CLOUD PHYSICS - tutorial 2

Microphysics

1 Experimental data

You will use data collected by an aircraft during the Second Aerosol Characterization Experiment (ACE2) in Stratocumulus clouds.

Data from two traverses through the stratocumulus cloud layer are in files:

tutorial_ACE2_fr9721_130702.1R0010

tutorial_ACE2_fr9721_130832.1R0010.

The files contain data averaged over 0.1s, corresponding to an average over 10m along the flight track. Columns contain:

1- time (s)

2 - time (s) from midnight

3 - true air velocity (m/s)

4 - height (m)

5 - pressure (hPa)

6 - temperature (C)

7 - specific humidity (g/kg)

8 - air density (kg/m^3)

9 - concentration (cm^{-3})

10 - liquid water content (g/m^3)

11 - mean diameter (micron)

12 - mean volume diameter (micron)

13 - effective diameter (micron)

14-32 diameters corresponding to 5,10,15....,95 percentiles of distribution.

For each file:

(a) Plot vertical profiles of:

- temperature,
- concentration,
- specific humidity,
- specific liquid water mass,

- specific total water content,
- mean volume diameter,
- 5th and 95th percentile of the distribution,
- width of the droplet size distribution (difference between 95th and 5th percentile of the droplet size distribution),
- potential temperature,
- liquid water potential temperature
- saturated equivalent potential temperature.

(b) Calculate the condensation rate and show that the specific mass of liquid water can be approximated by a linear relationship: $q_l(z) = c_q(T_{clbase}, p_{clbase})(z - z_{clbase})$, where $c_q(T,p) = \frac{c_{pd}}{L_v}\Gamma_d(1-\gamma')$.

(c) Show the relationship between mean diameter, mean volume diameter and effective diameter.

(d) Discuss all the results.

2 Liquid Water Path (LWP)

The Liquid Water Path is defined as:

$$LWP = \int_{z_{cl.base}}^{z_{cl.top}} LWC dz.$$

Assume we have a shallow stratocumulus cloud that develop according to the moist adiabatic process. For such a cloud $LWC(z) = c_w(T_0, p_0)h$, where $h = z - z_{cl.base}$ is the height above the cloud base (see tutorial 1: LWC).

Calculate LWP for clouds which cloud base pressure is: $900, 800hPa$ and the cloud base temperature varies between 0 to 20^0C. Show how the LWP varies for different cloud depths (shallow enough to obey the linear relationship: $LWC(h) = c_w(T_0, p_0)h$; see tutorial_1_LWC).

3 Optical thickness

Optical thickness is defined as:

$$\tau = \pi Q_{ext} \int_{z_{cl.base}}^{z_{cl.top}} N r_s^2 dz,$$

where Q_{ext} is the extinction coefficient, that depends on the size parameter $x = 2\pi r/\lambda$ (r - particle size, λ - wavelength). In the case of clouds we can assume that $Q_{ext} = 2$.

Assume we have a shallow stratocumulus cloud that forms in the moist adiabatic process. Cloud droplet number concentration N is constant. Let's define a parameter k that depends upon the droplet spectral shape, $k = r_v^3/r_e^3$. This parameter is approximately 0.67 for continental clouds and 0.8 for marine clouds.

Show that for a shallow adiabatic cloud (i.e. a cloud where $LWC = c_w(T_0, p_0)h$) the optical thickness can be expressed as:

$$\tau = \frac{3}{5}\pi Q_{ext} A^{2/3}(kN)^{1/3}H^{5/3},$$

where $A = c_w/(\frac{3}{4}\pi\rho_l)$, c_w is the liquid water content condensation rate (see lecture_2 thermodynamics, and tutorial_2 LWC), H is the cloud depth.

Calculate the optical thickness for clouds having different N, H. Discuss the difference between continental and marine clouds. How does the optical thickness depend on temperature and pressure at the cloud base?