

CLOUD PHYSICS - tutorial 1

Cloud Liquid Water Content

1 Lapse rate

Plot vertical profiles of the pseudo-adiabatic lapse rate, temperature, saturation specific humidity, pressure and density for an air parcel initially saturated at $T_0 = 10^\circ\text{C} = 283.15\text{K}$ and $p = 900\text{hPa}$.

The pseudo-adiabatic lapse rate is given by the following formula:

$$\Gamma_{s,pa} = \frac{g}{c_{pd}} \cdot \frac{1 + q_s \frac{L_{lv}}{R_d T}}{1 + q_s \frac{L_{lv}^2}{c_{pd} R_v T^2}}$$

2 Specific liquid water mass (q_l)

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

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

where q_l is the specific mass of liquid water, Γ_s is the moist adiabatic (or pseudo-adiabatic) lapse rate, and $c_p = q_d c_{pd} + q_s c_{pv} + q_l c_l$ is the specific heat capacity at constant pressure.

The condensation rate is defined as: $c_q = \frac{c_p}{L_v} (g/c_p - \Gamma_s)$. 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., $T_0 = 10^\circ\text{C}$, $p_0 = 900\text{hPa}$.
- (b) Assume that the condensation rate, c_q , is constant and takes its value at the cloud base, $c_q(T_0, p_0)$. Equation 1 can be integrated to yield:

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

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

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

3 Liquid water content (LWC)

The liquid water content (LWC) is defined as:

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

Equation 1 can be written in the form:

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

- (a) Plot LWC as a function of height above the cloud base for the given conditions at the cloud base, e.g. $T_0 = 10^\circ\text{C}$, $p_0 = 900\text{hPa}$.
- (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 air density at the cloud base.

- (c) Determine the range of heights above the cloud base for which this linear approximation remains valid.

4 Isolines of condensation rate

Plot isolines of c_q and $c_{LWC} = \rho c_q$ on a $p - T$ diagram. Show how these parameters change along a line of constant equivalent potential temperature, θ_e .

$$\theta_e = \theta \exp \left(\frac{q_s L_v}{c_{pd} T} \right).$$

5 Discuss the results