Aerosol properties

Elisabetta Vignati

Joint Research Centre
Institute for Environment and Sustainability
Ispra, Italy

YSSS, Odessa, 3-9 July 2011

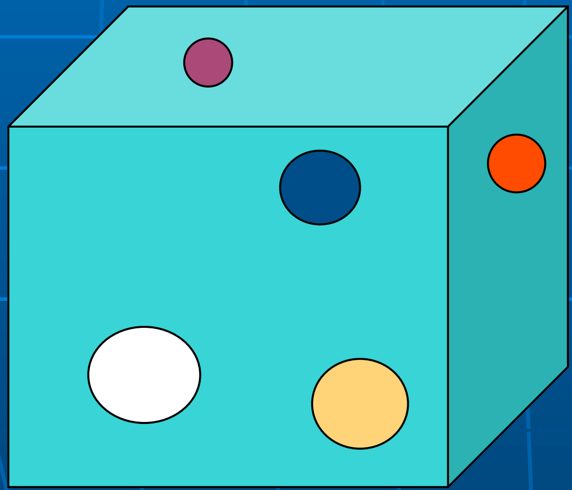
We will look at

Physical and chemical characteristics of aerosol particles in ACTM:

- chemical components and their importance with the spatial scales
- particle dimension and the concept of size distributions (number, surface and mass) and their mathematical description (as size bins, as log-normal modes)
- aerosol-cloud interaction: chemical and physical properties of cloud condensation nuclei

Aerosols, particles, PM

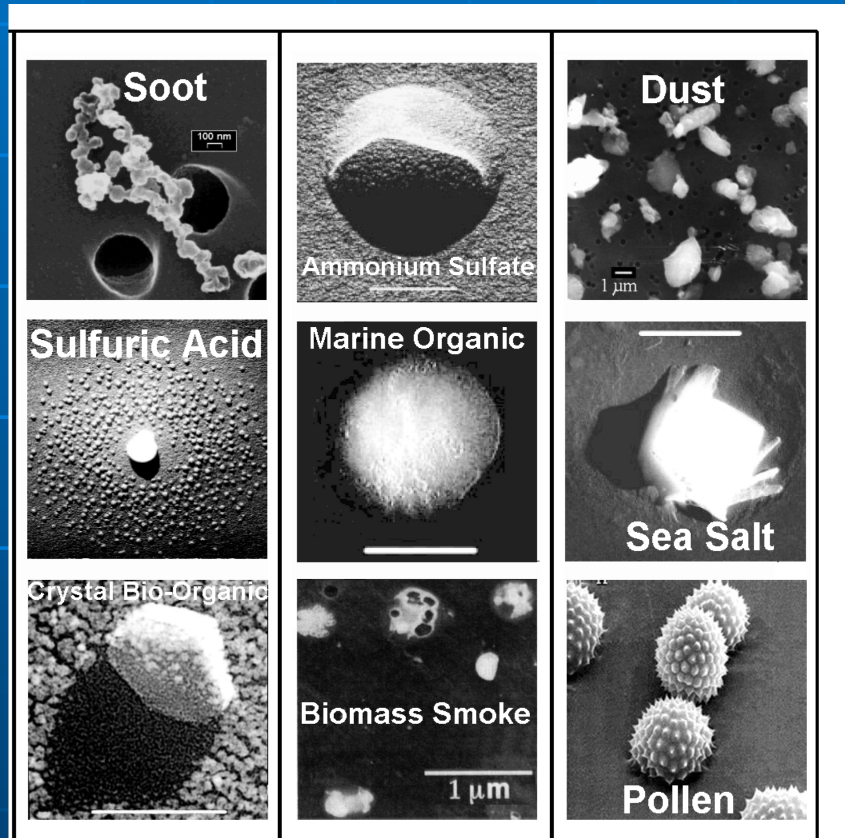
- definition



Volume of air that contains particles in suspension, in liquid or solid phase

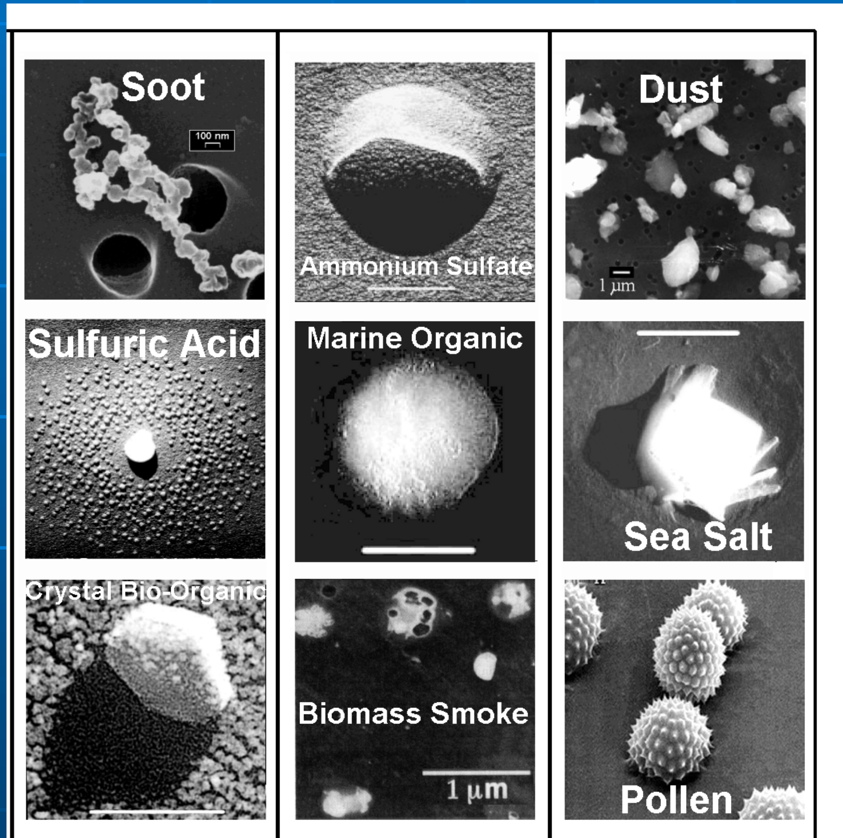
Particles: how do they look like?

They are very different in:
in form
dimension
chemical composition



Particles: how do they look like?

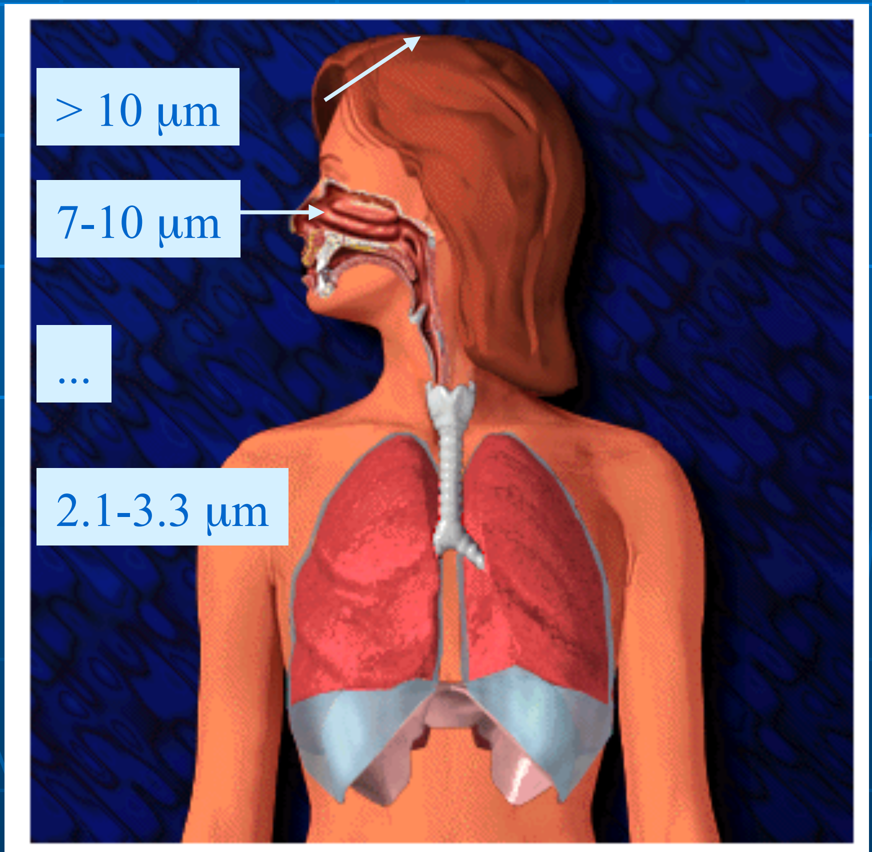
They are very different in:
in form
dimension
chemical composition



Their description in models is complex

Why are they important?

- When inhaled they have effects on health



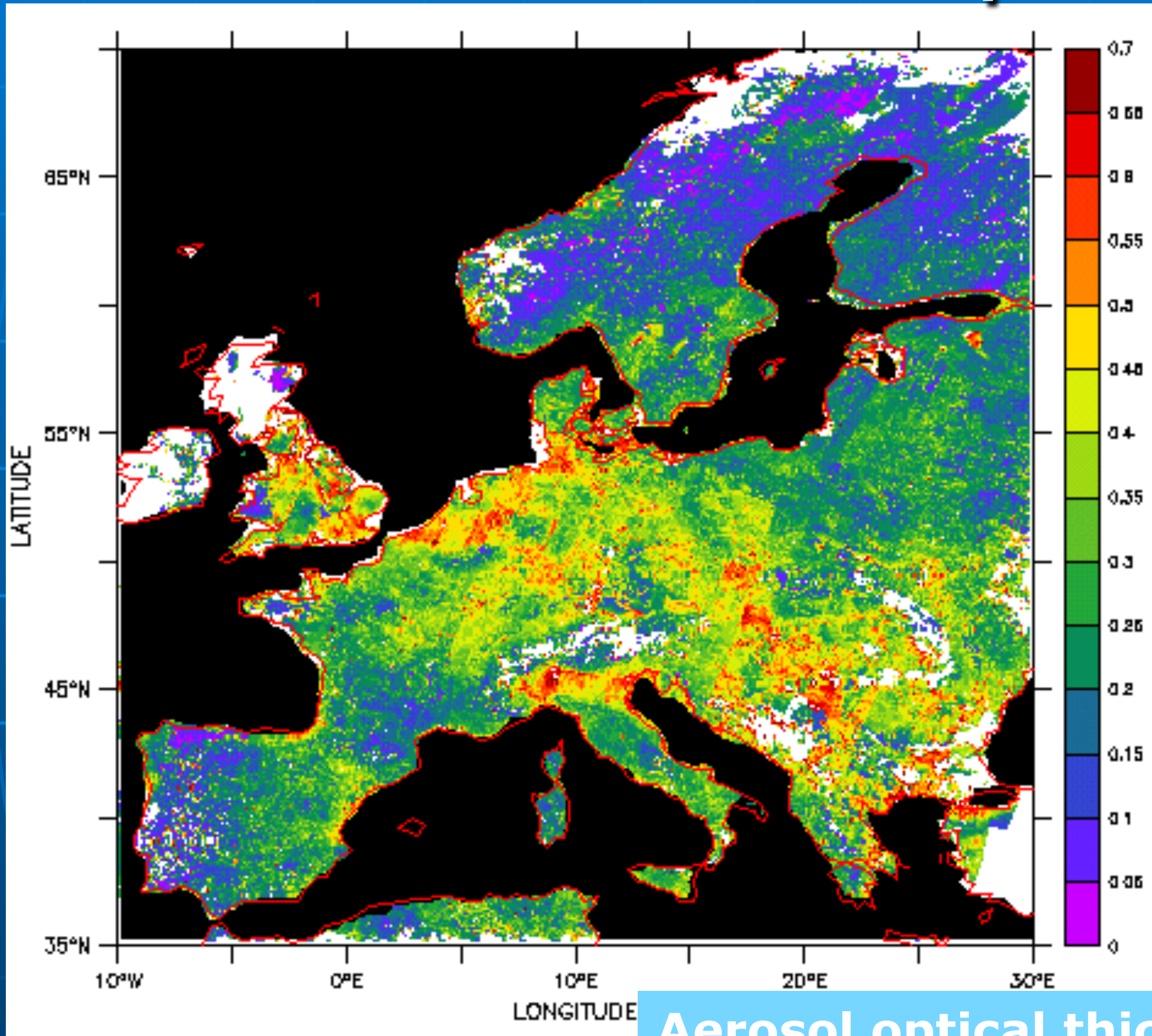
Why are they important?

- When inhaled they have effects on health
- They influence ecosystems, through their deposition
- They cause visibility degradation

Why are they important?

- When inhaled they have effects on health
- They influence ecosystems, through their deposition
- They cause visibility degradation
- They influence the climate:
  - Absorbing and scattering solar radiation and
  - Influencing the dimension, the abundance and the formation speed of cloud droplets

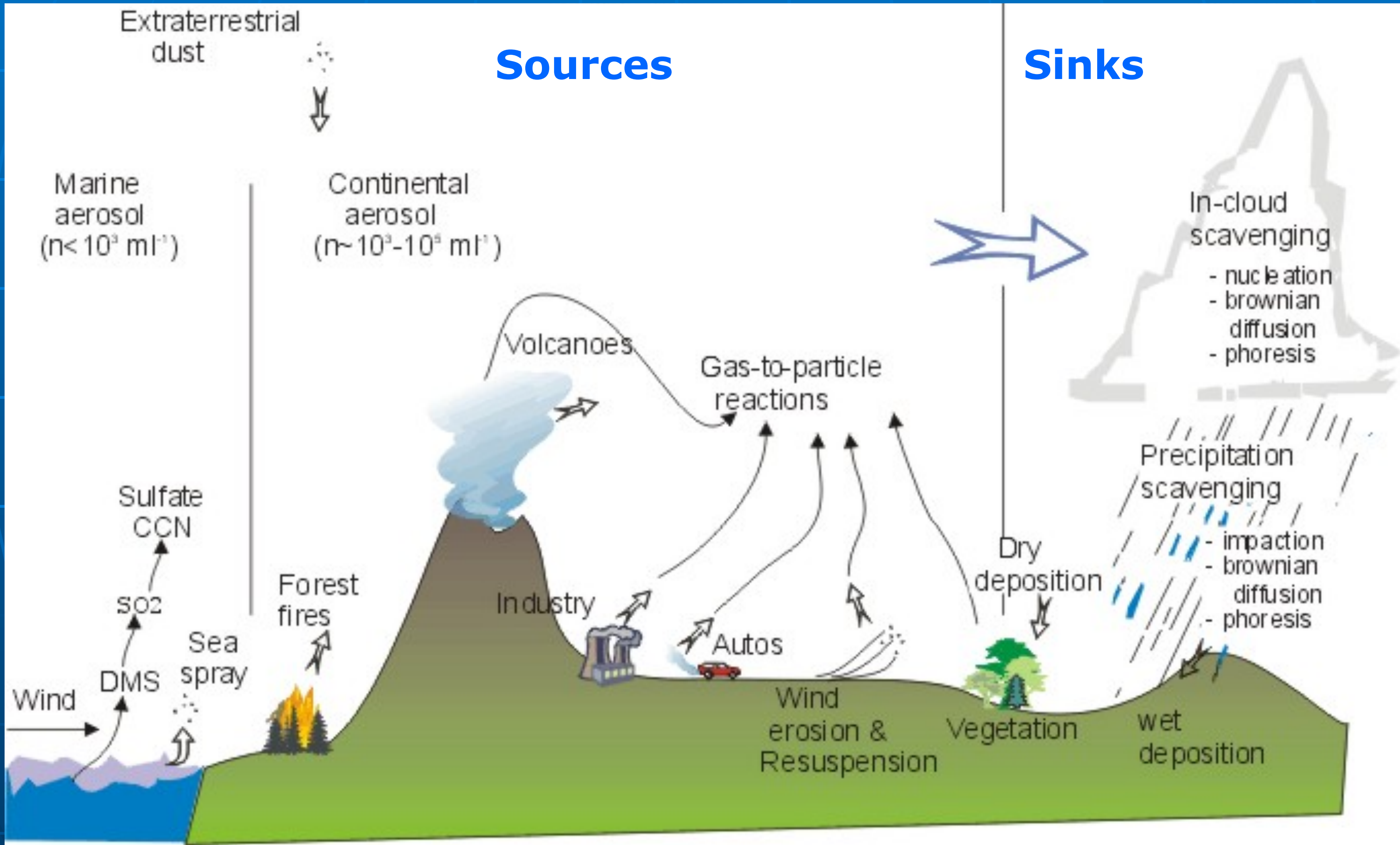
Aerosols over Europe



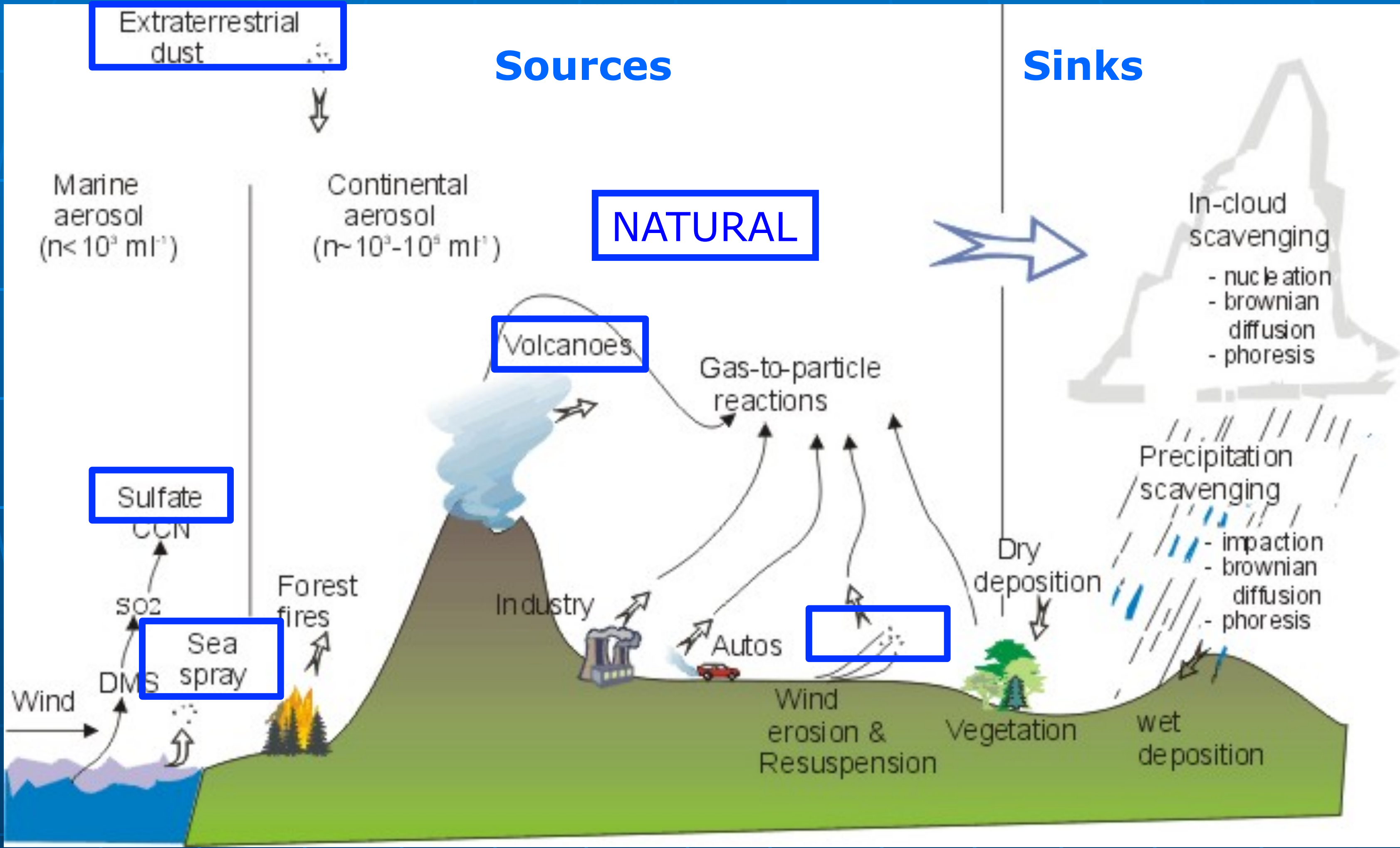
Aerosol optical thickness

Robles-Gonzales et al, 2000

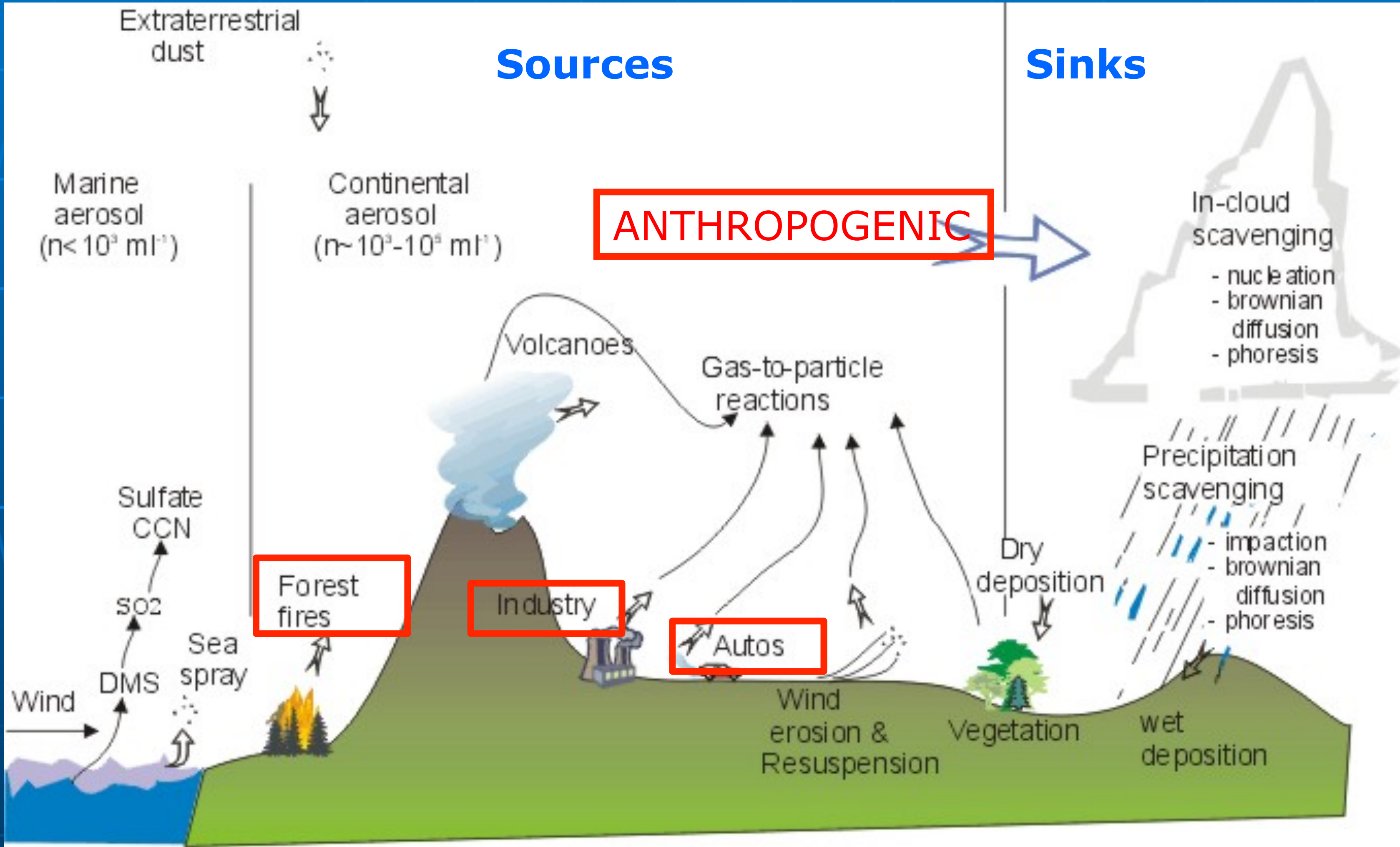
Atmospheric aerosols: sources and sinks



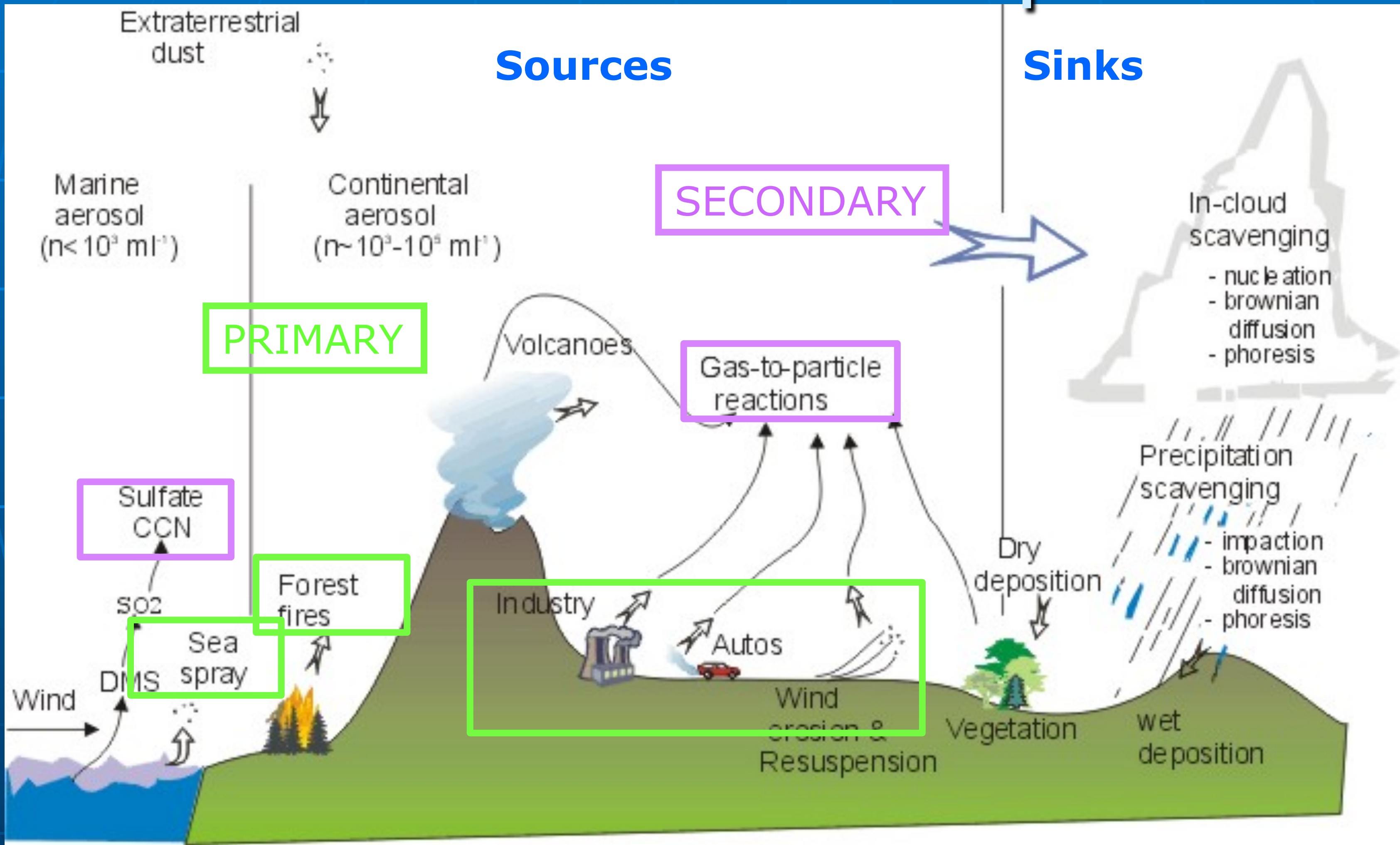
natural sources



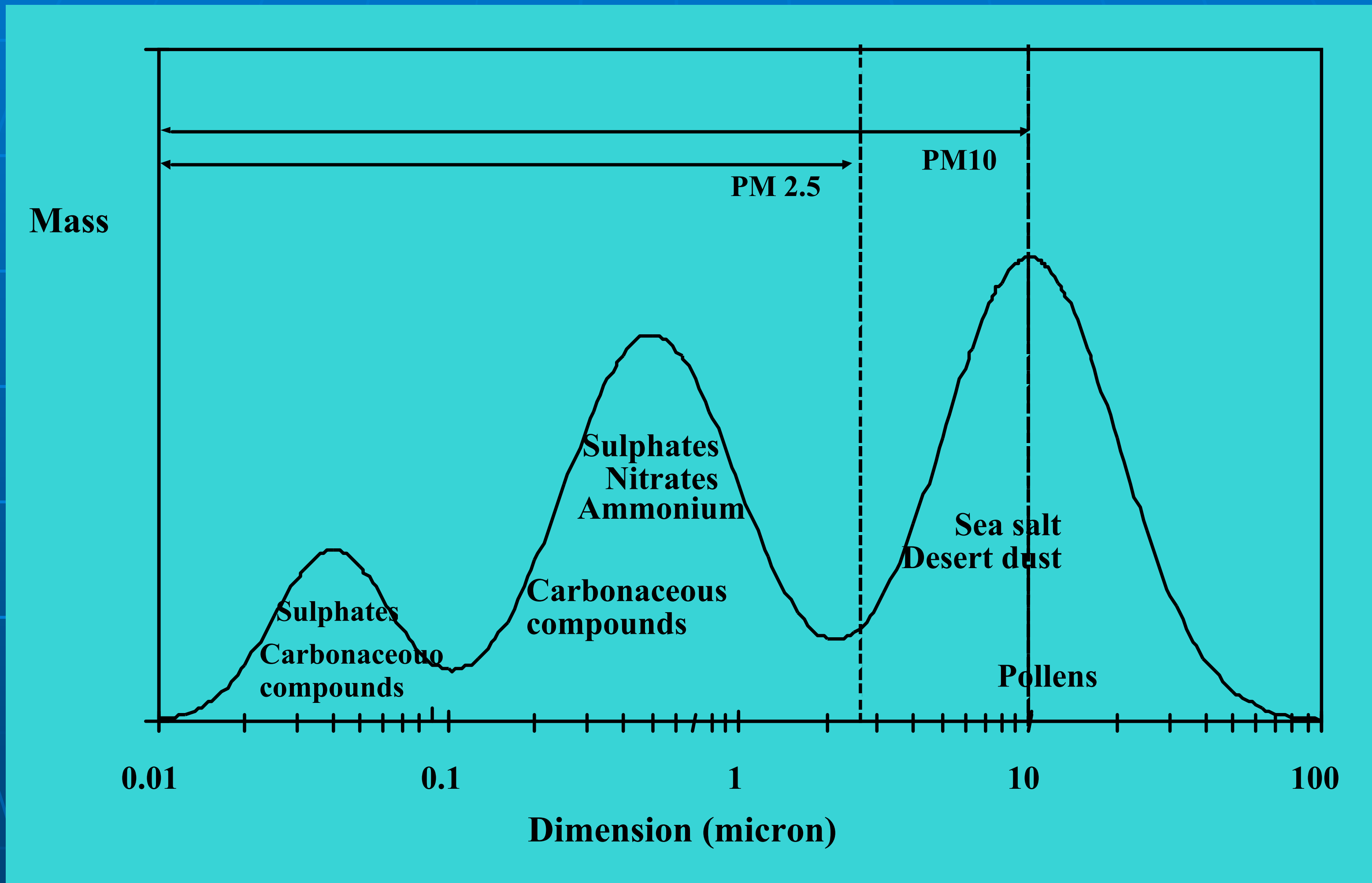
man-made aerosols



directly emitted or formed in the atmosphere



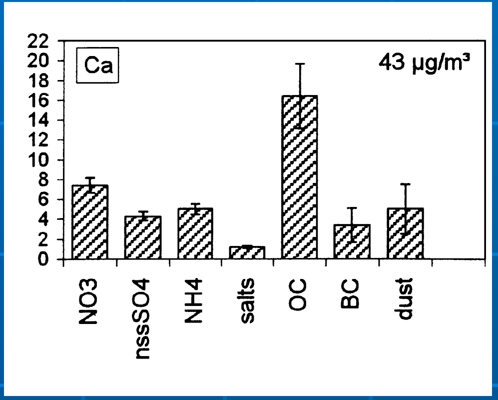
Properties



PM10: total mass of particles with dimension less then 10 μm
PM2.5: total mass of particles with dimension less then 2.5 μm

Aerosol chemical composition

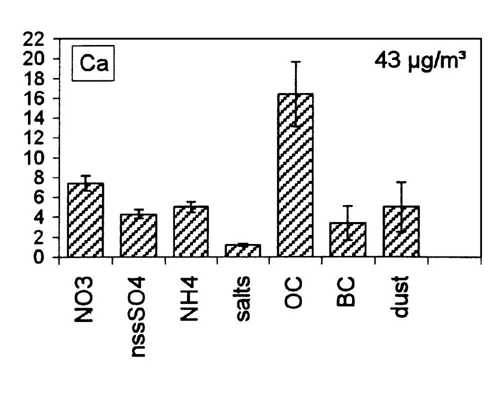
urban



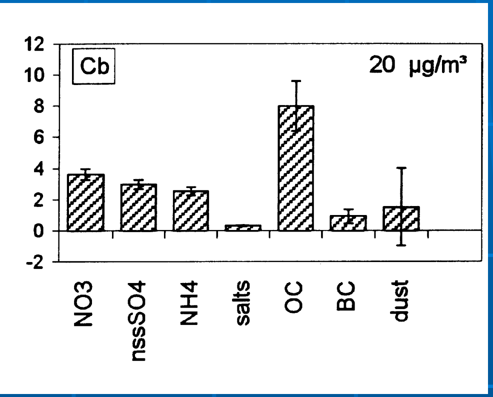
Raes et al, Atm. Env., 2000

Aerosol chemical composition

urban



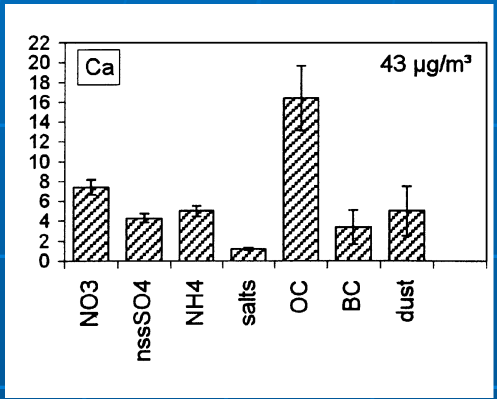
continental



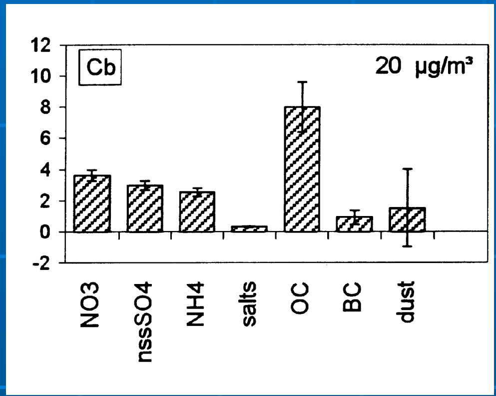
Raes et al, Atm. Env., 2000

Aerosol chemical composition

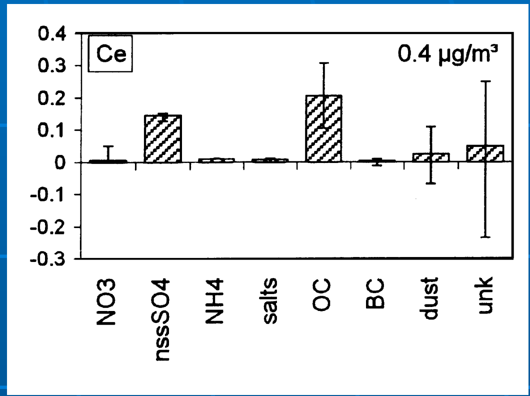
urban



continental

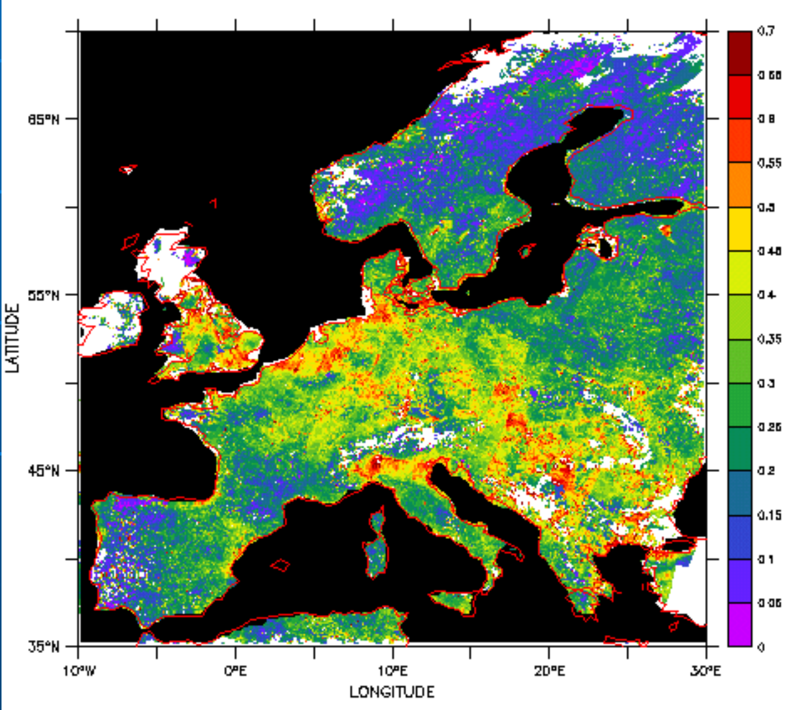


Atlantic clean



Raes et al, Atm. Env., 2000

Chemical composition and scale



regional

sulphates

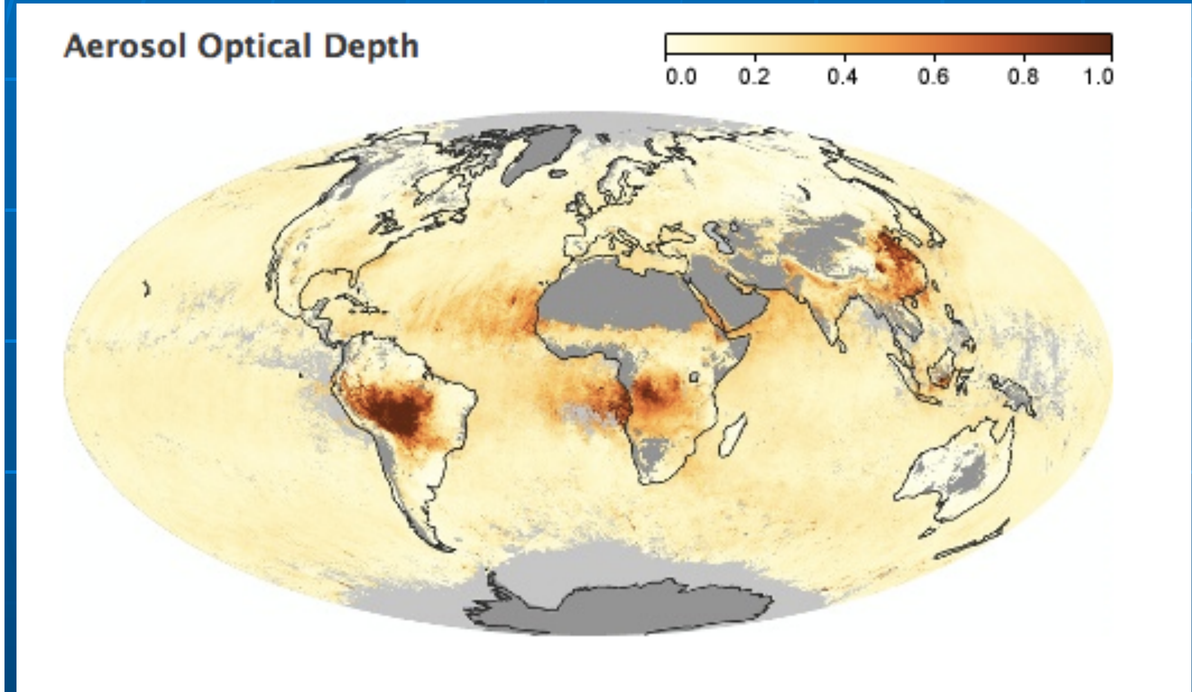
Carbonaceous part.

Ammonium

Nitrates

Sea salt

Desert dust



NASA

global

Sea salt

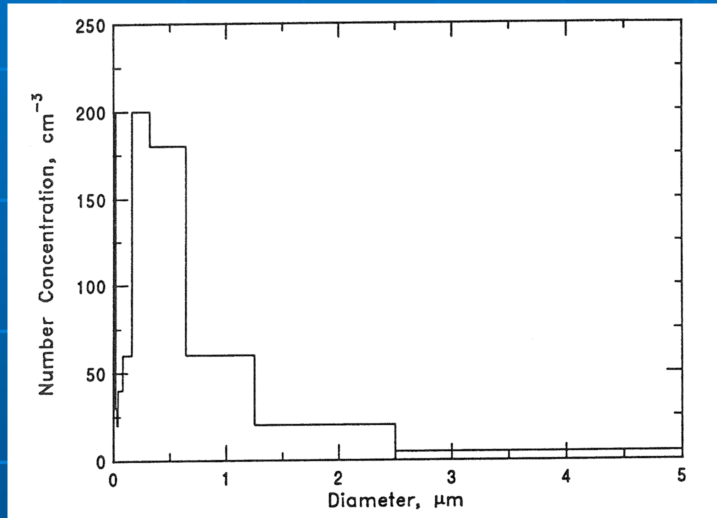
Desert dust

Carbonaceous part.

sulphates

How to describe particles with such different dimensions?

Size Range (μm)	Concentration (cm^{-3})
0.001–0.01	100
0.01–0.02	200
0.02–0.03	30
0.03–0.04	20
0.04–0.08	40
0.08–0.16	60
0.16–0.32	200
0.32–0.64	180
0.64–1.25	60
1.25–2.5	20
2.5–5.0	5
5.0–10.0	1



Discrete function

Continuous size distributions

$$N = \int_0^\infty n(D)\,dD$$

$n(D)dD$ = number of particles per cm^{-3} with diameter between D and D+dD

Continuous size distributions

$$N = \int_0^\infty n(D)\,dD$$

n(D)dD = number of particles per cm^{-3} with diameter between D and D+dD

$$n(D)dD = \frac{dN}{dD}$$

Continuous size distributions

$$N = \int_0^{\infty} n_N(D)\, dD$$

n(D)dD = number of particles per cm^{-3} with diameter between D and D+dD

$$n_N(D) = \frac{dN}{dD}$$

$$n_N(D) = \frac{dN}{d \log D}$$

Distributions also for…

number

$$n_N(D) = \frac{dN}{dD}$$

Distributions also for...

number

$$n_N(D) = \frac{dN}{dD}$$

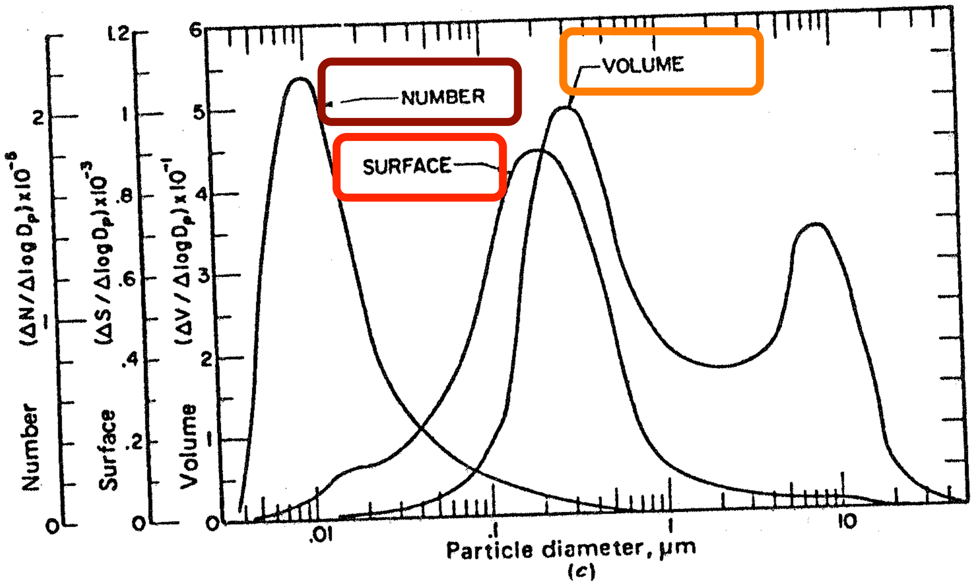
surface

$$n_S(D) = \pi D^2 n_N(D)$$

volume

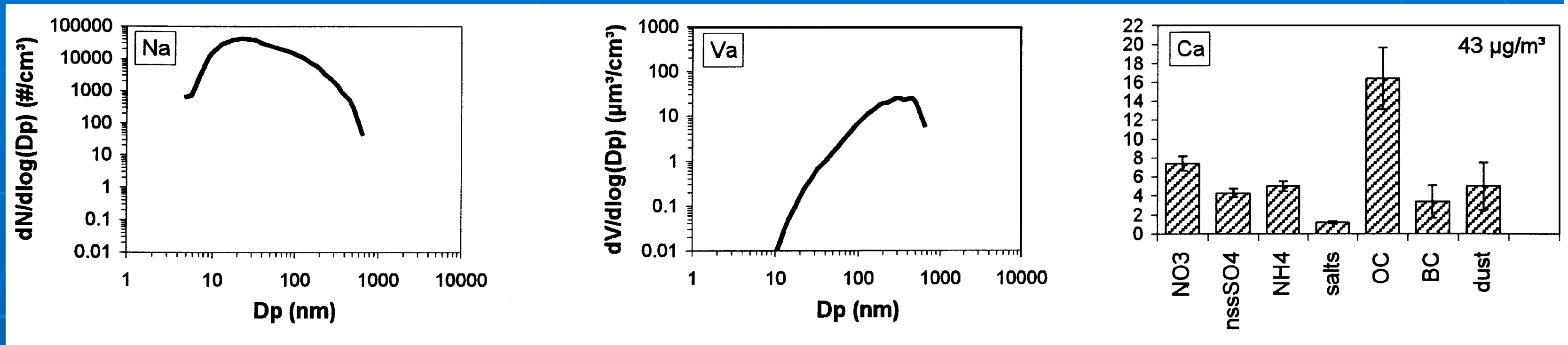
$$n_V(D) = \frac{\pi}{6} D^3 n_N(D)$$

How do they look like?



Measured size distributions

urban



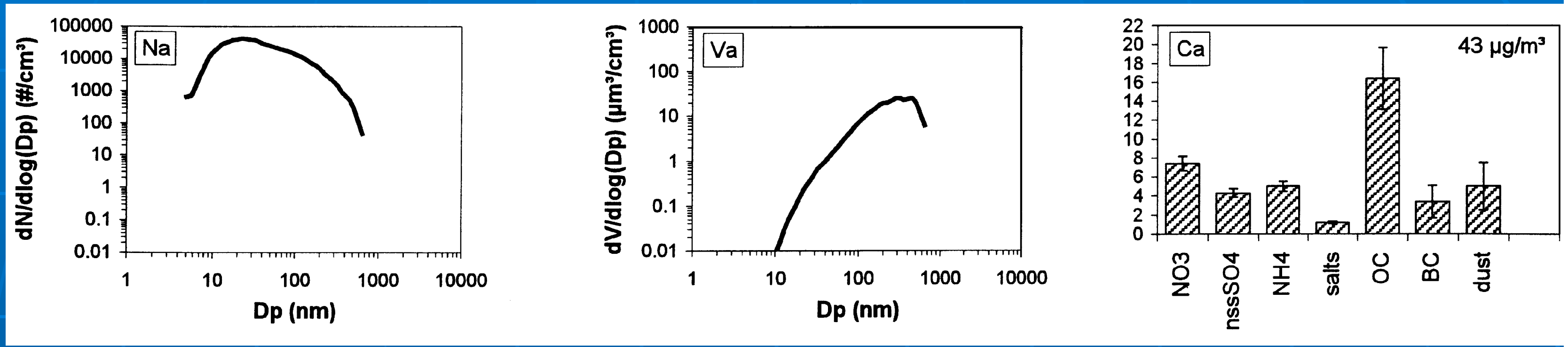
Volume distribution

Number distribution

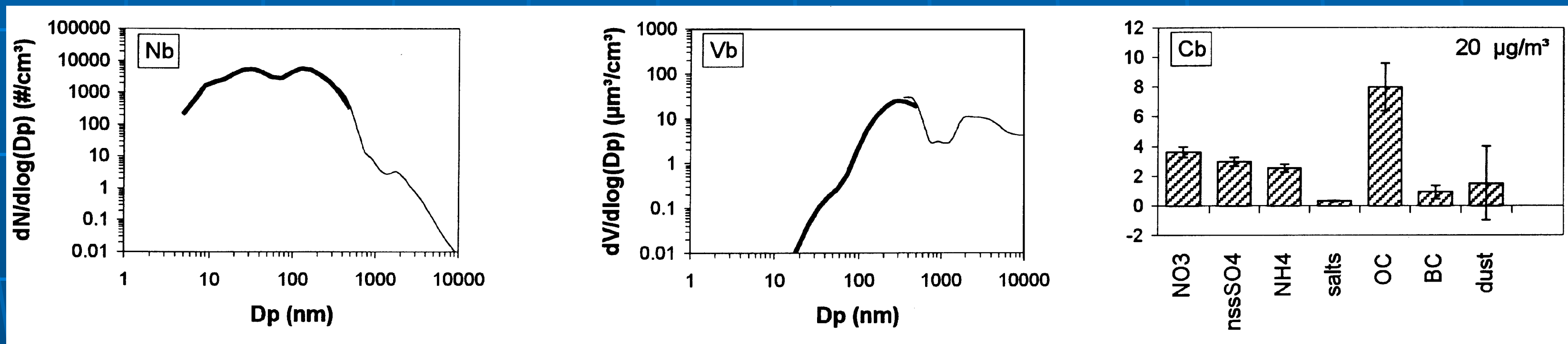
Chemical composition

Measured size distributions

urban

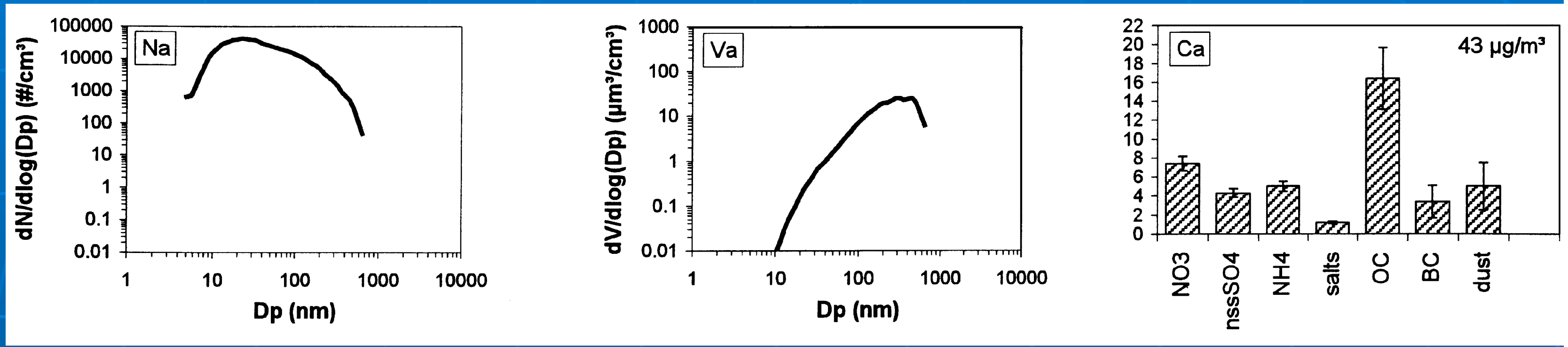


continental

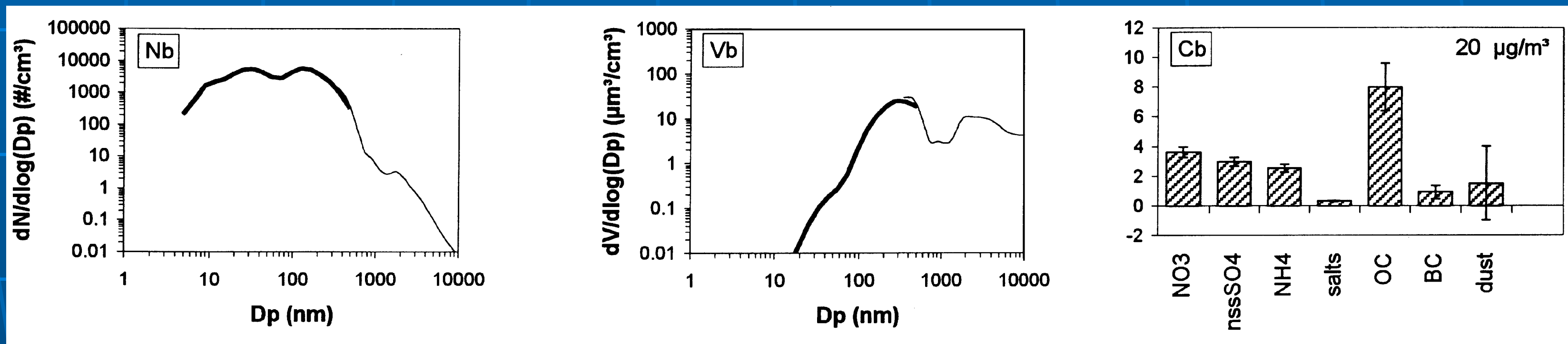


Measured size distributions

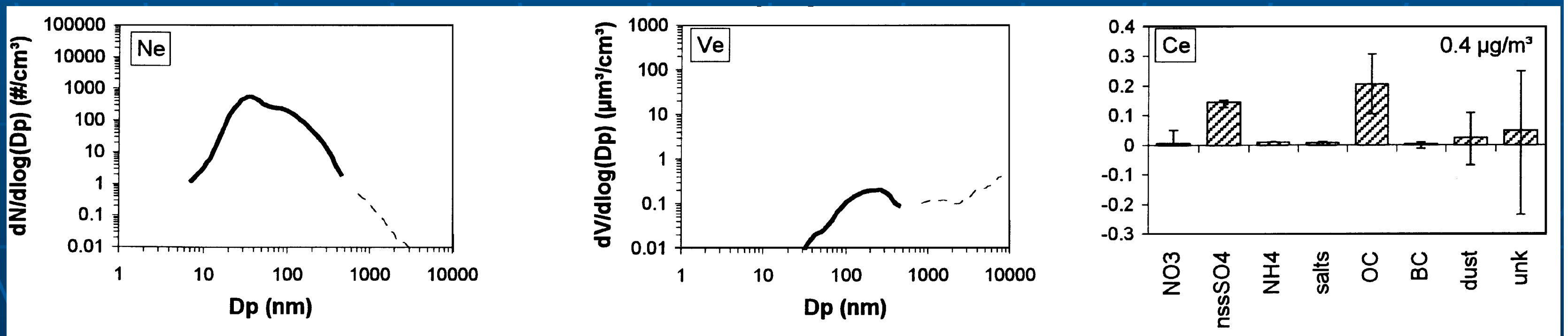
urban



continental

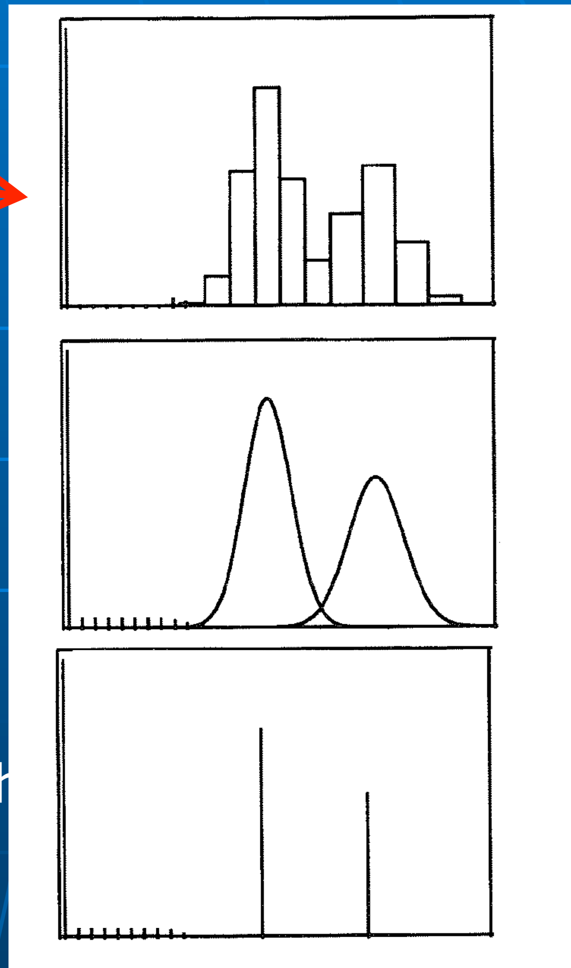


Atlantic clean



How do we model a size distribution?

Sectional- size bins



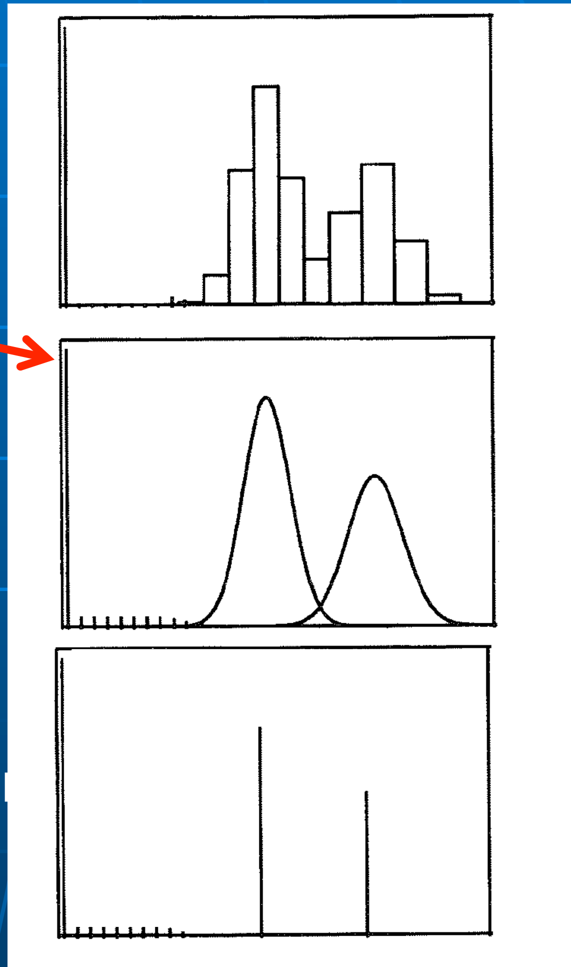
Strenghts:
Flexible in representing aerosol distributions
Multicomponent simulations
Well developed codes

Limitations:
Significant numerical diffusion for particle growth
Computationally intensive
Accuracy depens on the number of classes

Whitby and McMurry, 1997

How do we model a size distribution?

Modal



Strenghts:
Flexible model structure
Computationally fast

Limitations:
Accuracy depends on the form of the distribution which is used

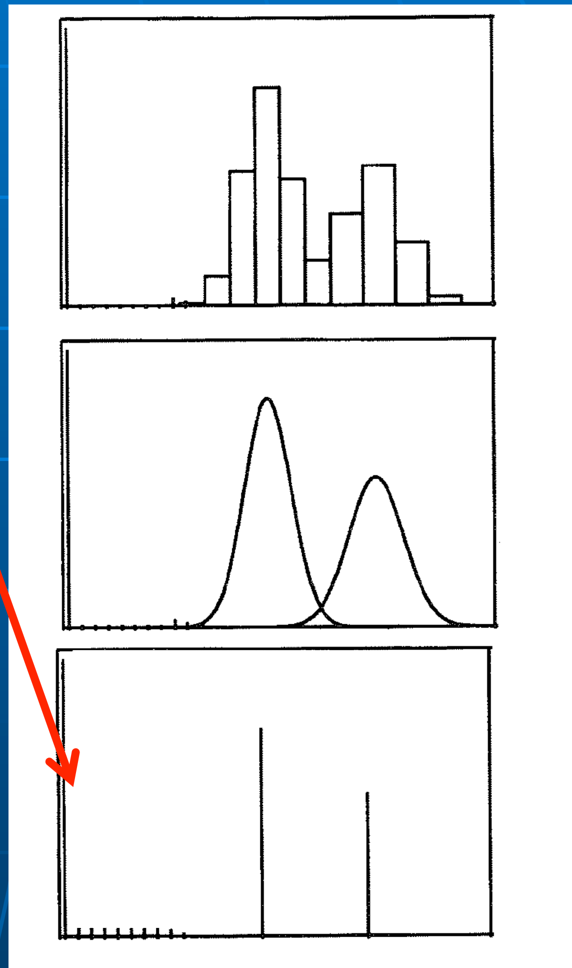
Whitby and McMurry, 1997

How do we model a size distribution?

Monodisperse

Strenghts:
Flexible model structure
Computationally very fast

Limitations:
Useful for rough estimates of dynamics
No information on size distributions



Whitby and McMurry, 1997

The log-normal distribution

$$\frac{dN}{d\ln D} = \frac{N}{(2\pi)^{1/2} D \ln\sigma} \exp\left(-\frac{(\ln D - \ln \bar{D})^2}{2\ln^2\sigma} \right)$$

N=total particle number; D=diameter; σ=standard deviation;

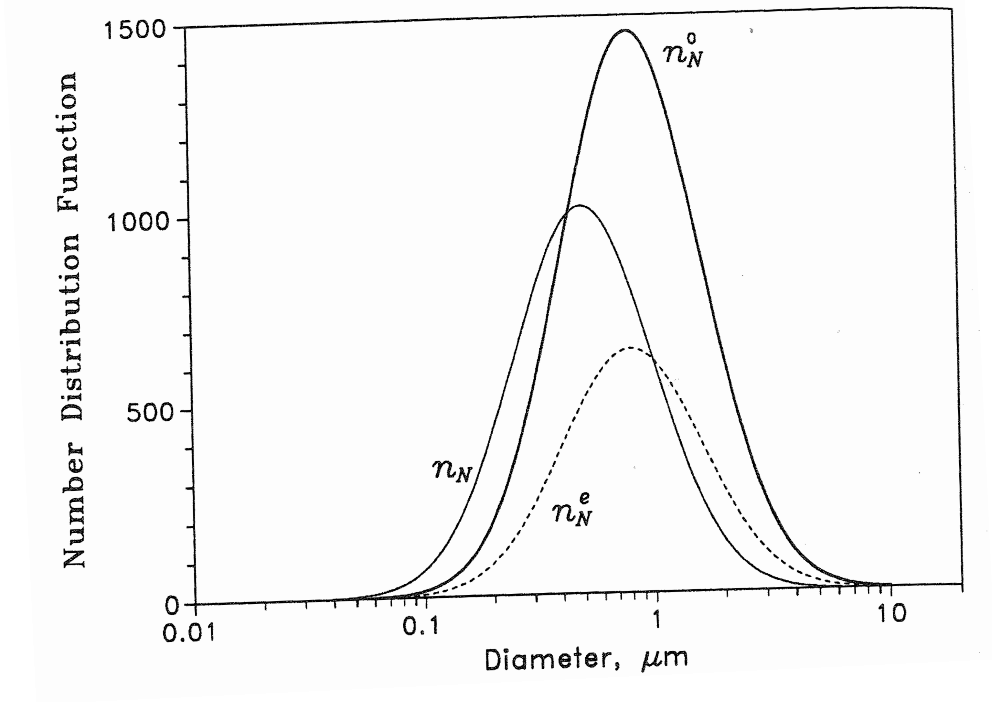
D- = mean diameter

The log-normal distribution

$$\frac{dN}{d\ln D} = \frac{N}{(2\pi)^{1/2} D \ln \sigma} \exp\left(- \frac{(\ln D - \ln \bar{D})^2}{2 \ln^2 \sigma} \right)$$

N=total particle number; D=diameter; σ=standard deviation;

D- = mean diameter



Cloud condensation Nuclei (CCN)

- If particles were not present in the atmosphere cloud could not be formed
- Cloud condensation nuclei are particles that can activate to grow to cloud droplets in presence of water vapour supersaturation

- Supersat. ratio (S) =

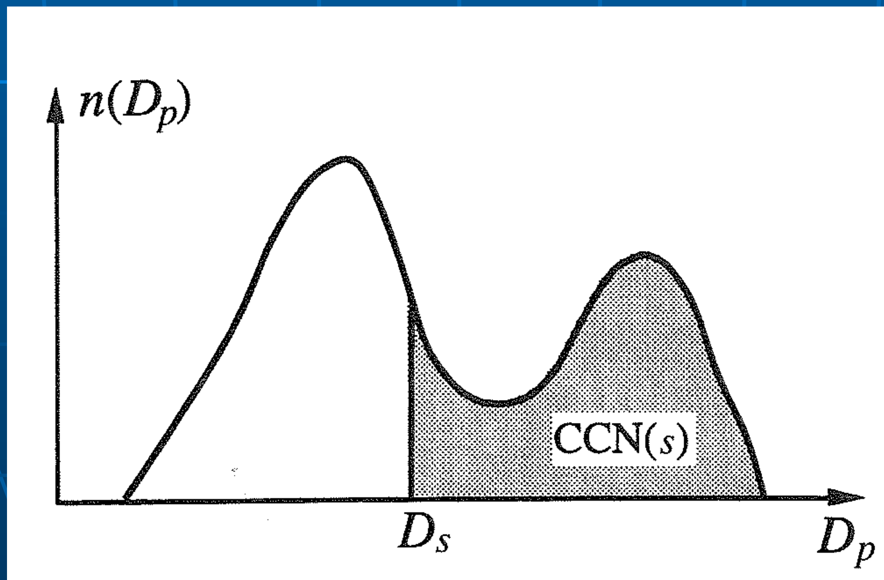
= f (chem. comp; diameter of activation)

1. The higher is S, the smaller is the diameter of the particle to be activated
2. The more soluble the particle, the lower is S to be able to activate the particle

- Supersat. ratio (S) =

= f (chem. comp; diameter of activation)

1. The higher is S, the smaller is the diameter of the particle to be activated
2. The more soluble the particle, the lower is S to be able to activate the particle



- CCN given for a certain supers., as CCN(s) … CCN(0.5%) … CCN(1%)

- CCN given for a certain supers., as CCN(s) … CCN(0.5%) … CCN(1%)
- For particles with same chem. comp.

$$CCN(s) = \int_{D_s}^{\infty} n(D_p)\, dD_p$$

D_p = activation diameter

- CCN given for a certain supers., as CCN(s) … CCN(0.5%) … CCN(1%)
- For particles with same chem. comp.

$$CCN(s) = \int_{D_s}^{\infty} n(D_p)\, dD_p$$

D_p = activation diameter

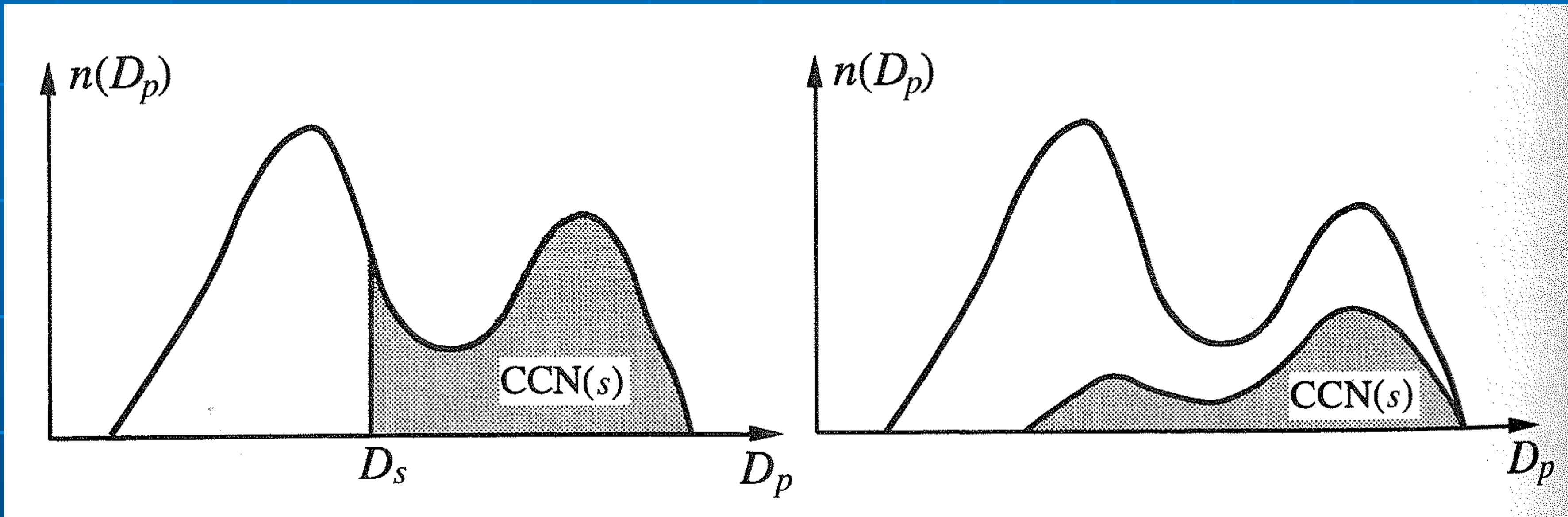
- For particles with different chem. comp.

$$CCN(s) = \int_{0}^{\infty} f_s(D_p)\, n(D_p)\, dD_p$$

f_s = fraction of part. activated at s

CCN from particles with

same chemical composition | different chemical composition



How are CCN modelled?

- For long time empirical functions have been used ….

$$CCN(s) = cs^{k}$$

c and k are empirically derived

How are CCN modelled?

- For long time empirical functions have been used ….

$$CCN(s) = cs^k$$

c corresponds to s=1%

c(cm-3)	k	Location
190	0.8	Pacific
250	0.5	North Atlantic
400	0.3	Polluted Pacific
600	0.5	Continental
3500	0.9	Cont. (Buffalo, NY)

Hegg and Hobbs, 1992