CLOUD PHYSICS - tutorial 1

Liquid water content - LWC

1. Lapse rates

Plot the adiabatic and pseudo-adiabatic normalised lapse rates for the initially saturated air at 300 K and pressures p=1 000 hPa, and p=800 hPa.

2. Specific liquid water mass (q$_l$)

The amount of water vapor condensed in adiabatic process is given by:

$$dq_l = \frac{c_p}{L_v}\left(\Gamma_d - \Gamma_s\right) dz \tag{1}$$

where q_l is the specific mass of liquid water, Γ_d is the dry adiabatic lapse rate, Γ_s is the moist adiabatic (or pseudo-adiabatic) lapse rate, $c_p = q_d c_d + q_s c_v + q_l c_l$ is the specific heat at constant pressure.

Let's define $c_q = \frac{c_p}{L_v}\left(\Gamma_d - \Gamma_s\right)$. c_q is called the condensation rate. The condensation rate is a function of temperature, T, and pressure, p, i.e. $c_q(T_0, p_0)$.

- Plot $q_l(z)$ for given conditions at the cloud base, i.e. T_0, p_0 (e.g. $T_0 = 10C, p_o = 900hPa$).
- Let's assume that the condensation rate, c_q, is constant and takes the same value as at the cloud base, $c_q(T_0, p_0)$. Eq.1 can be integrated:

  $$q_l(z) = c_q(T_0, p_0)(z - z_0), \text{ where } z_0 \text{ is the cloud base height.}$$

  Show for which heights above the cloud base this relation is valid.
- Is there any difference if Γ_s is taken in the adiabatic or pseudo-adiabatic form?

3. Liquid water content (LWC)

The liquid water content (LWC) is:

$$LWC = \frac{m_l}{V} = \frac{m_l}{m} \cdot \frac{m}{V} = \rho q_l \text{ where } \rho \text{ is the air density.}$$

Eq.1 can be written in a form:

$$d\left(\frac{LWC}{\rho}\right) = \frac{c_p}{L_v}\left(\Gamma_d - \Gamma_s\right) dz \tag{2}$$

- Plot LWC as a function of height above the cloud base.

- Show that, as in the case of the specific mass of liquid water, q_l, the liquid water content can be approximated by a linear function:

  $$LWC(z) = c_{LWC}\,(z - z_0)$$

  where $c_{LWC} = \rho_0 c_q(T_0, p_0)$, and ρ_0 is the density of the air at the cloud base.

- Show for which heights above the cloud base the linear approximation is valid.