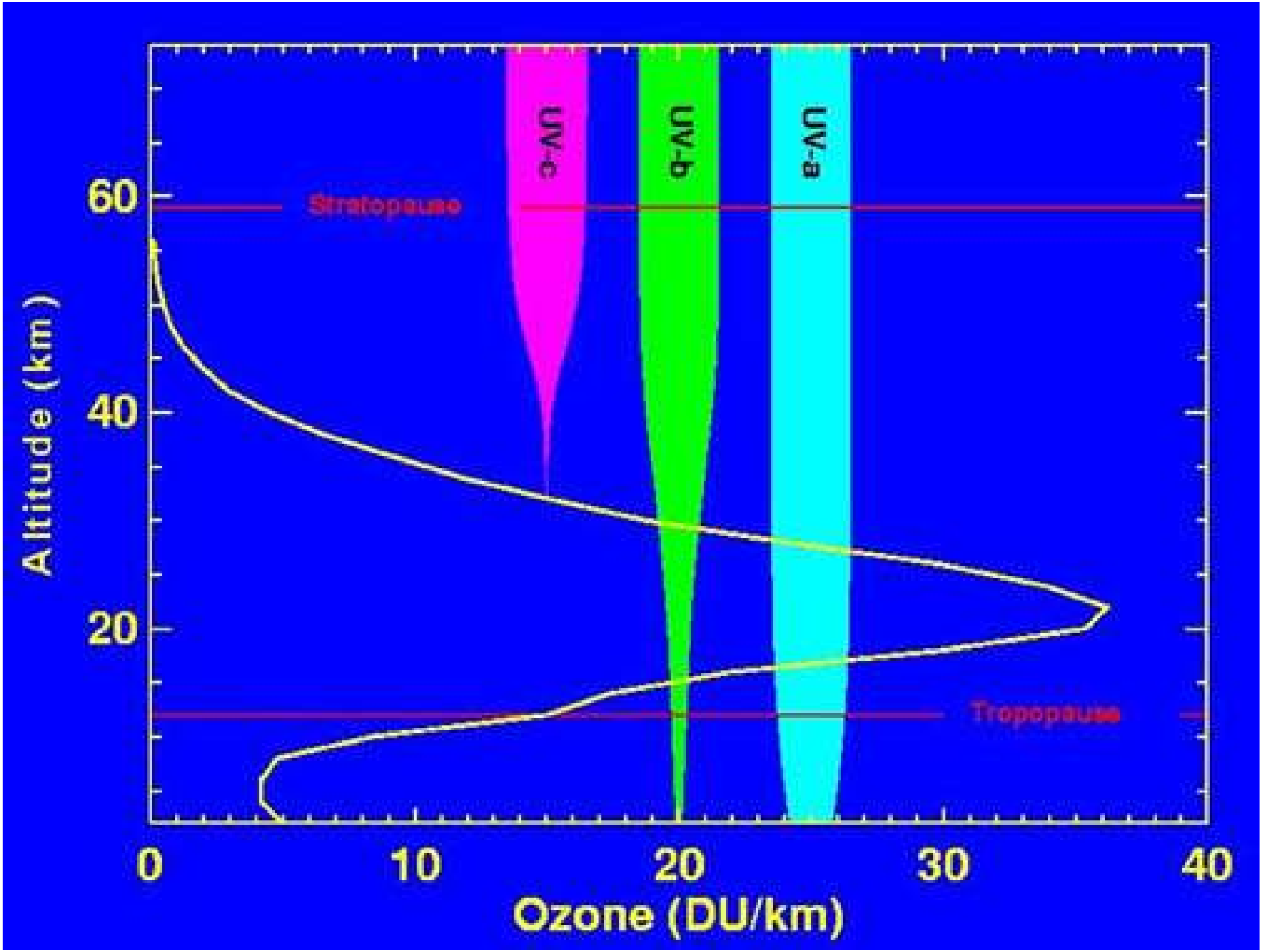
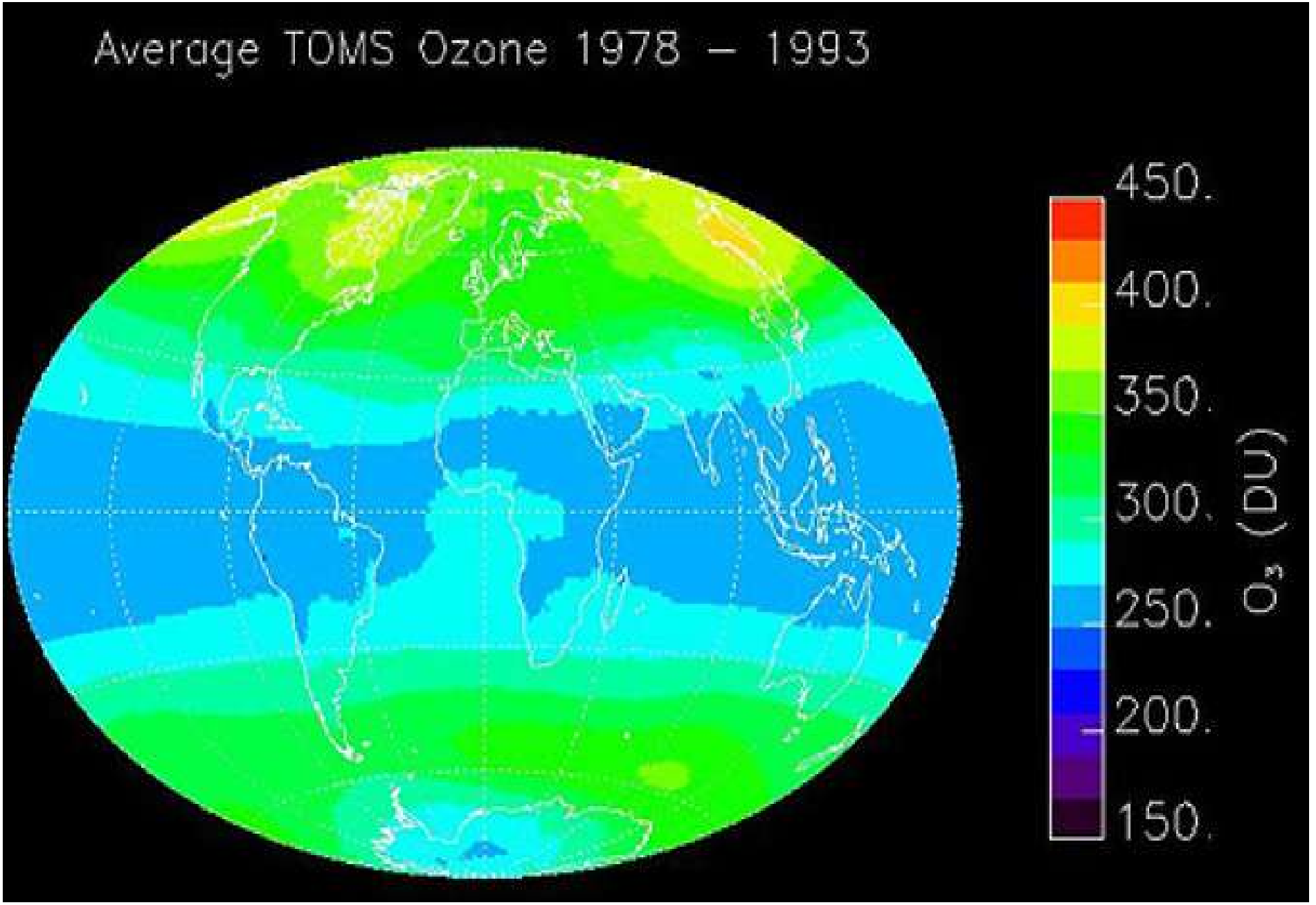
Ozone Depletion and the Ozone Hole Preview:

- Stratospheric sunscreen, tropospheric pollutant
- 60's & 70's theories suggested depletion mechanisms
- 1985 discovery of ozone was a big surprise
- lead to increased research effort
- Chlorine and PSC hypothesized as cause
- lead to international restrictions and bans
- 80's & 90's ozone hole continued to expand and mid-latitude loss continues
- Present: growth slowed although 2003 was big
- Chlorine concentrations stabilizing, CFC's eliminated

Ozone as natural sunscreen





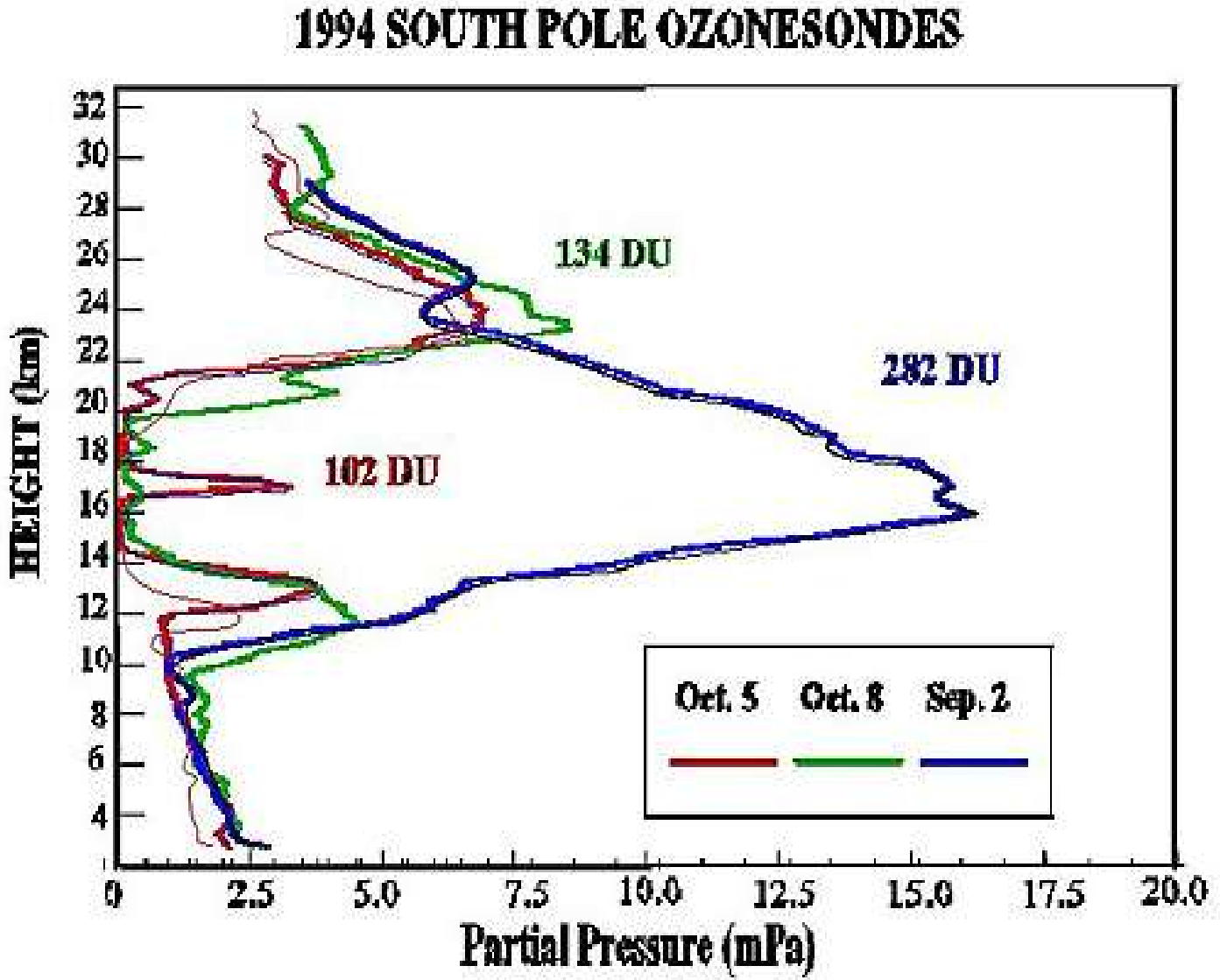
Average Ozone Column 1978-1993

Stratospheric Ozone: Brief Historical Perspective

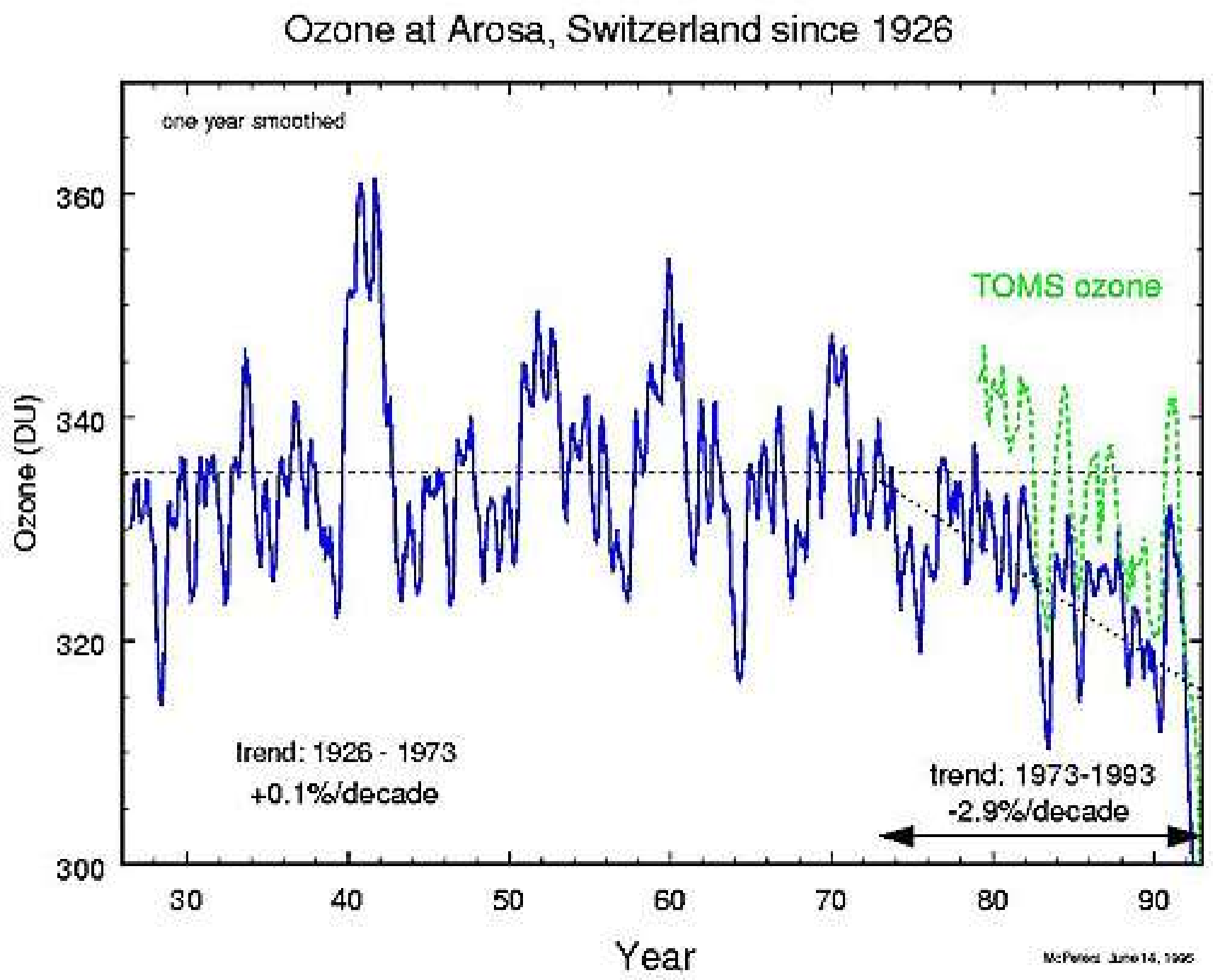
- 1881: Hartley first hypothesized the presence of ozone (lab)
- 1924: Dobson invented spectrophotometer of measure ozone
- 1929: Gotz using Dobson s instrument found that ozone was in the stratosphere (~25 km)
- 1930: Chapman developed theory of stratospheric ozone origin
- 1949: Brewer, role of circulation in controlling ozone layer
  Catalytic cycles: Hydrogen (Hunt, 1966); NOx from tropospheric N2O (Crutzen, 1970); NOx from aircraft (Johnston, 1971); CFCs (Molina & Rowland, 1974)
- 1985: Farman discovers the ozone hole over Antarctica
- 1986: Solomon/McElroy unravel the role of polar stratospheric clouds and halogen catalysis
- Regulation of CFC production: Montreal Protocol (1987); London Agreement (1990); Copenhagen amendment (1992)

Jeagle, 2004

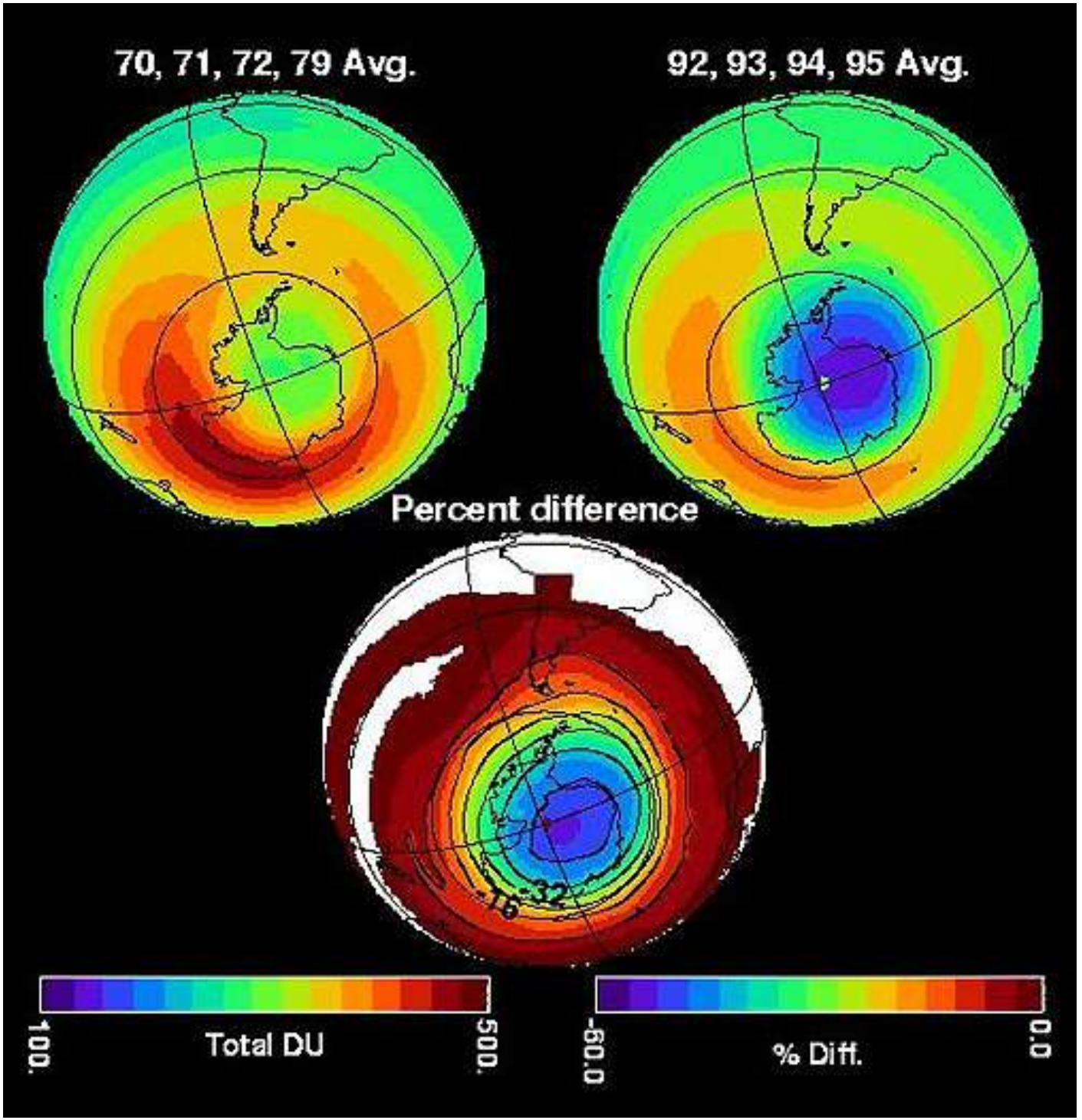
Antarctic Ozone Measurements vs Altitude

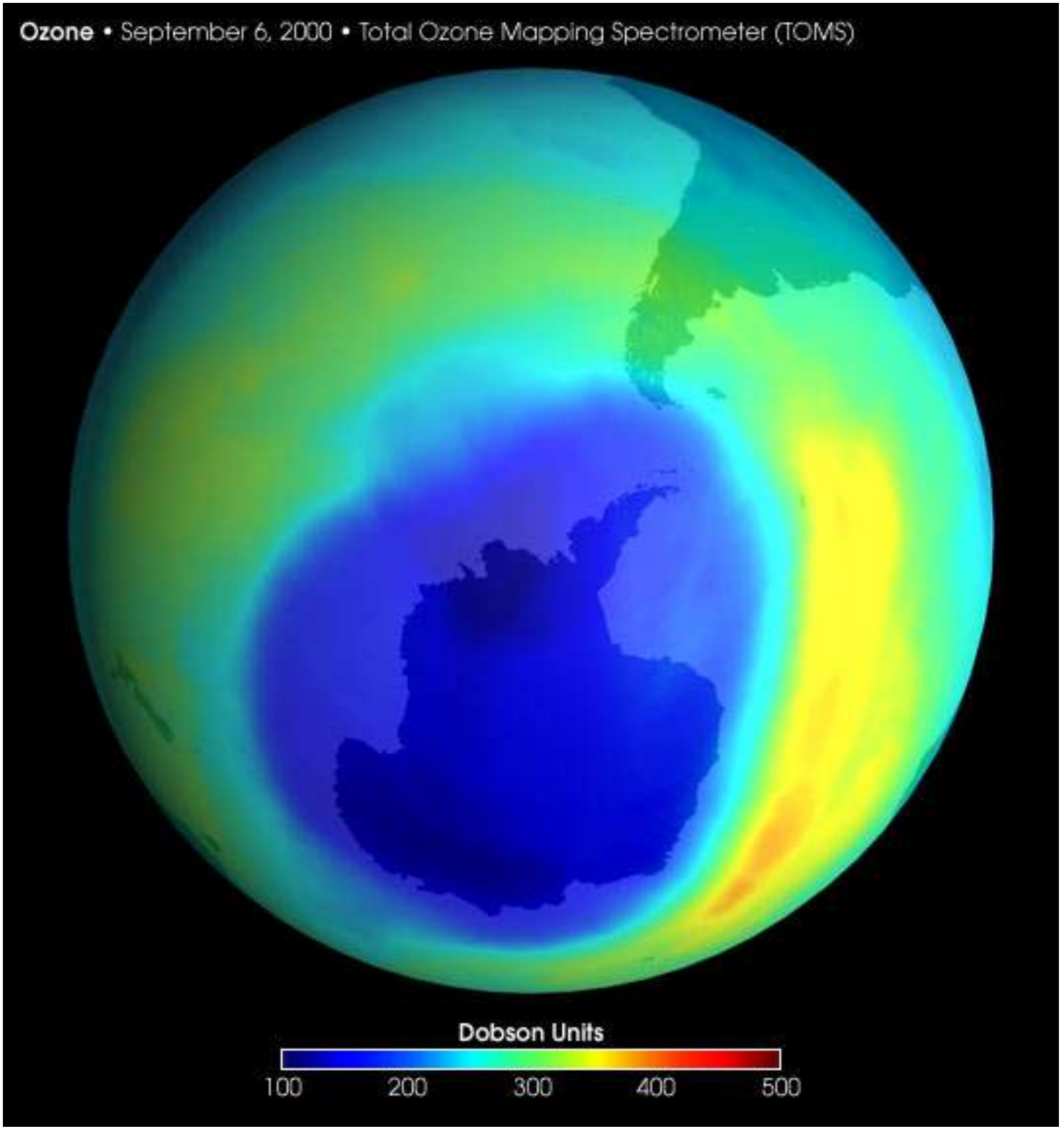


Measurements made by balloon ozonesondes before and after intense depletion.

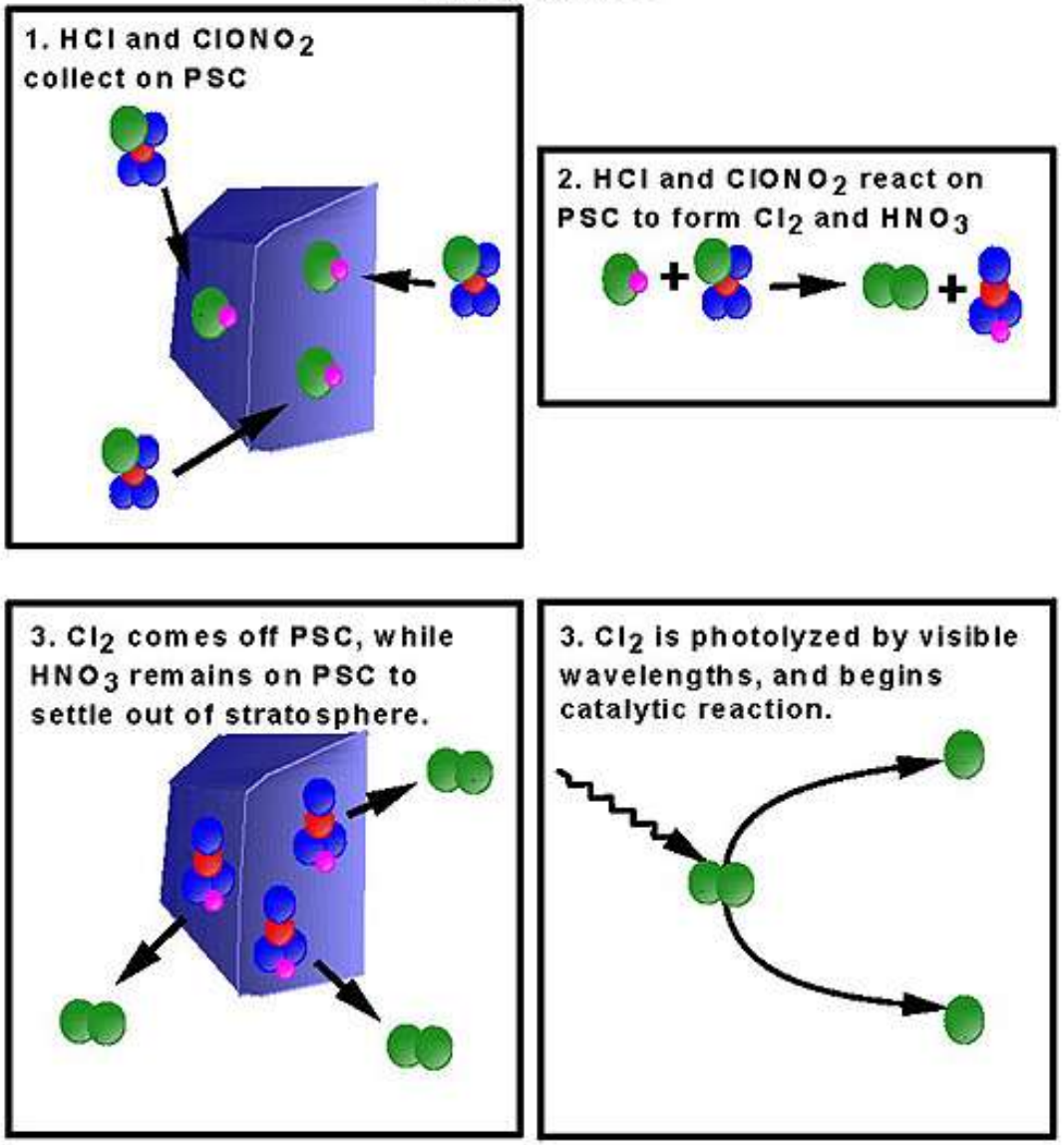

Ozone at Arosa, Switzerland since 1926
one year smoothed
TOMS ozone
Ozone (DU)
360
340
320
300
30
40
50
60
70
80
90
Year
trend: 1926 - 1973
+0.1%/decade
trend: 1973-1993
-2.9%/decade

October average ozone concentrations




Ozone • September 6, 2000 • Total Ozone Mapping Spectrometer (TOMS)
Dobson Units
100
200
300
400
500

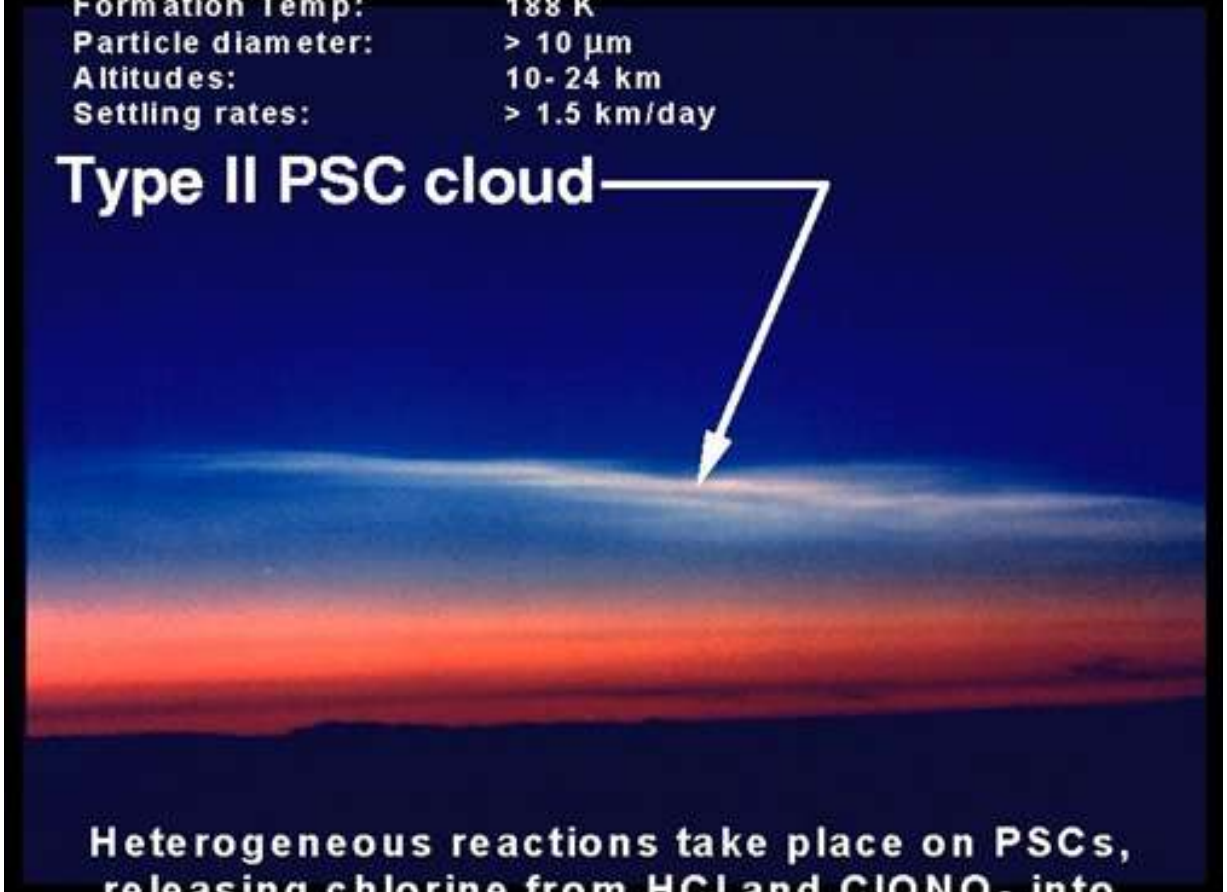
Polar Stratospheric Cloud Surface Reaction



Polar Stratospheric Clouds

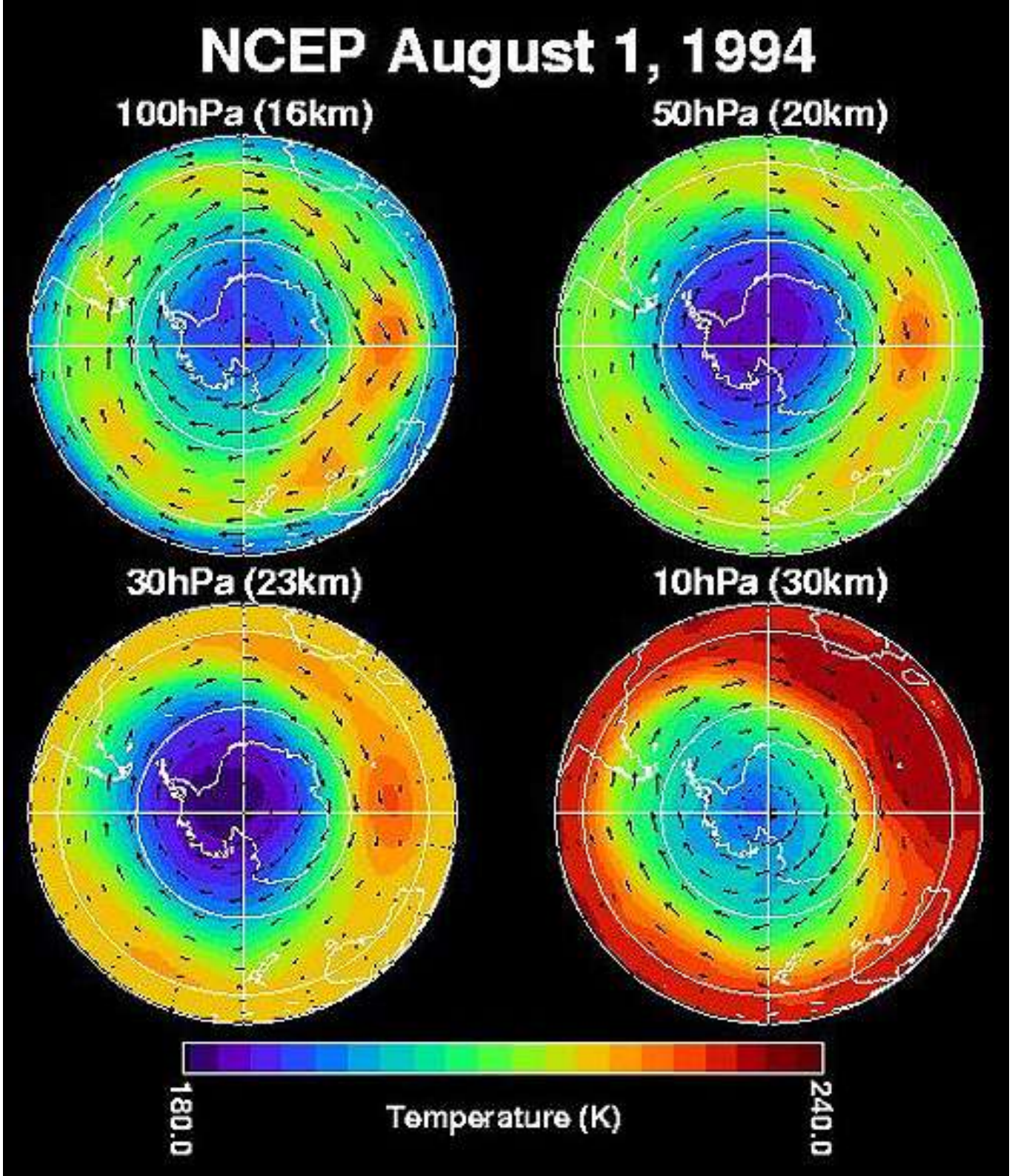
Type I PSC:	Nitric acid trihydrate ($HNO_3 \cdot 3H_2O$) Ternary solution (H_2O, H_2SO_4, HNO_3)
Formation Temp:	195 K
Particle diameter:	1µm
Altitudes:	10-24 km
Settling rates:	1km/30 days

Type II PSC:	Water Ice
Formation Temp:	188 K
Particle diameter:	> 10 µm
Altitudes:	10-24 km
Settling rates:	> 1.5 km/day

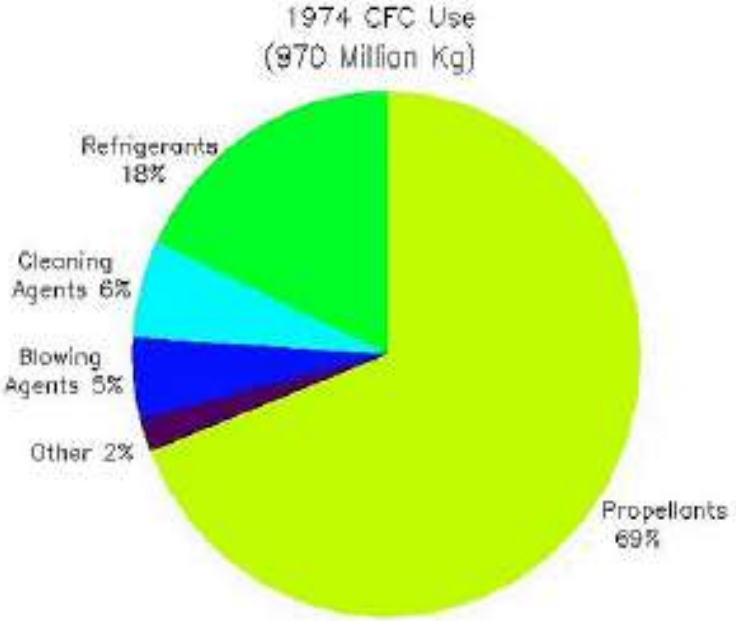


Heterogeneous reactions take place on PSCs, releasing chlorine from HCl and $ClONO_2$ into reactive forms (ClO) that can rapidly destroy ozone.

PSC over Norway, January 1989, taken from the NASA DC-8


NCEP August 1, 1994
100hPa (16km)
50hPa (20km)
30hPa (23km)
10hPa (30km)
180.0
Temperature (K)
240.0

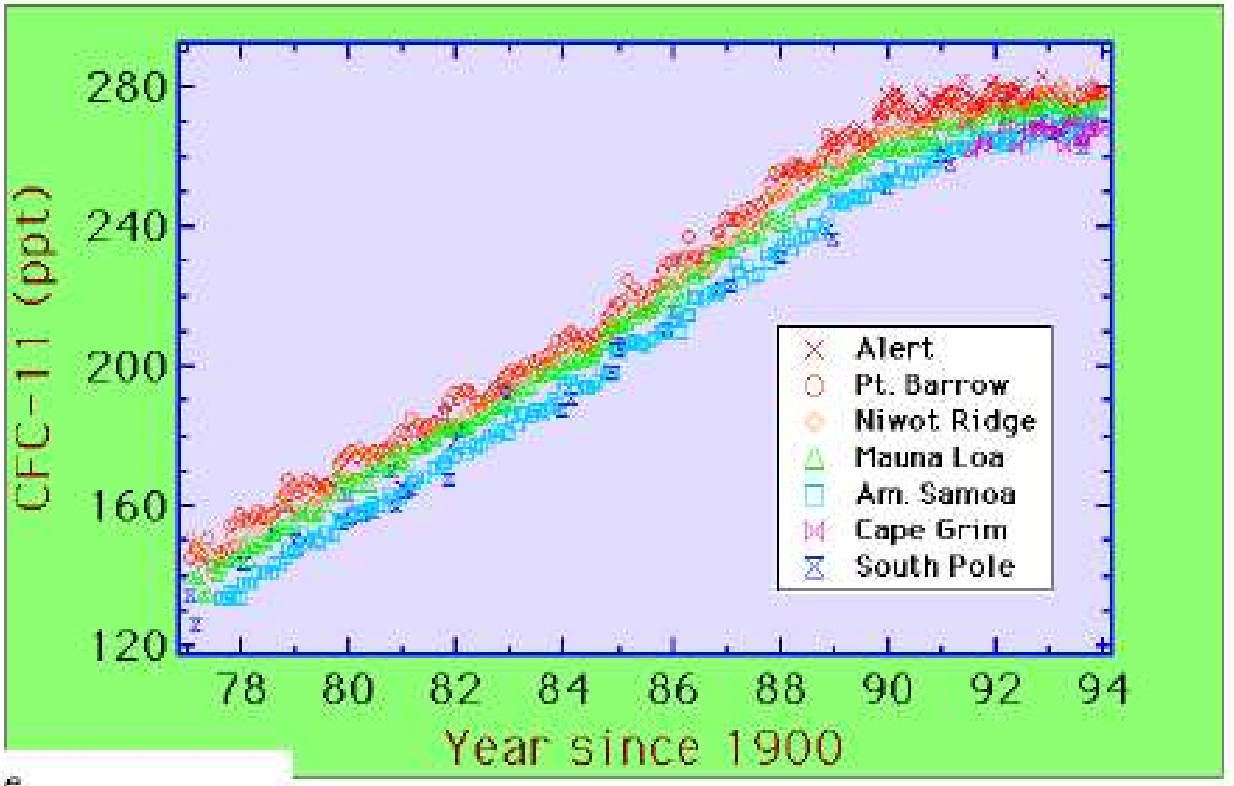
"wonder gas" CFCs were invented in 1928



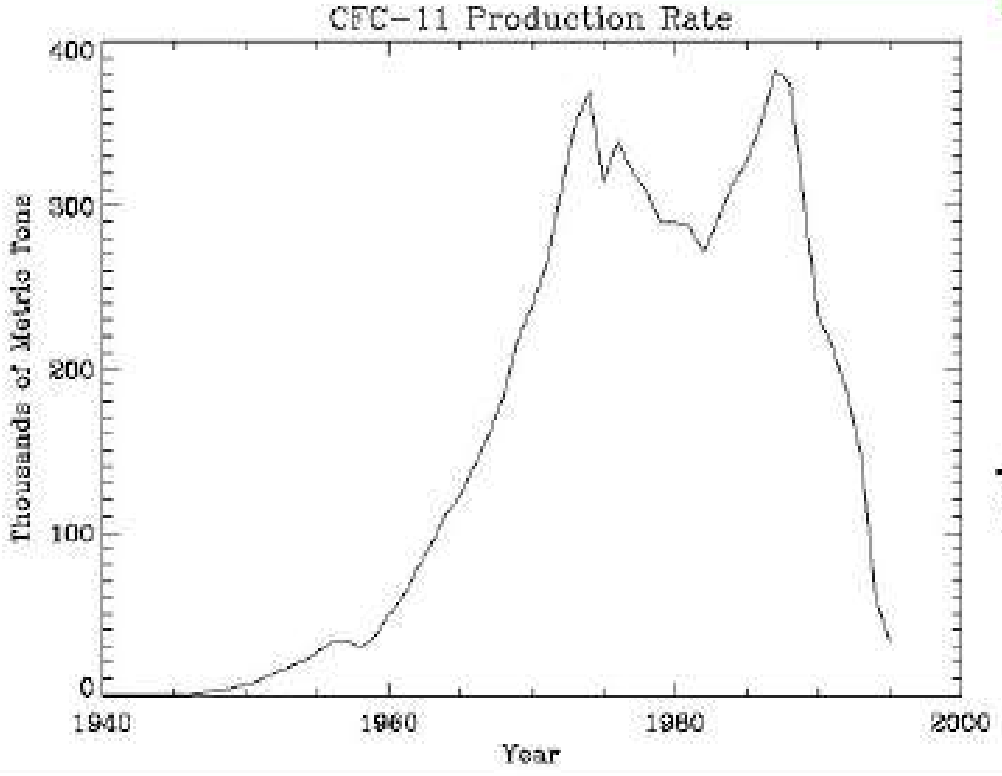
Use of CFCs increases rapidly

Jeagle, 2004

1970-1994: rapid increase in CFC-11 atmospheric levels

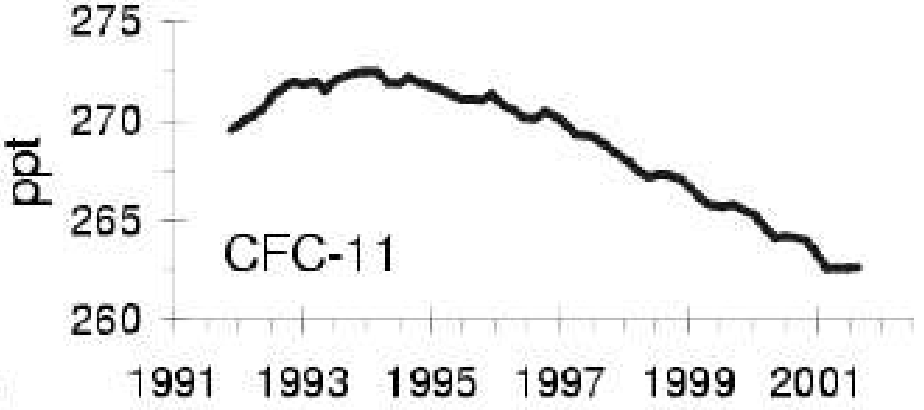


CFC-11 production rate

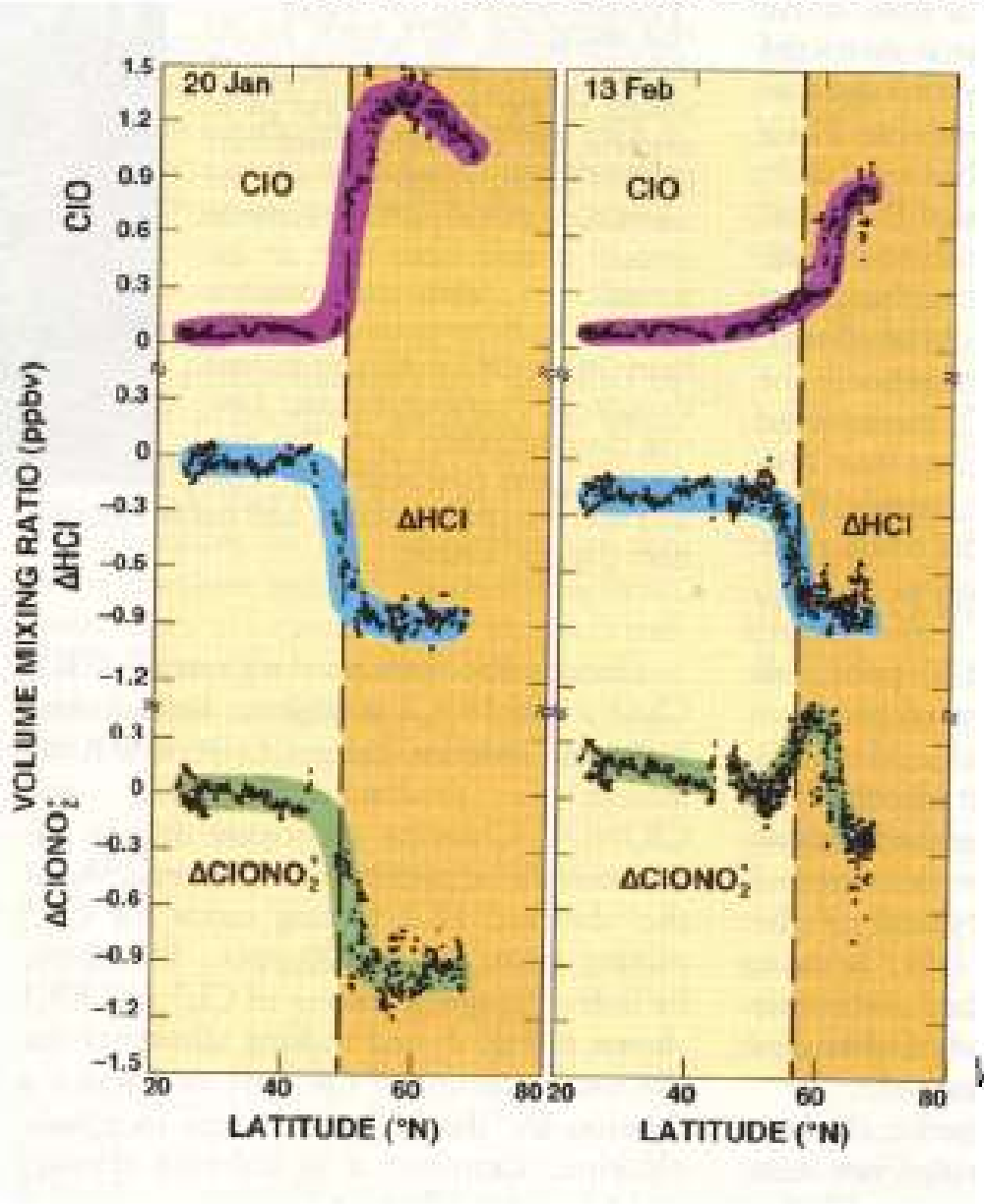


Elkins et al., Nature, 1993.

1994-today: CFC-11 is decreasing



Field observations confirming PSC theory



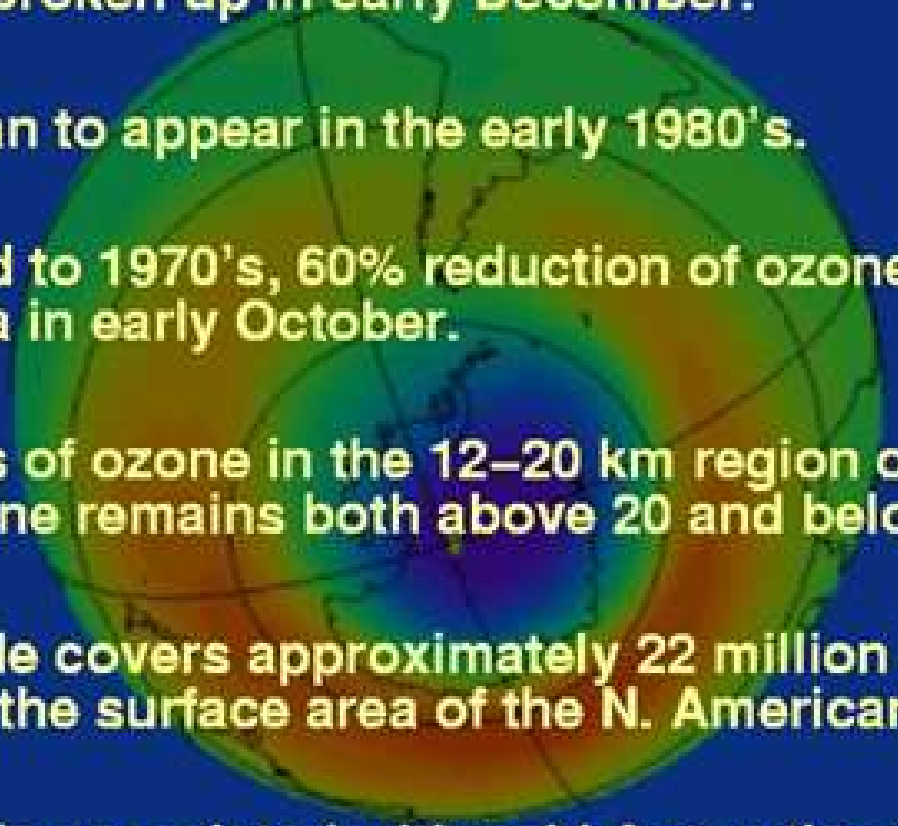
Simultaneous observations of ClO and HCl inside polar vortex (Arctic 1993)

→ ClO increases and HCl decrease inside the polar vortex

Webster et al., Science, 261, 1130,1993.

Ozone Hole Observations

- Begins to develop in August, fully developed by early October, broken up in early December.
- First began to appear in the early 1980's.
- Compared to 1970's, 60% reduction of ozone over Antarctica in early October.
- 100% loss of ozone in the 12–20 km region over Antarctica, some ozone remains both above 20 and below 12 km.
- Ozone hole covers approximately 22 million km^2 (slightly less than the surface area of the N. American continent).
- Ozone hole associated with cold Antarctic stratospheric temperatures.



Regulations on the production of CFCs

- **Vienna convention (1985):** .Convention for the Protection of the ozone layer. signed by 20 nations (research, future protocols)
- **Montreal Protocol (1987):** .Protocol on substances that deplete the ozone layer. Ratified in 1989. Legally binding controls freezing production to 1985 levels.
- **London Amendment (1990):** Phaseout of production by 2000 for developed nations and by 2010 for developing nations
- **Copenhagen Agreement (1992):** Phaseout for developed nations by 1996.

The Montreal Protocol is Working!

- Without the Montreal Protocol, ozone depletion in 2050 would be at least 50% at midlatitudes in the Northern Hemisphere and 70% at midlatitudes in the Southern Hemisphere, about 10 times larger than today.

- Surface UV-B radiation in 2050 would at least double at midlatitudes in the Northern Hemisphere and quadruple at midlatitudes in the Southern Hemisphere compared with an unperturbed atmosphere. This compares to the current increases of 5% and 8% in the Northern and Southern Hemispheres, respectively, since 1980.

WMO 1998 Scientific Assessment of Ozone Depletion