

## CLOUD PHYSICS - tutorial 1

### Cloud Liquid Water Content

#### 1 Lapse rates

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

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 in 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,  $\Gamma_s$  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.

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 the value as at the cloud base,  $c_q(T_0, p_0)$ . Equation 1 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  $q_{l,lin}(z)$ .

- (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%.

#### 3 Liquid water content (LWC)

The liquid water content (*LWC*) is:

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

Equation 1 can be written in a form:

$$d \left( \frac{LWC}{\rho} \right) = \frac{c_p}{L_v} (g/c_p - \Gamma_s) dz \quad (2)$$

- (a) Plot  $LWC$  as a function of height above the cloud base for 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  $\rho_0$  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  $c_{LWC} = \rho c_q$ .

#### 5 Discuss the results