CLOUD PHYSICS - tutorial 2

Microphysics

1 Experimental data

You will use data collected by an aircraft during the Second Aerosol Characterization Experiment (ACEi-2) in stratocumulus clouds.

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

tutorial_ACE2_fr9721_130702.1R0010

tutorial_ACE2_fr9721_130832.1R0010.

The files contain data averaged over 0.1s, corresponding to an average over a 10m distance along the flight track. The 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 demonstrate that the specific mass of liquid water can be approximated as a linear function of height above cloud base: $q_l(z) = c_q(T_{clbase}, p_{clbase})(z - z_{clbase})$, where $c_q(T,p) = \frac{c_{pd}}{L_v}\Gamma_d(1-\gamma')$.

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

(d) Discuss all obtained 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 develops following a 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 cloud base (see tutorial 1: LWC).

Calculate the Liquid Water Path (LWP) for clouds which cloud-base pressures of: 900 and 800hPa, where the cloud-base temperature ranges from 0 to 20°C. Show how LWP varies with cloud depth (for layers shallow enough to obey the linear relationship: $LWC(h) = c_w(T_0, p_0)h$; see tutorial_1_LWC).

Calculate the Liquid Water Path (LWP) value using data from two traverses through the stratocumulus layer. Plot the corresponding points on the LWP-cloud depth figure.

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 efficiency, which depends on the size parameter $x = 2\pi r/\lambda$ (r is particle radius, and λ is wavelength). For cloud droplets, we can assume $Q_{ext} = 2$.

Assume a shallow stratocumulus cloud that develops via a moist adiabatic process. The cloud droplet number concentration N is constant. We define a parameter k that depends on the droplet spectral shape as $k = r_v^3/r_e^3$. This parameter is approximately 0.67 for continental clouds and 0.8 for marine clouds.

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

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

Calculate the optical thickness value using data from two traverses through the stratocumulus layer. Perform the calculations using both the defining equation for cloud optical thickness and an expression derived for an adiabatic cloud.