OUTLINE

1. Nucleation of water droplets (6.1)

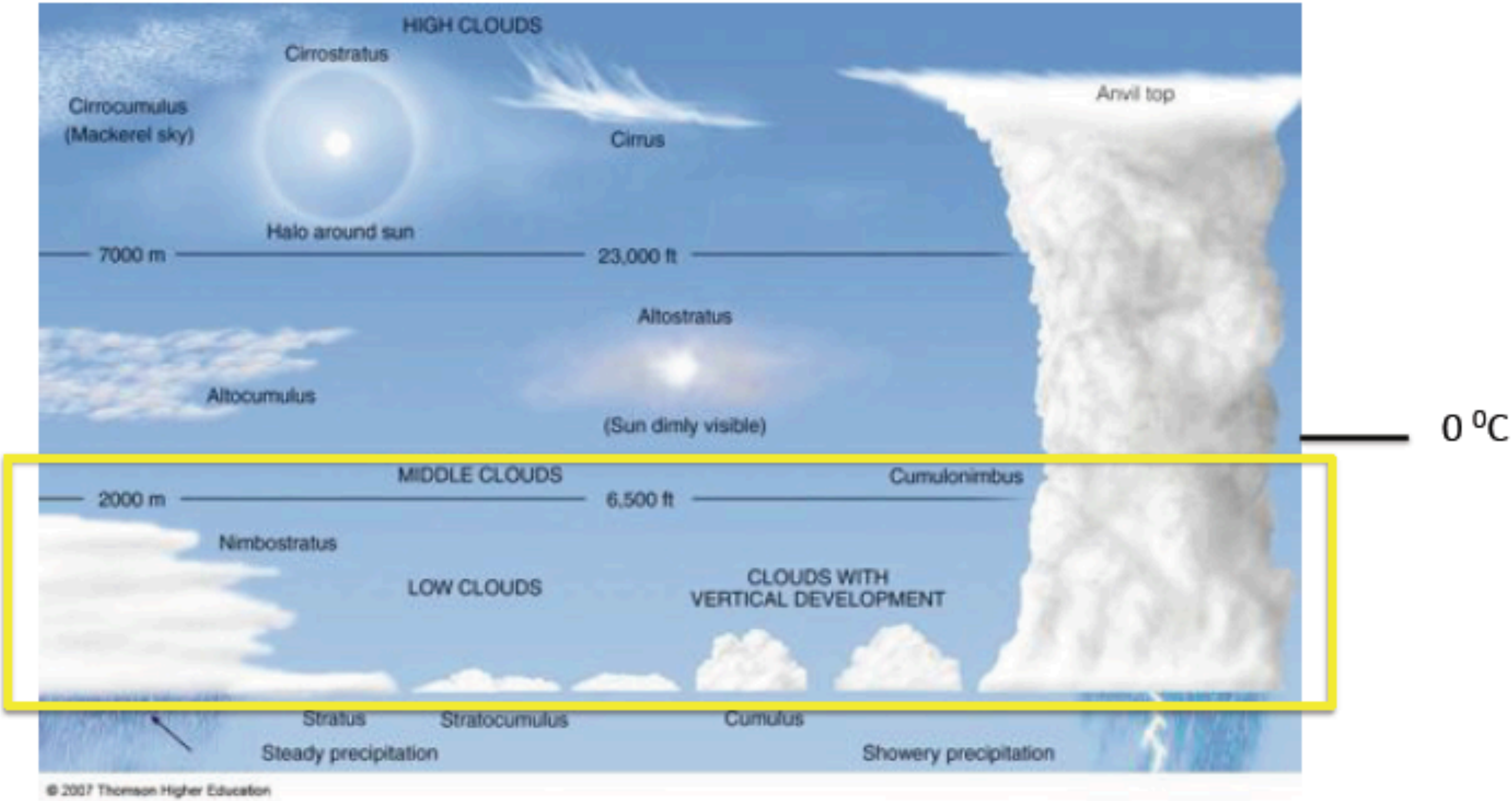
2. **Microstructures of warm clouds (6.2)**

3. Cloud Liquid Water Content and Entrainment (6.3)

4. Growth of Water Droplets and Formation of Rain (6.4)

5. Microphysics of Ice Clouds (6.5)

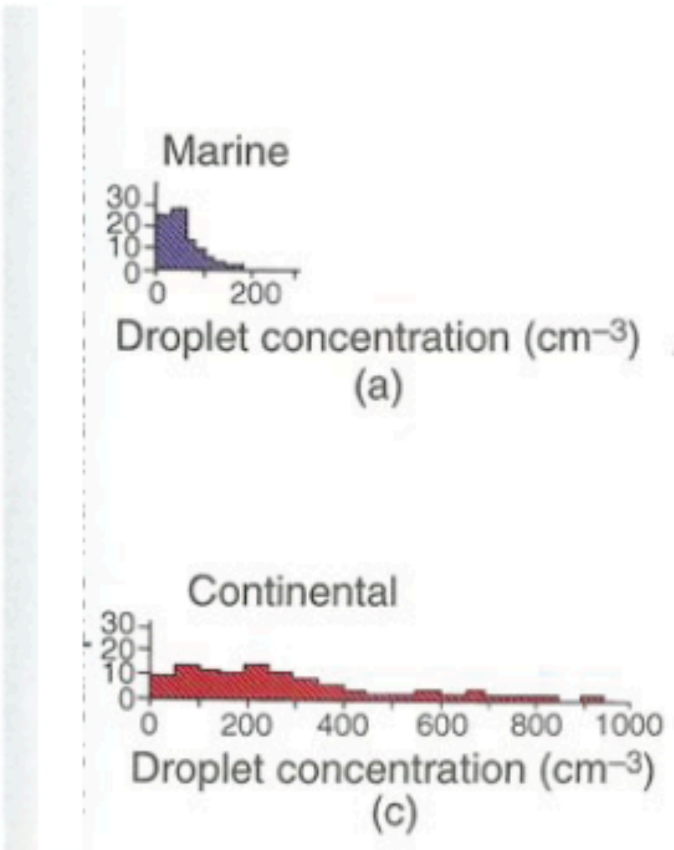
6. Lightning and Chemistry (6.7)



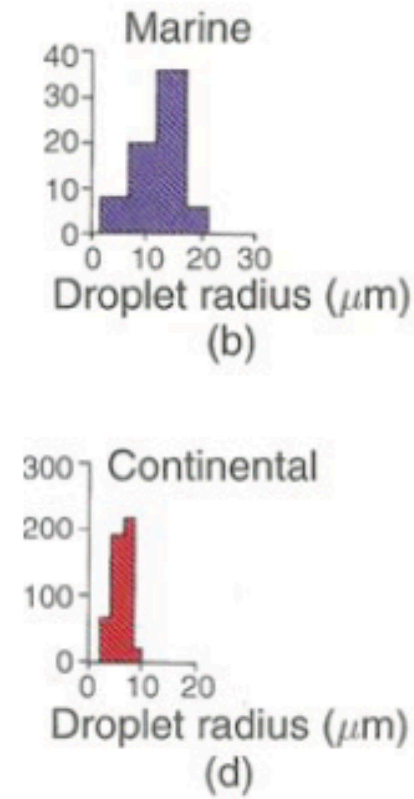
Clouds below the 0 ^{0}C isotherm is referred to as *warm clouds*.

1. Droplet number concentration (#/cm^3)
2. Droplet size distribution (histogram of size)
3. Liquid water content (LWC; g m^{-3})

Number concentration (histogram)

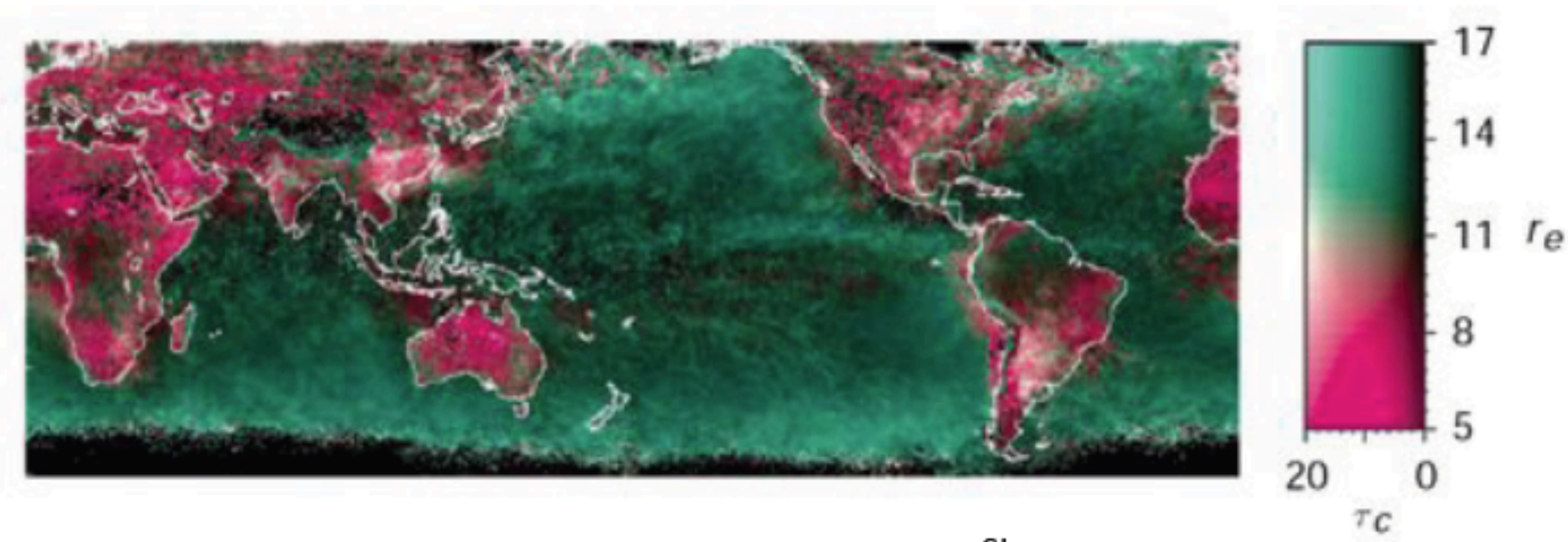


Size distribution (histogram)



T-P-S: what differences in cloud microphysics are there between clouds over ocean and clouds over land? Why?

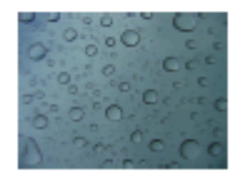
MODIS retrieval of lower-level cloud optical depth (τ_c) and effective radius (r_e in μm)



Air over land is generally more polluted, that is, more aerosols to serve as CCN. Consequently, each CCN shares a smaller size of the "pie" – smaller droplets.

Size distribution

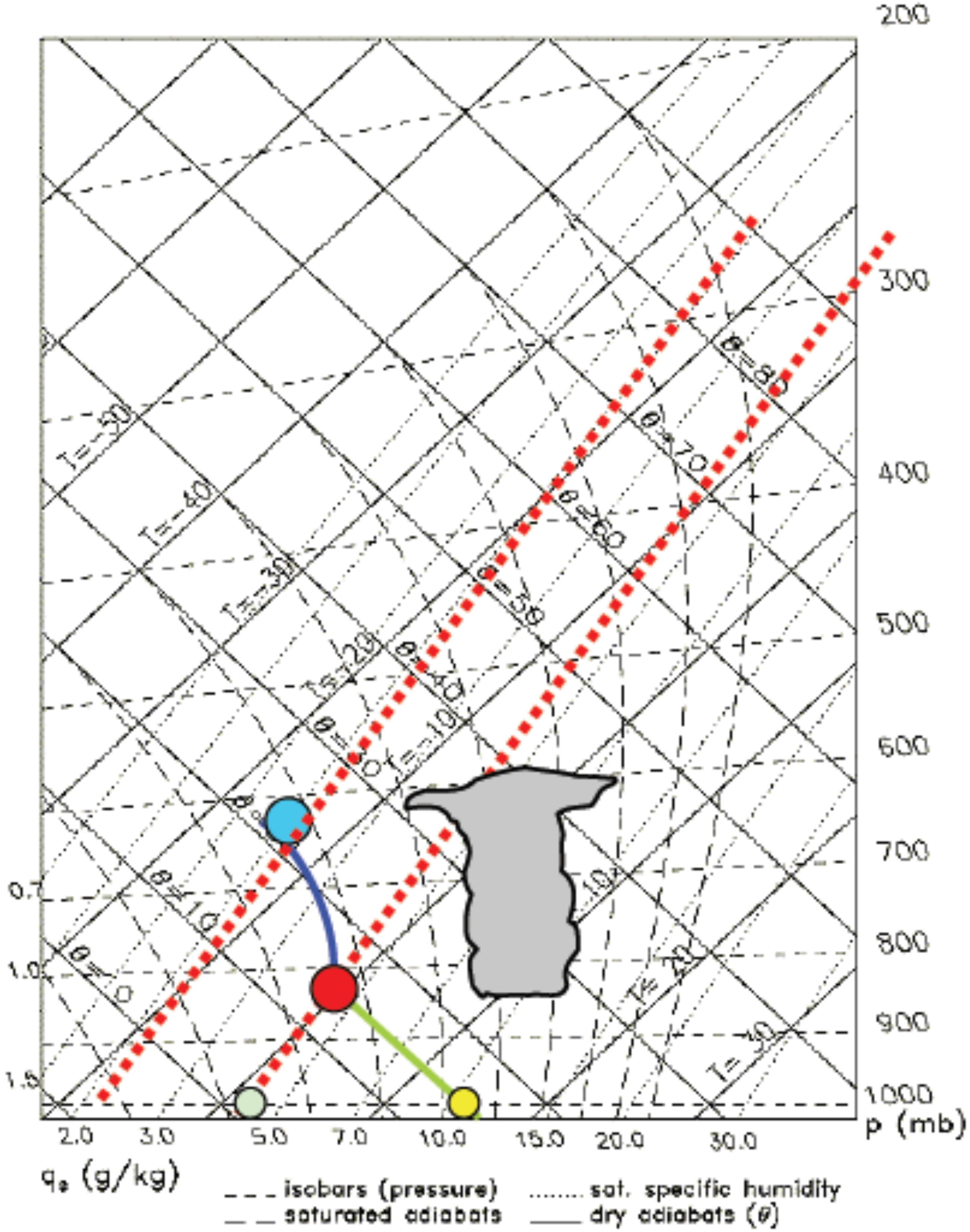
$$LWC = \int_0^\infty \rho n(r) \frac{4}{3}\pi r^3 dr$$



Cloud thickness

$$\tau_c = \frac{3LWC \times \Delta z}{2\rho r_e}$$

Effective radius



<u>Exercise 3.9</u> *An air parcel w/ an initial T of 15 ^{0}C and T_d of 2 ^{0}C is lifted adiabatically from the 1000-hPa (mb) level.*

1) Determine its lifting condensation level (LCL).

2) If this air parcel is lifted a further 200 hPa above its LCL, <u>how much liquid water is condensed during this rise?</u>

1) ~ 840 hPa

2) 4.4 – 2.2 = 2.2 g/kg

↑

This is called adiabatic liquid water content (LWC)

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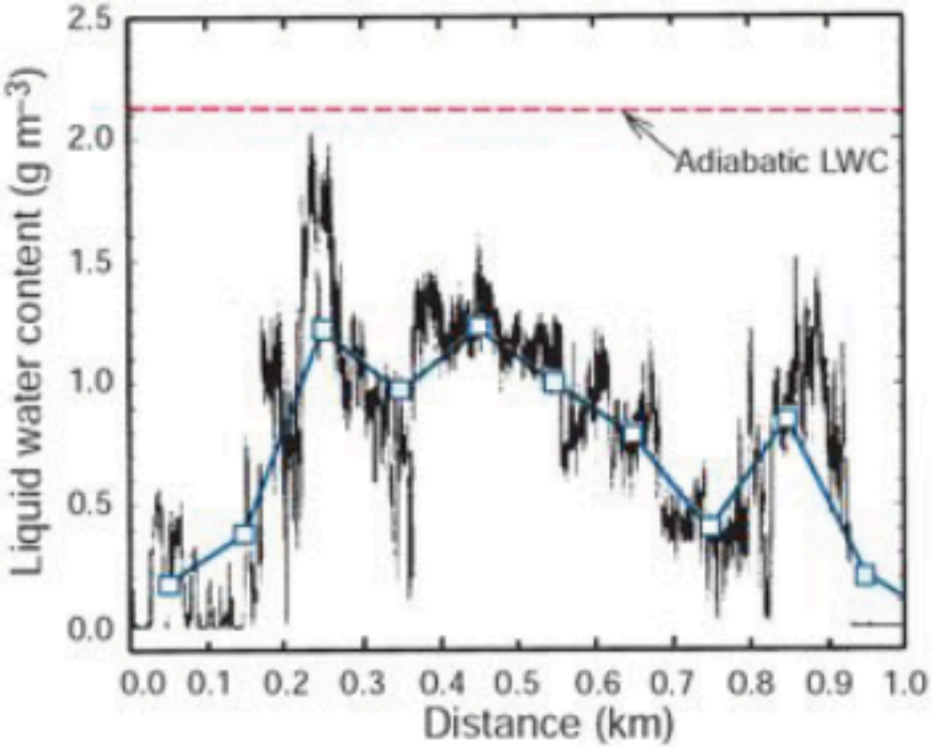

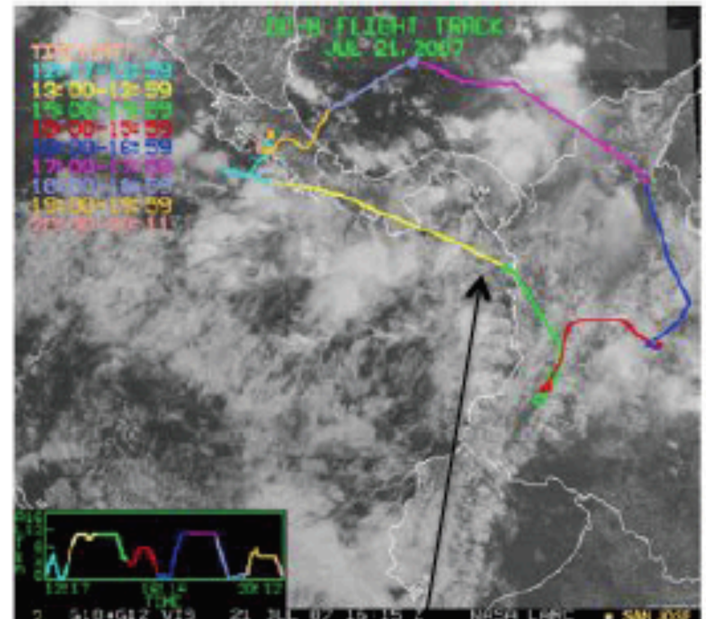

Adiabatic LWC:

LWC assuming entire volume that is occupied by the clouds is the liquid released using qSAT calculated from the temperature and pressure at the cloud base as compared to qSAT using T and p at each layer in the cloud.

Cloud Liquid Water Content and Entrainment

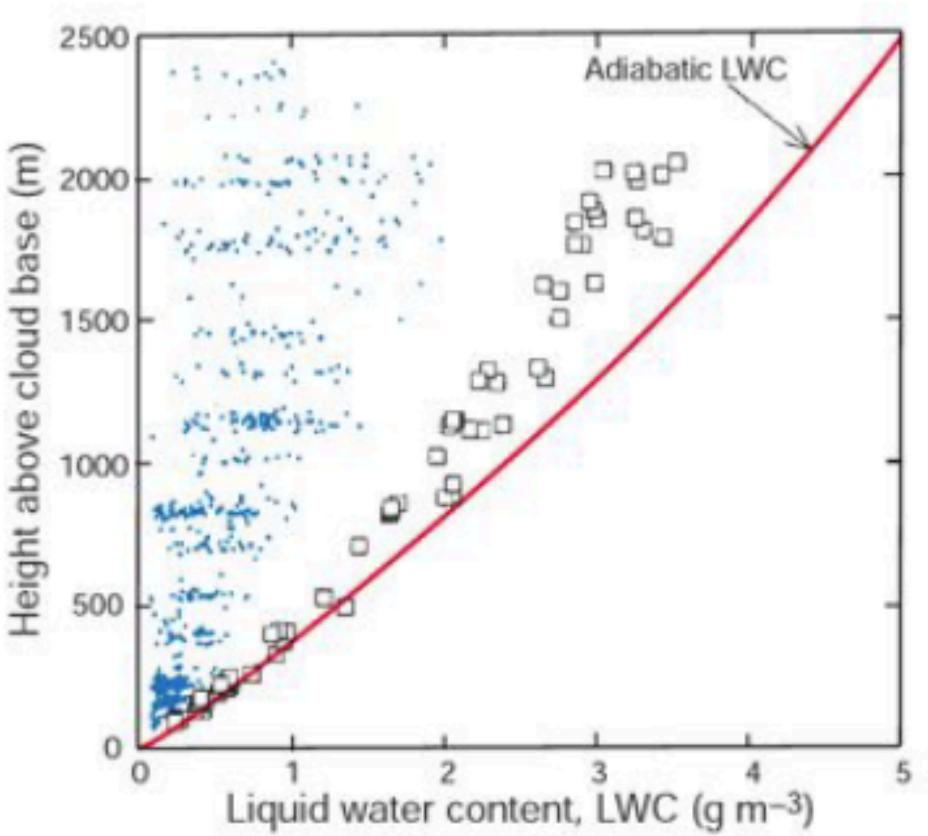

Fig. 6.11

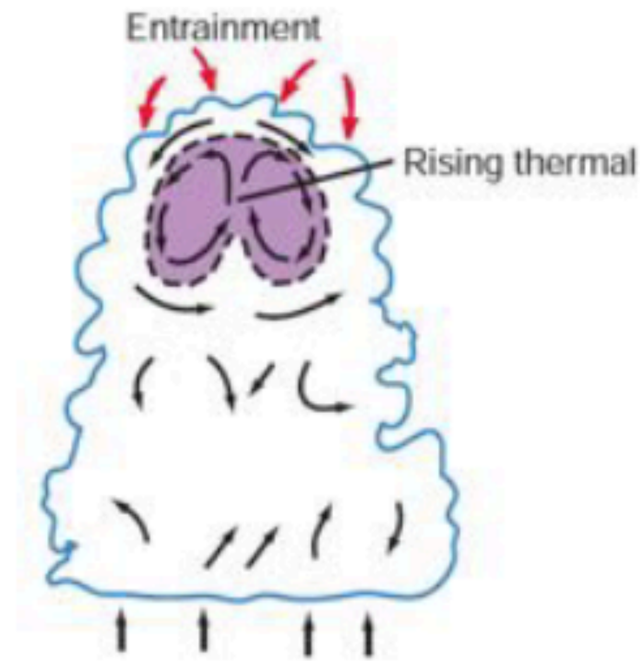

Fig. 6.12

Skip exercise 6.2

OUTLINE

1. Nucleation of water droplets (6.1)
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5. Microphysics of Ice Clouds (6.5)
6. Cloud Names, Lightning and Chemistry (6.7)

Growth of Water Droplets and Formation of Rain (6.4)

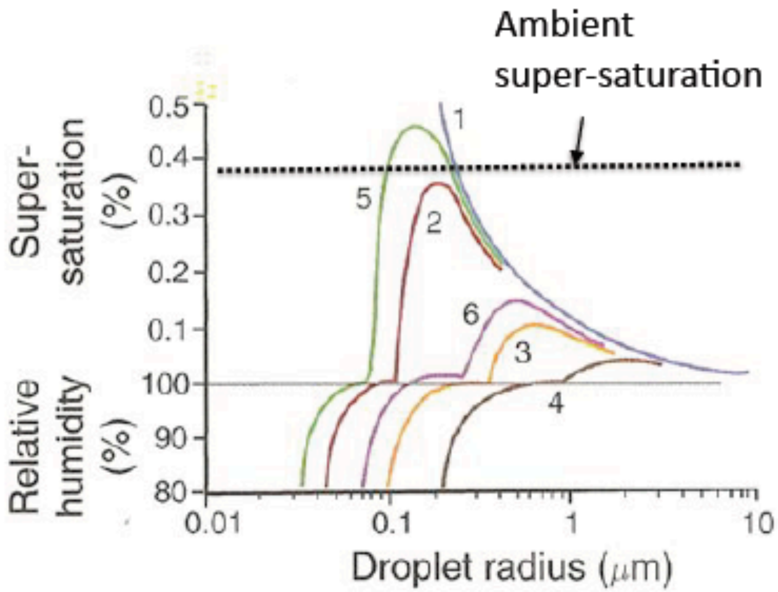
Two possible mechanisms for liquid precipitation (rain) formation:

1) Growth by condensation (i.e., within a rising air mass)

2) Growth by collision and coalescence with other cloud droplets

We will learn: (1) is too slow, so (2) is the dominant mechanism

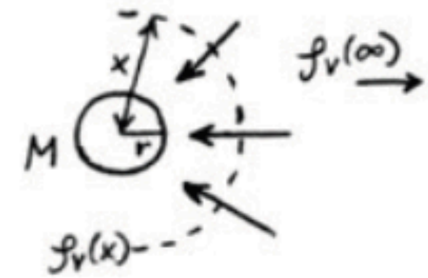
Condensation to form rain drops



Once a droplet passes over the peak in its Koehler curve or exceeds the critical radius, it will continue to grow (assuming enough vapor supply).

Now, we consider ***the rate at which a droplet grows***.

Growth by condensation

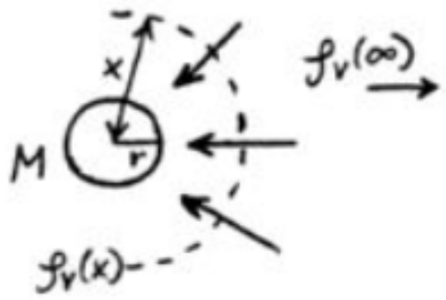


This is a ***diffusion problem***: assuming there is a vapor density gradient. The flux of water vapor across a sphere of radius x is :

$$4\pi x^2 D \frac{d\rho_v}{dx}$$

Diffusion coefficient

~~Condensation~~ to form rain drops



$$\frac{dM}{dt} = 4\pi x^2 D \frac{d\rho_v}{dx}$$

The rate of increase of droplet mass	=	The rate of flow of vapor across a spherical surface at x

See section 6.4.1 for full derivation

Droplet growth rate equation

$$\frac{dr}{dt} = \frac{1}{r} * \frac{D\rho_v(\infty)}{\rho_l} S \qquad \text{Eq. 6.21}$$

r: radius of the drop.
D: diffusion coefficient.
$\rho_v(\infty)$:water vapor. density of ambient air well removed from the droplet.
ρ_l : liquid water density.
S: supersaturation of the ambient air (as a fraction)

KEY: growth rate is inversely proportional to size, i.e., as rain drop gets bigger, growth gets slower

~~Condensation~~ vs. Collision and Coalescence

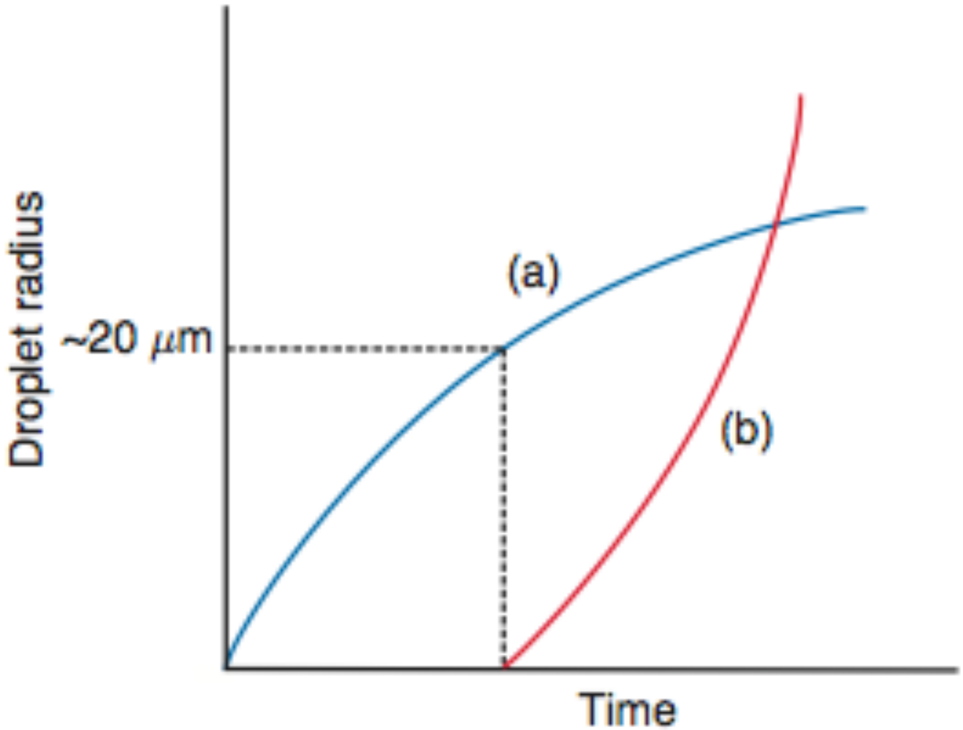


Fig. 6.15 Schematic curves of droplet growth (a) by condensation from the vapor phase (blue curve) and (b) by collection of droplets (red curve).

Collision and Coalescence to Form Rain Drops

General idea: a cloud droplet grows large enough to fall, then as it falls it accumulated mass by taking-on the cloud droplets that it runs into.

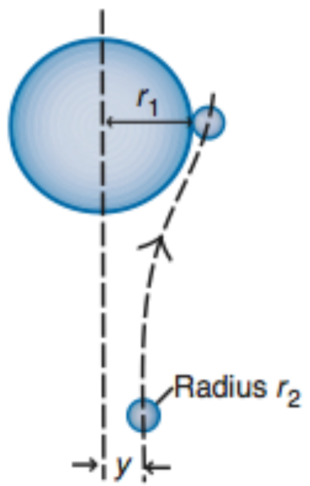


Fig. 6.19 Relative motion of a small droplet with respect to a collector drop. y is the maximum impact parameter for a droplet of radius r_2 with a collector drop of radius r_1.

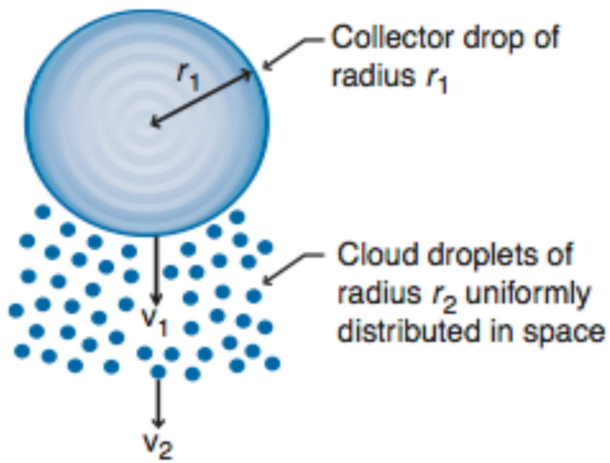
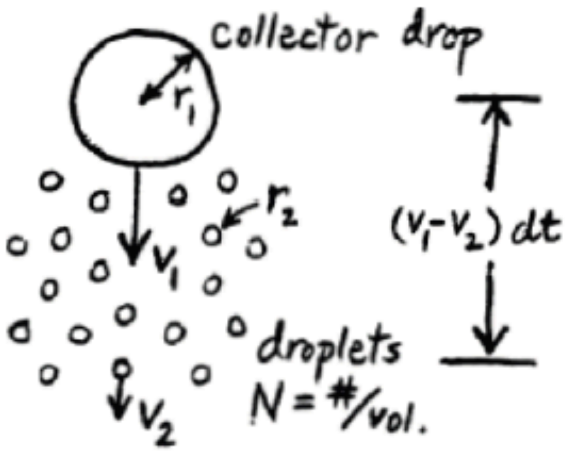


Fig. 6.23 Schematic illustrating the continuous collection model for the growth of a cloud drop by collisions and coalescence.

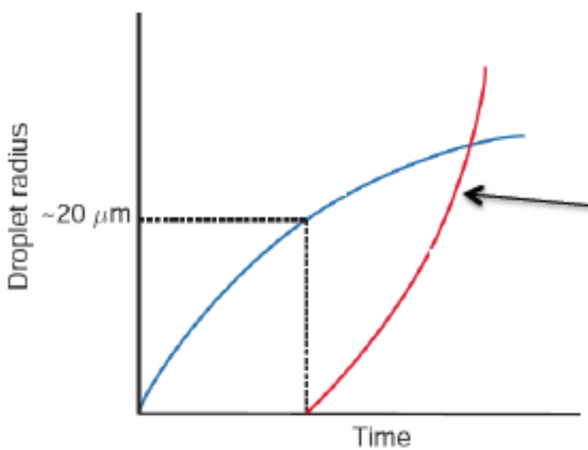
Collision and Coalescence to Form Rain Drops

See box 6.2 on page 224 if you are curious about terminal velocity.



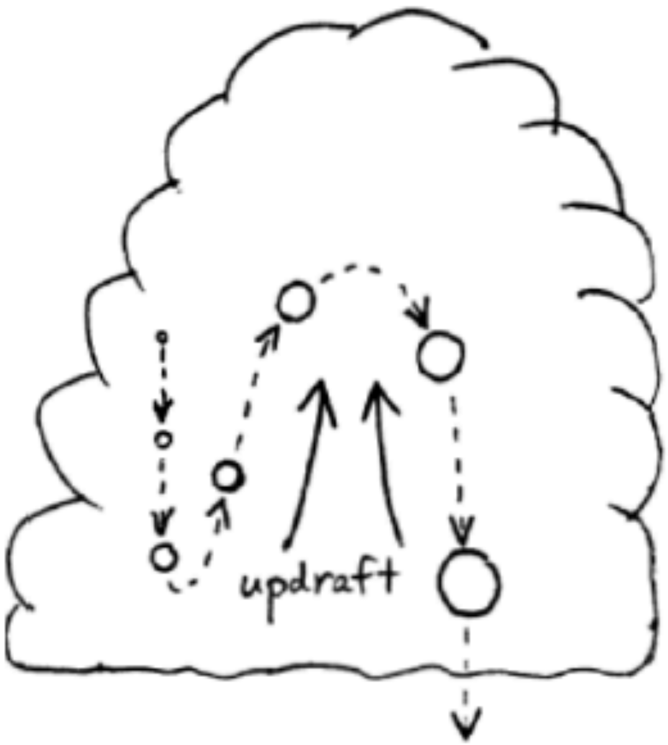
$$\frac{dr_1}{dt} = \frac{1}{18}\frac{g w_l E}{\eta} r_1^2$$

- g : *gravity*
- w_l : *LWC* $(kg\ m^{-3})$
- E : *collection* efficiency
- η: viscosity of the air.
- r_1 : radius of cloud droplet



The growth rate (dr/dt) is proportional to r^2, meaning bigger droplets grow faster (the red curve).

Collision and Coalescence to Form Rain Drops



Strong updrafts make the droplets spend more time inside the cloud to grow even bigger.

Skip section 6.4.3