

CLOUD PHYSICS - tutorial 1

Cloud Liquid Water Content

1 Lapse rates

Plot the adiabatic and pseudo-adiabatic normalised lapse rates

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

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 saturated adiabatic ascent is given by:

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

or

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

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

- Plot $q_l(z)$ for given conditions at the cloud base, e.g. $T_0 = 10C, p_0 = 900hPa$.
- 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.1 and 2 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 height above the cloud base. Plot $q_{l,lin}(z)$.

- 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.1 and 2 can be written in a form:

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

or

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

- (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:

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

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

- (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 $c_{LWC} = \rho c_q$.