Air pollution II

Air pollution II

- Air pollution problems
  - Indoor air pollution
  - Acid rain
  - Ozone depletion
  - Global warming

Indoor air pollution

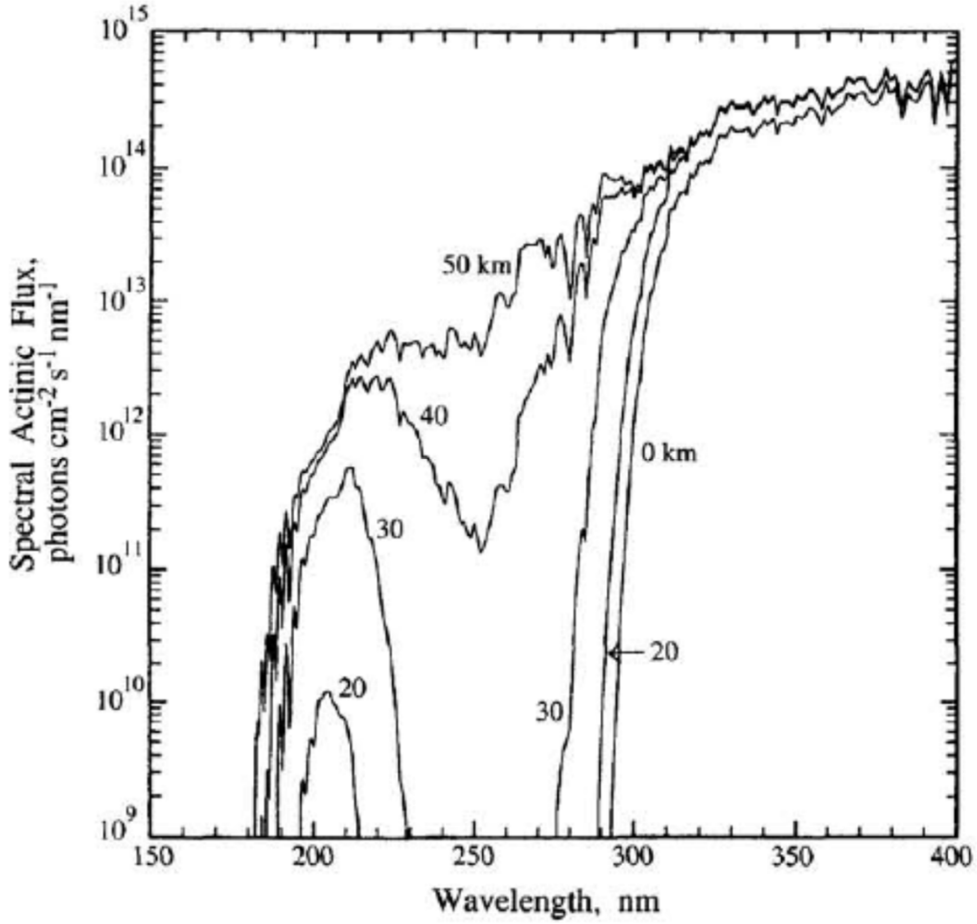
- Difficult to regulate!
- CO and NO_x from gas ranges, ovens, heaters, and cigarette smoke
- Cigarette smoke also contains toxic compounds including carcinogens
- Bioaerosols: bacteria, viruses, fungi, mites, and pollen
- Radon: emitted from the ground (high in basements)
- Volatile organic compounds
  - ex) formaldehyde: emitted from building materials ("sick building syndrome")
- Heavy metals: emitted from paints

Acid rain

- SO_2 and NO_x in the air undergo series of reactions to form sulfuric acid (H_2SO_4) and nitric acid (HNO_3)
- pH in natural rain has a pH near 5.6 (why?)
- Rain pH in polluted areas can go below 5, sometimes even close to 2
- Adverse effects
  - Acidification of rivers, lakes, and soil: damage aquatic/terrestrial ecosystem including fish deaths
  - Nutrient leaching from soil (ex: Mg)
  - Mobilize aluminum from soil: enhanced uptake of Al by plants, increase Al concentration in waters (toxic effect)

Ozone depletion

- Ozone protects life if it is in the stratosphere
- Ozone layer (20-40 km or up above the ground): absorbs UV light



Ozone depletion

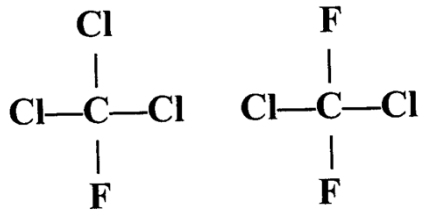
- Photoreactions of ozone to absorb UV light

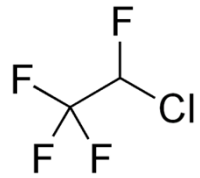
$$O_2 + UV \rightarrow 2O$$

$$O + O_2 + M \rightarrow O_3 + M \qquad (M\text{: a third molecule})$$

$$O_3 + UV \rightarrow O_2 + O$$

- CFCs (chlorofluorocarbons)
  - Good for refrigerants, propellants, and solvents
  - Stable in the troposphere → can reach the stratosphere without break-down
  - Causes ozone depletion





Ozone depletion

- Ozone destruction mechanism by CFCs

$$CCl_3F + UV \rightarrow CCl_2F + Cl$$

$$Cl + O_3 \rightarrow ClO + O_2$$

$$ClO + O \rightarrow Cl + O_2$$

$$O_3 + O \rightarrow 2O_2$$

  - Cl atom acts as a catalyst
  - One CFC molecule can destroy uncountable number of ozone molecules

Ozone depletion

- Efforts to stop ozone depletion
  - **Montreal Protocol** on Substances That Deplete the Ozone Layer
    - An international treaty agreed on September 16, 1987
    - Became effective in January 1989
    - Eight revisions: 1990, 1991, 1992, 1993, 1995, 1997, 1999, and 2007
    - Goal: complete phase-out of CFCs

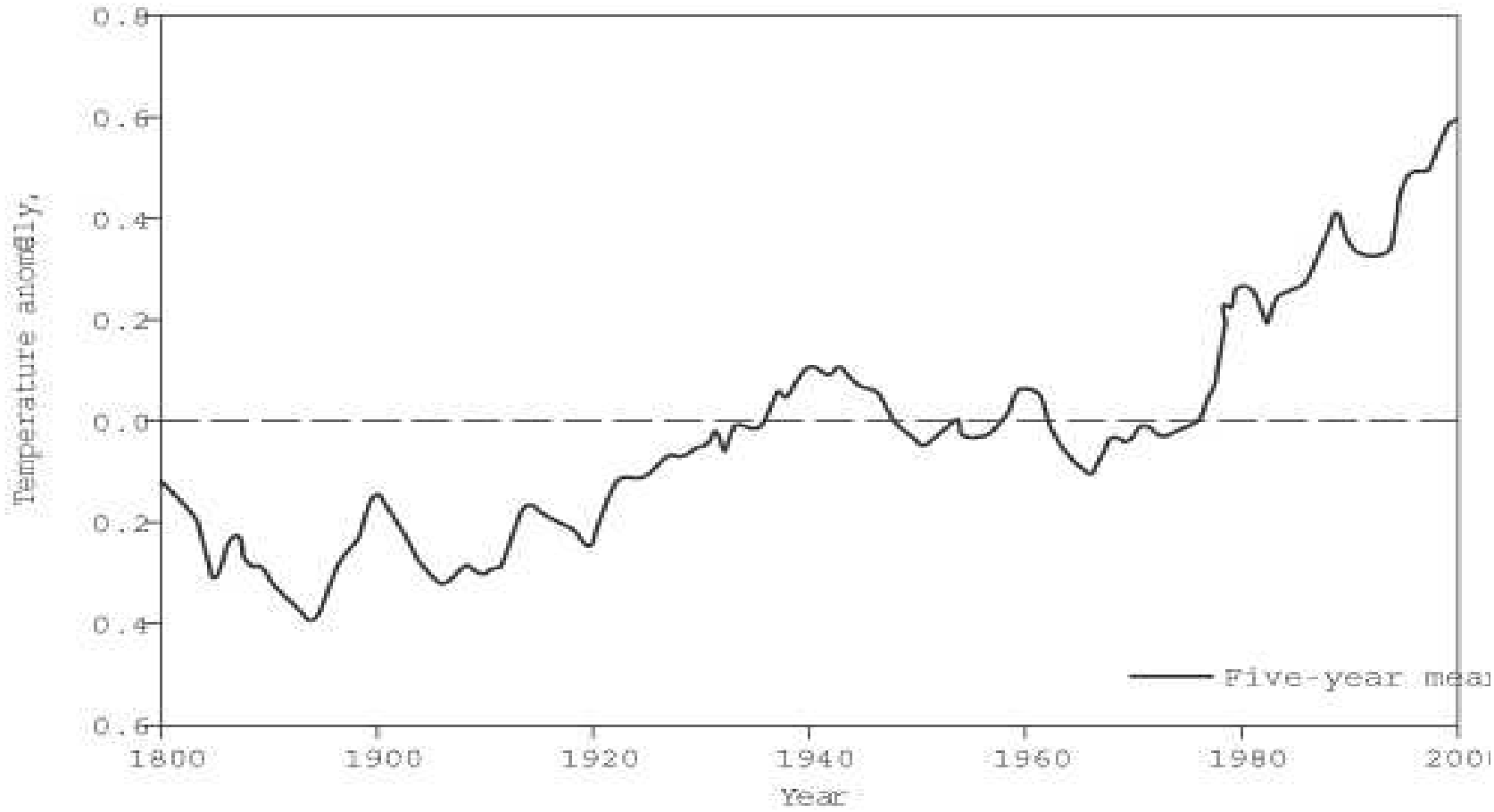
Ozone depletion

- Substitutes: HFCs and HCFCs
  - Hydrochlorofluorocarbons (HCFCs)
    - More reactive than CFCs in the troposphere

      → only small amount reaches the stratosphere
    - Still has some ozone depletion potential

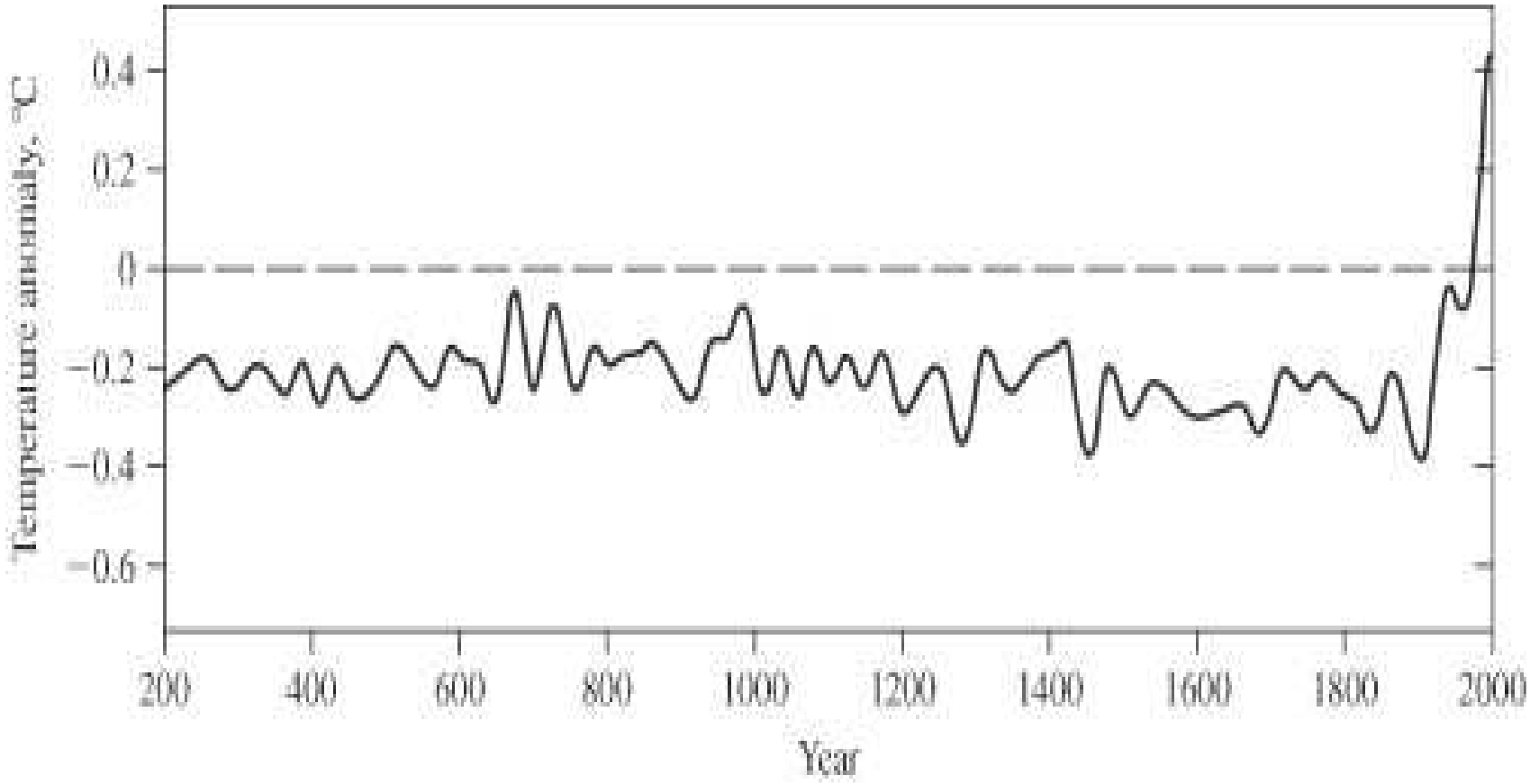
    → used just as a transitional substitute of CFCs, amendments of Montreal Protocol also targets on the phase-out of HCFCs
  - Hydrofluorocarbons (HFCs)
    - No chlorine atoms → no ozone depletion potential
  - Problem: HFCs and HCFCs are greenhouse gases
    - HFCs are not considered as a permanent substitute of CFCs as well!

Global warming

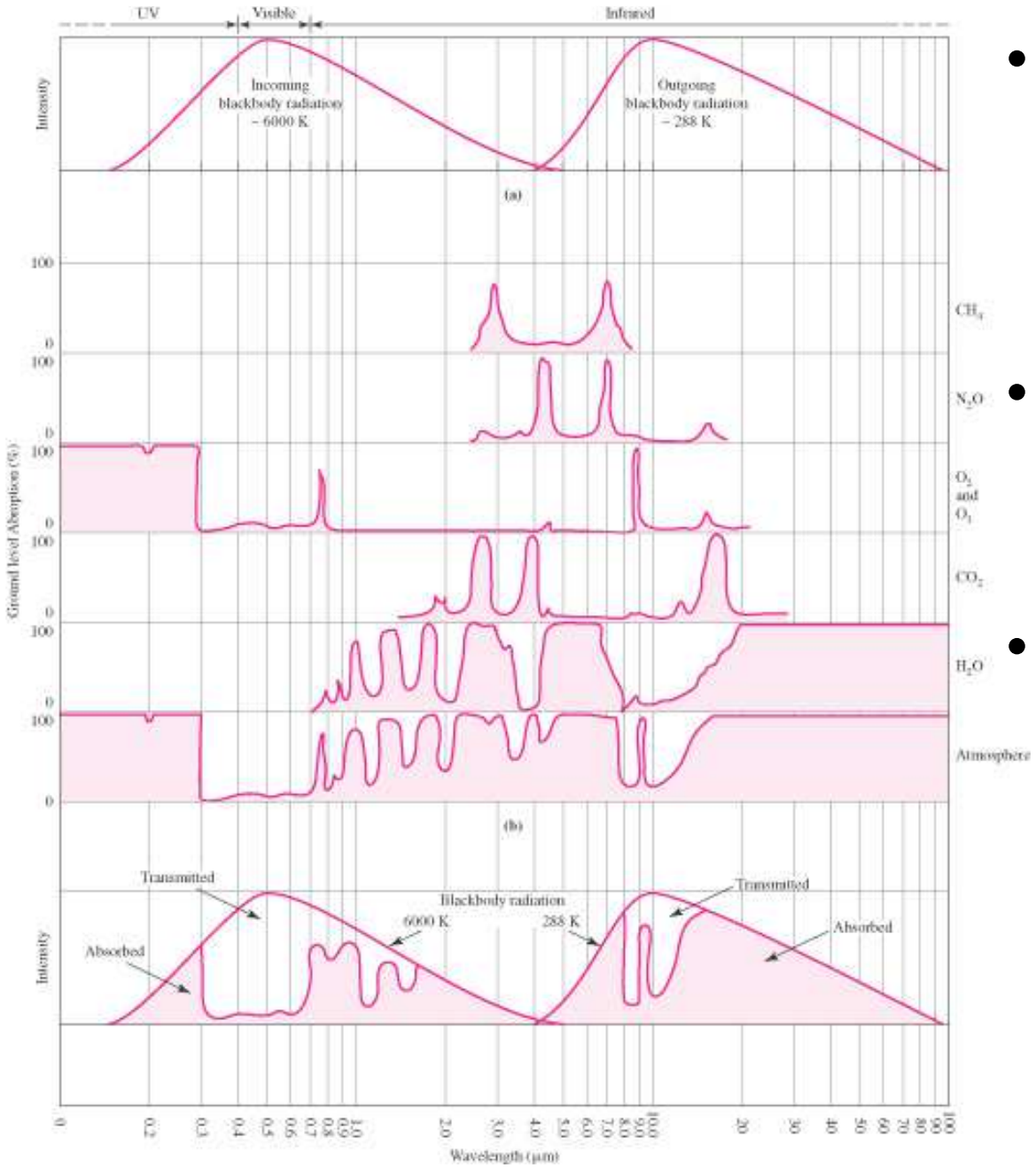


The temperature of the globe is really increasing!

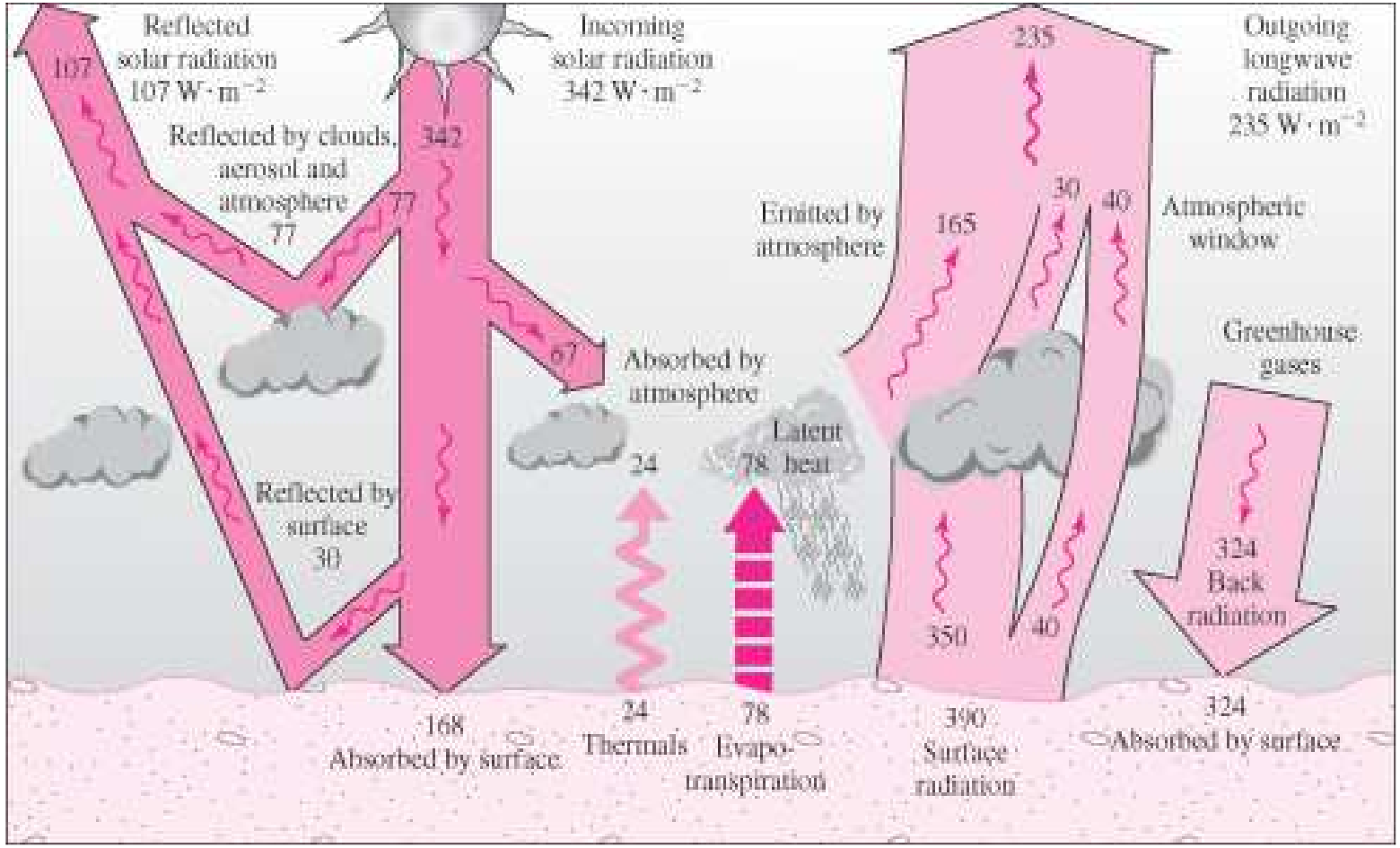
Global warming



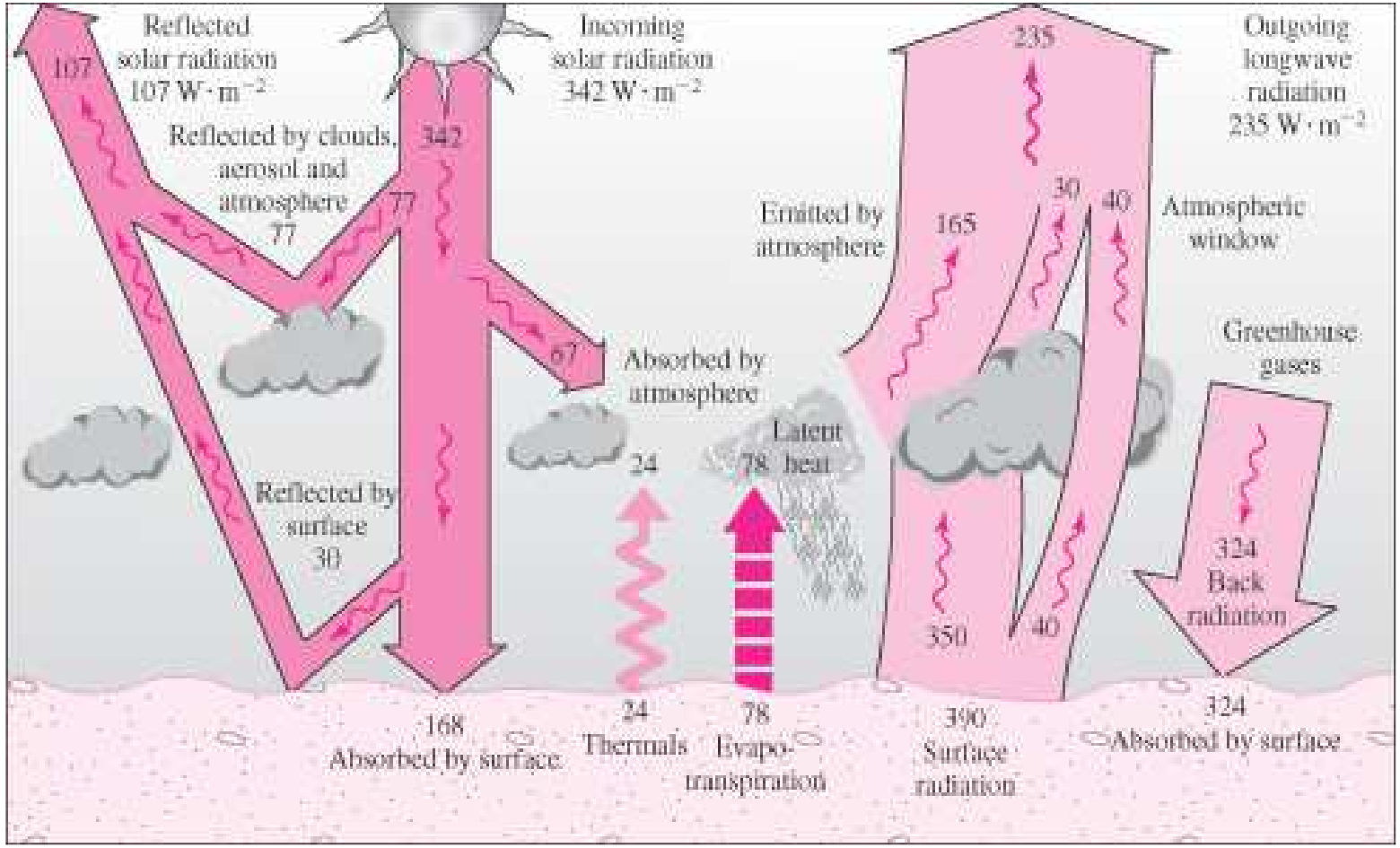
The “hockey stick” graph



- The earth receives short-wave radiation from the Sun
- The Earth's surface emits long-wave radiation
- Some molecules absorb the long-wave radiation → prevent energy to be released out of the Earth



- The greenhouse gases (GHGs) work like the glass on a greenhouse or a blanket
- Maintain the Earth's temperature good for life (without GHGs, the Earth's temperature will be around -17°C)



- 30% increase in the atmospheric CO_2 concentration since 1750
- The increased levels of greenhouse gases changes the radiation balance: greater back radiation → higher surface temperature

Greenhouse gases (GHGs)

- CO_2 is major, but others can also be significant
- Overall greenhouse effect depends on concentration, global warming potential, and lifetime

Chemicals	**Lifetime (year)**	**Global warming potential (kg CO_2/kg chemical)**
Carbon dioxide (CO_2)	30-200	1
Methane (CH_4)	12	62
Nitrous oxide (N_2O)	114	275
CFC-12 (CF_2Cl_2)	100	10200
HCFC-22 (CHF_2Cl)	12	4800
Tetrafluoromethane (CF_4)	50000	3900
Sulfur hexafluoride (SF_6)	3200	15100

Global warming

- Efforts to reduce GHG emissions: **Kyoto Protocol**
  - Adopted on December 11, 1997
  - Became effective in 2005
  - Targets to reduce GHG emissions in developed countries by an average of 5.2% compared to 1990 levels during the first commitment period (2008-2012)
  - U.S. did not ratify the protocol
  - Korea: classified as a “developing country”, no binding targets

Global warming

- Kyoto Protocol
  - Doha amendment (2012)
    - Reduce GHG emissions by 25-40% compared to 1990 levels during the second commitment period (2013-2020)
    - Major CO_2-producing countries (U.S., China, and India) are not included
      - U.S. (2^{nd}), Japan, Russia, Canada did not participate
      - China (1^{st}) and India (3^{rd}) are classified as developing countries
    - Korea: still classified as a developing country, but “voluntarily” promised to reduce the GHG emissions

Global warming

- Paris agreement (Dec 2015)
  - For post-2020 reduction of GHG emissions (effect of Kyoto Protocol ends in 2020)
  - A bottom-up approach (cf. Kyoto Protocol: top-down)
    - Each country submit “Nationally Determined Contributions (NDC)” for GHG reduction
    - The NDC should be “ambitious”, “represent a progression over time”, and set “with the view to achieving the purpose of this Agreement”
    - Korea: set NDC as “37% reduction compared to 2030 BAU* value”

**BAU: Business As Usual*

Air pollution I

Air pollution I

- Units for air pollutants
- Classification of air pollution problems
- Types of air pollutants

Today's goal


오 존 (O_3)
0.002 ppm


미세먼지(PM-10)
newstown.co.kr


중 구
초미세먼지 (PM2.5)
3 μg/m³(기준 50 이하)


그야말로... 먼지_
초미세 먼지는?
미세한 먼지!
초미세
더 작은 먼지_

Units of measurement

- volume/volume units (for gas phase pollutants)
  - ppm = parts per million
  - ppb = parts per billion
  - ppt = parts per trillion
- mass/volume (for gas & particle phase pollutants)
  - usually $\mu g/m^3$

Unit conversion

Consider a pollutant "*i*"

Ideal gas law: $PV = nRT$

$$\frac{n_{air}}{V_{air}} = \frac{P_{air}}{RT} = \frac{mole_{air}}{m^3{}_{air}}$$

R = ideal gas constant = 8.21 x 10^{-5} m^3-atm/K-mole

$$ppm_i = \frac{moles\ of\ pollutant\ i}{moles\ of\ air} \times 10^6 = \frac{\mu mole_i}{mole_{air}}$$

So, $$\frac{\mu g_i}{m^3{}_{air}} = ppm_i \times MW_i \times \frac{P_{air}}{RT}$$

Unit conversion

Q: Convert 10 ppb of SO_2 to $\mu g/m^3$ at 20°C, 1 atm.

Air pollution problems

- Classification of air pollution problems
  - **Microscale**: less than the size of a house or slightly bigger
  - **Mesoscale**: a few hectares to the size of a city or slightly bigger
  - **Macroscale**: size of a county to a country and to the globe

Air pollution problems

- Microscale air pollution problems
  - Indoor air pollution: pollutants from burners, ovens, heaters, cigarette smoke, and underground
  - Cigarette smoke on streets

http://www.compacappliance.net

http://www.odamindia.org

http://www.edaily.co.kr

Air pollution problems

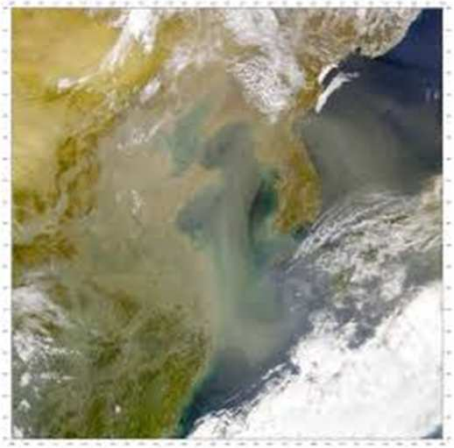
- Mesoscale air pollution problems
  - Vehicle exhaust
  - Smoke from power plants, factories, etc.
  - Smog

http://web.ornl.gov

http://www.bbc.com

Air pollution problems

- Macroscale air pollution problems
  - Acid rain
  - Yellow dust
  - Ozone depletion
  - Global warming



http://en.wikipedia.com

http://breitbart.com

Air pollutants

- **Carbon monoxide (CO)**
  - Generated by incomplete combustion of carbon
  - Natural sources: oxidation of methane (CH_4) in the atmosphere
  - Anthropogenic sources: motor vehicles, fossil fuel burning, solid waste disposal, burning of plant materials
  - Reacts with hemoglobin in the blood to form carboxyhemoglobin (CoHb)
  - Carbon monoxide poisoning: lots of deaths in 1950s-1980s in Korea caused by indoor briquette burning

Air pollutants

- **Lead (Pb)**
  - A cumulative poison
  - Usually occurs in the atmosphere as a particulate
  - Natural sources: volcanic activity and airborne soil
  - Anthropogenic sources: smelters and refining processes, and incineration of lead-containing wastes
  - In the past, lead used to be added to gasoline → significant air pollution problems → lead addition currently prohibited

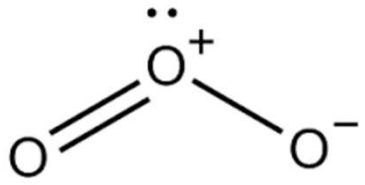
Air pollutants

- **Nitrogen oxides**
  - NO, NO_2, N_2O, NO_3, N_2O_3, N_2O_4, N_2O_5
  - NO2 itself has adverse effects on respiratory tract
  - NO and NO_2 are involved in the formation of photochemical smog and acid rain
  - $NO_x = NO + NO_2$
  - Anthropogenic sources: combustion processes in motor vehicles, power plants, and the industry
  - N_2 is an inert gas, but reacts with oxygen at high temperature (>1600 K):

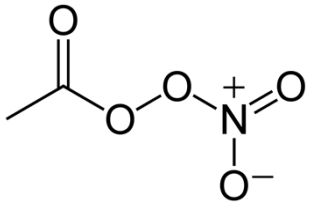
    $N_2 + O_2 \rightarrow 2NO$

Air pollutants

- **Photochemical oxidants**
  - Chemicals produced by reaction in the atmosphere in the presence of sunlight
  - Classified as secondary pollutants
  - **O_3** (major), peroxyacetyl nitrate (PAN), acrolein, peroxybenzoyl nitrates (PBzN), aldehydes, nitrogen oxides
  - Toxic effects because of their oxidizing ability: cause eye, nose, and throat irritation, and affect lung function
  - Major pollutants in photochemical smog



ozone

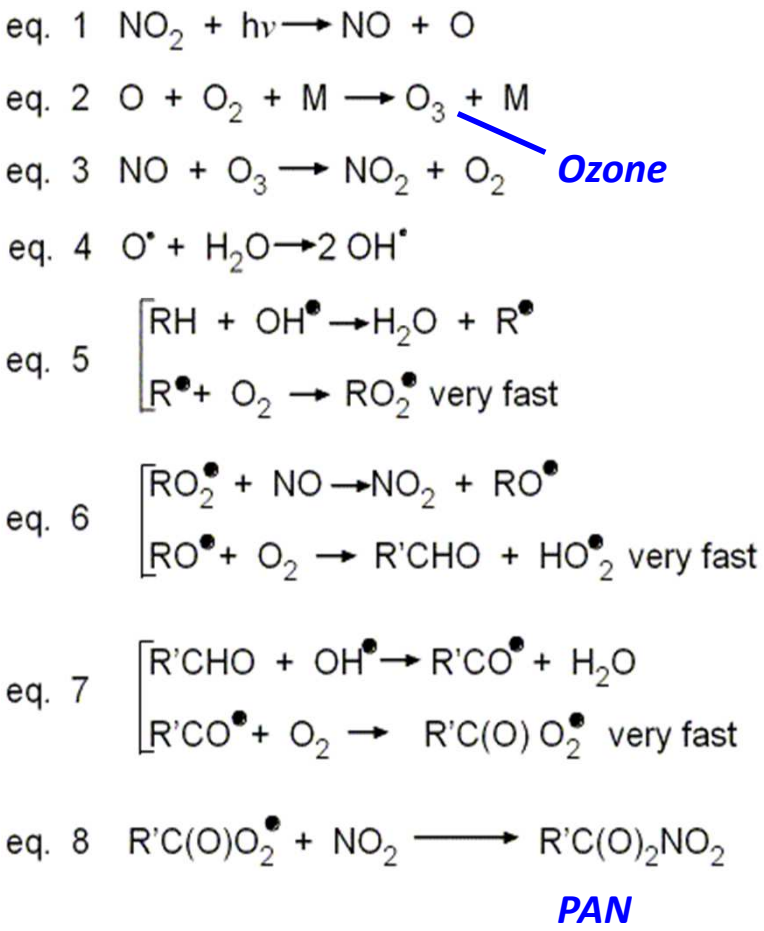


PAN

Primary vs. secondary pollutants

- **Primary pollutants**
  - Pollutants that are emitted directly from sources

- **Secondary pollutants**
  - Pollutants that are formed in the atmosphere by chemical reactions between primary pollutants and chemical species normally found in the atmosphere



Air pollutants

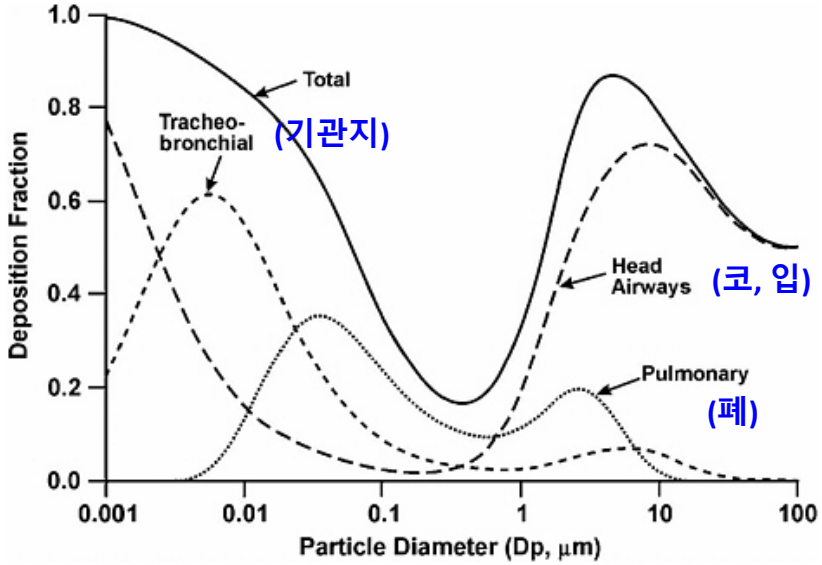
- Sulfur oxides
  - SO_2, SO_3, SO_4^{2-}
  - Called SO_x
  - Sources
    - Direct emission of SO_x from power plants, industry, volcanoes, and the oceans (as a primary pollutant)
    - Oxidation of H_2S produced by natural biological processes or the industry (as a secondary pollutant)
  - Involved in “London smog” and acid rain

Air pollutants

- **Particulates**
  - Particles suspended in the air
  - Natural sources: sea salt, soil dust, volcanic particles, smoke from forest fires
  - Anthropogenic sources: fossil fuel burning, industrial processes
  - Damage respiratory organs

Air pollutants

- Particulates
  - Large particles are trapped at the upper respiratory system, but small particles go deeper → small particles are more significant!
  - Korean government regulate "PM_{10}" and "$PM_{2.5}$"



Deposition of inhaled particles in the human

Raabe (1994) Internal Radiation Dosimetry

- PM_{10}: particulate matter less than 10 μm size
- $PM_{2.5}$: particulate matter less than 2.5 μm size

Air pollutants

- **Other hazardous air pollutants**
  - Toxic organic compounds, heavy metals, arsenic, etc.
  - Korean government regulates 35 hazardous air pollutants
  - Some examples: cadmium, mercury, asbestos, dioxin, benzene