Cloud Physics Lab

LAB 8: Growth by Collision-Coalescence I

Growth Rate in Terms of Radius

Introduction:

Because cloud-base rarely extends to the surface, for rain to reach the surface it must generally fall through subsaturated air. In this regard, the thought experiment of a small drop falling through cloud base in a subsaturated environment is intuitive. For a given relative humidity, evaporation is mostly a matter of time, and for smaller drops the settling time increases with the square of the drop radius, which thus allows more time for evaporation and further reduces the drop radius. Clearly, large-drops are required for precipitation to reach the surface as precipitation. However, it is not possible to grow rain-drops by condensation alone.

In this lab, student will investigate the growth process of cloud droplet by collision and coalescence process.

Objective:

a) Plot and study growth rate in terms of cloud drop radius for different liquid water contents.
b) Plot and study growth rate in terms of cloud drop radius for different collection efficiencies.

Theory:

Rain at least in warm clouds, requires cloud droplets to become aggregated into larger rain drops. This process of aggregation involves two steps: collisions between droplets and their subsequent coalescence. This two steps processes of aggregation are generally referred to as collection to emphasize the role of the larger drop in initiating the process.

Collision and Coalescence

- Collision refers to droplets hitting (colliding) with each other.
- Coalescence refers to droplets that have collided sticking together.

collision efficiency (E_{coll}) = (# collisions) / (# encounters in geometric sweep)
coalescence efficiency (E_{coal}) = (# coalescences) / (# collisions)
collection efficiency (E) = $E_{coll} \times E_{coal}$

- *Collision and Coalescence* is a dominant process for precipitation formation in warm clouds (tops warmer than about -15°C).

- Some cloud droplets will grow large enough and will start to fall in the cloud.
- Since the bigger drops fall faster than the smaller drops, they will "collect" the smaller drops - the bigger drop grows.
- Turbulence can cause additional collisions.
- Droplet fall speed is called its *terminal velocity*.
- Need droplets of different sizes for this process to really work (see fig. 1).

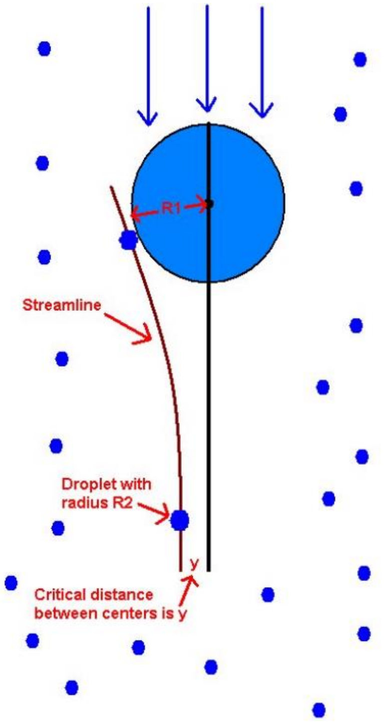

Figure 1: Collision and Coalescence

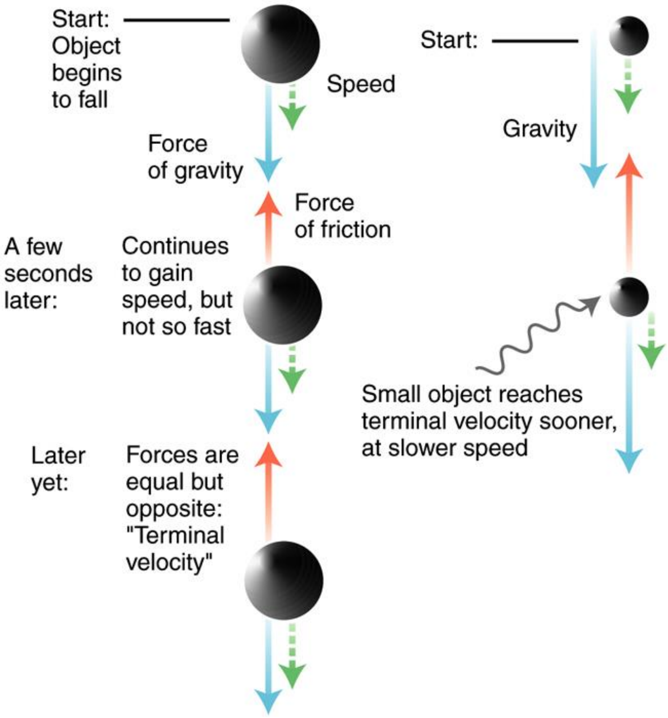

Figure 2: Terminal velocity

Terminal Velocity

- Terminal velocity is the maximum velocity reached by a falling (not pushed) object, relative to the medium through which it is falling.
- Terminal velocity is a balance between the force of gravitational attraction and the drag from friction (see fig. 2).

Table 1 shows empirical formulas for terminal velocity for droplets in varying size ranges.

Table 1: Empirical formulas for terminal velocity for different droplet sizes.

Radius	Terminal Velocity	Parameter Values
$r < 40\ \mu m$	$u = ar^2$	$a = 1.19 \times 10^6\ \text{cm}^{-1}\text{s}^{-1}$
$40\ \mu m \le r < 0.6\ mm$	$u = br$	$b = 8 \times 10^3\ \text{s}^{-1}$

$r \geq 0.6$ mm	$u = c\left(\rho / \rho_o\right) r^{1/2}$	$c = 2.2 \times 10^3\ \text{cm}^{1/2}\ \text{s}^{-1}\ :\ \rho_o = 1.20\ \text{kg m}^{-3}$

Growth Rate in Terms of Radius

The simplified expression for growth rate is given by:

$$\frac{dR}{dt} = \frac{EM}{4\rho_L} u(R) \qquad (1)$$

where R is the radius of the collector drop, E is the collection efficiency, M is the cloud liquid water content, ρ_l is the water density, and $u(R)$ is the cloud droplet terminal velocity.

If we assume a terminal velocity that is linear with radius, $u = bR$, where the value of b is given in table 1, then equation (1) can be integrated analytically to determine the droplet radius as a function of time.

$$(\ln \frac{R_f}{R_o}) = \frac{EMb}{4\rho_L} \Delta t \qquad (2)$$

or

$$R_f = R_o \exp\left(\frac{EMb}{4\rho_L} \Delta t \right) \qquad (3)$$

Materials and Procedures:

1. Run the Matlab script **Lab8a.m** to plot the drop growth rate for different cloud liquid water content.
2. Run the Matlab script **Lab8b.m** to plot the drop growth rate for different collection efficiencies.

Analysis and Conclusions:

1. Use figure 1 to explain how cloud liquid water content can affect the growth of cloud drops.
2. Use figure 2 to explain how collection efficiencies can affect the growth of cloud drops.

Note: *The magenta horizontal line represents the cut-off radius between drizzle and rain.*

Questions:

1. What did you further learn about cloud droplet growth by collision and coalescence process?
2. In fig. 1 the growth rate becomes faster when the drop become larger. Why?
3. Fig. 1 indicates that the increase in the drop radius is not linear with increasing the cloud liquid water content. Explain.
4. By comparing fig. 1 and fig. 2 determine how drop growth is influenced by cloud liquid water content and collection efficiency. Which one has is more effective than the other and why?