JÜLICH FORSCHUNGSZENTRUM

esa

→ ADVANCED ATMOSPHERIC TRAINING COURSE 2014

Earth´s Atmosphere

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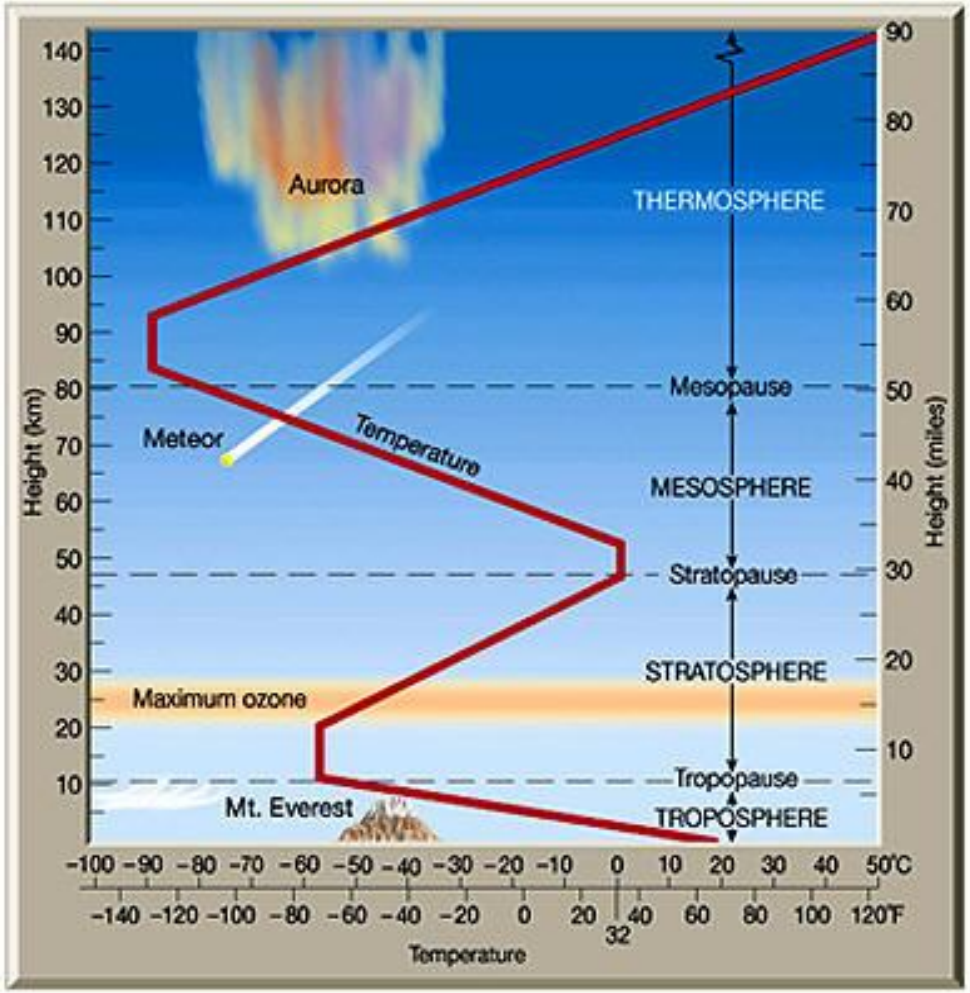
Forschungszentrum Jülich (IEK-7)

27–31 October 2014 | Forschungszentrum Jülich | Germany

Vertical temperature structure

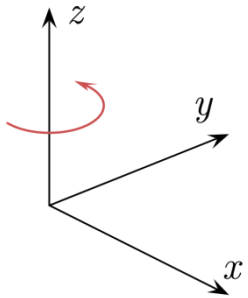


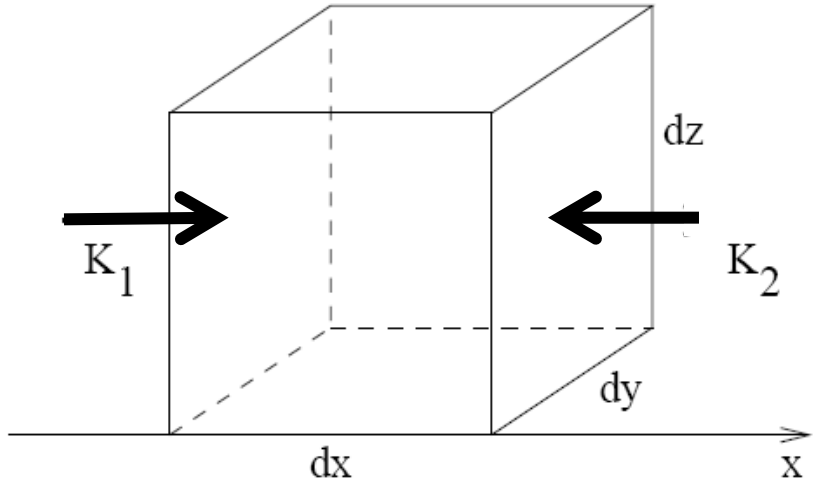
source: grossmont.edu

Content

- Basics on atmospheric dynamics
- Radiation and greenhouse effect
- Ozone in the atmosphere

Pressure force





$\vec{K}$: Force

p: Pressure

$$K_1 = p\,dy\,dz$$

$$K_2 = \left(p + \frac{\partial p}{\partial x}dx\right)\,dy\,dz$$

$$\Delta K = K_1 - K_2 = -\frac{\partial p}{\partial x}\, dx\, dy\, dz = -\frac{\partial p}{\partial x}\, dV$$

(net force)

$$dm = \rho\, dV$$

$$F_x = \frac{\Delta K}{dm} = -\frac{1}{\rho}\frac{\partial p}{\partial x}$$

$$\vec{F}_p = -\frac{1}{\rho}\,\mathrm{grad}\, p$$

V: Volume

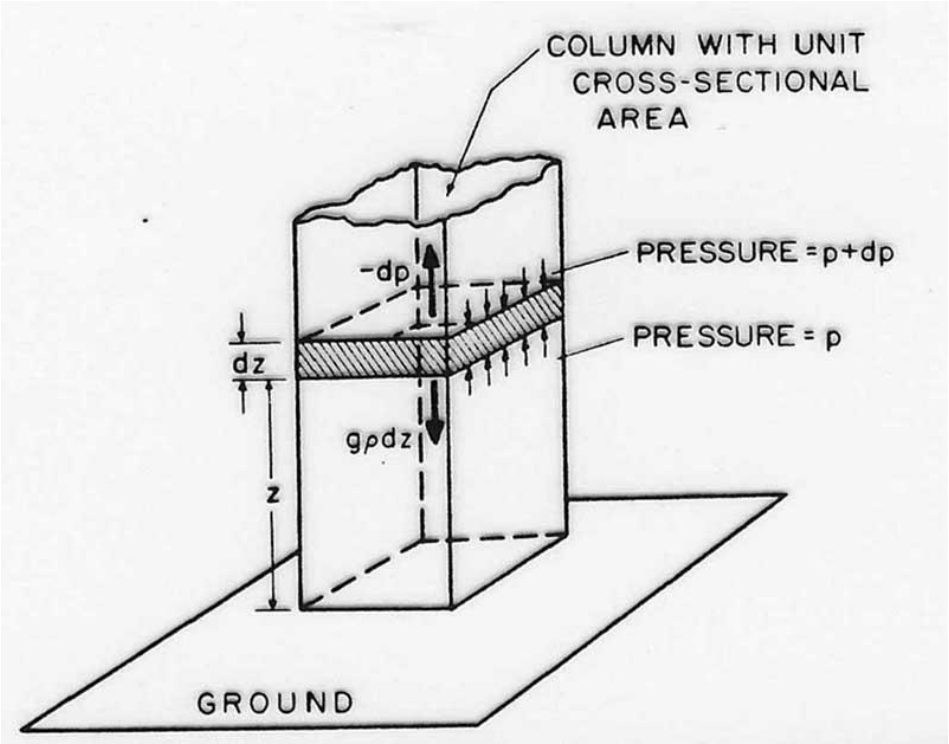
m: Mass

ρ: Density

F: Force per mass

Hydrostatic Equilibrium

- governs vertical pressure and density structure of the atmosphere
- equilibrium between vertical pressure force (upward) and gravitational force (downward)



$$-\frac{1}{\rho}\frac{\partial p}{\partial z} - g = 0 \quad \Rightarrow \quad \frac{\partial p}{\partial z} = -\rho g$$

$$p = \rho R T \quad \Rightarrow \quad \rho = \frac{p}{RT}$$

(Ideal gas law)

g: Gravitational constant

R: Gas constant

T: Temperature

p_s: Surface pressure

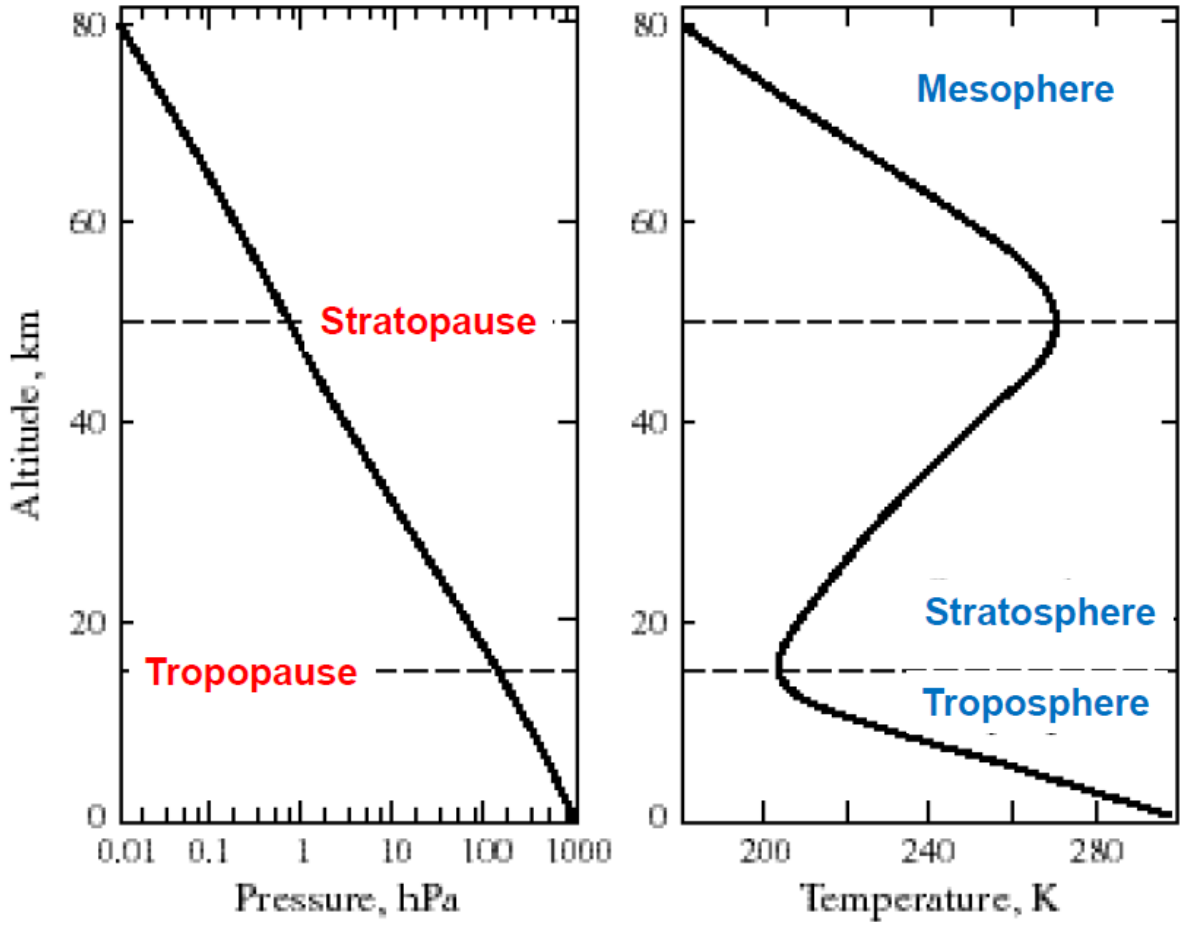
H: Scale height

$$\frac{\partial p}{\partial z} = -\frac{g}{RT}p$$

$$p(z) = p_s \exp\left(-\frac{z}{H}\right) \quad \text{with} \quad H = \frac{RT}{g} \quad (T = const)$$

~ 7 km up to about 100 km

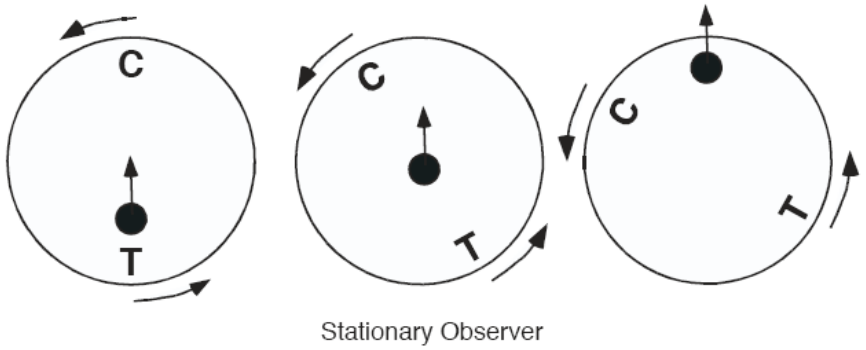
Vertical Profiles of Pressure and Temperature



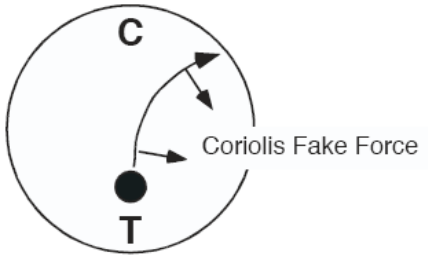
Geostrophic Equilibrium

- governs large-scale horizontal motions in the atmosphere
- equilibrium between horizontal pressure force and coriolis force

Coriolis Force



Stationary Observer

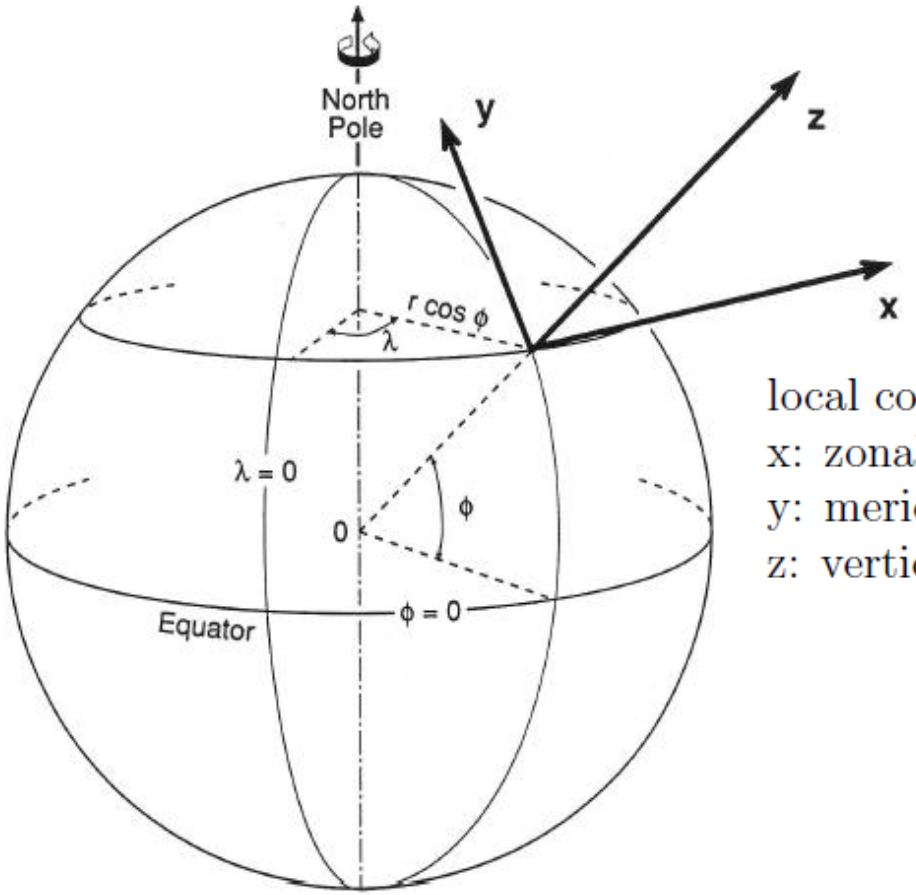


Rotating Observer

Coriolis force is „fake“ force that acts in rotating coordinate systems.

Rotation coordinate systems

Ω: Earth rotation frequency (1/86400s)



local coordinates
x: zonal component
y: meridional component
z: vertical component

$$\vec{F}_C = 2\vec{v} \times \vec{\Omega}$$

$\vec{F}_C$: Coriolis force

$$\vec{v} = (u, v, w)$$

$\vec{v}$: Wind vector

u: zonal component (positive=eastward)

v: meridional component (positive=northward)

w: vertical component

$$\vec{F}_C = 2 \begin{pmatrix} u \\ v \\ 0 \end{pmatrix} \times \begin{pmatrix} 0 \\ 0 \\ \Omega \sin \phi \end{pmatrix} = \begin{pmatrix} fv \\ -fu \\ 0 \end{pmatrix} \quad \text{mit} \quad f = 2\Omega \sin \phi$$

ϕ: latitude

f: Coriolis parameter

Geostrophic Equilibrium

$$\vec{F}_C + \vec{F}_p = 0$$

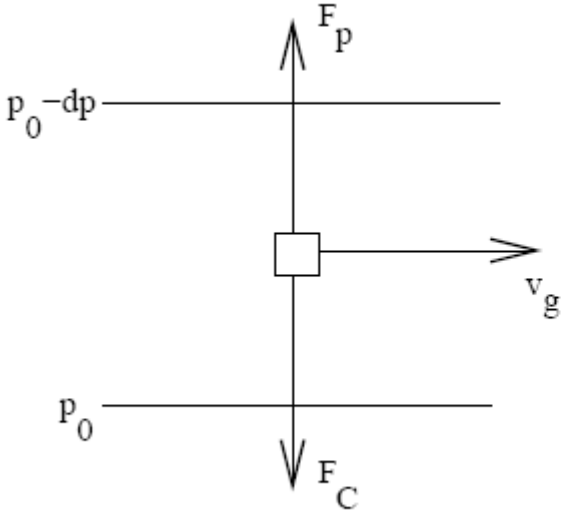
$$fv - \frac{1}{\rho}\frac{\partial p}{\partial x} = 0 \quad , \quad -fu - \frac{1}{\rho}\frac{\partial p}{\partial y} = 0$$

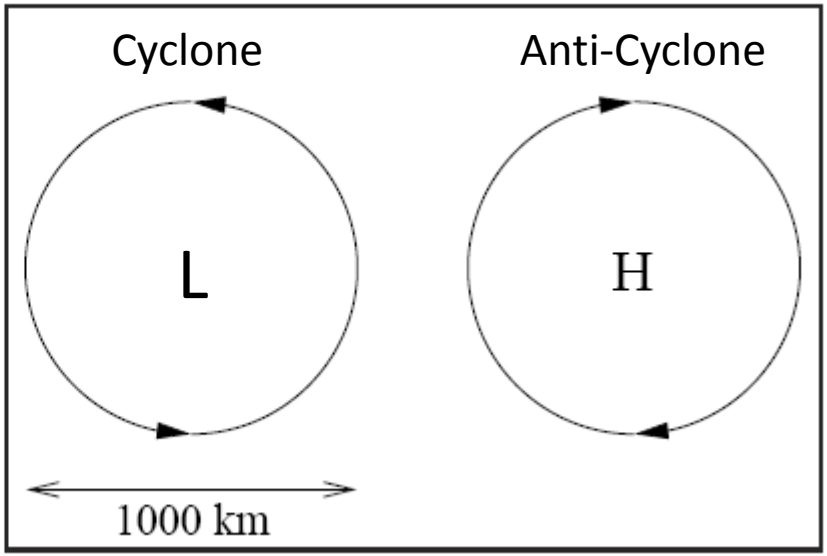
$$u = -\frac{1}{\rho f}\frac{\partial p}{\partial y} \quad , \quad v = \frac{1}{\rho f}\frac{\partial p}{\partial x}$$

Geostrophic wind

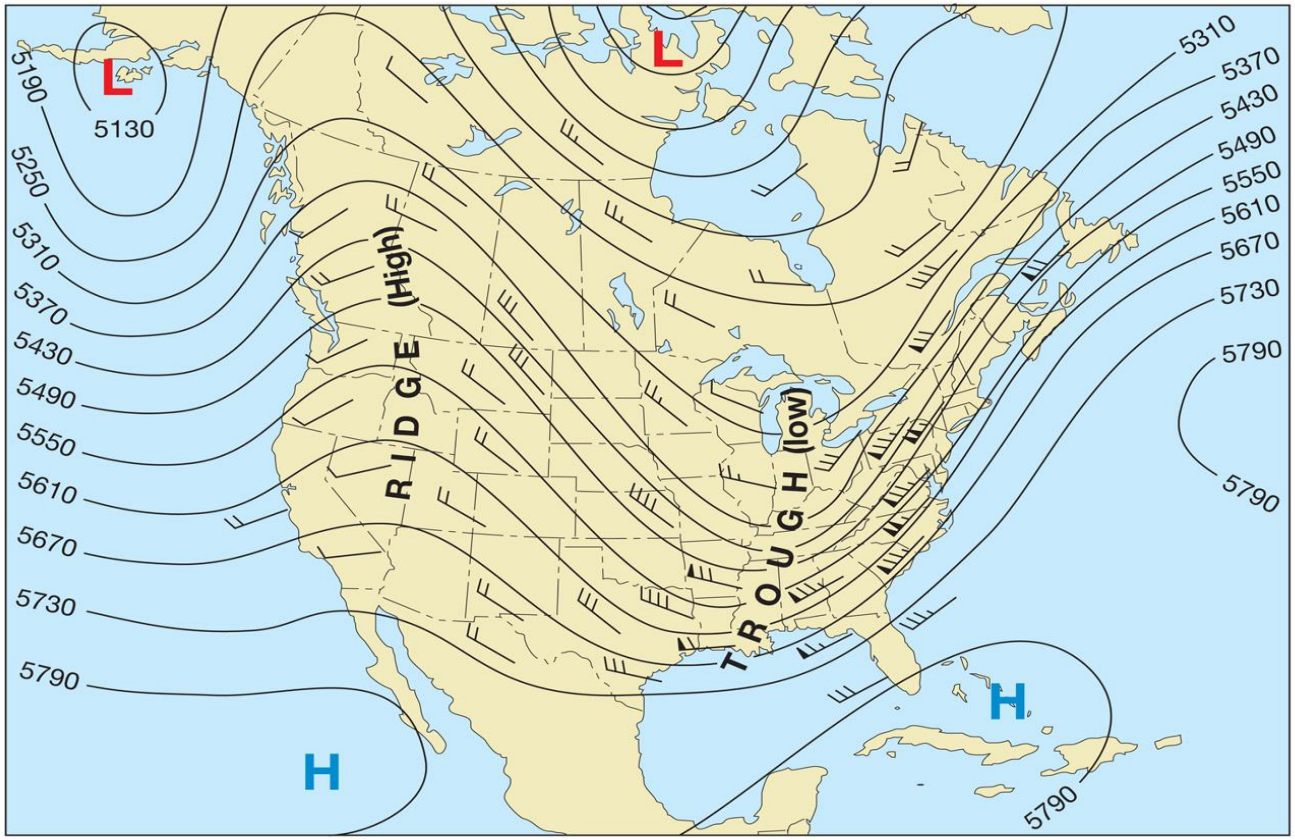
Geostrophic wind

T



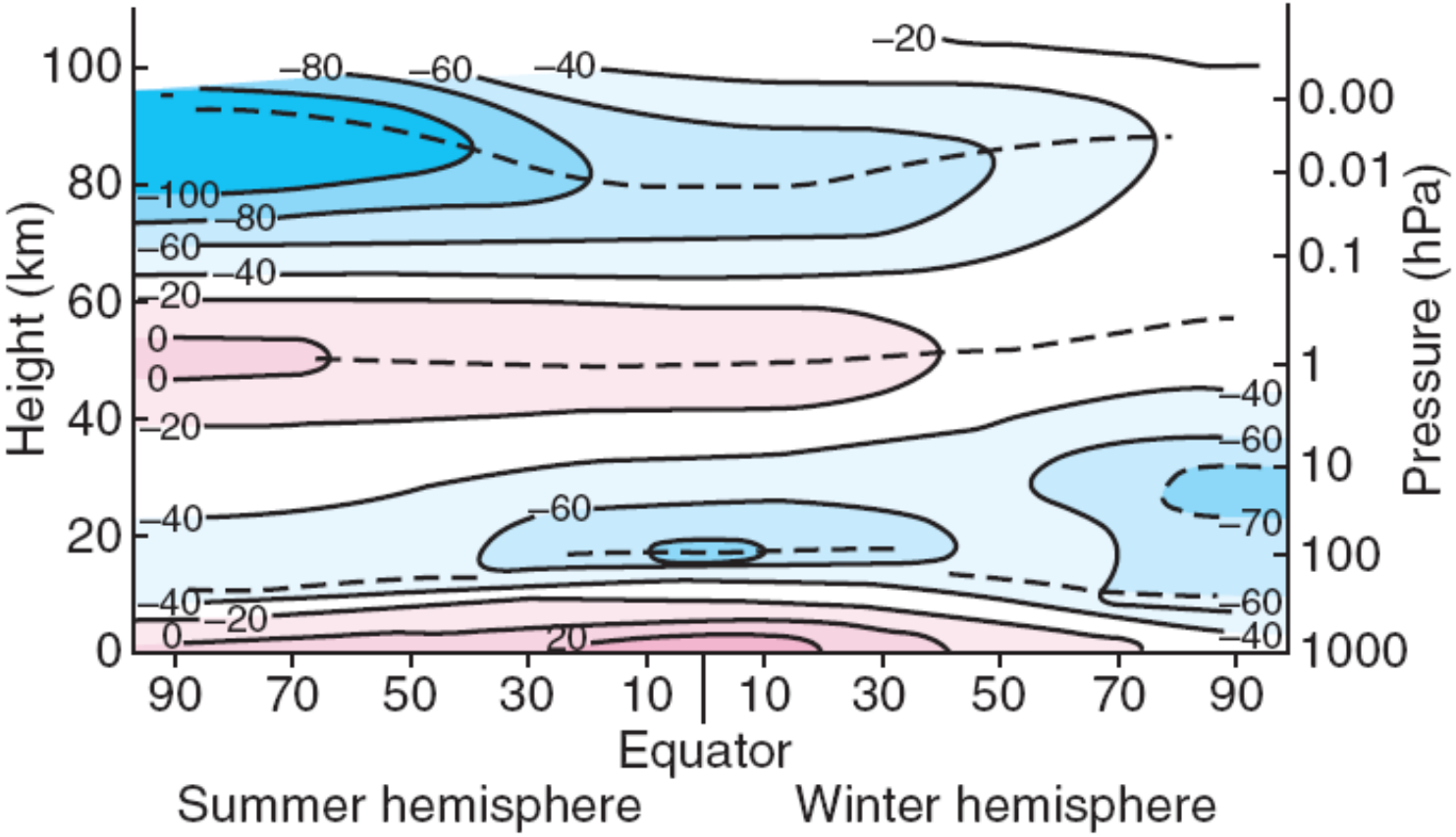


Geostrophic wind

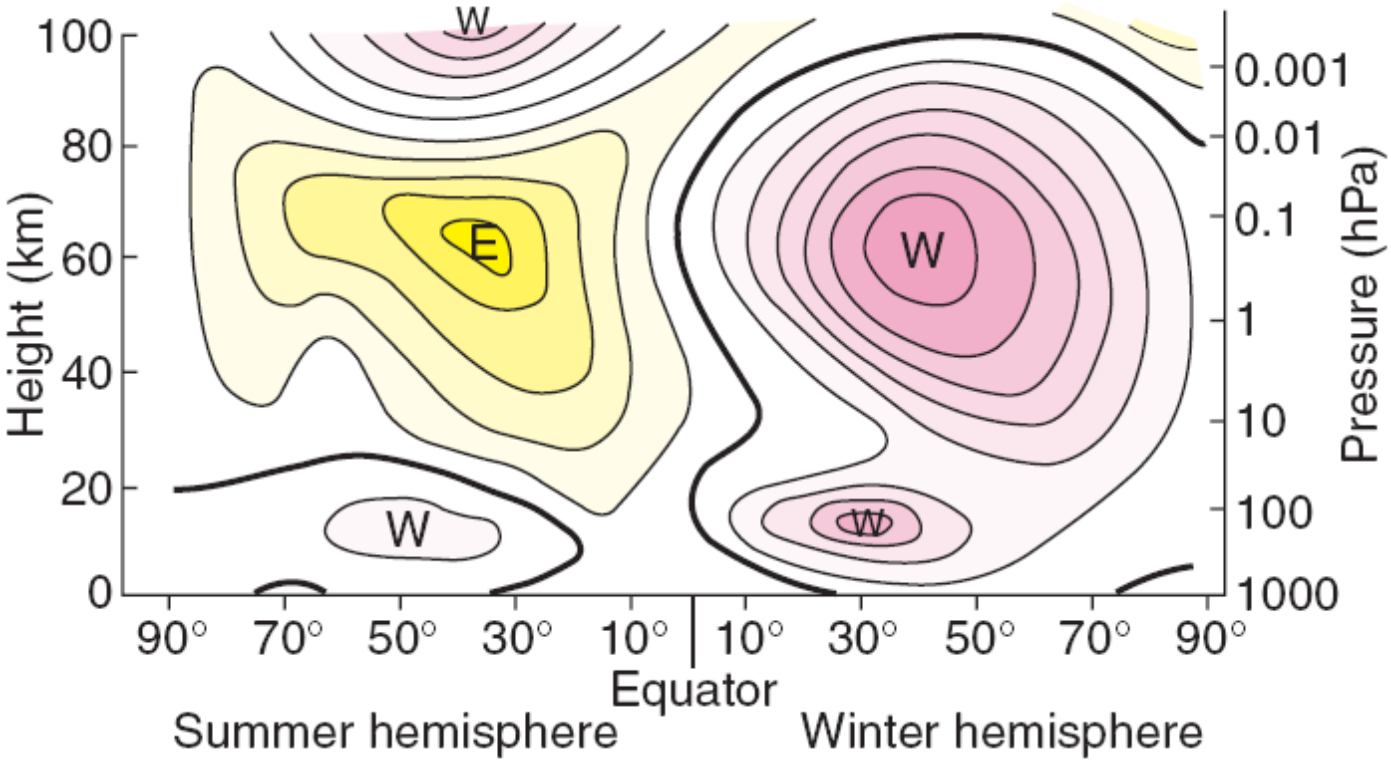


ff	Miles per hour
◎	Calm
	1–2
	3–8
	9–14
	15–20
	21–25
	26–31
	32–37
	38–43
	44–49
	50–54
	55–60
	61–66
	67–71
	72–77
	78–83
	84–89
	119–123

Latitudinal temperature structure



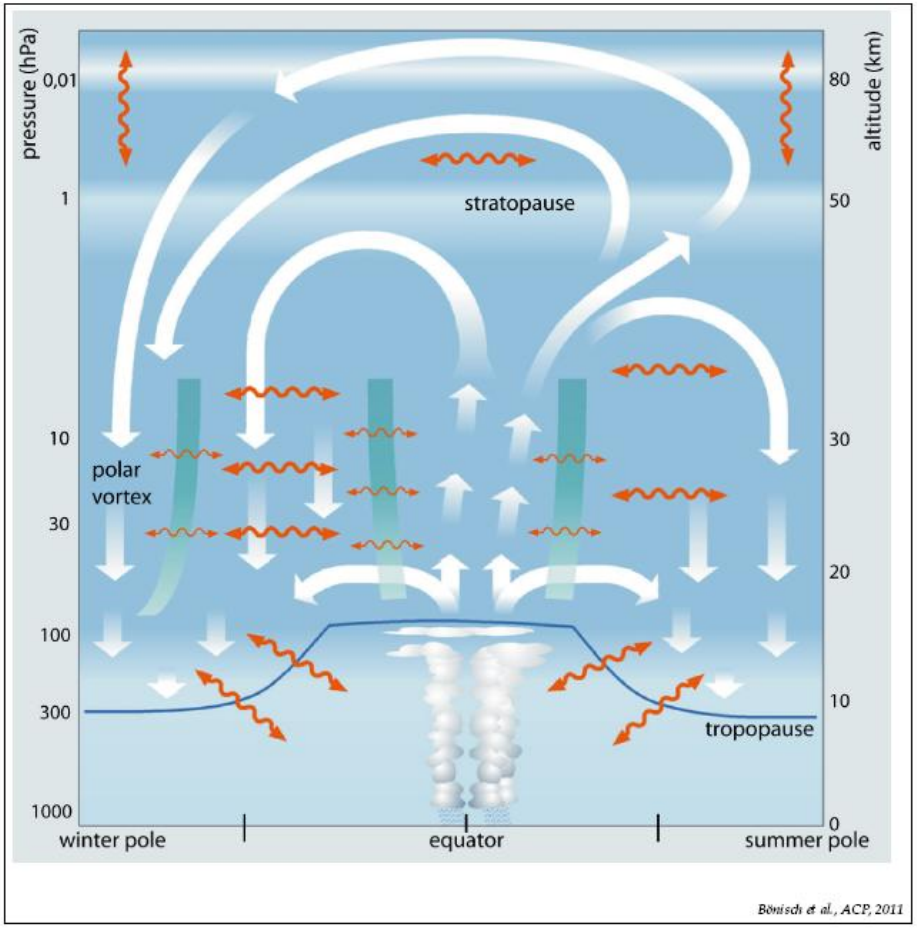
Latitudinal structure of zonal wind (geostrophic)



W = Westwind (blows eastward, positive values)
E = Eastwind (blows westward, negative values)

$$u = -\frac{1}{\rho f}\frac{\partial p}{\partial y} \quad ;$$

Meridional mean circulation

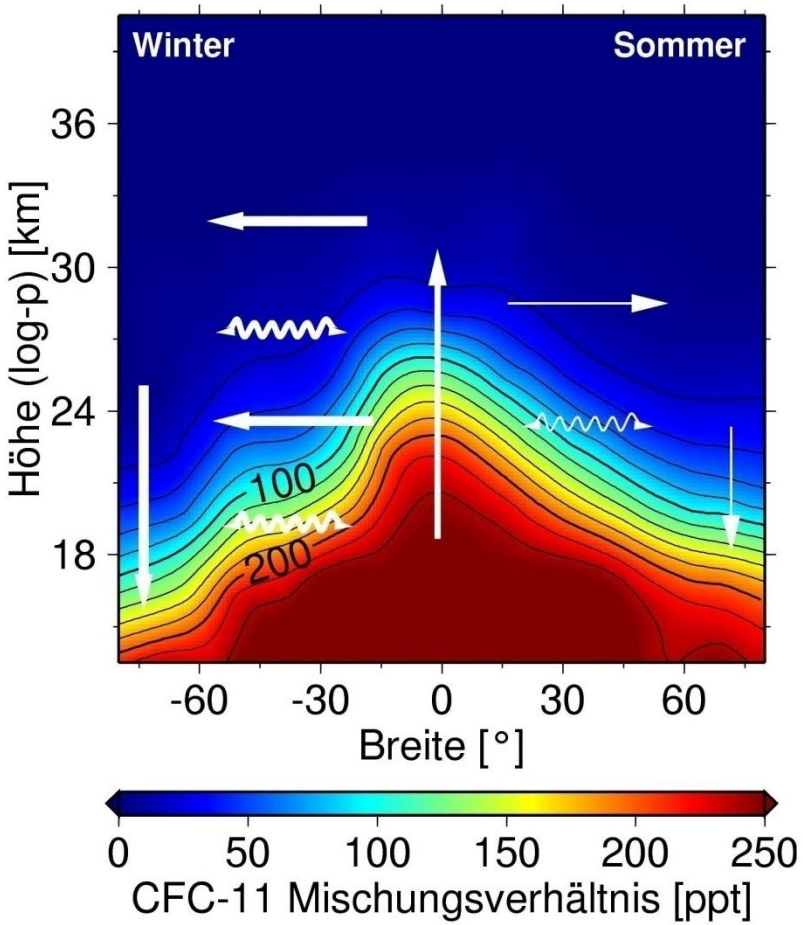


(1) Residual mean circulation
(2) Eddy mixing

Figure from
Bönisch et al., 2011

See talk of
Peter Preusse

Signatures of meridional circulation in CFC-11



MIPAS observations

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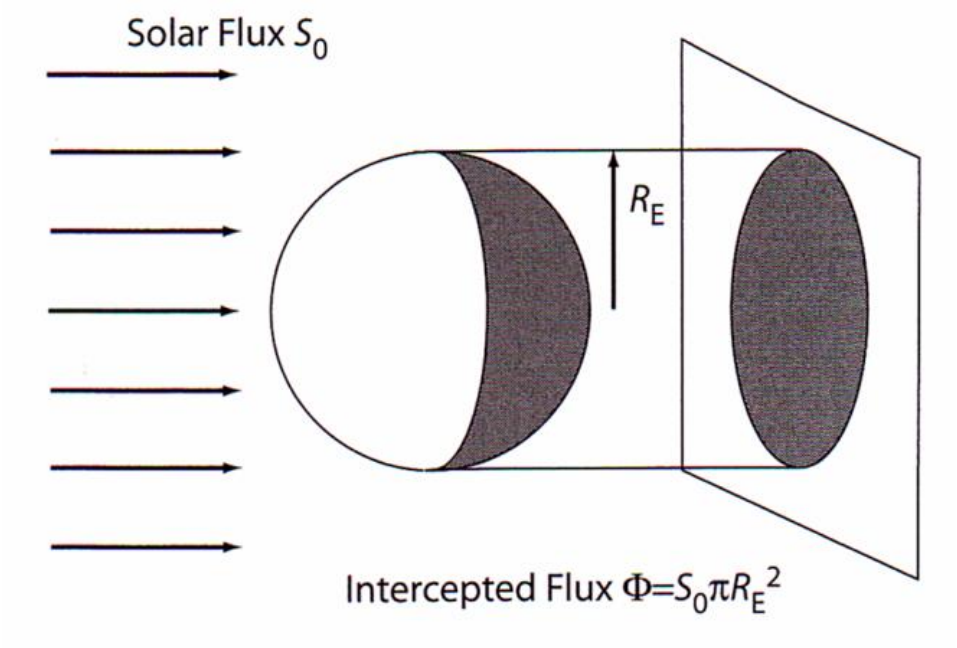
Solar constant S_o



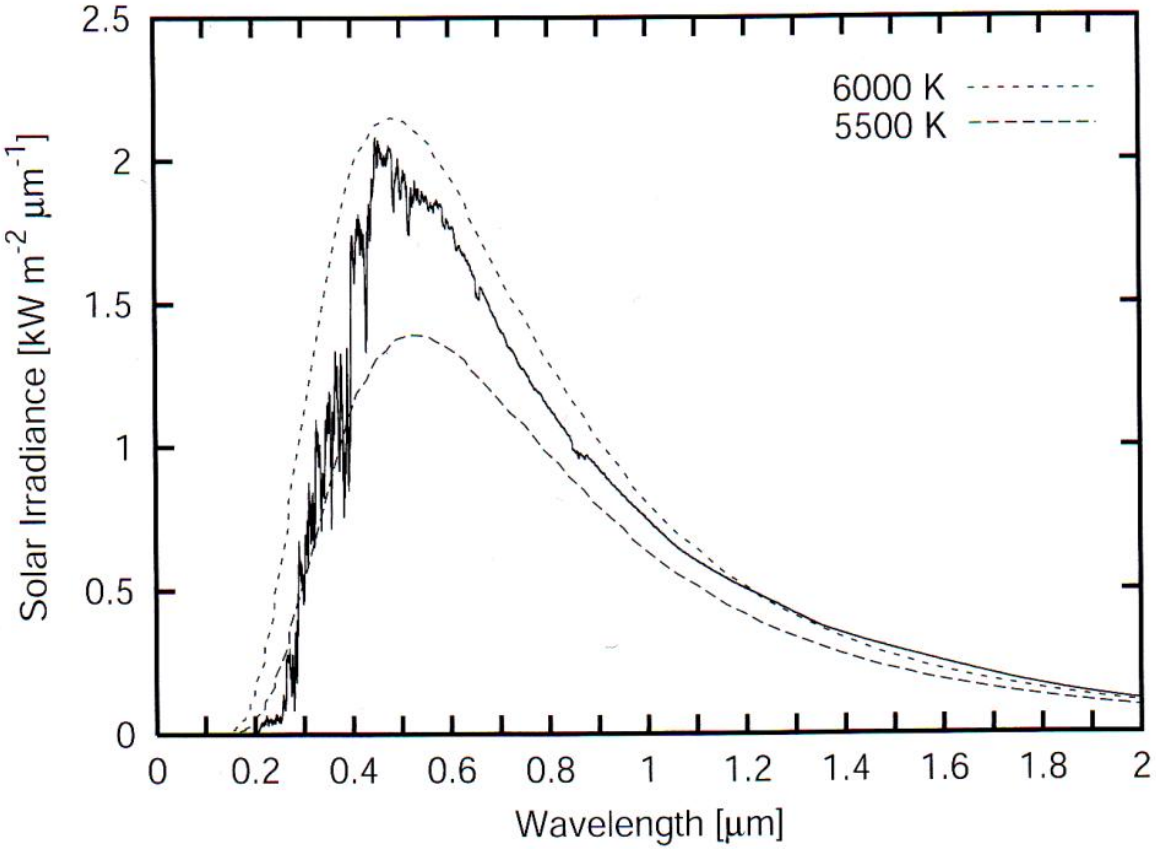
Shadow area:
πR_E^2

Earth´s surface:
$4 \pi R_E^2$

$S_o = 1370\ Wm^{-2}$

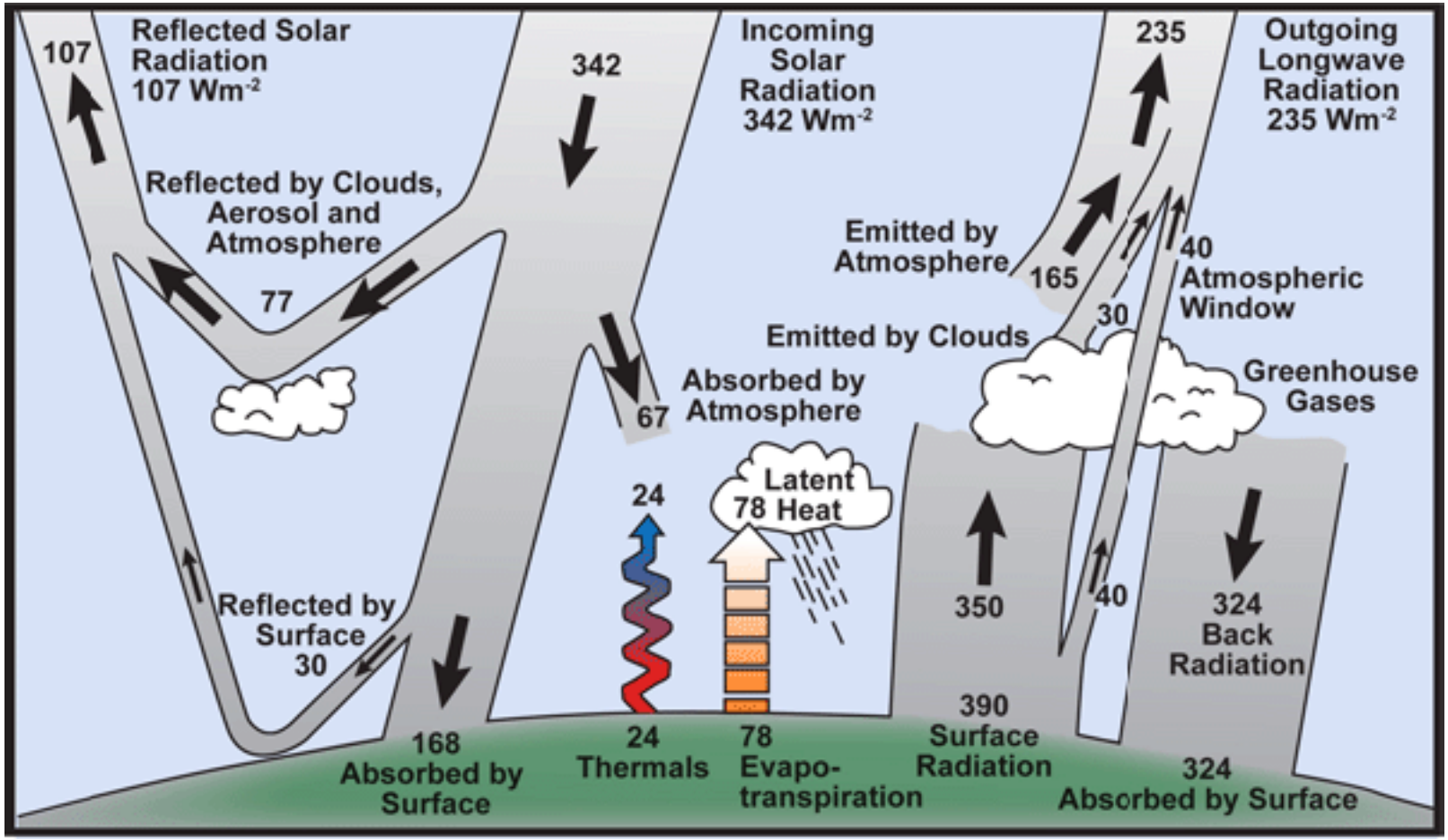
$S_o/4 = 342\ Wm^{-2}$ (global average)

Sun Spectrum

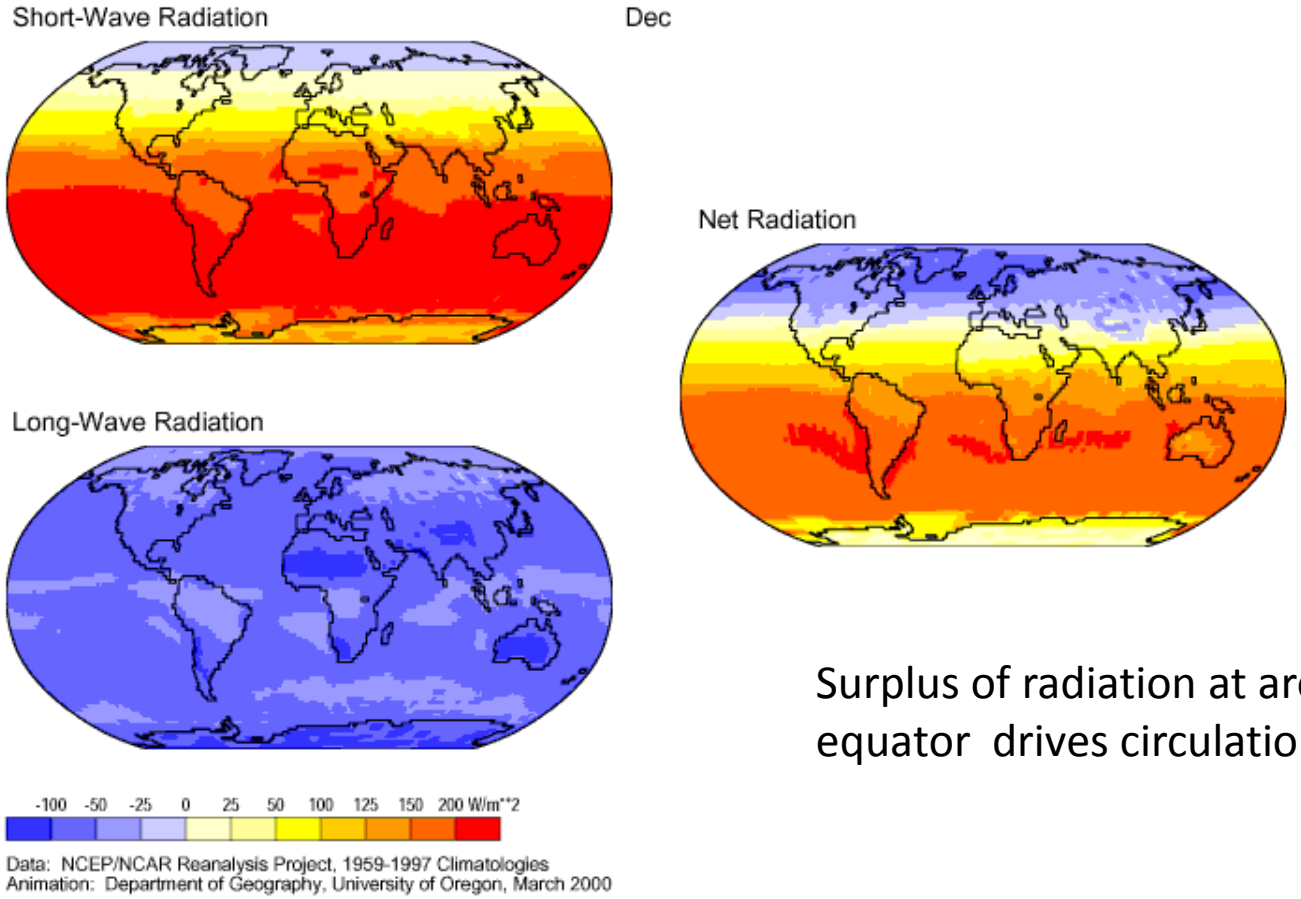


corresponds to Black Body with temperature of 5700 K

Earth´s radiation budget



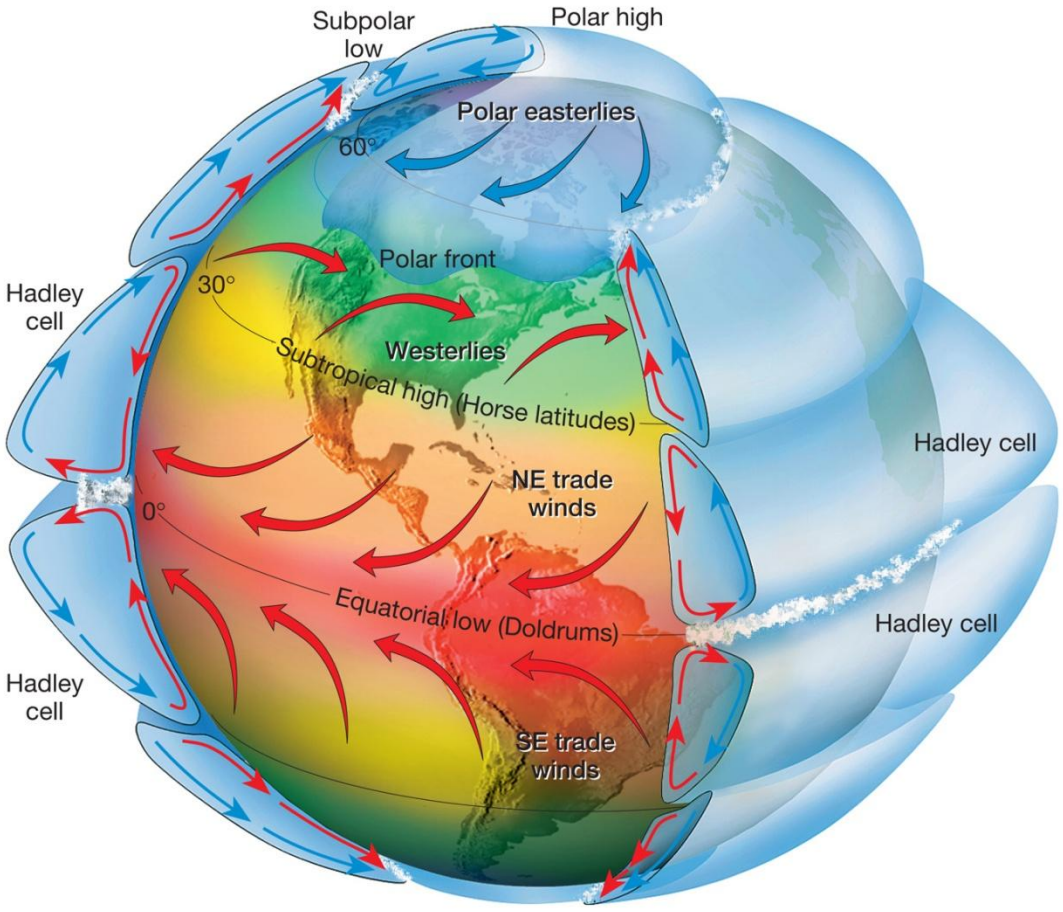
Annual variation of short-wave, long-wave and net radiation



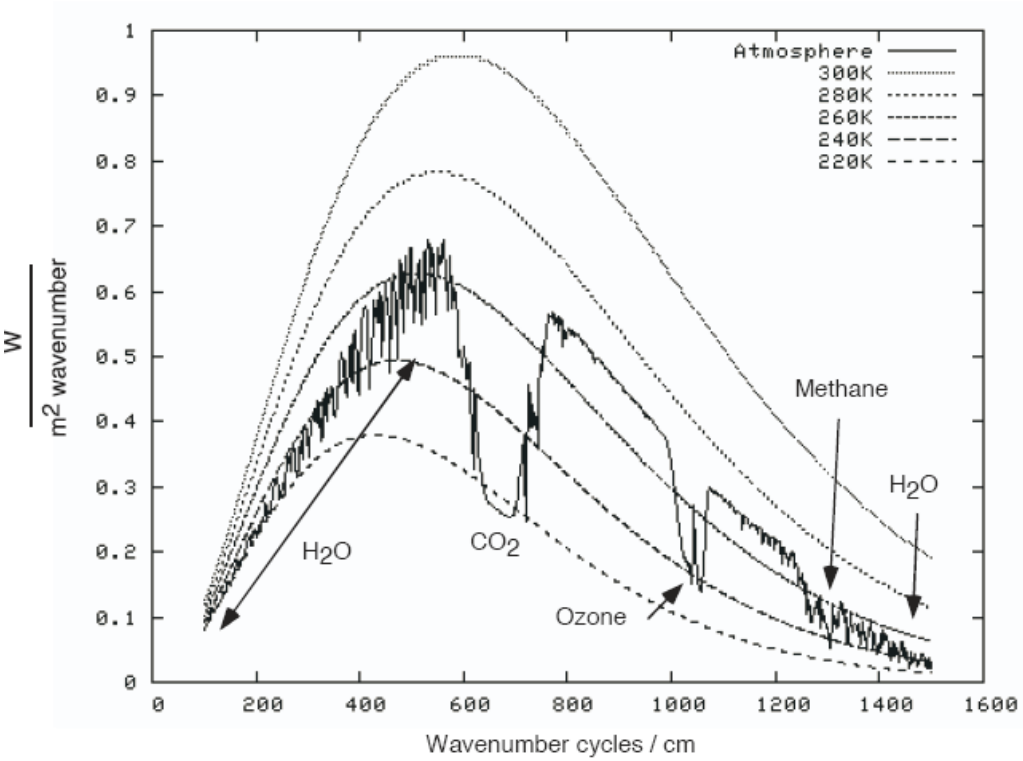
Surplus of radiation at around equator drives circulation

Heat transfer in the troposphere

Intertropical Convergence Zone (ITTZ)

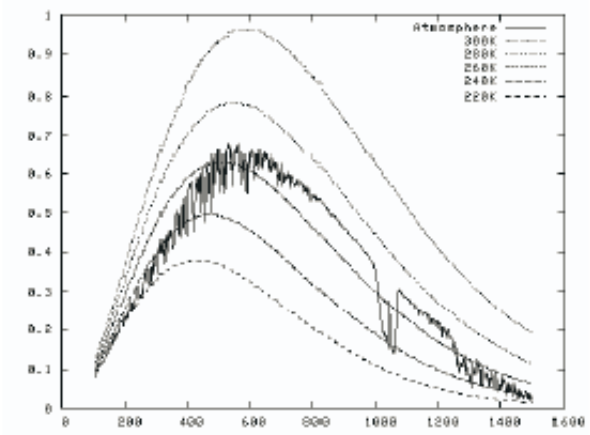


GH effect in a nutshell: Earth radiation at top of atmosphere



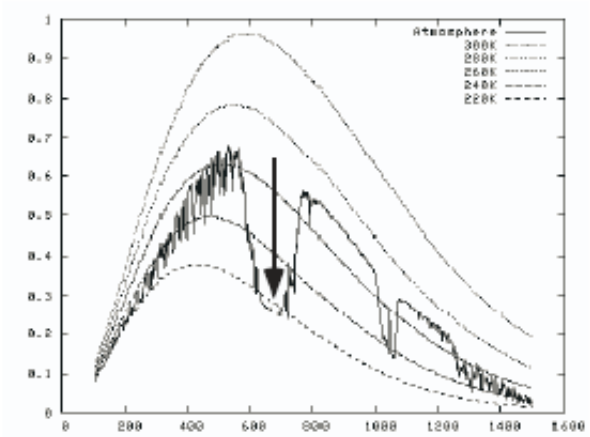
- Greenhouse gases produce a bite out in outgoing IR spectrum;
- Warmer surface and more radiation in window region (around 800 cm^{-1})

Earth radiation at the top of the atmosphere



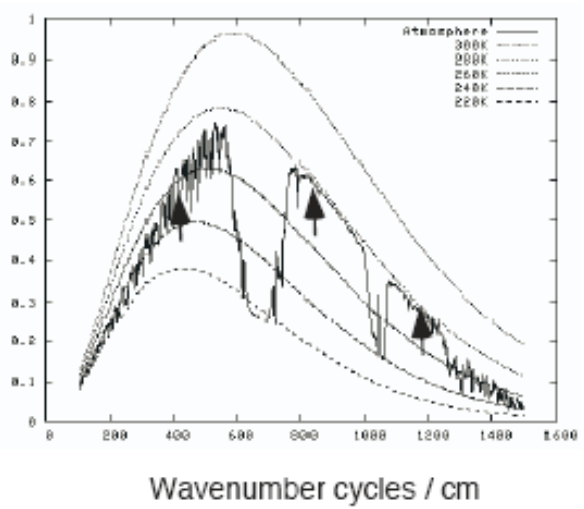
No CO_2

I_{out} = 249 W/m^2



1000 ppm CO_2

I_{out} = 223 W/m^2



1000 ppm CO_2

8.5 K warmer

I_{out} = 249 W/m^2

W / m^2 wavenumber

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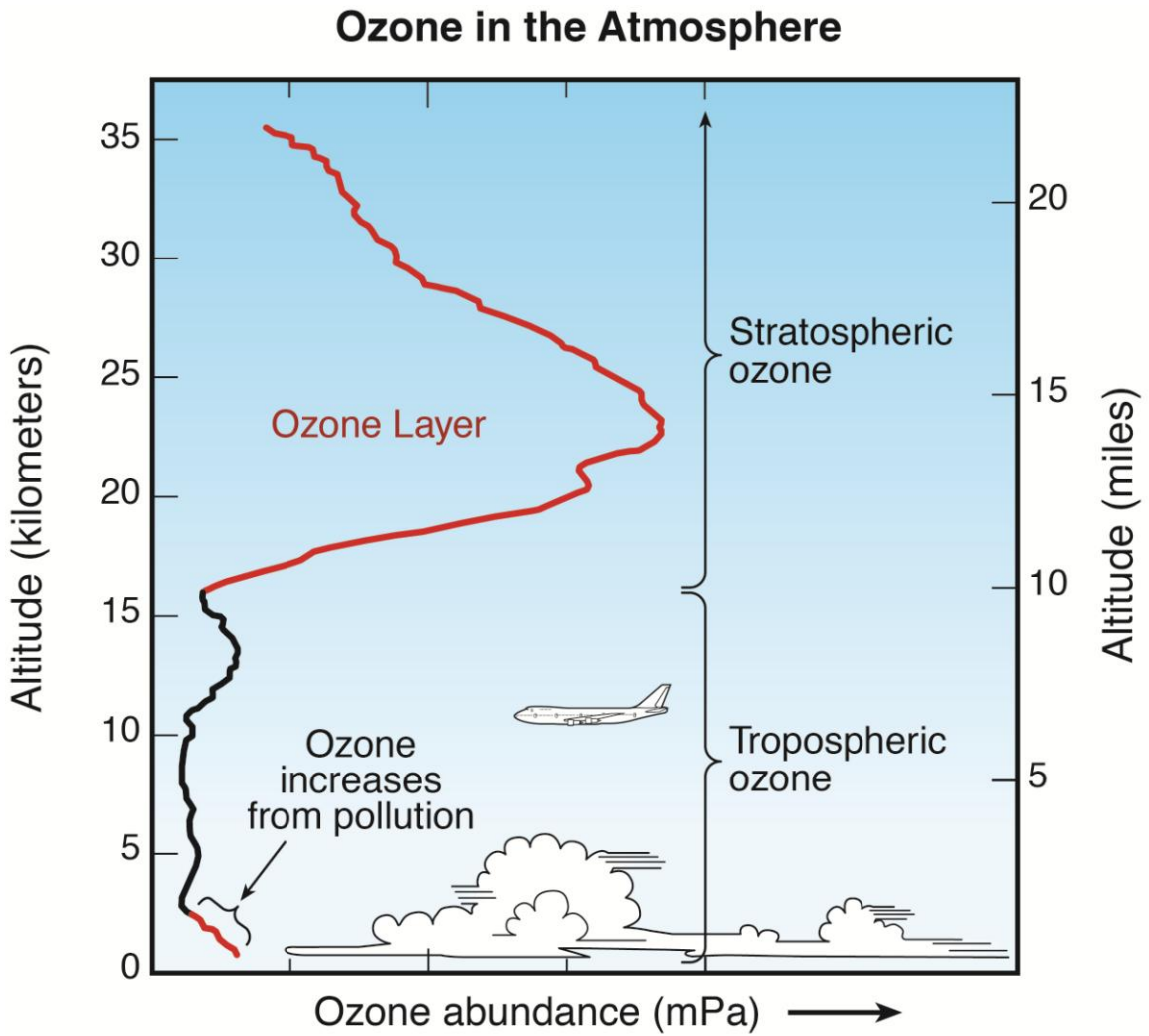
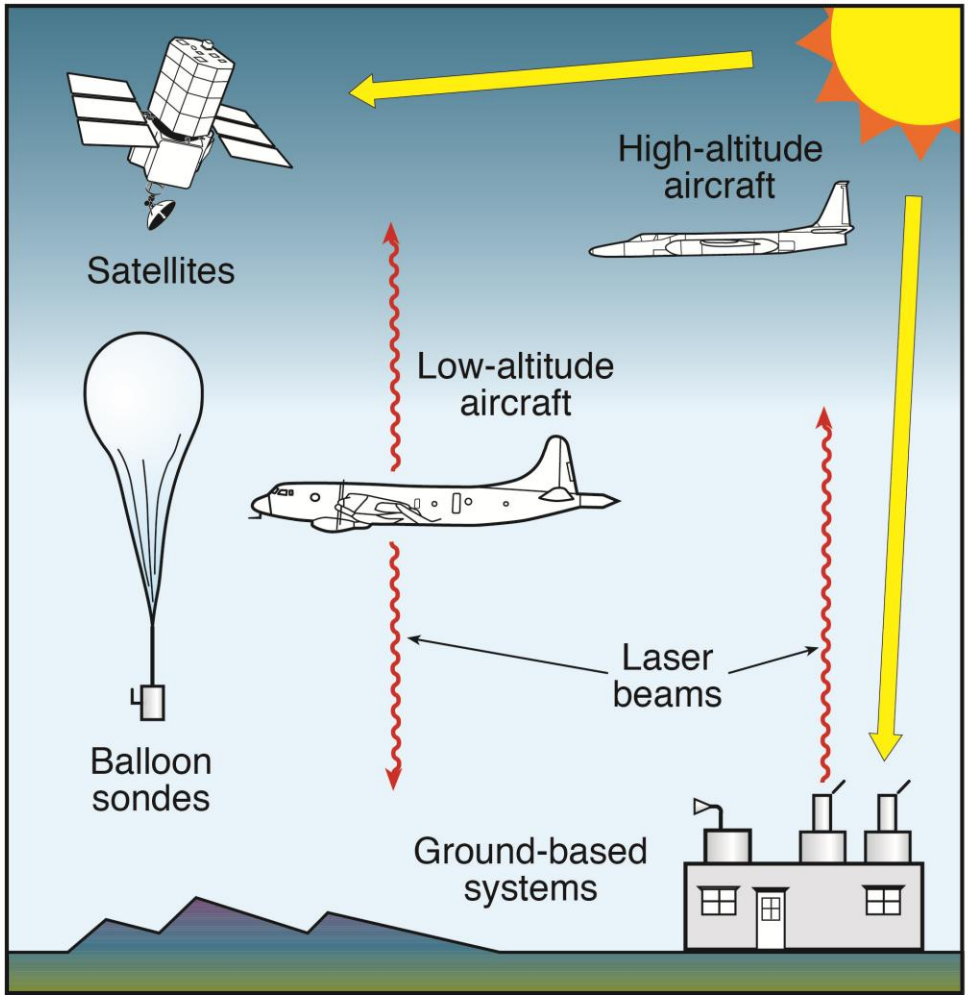
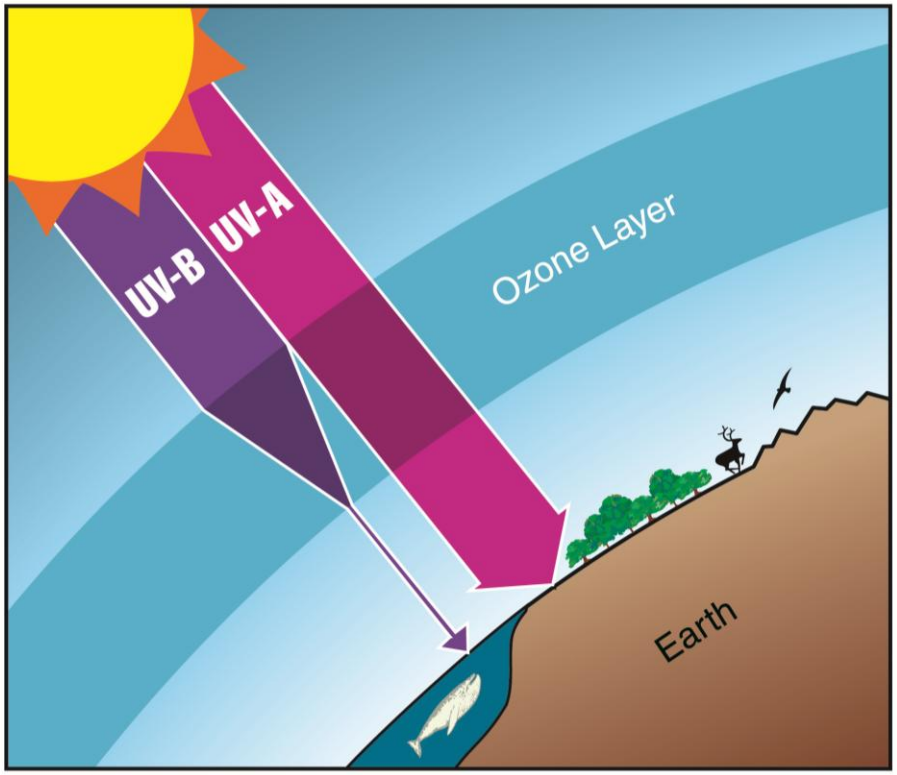


Ozone in the stratosphere protects us from UB-V

Ozone in the troposphere indicates poor air quality

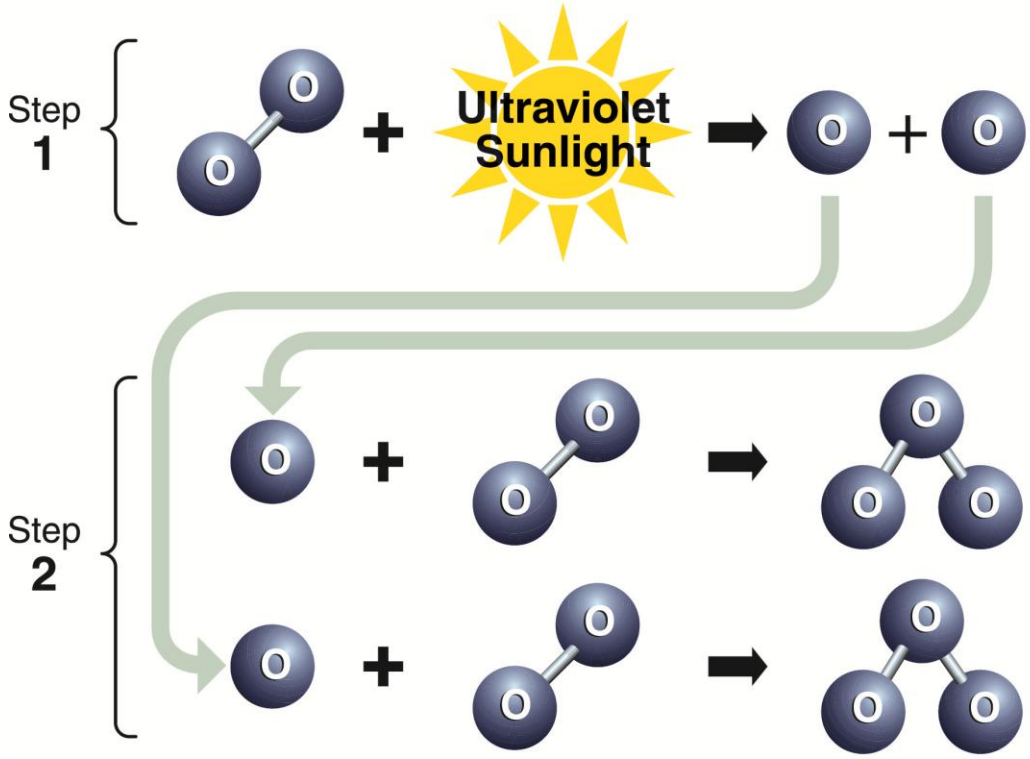
Measuring Ozone in the Atmosphere





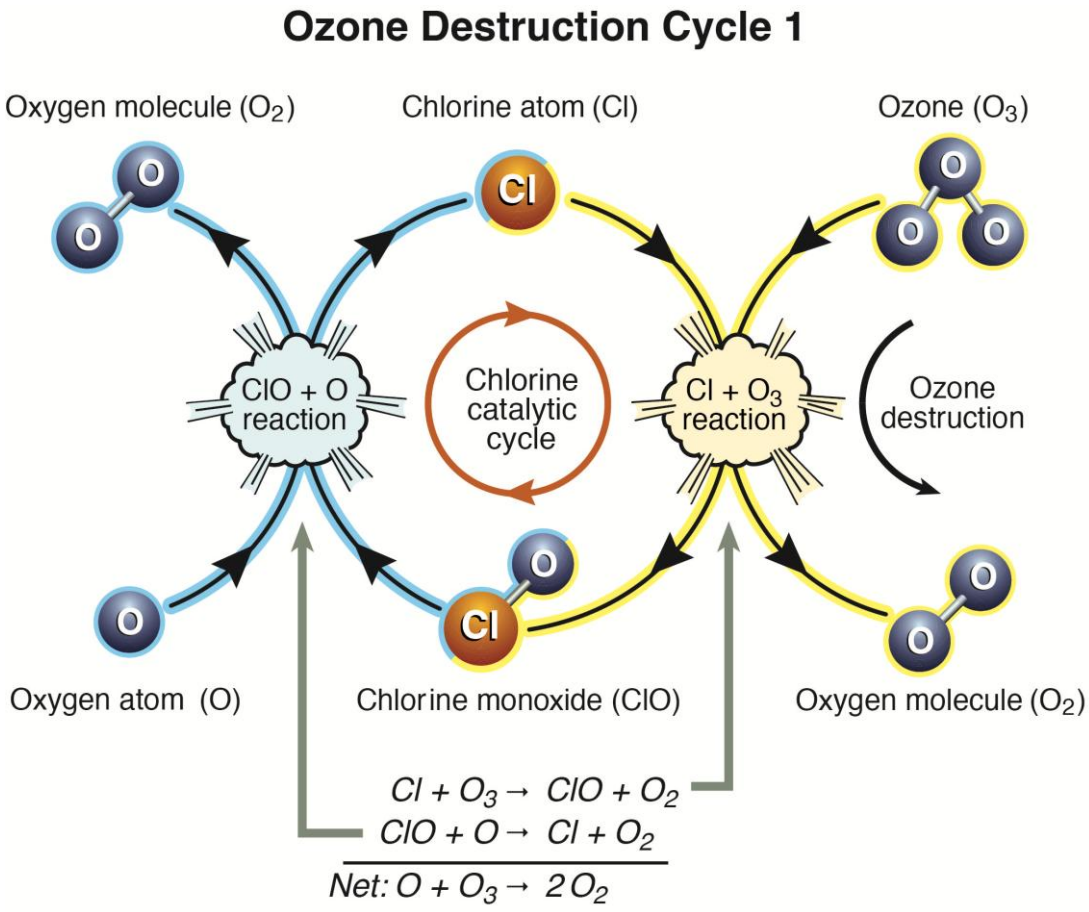
- The ozone layer protects us from harmful UV-B radiation (280 to 315 nm)
- UV-B causes skin cancer, suppresses the immune system and damages terrestrial plant life and aquatic eco-systems

Stratospheric Ozone Production



Overall reaction: $3\,O_2 \xrightarrow{\text{sunlight}} 2\,O_3$

Catalytic ozone depletion in the stratosphere



Ozone Destruction Cycles in Polar Regions

Cycle 2

$$ClO + ClO \rightarrow (ClO)_2$$

$$(ClO)_2 + \text{sunlight} \rightarrow ClOO + Cl$$

$$ClOO \rightarrow Cl + O_2$$

$$2(Cl + O_3 \rightarrow ClO + O_2)$$

$$\text{Net: } 2\,O_3 \rightarrow 3\,O_2$$

Cycle 3

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

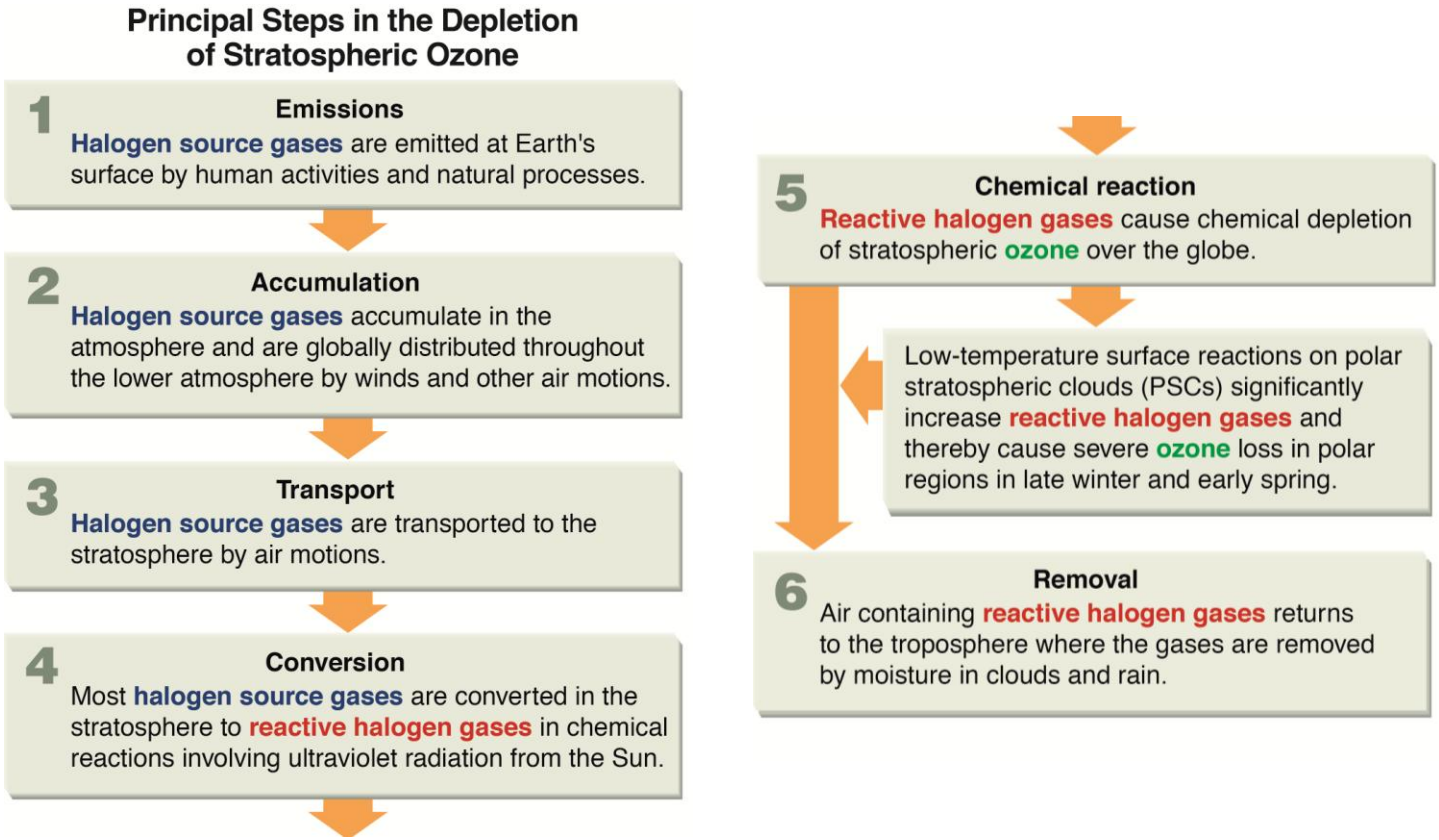
or

$$ClO + BrO \rightarrow BrCl + O_2$$
$$BrCl + \text{sunlight} \rightarrow Cl + Br$$

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

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

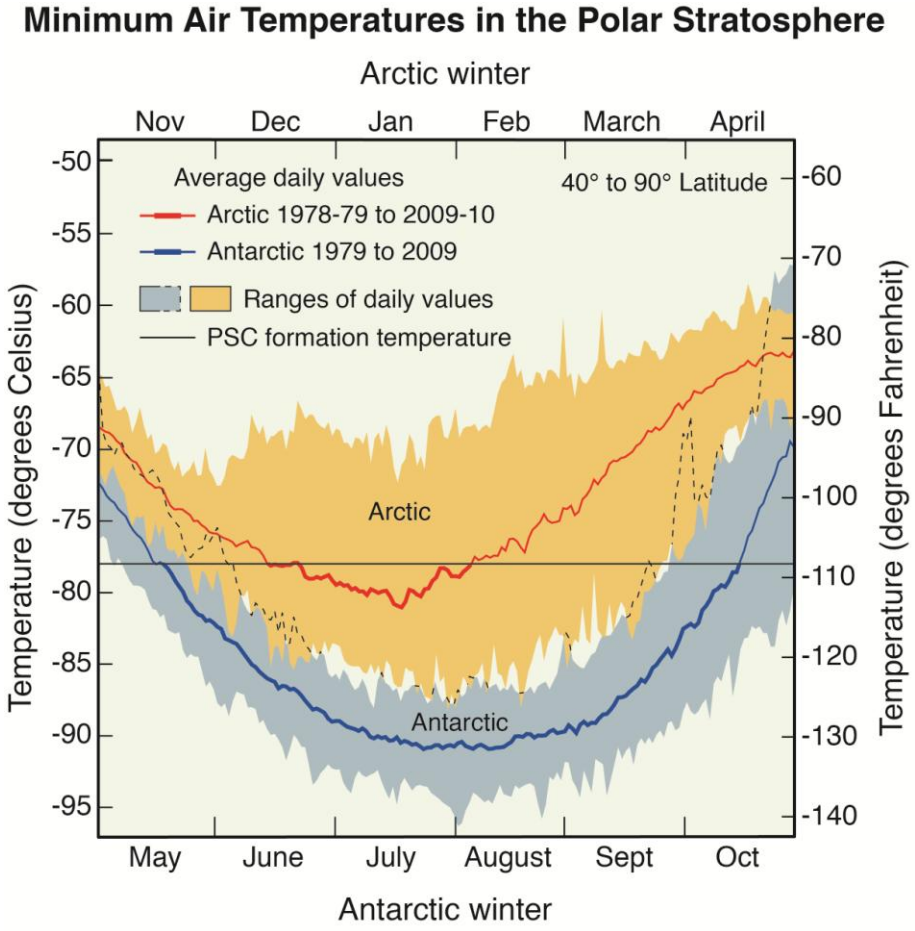
$$\text{Net: } 2\,O_3 \rightarrow 3\,O_2$$



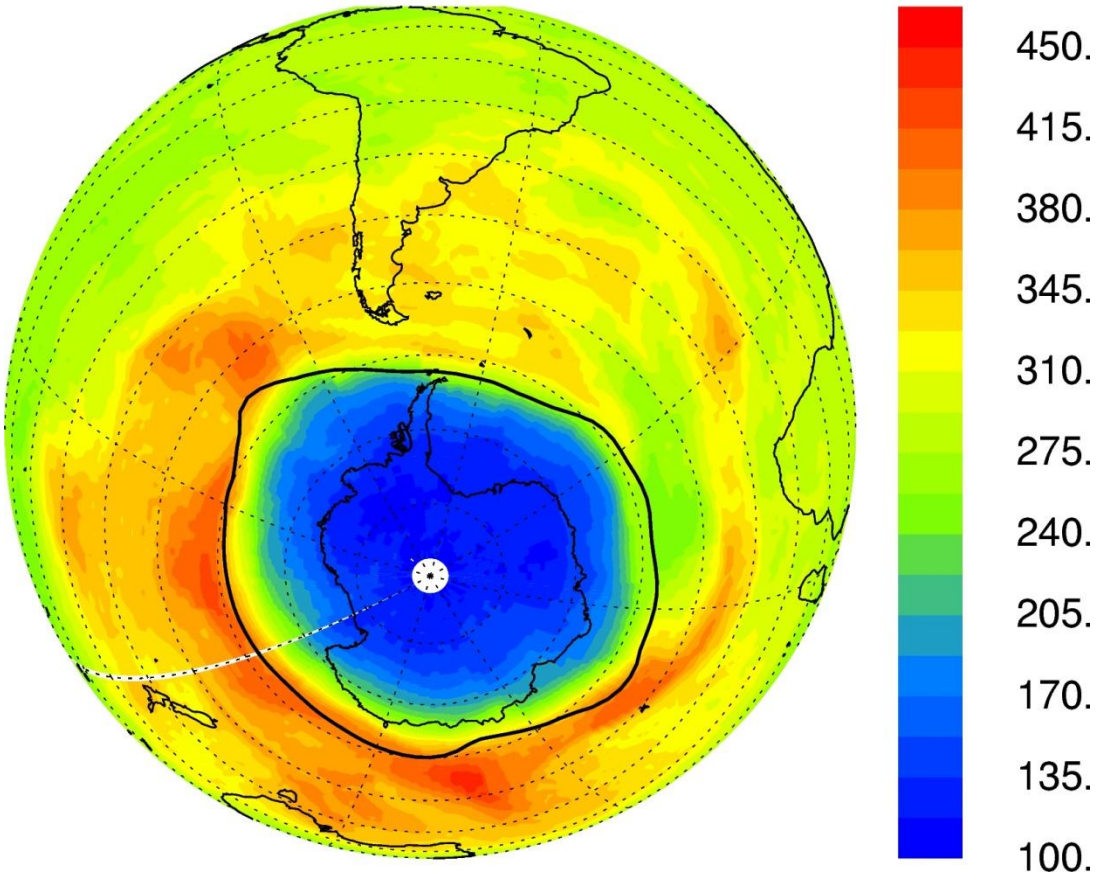
Step 4: Neglects conversion to reservoir gases such as $ClONO_2$ and HCl.

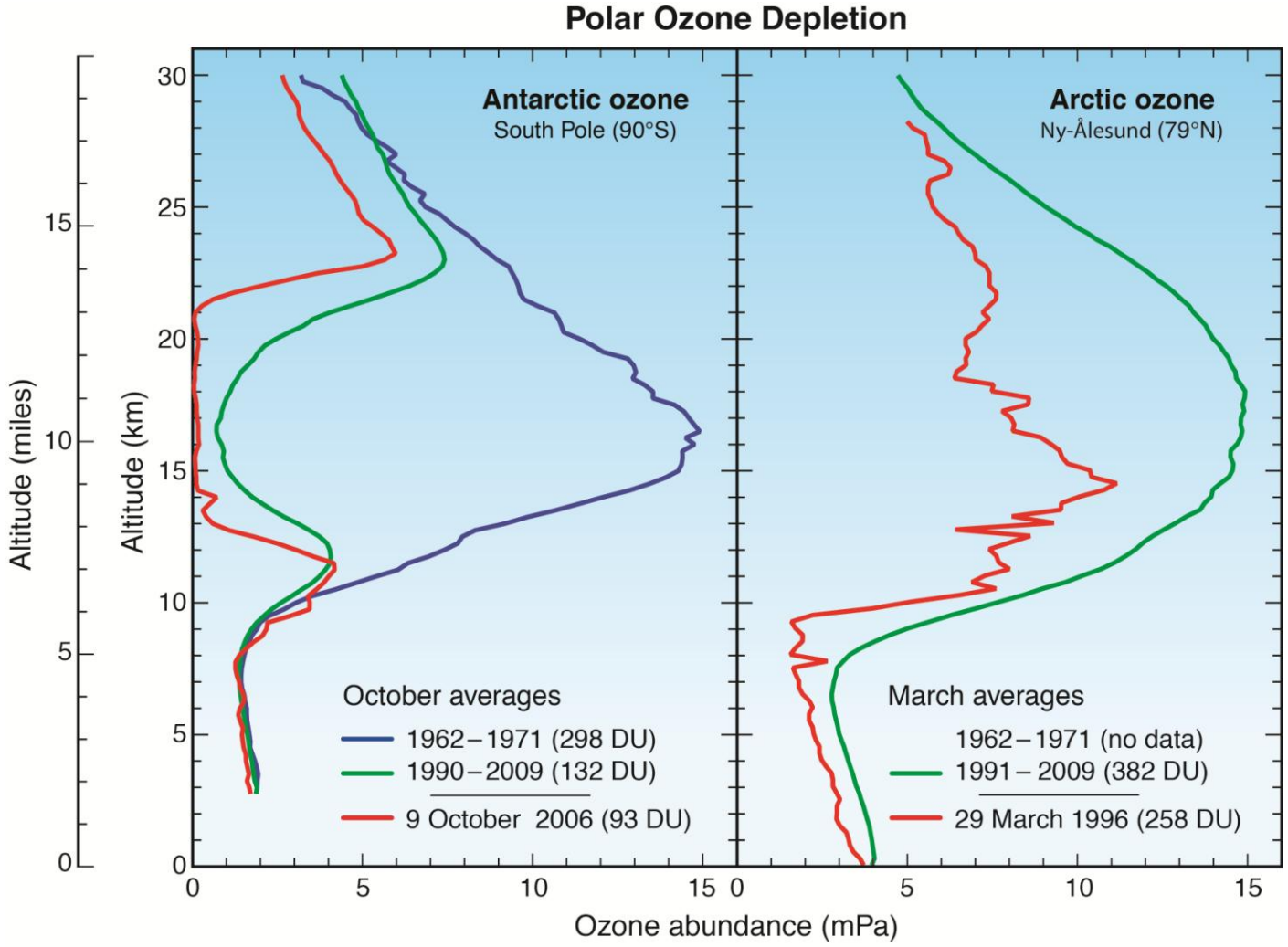
Source: NOAA: Twenty Questions and Answers About the Ozone Layer: 2010 Update

Severe chlorine activation on Polar stratospheric clouds (PSC)

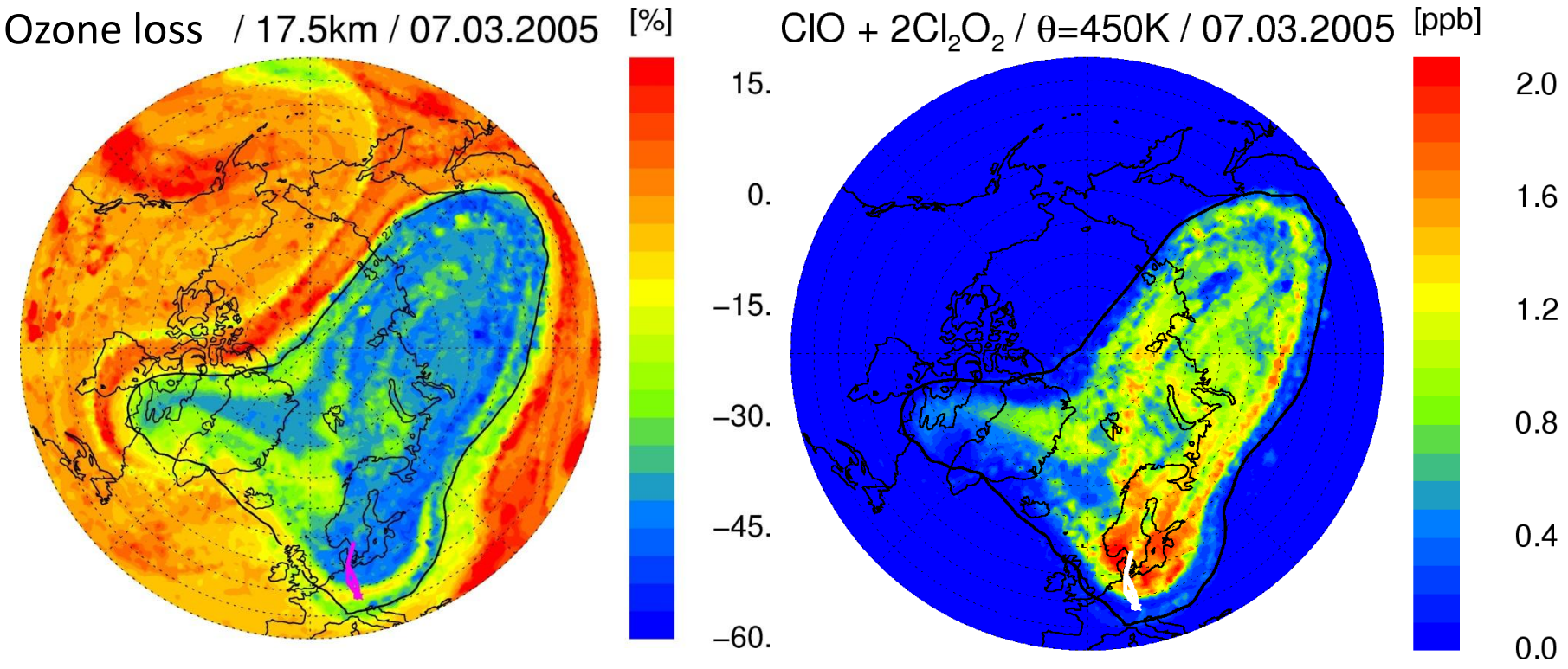


EP TOMS Ozone Col. 02.10.2001



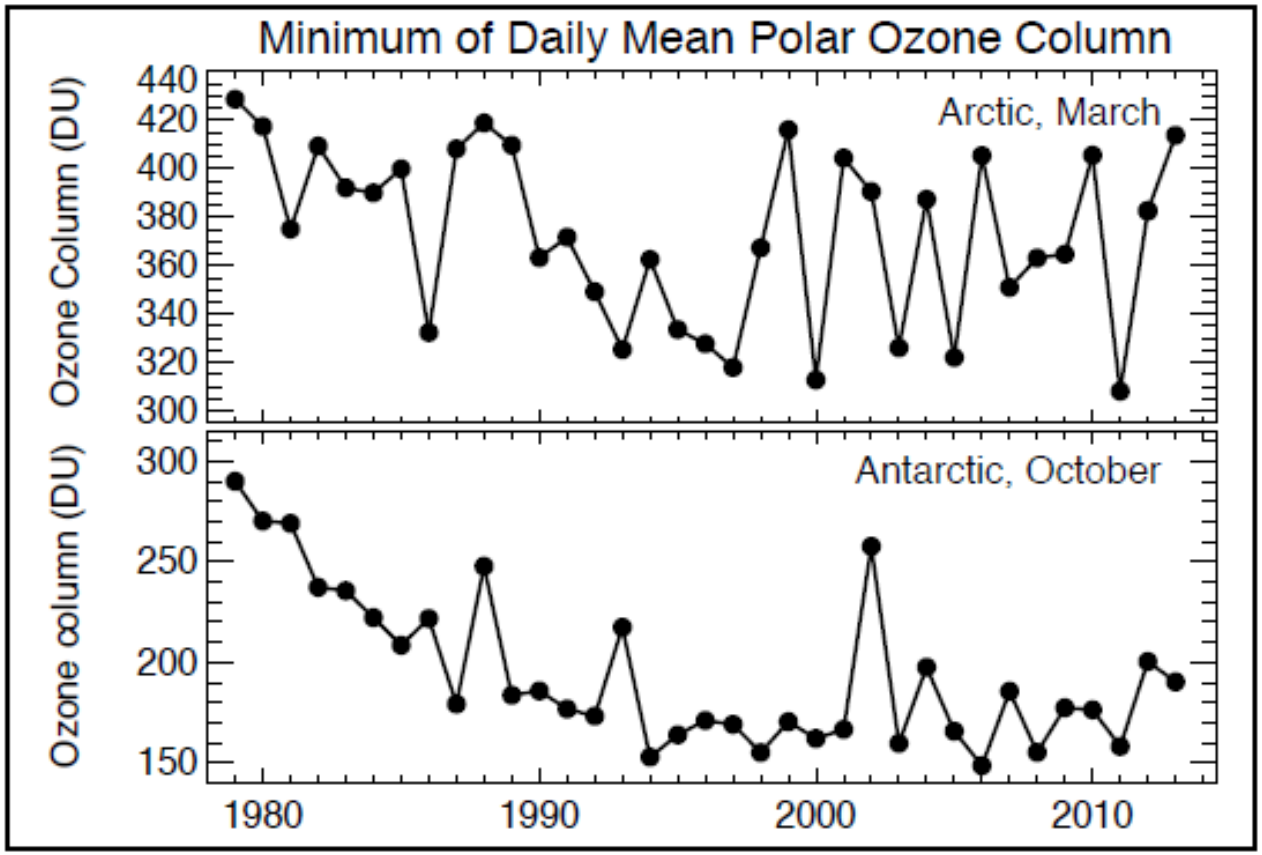

Polar Ozone Depletion
Antarctic ozone
South Pole (90°S)
Arctic ozone
Ny-Ålesund (79°N)
Altitude (miles)
Altitude (km)
Ozone abundance (mPa)
October averages
1962–1971 (298 DU)
1990–2009 (132 DU)
9 October 2006 (93 DU)
March averages
1962–1971 (no data)
1991–2009 (382 DU)
29 March 1996 (258 DU)

CLamS simulation of Arctic ozone loss



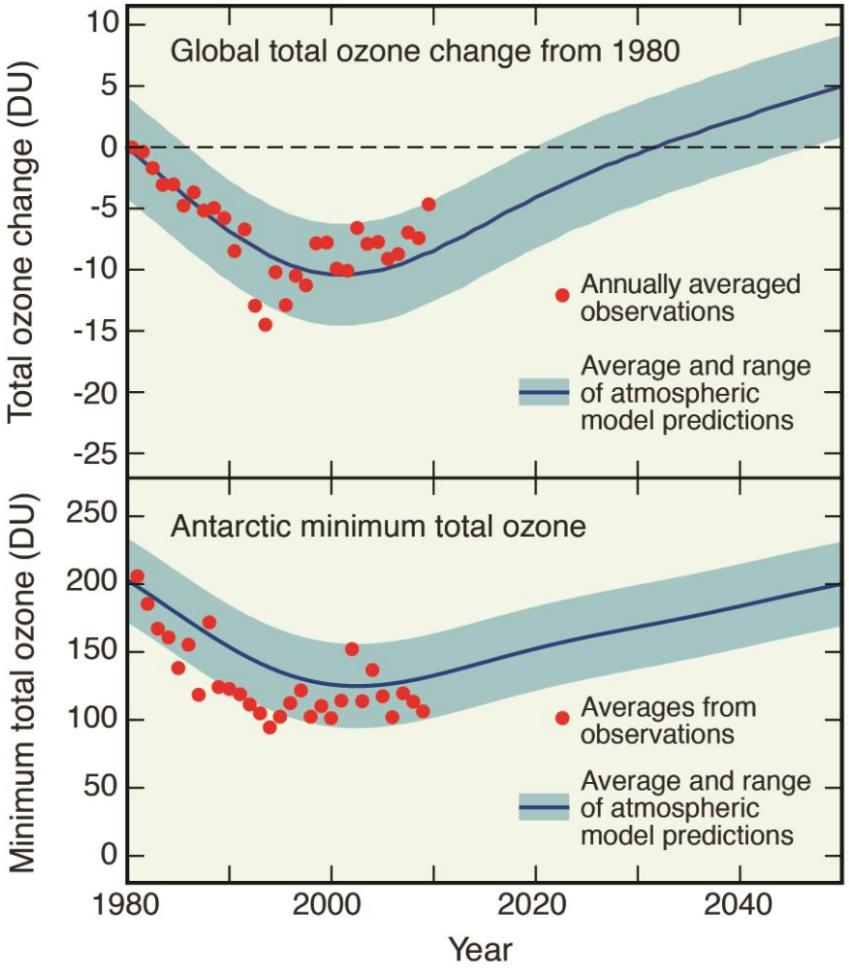

HALOX

Temporal evolution of ozone hole

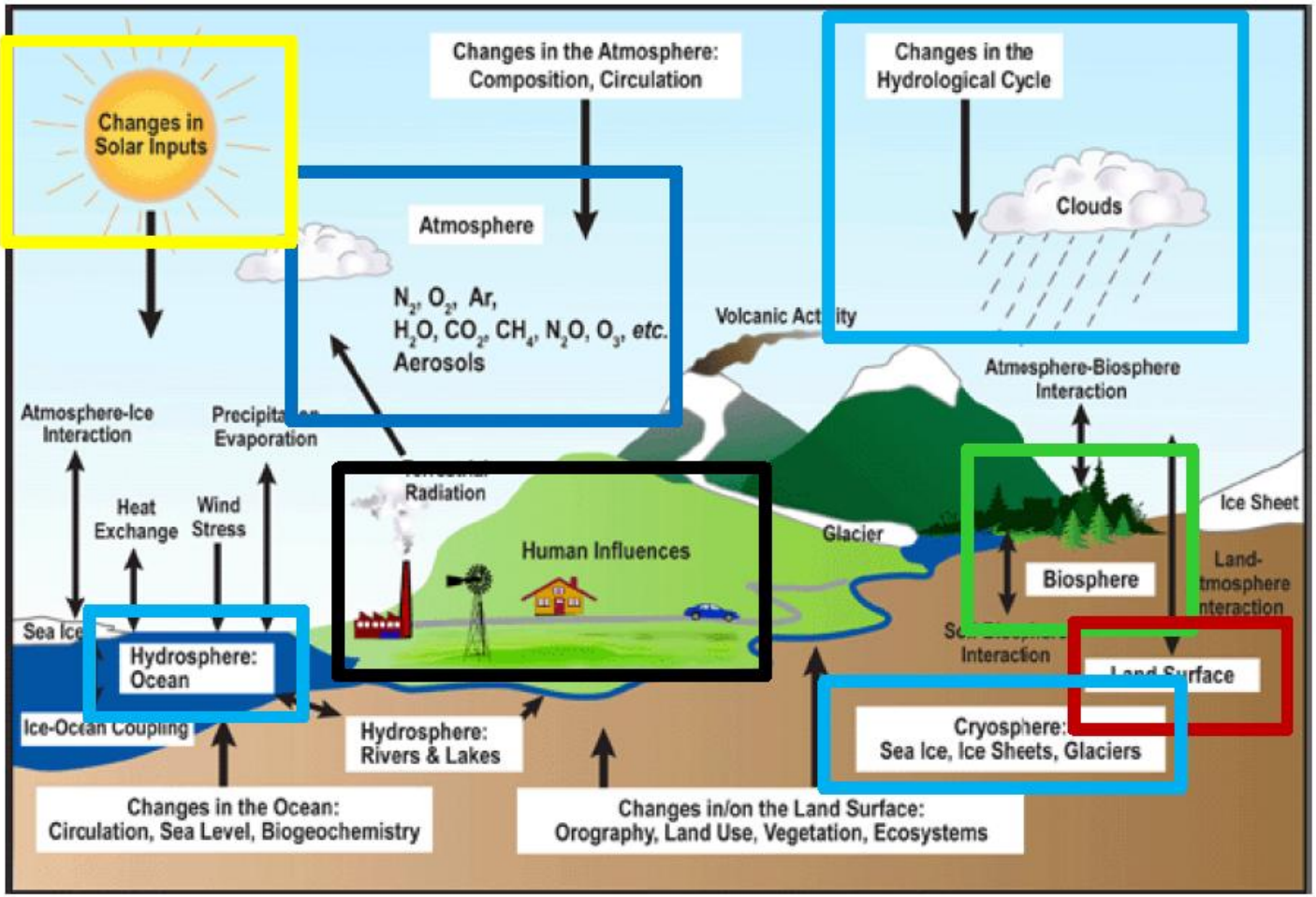


Simulations of Stratospheric Ozone Depletion

Results from chemistry-climate models



Schematic view of the components of the climate system, their processes and interactions.



Thank you for your attention!