# Atmospheric Physics

## Lecture 10

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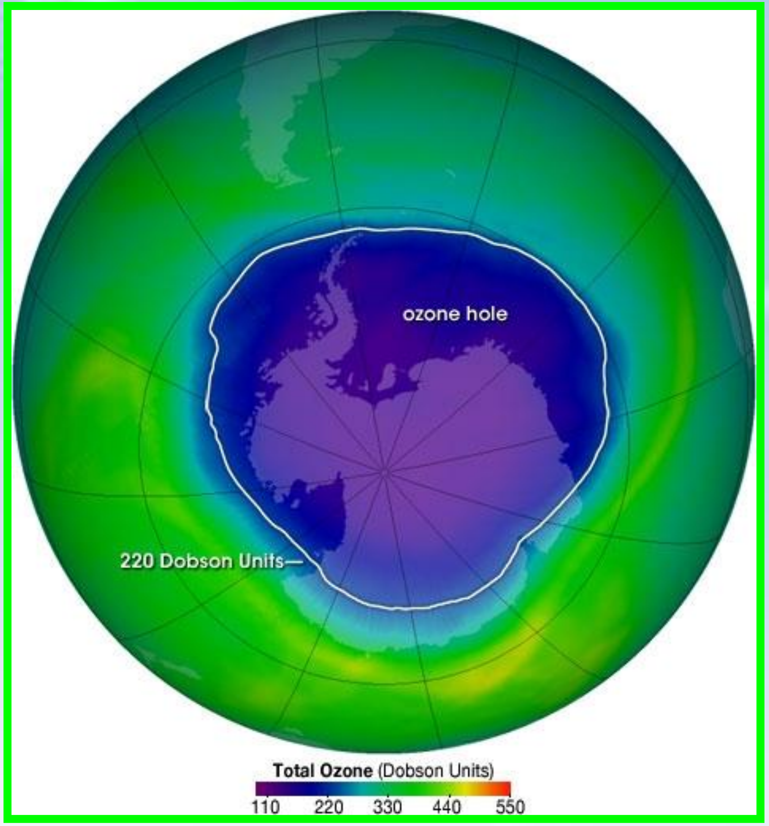
# What is the Ozone Hole?

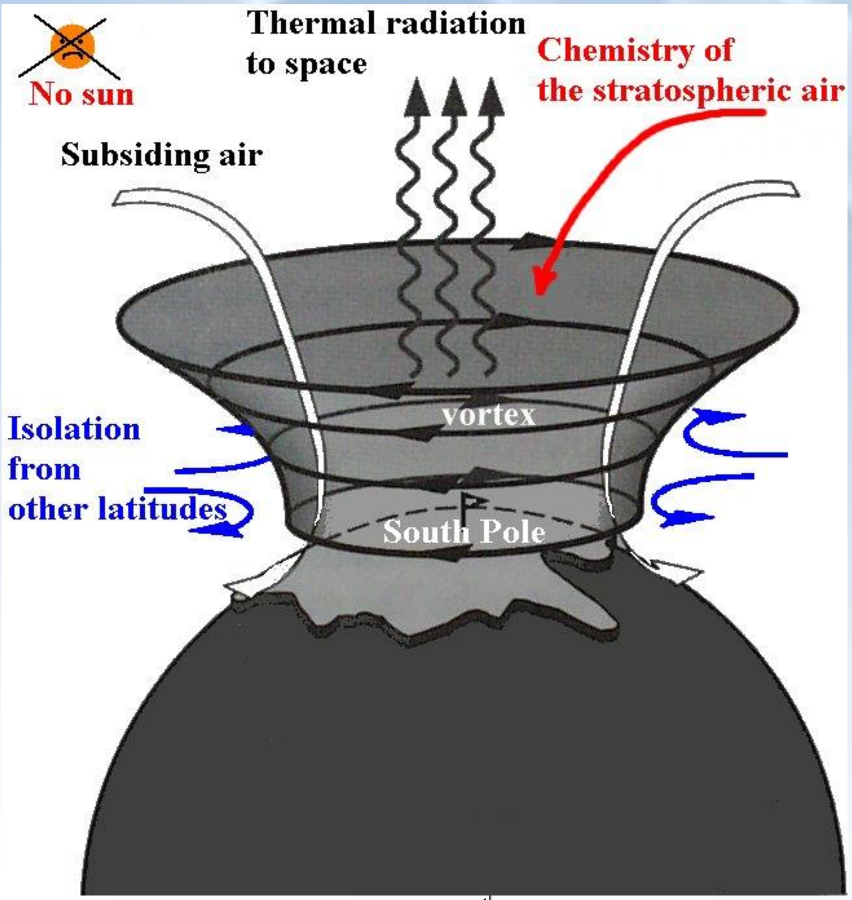
The ozone hole is not technically a "hole" where no ozone is present, but is actually a region of depleted ozone in the stratosphere over the Antarctic that happens at the beginning of Southern Hemisphere spring (August-October).

The average concentration of ozone in the atmosphere is about 300 Dobson Units; any area where the concentration drops below 220 Dobson Units is considered part of the ozone hole.



# The Antarctic polar vortex

As winter arrives, a vortex of winds develops around the pole which isolates the air within it.



# Why has caused the depletion Stratospheric Ozone over some regions of the Earth?

Mechanism of ozone destruction in the polar stratosphere:

two ingredients are necessary:

**cold temperature** and **sunlight**.

# Polar stratospheric clouds (PSCs)

Clouds can be formed in the stratosphere in the Antarctic because of **VERY LOW** temperatures ( as low as -90 $^{o}C$) reached during the long polar night (no sun light).

thin clouds form of ice, nitric acid mixtures

The lowest temperatures are common in the Antarctic, where the polar vortex is more stable than in the Arctic.

NOTE: The stratosphere is very dry and generally cloudless.

Therefore, the temperature should be extremely low to condense the small amount of water vapor present.

PSCs provide a reaction surface for the ozone destruction reactions involving chlorine and bromine.

Many of the chemical reactions require sunlight, so the ozone destruction does not begin until the polar night ends in the late winter or early spring.

Frozen particles in these clouds allow "chlorine reservoir" molecules to react to form $Cl_2$

$$ClONO_2\,(g) + HCl\,(s) \rightarrow \mathbf{Cl_2\,(g)} + HNO_3\,(s)$$

$$ClONO_2 + H_2O \rightarrow HO\mathbf{Cl}\ \mathbf{(g)} + HNO_3\,(g)$$

$Cl_2$ & HOCl accumulates during winter when the first light of spring arrives $Cl_2$ & HOCl are cleaved into Cl & ClO atoms

Inert chlorine reservoir species, HCl and $ClONO_2$, are transformed into active chlorine species, Cl and ClO, via heterogeneous reactions on PSCs surfaces.

Two major processes:

**1) via $Cl_2$ photolysis:**

$$Cl_2 + \text{light} \rightarrow Cl + Cl$$

$$\mathbf{2[Cl + O_3 \rightarrow ClO + O_2]}$$

## 2) dimer mechanism

$$2[Cl + O_3 \rightarrow ClO + O_2]$$

$$ClO + ClO + M \rightarrow Cl_2O_2 + M$$

$$Cl_2O_2 + hn \rightarrow Cl + Cl + O_2$$

Net reaction: $2\ O_3 + hn \rightarrow 3\ O_2$

## In the warmer Arctic a large proportion of the loss may be driven by:

$$ClO + BrO \rightarrow Br + Cl + O_2$$

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

$$Br + O_3 \rightarrow BrO + O_2$$

Net reactio: $2\ O_3 \rightarrow 3\ O_2$

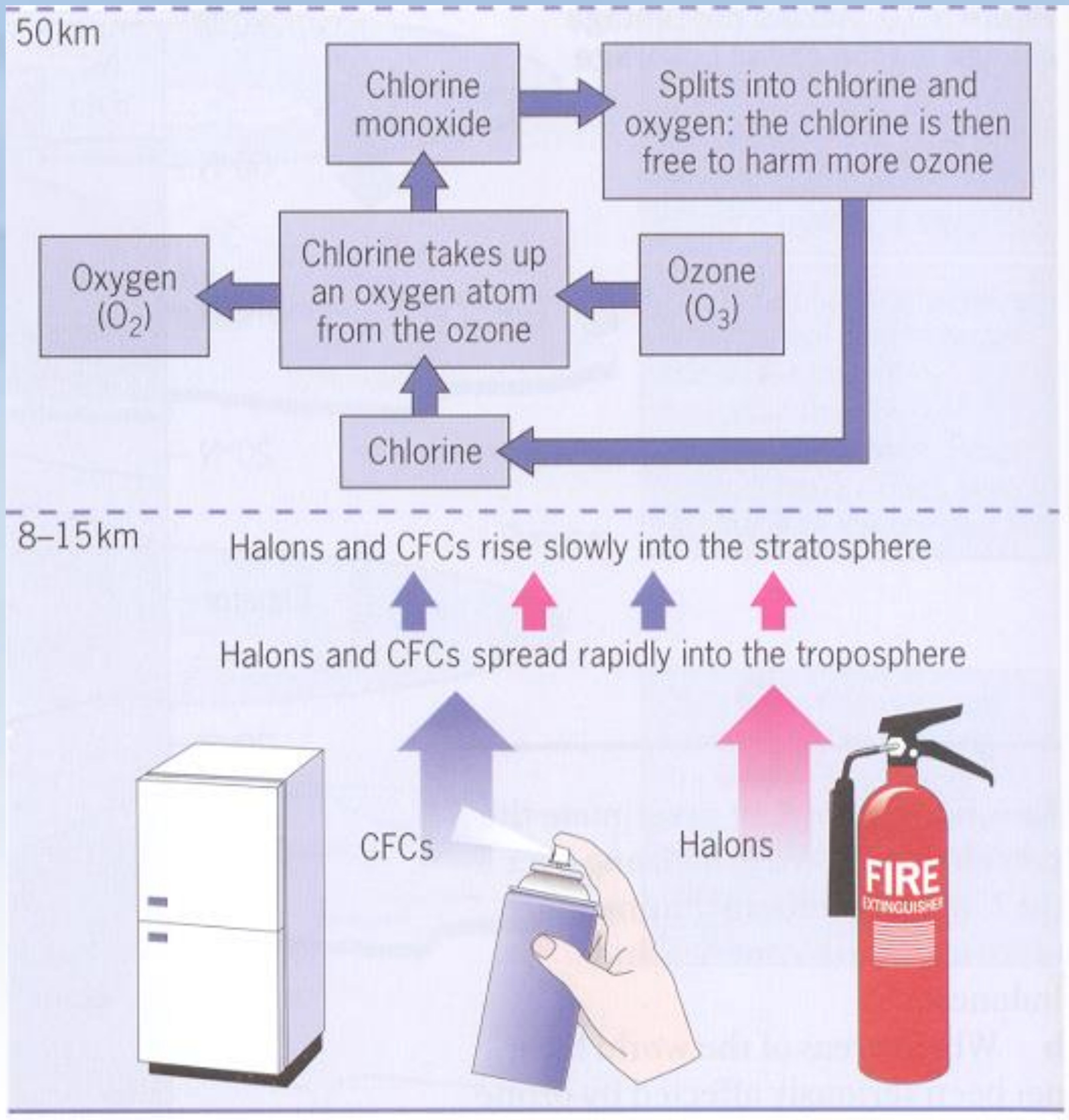
# What causes Ozone Depletion?

The Ozone Hole is caused by chemicals called CFCs, short for chlorofluorocarbons. CFCs escape into the atmosphere from refrigeration and propellant devices and processes, and they are so stable they last for decades. This long life allows some CFCs to eventually reach the stratosphere.


The chemicals that make up CFCs, mainly chlorine and fluorine, float around the stratosphere, breaking up ozone molecules.

One molecule of CFC can destroy more than 100,000 molecules of stratospheric ozone.

Today, no spray cans contain CFCs. Other chemicals are gradually replacing the CFCs in air conditioners.



50 km
Chlorine monoxide
Splits into chlorine and oxygen: the chlorine is then free to harm more ozone
Oxygen ($O_2$)
Chlorine takes up an oxygen atom from the ozone
Ozone ($O_3$)
Chlorine
8–15 km
Halons and CFCs rise slowly into the stratosphere
Halons and CFCs spread rapidly into the troposphere
CFCs
Halons
FIRE
EXTINGUISHER

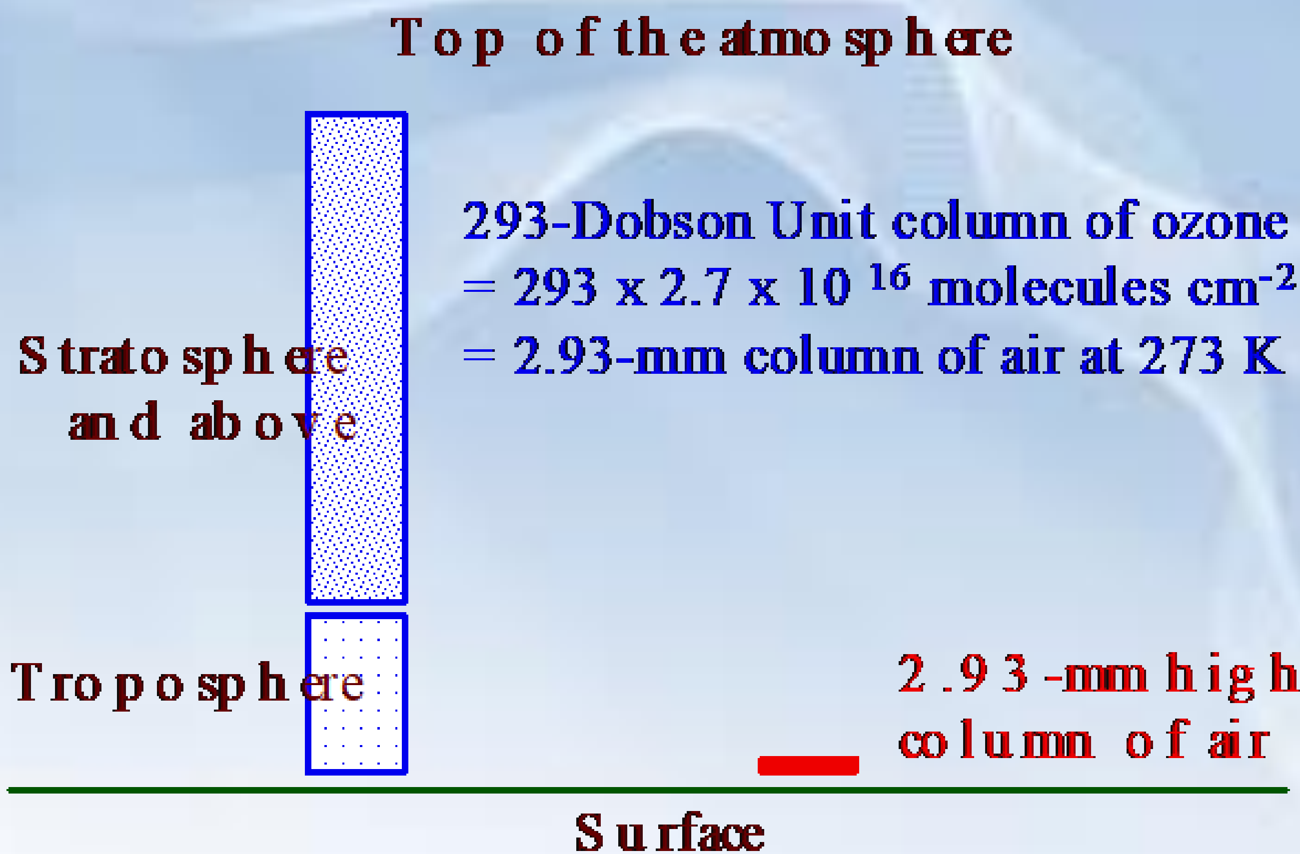
# Sources that harm ozone layer

# Sources of chloroflurocarbons

Table 13.1 Chlorofluorocarbons and Other Halogen Compounds[a]

| *Chemical* (symbol) | *Emission* ($10^3$ tonne/yr) | *Atmospheric concentration* (pptv) | *Atmospheric lifetime*[b] (years) | *Applications* | *Growth rate* (%/yr) | *Ozone depletion potential*[c] |
|---|---|---|---|---|---|---|
| CFC-11 ($CFCl_3$) | 260 | 270 | 76 | Refrigeration, foams, aerosol spray | 5 | 1.0 |
| CFC-12 ($CF_2Cl_2$) | 450 | 460 | 139 | Air conditioning, foams, refrigeration, aerosol spray | 5 | 3.0 |
| CFC-113 ($CFCl_2CF_2Cl$) | 150 | 65 | 92 | Solvent | 10 | 1.3 |
| Carbon tetrachloride ($CCl_4$) | 75 | 110 | 67 | Solvent | 1 | 0.35 |
| Methyl chloroform ($CH_3CCl_3$) | 520 | 135 | 8 | Solvent | 7 | 0.024 |
| Methyl bromide ($CH_3Br$) | 60 | ~15 | 1.5 | Fumigation | 15 | — |
| HCFC-22 ($CHF_2Cl$) | 220 | 110 | 15 | Refrigeration, air conditioning | 7 | 0.35 |
| Halon 1301 ($CF_3Br$) | 3 | ~3 | 110 | Fire extinguishers, fumigation | 20 | — |
| Halon 1211 ($CF_2BrCl$) | 80 | ~2 | 25 | Refrigeration, foams | 15 | — |
| Methyl chloride ($CH_3Cl$) | — | 600 | 1.5 | — | ~0 | — |

# Column Abundance of Ozone

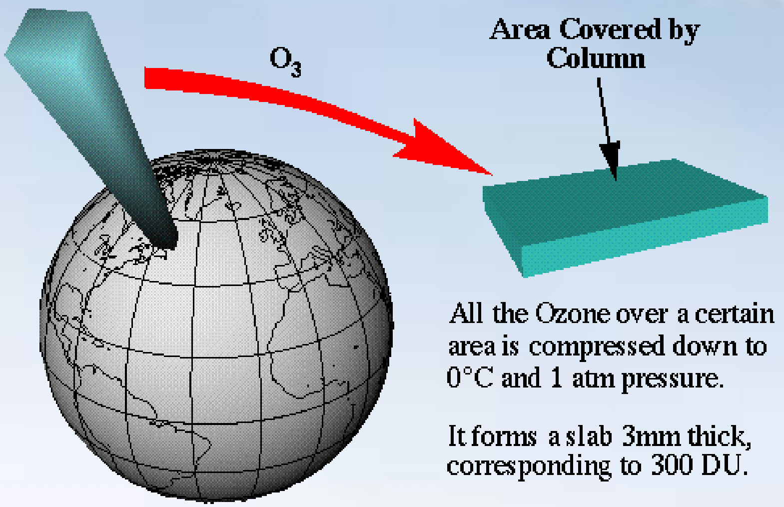



293-Dobson Unit column of ozone
= 293 x 2.7 x $10^{16}$ molecules $cm^{-2}$
= 2.93-mm column of air at 273 K and 1 atm

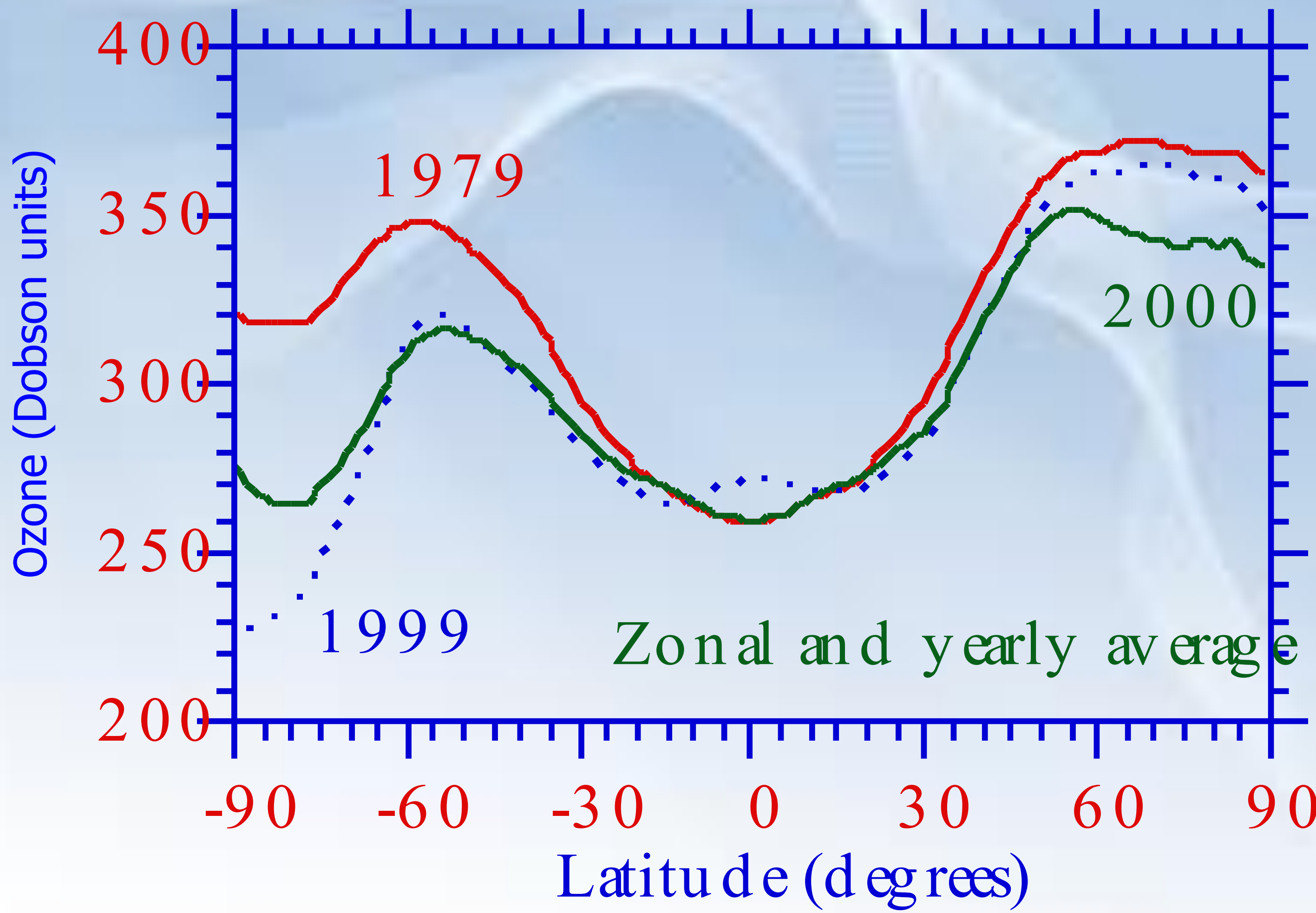
# What is a Dobson unit?

1 Dobson Unit (DU) is defined to be 0.01 mm thickness at STP - (0C and 1 atmos press).

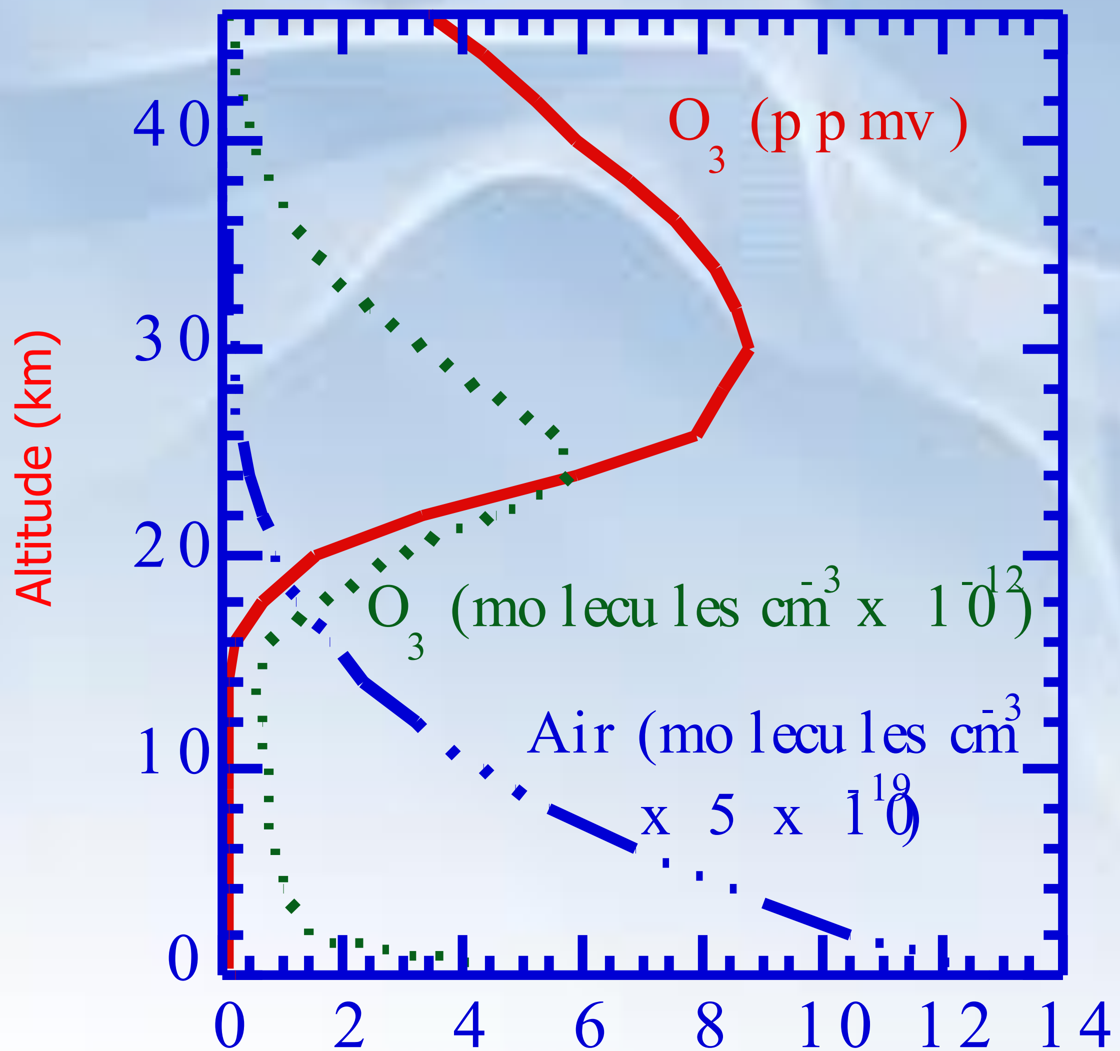
A slab 3mm thick corresponds to 300 DU



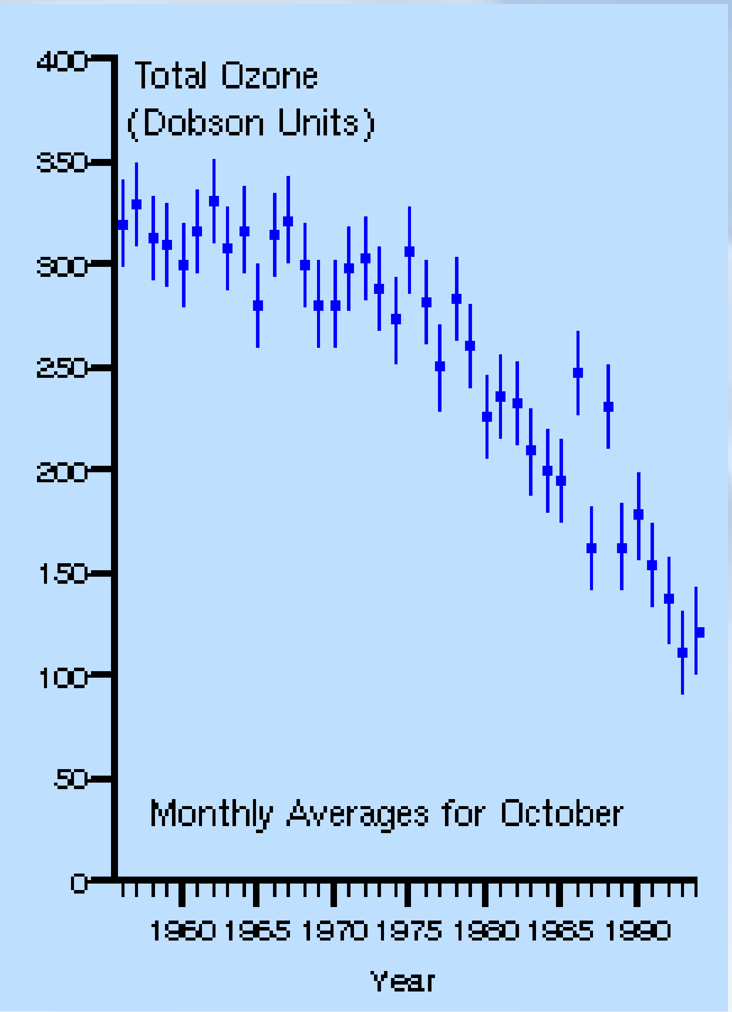
# Variation with Latitude of Yearly- and Zonally-Averaged Ozone in '79, '99, '00



# Vertical Profile of Ozone

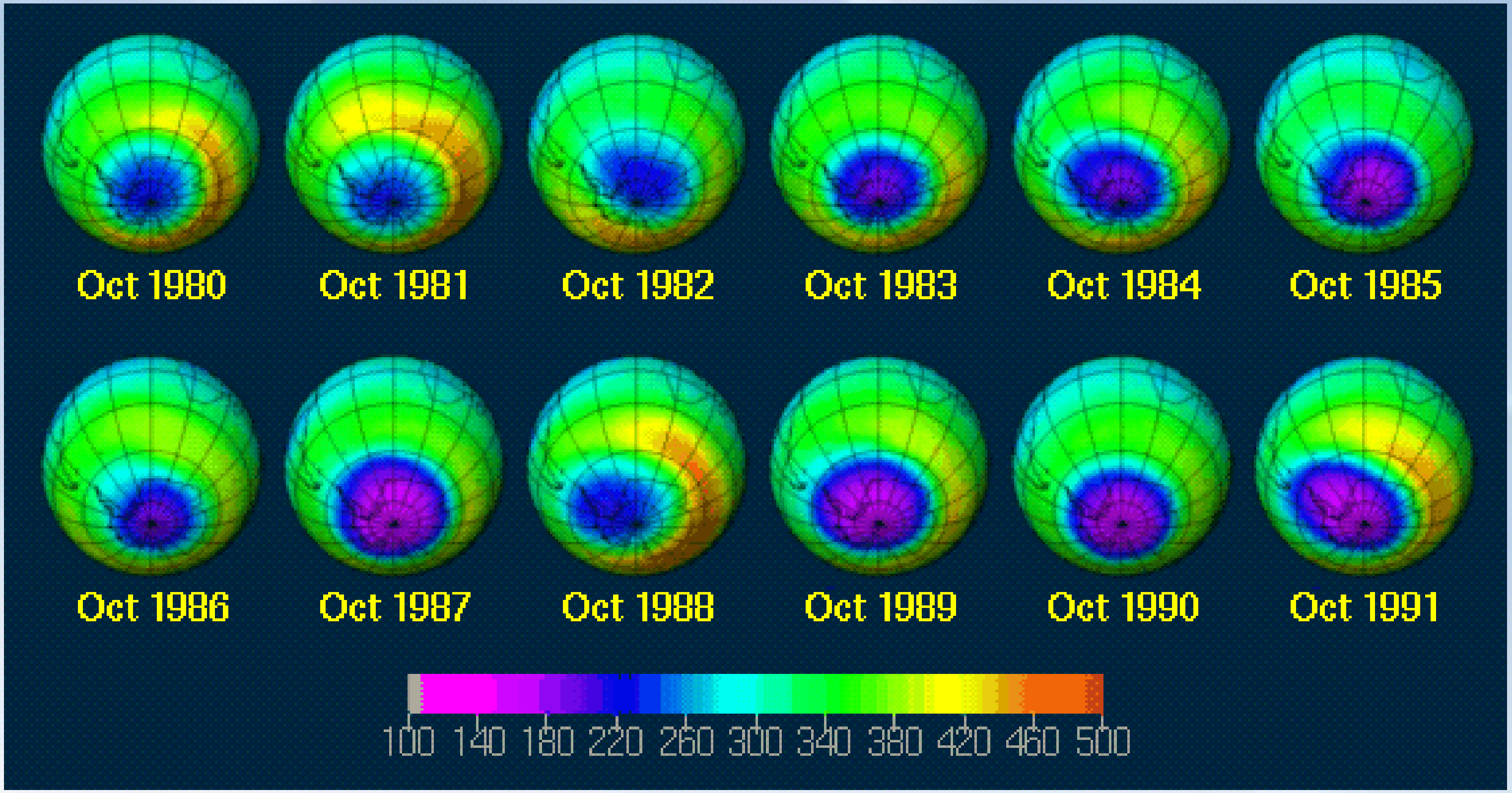


# Total ozone – October monthly averages




Halley Bay, Antarctica

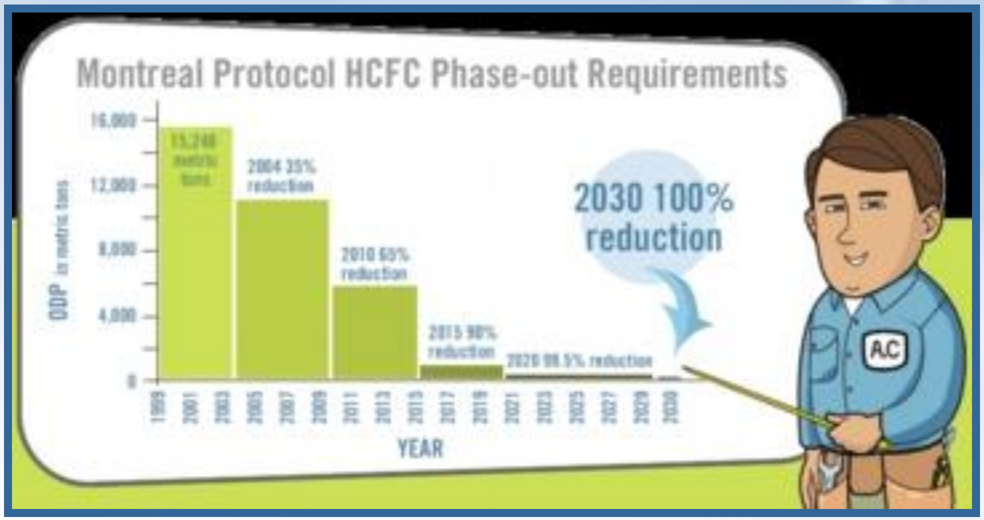
# Monthly averages for October



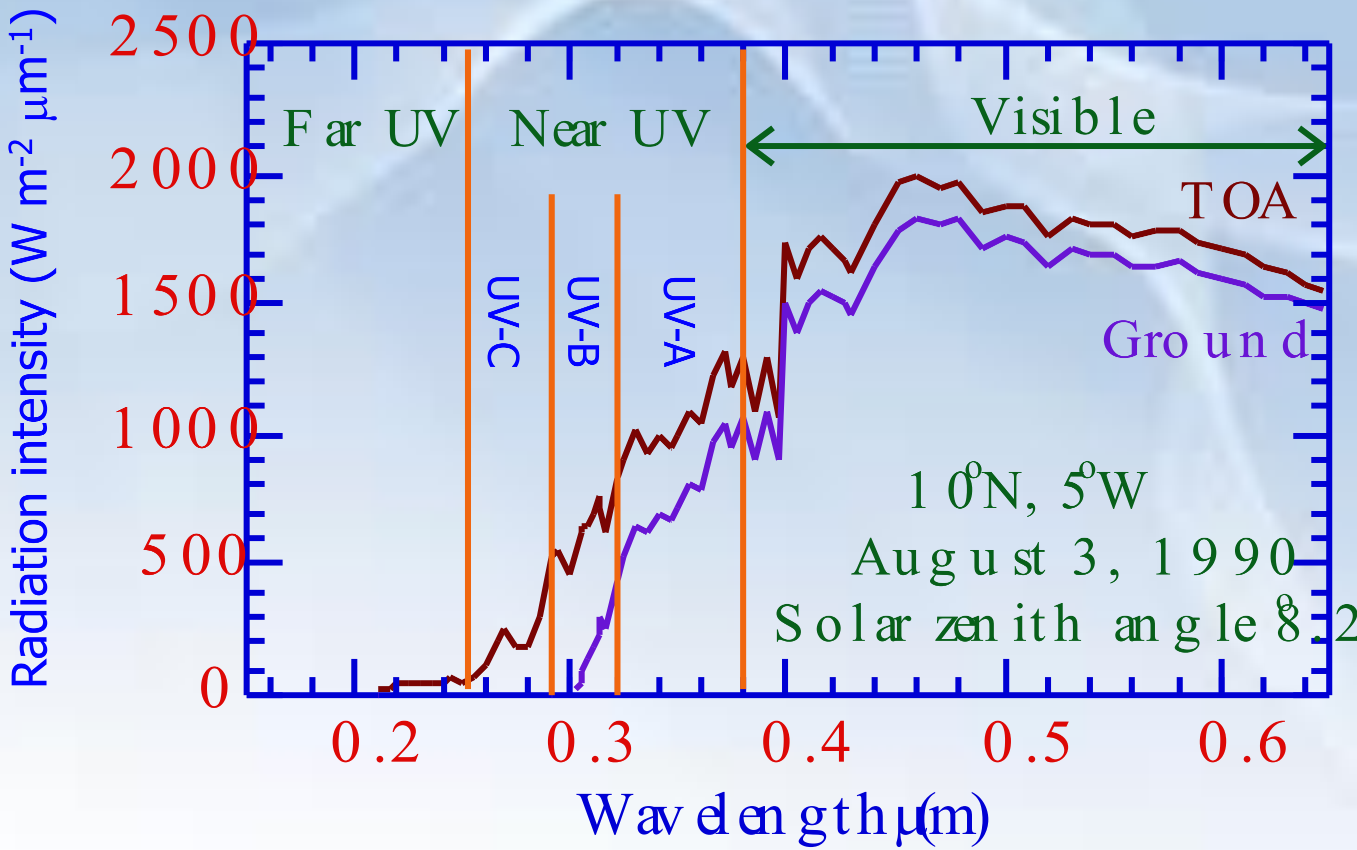
# What is the Montreal Protocol?

The Montreal Protocol is a landmark international agreement designed to protect the stratospheric ozone layer.

The Montreal Protocol says that the production and consumption of compounds that deplete ozone in the stratosphere--chlorofluorocarbons (CFCs), halons, carbon tetrachloride, and methyl chloroform--are to be phased out by 2030.



# Downward Solar Radiation at Top of Atmosphere (TOA) and Ground



# Major Absorbers of UV Radiation at Different Altitudes

| Spectrum | Wavelengths (mm) | Dominant Absorbers | Location of Absorption |
|---|---|---|---|
| Far-UV | 0.01-0.25 | $N_2$ | Thermosphere |
| | | $O_2$ | Thermosphere |
| Near-UV | | | |
| UV-C | 0.25-0.29 | $O_3$ | Stratosphere |
| UV-B | 0.29-0.32 | $O_3$ | Stratosphere |
| | | | Troposphere |
| UV-A | 0.32-0.38 | Particles | Polluted troposphere |
| | | $NO_2$ | Polluted troposphere |
| | | Particles | Polluted troposphere |

# ozone depletion. Global

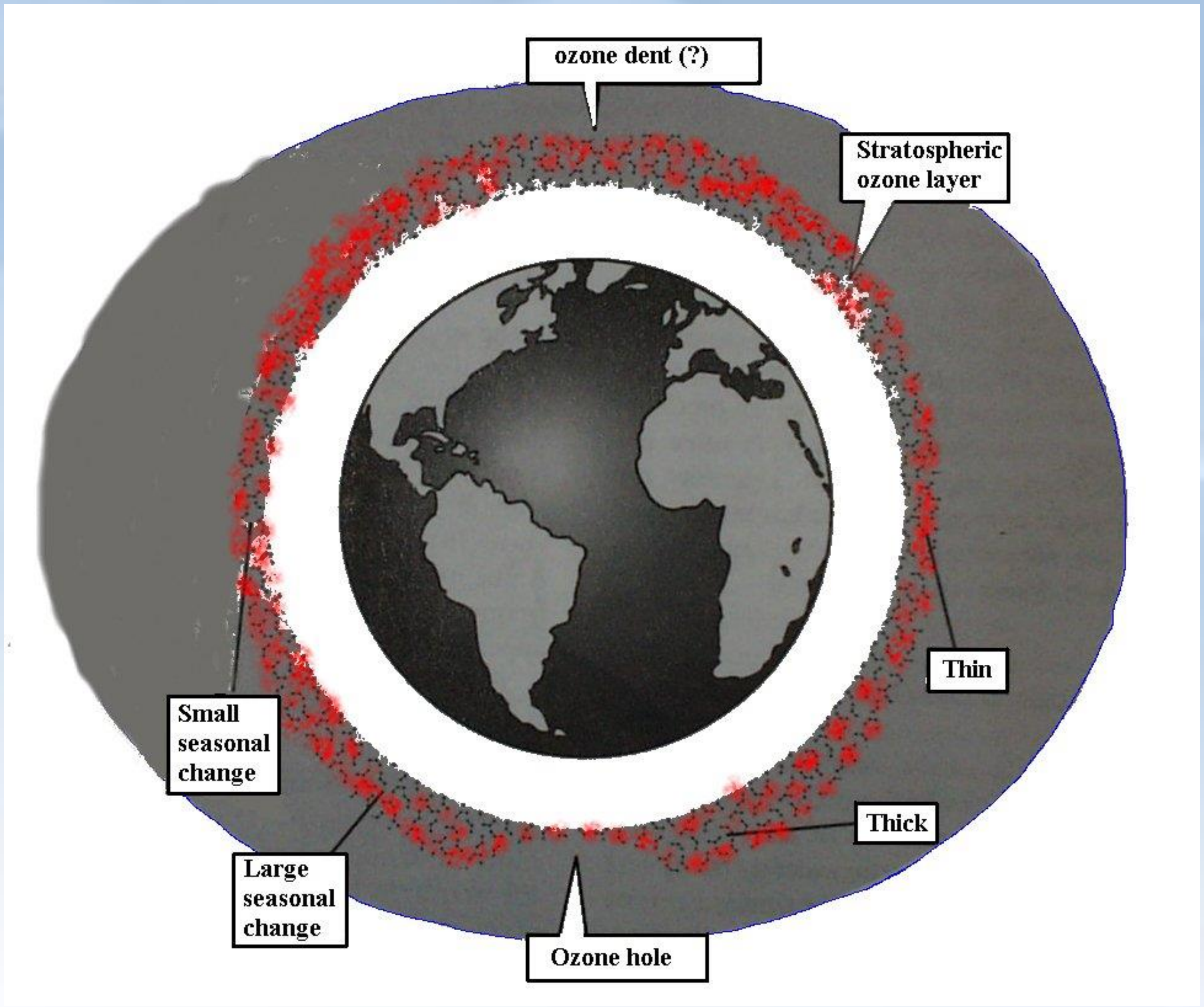
Ozone depletion over different regions;

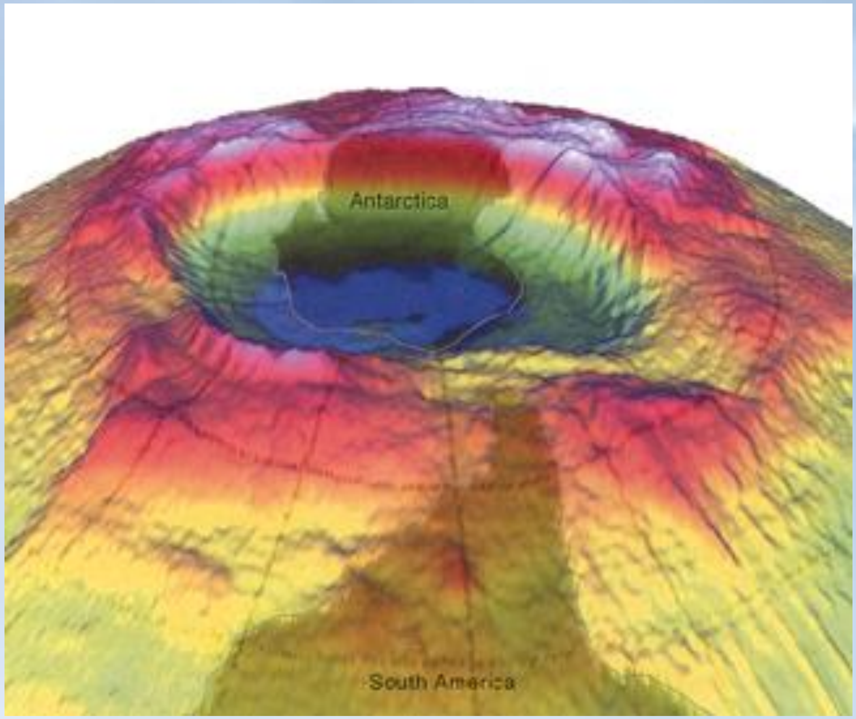
Arctic: local ozone reductions are up to 15% only (because the vortex is not very stable, and PSCs are not common).

Tropical latitudes: no ozone reduction was observed so far;

Mid-latitudes (30°-60°N): ozone depletion is detected (winter ozone depletion of 6-8%) (exact cause is unknown; probably, due to stratospheric aerosols);

# Global variation in the thickness of the ozone layer




Antarctica
South America

# Thanks for your attention