Cloud Thermodynamics and Dynamics

Fog and Droplet Temperature

Fog

Cloud Touching the Ground

Radiation Fog

Forms as the ground cools radiatively at night, cooling the air above it to below the dew point.

Advection Fog

Forms when warm, moist air moves over a colder surface and cools to below the dew point.

Upslope Fog

Forms when warm, moist air flows up a slope, expands, and cools to below the dew point.

Fog

Evaporation Fog

Forms when water evaporates in warm, moist air, then mixes with cooler, drier air and re-condenses.

- *Steam Fog*

  Occurs when warm surface water evaporates, rises into cooler air, and recondenses, giving the appearance of rising steam.

- *Frontal Fog*

  Occurs when water from warm raindrops evaporates as the drops fall into a cold air mass. The water then recondenses to form a fog. Warm over cold air appears ahead of an approaching surface front.

Cloud Microphysics

Assume clouds form on multiple aerosol particle size distributions
Each aerosol distribution consists of multiple discrete size bins
Each size bin contains multiple chemical components
Three cloud hydrometeor distributions can form
- Liquid
- Ice
- Graupel

Each hydrometeor distribution contains multiple size bins.
Each size bin contains the chemical components of the aerosol distribution it originated from

Cloud Microphysics

Processes Considered

- Condensation/evaporation
- Ice deposition/sublimation
- Hydrometeor-hydrometeor Coagulation
- Large Liquid Drop Breakup
- Contact Freezing of Liquid Drops
- Homogeneous/heterogeneous Freezing
- **Drop Surface Temperature**
- Subcloud Evaporation
- Evaporative Freezing
- Ice Crystal Melting
- Hydrometeor-aerosol Coagulation
- Gas Washout
- Lightning

Drop Surface Temperature

Iterate for drop surface temperature at sub-100 percent RH

Subscript n is the Iteration Number.

$T_{s,n}$ - Drop surface temperature (K)

Ambient Temperature - T_a (K)

$p_{s,n}$ - Constants over Drop Surface

$\Delta p_{v,n}$ - Change in Water Vapor Partial Pressure

$p_{f,n}$ - Water Vapor Partial Pressure

$T_{f,n}$ – Temp. between Drop and air

D_v - Diffusion coefficient of water vapor

L_e - Latent Heat of Evaporation (J g^{-1})

κ_a - Thermal Conductivity Moist Air (J cm^{-1} s^{-1} K^{-1}),

R_v - Gas Constant for Water Vapor (4614 cm^3 hPa g^{-1} K^{-1})

p_a - Ambient Air Pressure (hPa)

0.3 - Ensure Convergence

$$p_{s,n} = p_{v,s}(T_{s,n})$$

$$\Delta p_{v,n} = 0.3(p_{s,n} - p_{v,n})$$

$$p_{f,n} = 0.5(p_{s,n} + p_{v,n})$$

$$T_{f,n} = 0.5(T_{s,n} + T_a)$$

$$T_{s,n+1} = T_{s,n} - \frac{D_v L_e}{\kappa_a(1 - p_{f,n}/p_a)} \frac{\Delta p_{v,n}}{R_v T_{f,n}}$$

$$p_{v,n+1} = p_{v,n} + \Delta p_{v,n} \qquad (18.72)$$

Drop Surface Temperature vs. RH

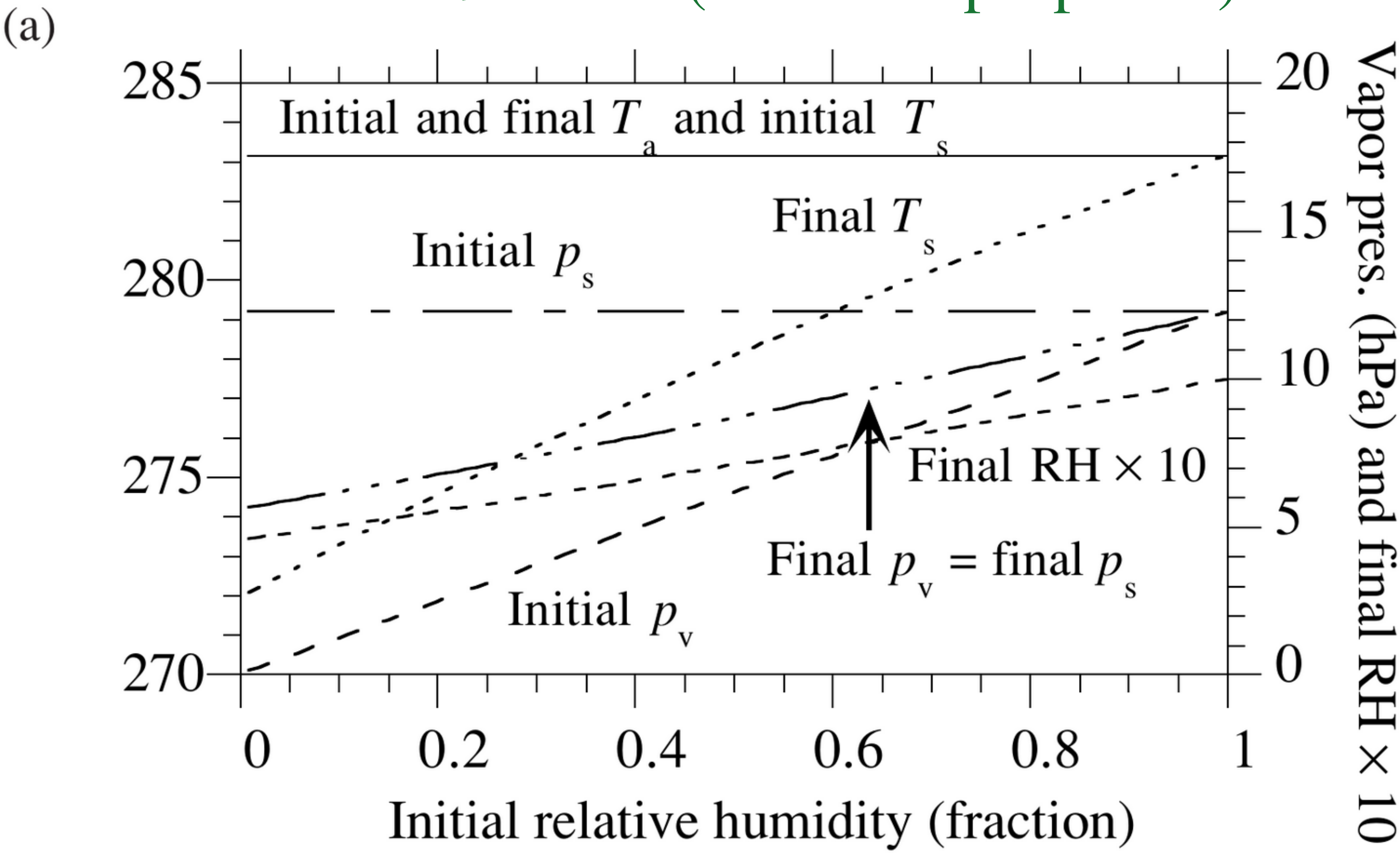
Figure 18.10 shows the variation in equilibrium drop surface temperature and other parameters for initial relative humidities of 1 to 100 percent under (a) lower-(b) mid- and (c) upper-tropospheric conditions. The figure shows that, under lower-tropospheric conditions (Fig. 18.10(a)), drop surface temperatures can decrease by as much as 10 K when RH = 1 percent. At RH = 80 percent, which is more typical below a cloud, the temperature depression is close to 2 K. Under mid-tropospheric conditions (Fig. 18.10(b)), supercooled drop temperatures can decrease by as much as 2.2 K when RH = 1 percent or 1 K when RH = 50 percent. Under upper-tropospheric conditions (Fig. 18.10(c)), the maximum temperature depression is about 0.5 K.

Drop Surface Temperature vs. RH

Air Temperature = 283.15 K

Pressure = 900 hPa (Lower-tropospheric)

Fig. 18.10a

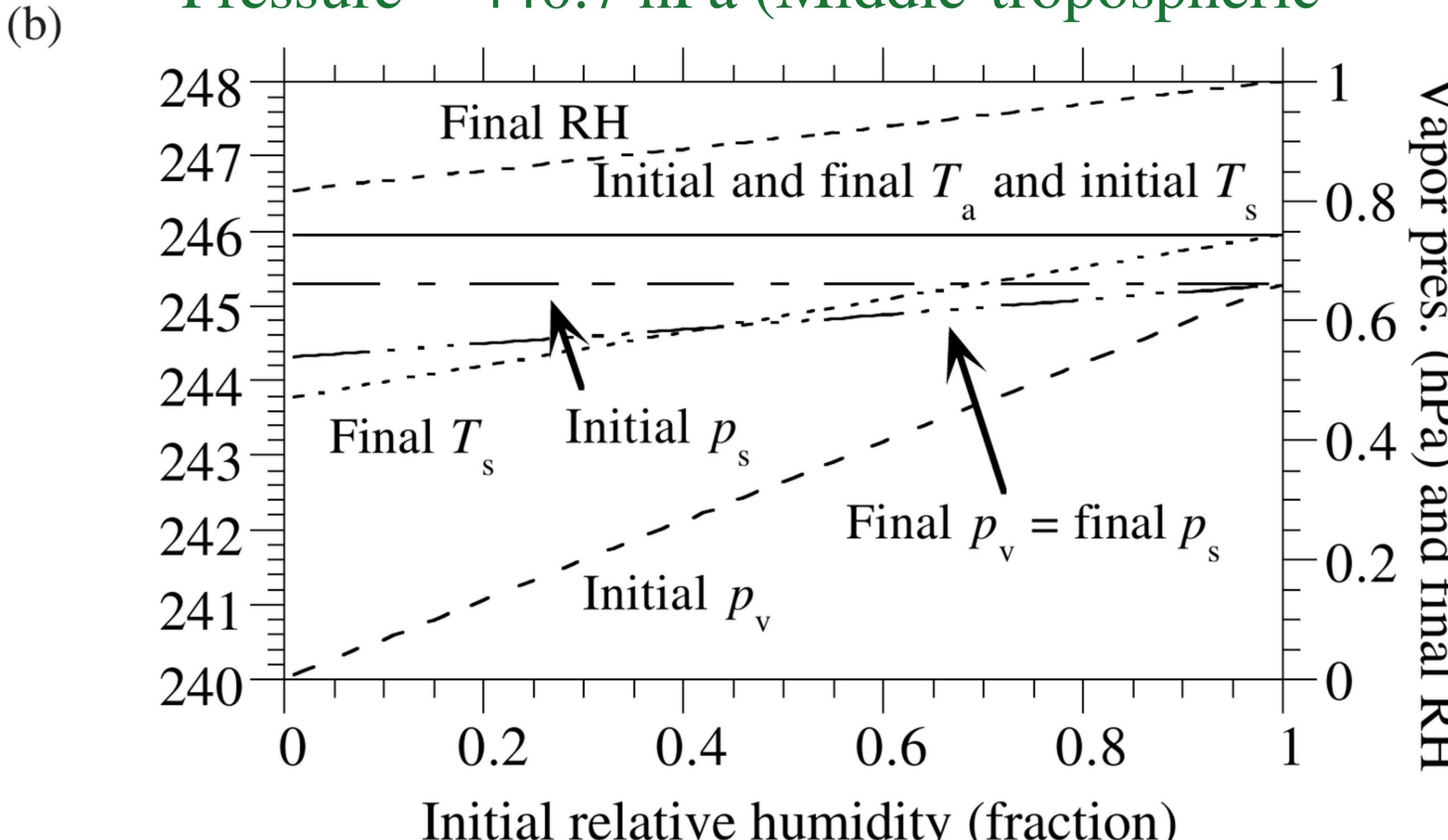


Drop Surface Temperature vs. RH

Air Temperature = 245.94 K

Fig. 18.10b

Pressure = 440.7 hPa (Middle-tropospheric

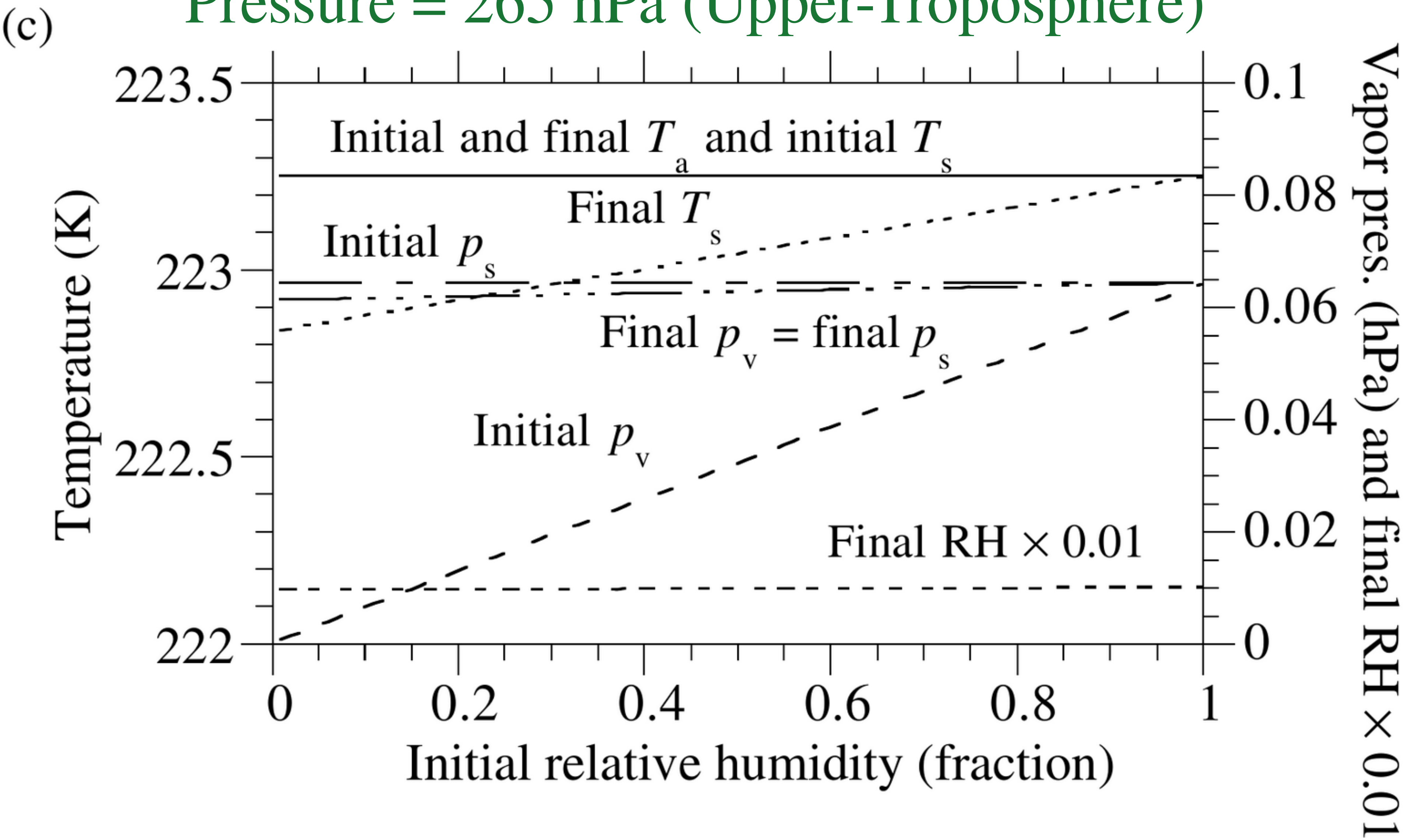


Drop Surface Temperature vs. RH

Air Temperature = 223.25 K

Pressure = 265 hPa (Upper-Troposphere)

Fig. 18.10c



Evaporative Freezing

When drops fall into regions of sub-100 percent RH below cloud base, they start to evaporate and cool. If the temperature is below the freezing temperature, the cooling increases the rate of drop freezing.

Incremental homogeneous/heterogeneous freezing due to evaporative cooling below a cloud base

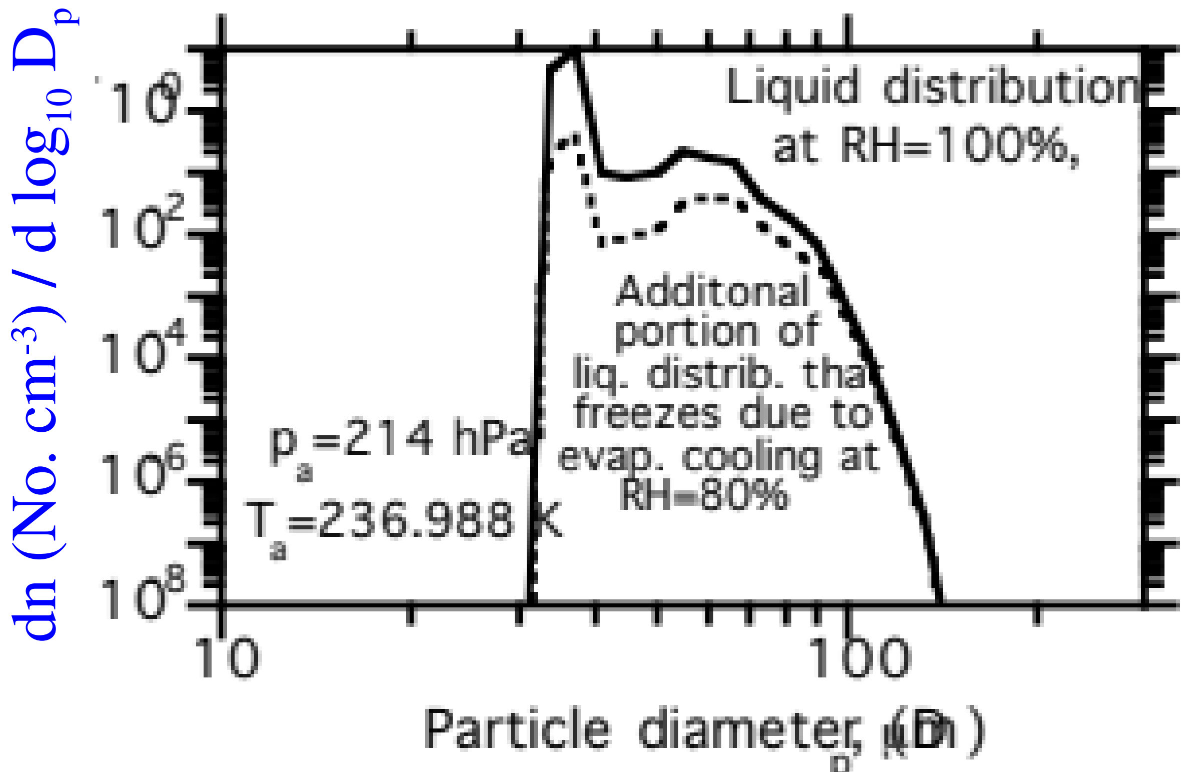


Fig. 18.12

Evaporation

Reduction in volume due to evaporation/sublimation (18.73)

$$v_{L,lq,k,t,m} = \mathrm{MAX}\left[v_{L,lq,k,t-h} - \frac{n_{lq,k} 4\pi r_k D_v}{\left(1 - p_{f,nf}/p_a\right)} \frac{\left(p_{v,s,0} - p_{v,nf}\right)}{\rho_L R_v T_{f,nf}} \frac{\Delta z}{V_{f,lq,k}}, 0 \right]_m$$

Reduction in precipitation size due to evaporation below cloud base

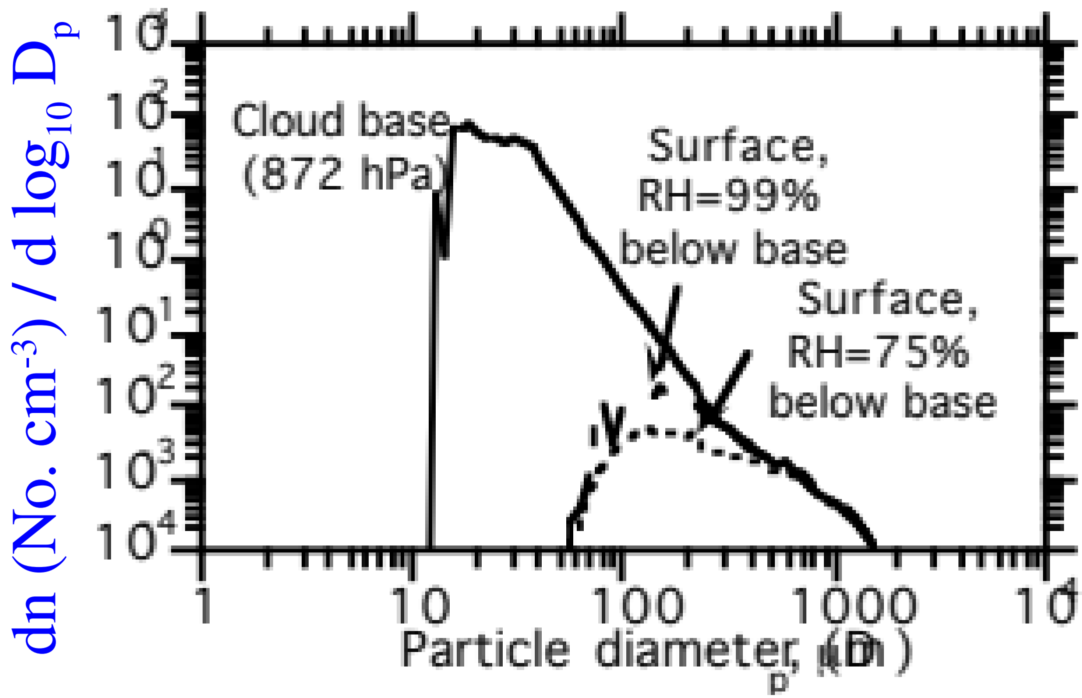


Fig. 18.11