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:
    - suspended particles
    - microscopic
    - solid or liquid
  - Gases:
    - Permanent gases

Gas	Symbol	ppmv	Residence Time (in years)
Nitrogen	N_2	780 840	14 000 000
Oxygen	O_2	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_2O	0 - 40 000	0.026 (9.5 days)
Carbon dioxide	CO_2	389	Multiple timescales
Methane	CH_4	1.8	8.4
Nitrous oxide	N_2O	0.314	120
Ozone	O_3	0.04	0.25 (91 days)
Aerosols		0.01 – 0.15	Up to 0.04 (14 days)

1.2 Atmospheric Variables

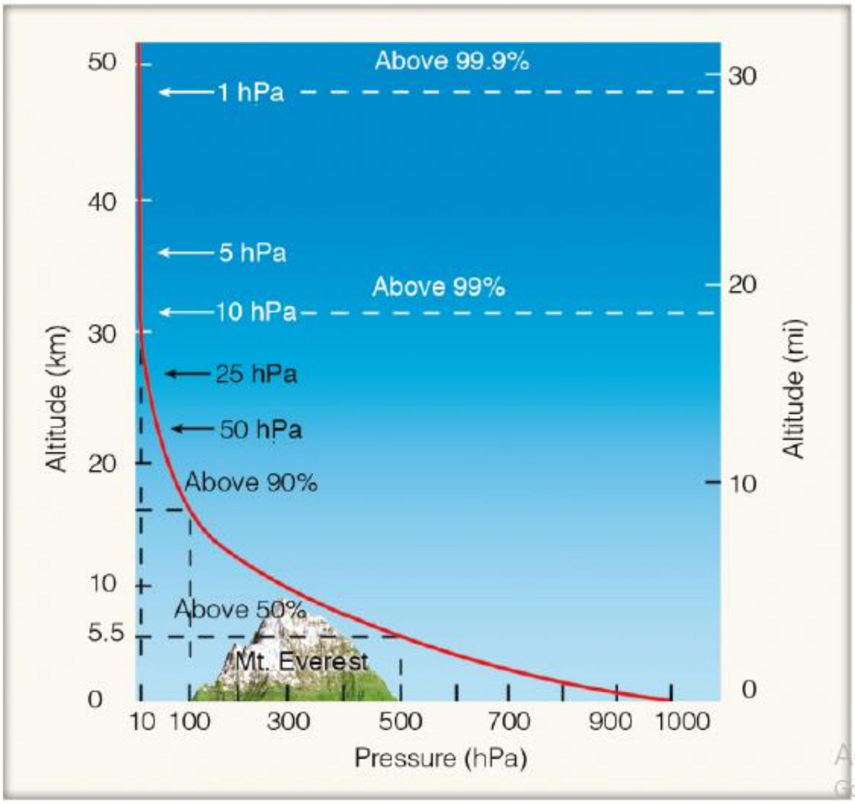
- Temperature (T) is a measure of the average speed of air molecules. Its units are Kelvin, Celsius, and Fahrenheit. Absolute Zero (0 K= -273 ^{o}C) is where molecules do not move.
- Pressure (P) is a force per unit area. The surface pressure results from the weight of the air above. Higher in the atmosphere there is less total air above and hence pressure decreases with height.
  - Pressure units
    - SI: Pascal (1 Pa = 1 N/m^2)
      1 hPa = 100 Pa
    - American: bar (force of 100 000 N on 1 m^2)
      1 bar = 100 000 Pa = 1000 hPa
      1 hPa= 1 millibar (mb)
  - Standard pressure (one atmosphere):
    - 1013.5 hPa = 1013.5 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 reduces with altitude for two reasons, both of which are related to gravity.

      The gravitational attraction between the earth and air molecules is greater for those molecules nearer to earth than those further away — they have more weight — dragging them closer together and increasing the pressure (force per unit area) between them.

Molecules further away from the earth have less weight and 'standing' on the molecules below them, causing compression.



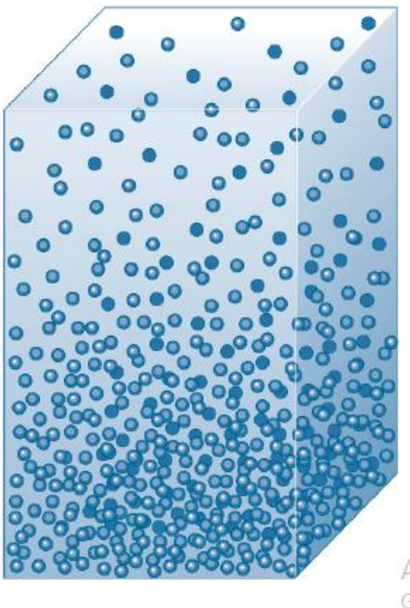
- Density (ρ): is the mass per unit volume,

$$\rho\ (\frac{kg}{m^3}) = m/V$$

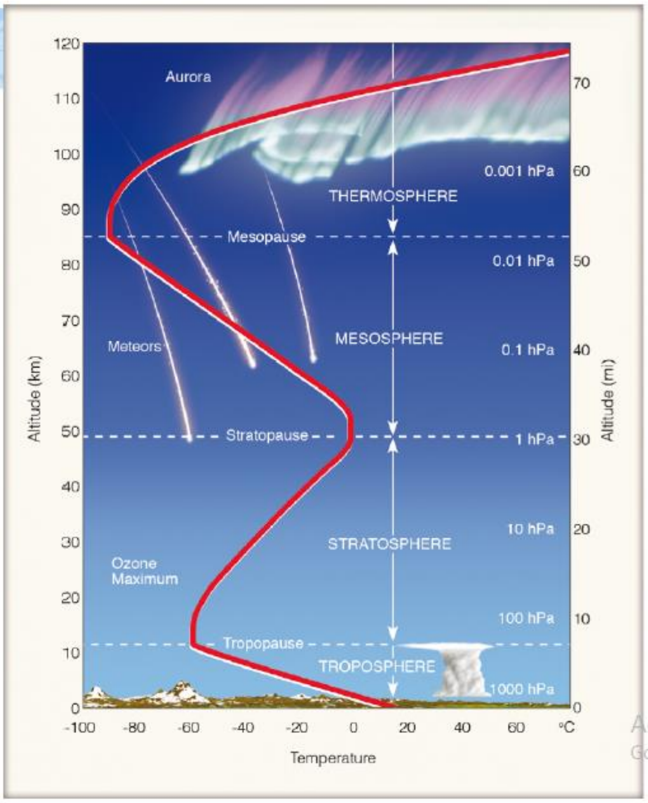
At the surface:

$\rho = 1.2\ kg/m^3$ at the surface

$\rho = 3.6 \times 10^{-9}\ kg/m^3$ at 150 km surface



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.