# Lecture – 2: Formation of Precipitation

## 1. Introduction: Thermodynamic Considerations

A necessary condition to the formation of precipitation is that the air becomes saturated with water vapor. Saturation is the first step in the formation of precipitation (i.e. it is necessary but not sufficient).

Saturation is typically quantified by relative humidity. The relative humidity (RH) is defined as:

$$RH = \frac{e_a}{e_s},$$

where $e_a$ is the actual water vapor pressure (say in kPa or mbars) and $e_s$ is the saturation vapor pressure. Air becomes saturated if $RH$ is 100%.

The actual vapor pressure is dependent on the water vapor concentration (or density $\rho_v$ ) of the parcel of air. These variables are related through the ideal gas law, given by

$$\rho_v = \frac{0.622 e_a}{R_d T}$$

where:

$\rho_v$ is the water vapor density
$R_d$ is the gas constant of dry air (=287.04 Joules kg$^{-1}$ K$^{-1}$)
$T$ is the absolute temperature (K)

NOTE: the 0.622 = 18/29 which is the ratio of the molecular weights of water and air.

The saturation vapor pressure is defined as the pressure at which the parcel of air is saturated with water vapor. That is - you cannot add more water vapor to this parcel of air without changing its temperature.

The saturation vapor pressure varies only with temperature. The relationship is known as the Claussius-Clapeyron equation. It can be approximated by

$$e_s(kPa) = 0.611 Exp\left[\frac{17.502 T_c}{T_c + 240.91}\right]$$

where $T_c$ is the air temperature (degrees C). The relationship between $e_s$ and $T_c$ is shown in Figure 1. Hence, $RH \rightarrow 100\%$ if

1) $\rho_v$ increases (for a fixed temperature) or
2) 2) if temperature decreases.

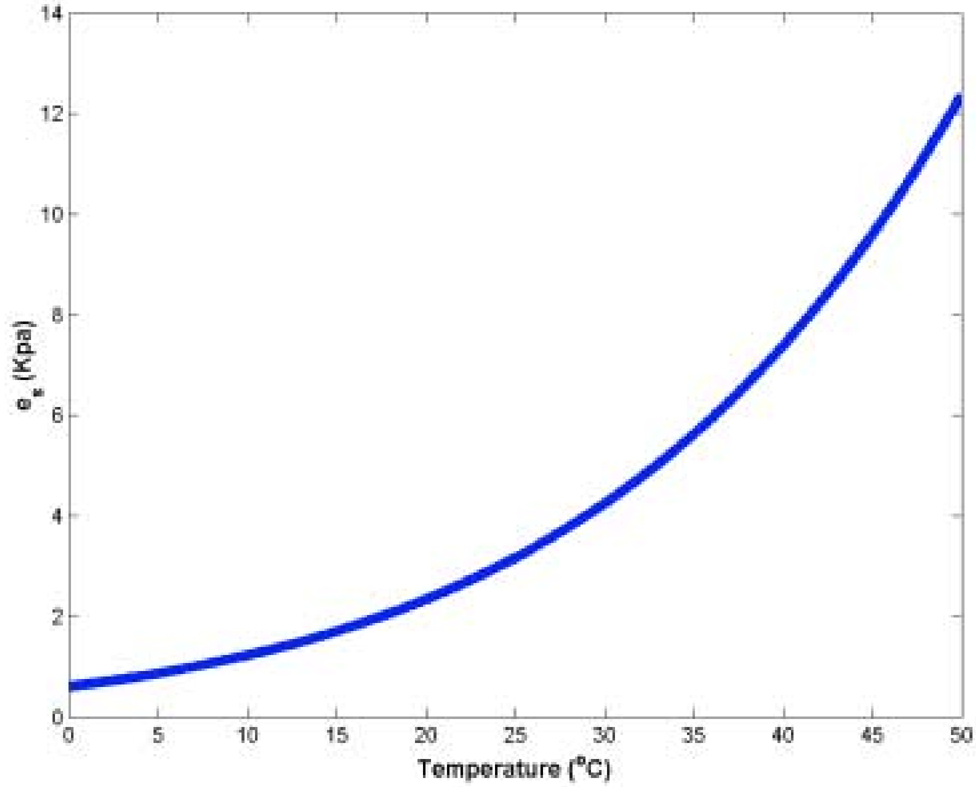


**Figure 1:** Exponential variation of saturation vapor pressure with air temperature.

Decreasing temperature decreases exponentially $e_s$ (see Figure 1) thereby forcing $e_s = e_a$.

One key mechanism for decreasing temperature is LIFTING the parcel of air to higher elevation. As a parcel of air is lifted to higher elevations – it becomes cooler, and its $e_s$ drops. The height or elevation at which $e_s = e_a$, clouds will form. The term LIFTING CONDENSATION LEVEL (LCL) is often used to describe this elevation or state.

Roughly speaking, the air cools by about 10K per 1000 m (or 1 Km). This quantity is known is the DRY ADIABATIC LAPSE RATE ($\Gamma_d$). By definition, $\Gamma_d = \frac{g}{C_p}$, where $g$ is the gravitational acceleration (=9.8 m s$^{-2}$) and $C_p$ is the specific heat capacity of dry air at constant pressure (=1005 Joules Kg$^{-1}$ K$^{-1}$).

**2. Classification of Precipitation Events:**

Hence, the "mechanism" by which air is lifted is nominally used to classify the type of precipitation.

Broadly speaking, there are 3 types of lifting mechanisms:

- *Orographic lifting*: In which air is forced to go over mountains (and it's the reason why windward slopes receive more precipitation).

- *Frontal surface lifting*: In which warmer air is forced to go above cooler air in equilibrium with a cooler surface.

- *Convective Lifting:* Warm air rises from a warm surface and progressively cools down.

All three mechanisms can lift air and hence result in the cooling process necessary to reduce $e_s$ and attain RH=100%.

**3. Formation of Precipitation**

As earlier stated, condensation is a NECESSARY but NOT SUFFICIENT condition to the formation of precipitation. Next, we briefly describe the remaining conditions necessary to the formation of precipitation.

3.1 Condensation Nuclei: These are particles in the atmosphere of the order of 0.1 to 10 $\mu$m. These particles originate from products of combustion, oxides of nitrogen, aerosols, salt particles, etc…

3.2 Growth of the water droplet: The saturated air tends to condense on these particles – and then water droplet grow in size, become heavier, and fall to the ground as precipitation.

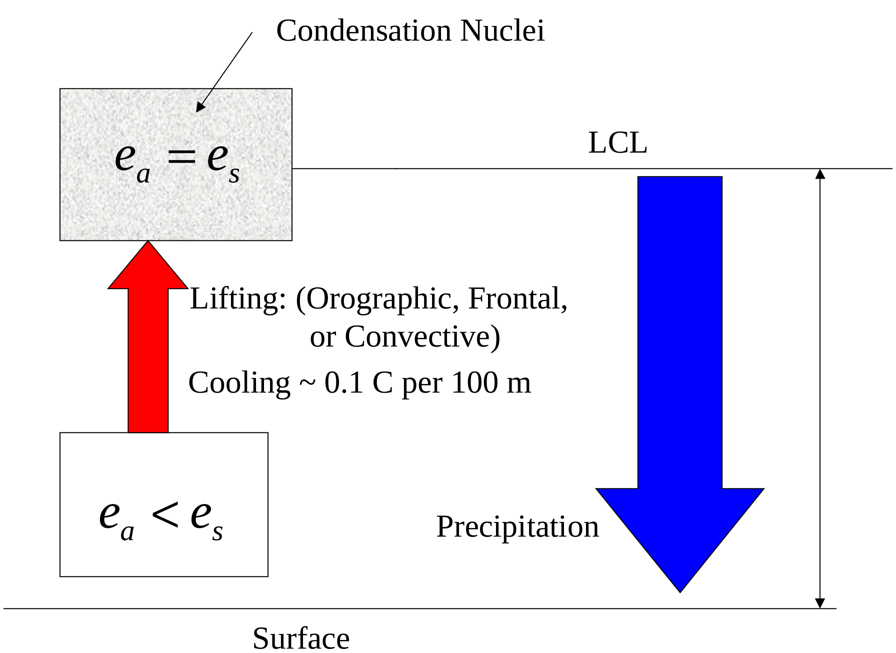


**Figure 2**: Summary of the key (idealized) processes leading to precipitation.