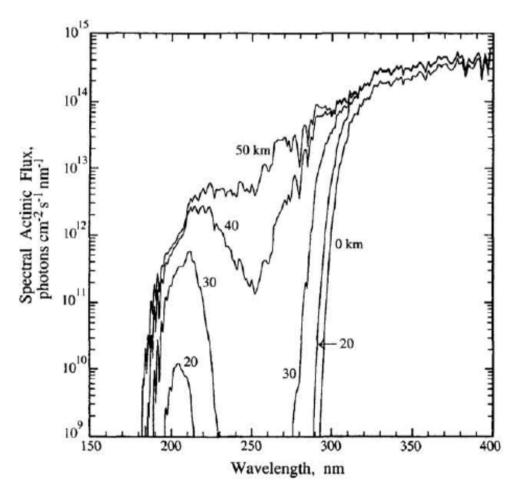
## Indoor air pollution

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



Photoreactions of ozone to absorb UV light

$$O_2 + UV \rightarrow 2O$$
  
 $O + O_2 + M \rightarrow O_3 + M$  (M: 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 destruction mechanism by CFCs

$$CCl_{3}F + UV \rightarrow CCl_{2}F + Cl$$

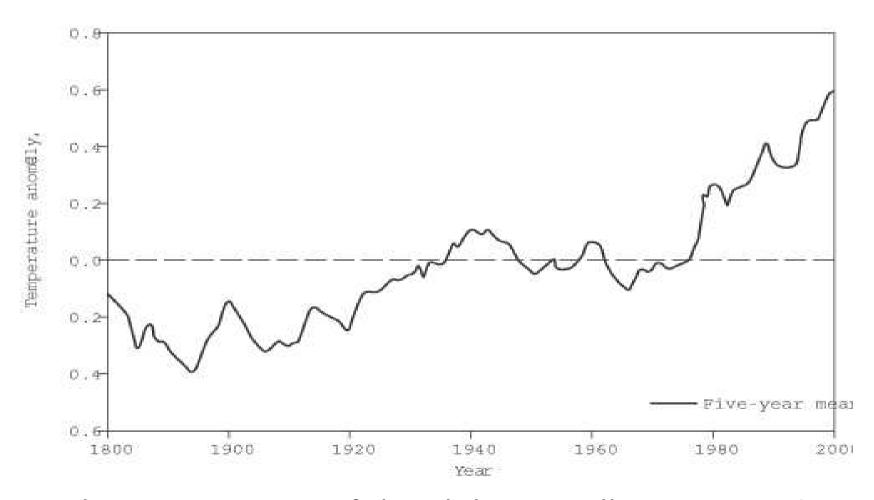
$$Cl + O_{3} \rightarrow ClO + O_{2}$$

$$ClO + O \rightarrow Cl + O_{2}$$

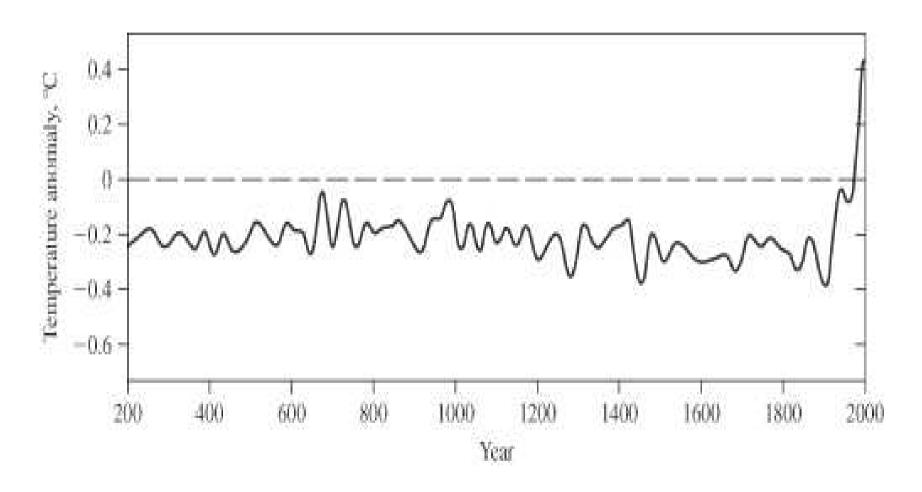
- Cl atom acts as a catalyst
- One CFC molecule can destroy uncountable number of ozone molecules

- 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

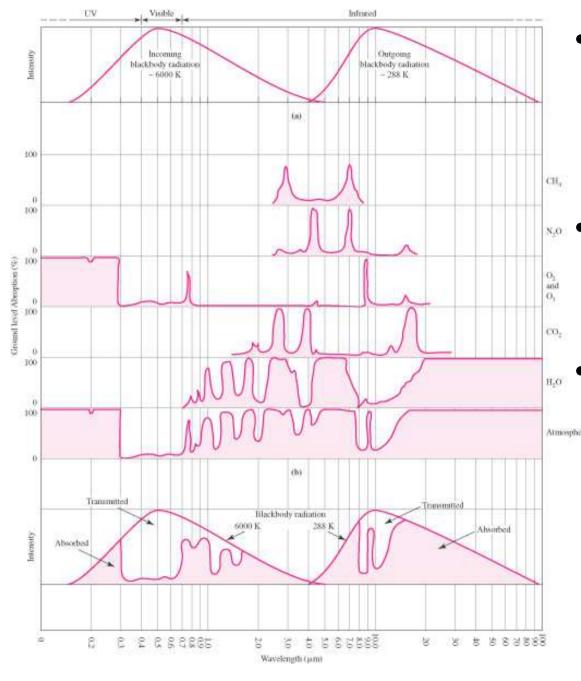
- Substitutes: HFCs and HCFCs
  - Hydrochlorofluorocarbons (HCFCs)
    - More reactive than CFCs in the troposphere
      - → only small amount reaches the stratosphere
    - Still has some ozone depletion potential
    - → used just as a transitional substitute of CFCs, amendments of Montreal Protocol 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!



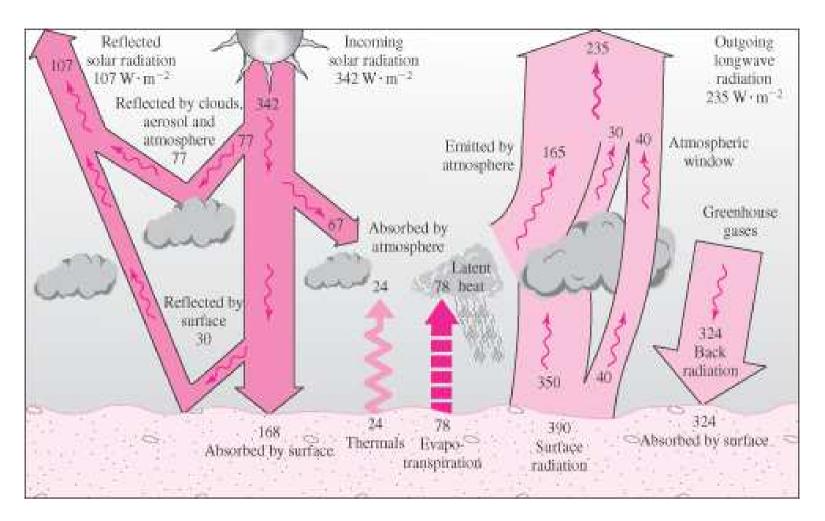
The temperature of the globe is really increasing!



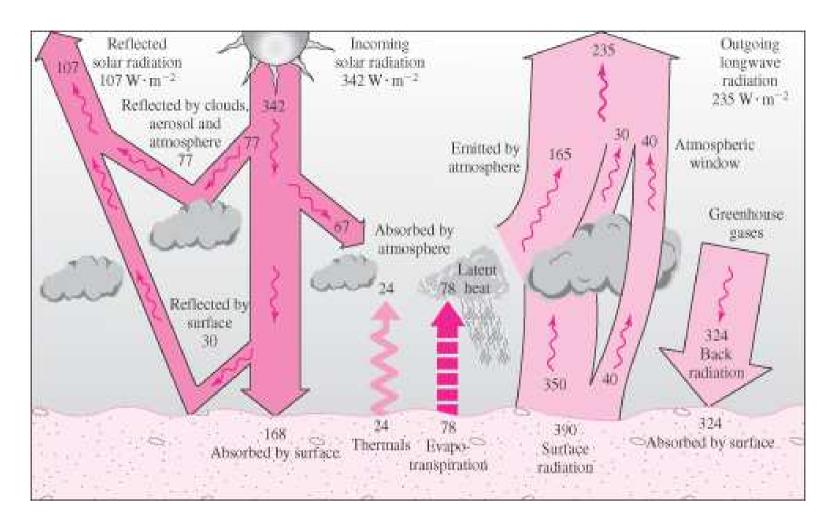
The "hockey stick" graph



- The earth receives short-wave radiation from the Sun
  - The Earth's surface emits long-wave radiation
  - Some molecules absorb the long-wave radiation  $\rightarrow$  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<sub>2</sub> concentration since 1750
- The increased levels of greenhouse gases changes the radiation balance: greater back radiation → higher surface temperature

## Greenhouse gases (GHGs)

- CO<sub>2</sub> 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 <sub>2</sub> /kg chemical)
Carbon dioxide (CO <sub>2</sub> )	30-200	1
Methane (CH <sub>4</sub> )	12	62
Nitrous oxide (N <sub>2</sub> O)	114	275
CFC-12 (CF <sub>2</sub> Cl <sub>2</sub> )	100	10200
HCFC-22 (CHF <sub>2</sub> CI)	12	4800
Tetrafluoromethane (CF <sub>4</sub> )	50000	3900
Sulfur hexafluoride (SF <sub>6</sub> )	3200	15100

- 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

#### Kyoto Protocol

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



- 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

# Reading assignment

Textbook Ch 12 p. 587-615