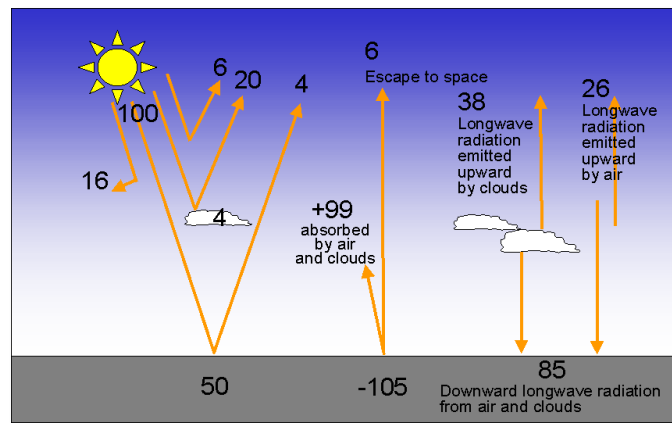
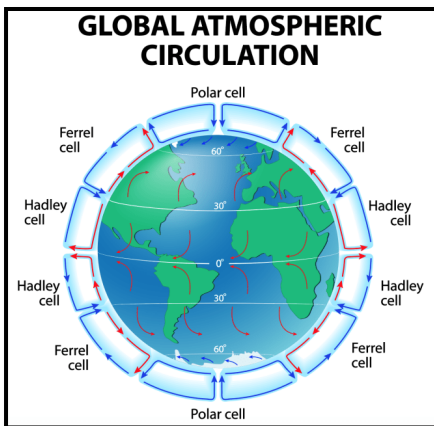


# Atmospheric Thermodynamics

## Lec. 1 Atmospheric Composition and Structure

Thermodynamics deals with the transformations of the energy in a system and between the system and its environment. Hence, it is involved in every atmospheric process, from the large scale general circulation to the local transfer of radiative, sensible and latent heat between the surface and the atmosphere and the microphysical processes producing clouds and aerosol.



### 1.1 Atmospheric Composition

- The atmosphere is a mixture of gas molecules, aerosols, and falling precipitation.
  - Aerosols: microscopic, solid or liquid, suspended particles.
  - Gases: permanent and variable gases

#### Permanent gases

Gas	Symbol	ppmv	Residence Time (in years)
Nitrogen	N <sub>2</sub>	780 840	14 000 000
Oxygen	O <sub>2</sub>	209 460	4 500
Argon	Ar	9 300	Forever
Neon	Ne	18	Forever
Helium	He	5	2 000 000
Xenon	Xe	0.09	Forever

#### Variable gases

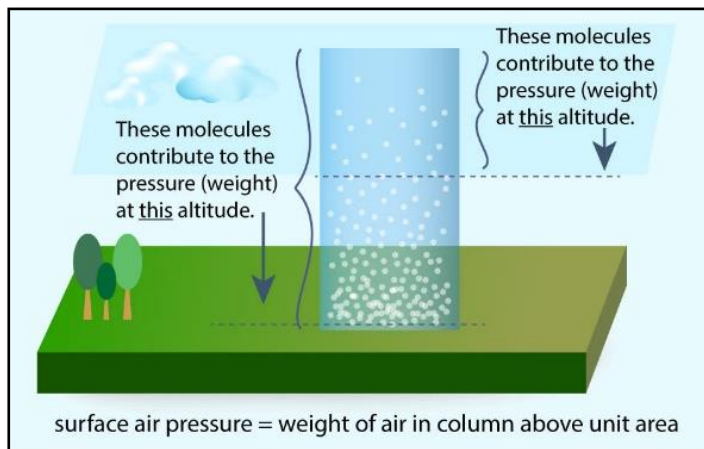
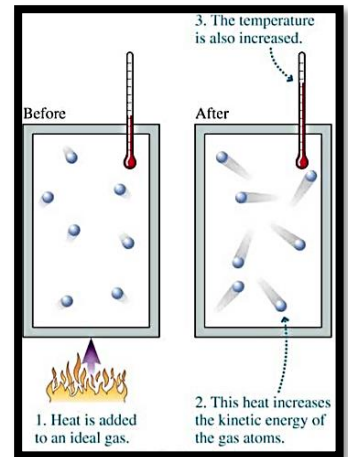
Constituent	Symbol	ppmv	Residence Time (in years)
Water vapour	H <sub>2</sub> O	0 - 40 000	0.026 (9.5 days)
Carbon dioxide	CO <sub>2</sub>	389	Multiple timescales
Methane	CH <sub>4</sub>	1.8	8.4
Nitrous oxide	N <sub>2</sub> O	0.314	120
Ozone	O <sub>3</sub>	0.04	0.25 (91 days)
Aerosols		0.01 - 0.15	Up to 0.04 (14 days)

## 1.2 Atmospheric Variables

○ Atmospheric variables are the fundamental, measurable elements of the atmosphere that define current weather conditions and drive climate, including temperature, air pressure, humidity, wind, and precipitation. These, along with cloud cover, radiation, and visibility, change daily based on factors like solar radiation, altitude, and topography.

- **Temperature (T)** is a measure of the average speed of air molecules. Its units are Kelvin, Celsius, and Fahrenheit. Absolute Zero ( $0\text{ K} = -273\text{ }^{\circ}\text{C}$ ) is where molecules do not move.

- **Pressure (P)** is a force per unit area. The surface pressure results from the weight of the air above. Higher in the atmosphere there is less total air above and hence pressure decreases with height.



- Pressure units:

- SI: Pascal ( $1\text{ Pa} = 1\text{ N/m}^2$ )

- $1\text{ hPa} = 100\text{ Pa}$

- American: bar (force of 100 000 N on  $1\text{ m}^2$ )

- $1\text{ bar} = 100\text{ 000 Pa} = 1000\text{ hPa}$

- $1\text{ hPa} = 1\text{ millibar (mb)}$

- Standard pressure (one atmosphere):  $1013.5\text{ hPa} = 1013.5\text{ mb}$

- Pressure and height:
  - As altitude increases, the air becomes less dense and air pressure decreases.

*Q. Why does atmospheric pressure change with altitude?*

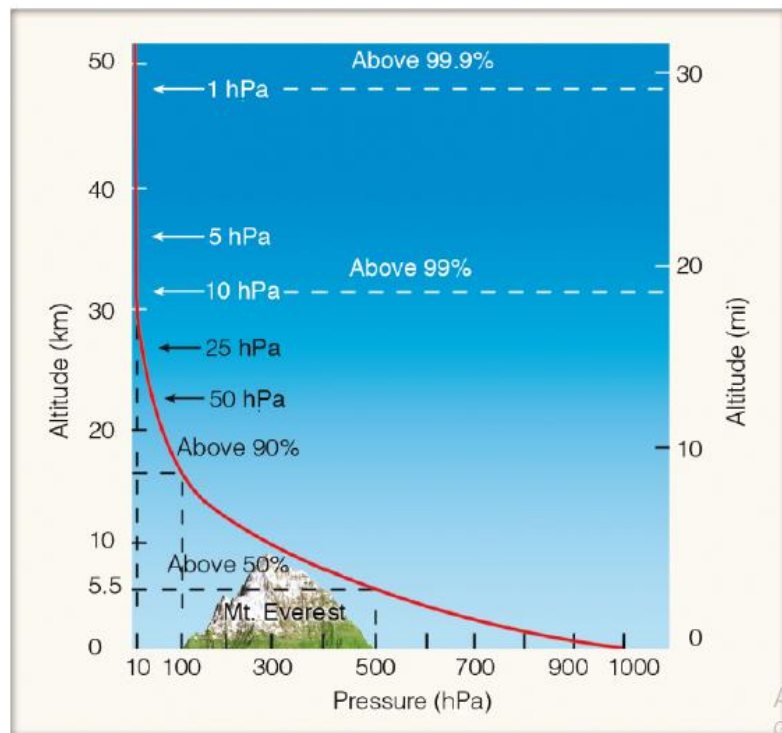
Ans. Atmospheric pressure decreases with altitude because **there is less air above you pressing down** as you go higher. Gravity keeps air concentrated near Earth's surface, making pressure high at low altitudes and lower at higher altitudes.

- Atmospheric pressure decreases with height at a non-linear, exponential rate, dropping by approximately 85 hPa per kilometer in the lower atmosphere. It decreases faster near the surface and slower at higher altitudes because air is compressible and becomes less dense.
- **Density ( $\rho$ ):** is the mass per unit volume,

$$\text{Density } \rho \left( \frac{kg}{m^3} \right) = \text{mass/Volume}$$

At the surface:  $\rho = 1.2 \text{ kg/m}^3$

At 150 km from the surface:  $\rho = 3.6 \times 10^{-9} \text{ kg/m}^3$



### 1.3 The Thermal Layers of the Atmosphere

- **The troposphere:**
  - Heated from below.
  - Well-mixed vertically.
  - Averages 11 km thick.
  - Contains 80% of the mass of the atmosphere.
  - All of our weather occurs in this part of the atmosphere.
- **The stratosphere:**
  - Heated from above.
  - Warm air over cold air is very stable. This means there is very little vertical mixing.
  - 11-50 km in height.
  - 20% of mass of atmosphere.
  - Heated by absorption of UV by ozone. Ozone peaks at 25 km (ozone layer).
- **The Mesosphere and the Thermosphere are of less importance in this context.**

