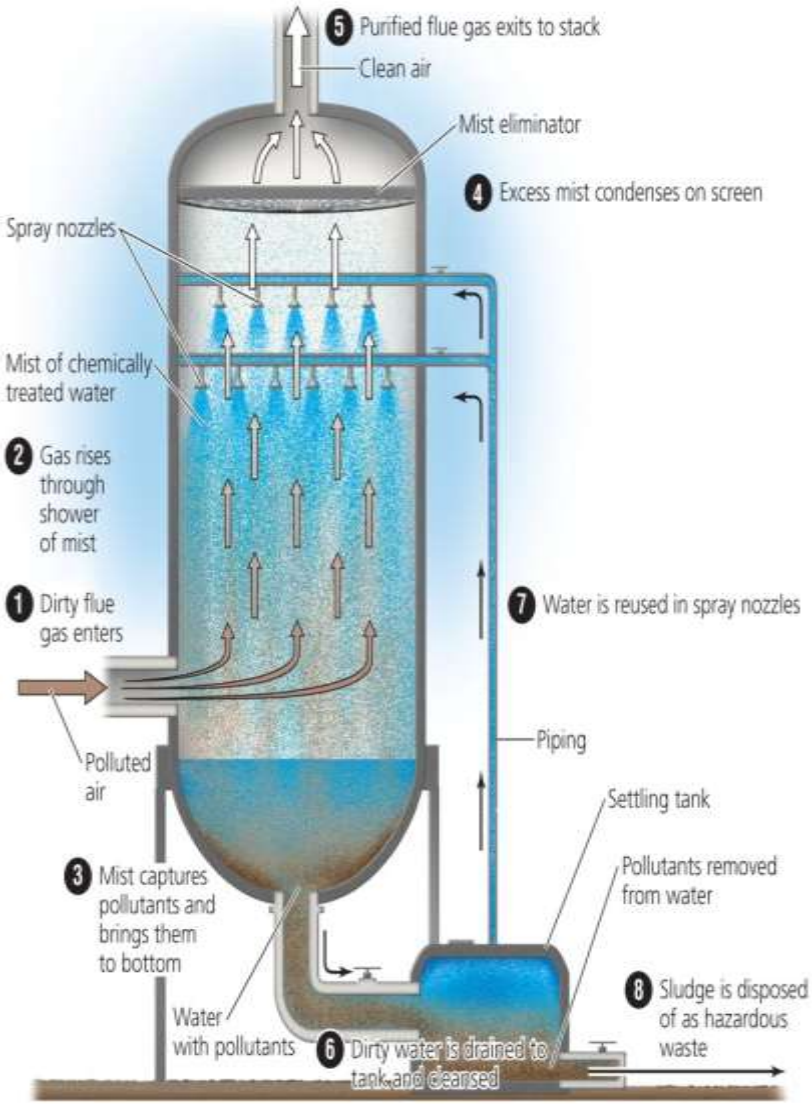
Other Air Pollutants

- **Carbon dioxide**
- **ChloroFluoroCarbons**
- Formaldehyde
- Benzene
- **Asbestos**
- Manganese
- Dioxins
- Cadmium



Reasons for the decline in U.S. pollution

- Cleaner-burning vehicles and catalytic converters decrease carbon monoxide
- Permit-trading programs and clean coal technologies reduce SO_2 emissions
- **Scrubbers** = *technologies that chemically convert or physically remove pollutants before they leave the smokestacks*
- Phaseout of leaded gasoline
- Improved technologies and federal policies



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Burning fossil fuels produces industrial smog

- **Smog** = unhealthy mixtures of air pollutants over urban areas
- **Industrial (gray air) smog** = industries burn coal or oil
  - Occurs in cooler, hilly areas
  - Government regulations in developed countries reduced smog
  - Coal-burning industrializing countries face significant health risks

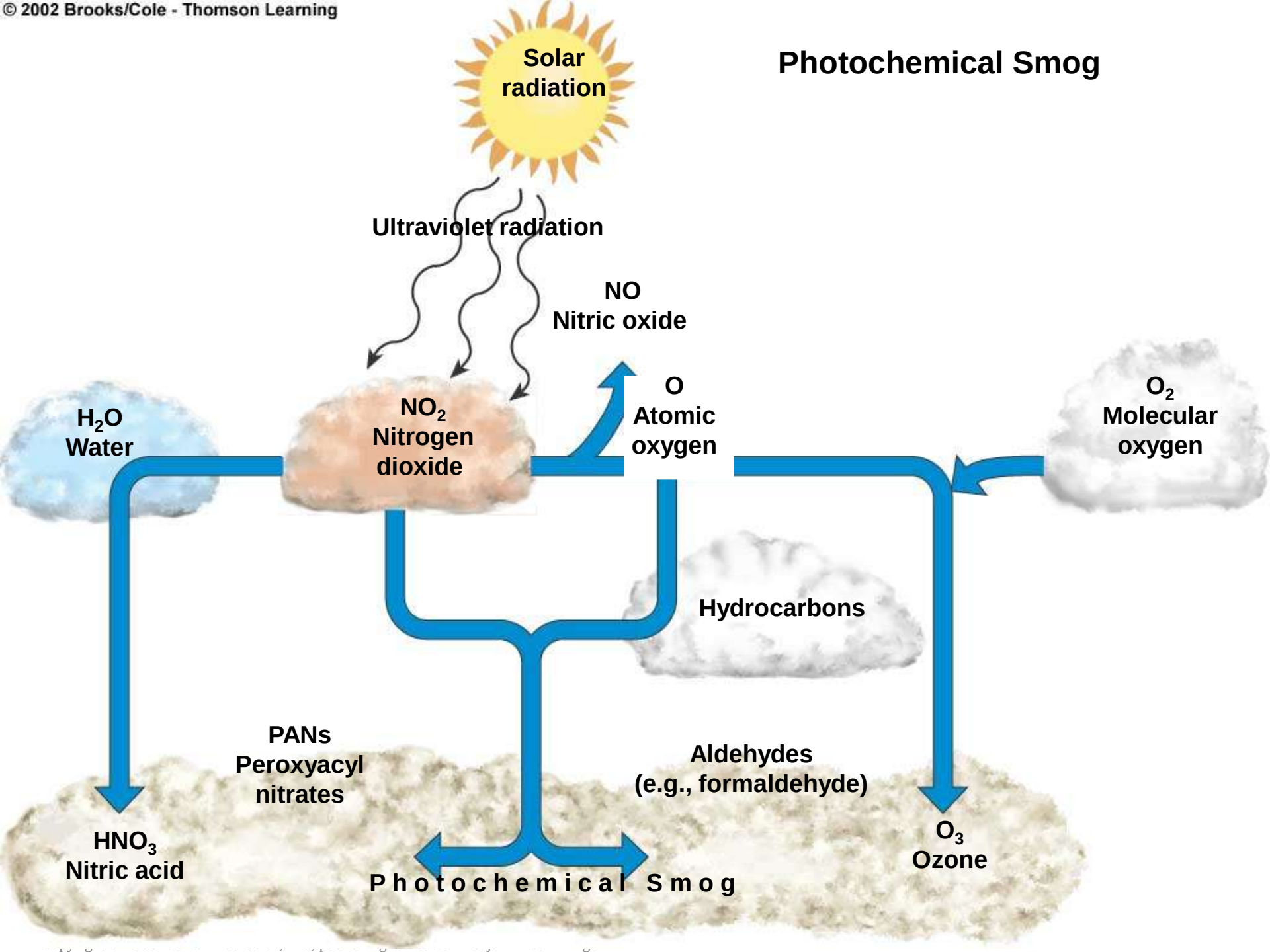
(b) Donora, Pennsylvania, at midday in the 1948 smog event

Photochemical (brown air) smog

(b) Photochemical smog over Mexico City

- Produced by a series of reactions
  - Hot, sunny cities surrounded by mountains
  - Light-driven reactions of primary pollutants and normal atmospheric compounds
  - Morning traffic exhaust releases pollutants
  - Irritates eyes, noses, and throats
  - Vehicle inspection programs in the U.S. have decreased smog

Photochemical Smog



Industrial smog

Coal and oil

Sulfur (S) in coal and oil

Oxygen (O_2)

Burning

Sulfur dioxide (SO_2)

Oxygen (O_2)

Sulfur trioxide (SO_3)

Water vapor (H_2O)

Sulfuric acid (H_2SO_4)

Ammonia (NH_3)

Ammonium sulfate ($(NH_4)_2SO_4$)

Carbon (C)

Oxygen (O_2)

Burning

Carbon monoxide (CO) and carbon dioxide (CO_2)

(a) Burning sulfur-rich oil or coal without adequate pollution control technologies

Photochemical smog

Nitrogen (N_2)

Oxygen (O_2)

Burning

Nitric oxide (NO)

Oxygen (O_2)

Nitrogen dioxide (NO_2)

UV radiation

Water vapor (H_2O)

Hydrocarbons

Nitric oxide (NO)

and

Oxygen atom (O)

Nitric oxide (NO)

and

Nitric acid (HNO_3)

Peroxyacyl nitrates (PANs)

Oxygen (O_2)

Ozone (O_3)

Acid rain

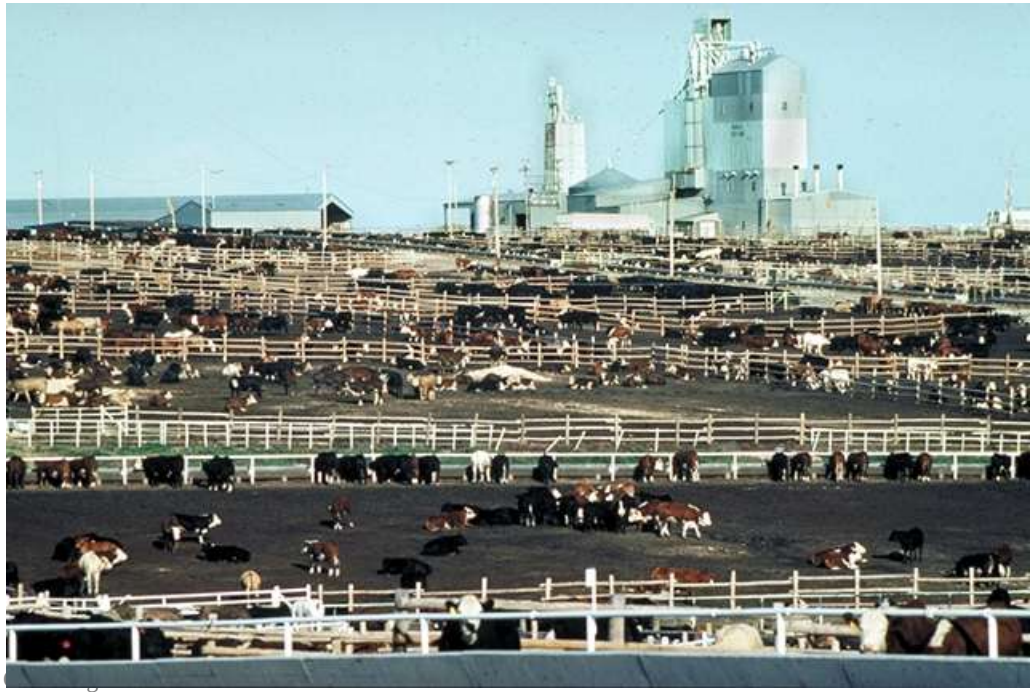
Volatile organic compounds (VOCs)

Various pollutants

(a) Formation of photochemical smog

Air quality is a rural issue, too

- **Airborne pesticides** from farms
- Industrial pollutants drifting from cities, factories and powerplants
- **Feedlots**, where cattle, hogs, or chickens are raised in dense concentrations
  - Voluminous amounts of methane, hydrogen sulfide, and ammonia

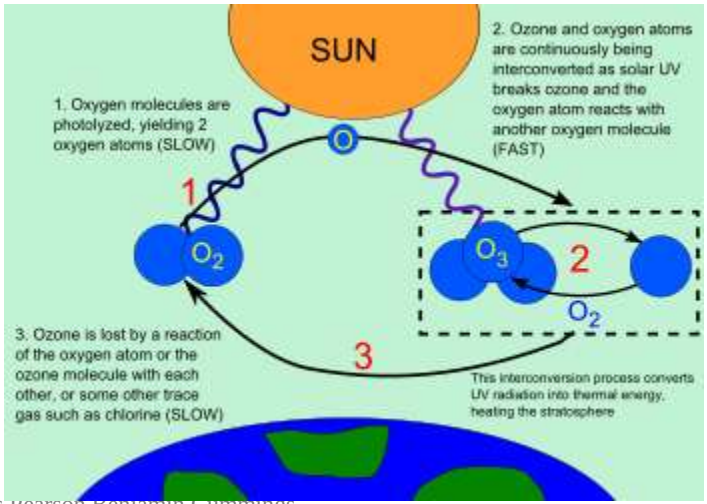


Industrializing nations face increasing pollution

- Outdoor pollution is increasing
- Factories and power plants do not control emissions
- Citizens burn traditional fuels (wood and charcoal)
- China has the world's worst air pollution
  - 80% of Chinese cities have emissions above the safety threshold
  - Asian brown cloud = a 2-mile thick layer of pollution that reduces sunlight, affects climate, decreases productivity, and kills thousands each year

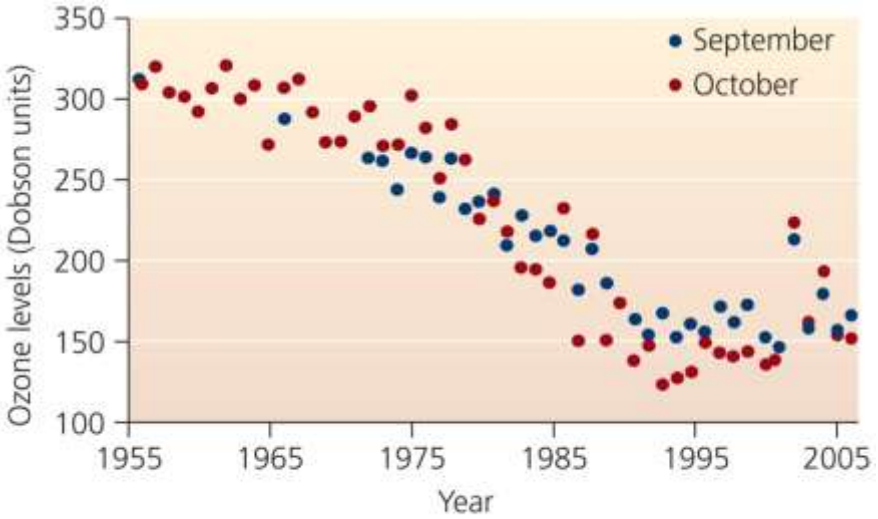
Synthetic chemicals deplete stratospheric ozone

- **Ozone layer** = ozone in the lower stratosphere
  - 12 ppm concentrations effectively block incoming damaging ultraviolet radiation
- **Chlorofluorocarbons (CFCs)** = chemicals that attack ozone
  - 1 million metric tons/year were produced
  - Releases chlorine atoms that split ozone

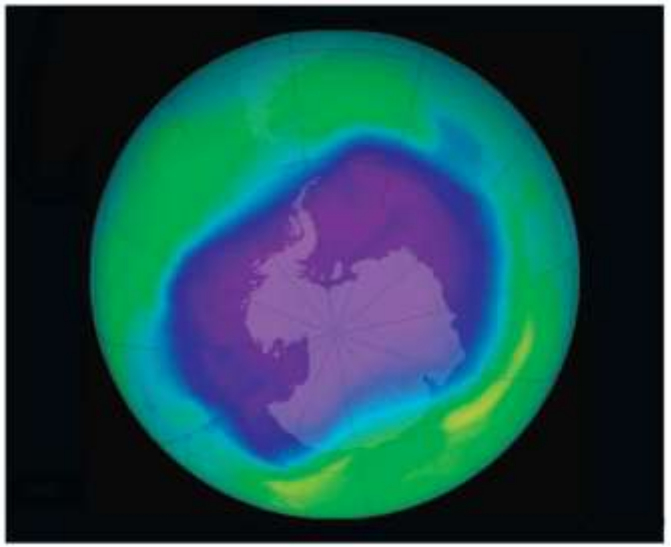


The hole in the ozone

- **Ozone hole** = ozone levels over Antarctica **had** declined by 40-60%
  - Depletion also in the Arctic and globally
  - Causes skin cancer, harms crops and decreases ocean productivity
  - IS UNRELATED TO CLIMATE CHANGE



(a) Monthly mean ozone levels at Halley, Antarctica



(b) The "ozone hole" over Antarctica, September 24, 2006

The Montreal Protocol addressed ozone depletion

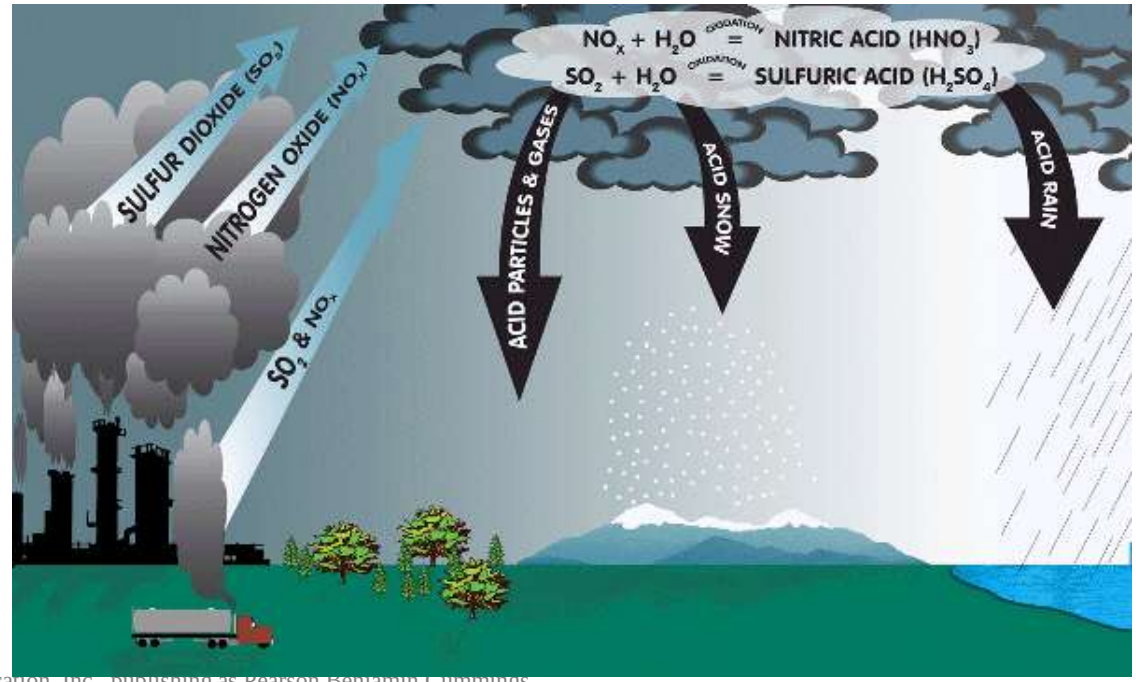
- **Montreal Protocol** = 180 nations agreed to cut CFC production in half
  - Follow-up agreements deepened cuts, advanced timetables and addresses other ozone-depleting chemicals
  - Today, production and use of ozone-depleting chemicals has decreased 95%
  - The ozone layer is beginning to recover
- Challenges still face us
  - *CFCs will remain in the stratosphere for a long time*
  - Nations can ask for exemptions to the ban

The Montreal Protocol is a success

- Considered the biggest environmental success story
  - Policymakers included industry in helping solve the problem
  - Implementation of the plan allowed an adaptive management strategy that changed strategies in response to new scientific data, technological advances, and economic figures

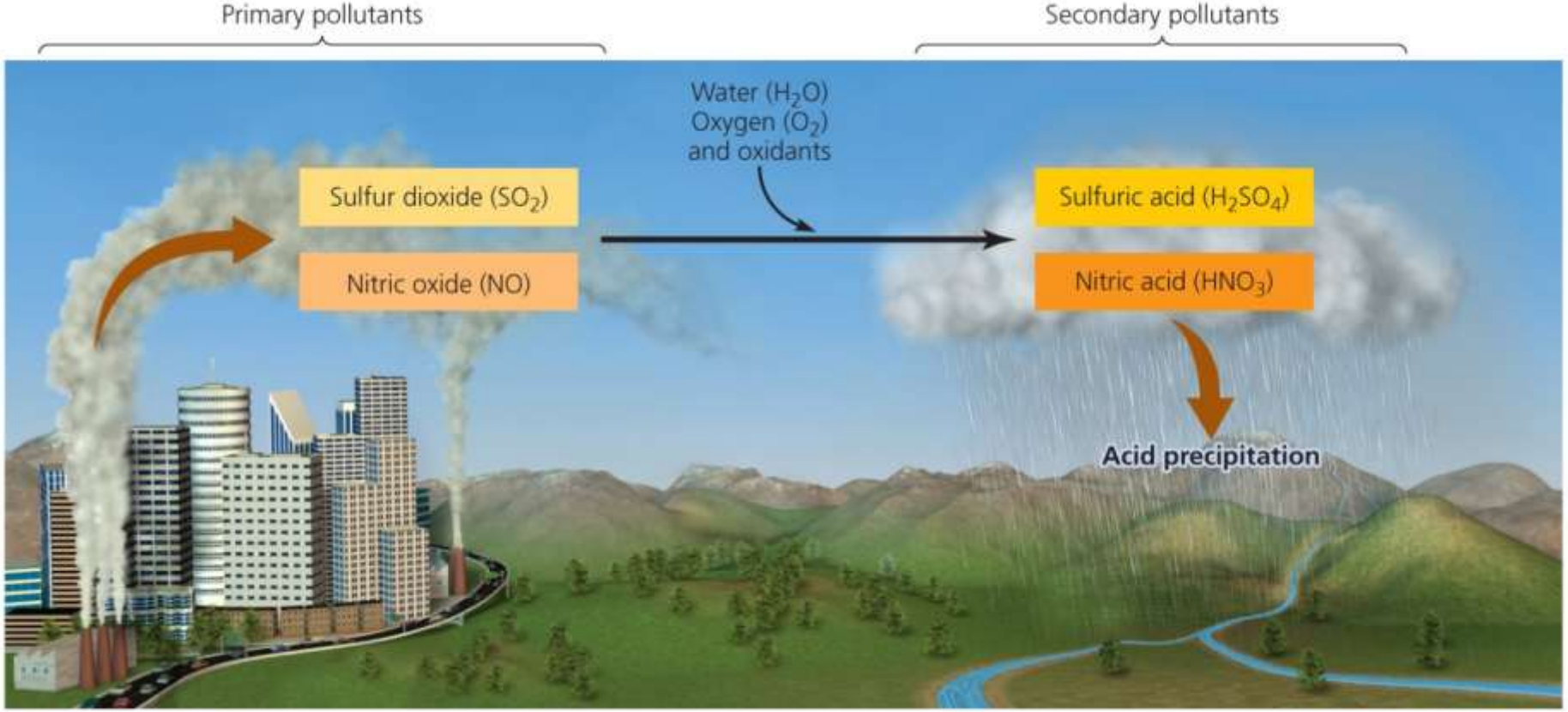
Acid deposition is another transboundary issue

- **Acidic deposition** = the deposition of acid, or acid-forming pollutants, from the atmosphere onto Earth's surface
  - **Acid rain** = precipitation of acid
  - **Atmospheric deposition** = the wet or dry deposition on land of pollutants



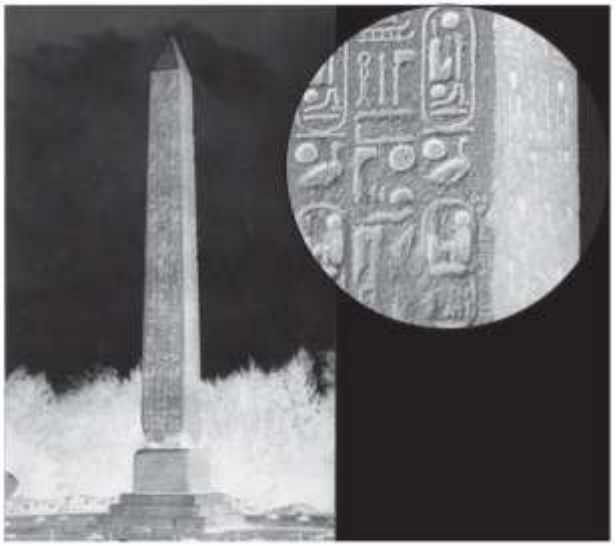
Sources of acid deposition

- Originates from burning fossil fuels that release sulfur dioxide and nitrogen oxides
  - These compounds react with water to form sulfuric and nitric acids



Effects of acid deposition

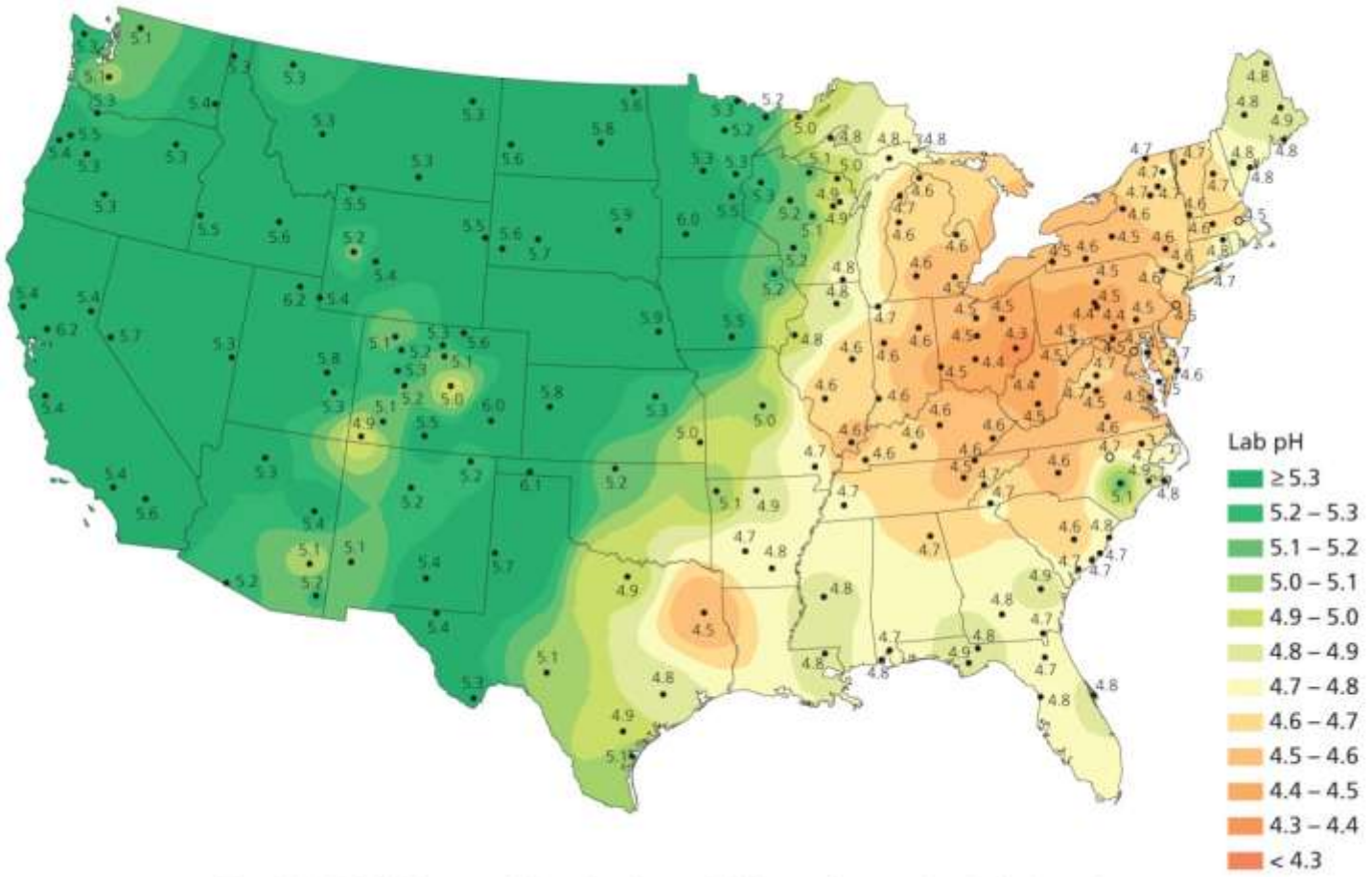
- Nutrients are leached from topsoil
- Soil chemistry is changed
- Metal ions (aluminum, zinc, etc.) are converted into soluble forms that pollute water
- Widespread tree mortality
- Affects surface water and kills fish
- Damages agricultural crops
- Erodes stone buildings, corrodes cars, erases writing on tombstones



(a) Before acid rain damage

(b) After acid rain damage

pH of precipitation in the U.S.



Many regions of acidification are downwind of major sources of pollution

Acid deposition has not been greatly reduced

- New technologies such as scrubbers have helped
- SO_2 emissions are lower
- But, NO_x emissions are higher
- Acid deposition's effects are worse than predicted
  - The Clean Air Act cannot restore ecosystems
  - More must be done to control acid deposition

Indoor air pollution

- Indoor air contains higher concentrations of pollutants than outdoor air
  - 6,000 people die per day from indoor air pollution
- *The average U.S. citizen spends 90% of the time indoors*
  - Exposed to synthetic materials that have not been comprehensively tested
  - To reduce heat loss and improve energy efficiency, building ventilation systems were sealed off ventilation and windows put in that did not open, trapping pollutants inside

Important Indoor Air pollutants

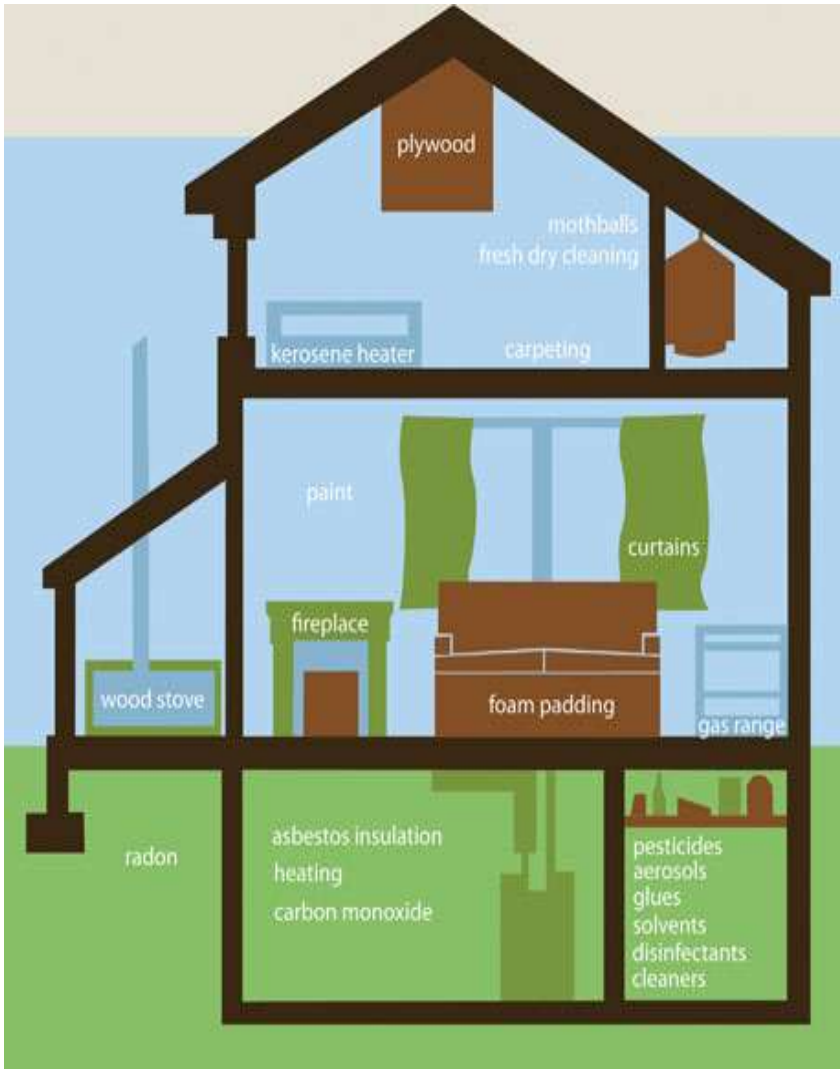
- Nitrogen dioxide
- Carbon monoxide
- Formaldehyde
- Volatile Organic Compounds (VOCs)
- House dust mites (and other allergens, e.g. from pets)
- Tobacco smoke
- Fine particles
- Chlorinated organic compounds (e.g. pesticides)
- Asbestos and man-made mineral fibers
- Radon

Tobacco smoke and radon

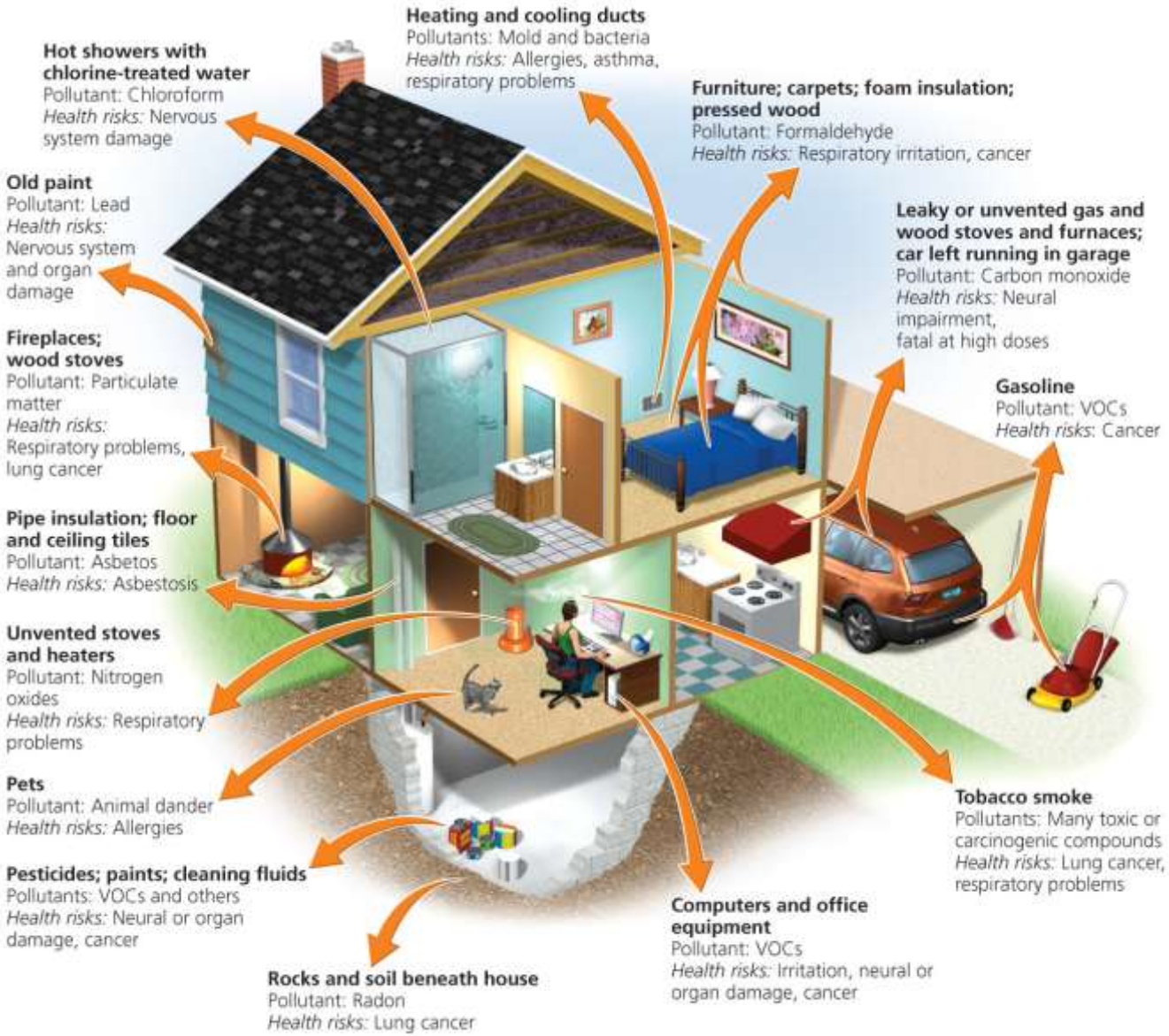
- The most dangerous indoor pollutants in the developed world
- Secondhand smoke from cigarettes is especially dangerous
  - Containing over 4000 dangerous chemicals
  - *Causes eye, nose, and throat irritation*
  - Smoking has declined in developed nations
- Radon causes 20,000 deaths a year in the U.S.
  - *A radioactive gas resulting from natural decay of rock; soil; or water, which can seep into buildings*
  - Most homes are now radon resistant

Volatile Organic Compounds (VOCs)

- The most diverse group of indoor air pollutants
  - *Released by everything from plastics and oils to perfumes and paints*
  - Most VOCs are released in very small amounts
  - Also include pesticides, which are found indoors more often than outdoors due to seepage
  - Formaldehyde, which leaks from pressed wood and insulation, irritates mucous membranes and induces skin allergies



Sources of indoor air pollution



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Living organisms can pollute indoors

- Tiny living organisms can also pollute
- Includes dust mites and animal dander worsen asthma
- Fungi, mold, mildew, airborne bacteria cause severe allergies, asthma, and other respiratory ailments
- **Sick building syndrome** = a sickness produced by indoor pollution with general and nonspecific symptoms
  - Solved by using low-toxicity building materials and good ventilation

We can reduce indoor air pollution

- In developed countries:
  - Use low-toxicity material
  - *Monitor air quality*
  - Keep rooms clean
  - *Limit exposure to chemicals*
- In developing countries:
  - Dry wood before burning
  - *Cook outside*
  - Use less-polluting fuels (natural gas)