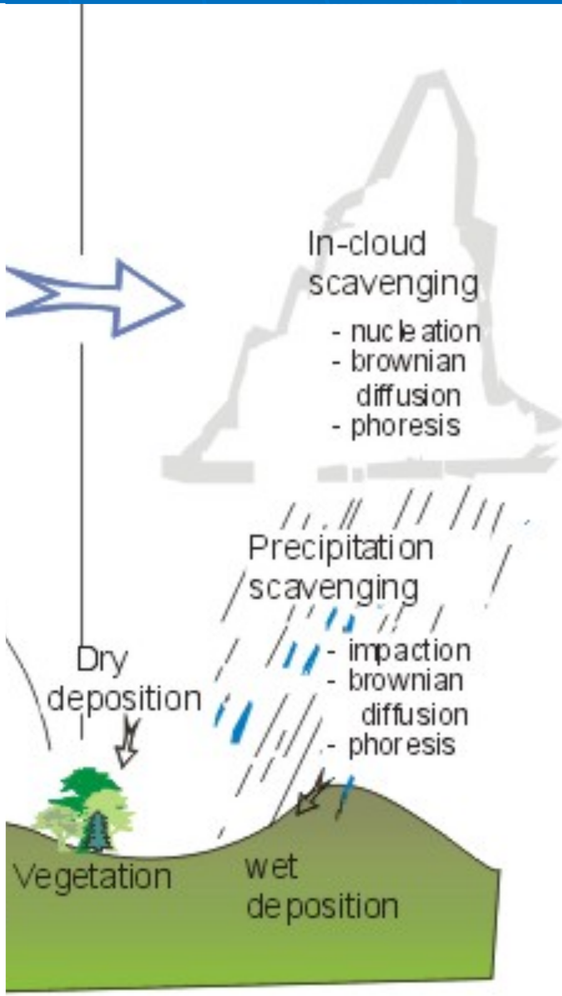
Removals

Types of removals

Dry deposition: Transport of particles from the atmosphere onto surfaces when precipitation is not present



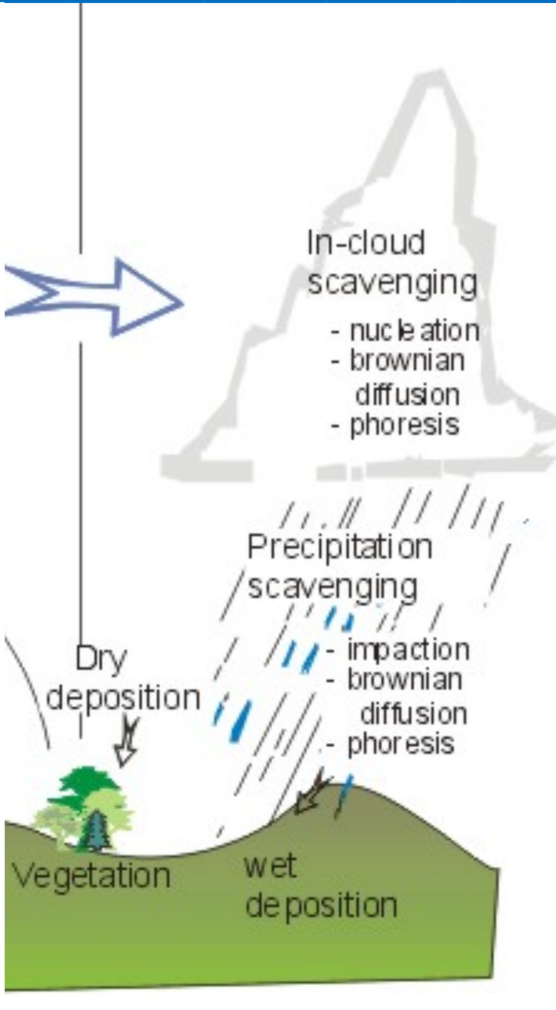
Types of removals

Dry deposition: Transport of particles from the atmosphere onto surfaces when precipitation is not present

Wet deposition: Process by which particles are removed by cloud (and fog) droplets, rain and snow and transported on Earth's surface;

divided in:
- In-cloud scavenging

- Below-cloud scavenging



Dry removal

- Not practical to implement a formulation of all microphysical processes that lead particles from the atmosphere to the surface

Dry removal

- Not practical to implement a formulation of all microphysical processes that lead particles from the atmosphere to the surface
- Most used formulation

$$F = -v_d C$$

F= dry deposition flux; v_d deposition velocity; C concentration

Dry removal

$$F = -v_d C$$

F= dry deposition flux; v_d deposition velocity; C concentration

F = material deposited per unit of surface and time

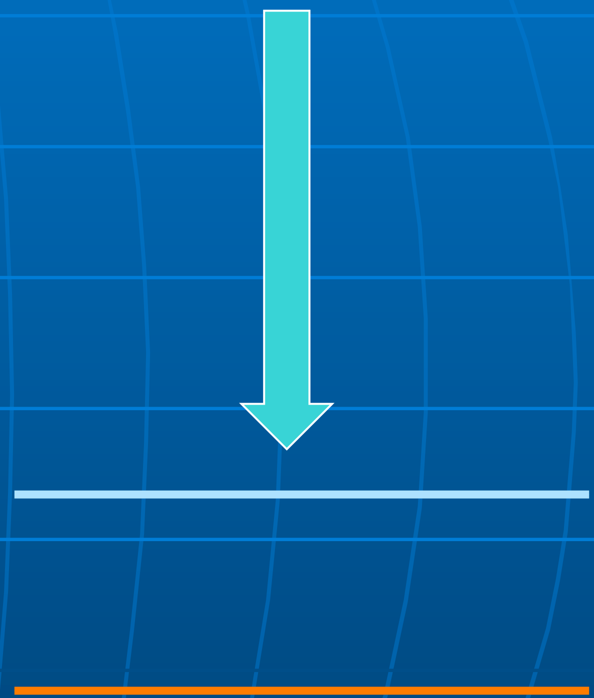
C is given a certain height and v_d as well

Advantages!
All processes are represented with v_d

Disadvantages!
It is difficult to correctly represent all processes with v_d

Dry deposition: 3 step process

- Aerodynamic transport through the surface layer

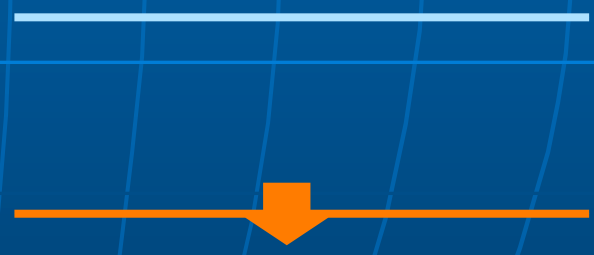


Dry deposition: 3 step process

- Brownian transport through stagnant *quasi-laminar sublayer*

Dry deposition: 3 step process

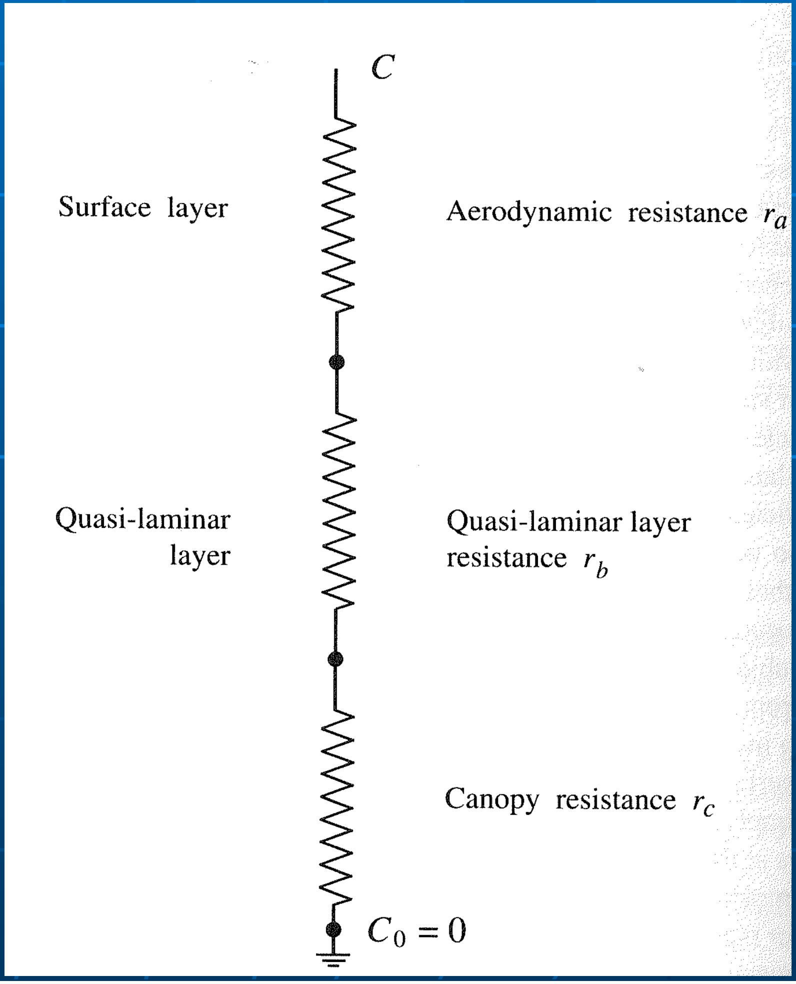
- Uptake at the surface



Resistant model for dry dep.

- In analogy with electrical resistance:

$$v_d^{-1} = r_t = r_a + r_b + r_c$$



Resistant model for dry dep.

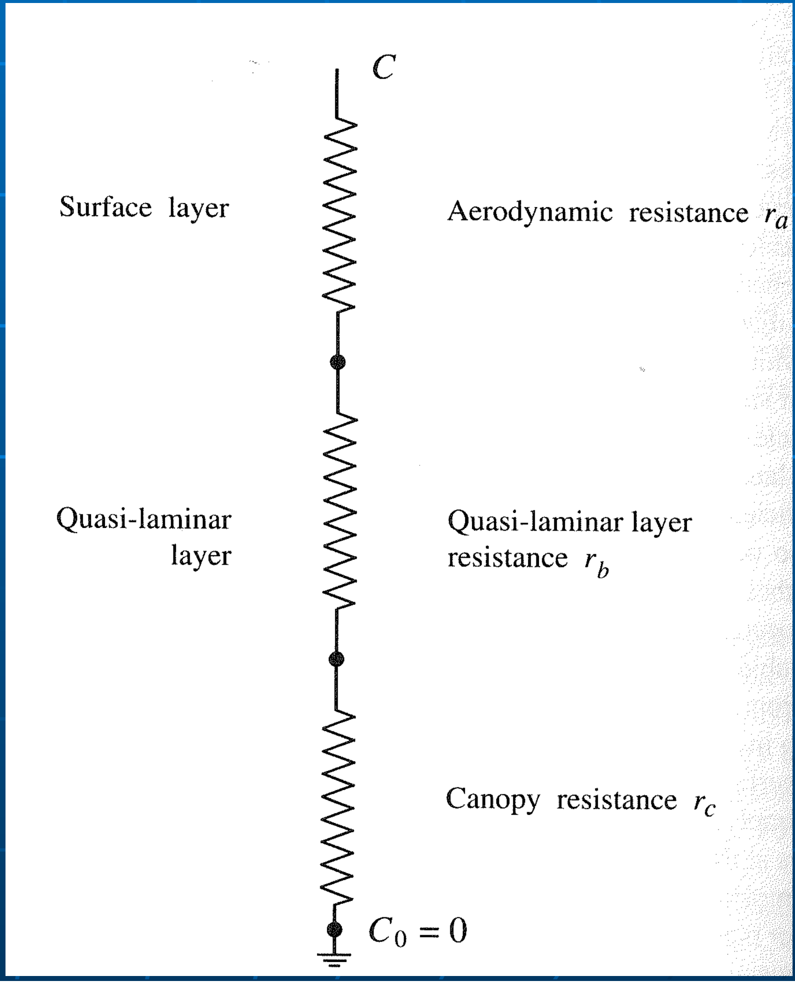
- In analogy with electrical resistance:

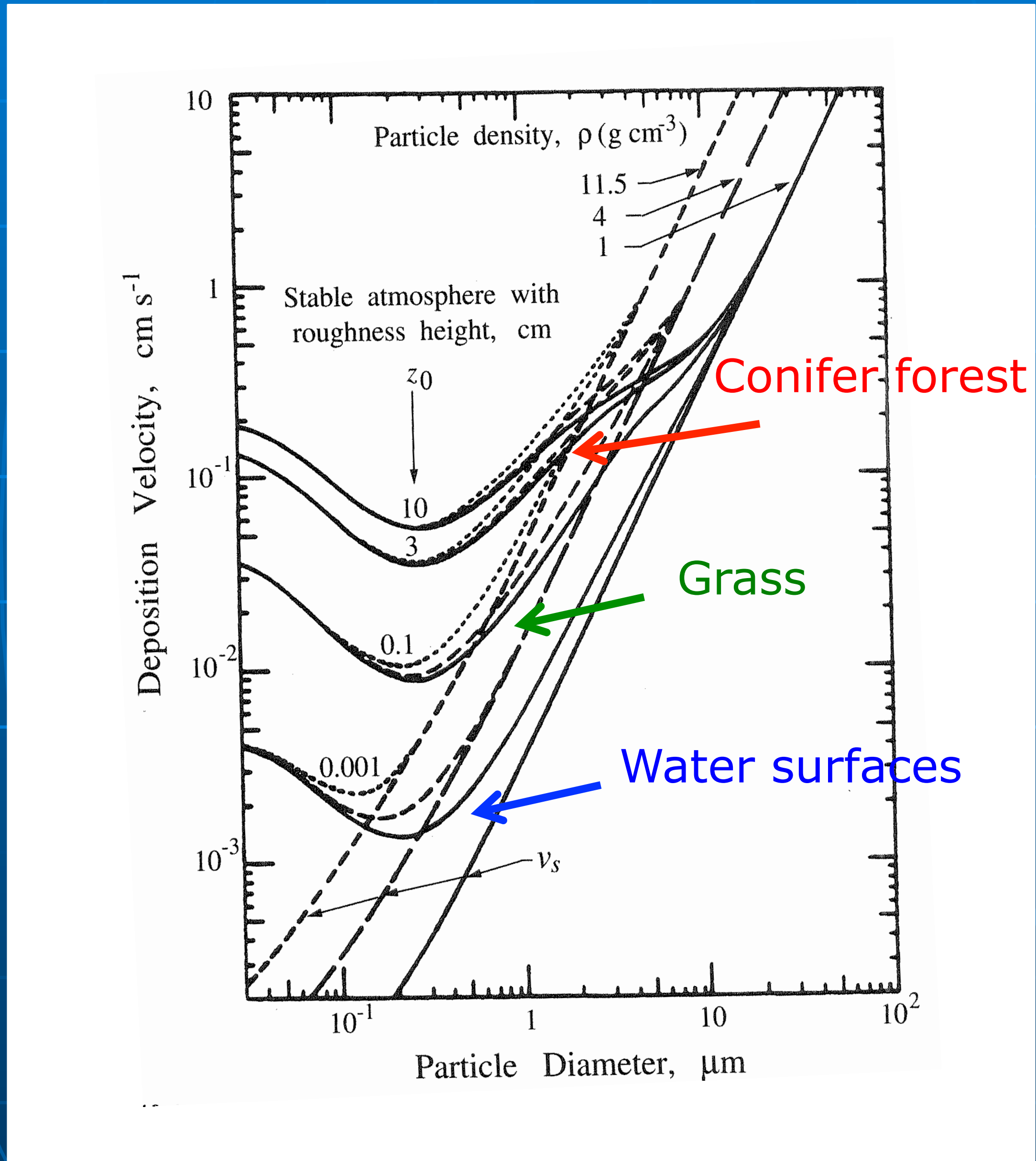
$$v_d^{-1} = r_t = r_a + r_b + r_c$$

$$v_d = \frac{1}{r_a + r_b + r_c} + v_s$$

v_s = particle settling velocity

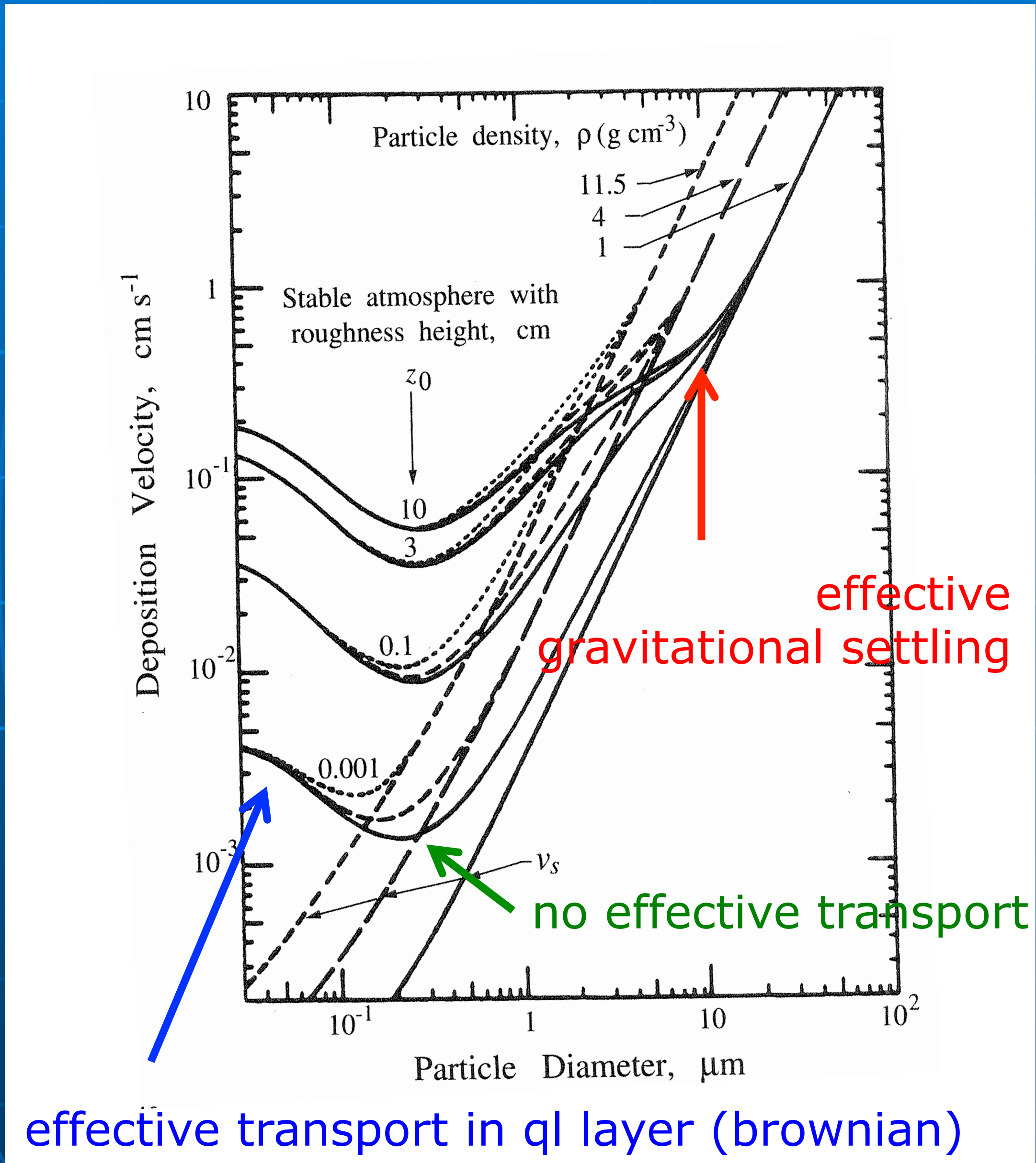
WARNING!!!!





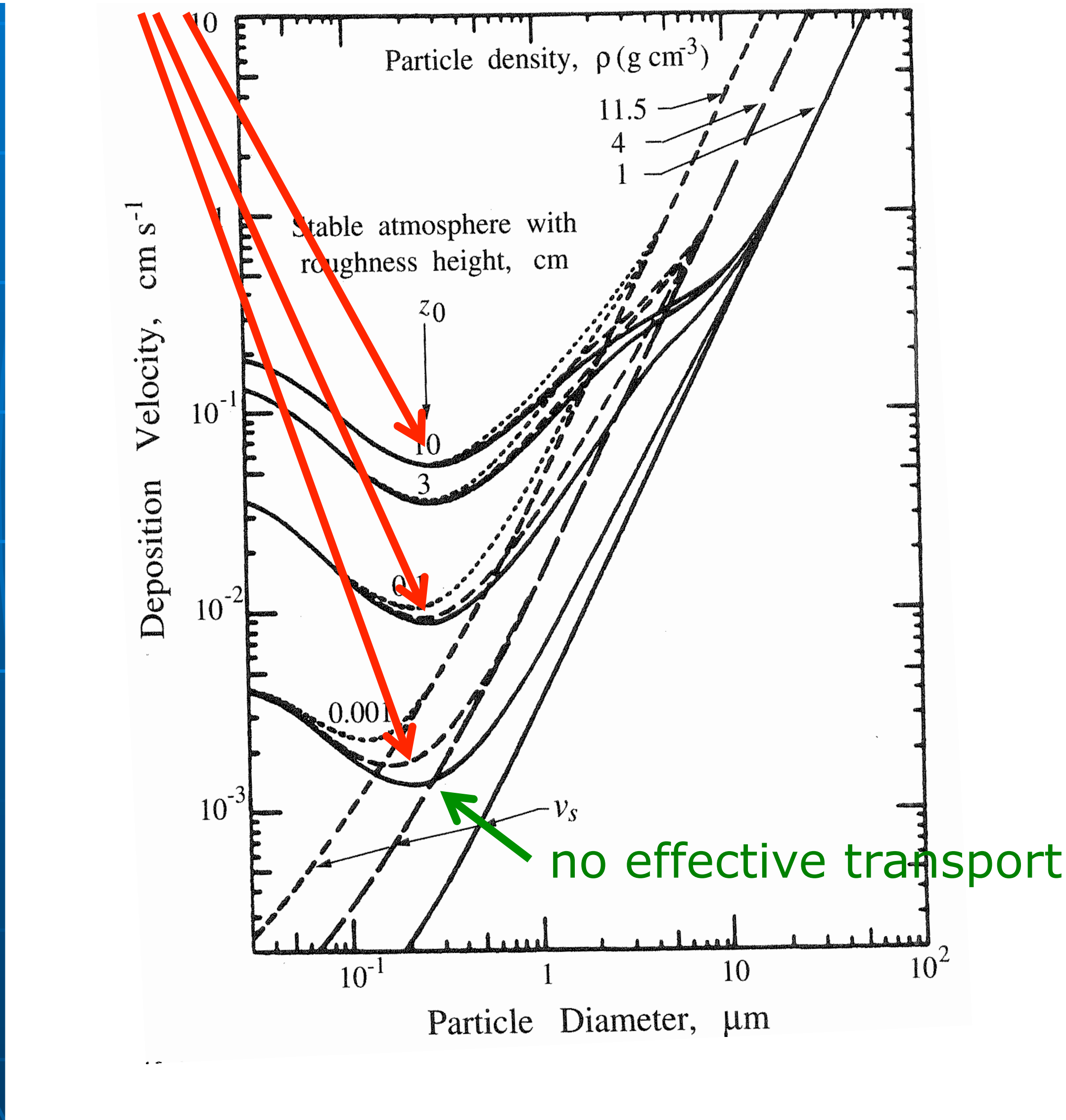
Particle density, ρ (g cm^{-3})
11.5
4
1
Stable atmosphere with roughness height, cm
z_0
10
3
0.1
0.001
v_s
Deposition Velocity, cm s^{-1}
Particle Diameter, µm
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-1}
1
10
10^{2}
Conifer forest
Grass
Water surfaces

Sehmel, 1980


Particle density, ρ (g cm⁻³)
11.5
4
1
Stable atmosphere with roughness height, cm
z0
10
3
0.1
0.001
vs
Deposition Velocity, cm s-1
10
1
10-1
10-2
10-3
10-1
1
10
102
Particle Diameter, µm
effective gravitational settling
no effective transport
effective transport in ql layer (brownian)

Sehmel, 1980

WARNING: in models with aerosols modelled only on mass basis, particles are assumed to be in this size range, probably underestimating particle dry deposition



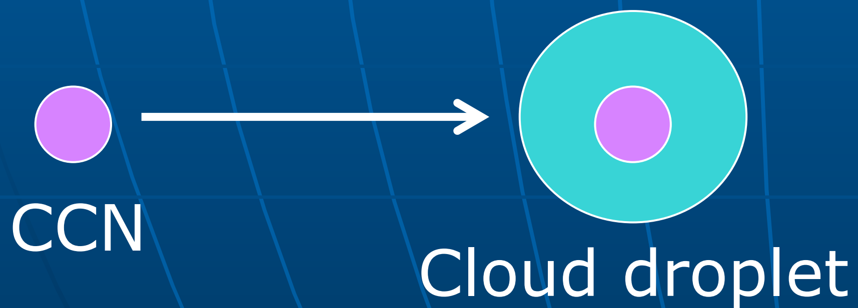
Sehmel, 1980

Wet removal

- One of the most complex process to model; for aerosols is the most uncertain:
  - various phases (aerosol, aqueous, cloudwater, rain, snow, ice cristal,…)
  - aerosol particles, cloud droplets, rain droplets, with their size distributions
  - clouds are a sub-grid scale phenomena
  - processes are reversible: cloud droplets may evaporate and release the particle

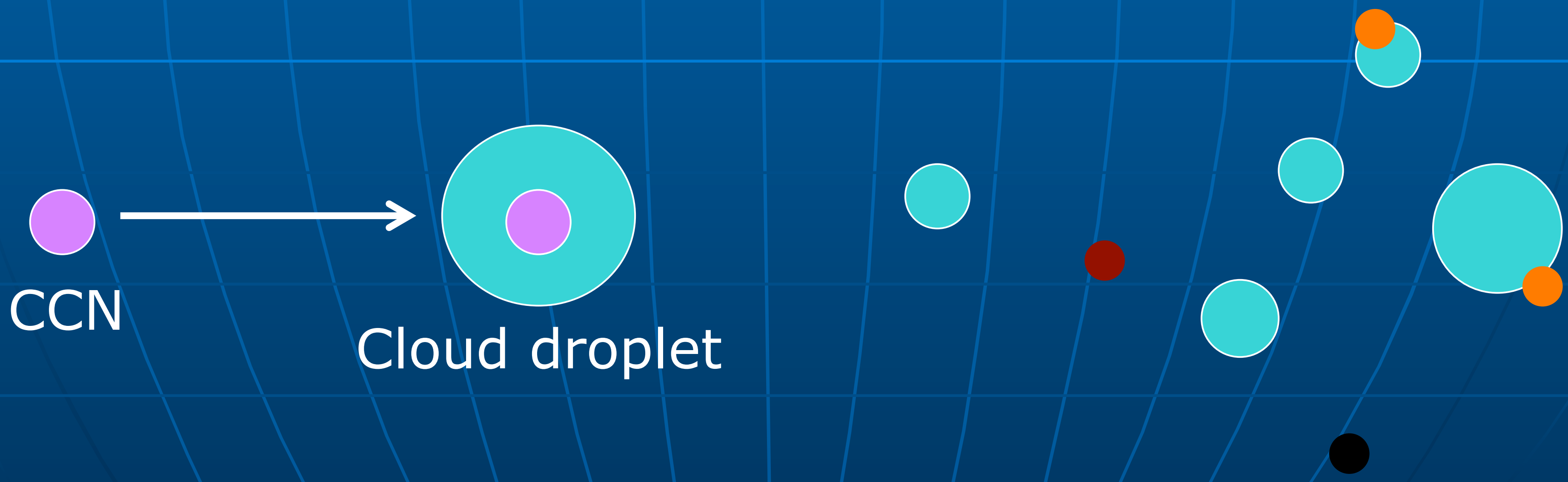
In-cloud scavenging

- Particles can be incorporated into cloud droplets (and rain droplets) inside a cloud by
  - Homogeneous nucleation



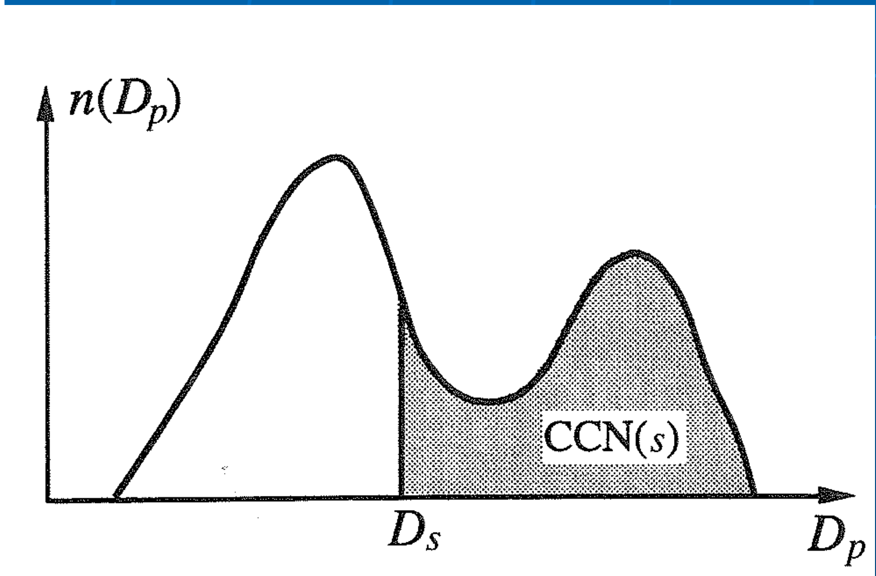
In-cloud scavenging

- Particles can be incorporated into cloud droplets (and rain droplets) inside a cloud by
  - Homogeneous nucleation
  - collection



Most of the models contain:

- Homogeneous nucleation from a CCN prescribed population!!!

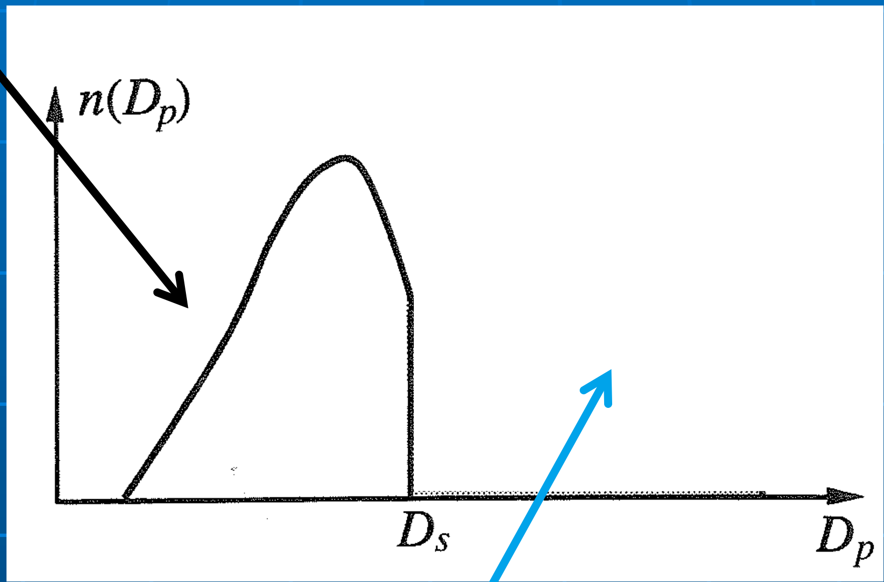


Fixing saturation ratio for clouds
-stratiform
-convective

- or using fixed CCN empirical function (most common)
- derivation of activation diameter (sofisticated !!!)

If the cloud rains out (100%):

Surviving particles



All the activated particles are removed

Removal of particles in models:

Scavenging parameter R:

$$\frac{\Delta C}{\Delta t} \propto R, f_{cl}, C, \ldots\ldots$$

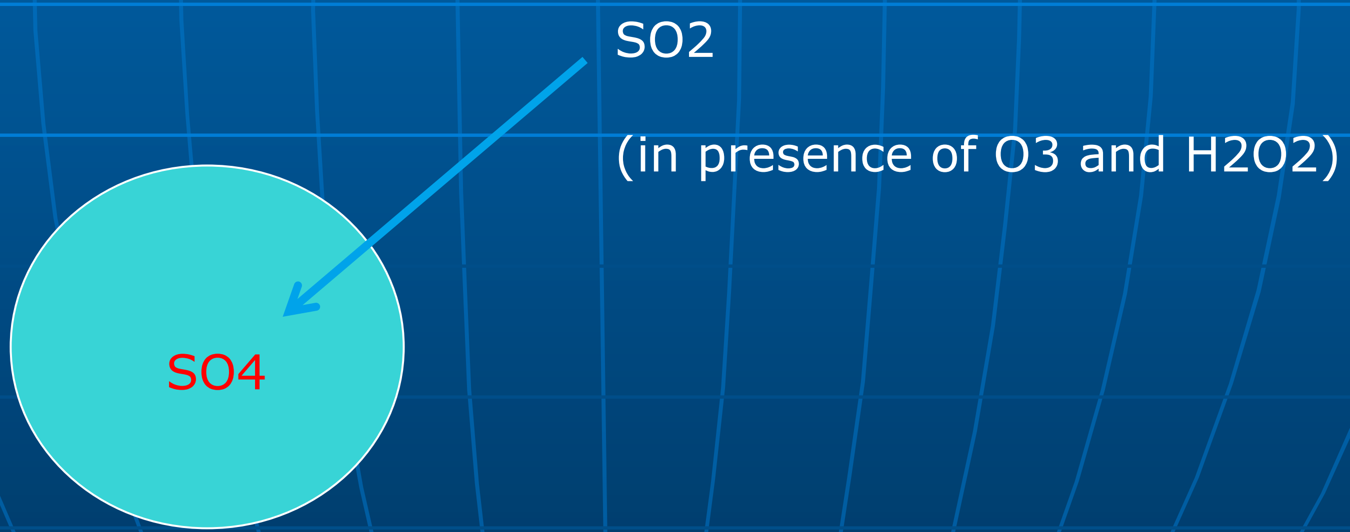
C = aerosol concentration; f_{cl} = fraction of clouds

Mode	**Stratiform** Liquid Clouds	**Stratiform** Mixed Clouds	**Stratiform** Ice clouds	**Convective** Mixed Clouds
Nucleation Soluble	0.10	0.10	0.10	0.20
Aitken Soluble	0.25	0.40	0.10	0.60
Accumulation Soluble	0.85	0.75	0.10	0.99
Coarse Soluble	0.99	0.75	0.10	0.99
Aitken Insoluble	0.20	0.10	0.10	0.20
Accumulation Insoluble	0.40	0.40	0.10	0.40
Coarse Insoluble	0.40	0.40	0.10	0.40

Table 3. Scavenging parameter R for the modes of HAM

If the cloud does not rain and evaporates instead?

- Taking into account that aqueous phase chemistry takes place on cloud droplets



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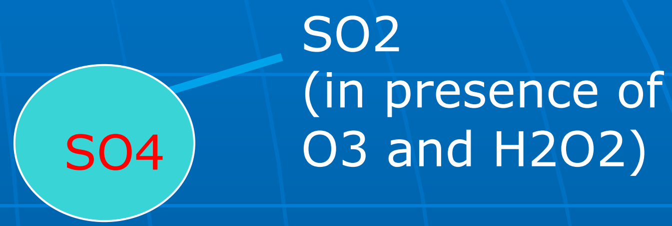

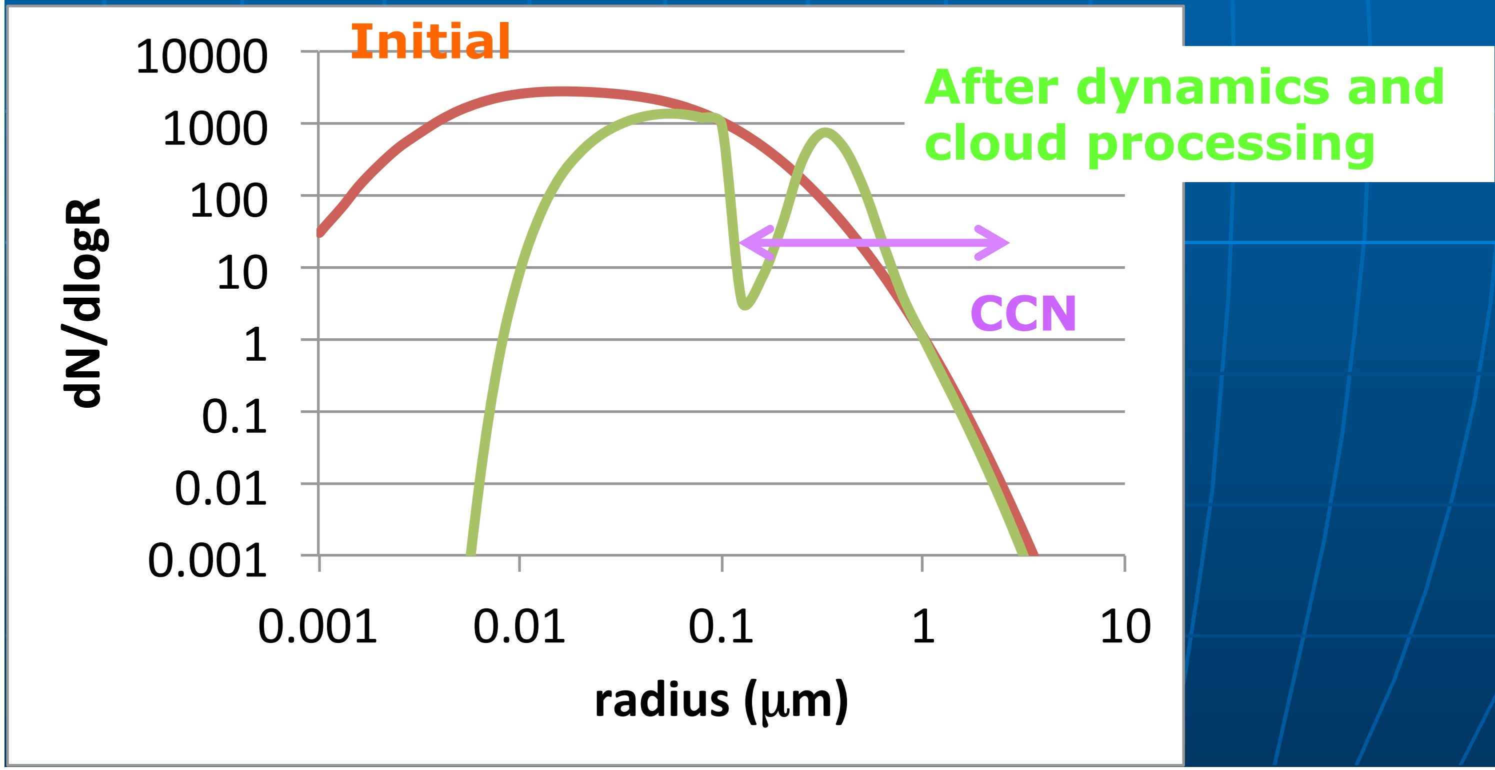

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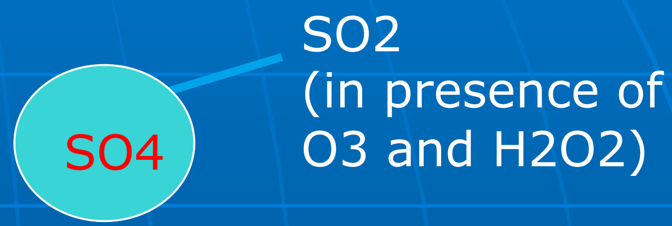
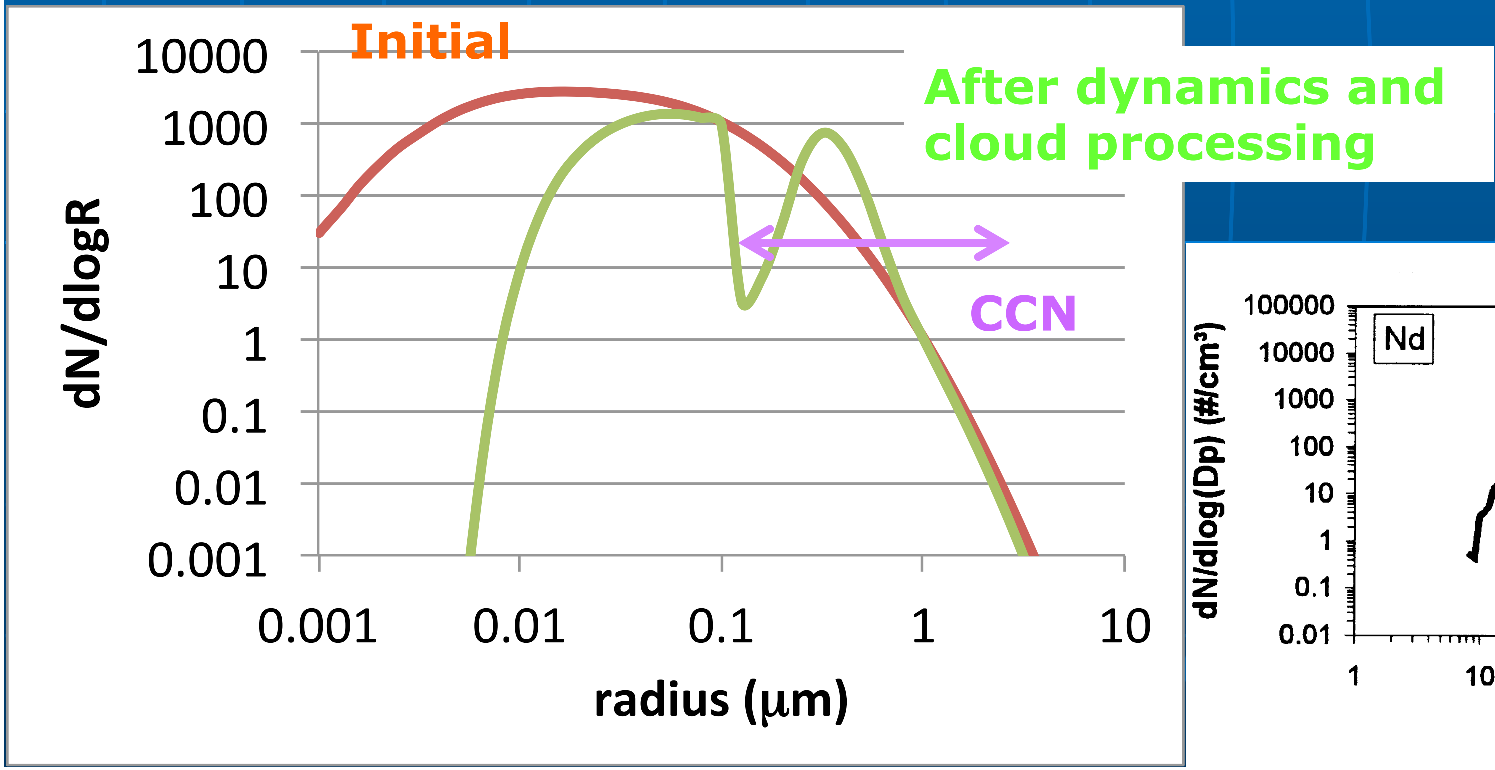
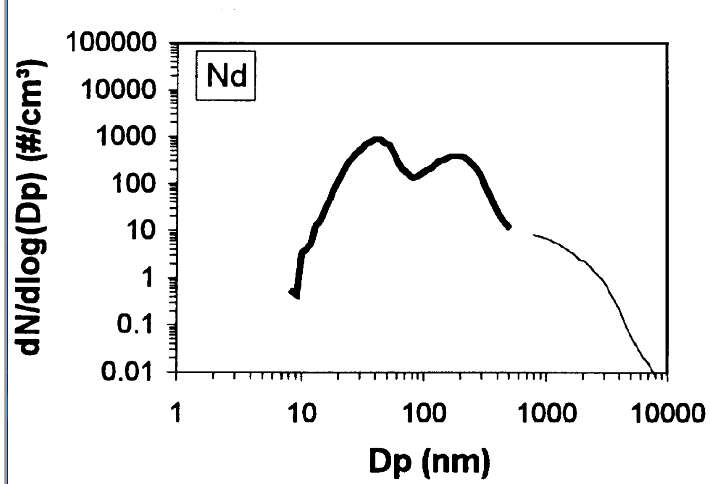


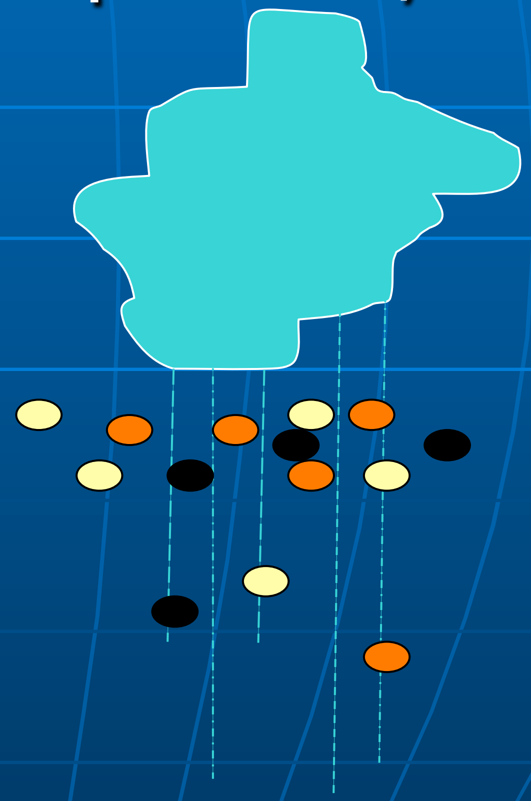


Measured



Below cloud scavenging

- Removal by precipitation of particles below cloud base by impaction, diffusion, ….

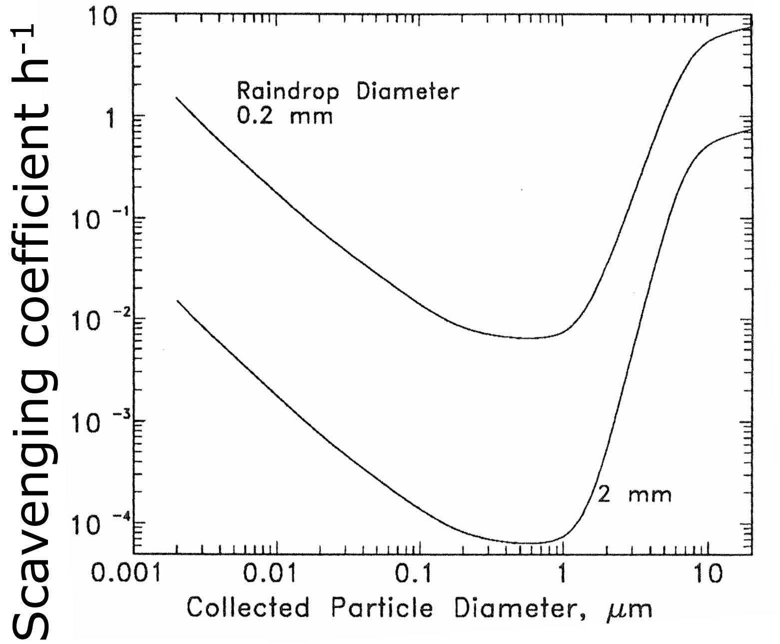


How do we model it?

$$\frac{\Delta C}{\Delta t} \propto R_r, R_s, f_{precipitation}, C, \ldots\ldots$$

C = aerosol concentration;
$f_{precipitation}$ = fraction of gridbox affected by precipitation;
R = scavenging efficiency for rain and snow

For rainfall intensity of 1 mm h^{-1}



Seinfeld and Pandis, 1998

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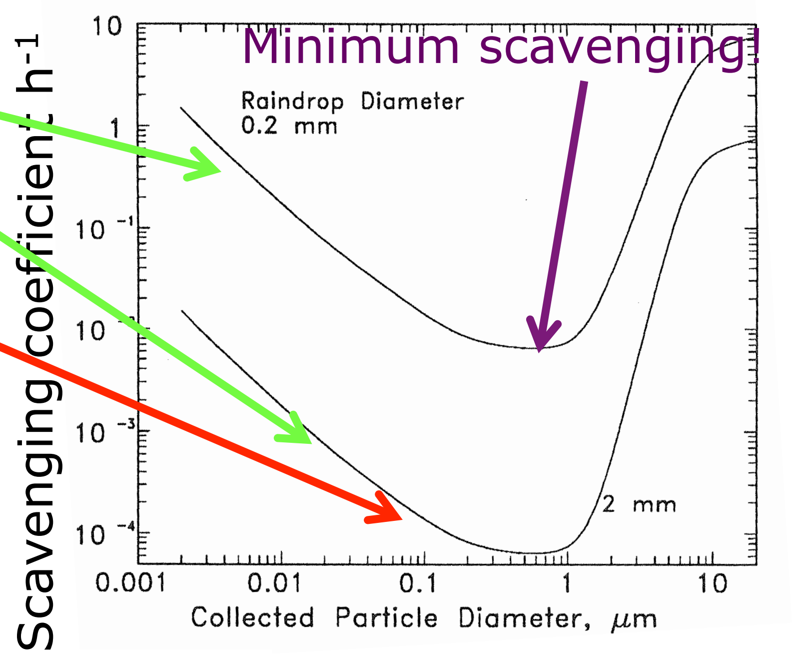
Rain droplet size distribution

Aerosol size distribution

For rainfall intensity of 1 mm h^{-1}



Seinfeld and Pandis, 1998

Cloud formation and growth

Conditions for a cloud to be formed

- Relative humidity has to exceed 100%; usually due to cooling of moist air parcel:

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Isobaric cooling

Colder land, water, colder air masses

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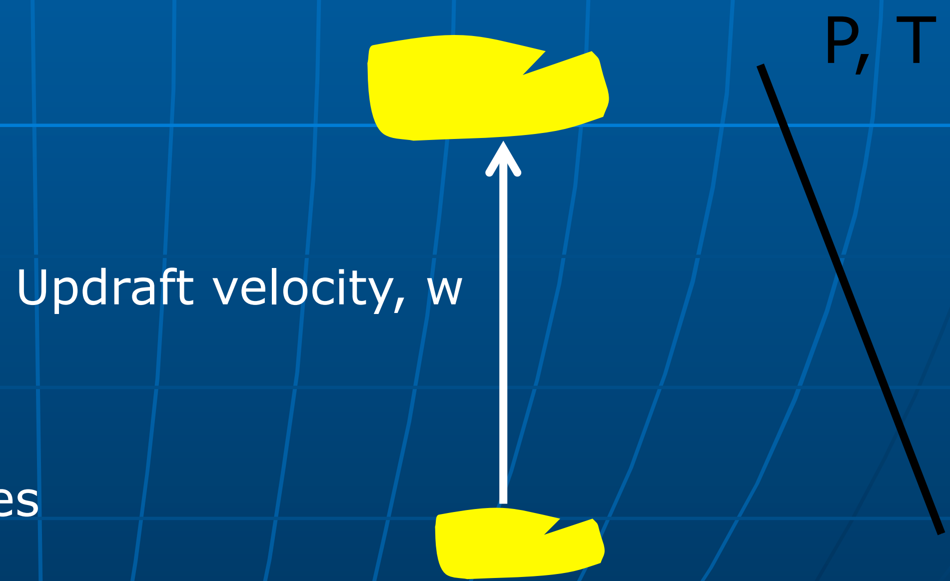
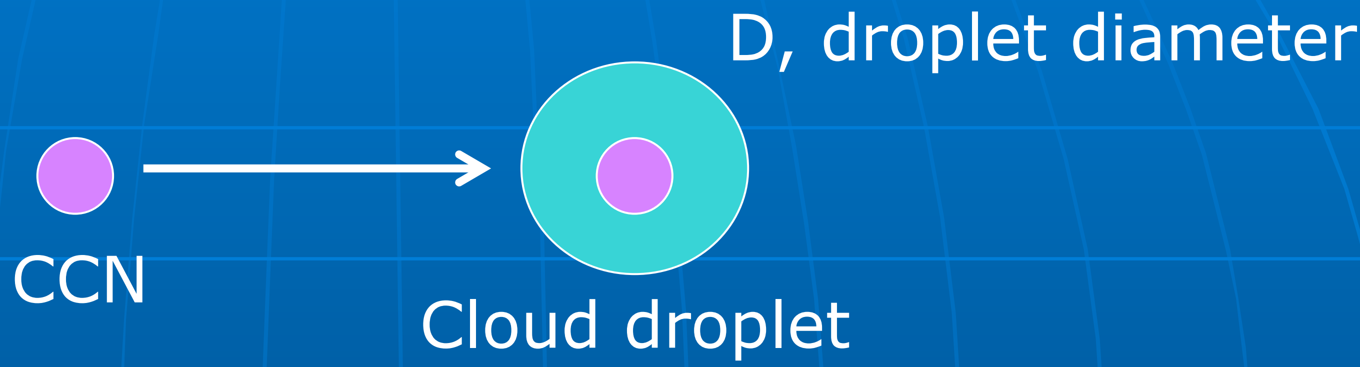
Isobaric cooling

Colder land, water, colder air masses

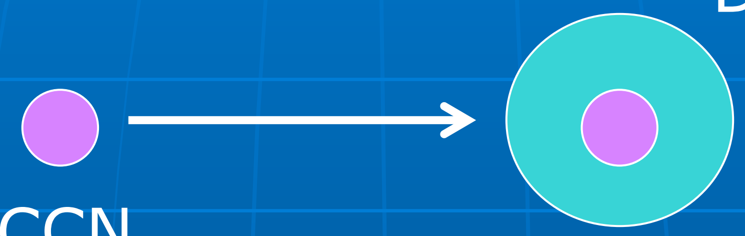
Adiabatic cooling



In supersaturated conditions



In supersaturated conditions

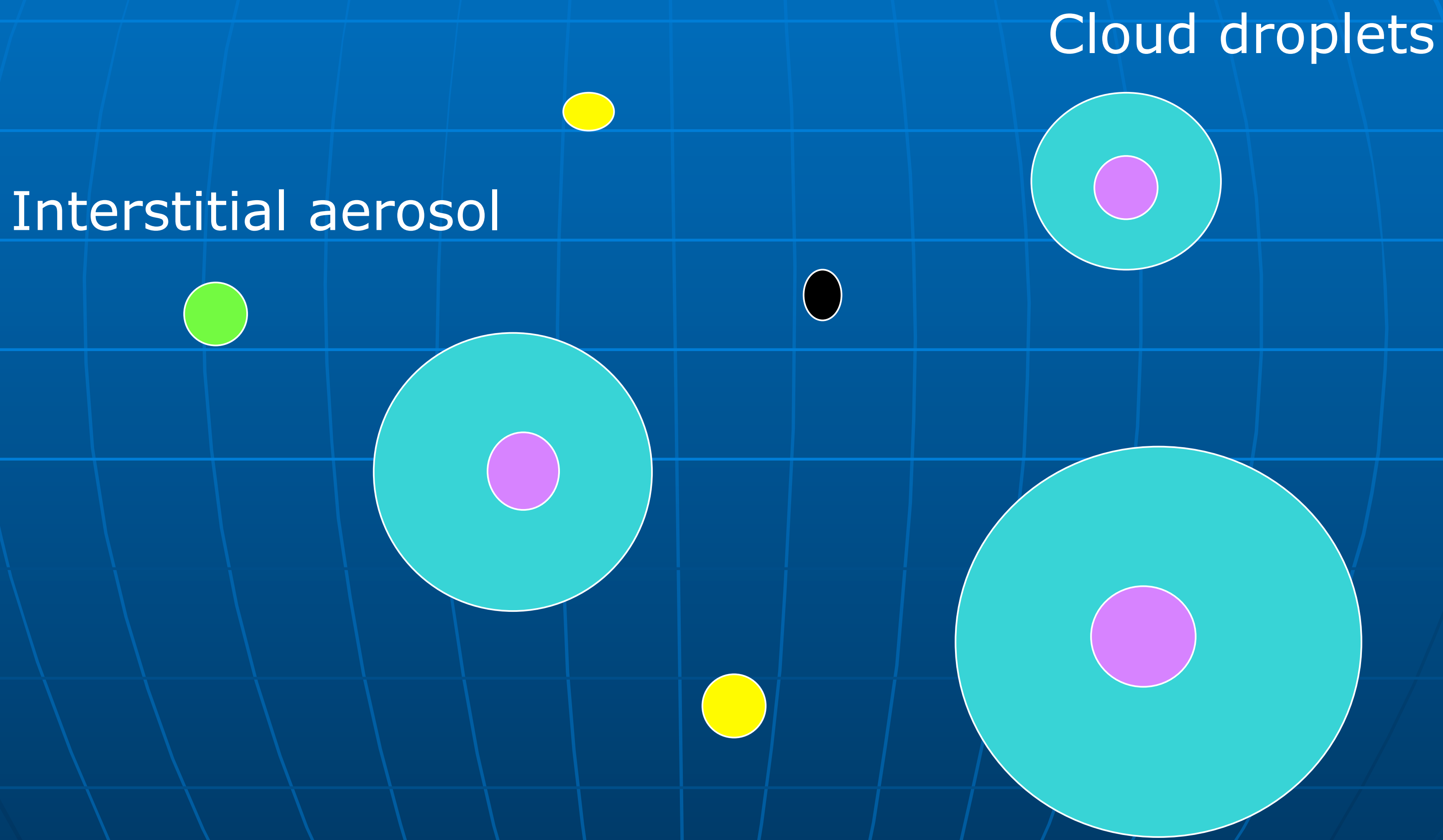


- the cloud droplet mass, m, grows

$$\frac{dm}{dt} = 2\pi D_v D(c_{w,\infty} - c_{w,eq})$$

D_v, water vapour diffusivity; $c_{w\infty}$=water conc. far from droplet; c_{weq} conc. at the droplet surface

A “cloudy” air volume



Cloud process modelling: source of large uncertainty

- Updraft velocity description
- Clouds are patchy, supersaturated condition close to unsaturated areas
- Accurate details of aerosol size distributions are needed
- Seldom in models modelled aerosols are coupled to cloud formation

Finally….

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Finally….

elisabetta.vignati@jrc.ec.europa.eu

I do not know I may appear to the world, but to myself I seem to have been only a poor boy playing on the sea-shore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.

I. Newton

Thank you!!!