CARACTERÍSTICAS RELEVANTES DEL MATERIAL PARTICULADO ATMOSFÉRICO

Néstor Y. Rojas, PhD
Profesor Asistente
Departamento de Ingeniería Química
Universidad de Los Andes

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Parte de este material es tomado de:

Atmospheric Aerosol Particles

Erik Swietlicki

Professor
Div. of Nuclear Physics, Physics Department
Lund University – Lund Institute of Technology

Erik.Swietlicki@nuclear.lu.se

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Resumen

1. Propiedades de las partículas relacionadas con efectos sobre la salud
2. Revisión de la caracterización de partículas en otras latitudes

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1. Material particulado y salud

Recordando: Preguntas claves

- ¿Cuál característica o propiedad de las partículas es la causa de los efectos tóxicos?
- ¿Es posible cambiar la regulación para controlar dicha propiedad?
- ¿Es realmente efectivo controlar PM_{10}?
- ¿Cómo afecta la composición química de las partículas la magnitud de su efecto?
- ¿Cómo influye el tamaño de partícula en su capacidad para provocar efectos tóxicos?

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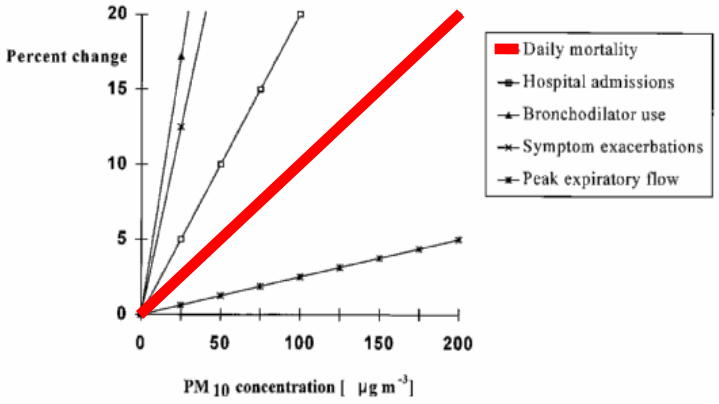
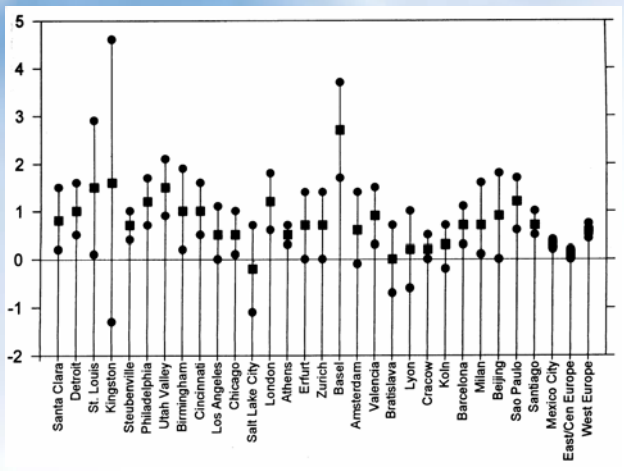
WHO - Health Effects of PM

WHO Health Risk Estimations for Particulate Matter

Fig. 1: Relationship of PM10 with different health effect indicators



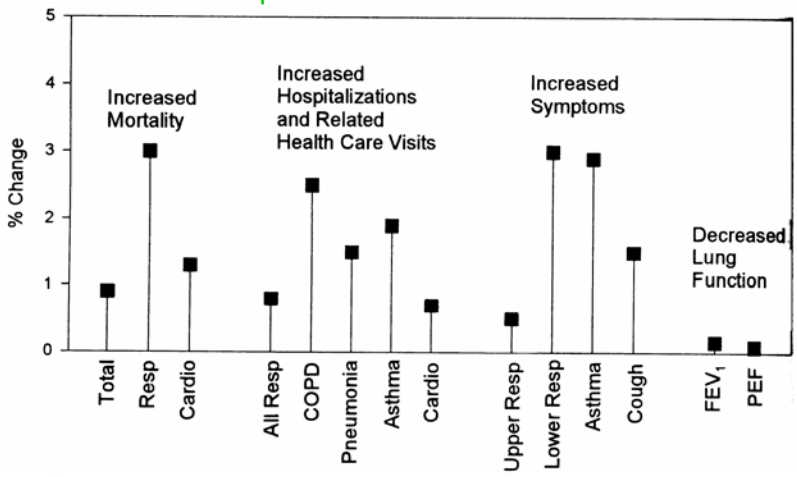
Short Term Mortality



Estimated per cent changes in daily mortality associated with a 10 µg/m³ increase in PM10 (with 95% confidence intervals) for a number of cities. (Pope et al. 1995)

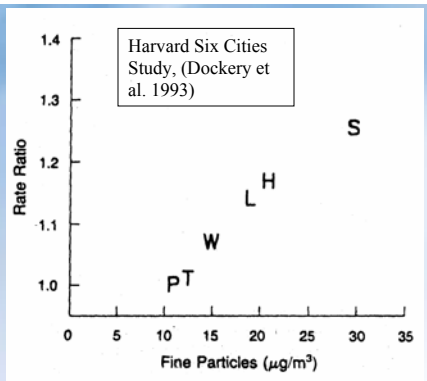
Health Effects from Short Term PM10 Exposure

Compilation of various studies



Percent change (increased risk) for a PM10-concentration increase (day to day) of 10 μg/m^3

Health Effects from Chronic PM Exposure



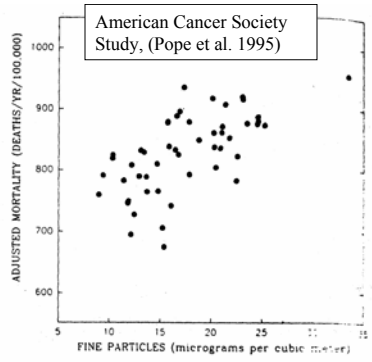


Figure 2. Age-, sex-, and race-adjusted population-based mortality rates for 1980 plotted against mean fine particulate air pollution levels for 1979 to 1983. Data from metropolitan areas that correspond approximately to areas used in prospective cohort analysis.

Both figures show how the risk for mortality increases in relation to PM2.5-concentrations taken as an average over several years (chronic exposure).

$PM_{2.5}$ gives a stronger relationship than PM_{10} (exposure-health effect)

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UNIVERSIDAD JAVERIANA - 1999

"AL AUMENTAR EN 10μg/m³ PM_{10} SE GENERA UN INCREMENTO DE POR LO MENOS EL 8% EN EL NÚMERO DE CONSULTAS POR ENFERMEDAD RESPIRATORIA EN LOS NIÑOS ENTRE 5 Y 14 AÑOS DE EDAD"

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1. Material particulado y salud

- Factores que pueden afectar la toxicidad
  - Composición global:
    - Sulfatos
    - Nitratos
    - Amonio
    - Cloro
    - Carbón elemental y orgánico
    - Minerales
    - Material biológico
  - Metales: plomo, mercurio, hierro, ...
  - Ácidos fuertes: nítrico, sulfúrico

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Composición química de las partículas

- DOH, 1995: No existe ninguna sustancia conocida lo suficientemente tóxica para explicar los efectos del material particulado sobre la salud ***a los niveles de exposición actuales***
- Diferencias en composición química en los estudios epidemiológicos no han mostrado diferencias en el resultado general del efecto de PM_{10} sobre la salud.
- Lippmann, 1998: Leve evidencia, sin explicación completa

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1. Material particulado y salud

- Antes de 1990
  - *"material particulado y SO_2 producen efectos sobre la salud y aumentan la mortalidad"*
  - Concentraciones de los 2 contaminantes bien correlacionadas
  - Recomendaciones de la OMS sobre los dos contaminantes

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1. Material particulado y salud

Schwartz, 1990

- Metodologías estadísticas mejoradas para demostrar los efectos del material particulado sobre la salud a concentraciones antes consideradas como seguras
- Efectos no relacionados con las concentraciones de SO_2
- Pero ¿cuál es el mecanismo de acción de las partículas?

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Compuestos sospechosos

- Adamson, 1999: Compuestos solubles en agua *(SOF)*
  - Extractos acuosos inyectados en tejido pulmonar
  - Pero: sólidos coloidales no excluidos del extracto

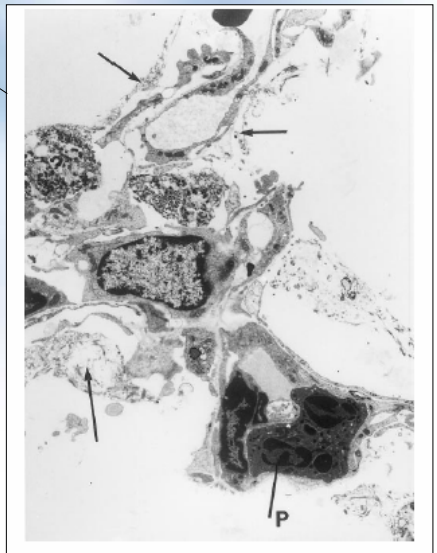

FIG. 10. Electron micrograph of an alveolar area, 3 days after instilling 1.0 mg of the soluble fraction. Extensive Type 1 epithelial necrosis is seen (arrows); there is adjacent PMN (P) and cell debris in the alveoli. Magnification 5500×.

Compuestos sospechosos

- Metales, iones metálicos
  - Pueden exacerbar el efecto de la fracción soluble
  - Evidencia toxicológica no concluyente: inducen o catalizan la producción de radicales libres que inflaman los tejidos
  - No hay suficiente información epidemiológica para demostrar que la reducción en el contenido de metales reduce también la morbilidad y mortalidad

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Particle hygroscopic properties

Importance for deposition in the lungs

Hygroscopic particles shifts the minimum in the deposition curve to smaller sizes.

Hygroscopic particles affect deposition:

- More particle mass (>200 nm) is deposited in the upper airways.
- Fewer very small (<100 nm) particles are deposited in the lower airways (number).

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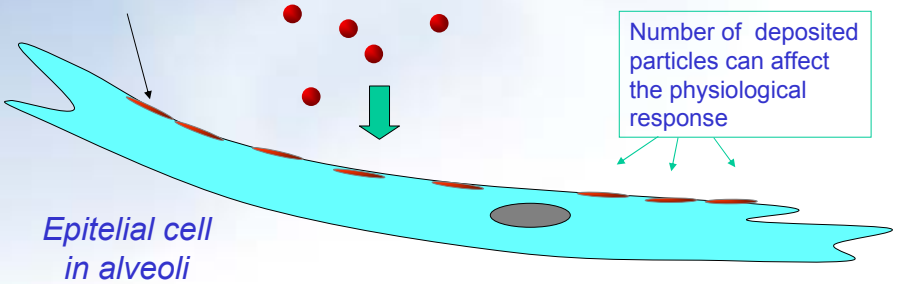
Soluble particles

The particles **lose** their original shape and physical properties after deposition

The response from the body depends on the particle ***mass***, ***composition*** and ***number***

Number of deposited particles can affect the physiological response



Epitelial cell in alveoli

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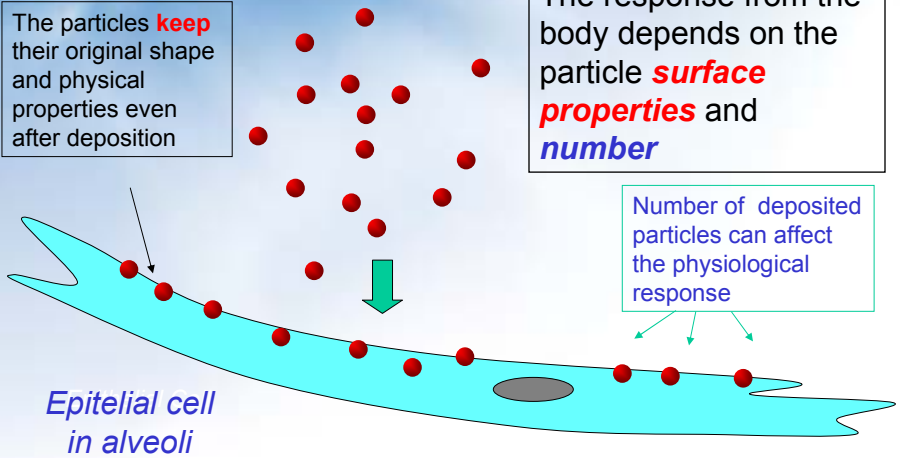
Insoluble particles

The particles **keep** their original shape and physical properties even after deposition

The response from the body depends on the particle ***surface properties*** and ***number***

Number of deposited particles can affect the physiological response



Epitelial cell in alveoli

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1. Material particulado y salud

Tamaño de las partículas

Lippmann, 1998: Evidencia limitada de mayor correlación de PM2.5 con efectos sobre la salud que PM10

Los dos parámetros están fuertemente correlacionados

- Efectos de partículas ultrafinas:
- Evidencias: Donaldson, 1998; Oberdörster, 1995.
  - Mayor potencial de inducción de efectos sobre la salud que partículas más grandes- inflamación, reducción de la función pulmonar (efecto de área superficial?)
  - número de partículas mejor relacionado con masa en inducción de efectos: ej. partículas de TiO_2
  - efecto de nanopartículas no depende de la composición química

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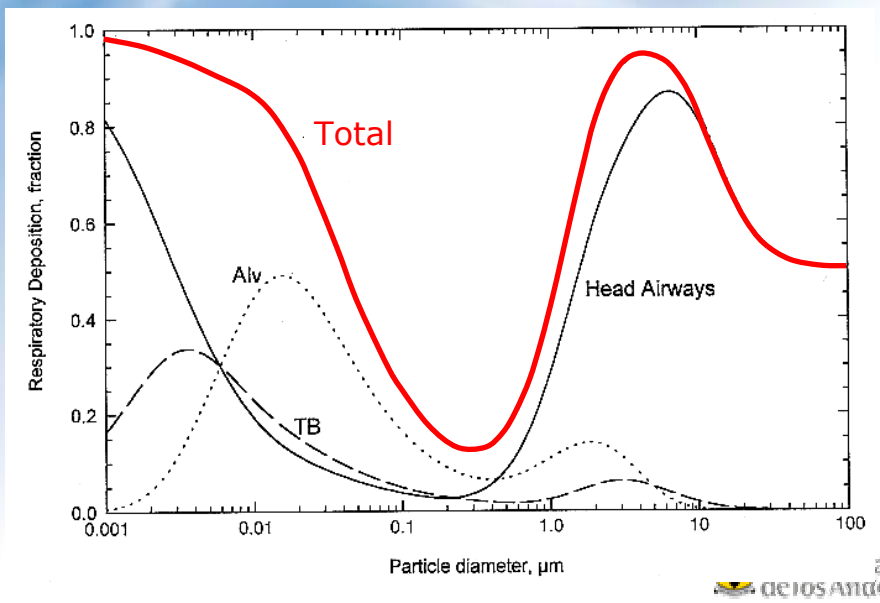
Lung Deposition av particles - ICRP



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1. Material particulado y salud

¿Cuál es la base toxicológica y epidemiológica?

- Muchos estudios toxicológicos indican que las concentraciones actuales de PM no son tóxicas para el ser humano
- Inconsistencia entre estudios toxicológicos y epidemiológicos
- Estudios epidemiológicos hechos con estaciones fijas de monitoreo, no con la medición de la exposición real

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1. Material particulado y salud

Revisión recomendada:

- HARRISON, Roy, 2003. Particulate matter in the atmosphere: which particle properties are important for its effects on health? The Science of the Total Environment 249, 85-101 (2000)
- GREEN, Laura C. What's Wrong with the National Ambient Air Quality Standard (NAAQS) for Fine Particulate Matter (PM2.5)? Regulatory Toxicology and Pharmacology 35, 327–337 (2002)

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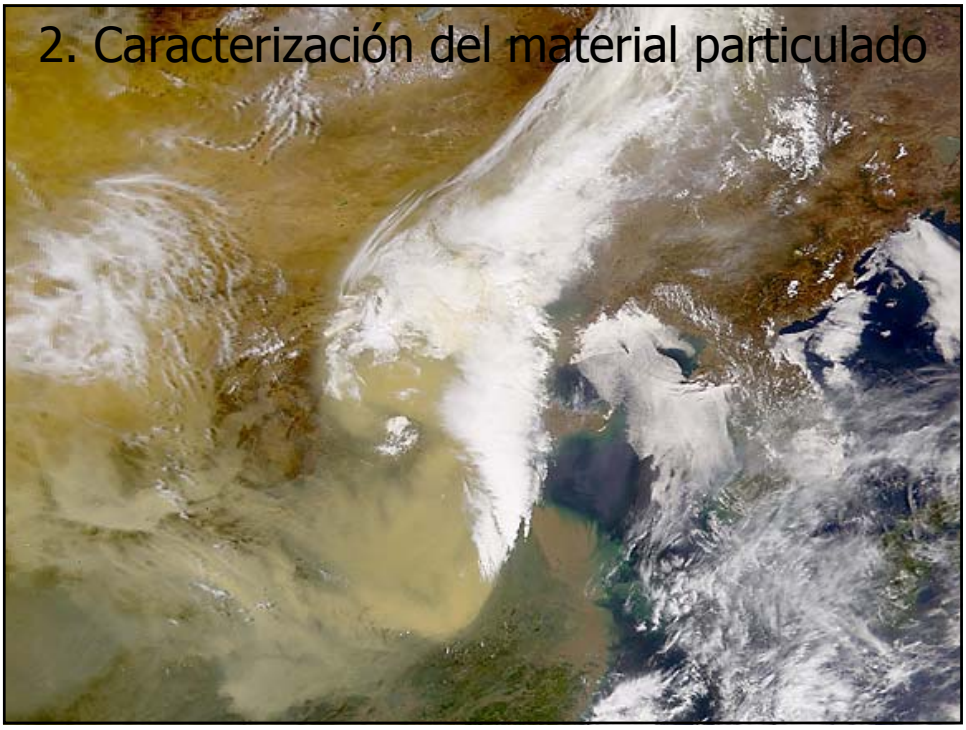
2. Caracterización del material particulado

Contaminación atmosférica en Santiago

2. Caracterización del material particulado



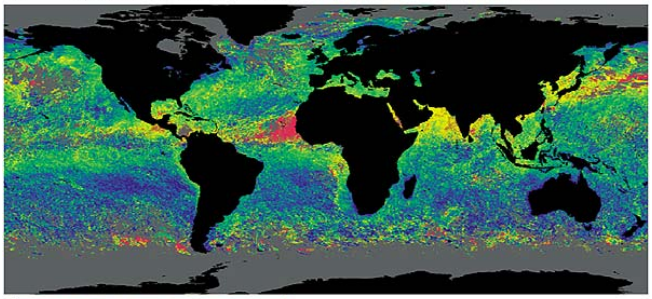
Global Aerosol Distribution

Aerosol Optical Depth

Extinction of visible light in the atmosphere.

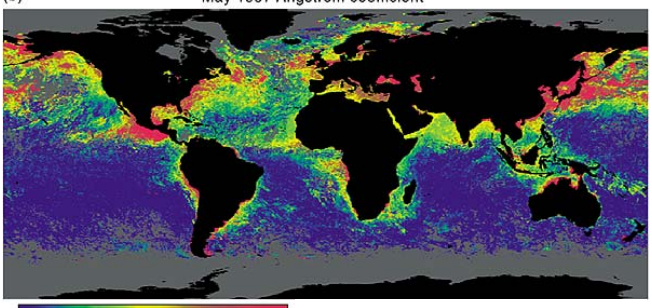
Particle concentrations

(a) May 1997 Aerosol optical depth at 865 nm from Polder on ADEOS



Low Conc. 0.0 0.1 0.2 0.3 0.4 0.5 High Particle Concentrations

(b) May 1997 Ångström coefficient



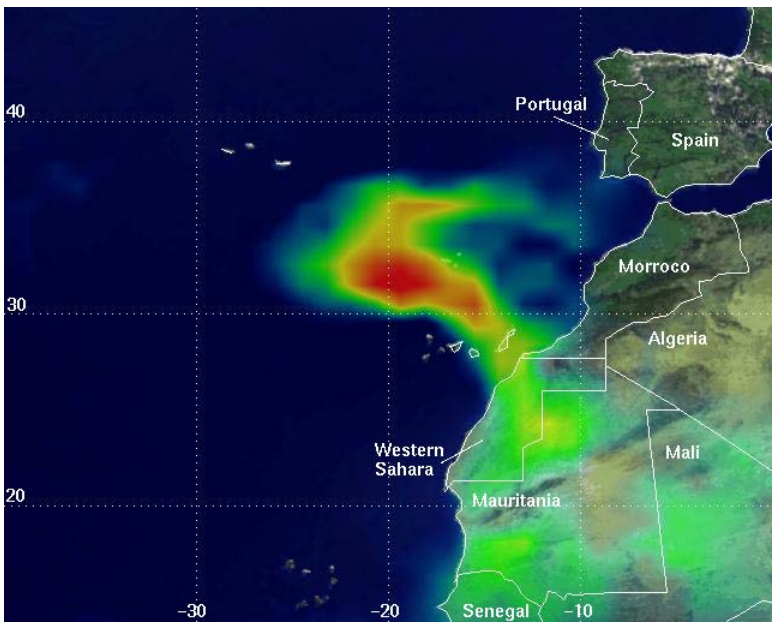
Ångström Coefficient

Wavelength dependence

Particle size information

Large Particles −0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2 Small Particles

TOMS Aerosol Index - Saharan Dust Storm

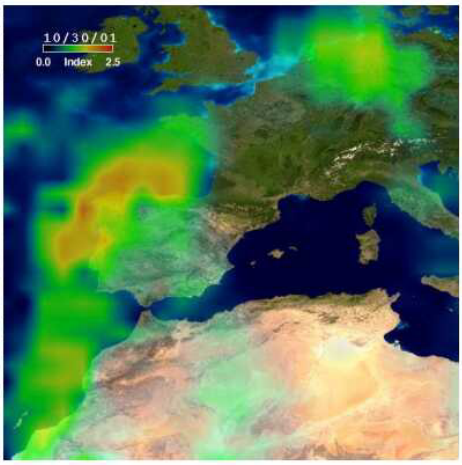


TOMS Aerosol Index - Saharan Dust

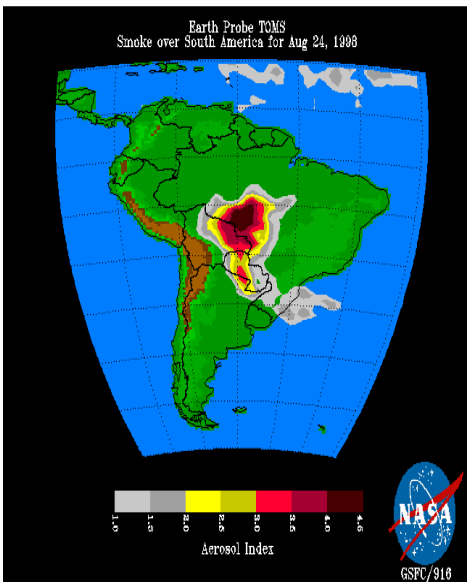
Dust over Europe, 30-March-2001

SeaWiFS

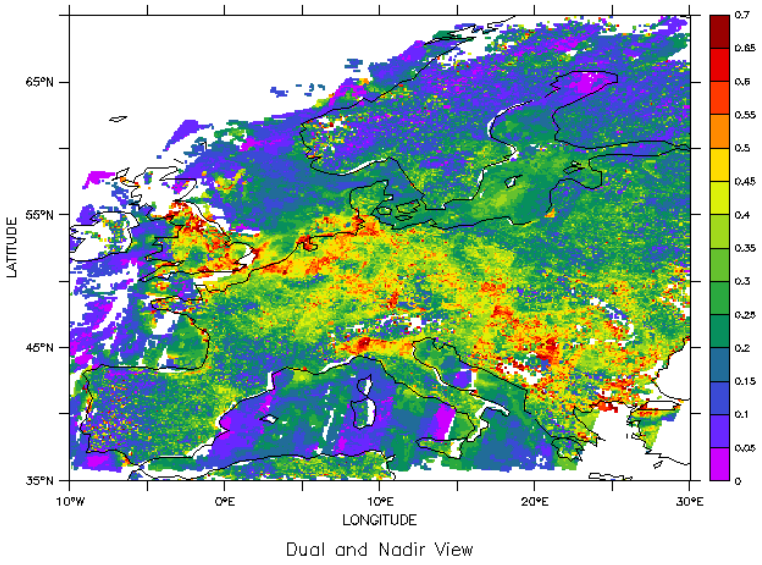
TOMS



TOMS Aerosol Index
South American Biomass Burning



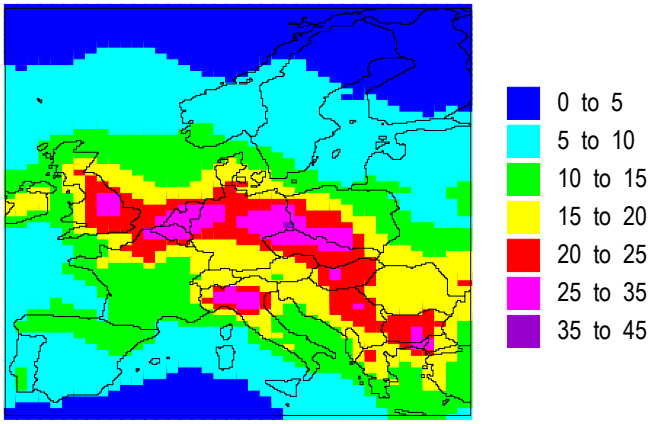
Aerosol Optical Depth over Europe



Dual and Nadir View

C. Robles-Gonzalez, J.P. Veefkind and G. de Leeuw, GRL 27(2000)955-959

PM2.5 Concentrations over Europe



Preliminary estimate of the average $PM_{2.5}$ ($\mu g/m^3$)concentration for August 1997, based on ATSR-2 data.

2. Caracterización del material particulado

Aerosol - Definition

"A collection of liquid or solid particles suspended in a mixture of gases
- normally air."

An aerosol is a **multi-phase** system

gas - liquid - solid

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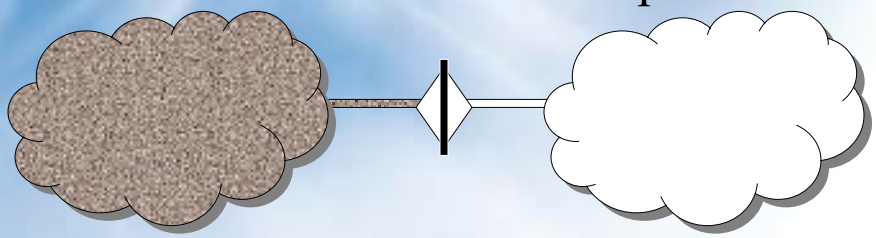
2. Caracterización del material particulado



- a) Partículas, sólidas y líquidas, suspendidas en el medio gaseoso
  - Análisis físico
  - Análisis químico
  - otros

- b) Gases: por ejemplo
  - CO
  - HC
    - total
    - por especie
  - SO_2
  - NO_x
  - N_2, O_2

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2. Caracterización del material particulado

Atmospheric Aerosols - Formation

- **Primary aerosol particles**
  - Emitted as particles at the source itself (e.g. soil dust, sea salt, soot)

- **Secondary aerosol particles**
  - Derived from precursor gases emitted at the source
  - Formed in atmospheric processes (e.g. sulphates, nitrates, secondary organics)

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2. Caracterización del material particulado

Size range of aerosol particles

The criterion of suspension determines the size range of aerosol particles:

Smallest particle: 1 nm (0.001 μm or 10^{-9} m)

Largest particle: 100 μm (10^{-4} m)

Spanning:

5 orders of magnitude in size

15 orders of magnitude in mass/volume !!

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2. Caracterización del material particulado

One litre of urban air ...

… contains ca. 10 million particles (10^4 cm^{-3})

We inhale 10-20 m^3 of air per day

ca. 100 billion particles per day

Mass loading in polluted atmospheres

ca. 100 µg/ m^3

= ca. 1 mg/ day

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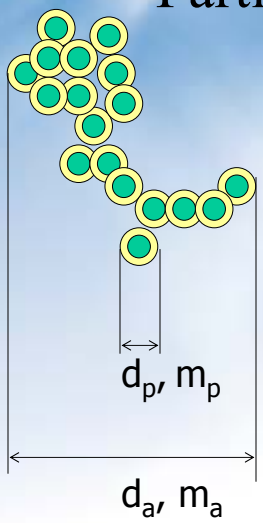
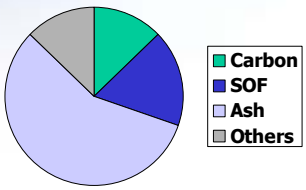
2. Caracterización del material particulado

Partículas Individuales



$m_p \propto d_p^{D_f}$ Dimensión Fractal

Composición química



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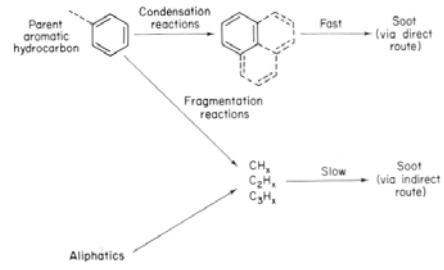
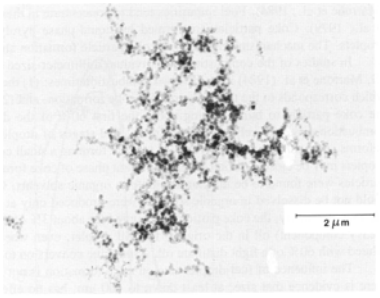
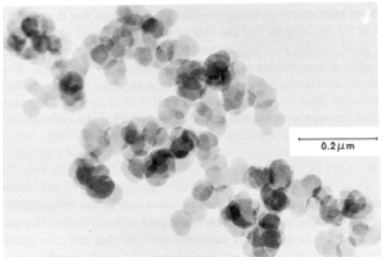
2. Caracterización del material particulado

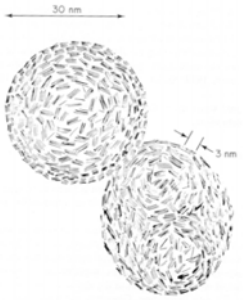




(a)



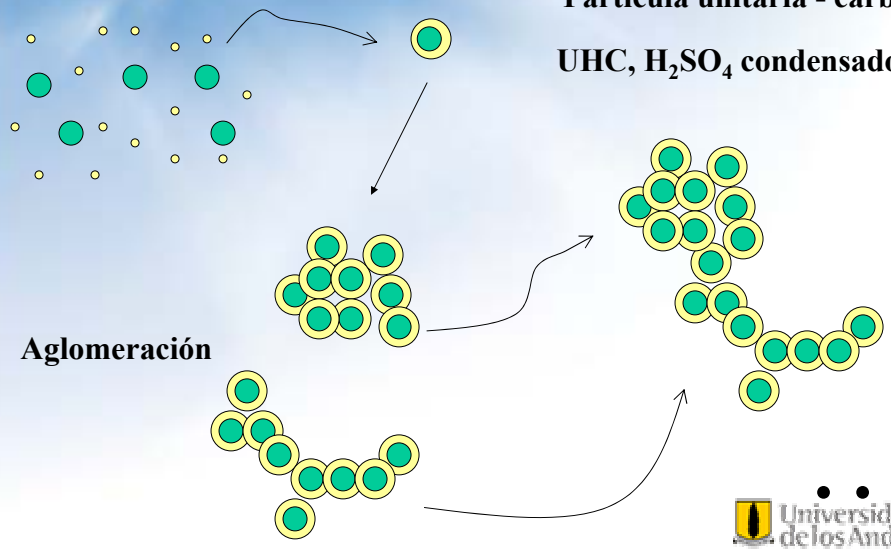
Primary
soot particles
~30 nm
C_8H



2. Caracterización del material particulado
Partículas: formación en la combustión

Partícula unitaria - carbón

UHC, H_2SO_4 condensados



Aglomeración

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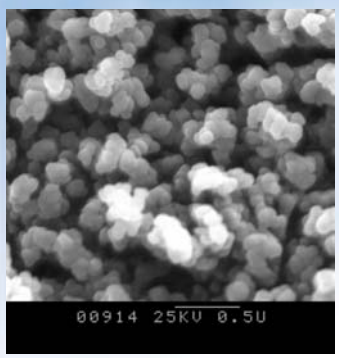
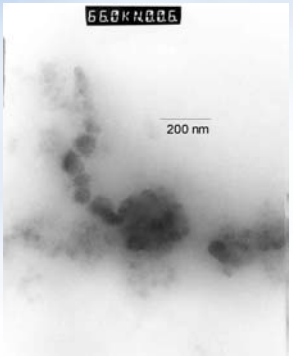
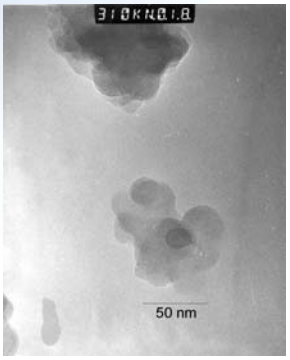
2. Caracterización del material particulado







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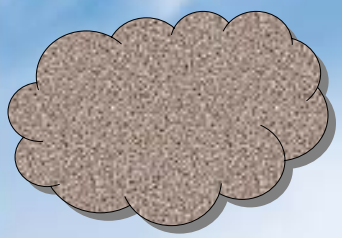
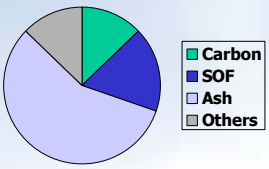


M: Concentración másica
TPM, $PM_{2.5}$, PM_{10}

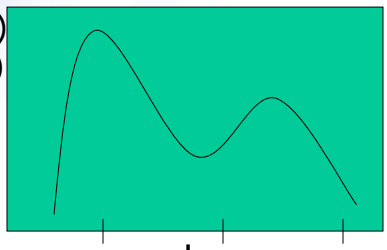
N: Concentración en número

Composición química



Distribución de tamaño

dM/dlog(dp)
dN/dlog(dp)



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2. Caracterización del material particulado

Atmospheric Aerosols - Nomenclature

- **TSP** (**T**otal **S**uspended **P**articulate matter)
- **PM** (**P**articulate **M**atter)

  PM-10 : Particles < 10 μm in diameter
  PM-2.5 : Particles < 2.5 μm in diameter

  PM-1 : Particles < 1 μm in diameter

  PM-2.5/PM-10 ratio ≈ 0.5 (variable)

Old standard **Black Smoke**; BS
BS/PM-10 normally< 1

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2. Caracterización del material particulado

Tamaño y expresión de la concentración

- Partículas grandes: concentración másica
- Partículas pequeñas (ultrafinas): concentración en número de partículas
- Número de partículas ultrafinas es altamente dependiente de la distancia a la fuente de emisión
  - Comparación muy difícil entre ciudades
  - Harrison, 1999: Selección muy cuidadosa del sitio de muestreo (background) para ver correlaciones entre número de partículas ultrafinas y PM_{10}

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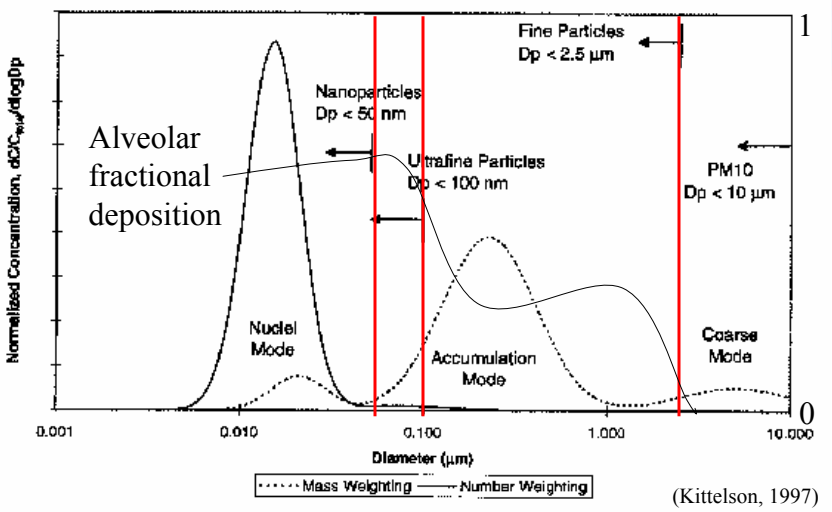
2. Caracterización del material particulado



(Kittelson, 1997)

Fig. 3. Typical engine exhaust size distribution both mass and number weightings are shown.

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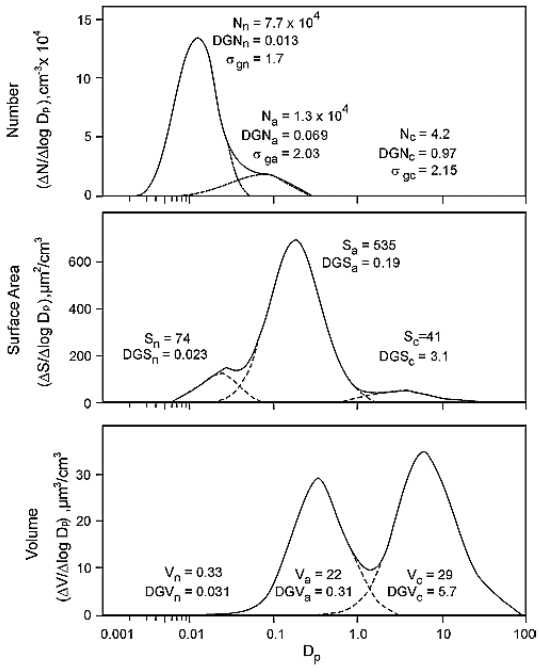
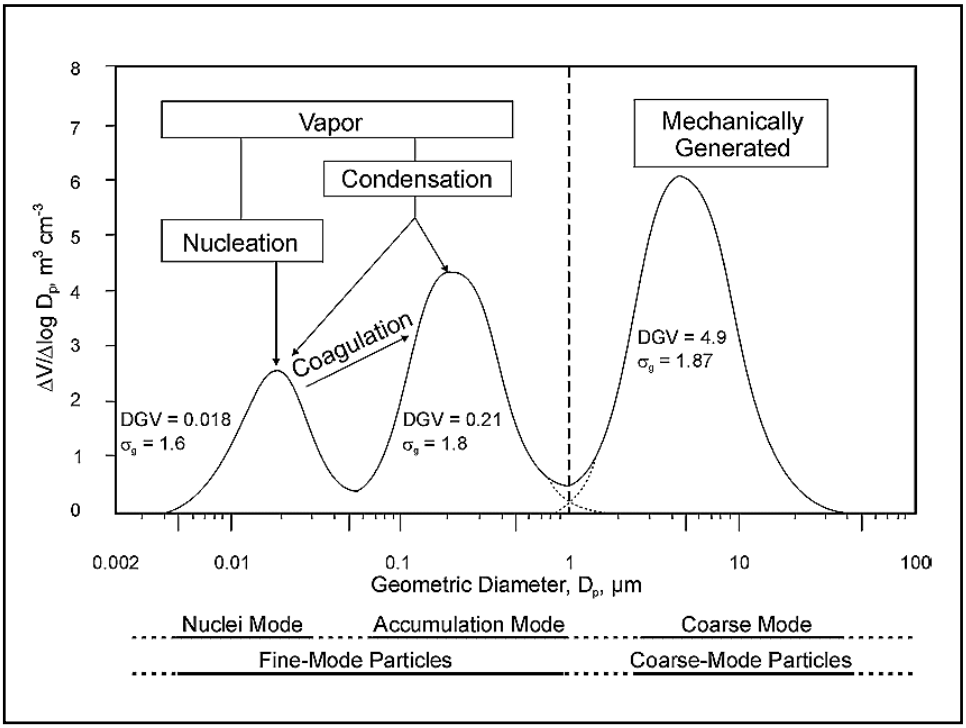
Particle Size Distributions

Particle Number

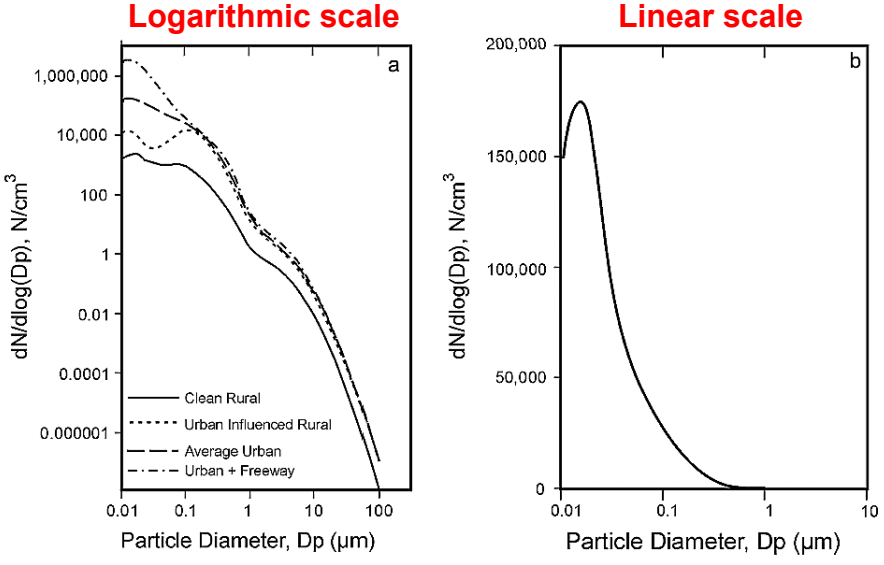
Particle Surface Area

Particle Volume or Mass



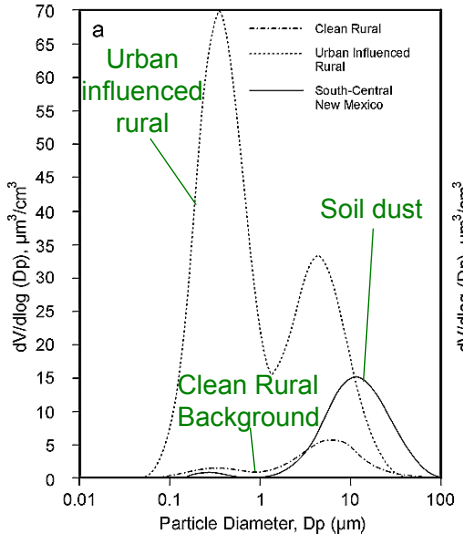


Particle Number Size Distributions

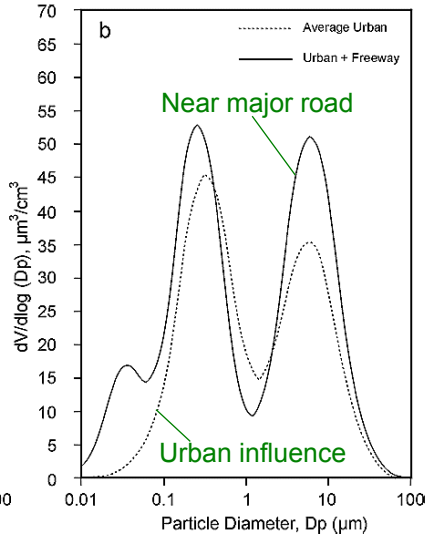


Particle Volume and Mass Size Distributions

Continental environments



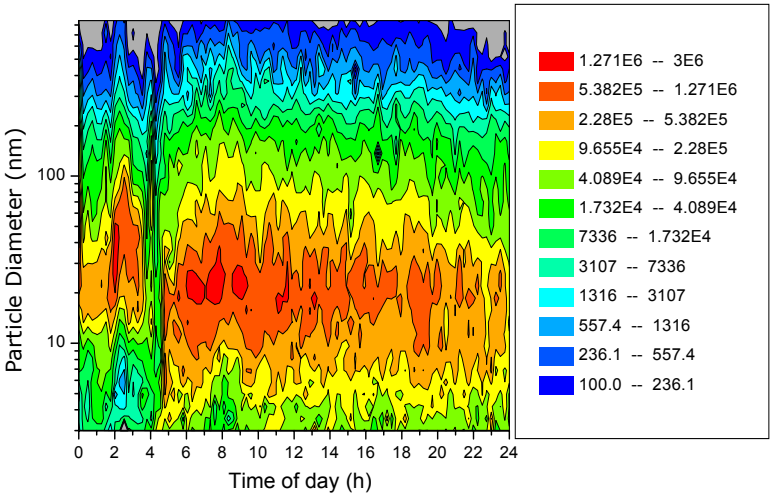
Urban Environments



Traffic tunnel in Stockholm

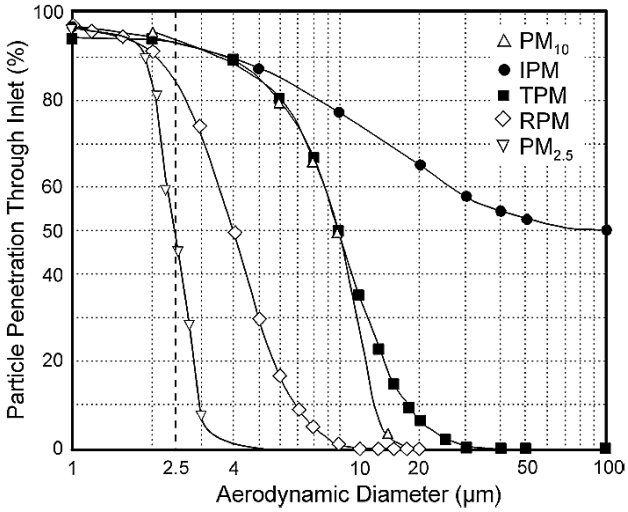
"Söderledstunnel"

Particle Number Size Distributions (3-850 nm, 24 hours)

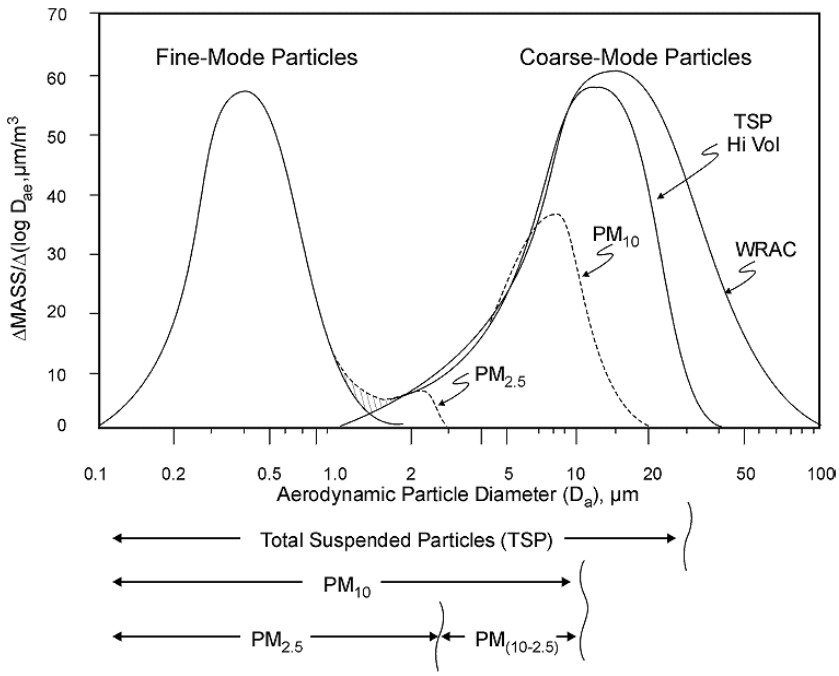


Most particles (tail-pipe emissions) are ≈ 20 nm

Aerosol Particle Separation - Conventions

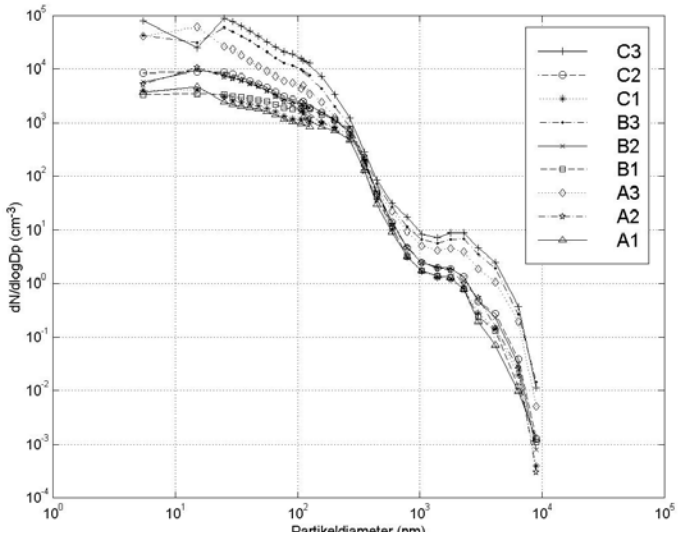


***IPM*: Inhalable particle fraction** (fraction inhaled through nose and mouth)
***TPM*: Thoracic particle fraction** (fraction passing the larynx)
***RPM*: Respirable particle fraction** (fraction reaching the alveoli)



Number size distributions in Stockholm

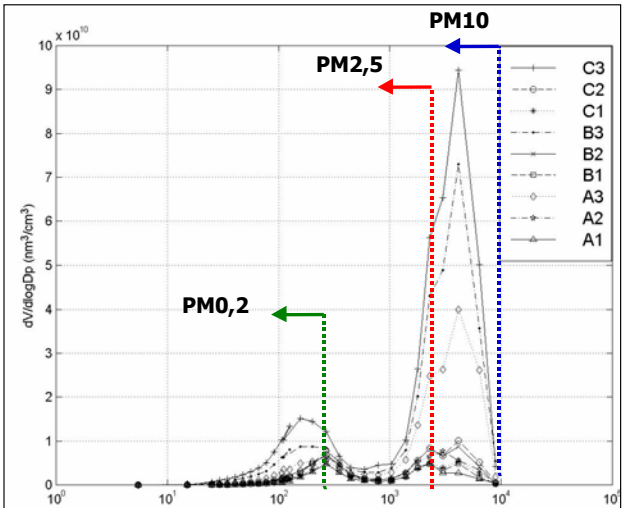
(various locations from surburb to busy downtown street canyon)



Particle Diameter (nm)

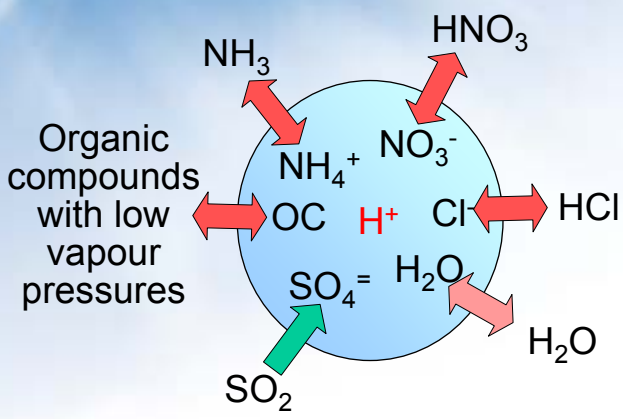
Volume size distributions in Stockholm

(various locations from surburb to busy downtown street canyon)



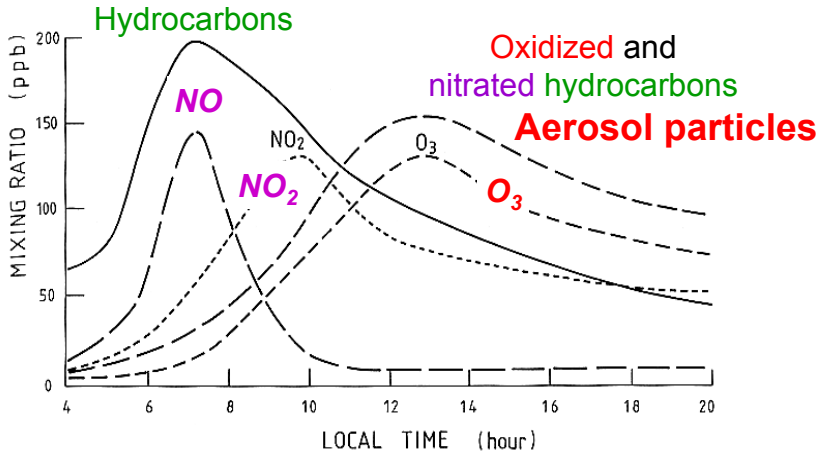
Particle Diameter (nm)

Exchange between phases



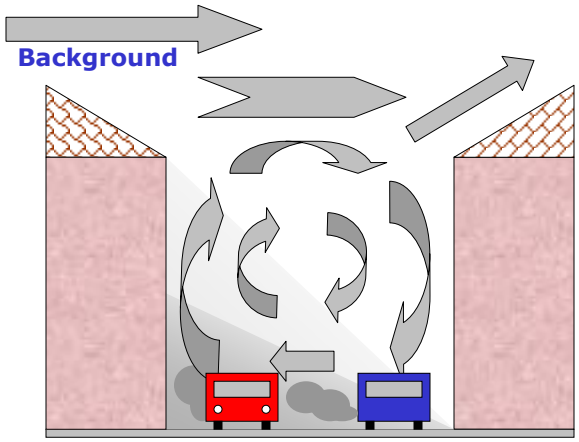
Ground-level ozone – Photochemical smog

In polluted environments (e.g. large cities), concentrations of hydrocarbons, nitrogen oxides, ozone and **aerosol particles** often follow a certain diurnal pattern.



Street Canyon Plume Dispersion

Concentrations are highest on the leeward side of the street



Urban Aerosols

- **Number**
  Most particles smaller than 0.1 μm
- **Surface**
  Most surface area between 0.1 - 0.5 μm
  (condensation, coagulation most efficient)
- **Mass / Volume**
  Bimodal - **Fine** (<1 μm) and **Coarse**
  (roughly equal mass in both modes)

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Urban Aerosols

- **Fine particle mode**
  Combustion processes
  Gas-to-particle conversion

- **Coarse particle mode**
  Mechanical disintegration processes
  - Traffic - soil dust, tire wear
  - Incomplete combustion - fly ash
  - Bioaerosols - plant debris, bacteria, fungi...
  - Sea salt

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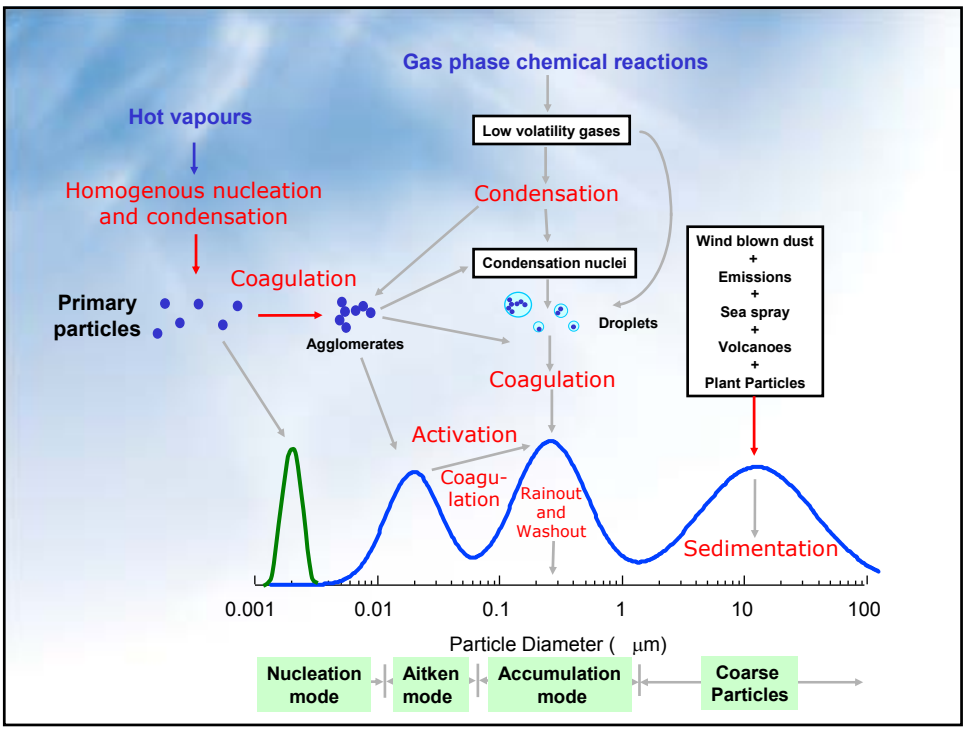
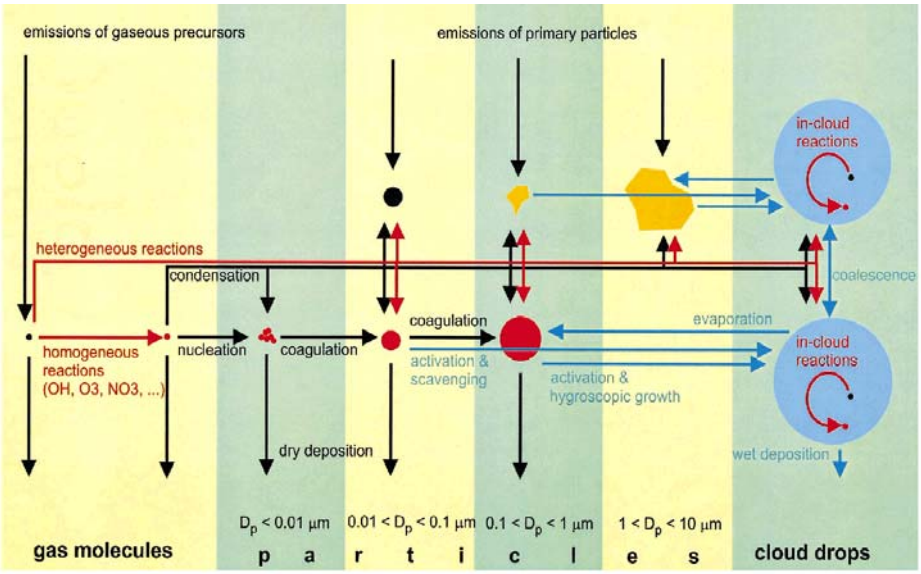


Processes affecting the Atmospheric Aerosol



Raes et al. Atm. Env. 34(2000)4215

Fig. 1. Scheme of the microphysical processes that influence the size distribution and chemical composition of the atmospheric aerosol. The scheme highlights the large range of sizes that are involved in the formation and evolution of aerosol particles, and how aerosols participate in atmospheric chemical processes through homogeneous, heterogeneous and in-cloud reactions.

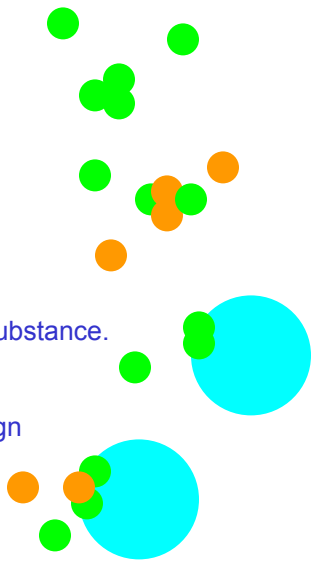
Nucleation

Homogeneous – homomolecular
Self-nucleation of a single species.
No foreign nuclei or surfaces involved.

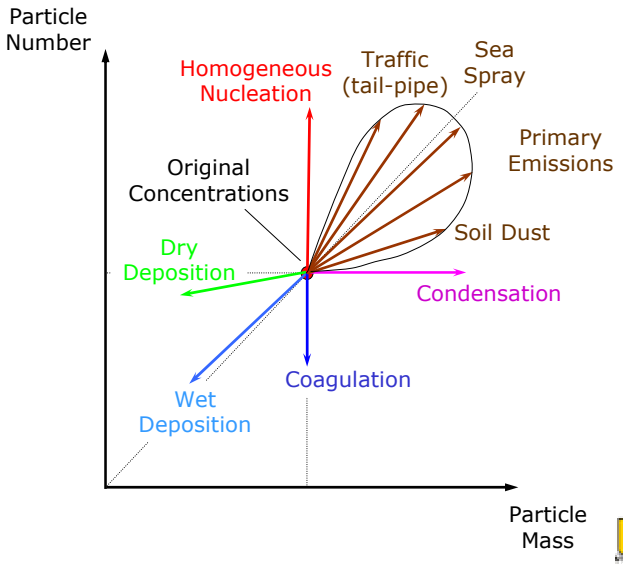
Homogeneous – heteromomolecular
Self-nucleation of two or more species.
No foreign nuclei or surfaces involved.

Heterogeneous – homomolecular
Nucleation of a single species on a foreign substance.

Heterogeneous – heteromomolecular
Nucleation of two or more species on a foreign substance.



Atmospheric Aerosol Processes
Effect on Concentrations



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Estimated Global Emission Rates of Particles into the Atmosphere (Tg yr^{-1})

Raes et al. Atm. Env. 34(2000)4215

	Source strength (Tg yr^{-1})	Reference
Sea salt		
Total	5900	Tegen et al. (1997)
0–2 µm	82.1	Gong et al. (1997)
2–20 µm	2460	
Soil dust		
< 1 µm	250	Tegen and Fung (1995)
1–10 µm	1000	
0.2–2 µm	250	Penner, personal comm.
2–20 µm	4875	
Organic carbon		
Total	69	Liousse et al. (1996)
Biomass burning	54.3	Penner, personal comm.
Fossil fuel	28.8	
Terpene oxidation	18.5	Griffin et al. (1999)
Black carbon		
Total	12	Liousse et al. (1996)
Biomass burning	5.6	
Fossil fuel	6.6	
Sulfate (as H_2SO_4)		
Total	150	Chin and Jacob (1996)
Natural	32	Koch et al. (1999)
Anthropogenic	111	
Nitrate	11.3[a]	Adams et al. (1999)
Ammonium	33.6	Adams et al. (1999)

[a]Nitrate source strength is based on a computed burden of 0.13 Tg and an assumed lifetime of 4.2 d (same as ammonium).

Ambient Aerosols Summary

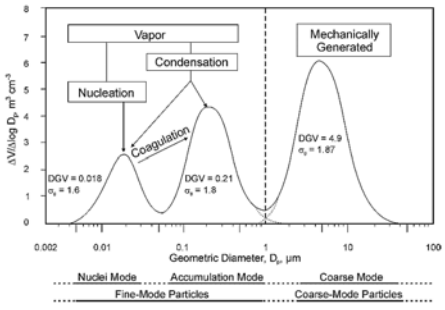
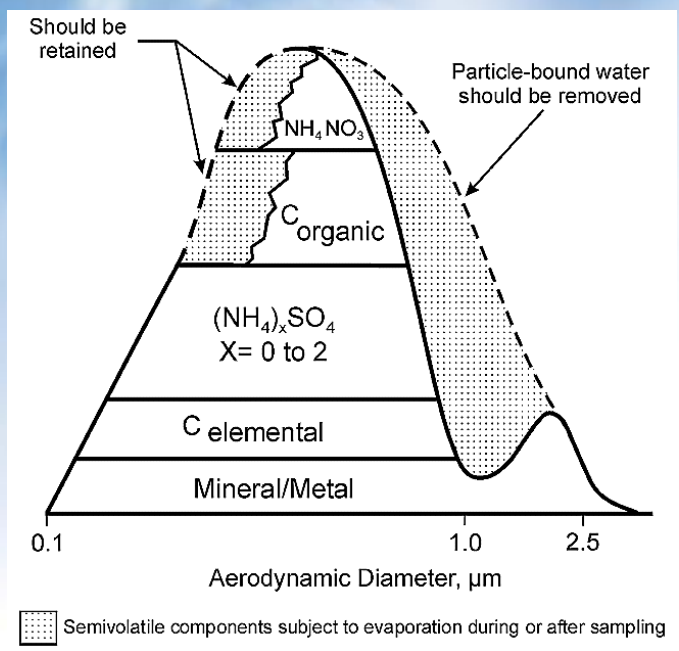


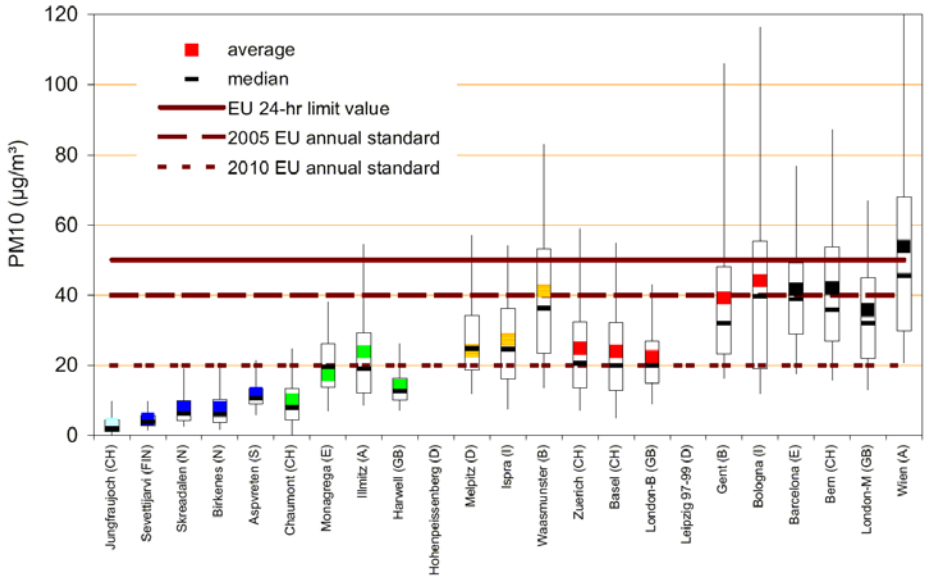
TABLE 3-1. COMPARISON OF AMBIENT PARTICLES FINE MODE (Nuclei Mode Plus Accumulation Mode) AND COARSE MODE

	Fine		Coarse
	Nuclei	Accumulation	
Formed from:	Combustion, high temperature processes and atmospheric reactions		Break-up of large solids/droplets
Formed by:	Nucleation Condensation Coagulation	Condensation Coagulation Evaporation of fog and cloud droplets in which gases have dissolved and reacted	Mechanical disruption (crushing, grinding, abrasion of surfaces) Evaporation of sprays Suspension of dusts Reactions of gases in/on particles
Composed of:	Sulfates Elemental carbon Metal compounds Organic compounds with very low, saturation vapor pressure at ambient temperature	Sulfate, SO_4^- Nitrate, NO_3^- Ammonium, NH_4^+ Hydrogen ion, H^+ Elemental carbon, Large variety of organic compounds Metals: compounds of Pb, Cd, V, Ni, Cu, Zn, Mn, Fe, etc. Particle-bound water	Suspended soil or street dust Fly ash from uncontrolled combustion of coal, oil, wood Nitrates/chlorides from HNO_3/HCl Oxides of crustal elements, (Si, Al, Ti, Fe) $CaCO_3$, NaCl, sea salt Pollen, mold, fungal spores Plant/animal fragments Tire, break pad, road wear debris
Solubility:	Probably less soluble than accumulation mode	Largely soluble, hygroscopic and deliquescent	Largely insoluble and non-hygroscopic
Sources:	Combustion Atmospheric transformation of SO_2 and some organic compounds High temperature processes	Combustion of coal, oil, gasoline, diesel fuel, wood Atmospheric transformation products of NO_x, SO_2, and organic compounds including biogenic organic species, e.g., terpenes High temperature processes, smelters, steel mills, etc.	Resuspension of industrial dust and soil tracked onto roads and streets Suspension from disturbed soil, e.g., farming, mining, unpaved roads Construction and demolition Uncontrolled coal and oil combustion Ocean spray Biological sources
Atmospheric half-life:	Minutes to hours	Days to weeks	Minutes to hours
Removal Processes:	Grows into accumulation mode	Forms cloud droplets and rains out Dry deposition	Dry deposition by fallout Scavenging by falling rain drops
Travel distance:	<1-10s of km	100s to 1000s of km	<1 to 10s of km (100s-1000s in dust storms)

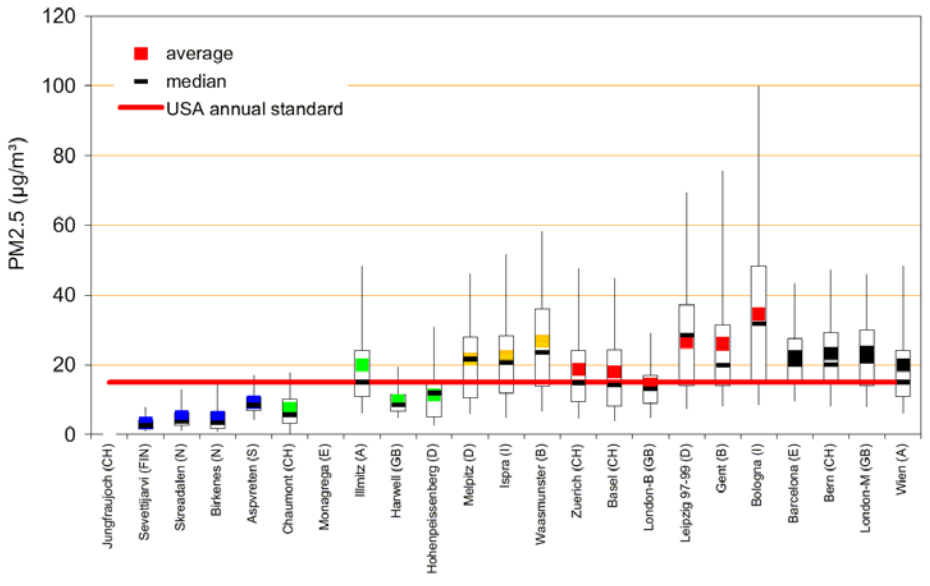
http://www.epa.gov/ncea/pdfs/partmatt/VOL_I_AQCD_PM_3rd_Review_Draft.pdf



European PM10 Concentrations



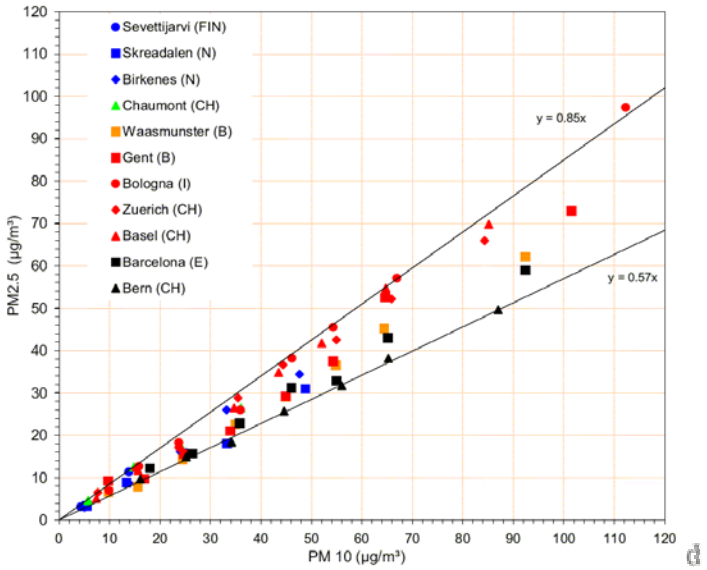
European PM2.5 Concentrations



European PM Concentrations

PM2.5 and PM10 correlated

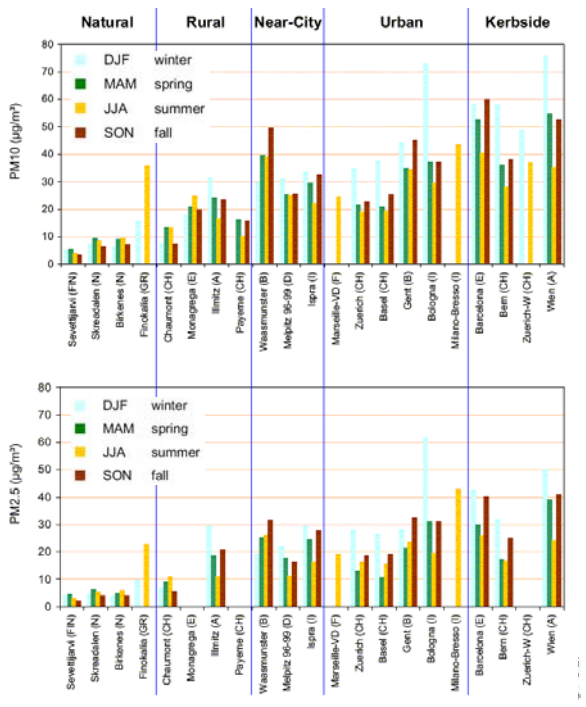
PM2.5 / PM10 ratio = 0.5 to 0.9



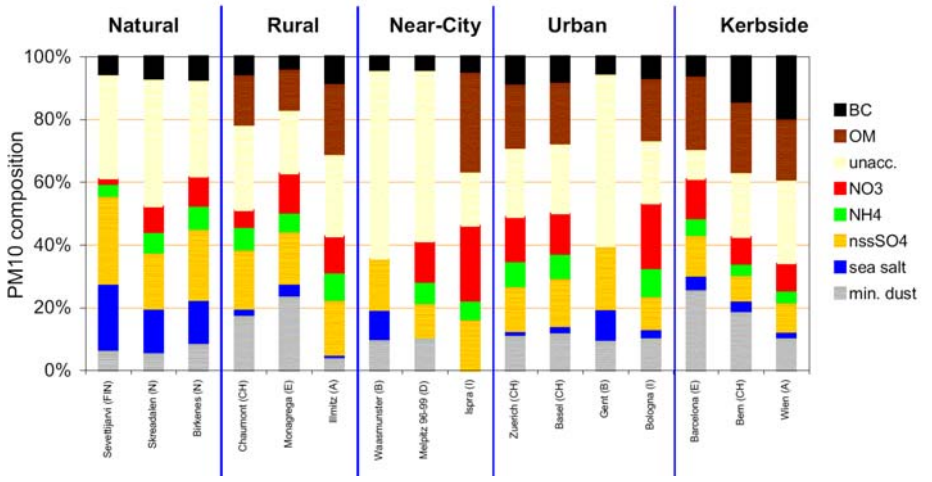
European PM Concentrations

PM2.5 and PM10 correlated

PM2.5 / PM10 ratio = 0.5 to 0.9



European PM10 Composition



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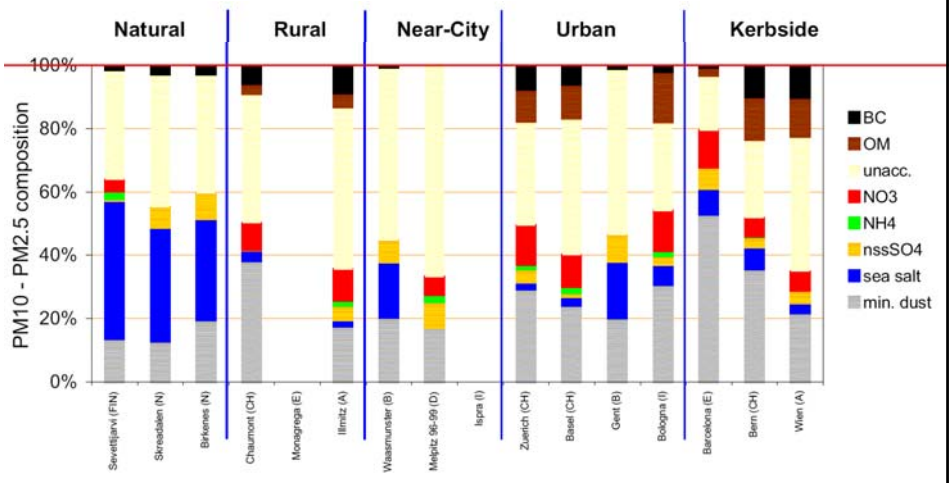
European Coarse Mode Composition
PM10-PM2.5



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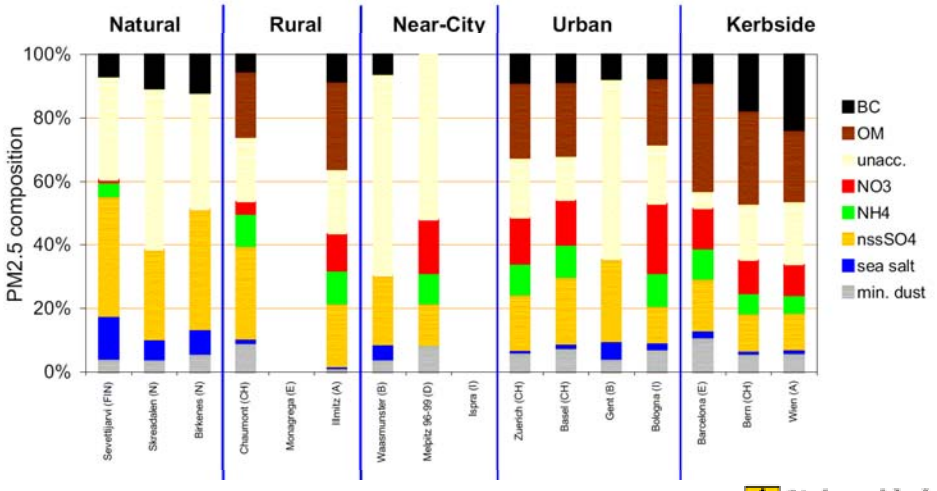
European PM2.5 Composition



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