CLOUD PHYSICS - tutorial 1

Cloud Liquid Water Content

1 Lapse rates

Plot the the vertical profiles of adiabatic and pseudo-adiabatic normalised lapse rates

$$\gamma = \frac{c_{pd}}{c_p} \frac{1 + q_s \beta_T \left(\frac{R_v}{R}\right)}{1 + q_s \beta_T \left(\frac{L_v}{c_p T}\right)}$$

$$\gamma_{pa} = \frac{1 + q_s \frac{L_{lv}}{R_d T}}{1 + q_s \frac{L_{lv}^2}{c_{pd} R_v T^2}}$$

for the initially saturated air at $T_0 = 273.15K$ and $p = 1000hPa$.

2 Specific liquid water mass ($\mathbf{q}_l$)

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

$$dq_l = \frac{c_p}{L_v} \left(g/c_p - \Gamma_s\right) dz \quad (1)$$

or

$$dq_l = \frac{c_{pd}}{L_v} \Gamma_d \left(1 - \gamma'\right) dz \quad (2)$$

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, $c_p = q_d c_{pd} + q_s c_{pv} + q_l c_l$ is the specific heat at constant pressure, and

$$\gamma' = \frac{1 + q_s \beta_T \left(\frac{R_v}{R}\right)}{1 + q_s \beta_T \left(\frac{L_v}{c_p T}\right)}.$$

The condensation rate is defined as: $c_q = \frac{c_p}{L_v} \left(g/c_p - \Gamma_s\right)$ or $c_q = \frac{c_{pd}}{L_v} \Gamma_d \left(1 - \gamma'\right)$. The condensation rate is a function of temperature, T, and pressure, p, i.e. $c_q(T, p)$.

(a) Plot $q_l(z)$ for given conditions at the cloud base, e.g. $T_0 = 10C, p_0 = 900hPa$.

(b) Assume that the condensation rate, c_q, is constant and takes the value as at the cloud base, $c_q(T_0, p_0)$. Eqs.**??** and **??** can be integrated as:

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

$q_{l,lin}$ increases linearly with hight above the cloud base. Plot $q_{l,lin}(z)$.

(c) For which heights above the cloud base $q_{l,lin}$ provides a good estimate of q_l. Assume that the estimates are correct if $(q_{l,lin} - q_l)/q_l$ is less than 3%, 5%, 10%.

(d) 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:

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

Eqs.**??** and **??** can be written in a form:

$$d\left(\frac{LWC}{\rho}\right) = \frac{c_p}{L_v}\left(g/c_p - \Gamma_s\right) dz \tag{3}$$

or

$$d\left(\frac{LWC}{\rho}\right) = \frac{c_{pd}}{L_v}\Gamma_d\left(1 - \gamma'\right) dz \tag{4}$$

(a) Plot LWC as a function of height above the cloud base for given conditions at the cloud base, e.g. $T_0 = 10C, p_0 = 900hPa$.

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

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

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

(c) Show for which heights above the cloud base the linear approximation is valid.

4 Isolines of condensation rate

Plot isolines of c_q and $c_{LWC} = \rho c_q$.