STRATOSPHERIC OZONE DEPLETION

GEOG/ENST 3331 – Lecture 17

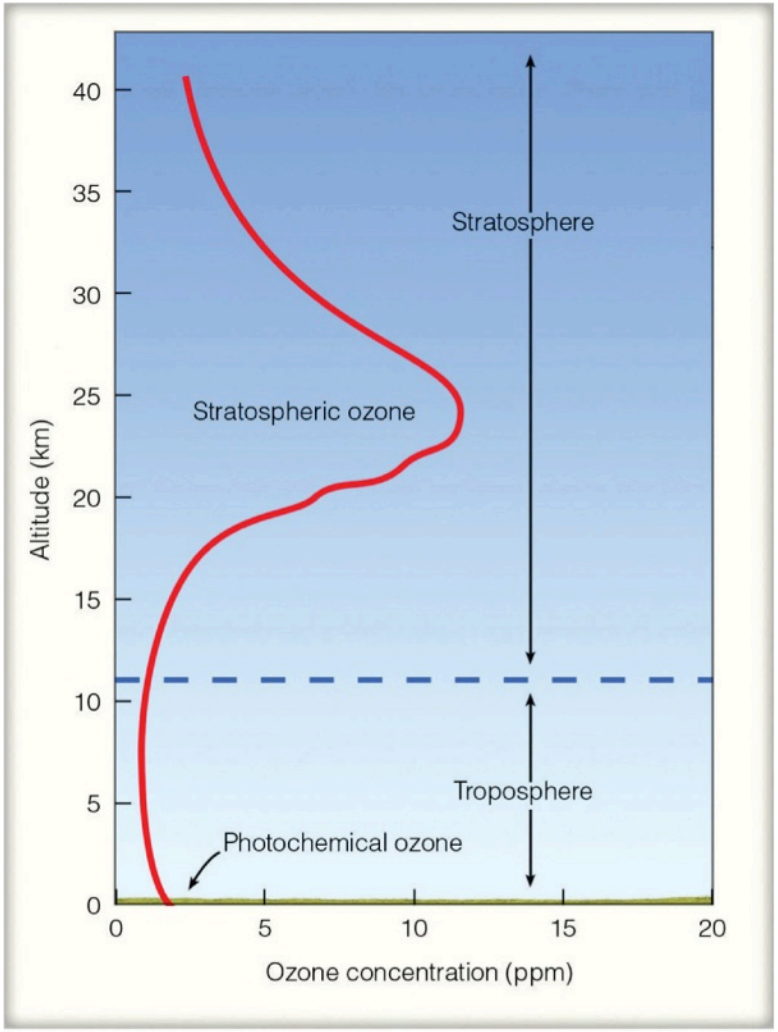
Ahrens: Chapter 18; Turco: Chapter 13

Stratospheric Ozone Depletion

- Stratospheric ozone
- Ozone distribution
- Ozone depletion

Ozone Levels in the Stratosphere

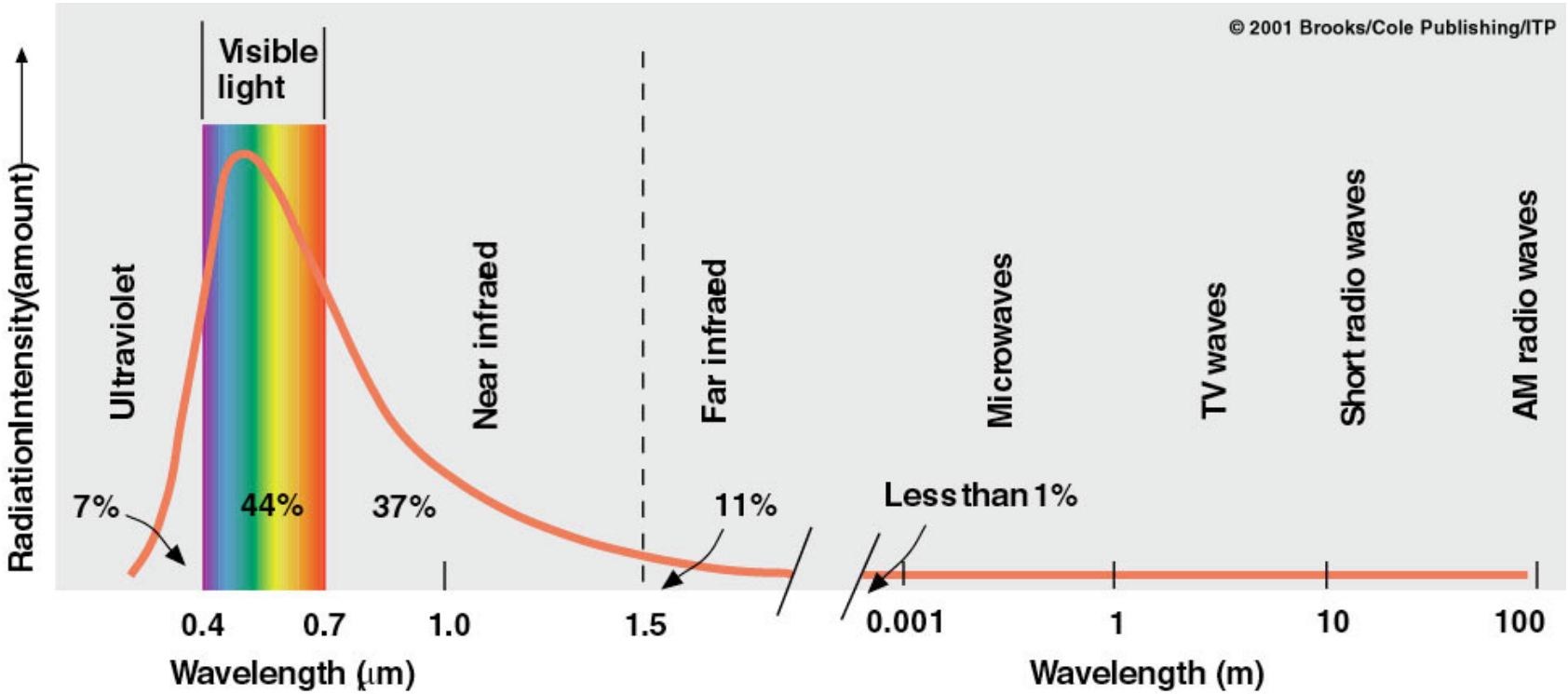
- Determined by:
  - Chemistry
  - Radiation
  - Dynamics



Ahrens: Fig. 18.5

Ozone and Radiation

- Ozone chemistry is dependent on the amount of short wavelength (ultraviolet) radiation received by the stratosphere.



Creation of Ozone

$O_2 + UV\ (<0.25\ \mu m) \rightarrow O + O$

$O + O \rightarrow O_2$

or

$O + O_2 \rightarrow \mathbf{O_3}$

Oxygen is abundant and these changes occur wherever there is $UV < 0.25\ \mu m$

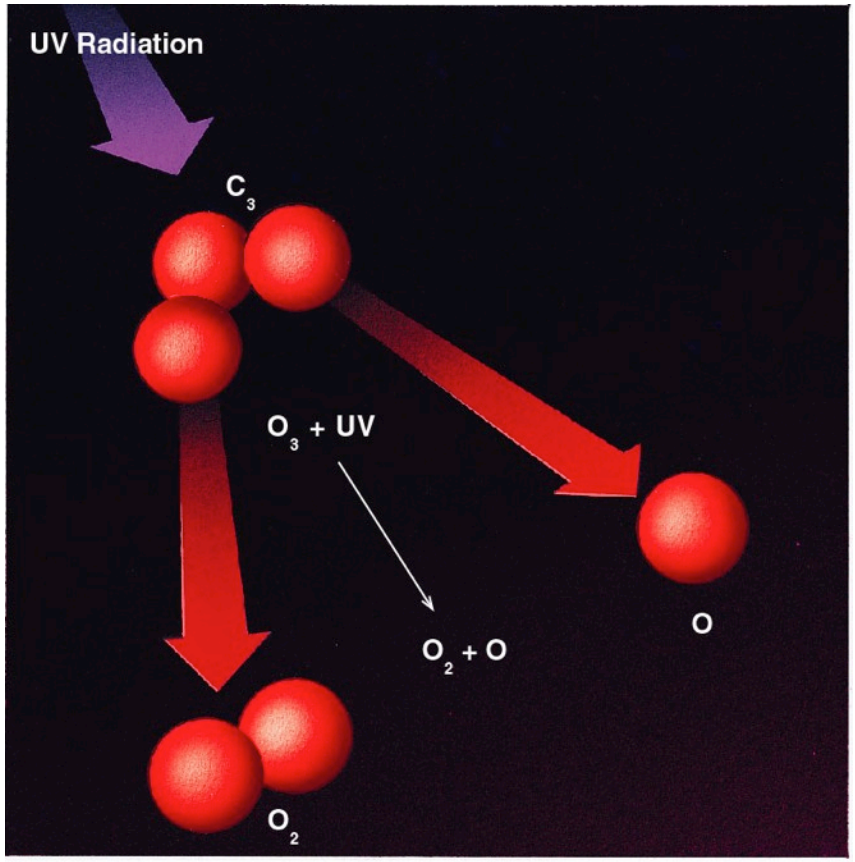
Destruction of ozone

$O_3 + UV\ (< 0.30\ \mu m) \rightarrow O + O_2$

$O + O_2 \rightarrow O_3$

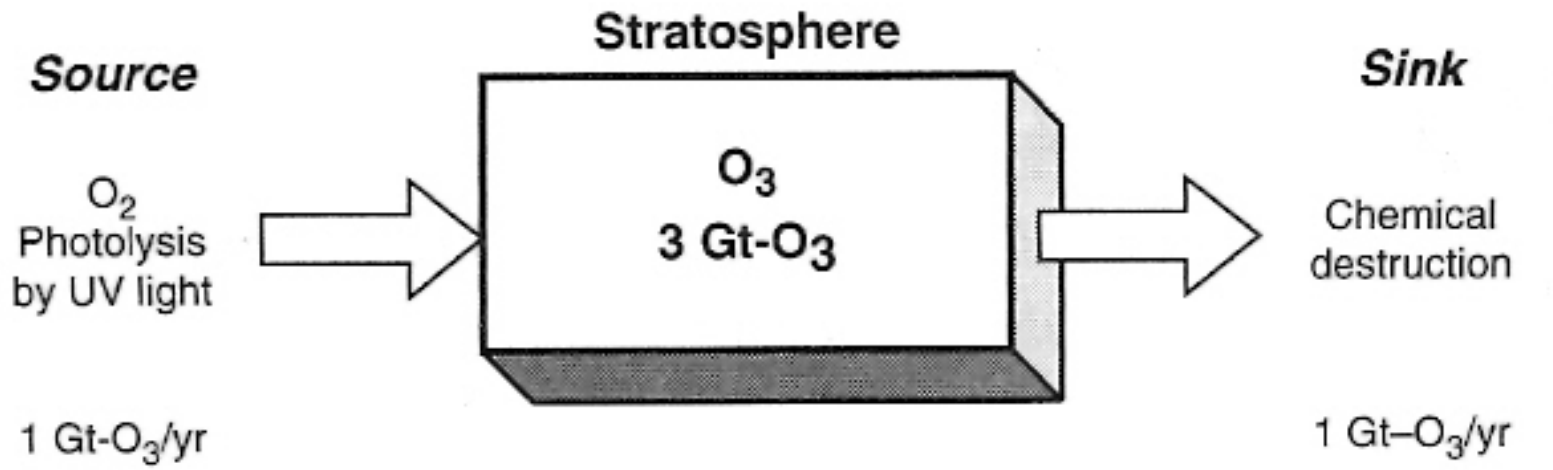
or

$O + O_3 \rightarrow 2O_2$



Ahrens: Fig. 18.6

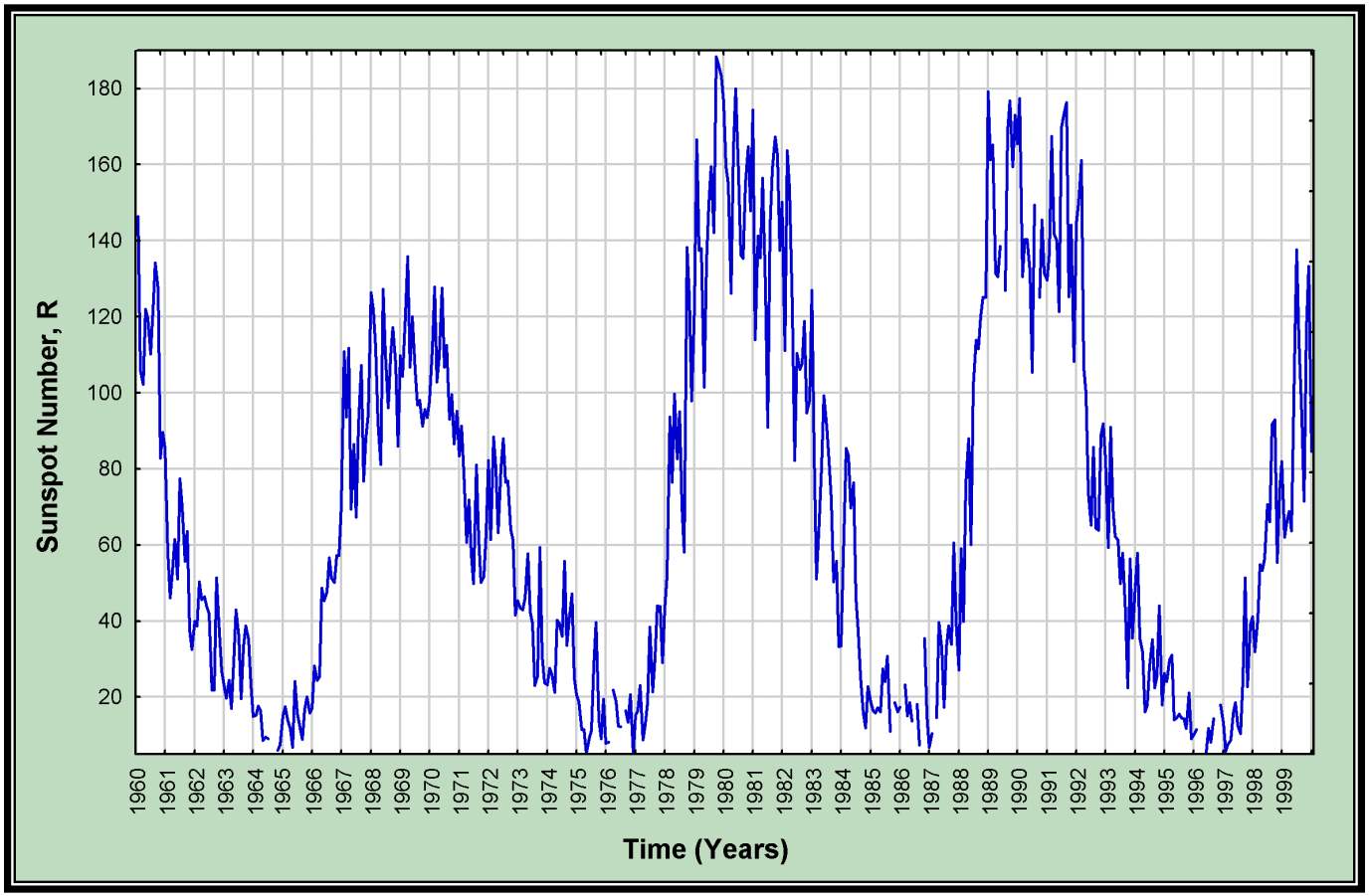
Ozone reservoir



Turco: Figure 13.2

Ozone and Radiation

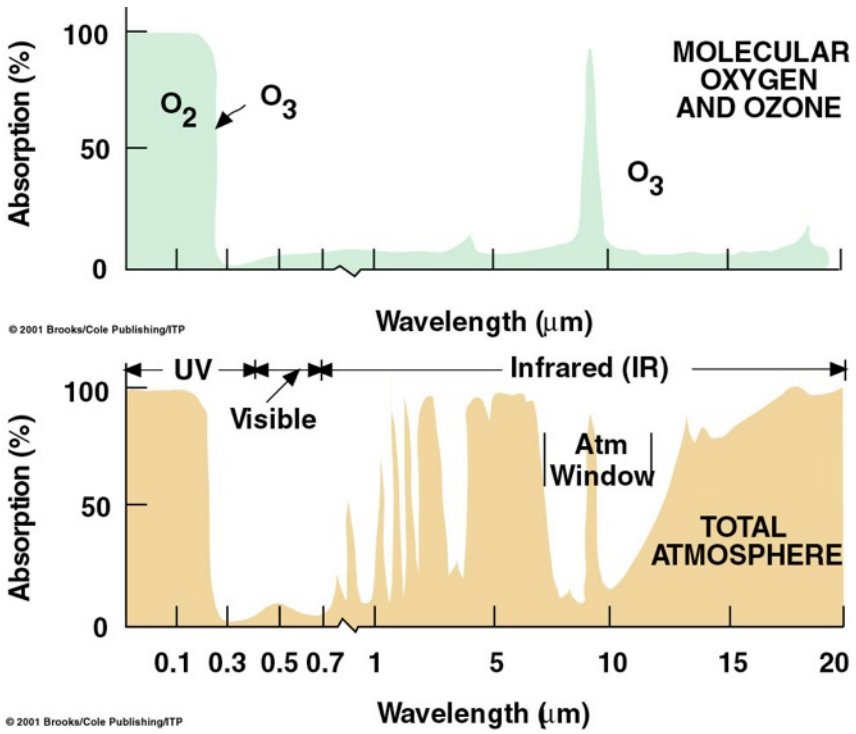
- Sunspot activity causes a variation in insolation
- Greater sunspot activity coincides with greater insolation
- Cycle of roughly 11 years
- Ozone levels are greater during years of high levels of sunspots



1960 1999

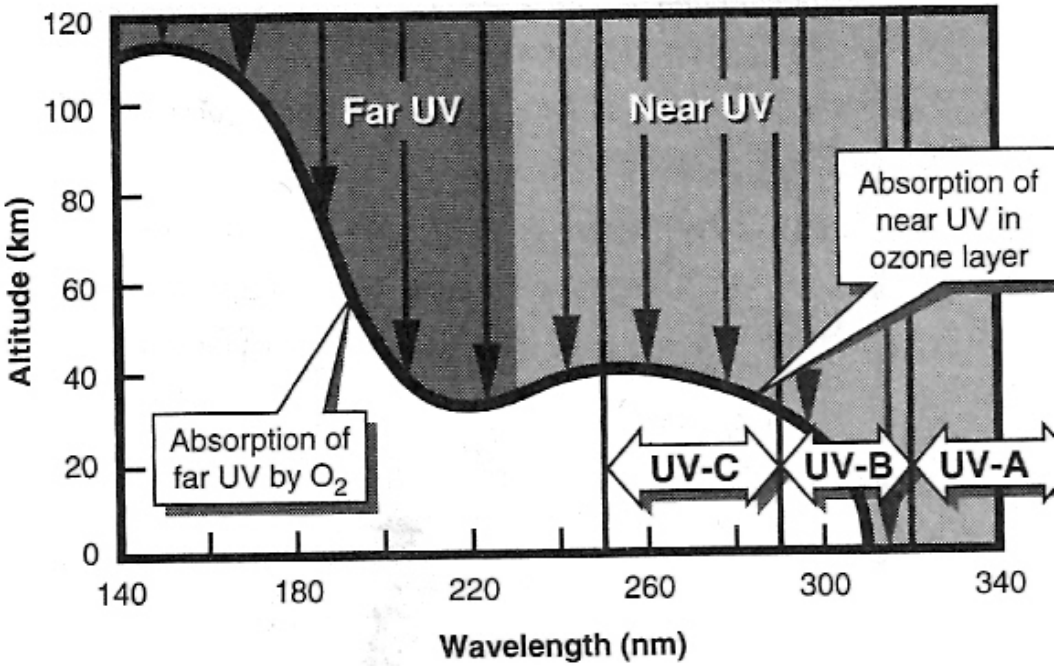
Benefit of the Ozone Layer

- Ultraviolet radiation is dangerous to Earth's biota
- Ozone layer in the stratosphere effectively blocks most UV radiation from reaching surface



“Near” UV spectrum regions

- UVA
  - 0.40 – 0.32 μm
  - Used in tanning salons
- UVB
  - 0.32 – 0.29 μm
  - Tanning/sunburns
- UVC
  - 0.29 – 0.10 μm
  - “Broadly biocidal”
  - Absorbed by O_2 and O_3



Turco: Figure 13.7
1000 nm = 1 μm

Increased UVB exposure

- Skin cancer
- Long-term vision damage
- Amphibians
- Leaf tissue damage
  - Increased plant mortality
  - Decreased crop yields
- Phytoplankton – base of marine food chain

Lecture outline

- Stratospheric ozone
- **Ozone distribution**
  - **Brewer-Dobson circulation**
  - **QBO**
  - **ENSO**
- Ozone depletion

Ozone distribution

- Most ozone *creation* occurs in the tropics
  - Greater intensity of insolation
- Dynamics redistributes ozone:
  - Brewer-Dobson Circulation
  - QBO (Quasi-biennial Oscillation)
- Highest *concentration* is in the polar regions
  - Slower destruction

Measuring Ozone

- Gordon Dobson (1889-1976)
  - Determined that temperature increases with height in stratosphere
  - Proposed existence of the ozone layer
  - Invented device for measuring ozone in a column of air

- Dobson Unit (DU)
  - 1 DU = 10 μm thick equivalent ozone depth (at STP)
  - 2.69×10^{20} molecules per m^2

Ozone distribution

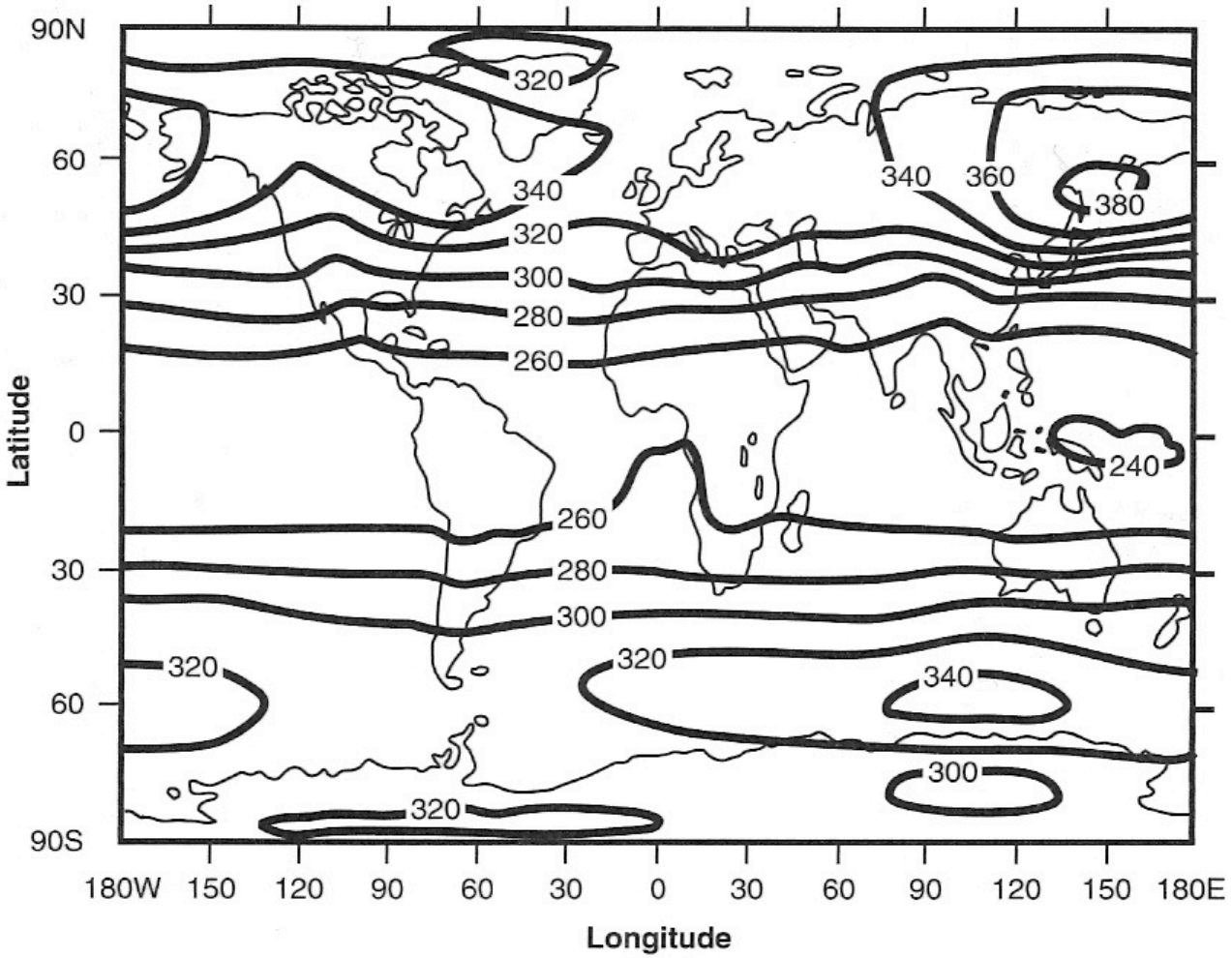
Greatest at high latitudes

Global coverage

Zonally symmetric

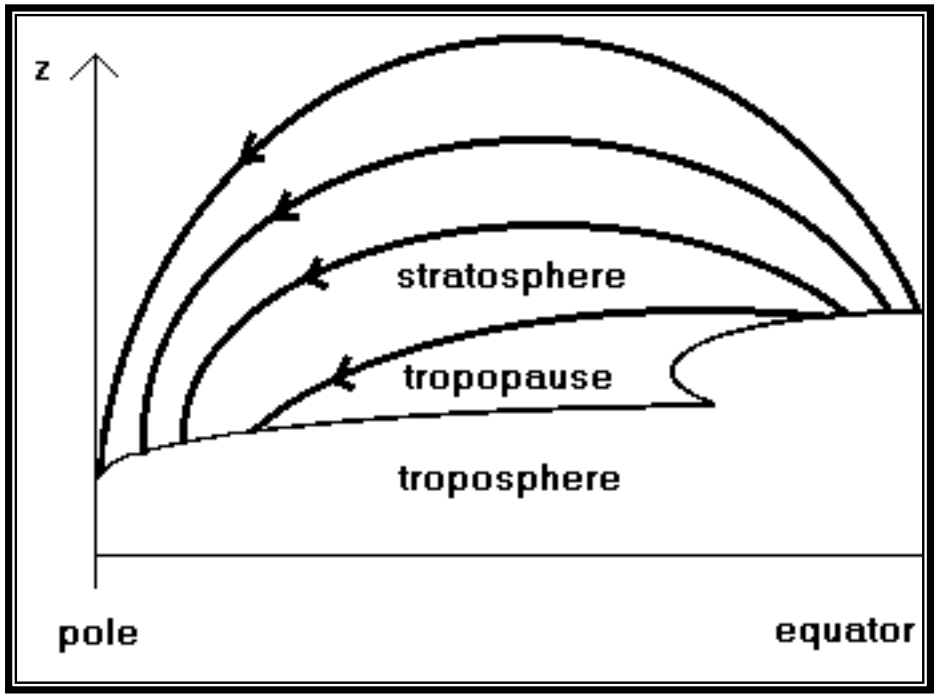
Turco: Figure 13.5

(Dobson Units)



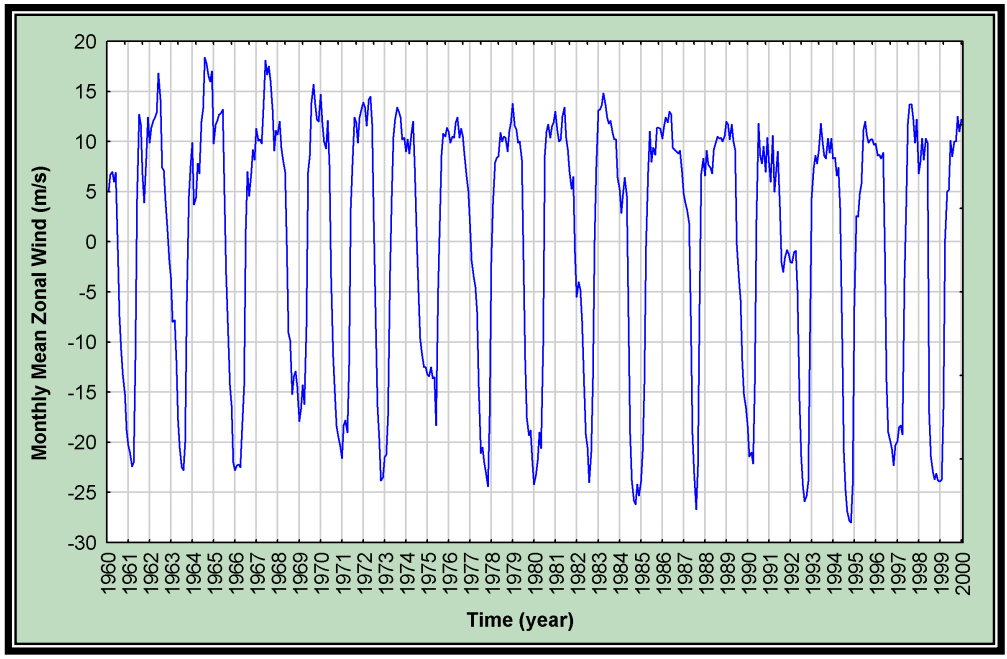
Brewer-Dobson Circulation

- Prominent in winter hemisphere
- Provides equator to pole transport of ozone



Quasi-biennial oscillation (QBO)

- 2 to 3 year oscillation in the upper troposphere and lower stratosphere
- Prevailing winds shift from westerly to easterly

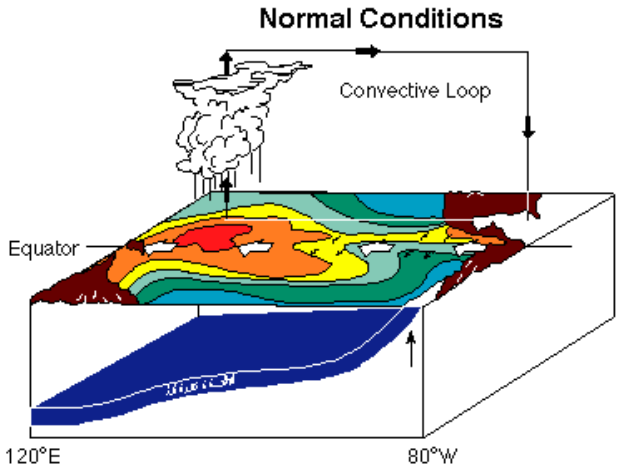


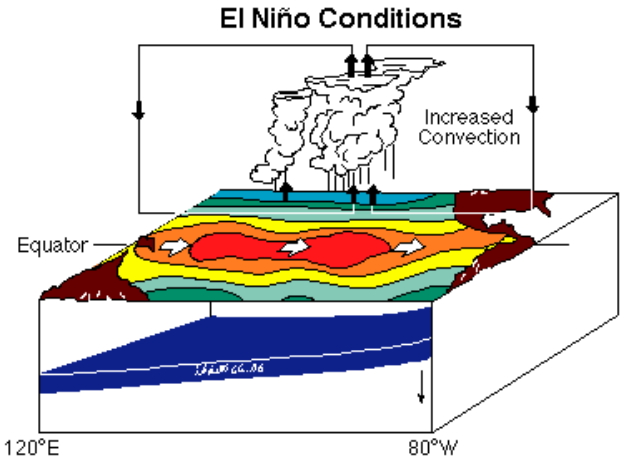
QBO and Ozone

- QBO appears to be linked to the Dobson-Brewer circulation
- High levels of ozone near the poles is associated with the westerly phase of the QBO

El Niño/ Southern Oscillation (ENSO)

- Linked to changes in the Dobson-Brewer Circulation
- Enhanced during El Niño years





Lecture outline

- Stratospheric ozone
- Ozone distribution
- **Ozone depletion**
  - **Catalytic destruction**
    - **Chlorine**
    - **Nitric oxide**
    - **Bromine**

More ozone chemistry

$$X + O_3 \rightarrow XO + O_2$$
$$XO + O \rightarrow X + O_2$$

Net: $O + O_3 \rightarrow 2O_2$

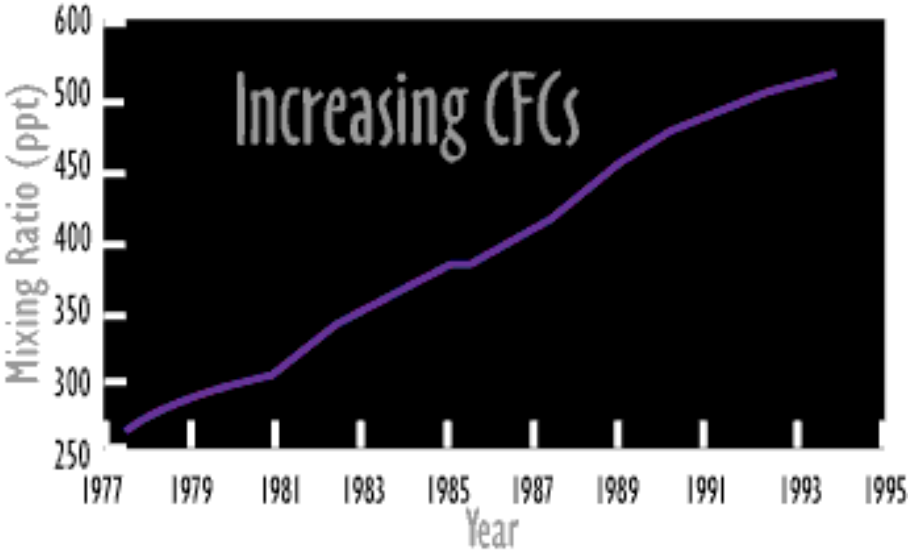
- The catalyst *X* can be NO, OH, Cl or Br
- Catalysts drive reactions but are not consumed
  - *X* remains in atmosphere to react again

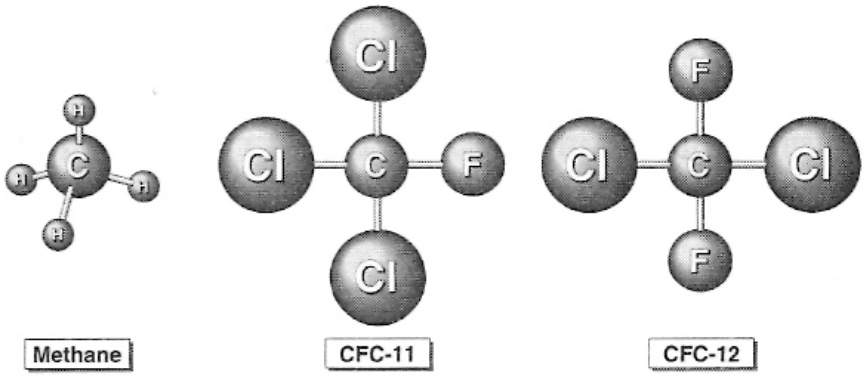
Chlorine (Cl) in the Stratosphere

- Biological processes: methyl chloride (CH_3Cl)
  - Accounts for 25% of chlorine in stratosphere
- Volcanoes: hydrogen chloride (HCl)
  - Negligible
- Anthropogenic: chlorofluorocarbons (CFCs)
  - Massive influx of chlorine

CFCs

- 'Halogen' family of chemicals
  - Aerosol propellants (spray)
  - Refrigerants, degreasers
  - Foam blowing agents
- Low reactivity, low toxicity
- Thermal absorption, solvent properties
- Split up by UV radiation in the upper stratosphere





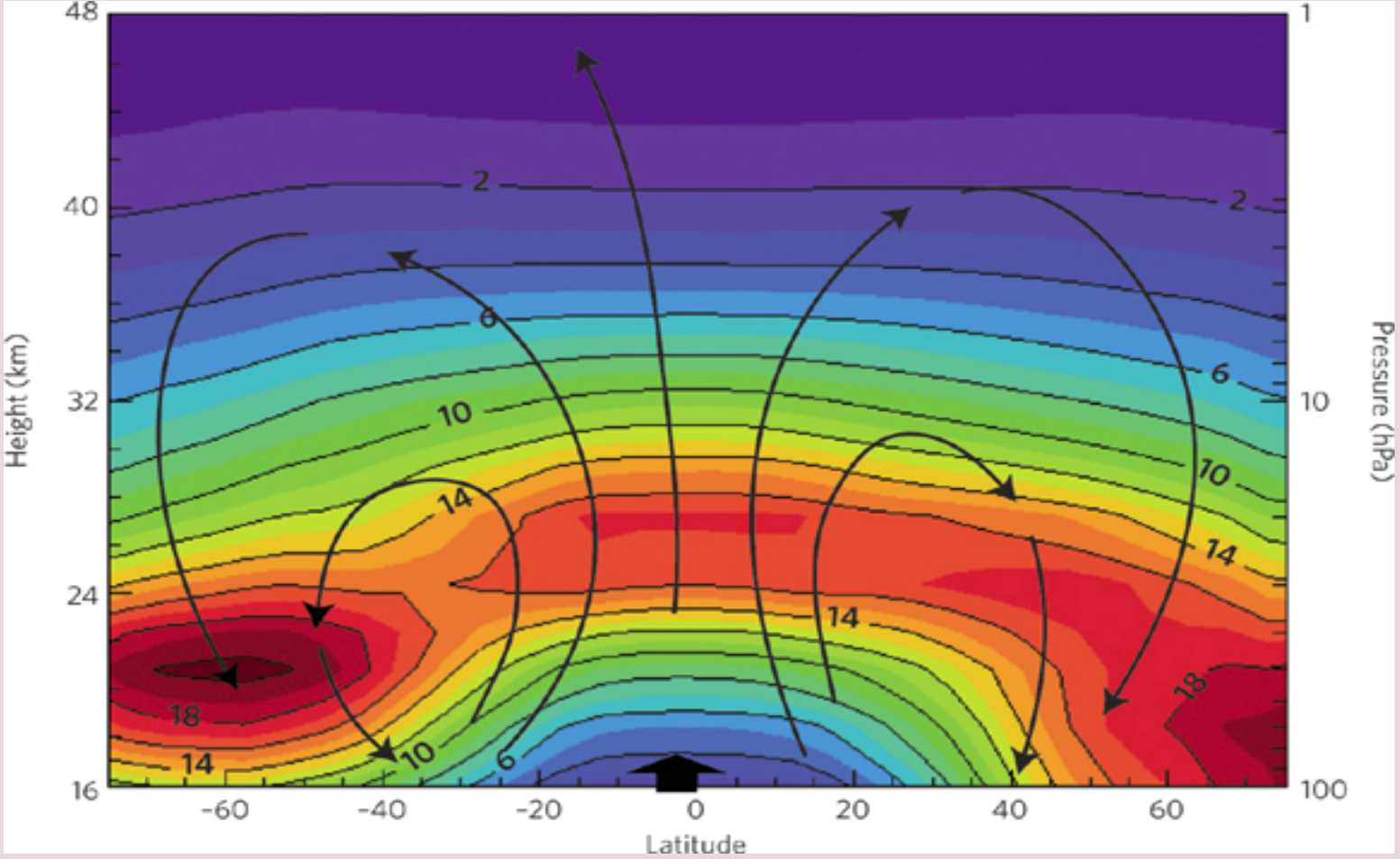
Turco: Figure 13.11

CFC Suspicions

- 1974 – Mario Molina and F. Sherwood Rowland noted that there are no tropospheric sinks for CFCs
  - Hypothesized that CFCs released into the atmosphere could have adverse effects on the ozone layer
- Such an impact was detected in the 1980s and afterward, particularly over Antarctica
- Molina and Rowland received the Nobel Prize in Chemistry in 1995
- Why Antarctica?

Molina

Rowland



Brewer-Dobson Circulation

Coloured contours represent ozone concentration (Dobson Units).

The bottom of the figure is the height of the tropical tropopause.

Gases – including CFCs – enter the stratosphere at the tropics

Image Source: Stevenson (2009)

Atmospheric life cycle of CFCs

1. Manufacture
2. Use and eventual escape
3. Build-up in troposphere
4. Slow exchange with stratosphere
   - 0.1 Mt-Cl/year
5. Dissociation by UV radiation
6. Chlorine catalyzes ozone destruction
   - Eventually turns into HCl
7. Returns to troposphere and rains out

CFCs in the stratosphere

- Reservoir: roughly 1 Mt-Cl
  - Each CFC molecule could catalyze destruction of up to 100 000 O_3 molecules
- Sink: 0.06 Mt-Cl/year
  - In the absence of any source it would take 20 years for CFCs to be removed
  - However, troposphere has an additional 10 Mt-Cl

Nitrogen monoxide

- NO also catalyzes destruction of ozone
- NO in troposphere is largely removed by rain

- Source of stratospheric NO is N_2O
  - Fossil fuels: 4 Mt-N/year of N_2O

- Other source: supersonic aircraft

- Not nearly as severe as CFCs

Bromine

- Similar gas to chlorine, also catalyzes ozone destruction
- 'Halon' family of chemicals
  - Fumigation (termites and crop pests)
  - Useful as fire retardants/extinguishers

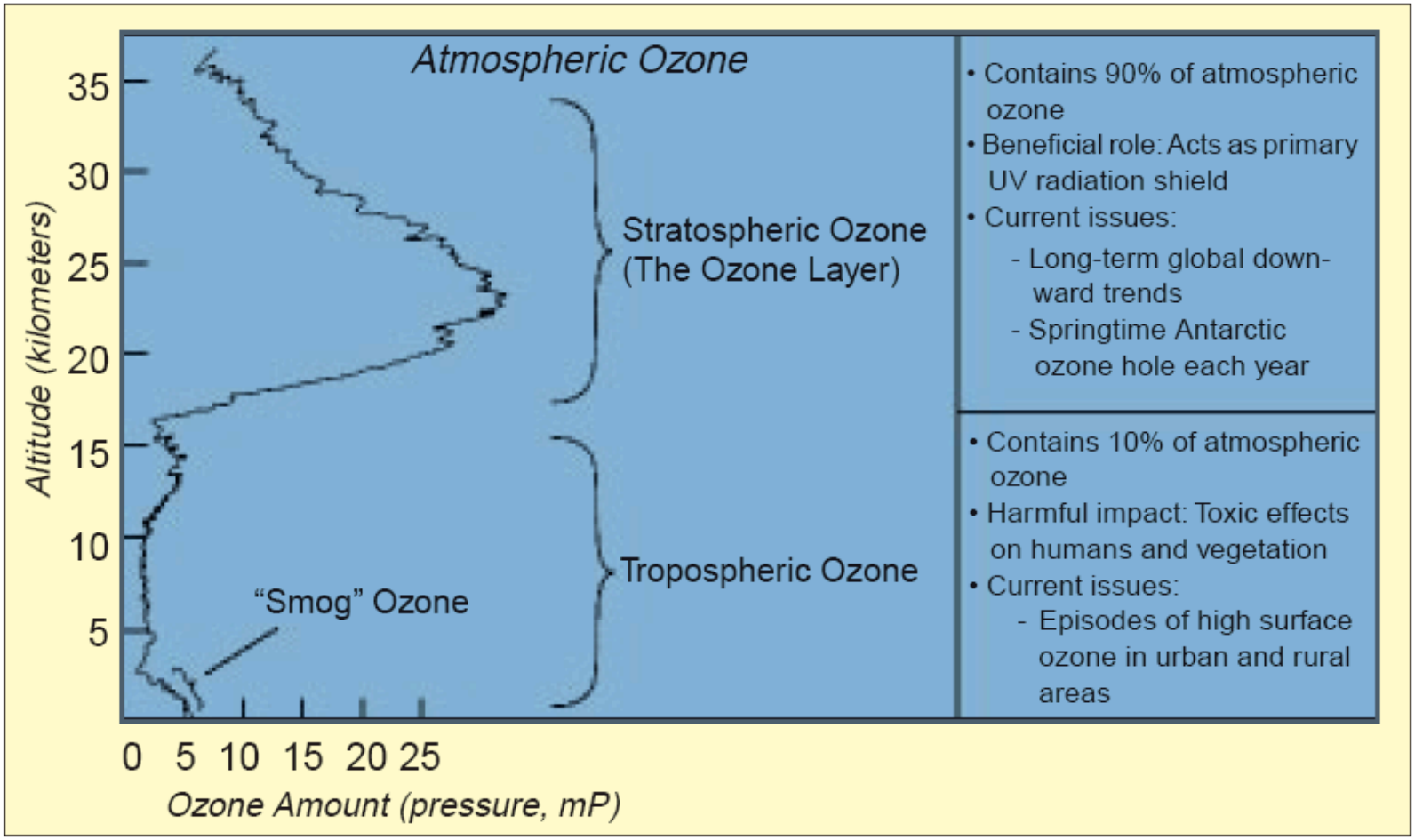
- Chlorine is 100 times as abundant in the atmosphere; but bromine is 10 times as effective per atom

The paradox of Ozone

- Stratospheric ozone essential for various life at the Earth's surface

- Ozone in the troposphere harmful to life on land and oceans

Ozone



Earth Observing System Science Plan, Fig. 7.1

Ozone in the troposphere

- Main component of photochemical (Los Angeles) smog
- Noxious substance that irritates eyes and lungs
  - Asthma, bronchitis
- Also harmful to trees, crops
  - US: several billion USD per year in crop damage

Next lecture

- Ozone holes
- Remediation
- **The Montréal Protocol**
- Other environmental global agreements