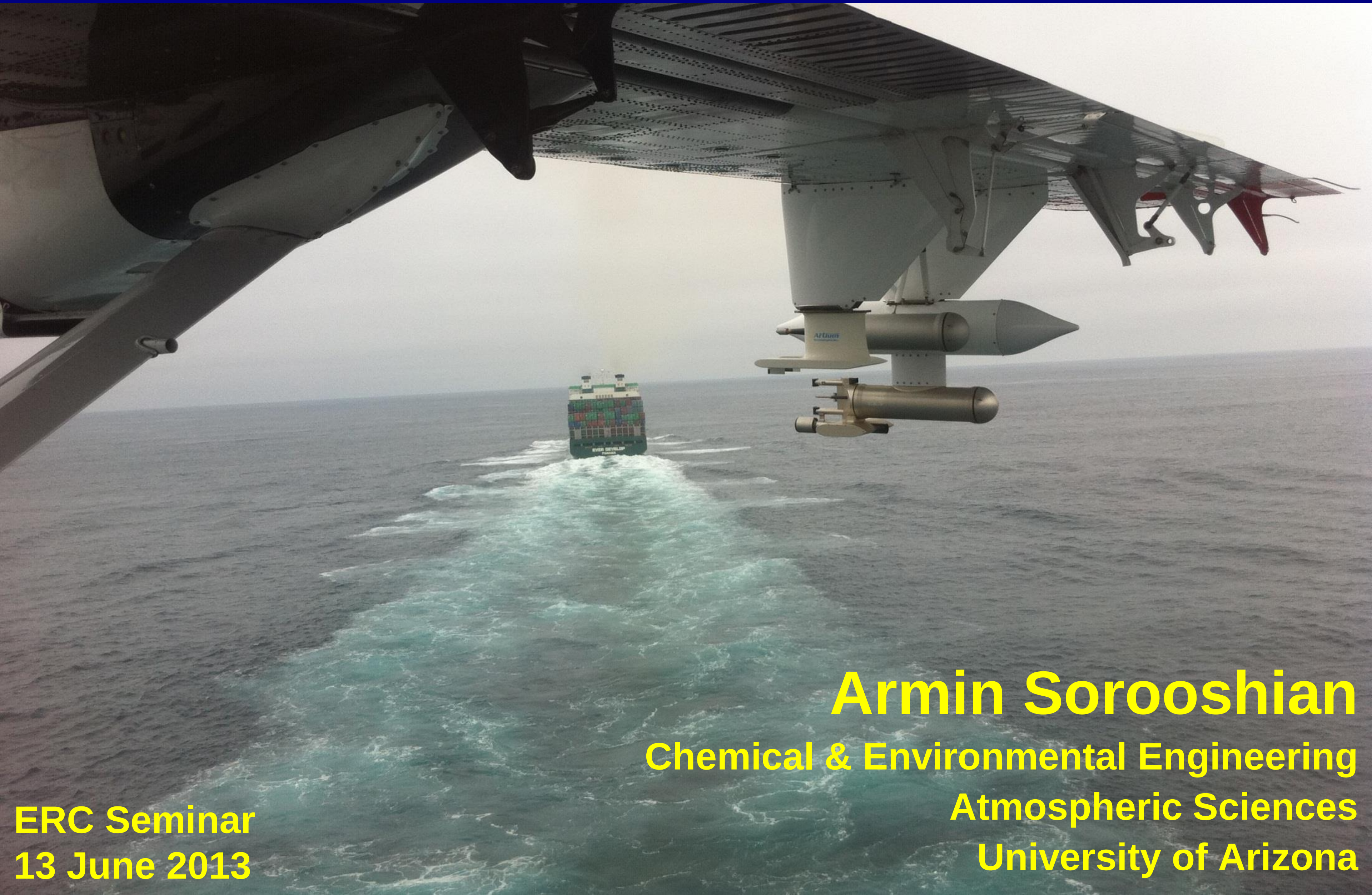
Chasing Aerosol Particles Down to Nano Sizes



Armin Sorooshian

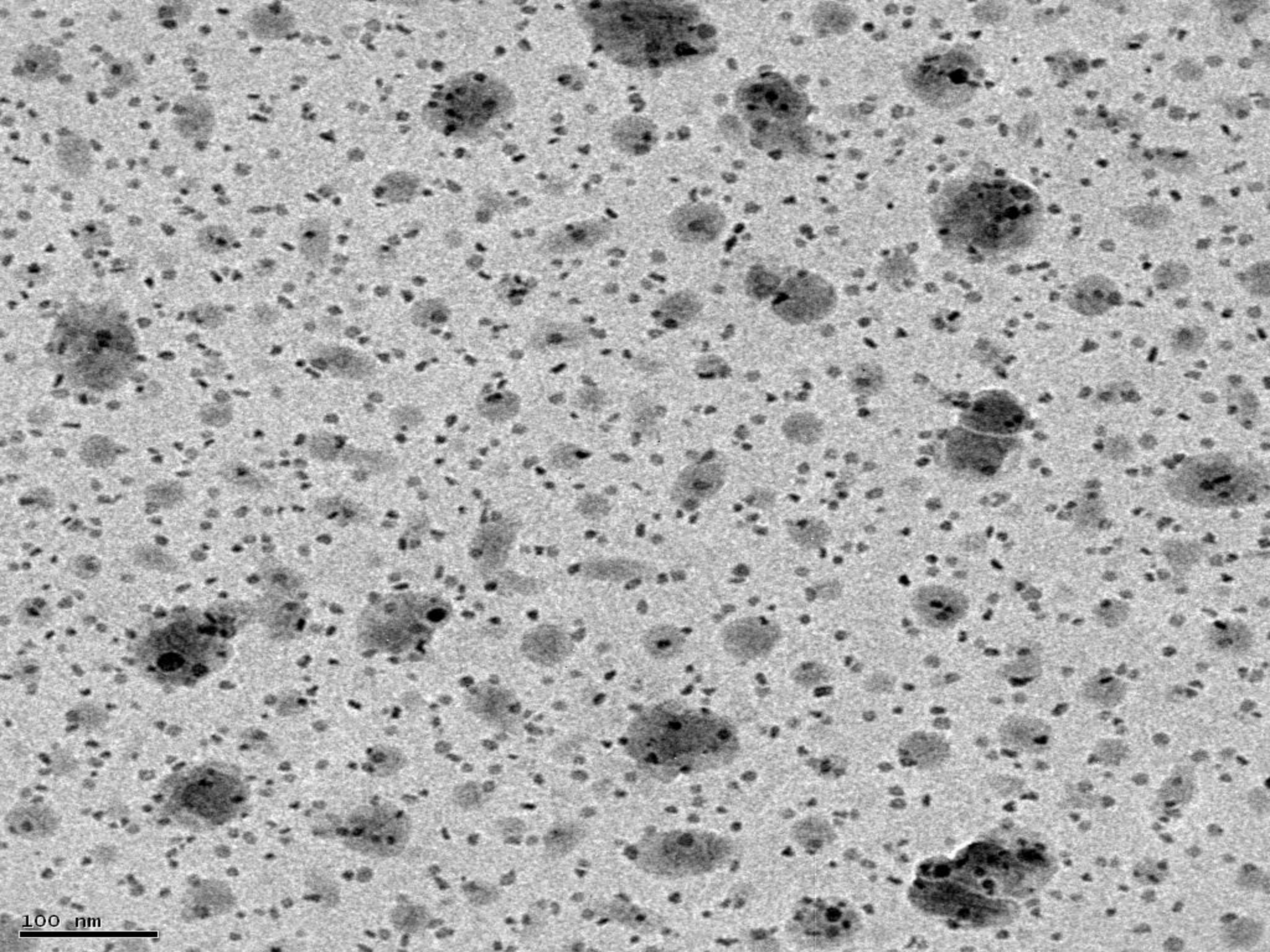
Chemical & Environmental Engineering

Atmospheric Sciences

University of Arizona

ERC Seminar

13 June 2013

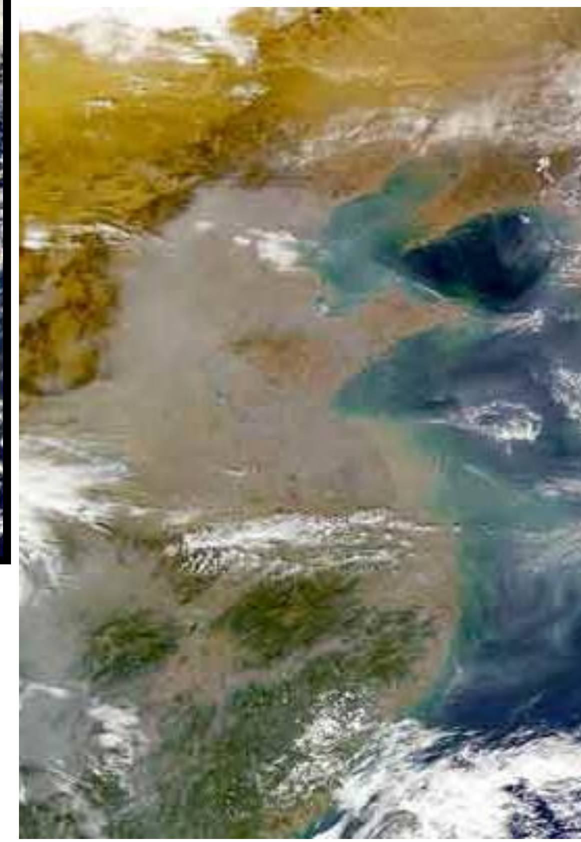

100 nm

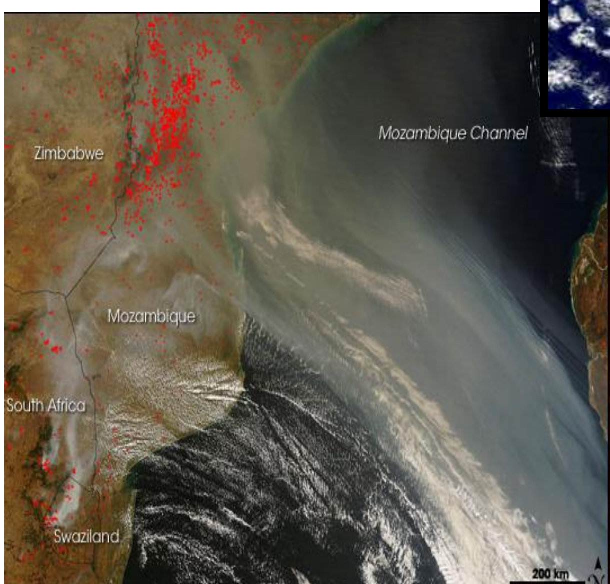
Outline of Talk

1. What are aerosol particles and why should we care about them?

2. What are some relevant aerosol properties, physical transformations, and measurement techniques for determining their effects in the work environment?

What are aerosol particles?





Why should we care about particles? Visibility, Public Health/Welfare

Increased aerosol concentrations

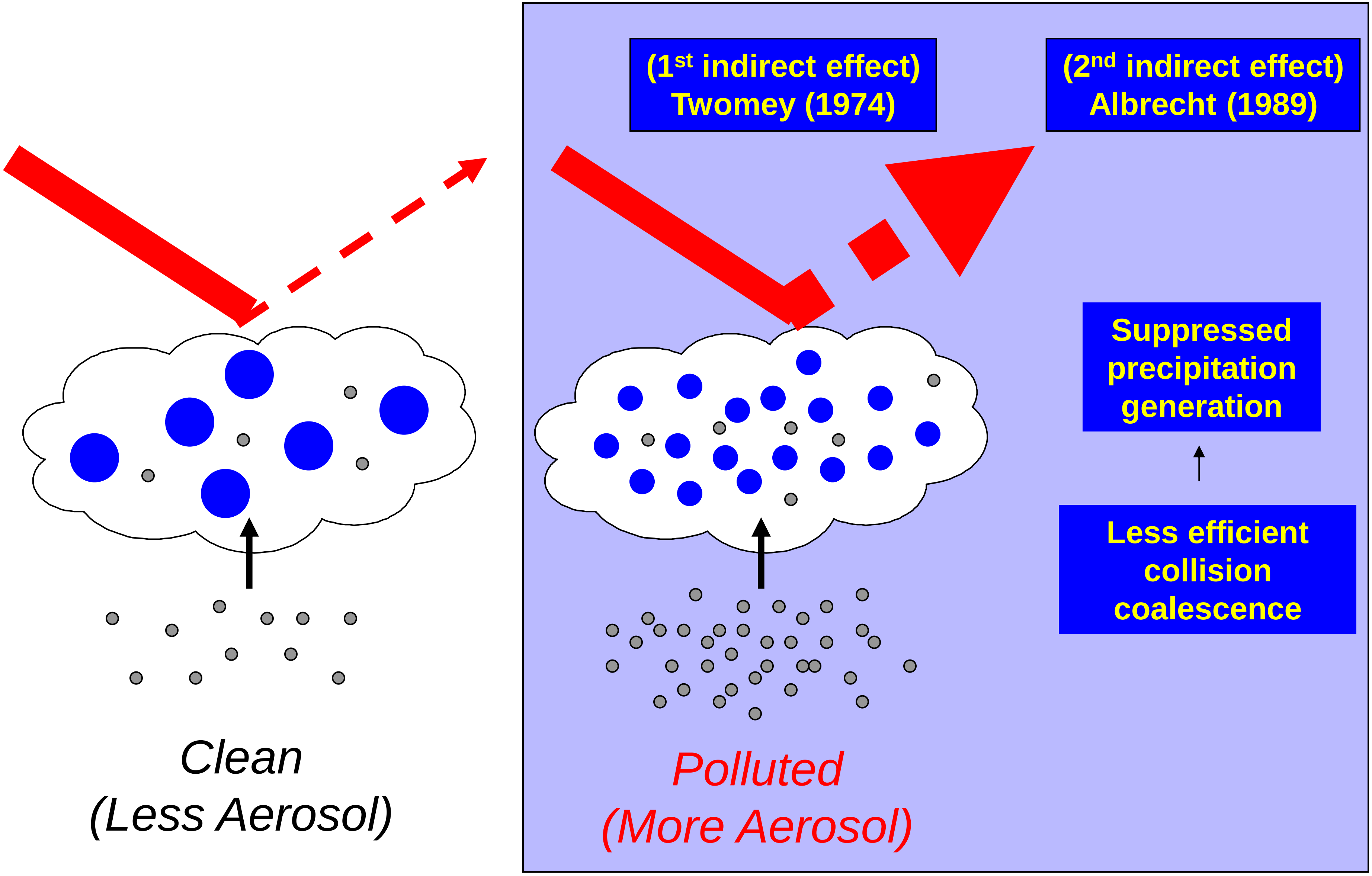
→

Cannot see mountains

Aerosols directly interact with solar radiation via absorbance and scattering

Optical Properties = f (size, shape, composition)

The Physical Basis for Aerosol Effects on Clouds

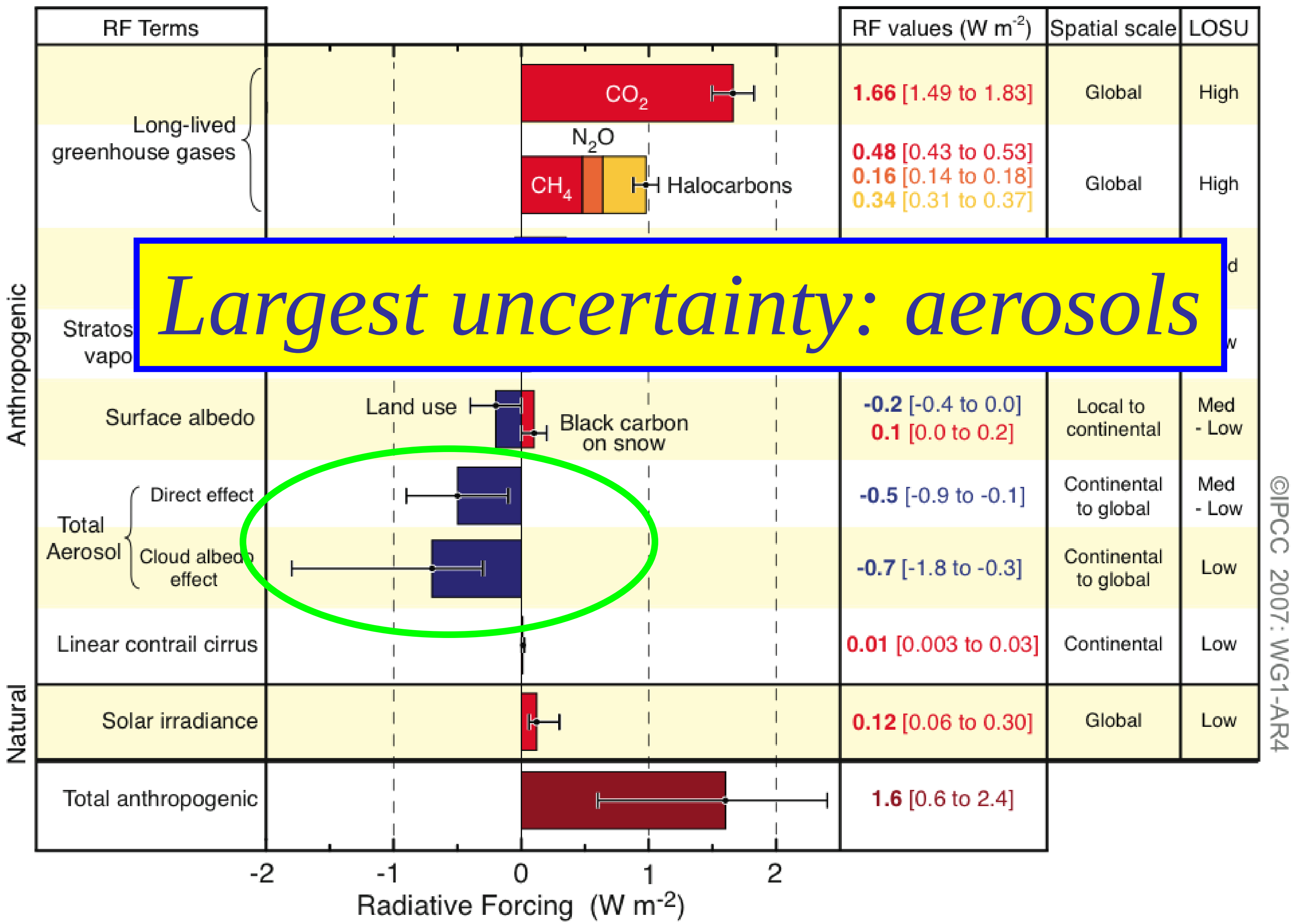


Visual demonstration of aerosol-cloud interactions

Courtesy: NASA (MODIS TERRA)

Ship tracks off coast of California (22 July 2011)

Aerosols and Climate Change



IPCC, 2007

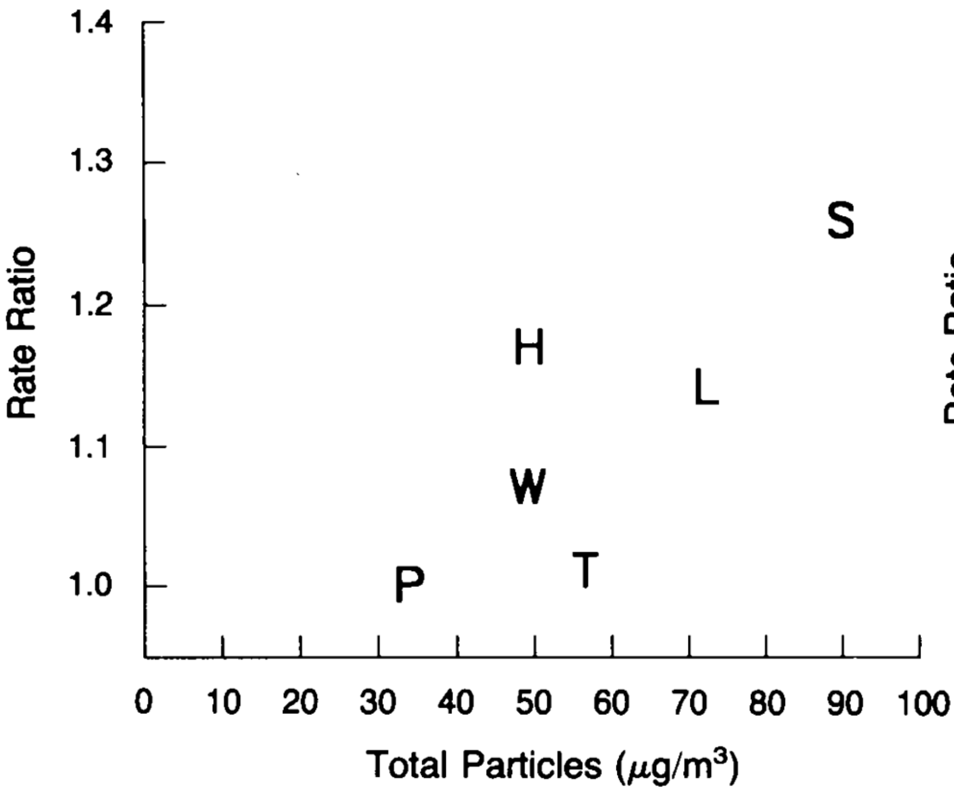
Why should we care about particles? Health

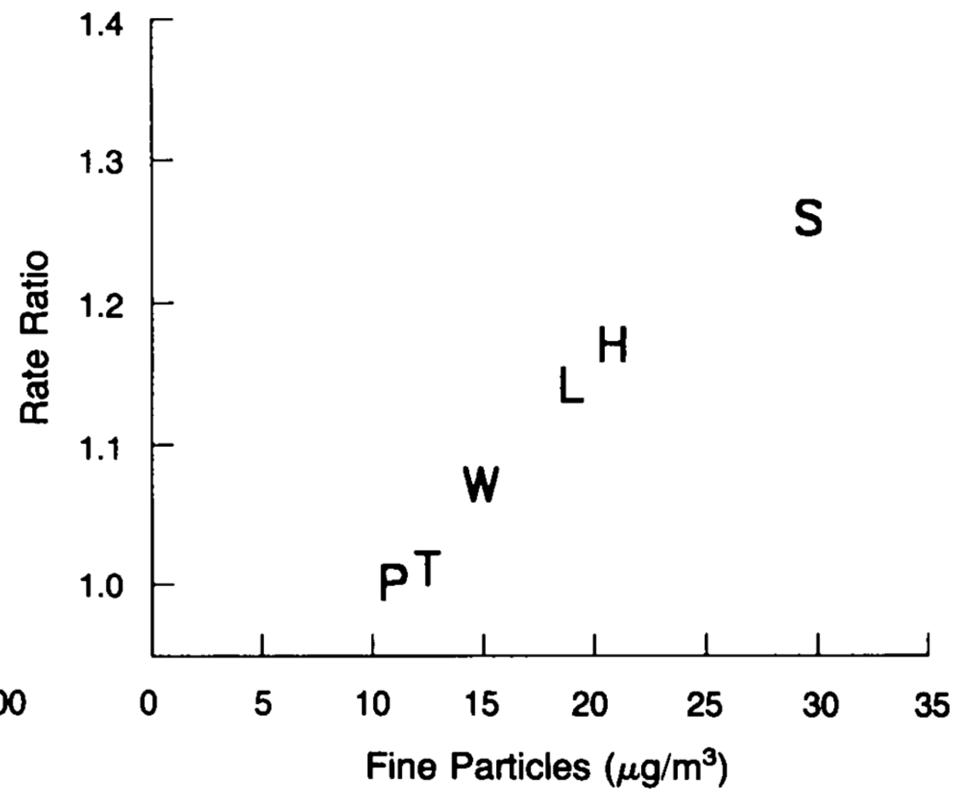
The New England
Journal of Medicine

Volume 329 | DECEMBER 9, 1993 | Number 24

AN ASSOCIATION BETWEEN AIR POLLUTION AND MORTALITY IN SIX U.S. CITIES

Douglas W. Dockery, Sc.D., C. Arden Pope III, Ph.D., Xiping Xu, M.D., Ph.D.,
John D. Spengler, Ph.D., James H. Ware, Ph.D., Martha E. Fay, M.P.H.,
Benjamin G. Ferris, Jr., M.D., and Frank E. Speizer, M.D.



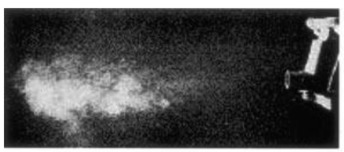


Why should we care about particles? Health

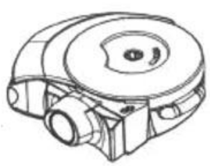
Dry, nonporous particles: Nektar Therapeutics

Liquid particles: Aradigm

Liquid particles: Aerogen



Dry, porous particle suspension in MDI: Alliance Pharmaceutical, Pulmospheres



Micronized crystals: Elan (formerly Dura Pharmaceutical)

Dry, porous particles: Alkermes

Technospheres and Medtone DPI: Mannkind Pharmaceuticals

Drug Delivery

The Focus

Particles in the Semiconductor Manufacturing Work Environment

Particles in the workplace

Web of Science Searches

Keywords: “Aerosol”, “Semiconductor”, “Health” = 2 papers

Keywords: “Particle”, “Semiconductor”, “Health” = 12 papers

Nanoparticles

(1) have a potentially high efficiency for deposition
(2) target both the upper/lower regions of the respiratory tract
(3) are retained in the lungs for a long period of time
(4) induce more oxidative stress and cause greater inflammatory effects than their larger fine-sized equivalents

Madl and Pinkerton, 2009, *Critical Reviews in Toxicology*

Particles in the workplace: From aerosolization to final health impact

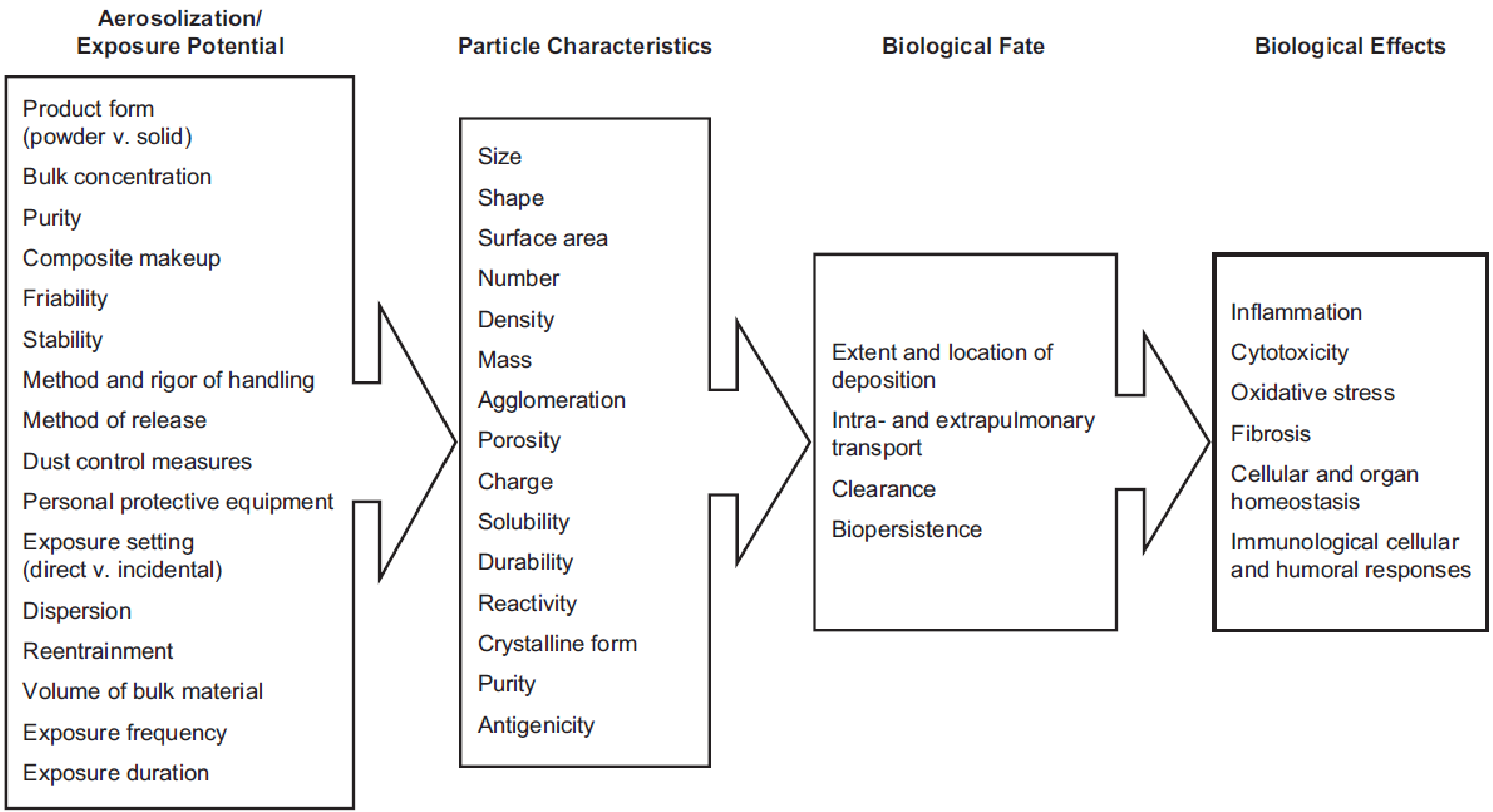


Figure 1. Potential important factors in correlating exposure, dosimetry, and health effects of inhaled nanoparticles.

Madl and Pinkerton, 2009, *Critical Reviews in Toxicology*

Respiratory Deposition

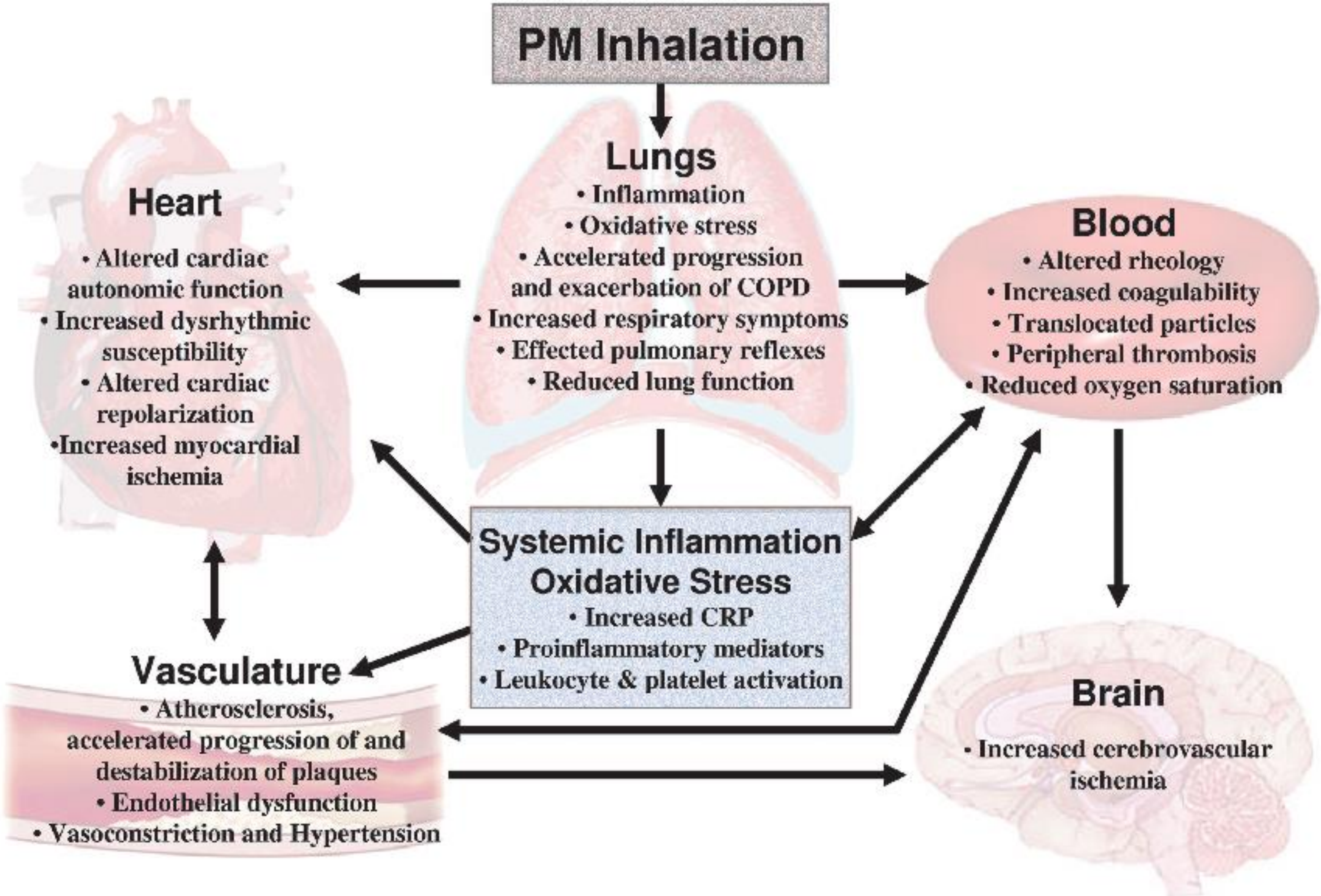
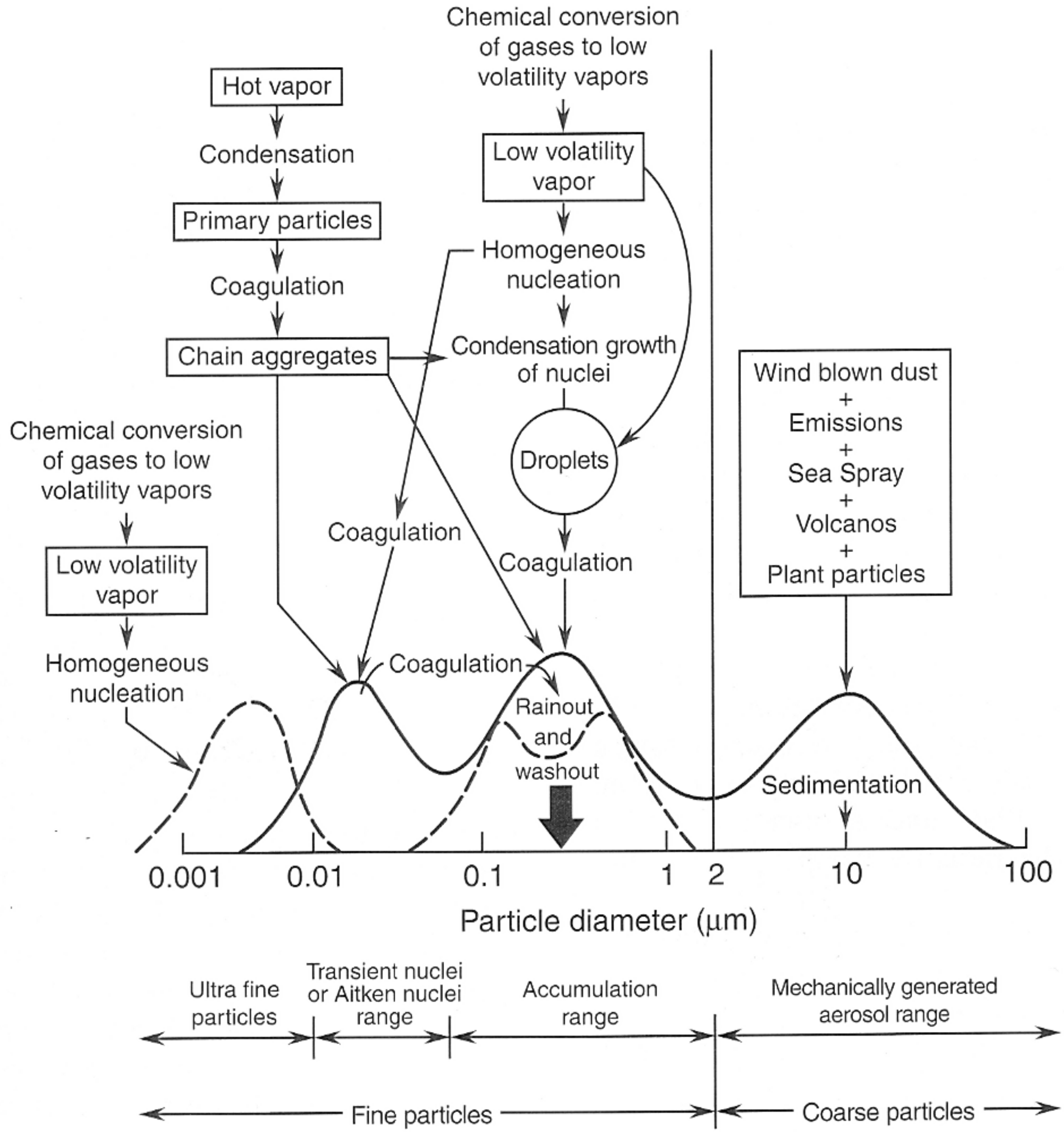


Figure 4. Potential general pathophysiological pathways linking PM exposure with cardiopulmonary morbidity and mortality.

Pope and Dockery (2006). JAWMA

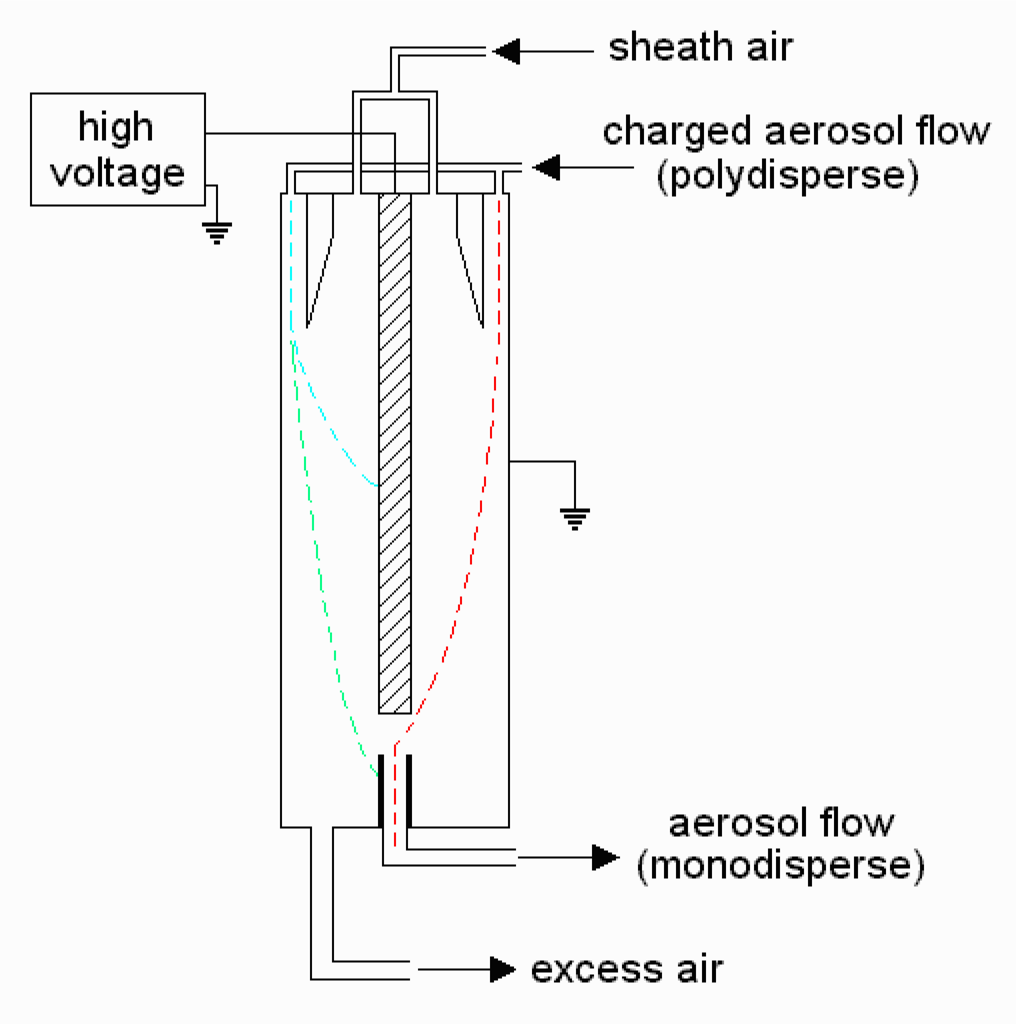
A critical aerosol measurement:
The size distribution

Aerosol Size Spectrum



Seinfeld & Pandis, 2006

Aerosol Instrumentation: Differential Mobility Analyzer



Aerosol Instrumentation: CN Counter

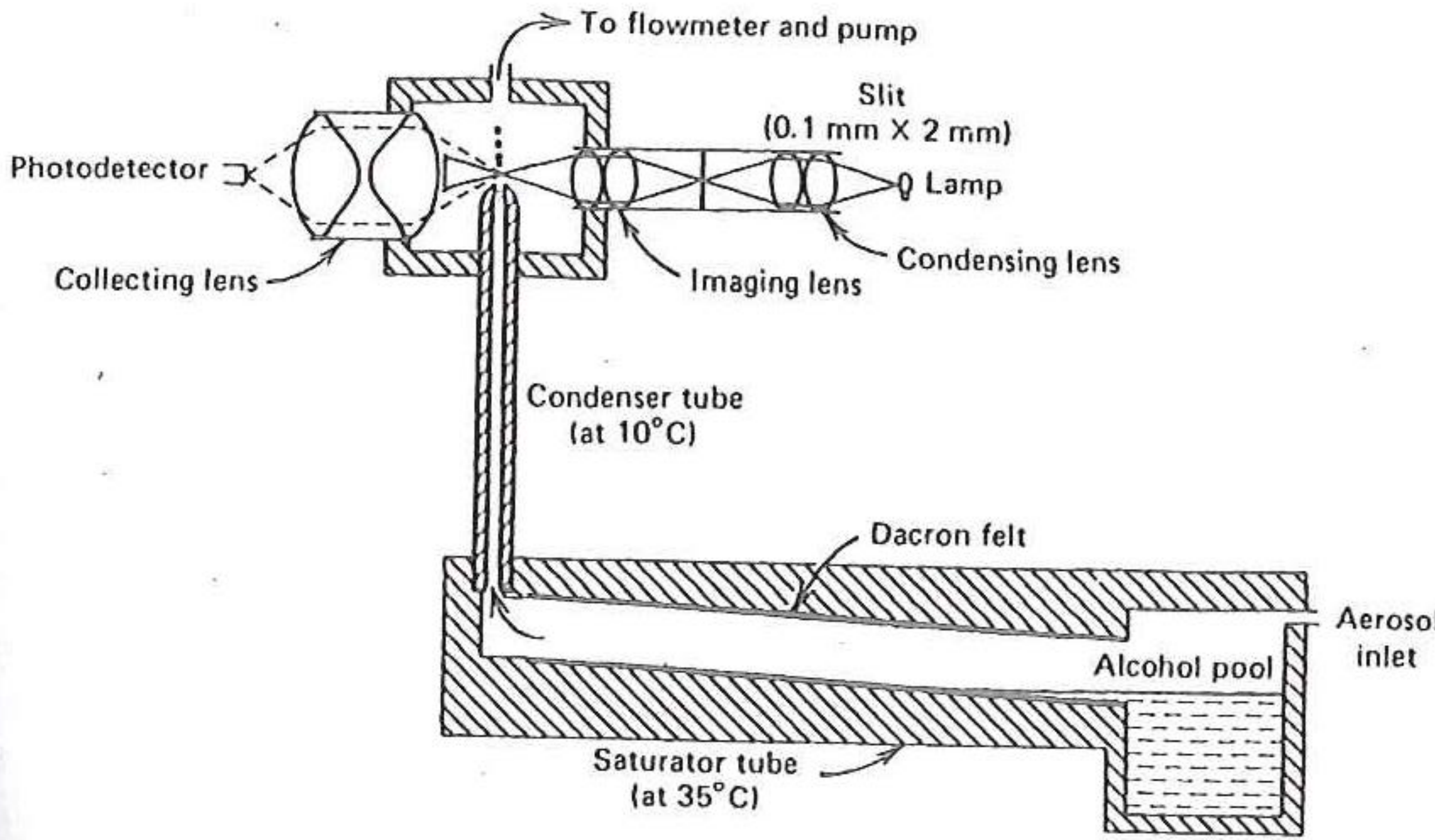


FIGURE 13.10 Schematic diagram of a continuous flow condensation nuclei counter. Reprinted with permission from Agarwal, J. K., and Sem, G. J. (1980).

Hinds, 1999

Ambient Size Distributions: Urban

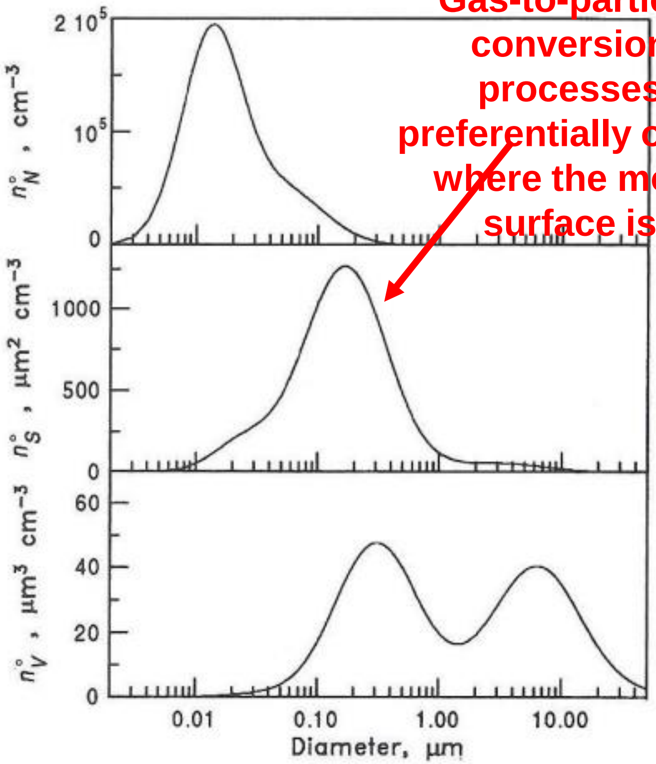


FIGURE 8.11 Typical urban aerosol number, surface, and volume distribution

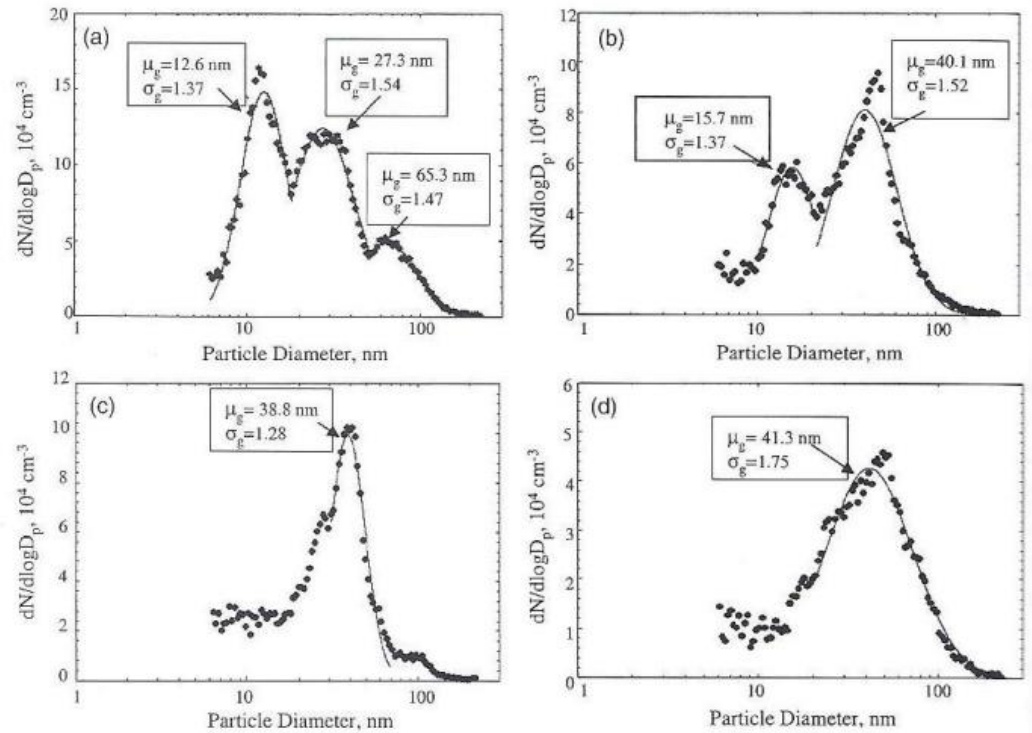


FIGURE 8.12 Measured and fitted multimodal number distributions at different distances downwind from a major road in Los Angeles (a) 30 m downwind, (b) 60 m downwind, (c) 90 m downwind, and (d) 150 m downwind. Please note the different scale for the y axis. Modal parameters given are the geometric mean diameter and geometric standard deviation (Zhu et al. 2002).

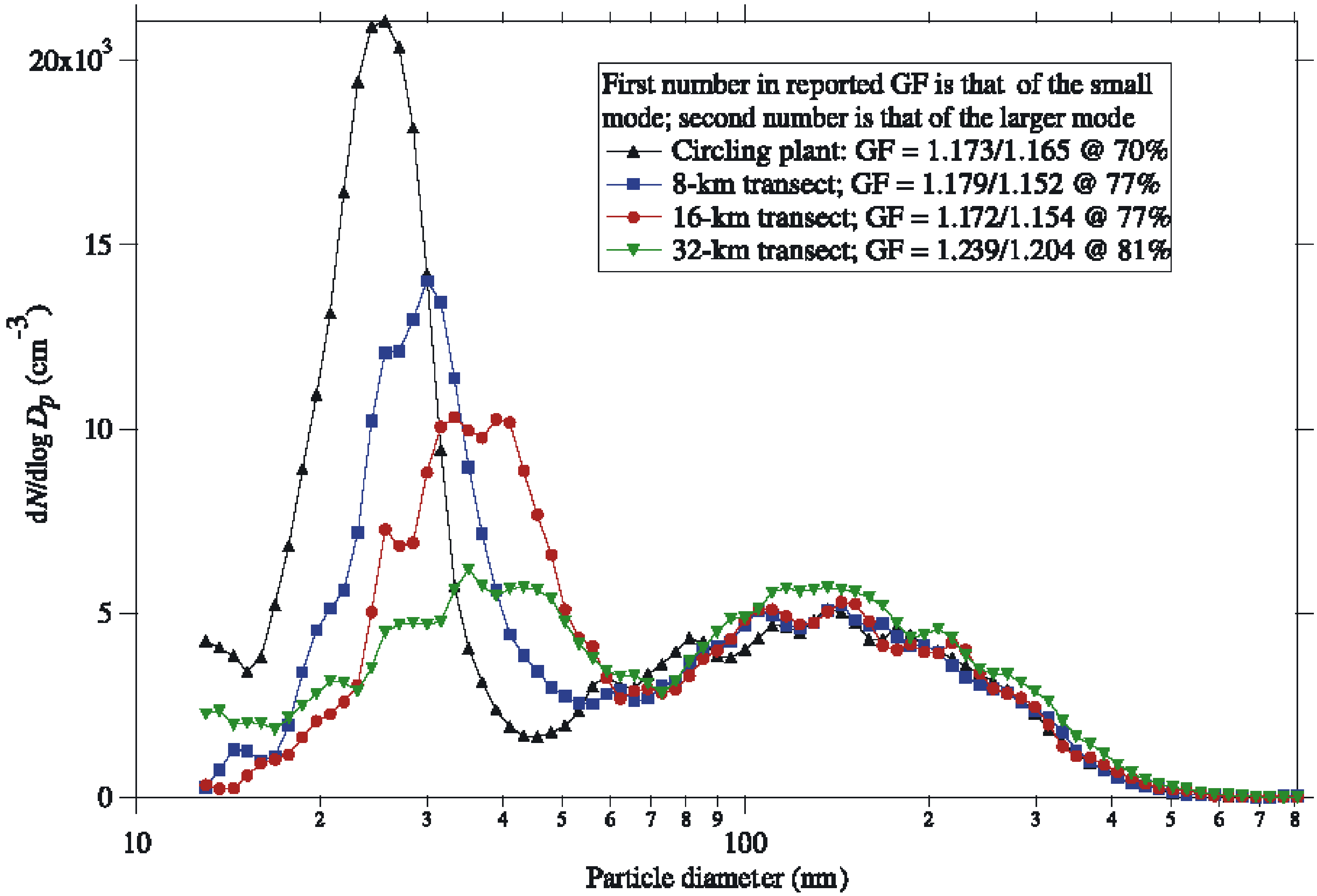
372

 # Concentration dominated by small particles (< 0.1 micron)
VERY high concentrations by sources with rapid decline with distance (e.g. freeways)

Sources: soil dust, sea salt, fly ash, tire wear particles, secondary organics/sulfate/nitrate

ICARTT: Conesville Power Plant Study (8/9/2004)
Cleveland, Ohio

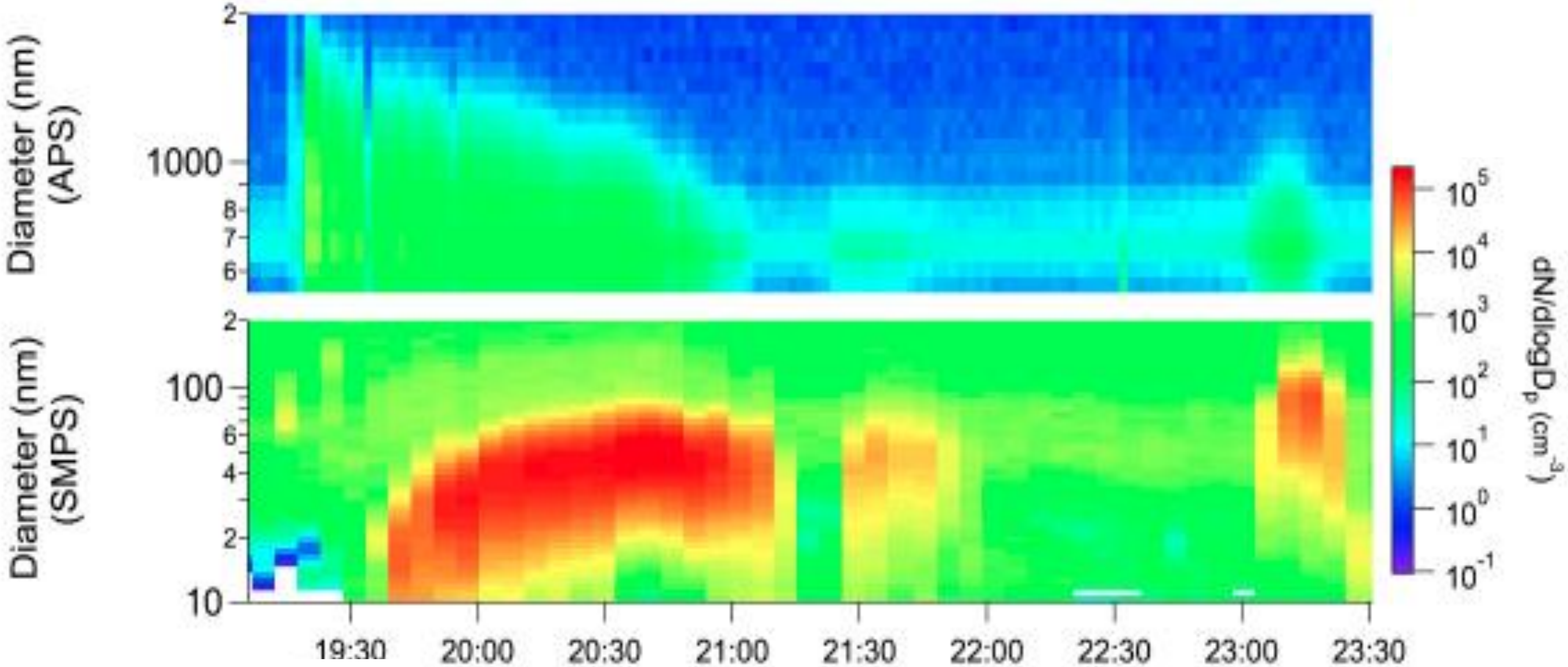
Evolution of Aerosol Size Distribution



Sorooshian et al. (2006), J. Geophysical Research

Field Work

Ambient example of a nucleation burst over the ocean as measured by a size distribution instrument on a Twin Otter aircraft



Wonaschuetz et al. (2013), Atmos. Chem. Phys. Disc.

Size dictates capture mechanisms:
(i) Filtration

Filtration

Six basic deposition mechanisms: inertial impaction, interception, diffusion, gravitational settling, electrostatic forces, interception of diffusing particles ("DR")

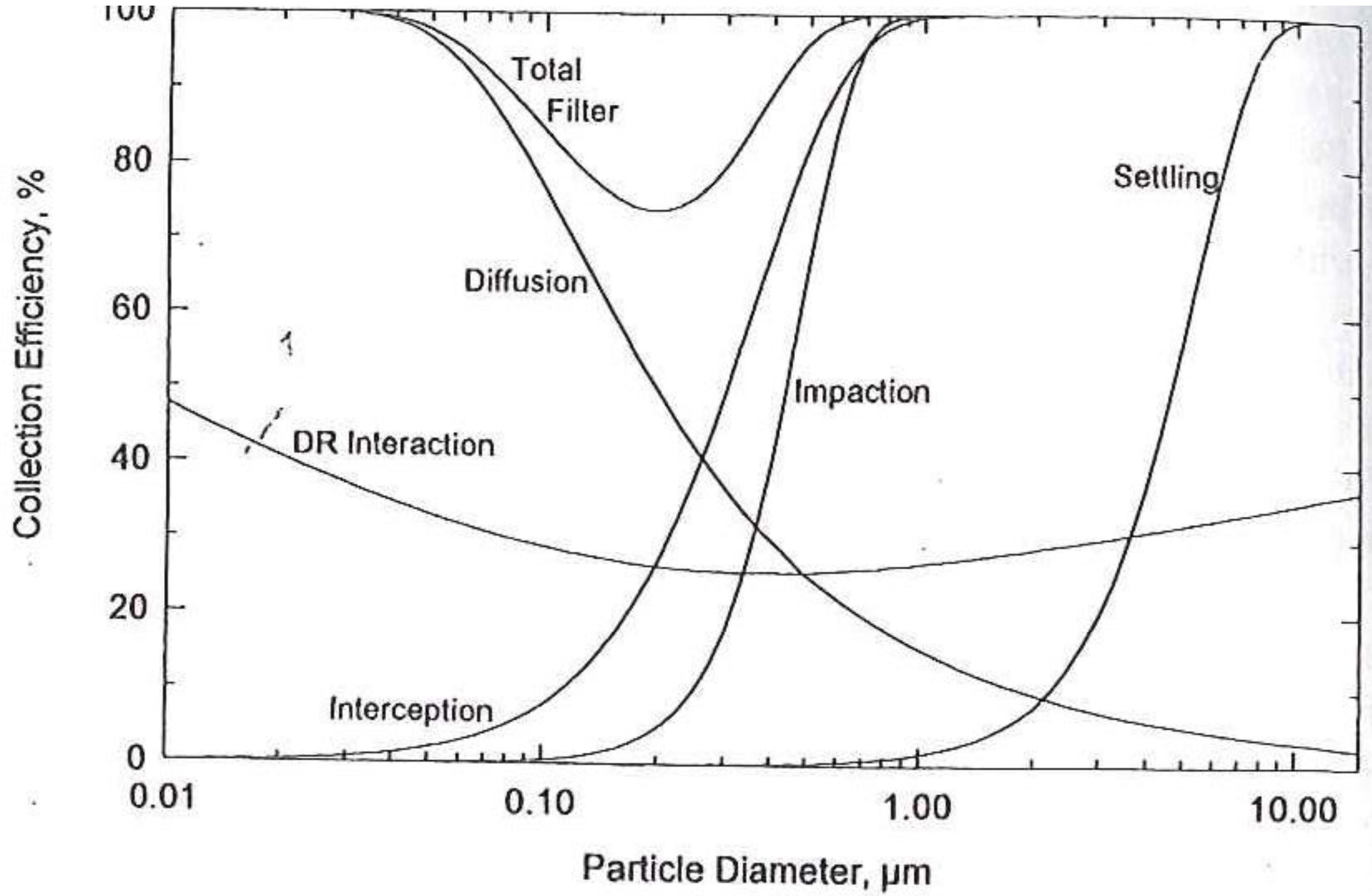


FIGURE 9.8 Filter efficiency for individual single-fiber mechanisms and total efficiency; t = 1 mm, α = 0.05, d_f = 2 µm, and U_0 = 0.10 m/s. [10 cm/s].

↑ thickness ↑ solidity ↑ face velocity

Hinds, 1999

Size dictates capture mechanisms:
(ii) Human respiratory system

Respiratory Deposition

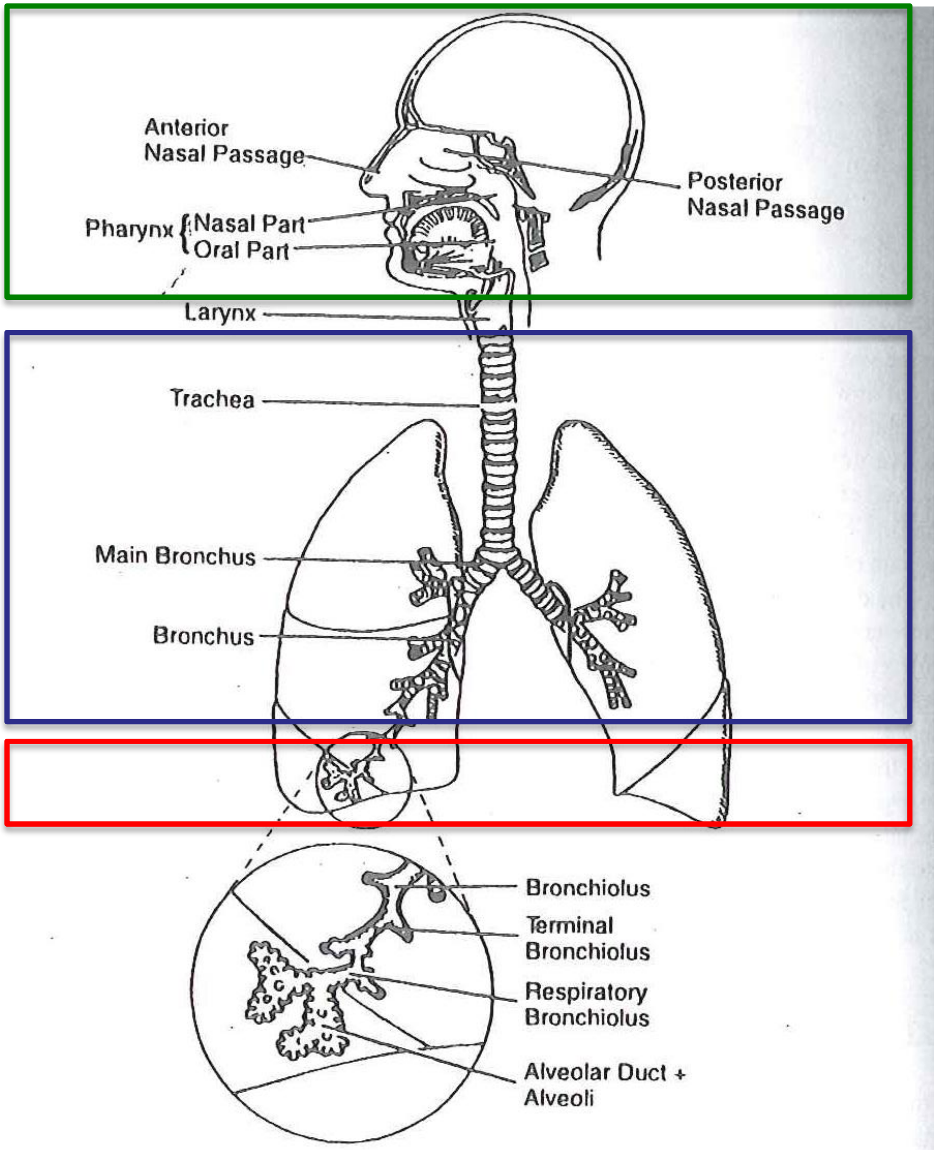


FIGURE 11.1 The respiratory system. Adapted from International Commission on Radiological Protection (1994).

Head Airways

Trachea and bronchi

Alveoli

This is where the gas exchange between air and blood stream happens

Deposition Upon Inhalation

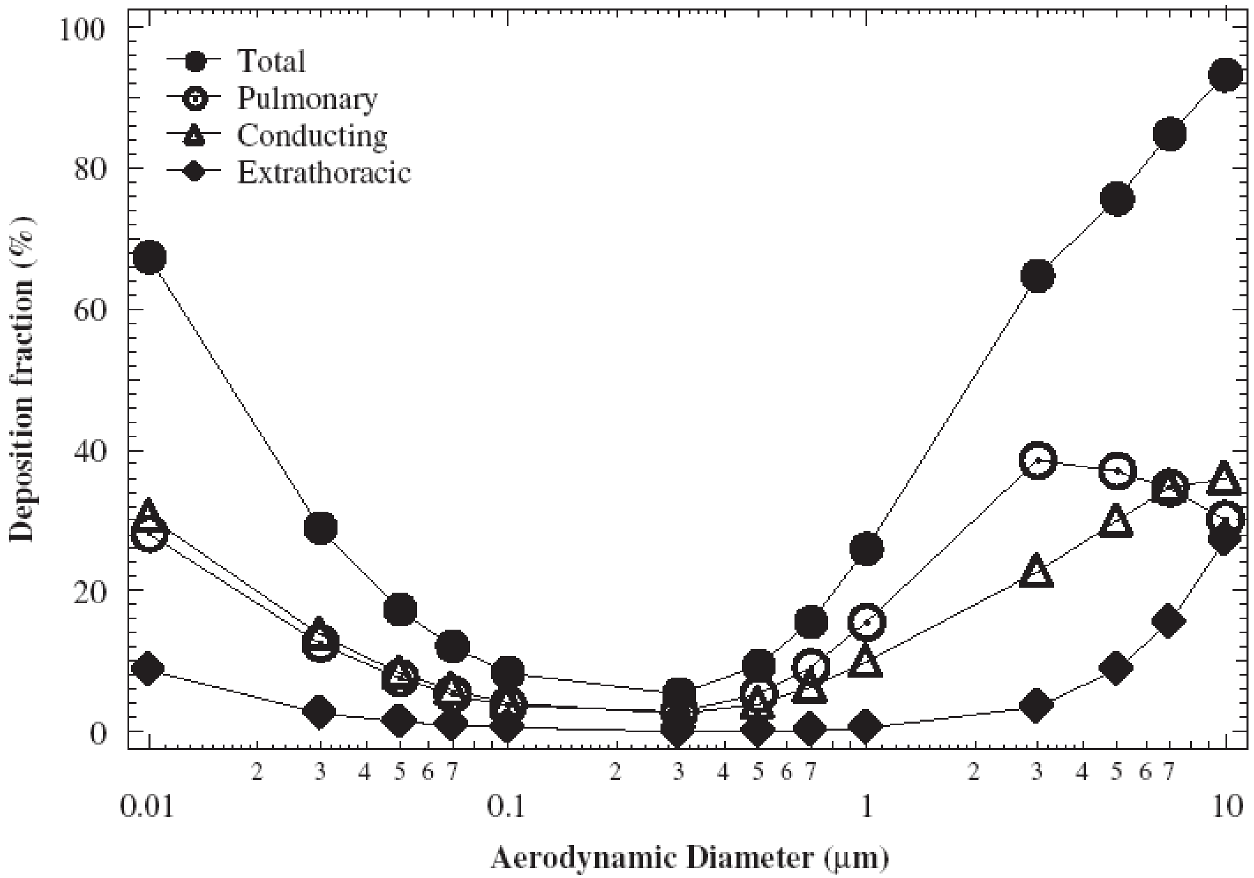


Fig. 2. Regional deposition fraction in the extrathoracic, conducting, and pulmonary airways during a single breath; model predictions are made using enhanced sedimentation efficiency by Haber et al. (2003) .

Park and Wexler (2008). J. Aerosol Science

Respiratory Deposition

TABLE 11.2 Relative Importance of Settling, Impaction, and Diffusion Mechanisms for Deposition of Standard Density Particles in Selected Regions of the Lung

Airway	Stopping Distance[a] Airway Diameter (%)			Settling Distance[b] Airway Diameter (%)			Rms Displacement[c] Airway Diameter (%)		
	0.1 μm	1 μm	10 μm	0.1 μm	1 μm	10 μm	0.1 μm	1 μm	10 μm
Trachea	0	0.08	6.8	0	0	0.52	0.04	0.01	0
Main bronchus	0	0.13	10.9	0	0	0.41	0.03	0.01	0
Segmental bronchus	0	0.31	27.2	0	0	0.22	0.05	0.01	0
Terminal bronchus	0	0.17	14.9	0	0.02	2.1	0.29	0.06	0.02
Terminal bronchiole	0	0.03	2.8	0	0.18	15.6	1.1	0.22	0.06
Alveolar duct	0	0	0.23	0.04	1.7	150	3.9	0.79	0.23
Alveolar sac	0	0	0.07	0.12	4.7	410	6.7	1.3	0.40

[a] Stopping distance at airway velocity for a steady flow of 3.6 m^3/hr [1.0 L/s].
[b] Settling distance = settling velocity × residence time in each airway at a steady flow of 3.6 m^3/hr [1.0 L/s].
[c] Rms displacement during residence time in each airway at a steady flow of 3.6 m^3/hr [1.0 L/s].

Coarse particle deposition by impaction

Medium-sized particles can settle (if they make it that far)

Fine particle deposition by diffusion

Hinds, 1999

Respiratory Deposition

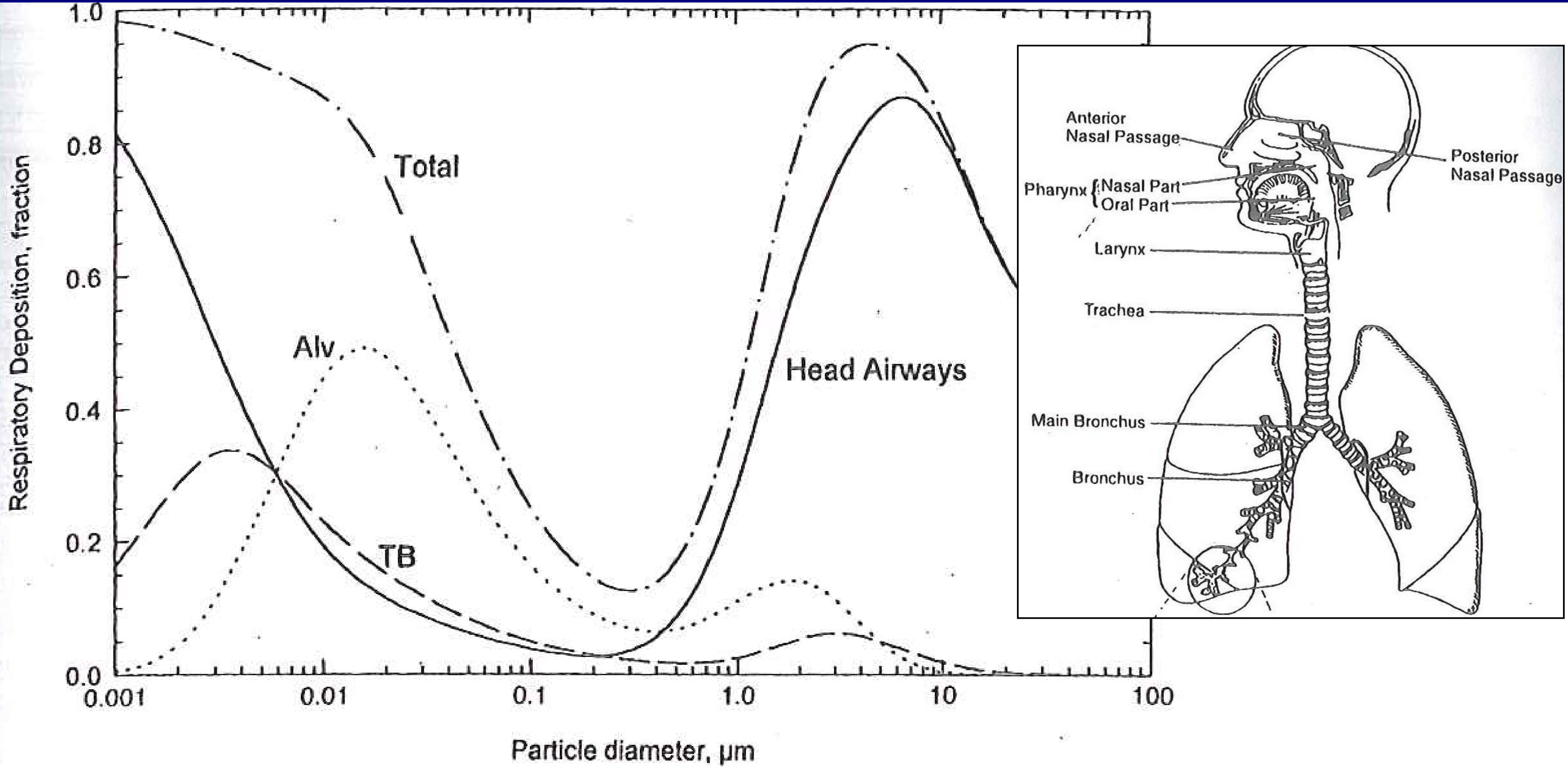
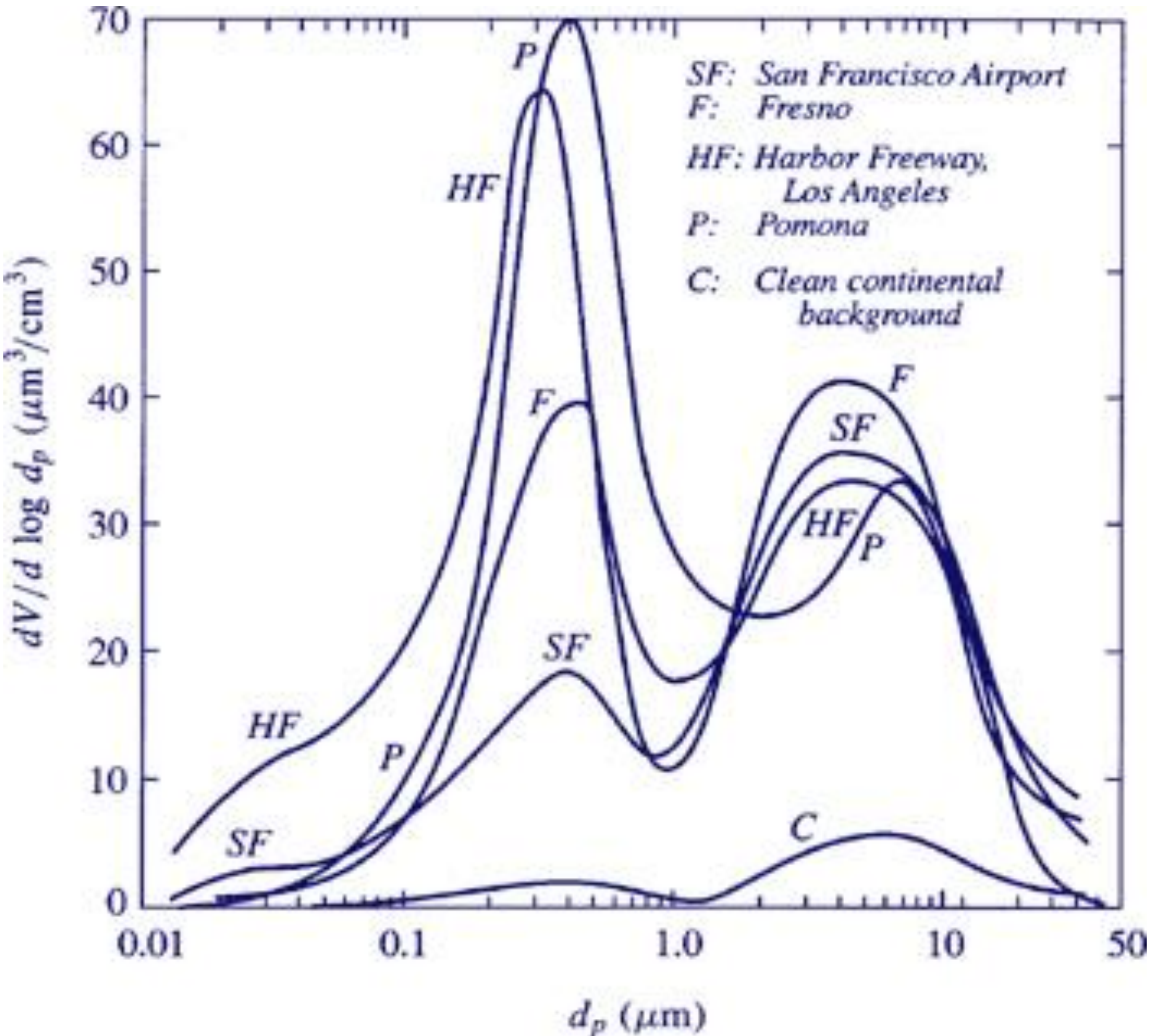


FIGURE 11.3 Predicted total and regional deposition for light exercise (nose breathing) based on ICRP deposition model. Average data for males and females.

Hinds, 1999

Respiratory Deposition



Typical aerosol volume distributions in a nice city to live in

Friedlander: "*Smoke, Dust, and Haze: Fundamentals of Aerosol Dynamics*", Second Edition, Oxford University Press, Inc. 2000

Respiratory Deposition

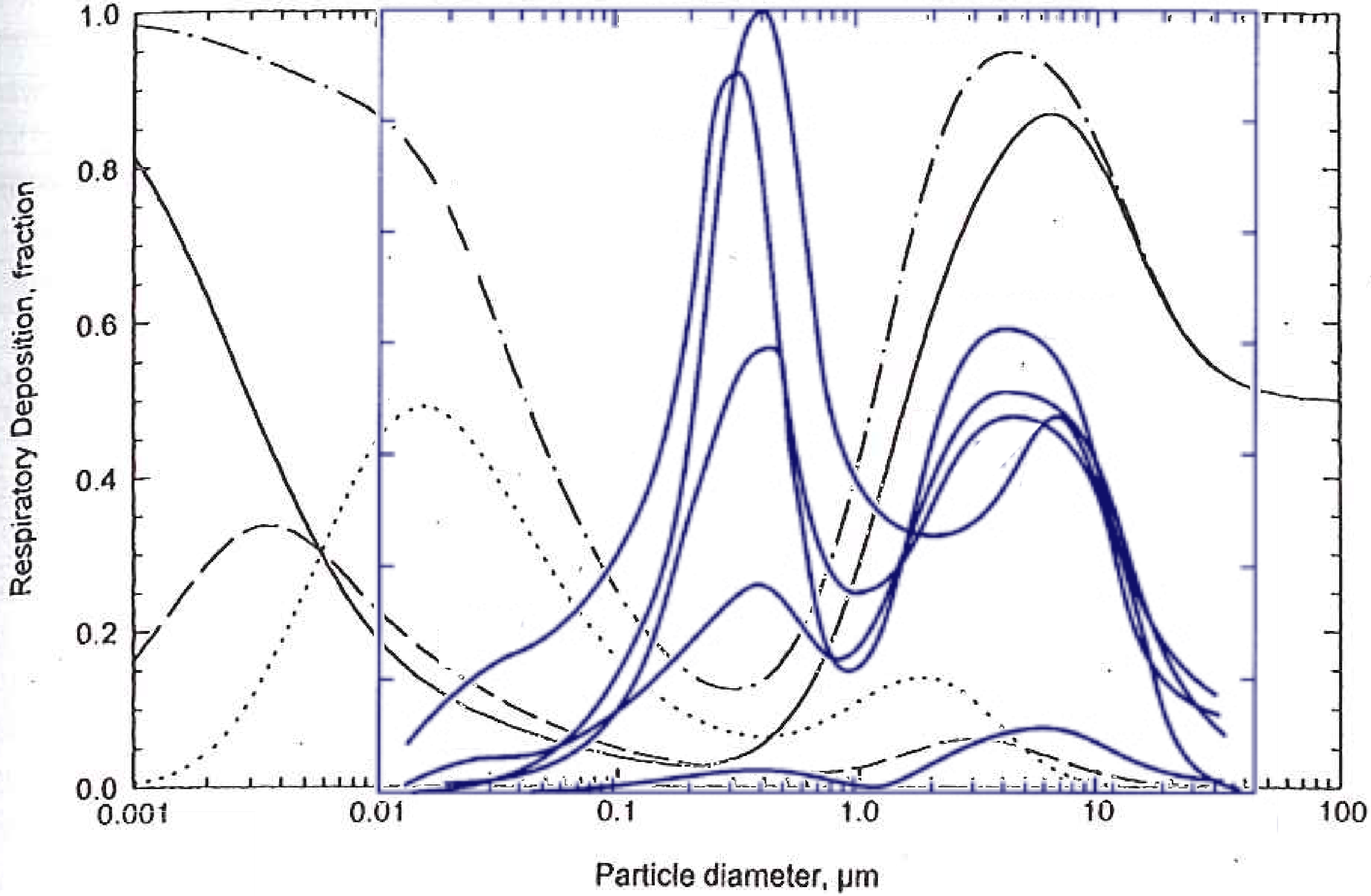


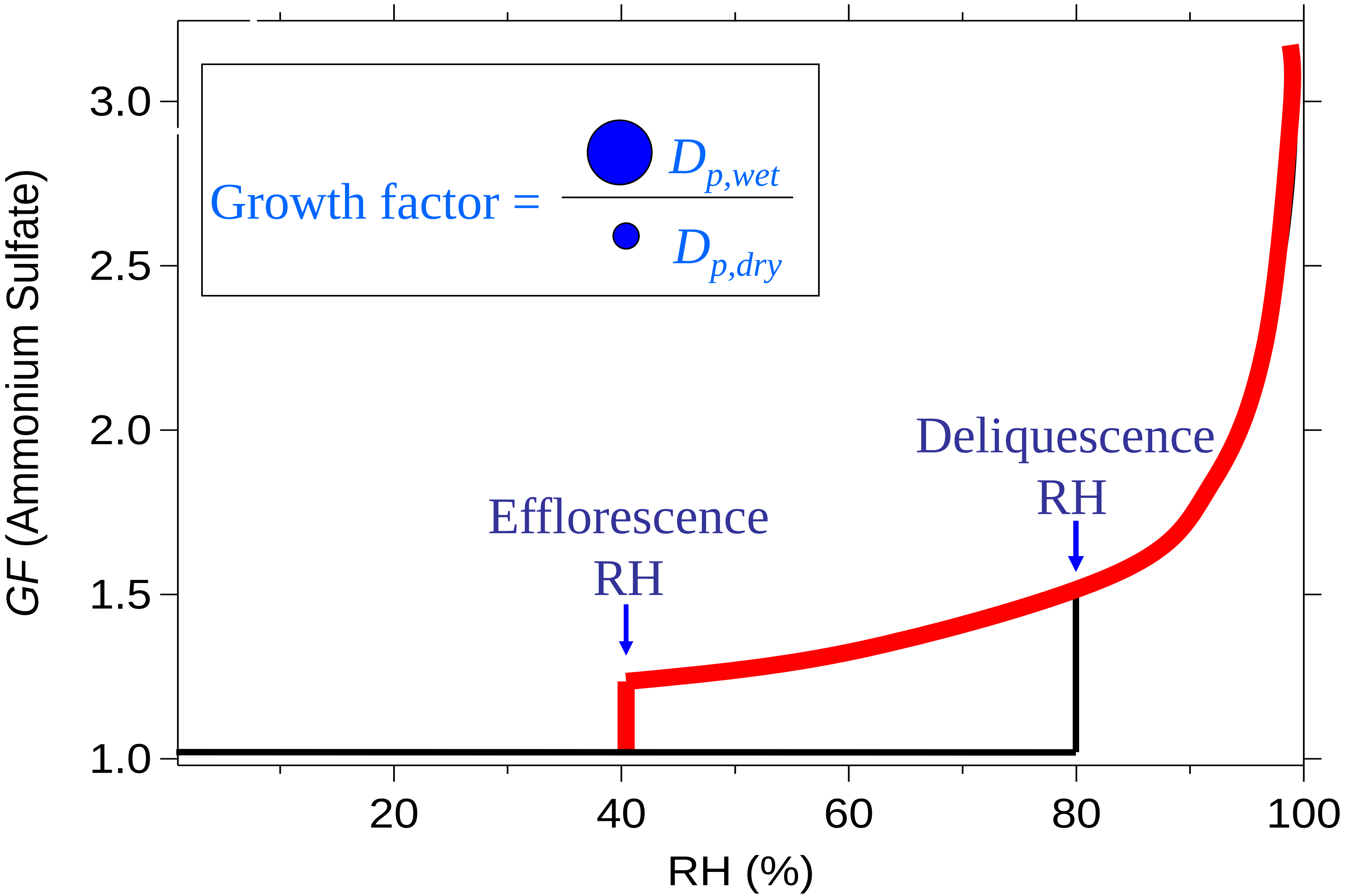
FIGURE 11.3 Predicted total and regional deposition for light exercise (nose breathing) based on ICRP deposition model. Average data for males and females.

Size dictates capture mechanisms:

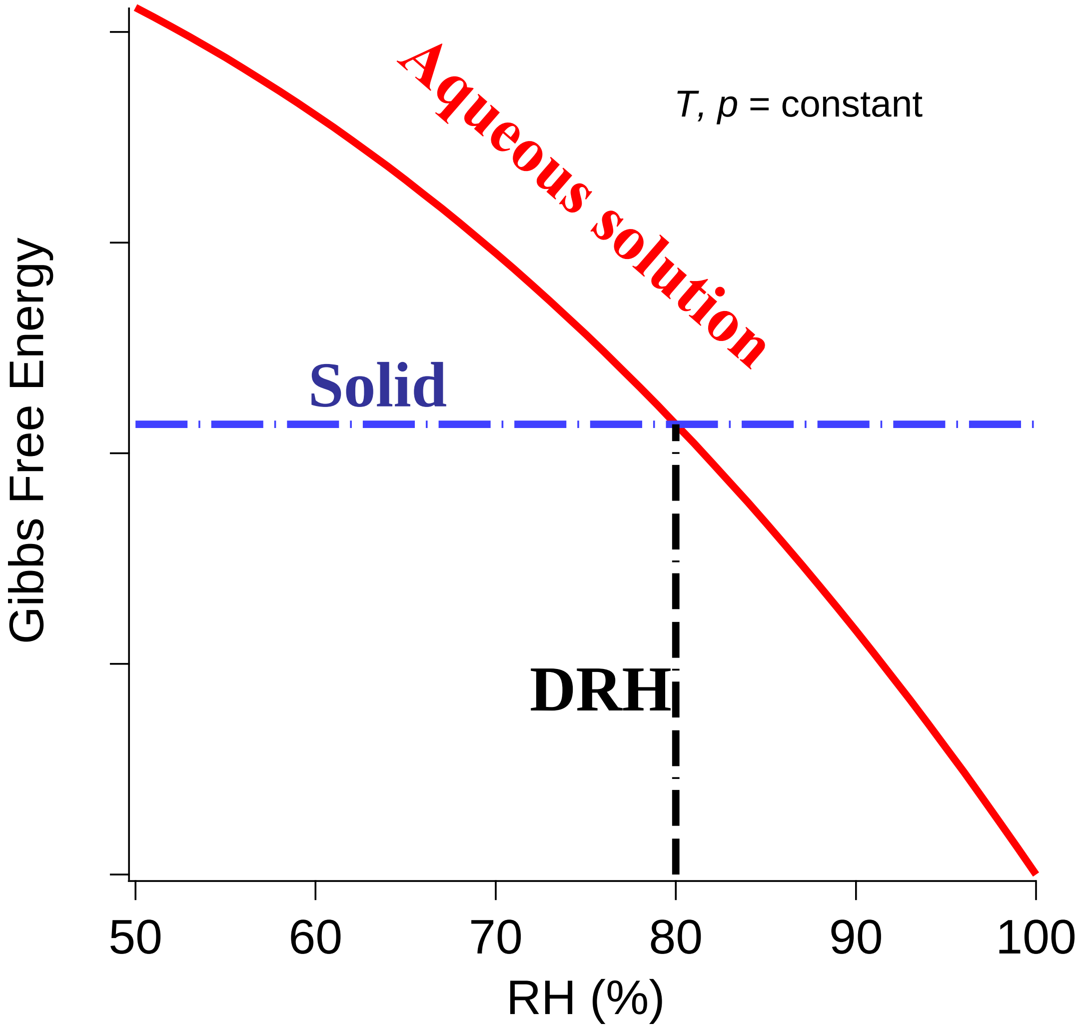
(ii) Human respiratory system

But the size of particles may change upon inhalation! Why?

Sub-saturated Water-Uptake



Sub-saturated Water-Uptake



Gibbs free energy of solid salt and its aqueous solution are equal at DRH

Aerosol Thermodynamics

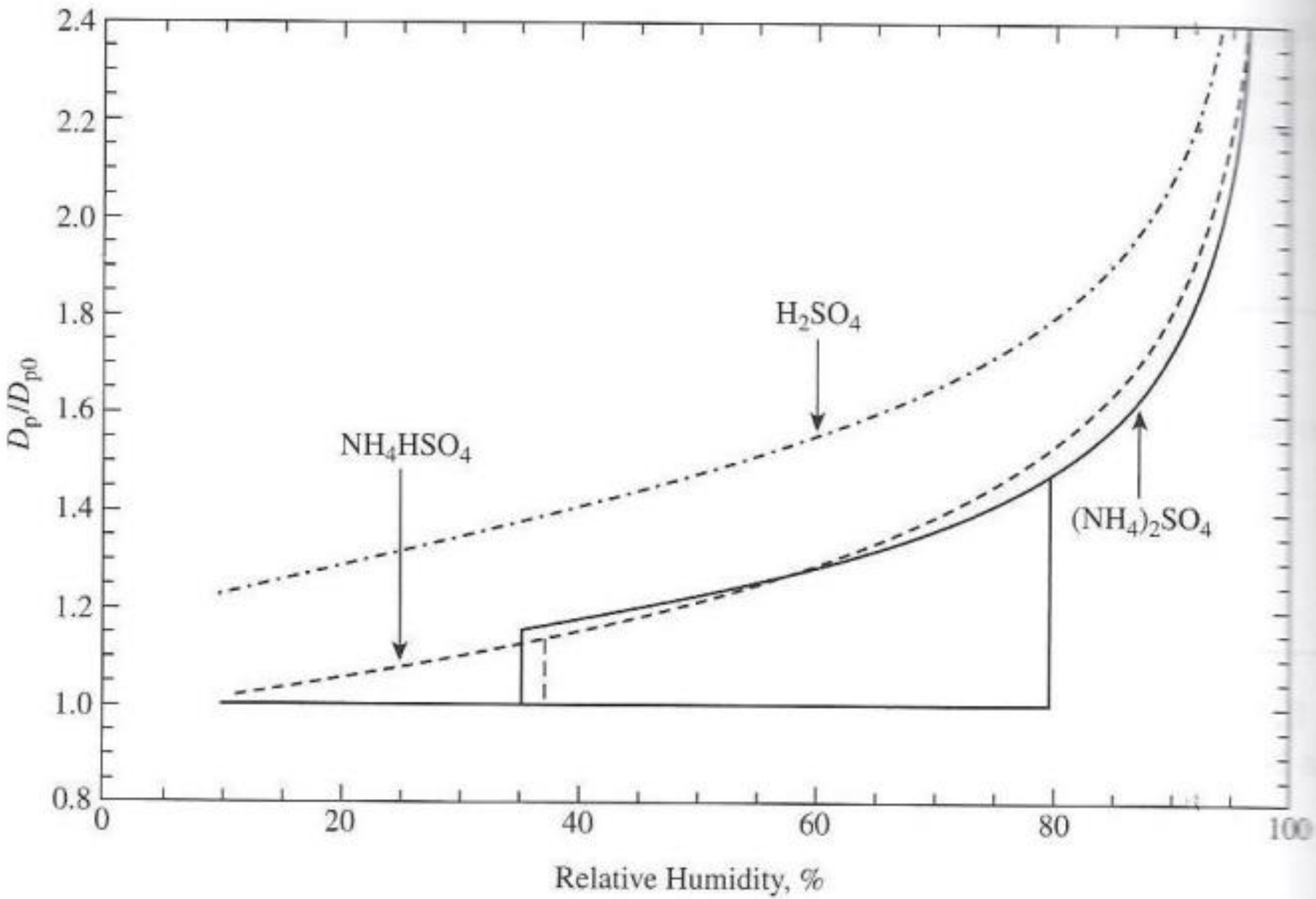


FIGURE 10.4 Diameter change of $(NH_4)_2SO_4$, NH_4HSO_4, and H_2SO_4 particles as a function of relative humidity. D_{p0} is the diameter of the particle at 0% RH.

Seinfeld & Pandis, 2006

Aerosol Thermodynamics

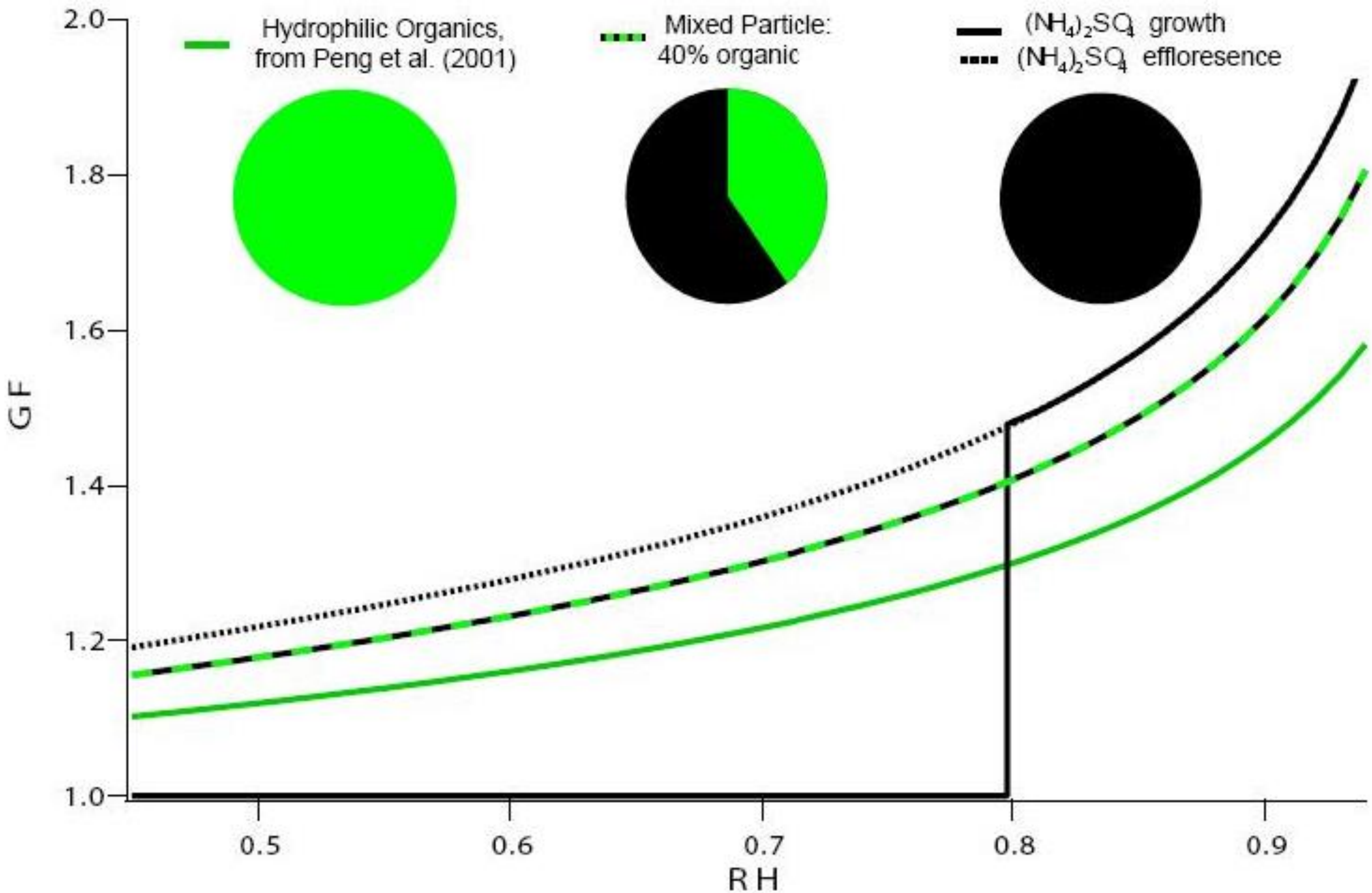
TABLE 10.1 Deliquescence Relative Humidities of Electrolyte Solutions at 298 K

Salt	DRH (%)
KCl	84.2 ± 0.3
Na_2SO_4	84.2 ± 0.4
NH_4Cl	80.0
$(NH_4)_2SO_4$	79.9 ± 0.5
NaCl	75.3 ± 0.1
$NaNO_3$	74.3 ± 0.4
$(NH_4)_3H(SO_4)_2$	69.0
NH_4NO_3	61.8
$NaHSO_4$	52.0
NH_4HSO_4	40.0

Sources: Tang (1980) and Tang and Munkelwitz (1993).

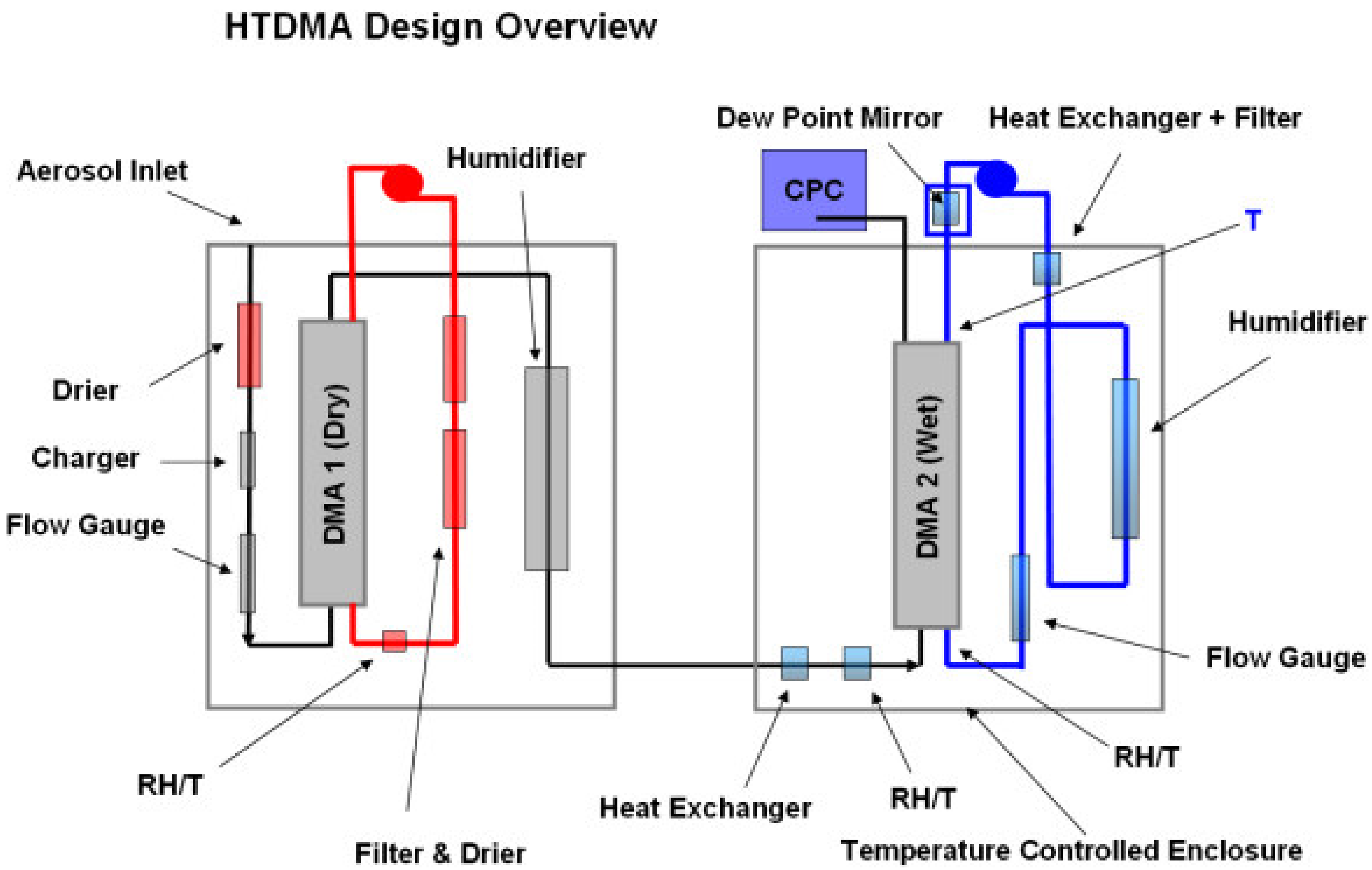
Seinfeld & Pandis, 2006

The important effect of composition on water uptake



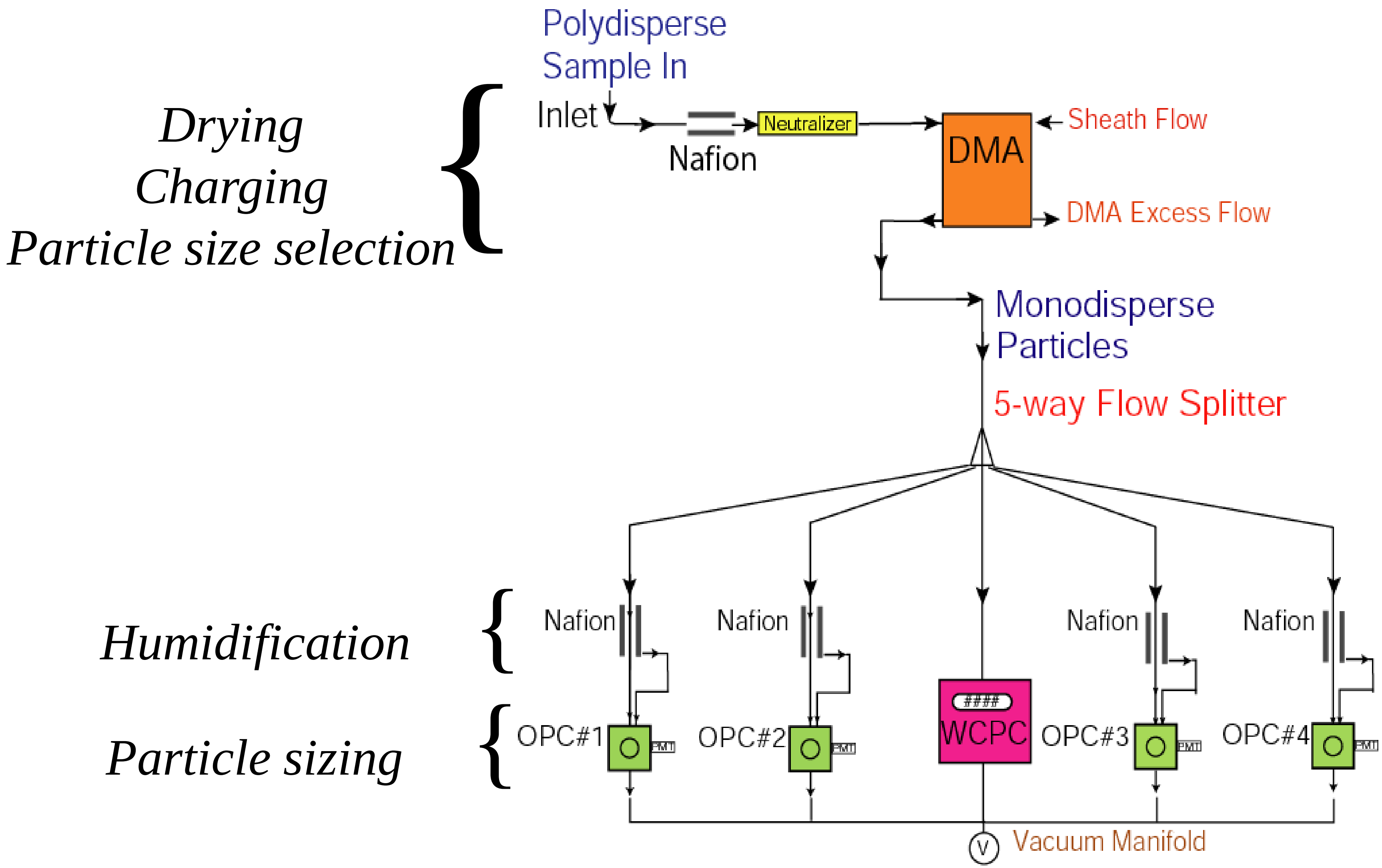
Hersey et al. (2009), Atmospheric Chemistry and Physics

Aerosol Instrumentation: Hygroscopic Tandem Differential Mobility Analyzer



Source: http://www.cas.manchester.ac.uk/

Differential Aerosol Sizing and Hygroscopicity Spectrometer Probe (DASH-SP)



Sorooshian et al., 2008 (Aerosol Science and Technology)

Field Experiment Case Studies of Particle Size, Composition, and Hygroscopicity

Impaction: Cascade Impactor

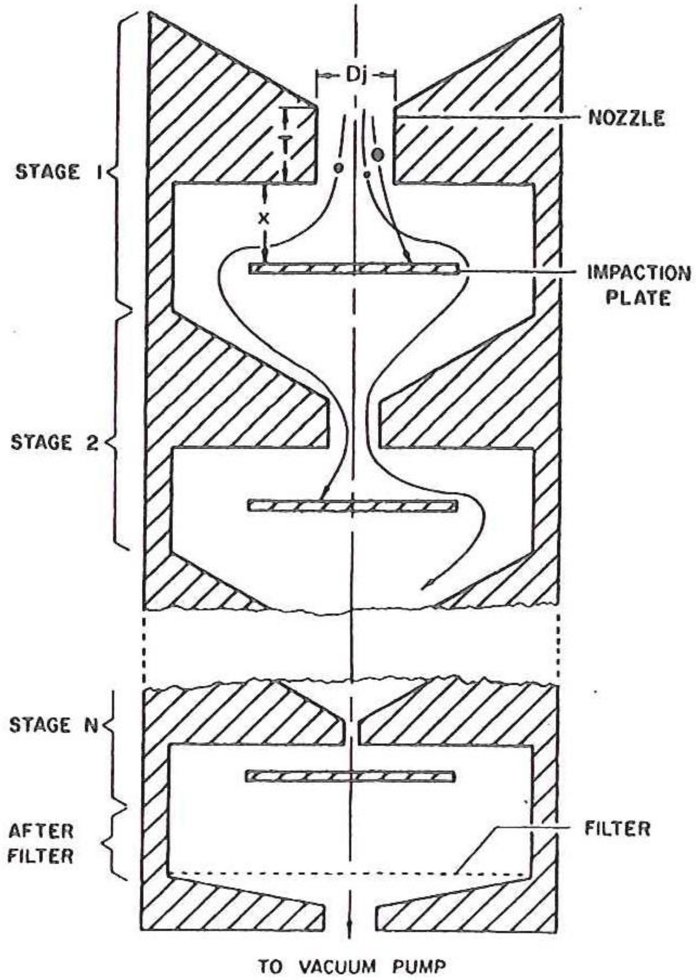
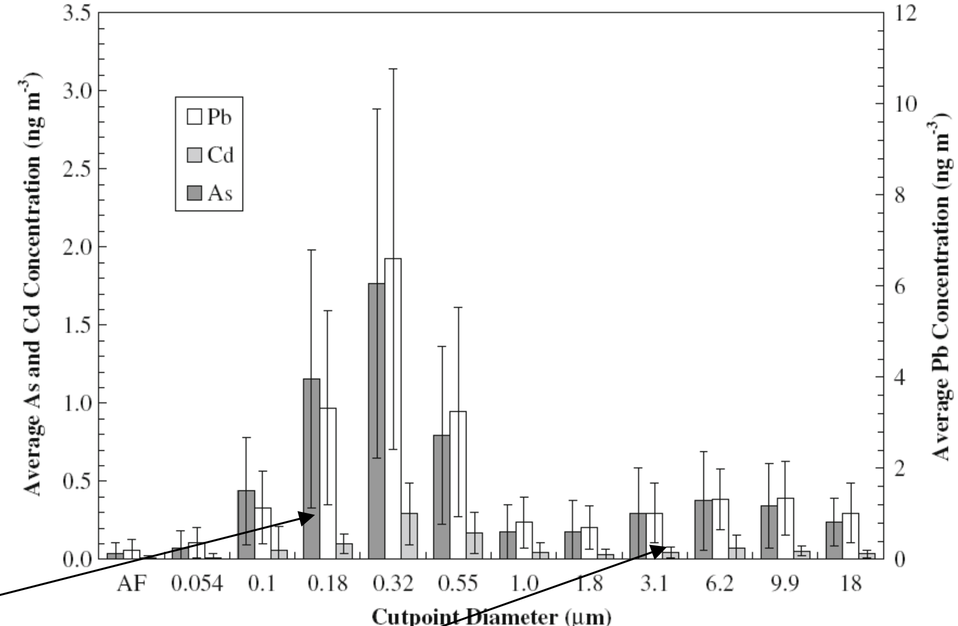
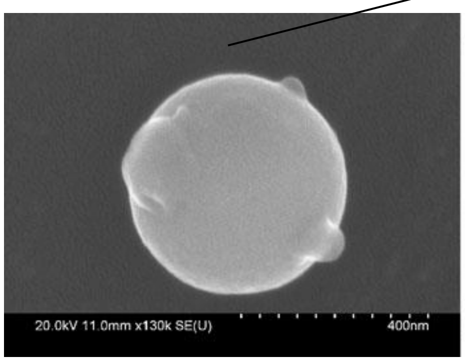


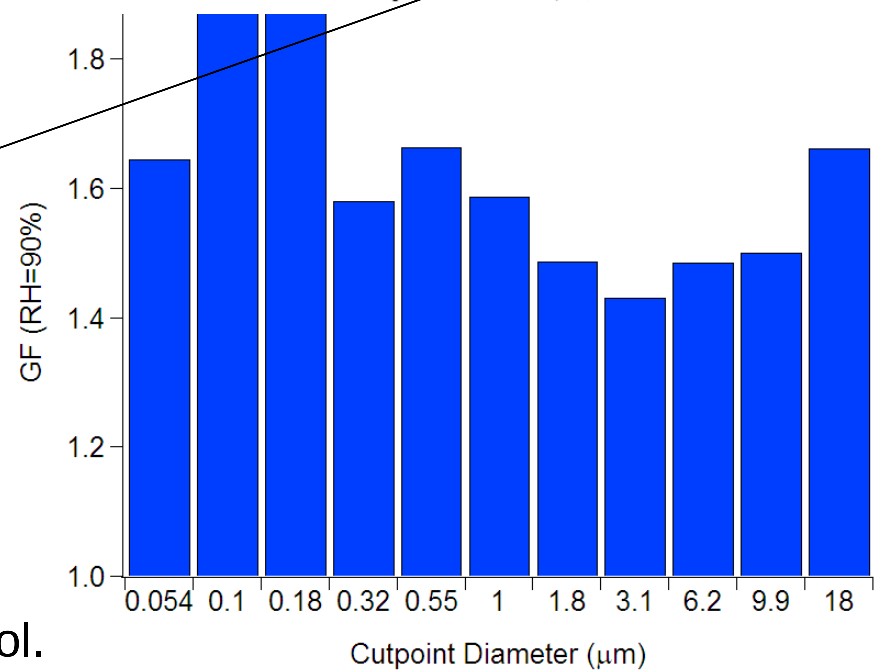
FIGURE 5.9 Cascade impactor (*a*) Schematic diagram. Reprinted with permission from *Aerosol Measurement*, by Dale Lundgren et al. Copyright 1979 by the Board of Regents of the State of Florida. (*b*) Eight stage Anderson ambient cascade impactor with nozzle plate and impaction plate shown at left.

Kulkarni, Baron, and Willeke, Aerosol Measurement (2011)

Arizona – Mine Tailings and Smelter Emissions

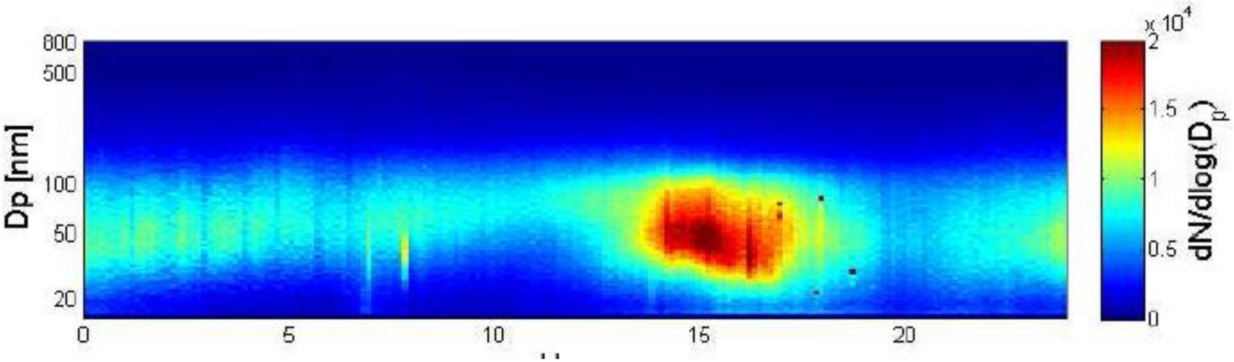


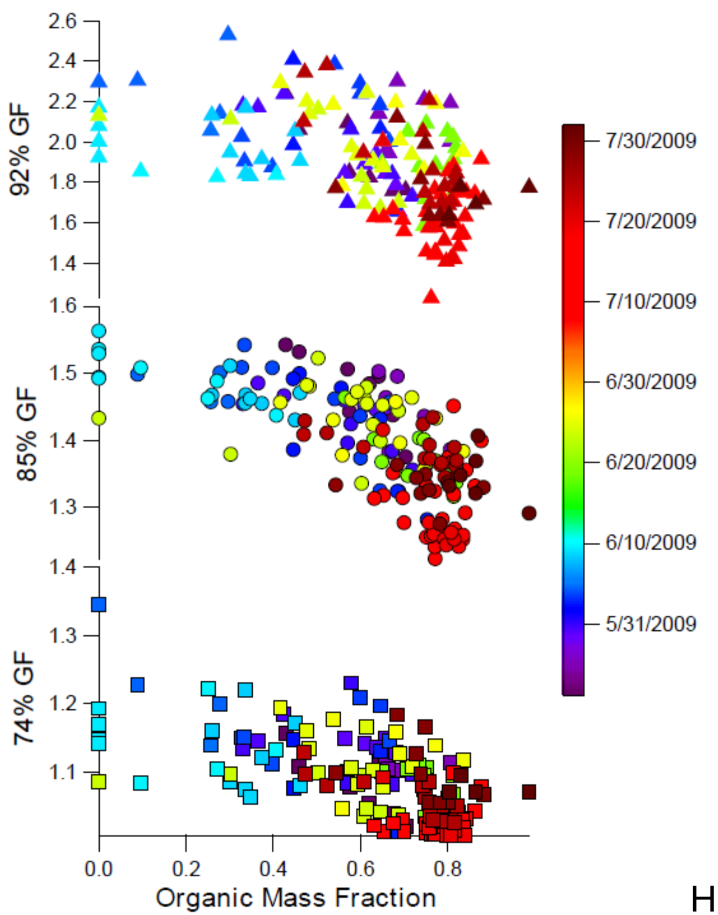


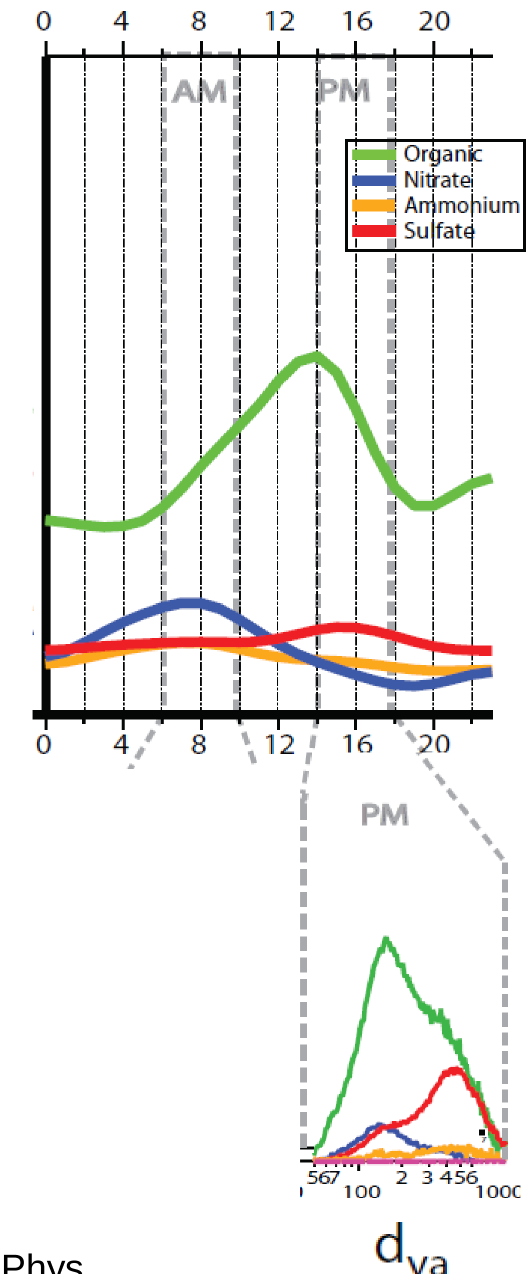


Csavina et al. (2011), Water Air Soil Pollut.
Sorooshian et al. (2012), Environ. Sci. Technol.

Los Angeles Basin: Surface Measurements in 2009



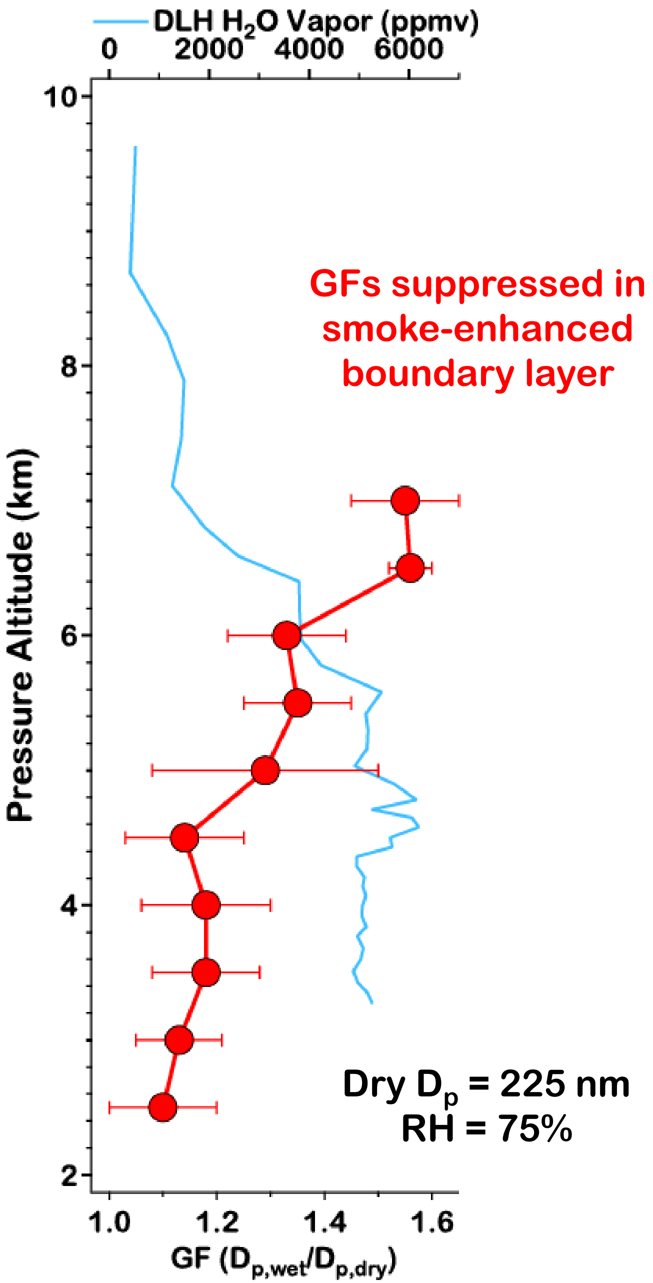


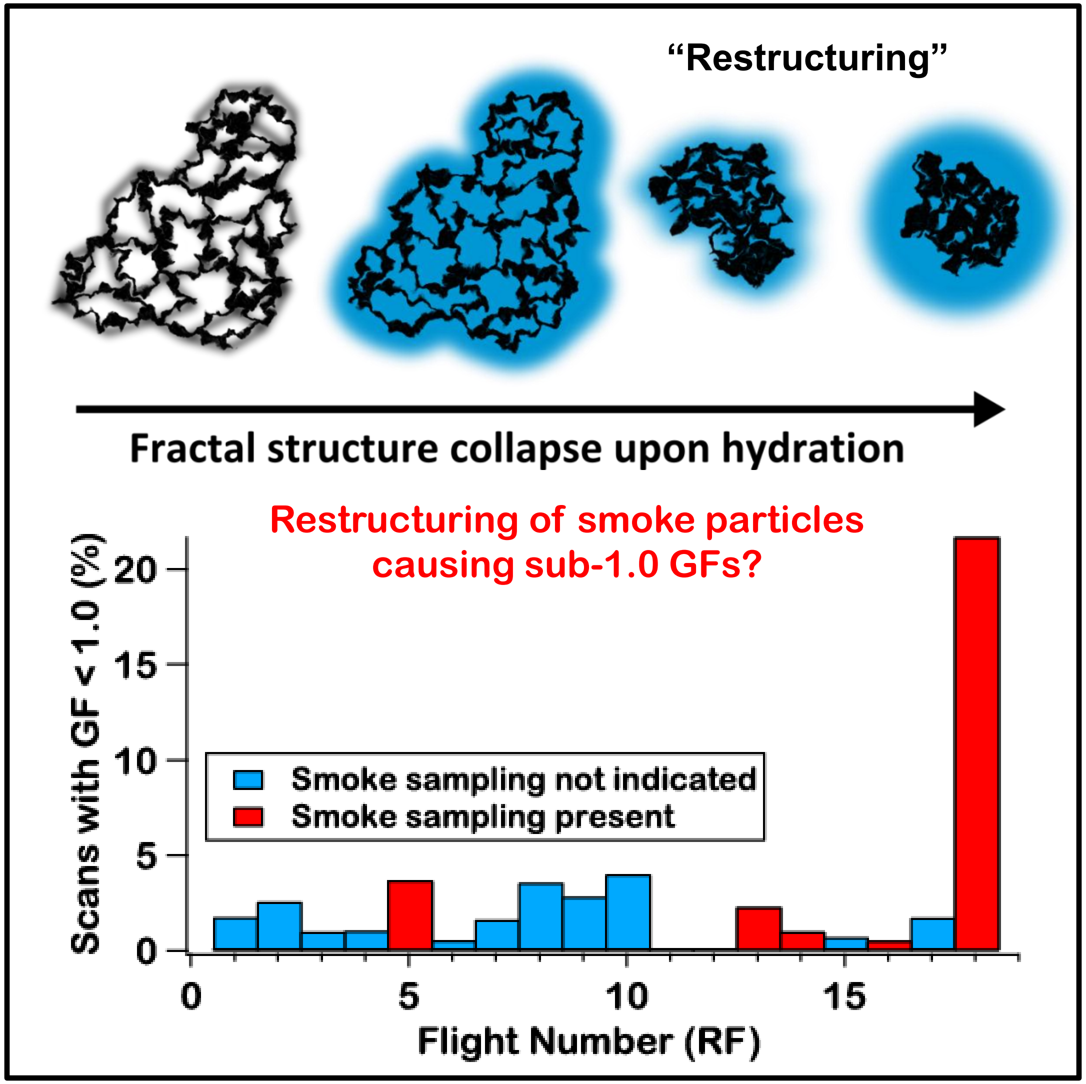


Hersey et al. (2011), Atmos. Chem. Phys.

Aerosol Hygroscopicity During RF18 (DC-8) / Colorado / Smoke Flight

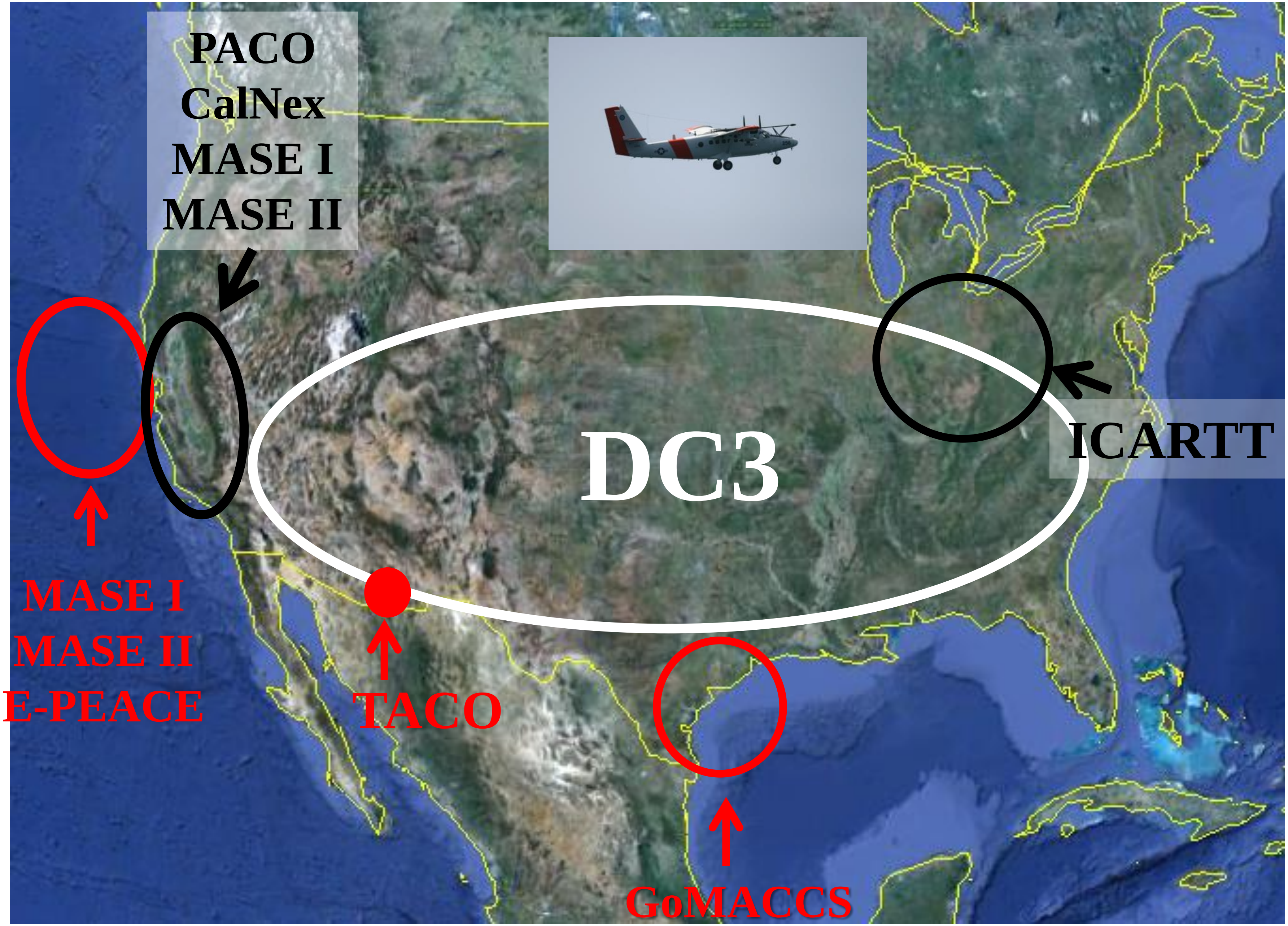
DC-8 / Taylor Shingler and Armin Sorooshian / University of Arizona





Thank you for your attention…

Surface and Airborne Measurements



Particle Shapes

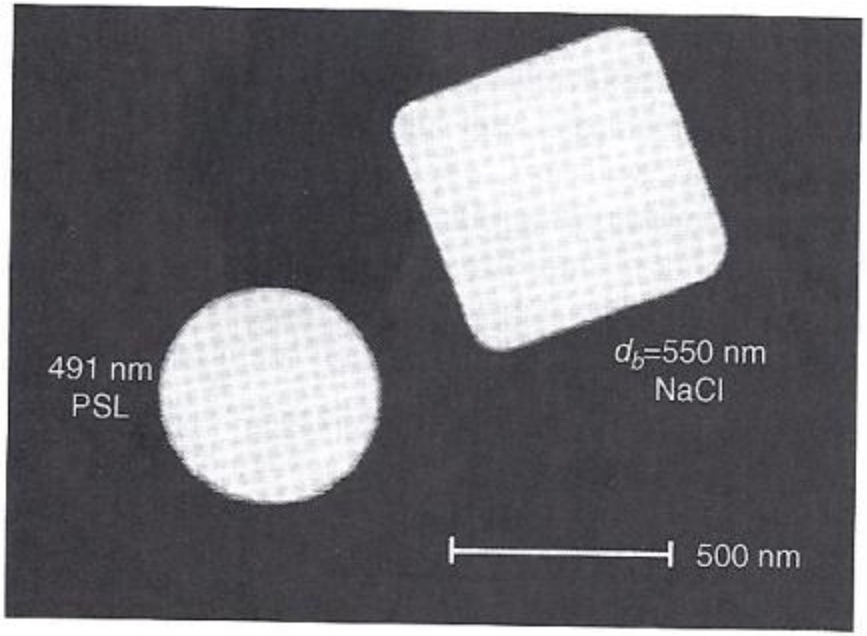


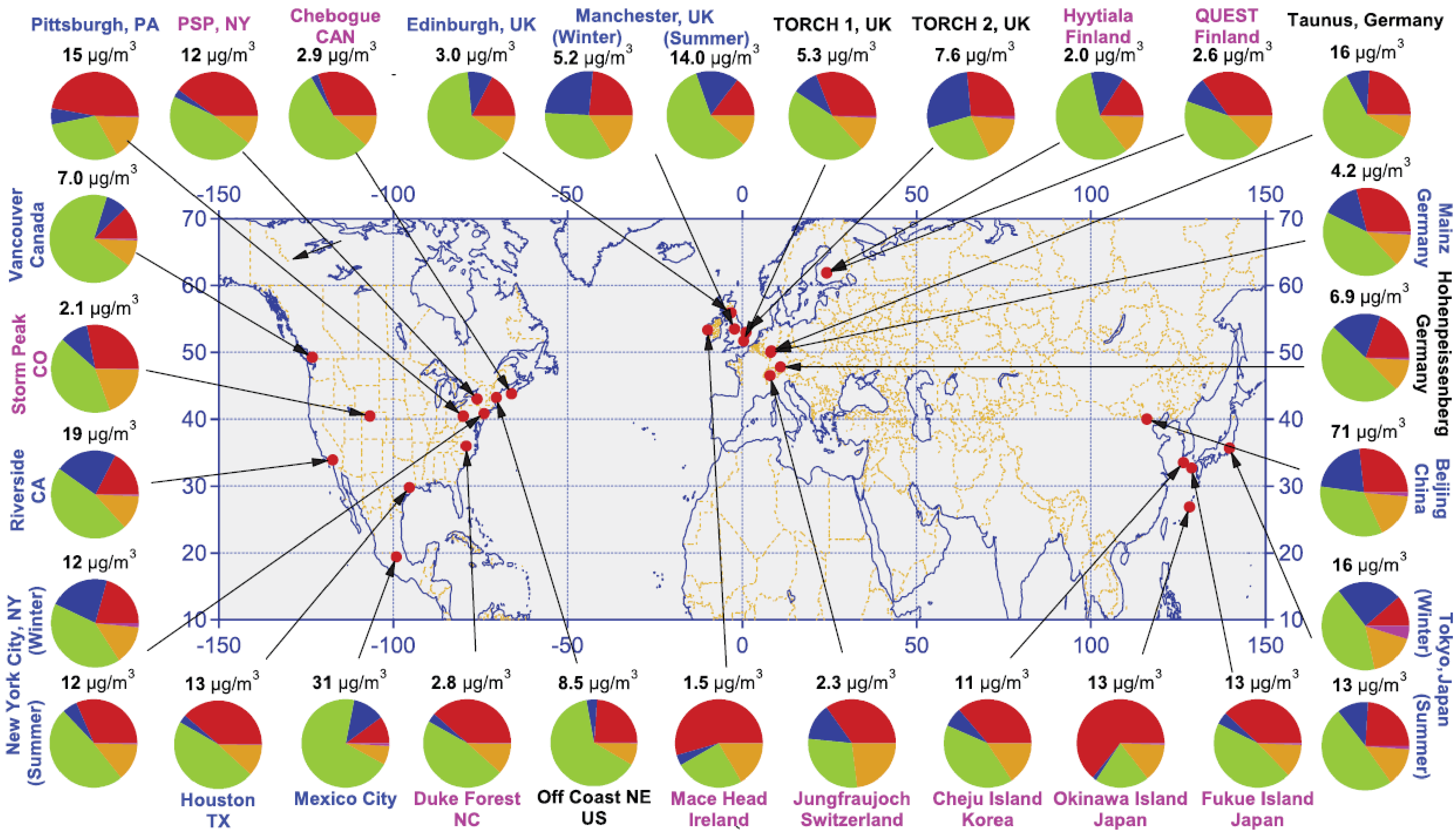
FIGURE 9.15 A micrograph of a single NaCl particle with electrical mobility equivalent diameter of 550 nm. The dry NaCl is almost cubic with rounded edges. Also shown is a polystyrene latex (PSL) particle with diameter of 491 nm (Zelenyuk et al. 2006).

Hinds, 1999

Secondary Organic Aerosol (SOA)

Green = organics; Red = sulfate; Blue = nitrate; Orange = ammonium

Excludes black carbon and dust



Zhang et al. (2007), Geophys. Res. Lett.

Adhesion

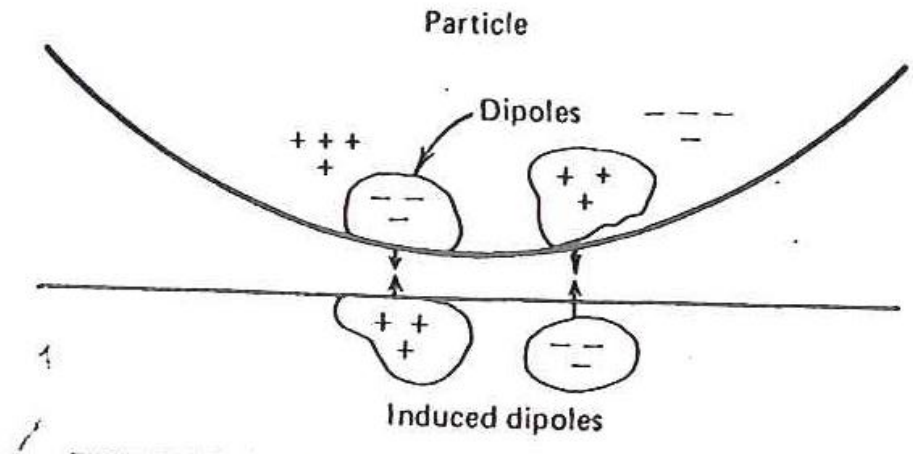


FIGURE 6.1 Van der Waals adhesive force.

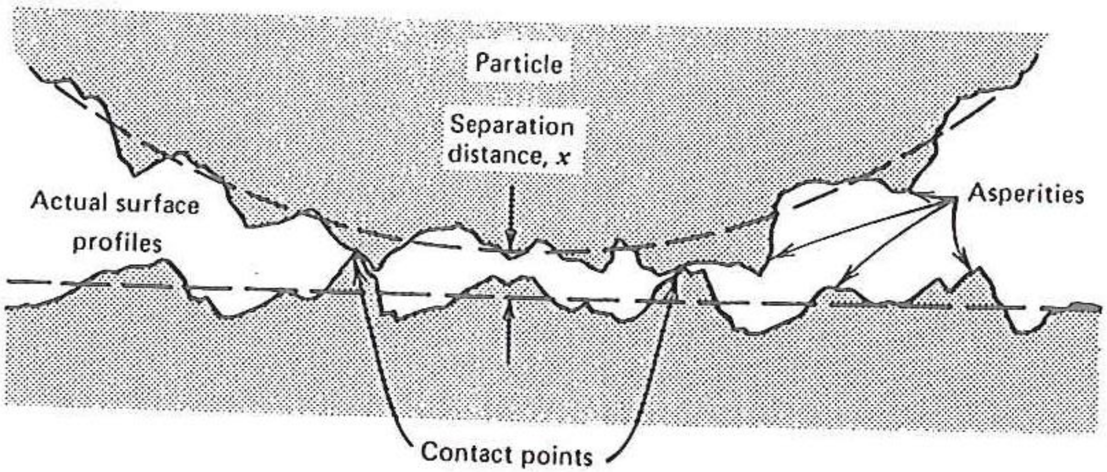


FIGURE 6.2 Submicroscopic surface contact geometry.

Hinds, 1999

Adhesion

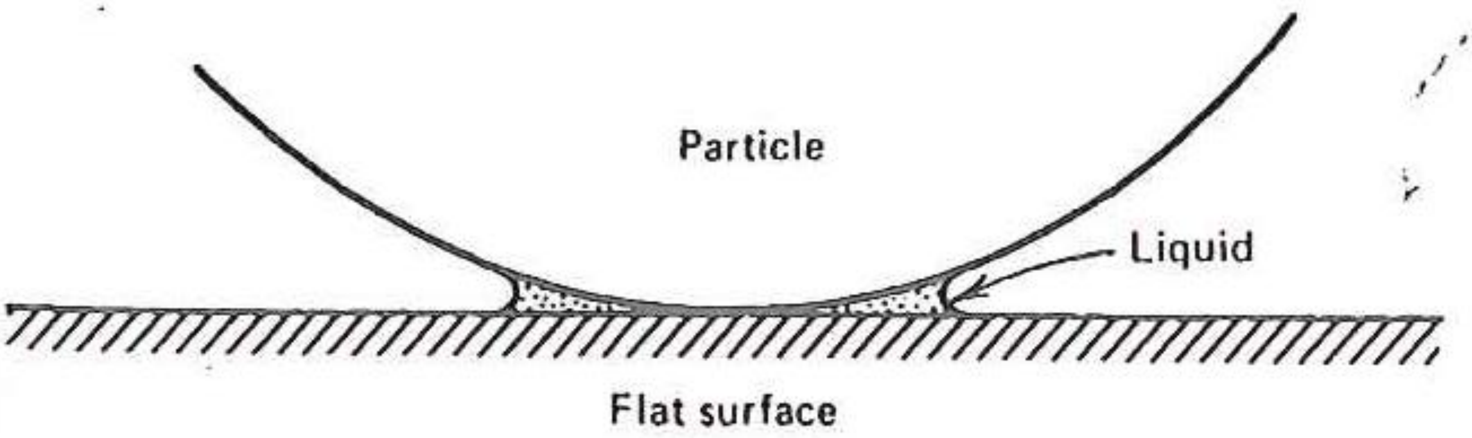
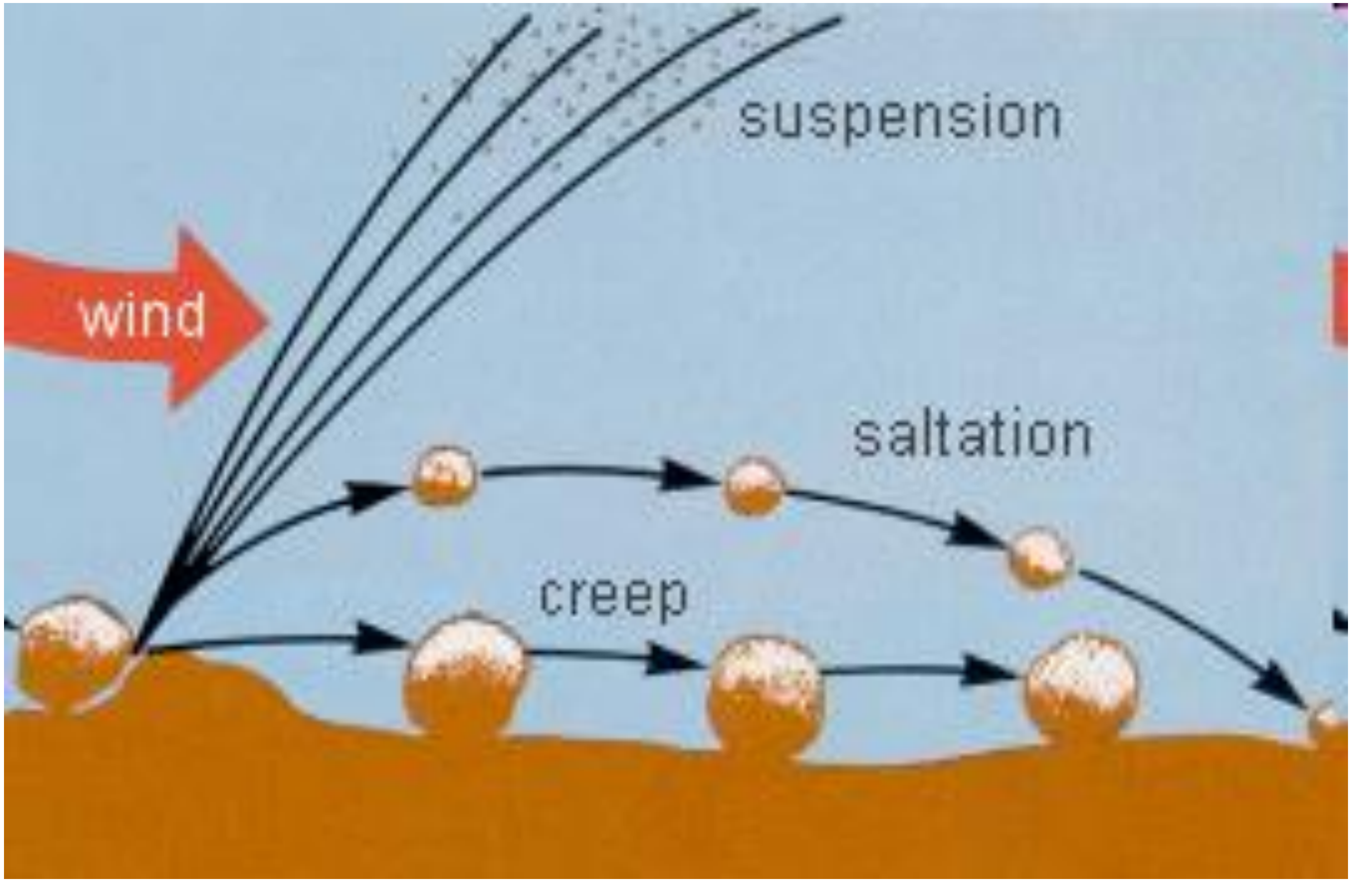


FIGURE 6.3 Adhesive force due to a liquid film.

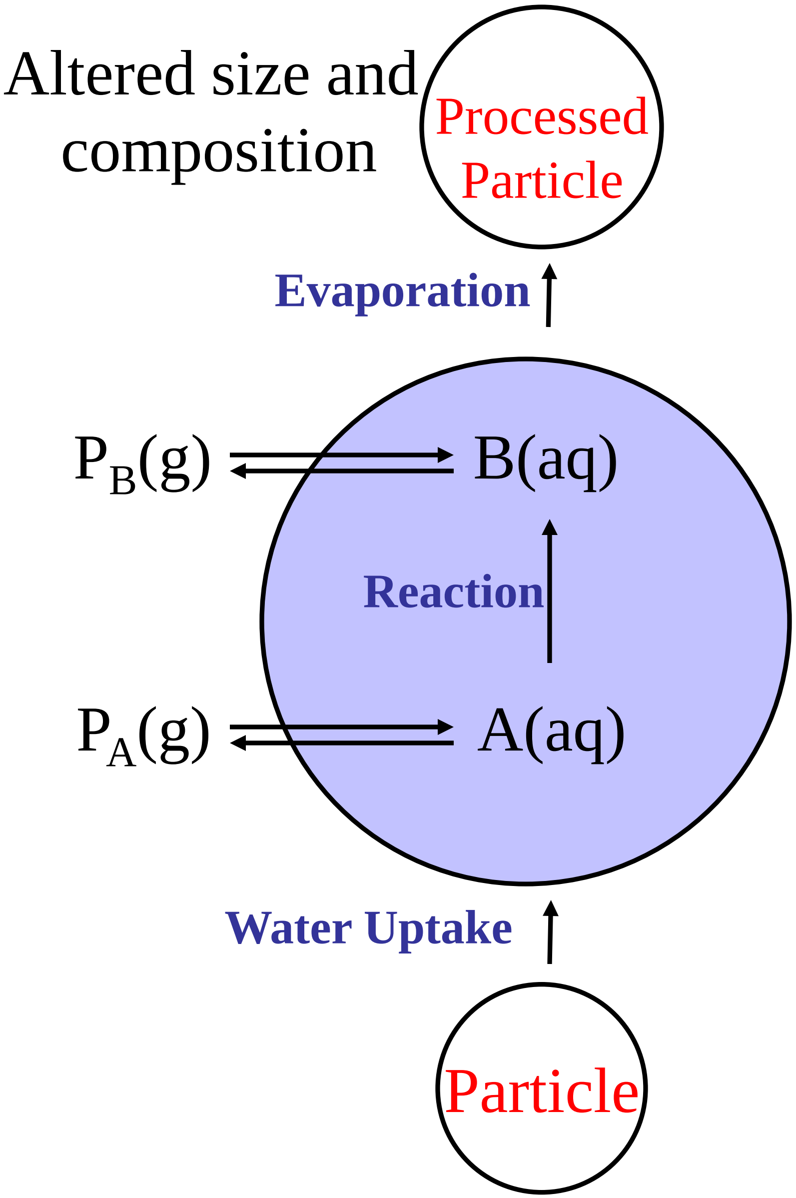
Hinds, 1999

Adhesion/Detachment



Clips: http://serc.carleton.edu/NAGTWorkshops/geomorph/visualizations/soil_erosion.html

Aqueous-Phase Processing



Composition helps predict size and drop nucleating potential

Models currently suffer from improper treatment of aqueous processing to modify aerosol properties