II Lectures on Atmospheric Mineral Dust
5-9 November 2012, Barcelona - Spain

ground observations of mineral dust

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- Aerosols and dust background
- In-situ dust characterization
- In-situ dust estimations (Visibility)
- Ground based remote sensing
- Summary

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Chad-2004 by Jahi-Chikwendiu
World Press Prize 2004

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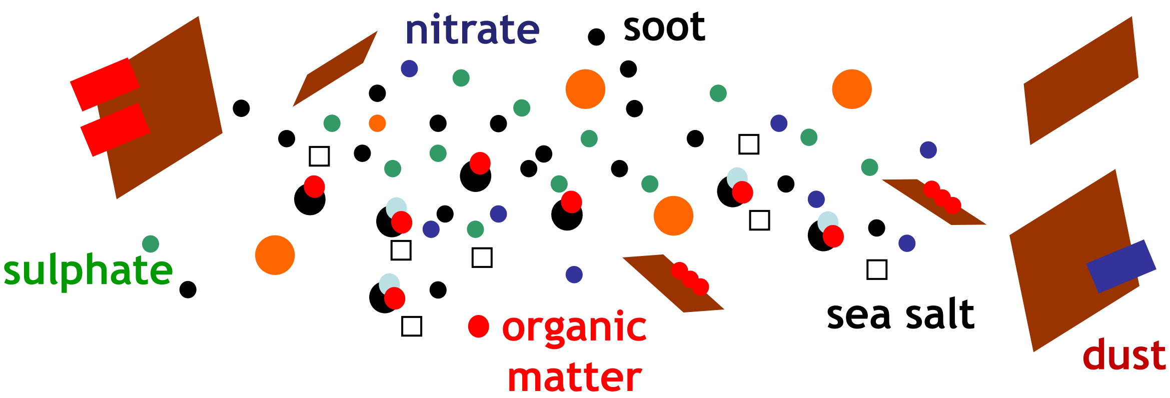
Aerosols: solid & liquid matter suspended in a gas.

Size 0.001 to 100 μm (1 μm= 10^{-6} m) = 1 nm (10^{-9} m) to 100 μm (10^{-6} m).



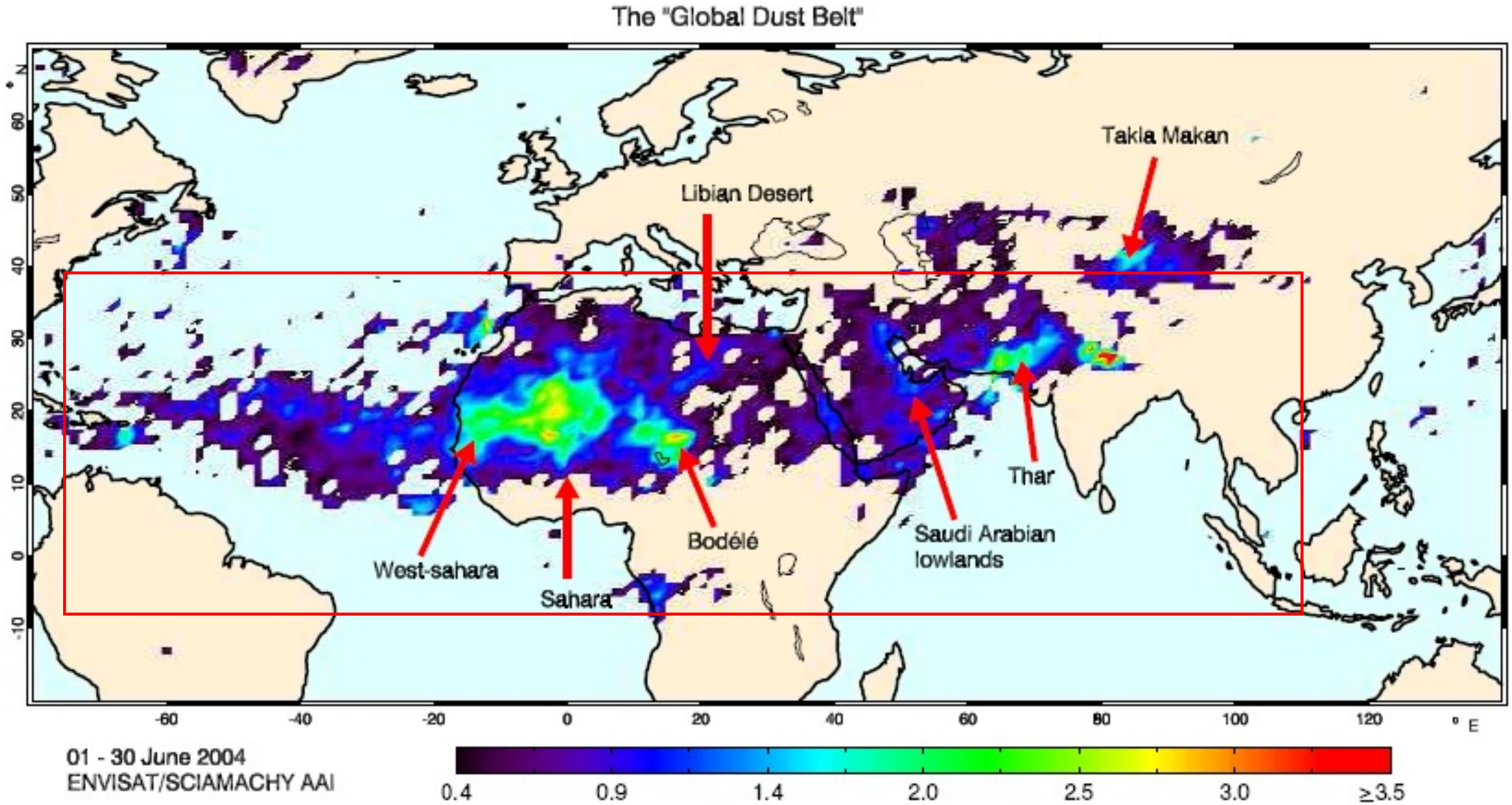
Mineral dust:

Small fragments of soil /crust of the Earth.

One of the most abundant aerosol in the Earth.

Mineral dust is one of the most important tropospheric aerosols on the global scale

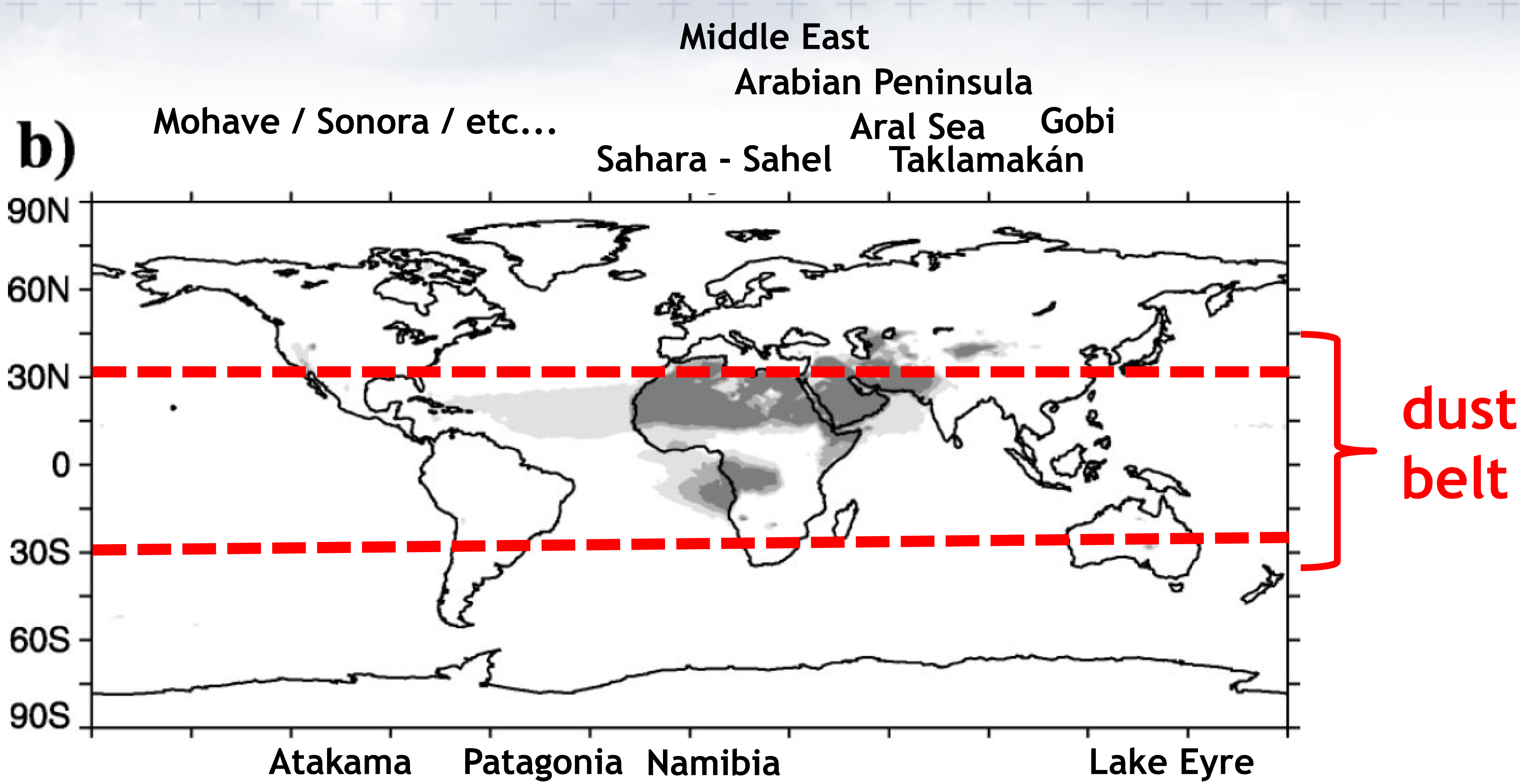
The global distribution is very heterogeneous



Sahara, Sahel, Arabian Peninsula, Thar desert (Middle East), Aral Sea (Central Asia), Taklamakan desert (China), Gobi Desert (China/Mongolia), Lake Eyre Basin (Australia)

(de Graaf, 2006)

Background



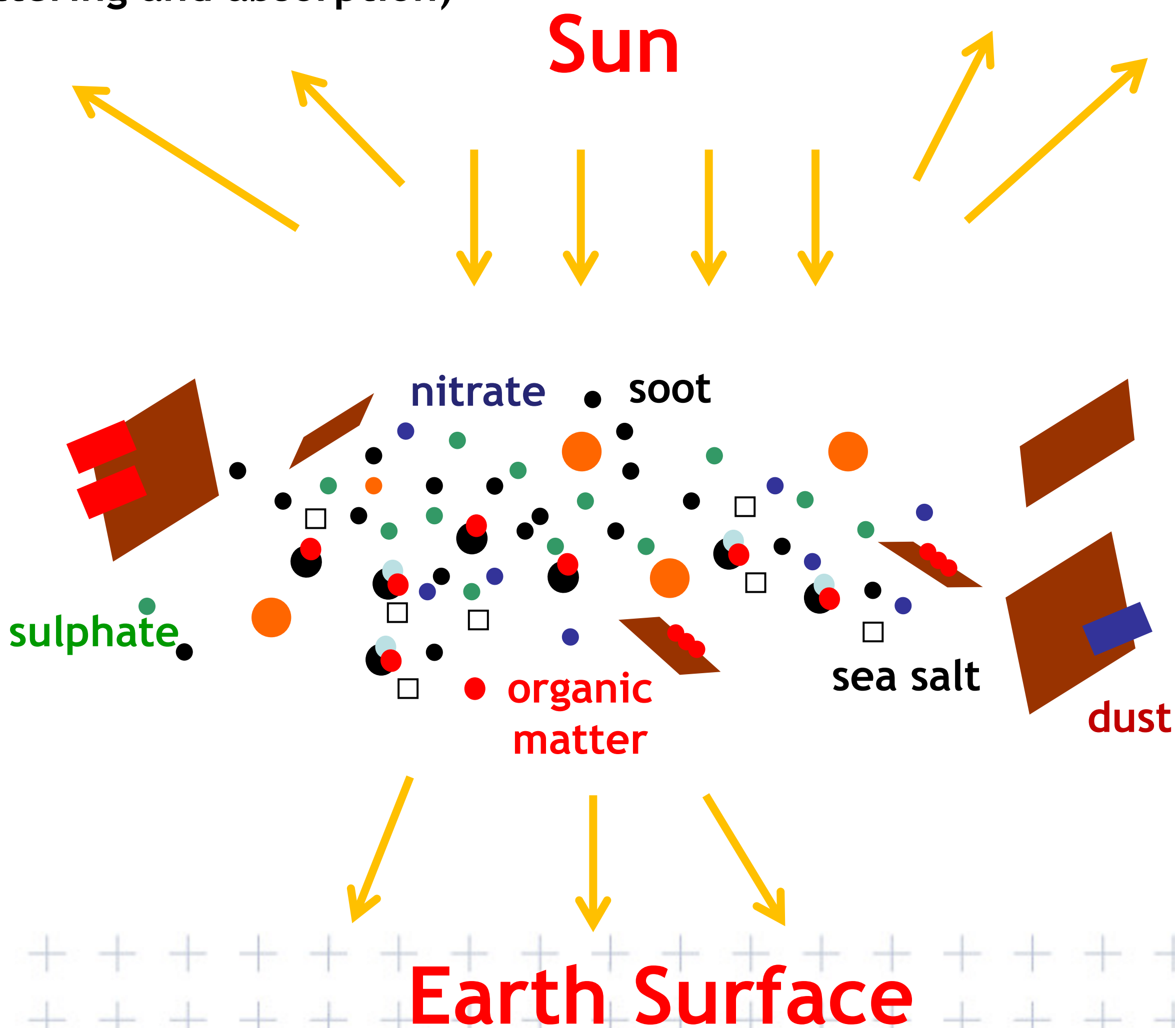
ENVIRONMENTAL CHARACTERIZATION OF GLOBAL SOURCES OF ATMOSPHERIC SOIL DUST IDENTIFIED WITH THE NIMBUS 7 TOTAL OZONE MAPPING SPECTROMETER (TOMS) ABSORBING AEROSOL PRODUCT

Joseph M. Prospero,[1] Paul Ginoux,[2] Omar Torres,[3] Sharon E. Nicholson,[4] and Thomas E. Gill[5]

Reviews of Geophysics, 40, 1 / *February 2002*

Aerosols & Climate

Direct effects: direct interaction between dust and radiation (scattering and absorption)



Aerosols & Climate

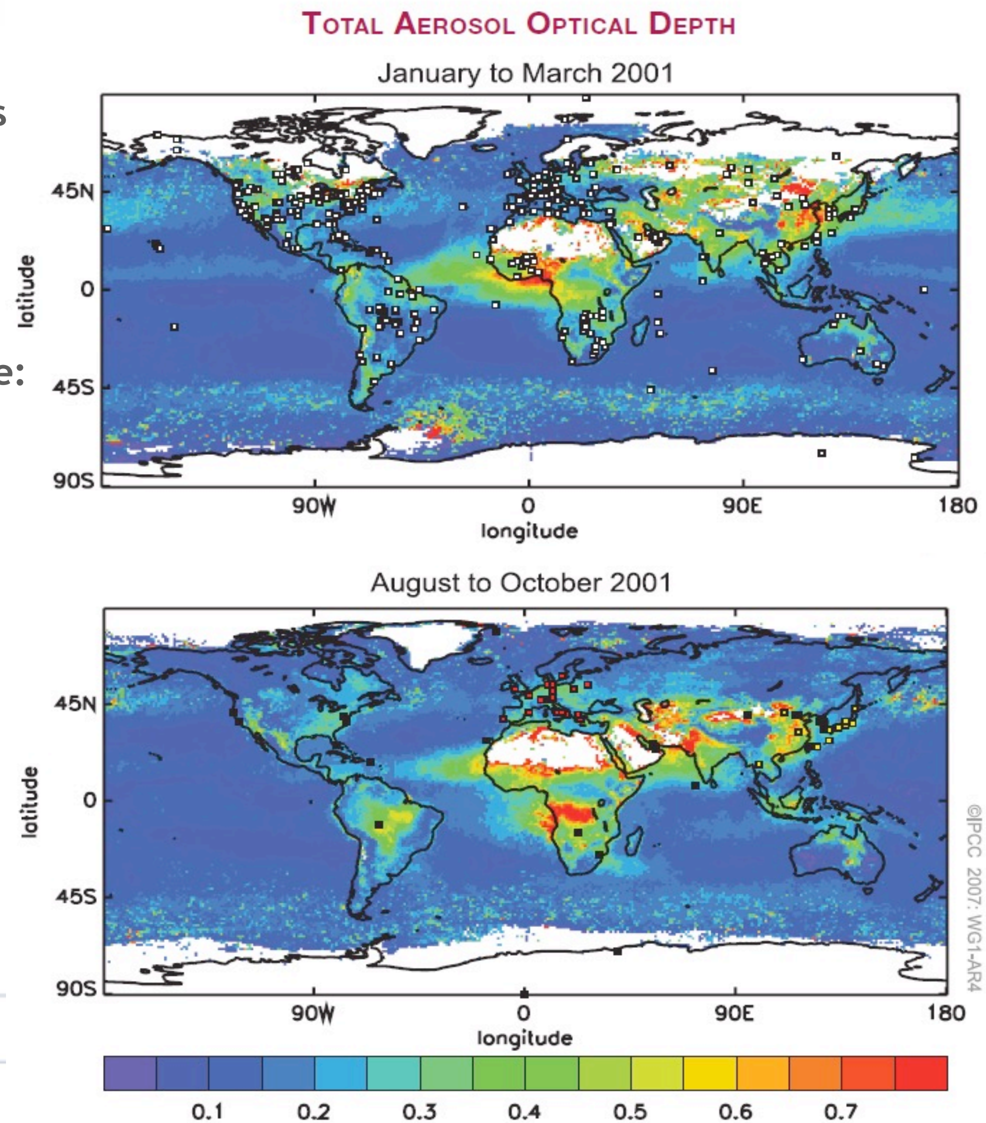
Direct effects: direct interaction between dust and radiation (scattering and absorption)

A total direct aerosol radiative forcing combined across all aerosol types can now be given for the first time as

-0.5 ± 0.4 W m^{-2}, with a medium-low level of scientific understanding

The direct radiative forcing for individual species remains less certain and is estimated from models to be:

- -0.4 ± 0.2 $w \cdot m^{-2}$ sulphate
- -0.05 ± 0.05 $w \cdot m^{-2}$ fossil fuel organic carbon
- $+0.2 \pm 0.15$ $w \cdot m^{-2}$ fossil fuel black carbon
- $+0.03 \pm 0.12$ $w \cdot m^{-2}$ biomass burning
- -0.1 ± 0.2 $w \cdot m^{-2}$ for nitrate
- -0.1 ± 0.2 $w \cdot m^{-2}$ for mineral dust



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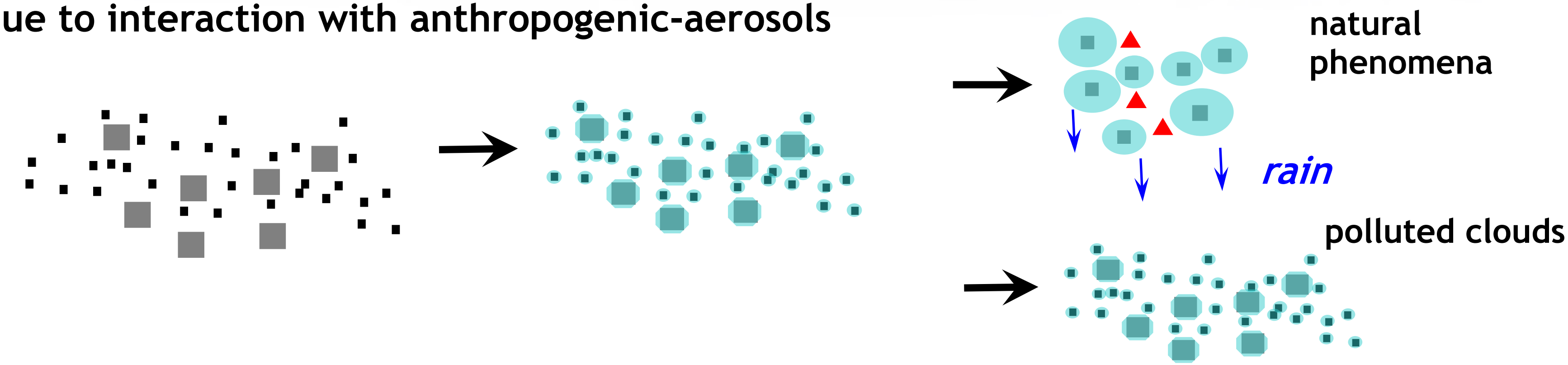
Aerosols & Climate

Indirect effects: change in the optical properties of clouds due to interaction with anthropogenic-aerosols

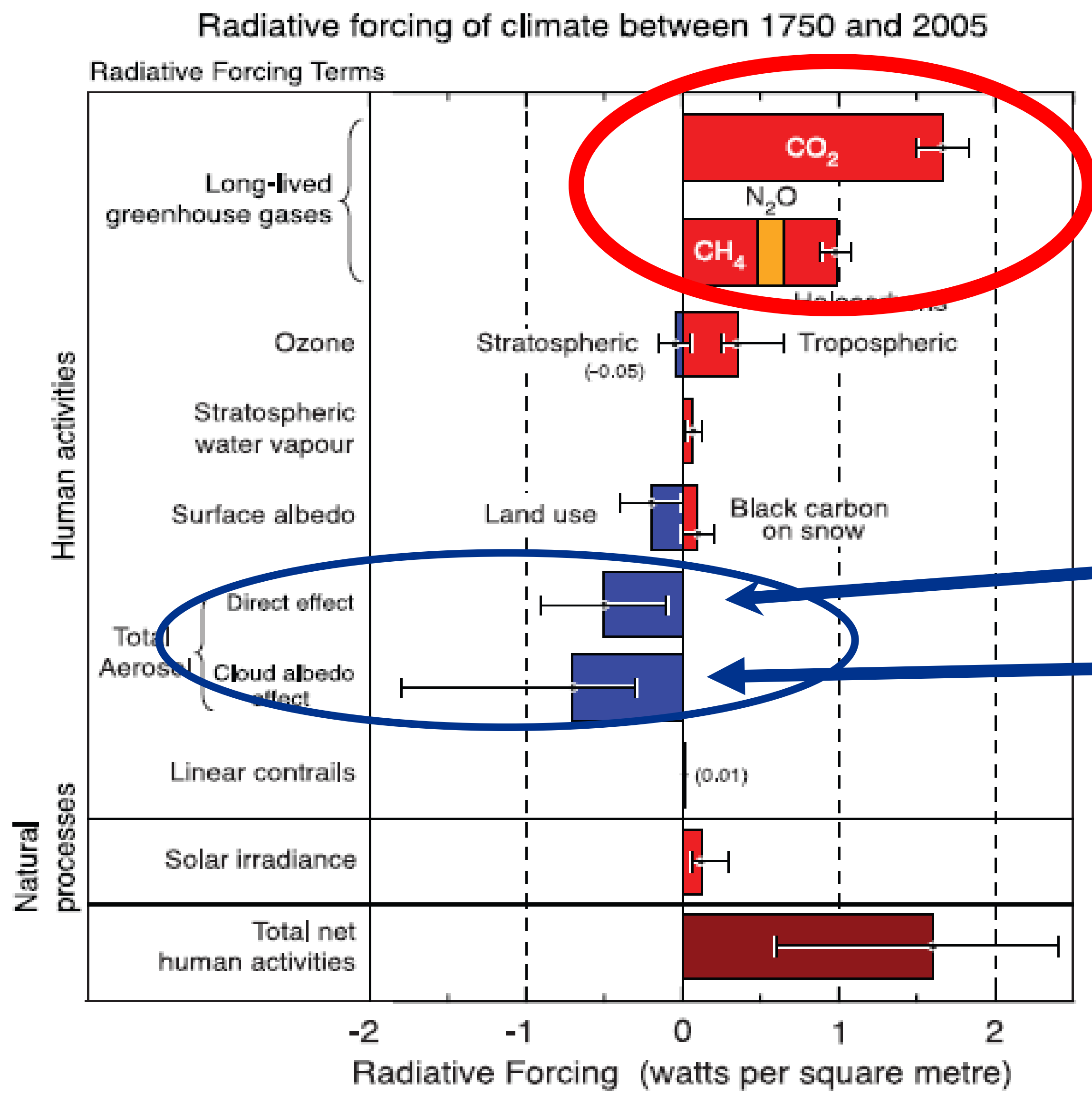


inhibited rain

- increase in life time of clouds
- change of optical properties
- change of optical properties

Anthropogenic aerosols effects on water clouds cause an indirect cloud albedo effect (referred to as the first indirect effect in the TAR), which has a best estimate for the first time of **-0.7 [-0.3 to -1.8] W m^{-2}**, with a low level of scientific understanding

Background



GREENHOUSE GASES RADIATIVE FORCING:

+1.5 w·m^{-2}

+1.0 w·m^{-2}

AEROSOL RADIATIVE FORCING:

Direct effect: –0.5 [±0.4] W m^{-2}

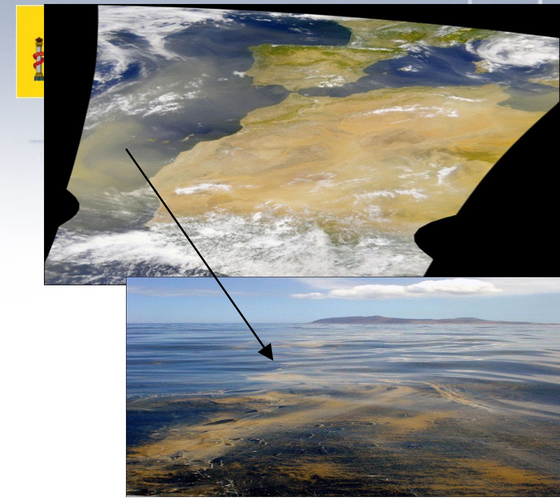
Indirect effect: –0.7 [-1.1, +0.4] W m^{-2}

IPCC's Fourth Assessment Report (2007)

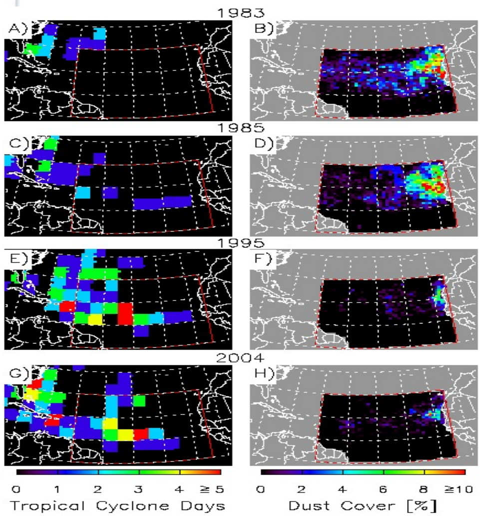
Background

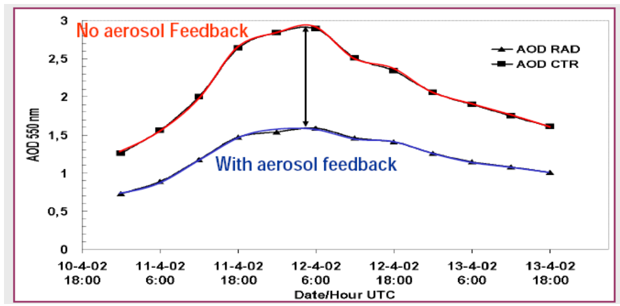
Human Health (Asthma, infections, Meningitis in Africa, Valley Fever in the America's)

Agriculture (negative & positive impacts)



Marine productivity (negative & positive impacts)





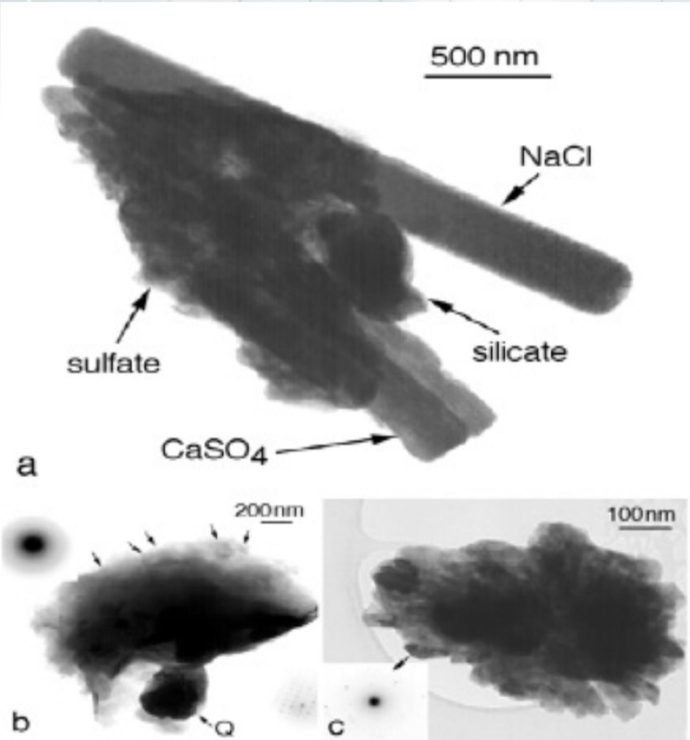
Improved Weather and Seasonal Climate prediction

Industry (Semi-conductor, etc.)

Energy (Thermal solar energy)

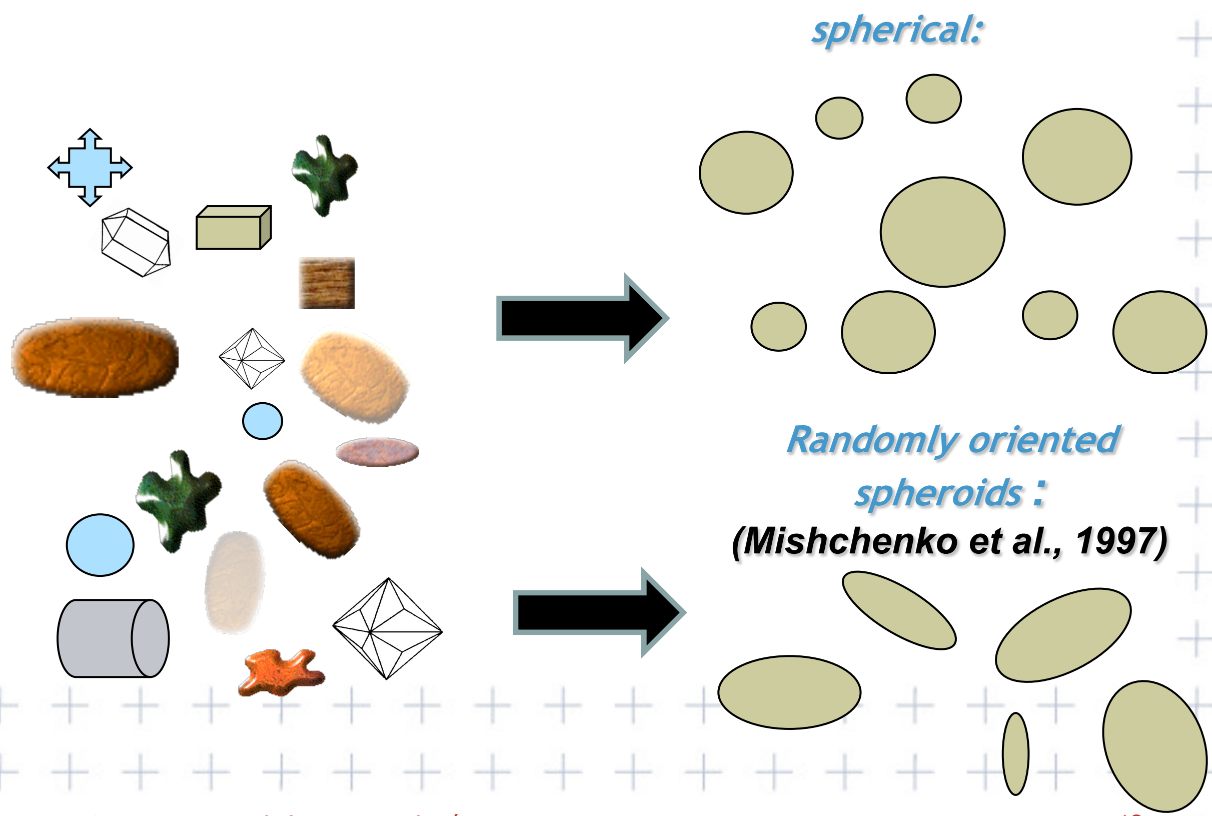
Aviation (air disasters)
Ground Transportation

Dust Particle Images



Busek and Posfai, 1996

aerodynamic diameter, measured in microns or micrometers (µm), a unit equal to one millionth of a meter.

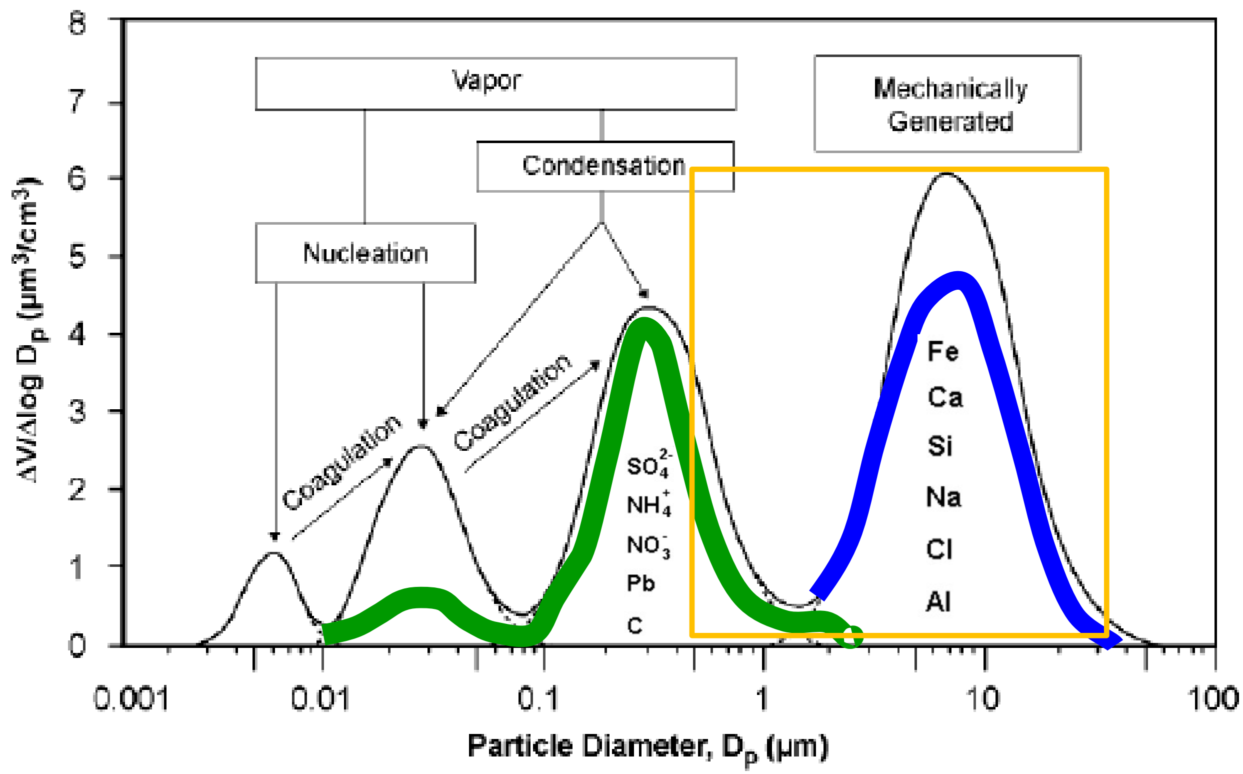


Background

PM_{10} (diameter <10 microm)

$PM_{2.5}$

$PM_{2.5\text{-}10}$



ultrafine <0.1 µm

accumulation 0.1 – 1 µm

Coarse 1 - 10 µm

Mineral dust :

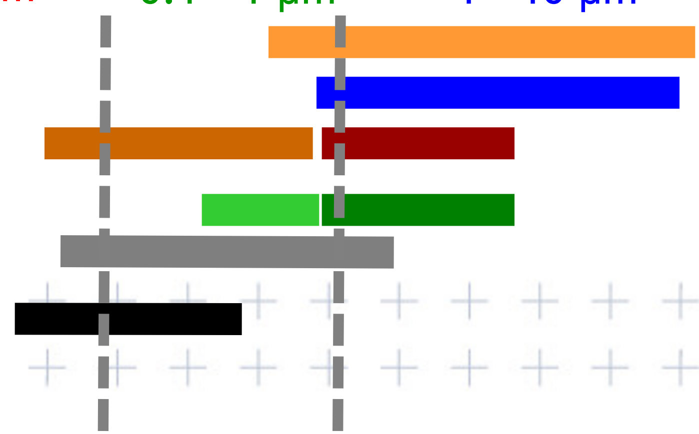
Marine salt:

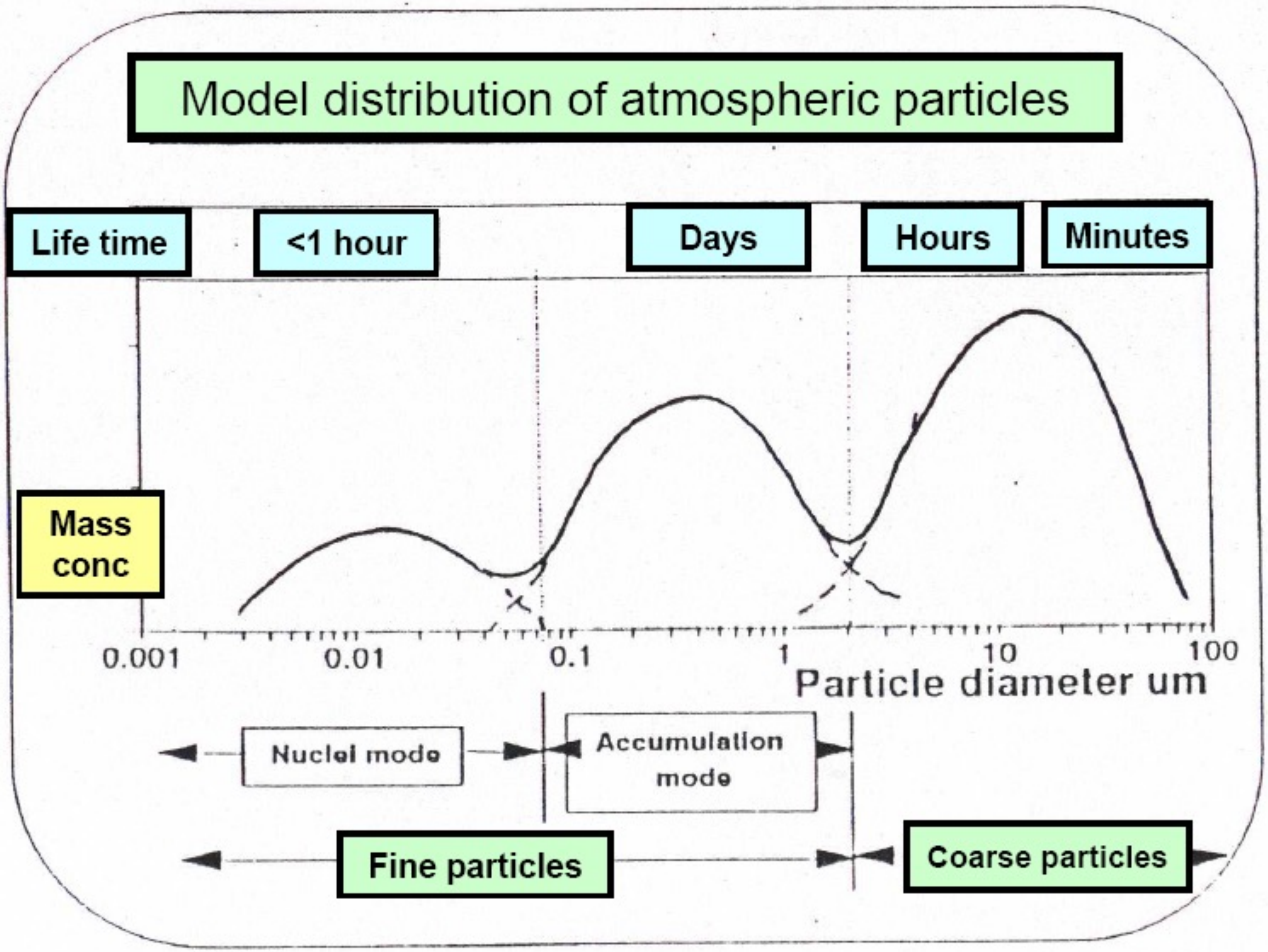
Sulfate:

Nitrate:

Organic aerosol:

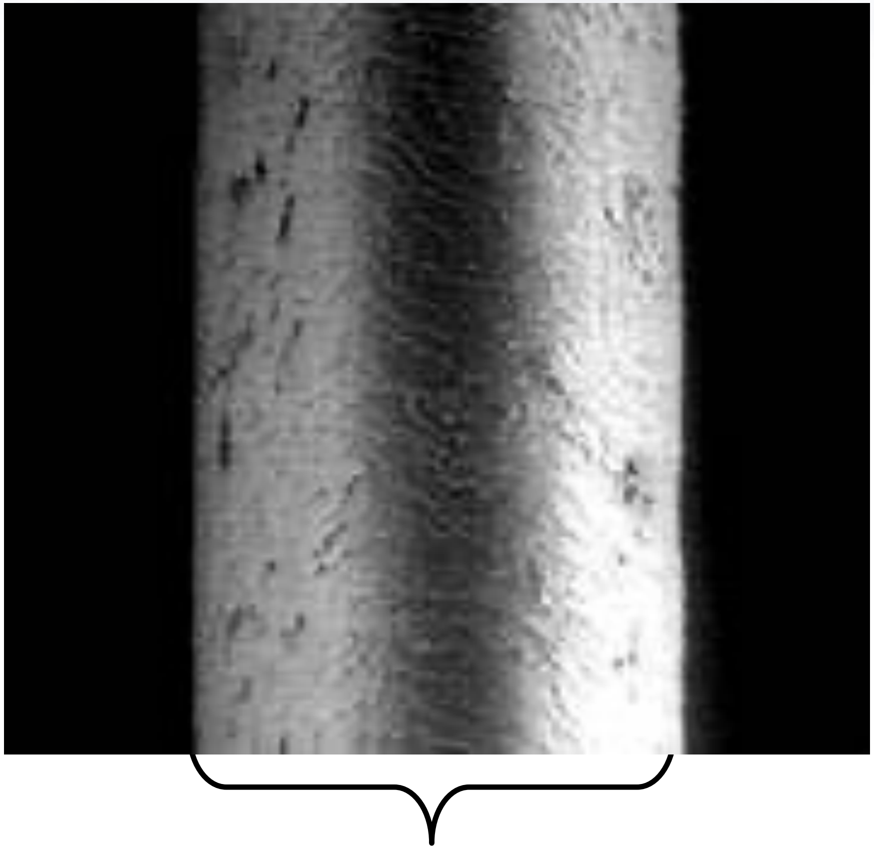
black carbon:

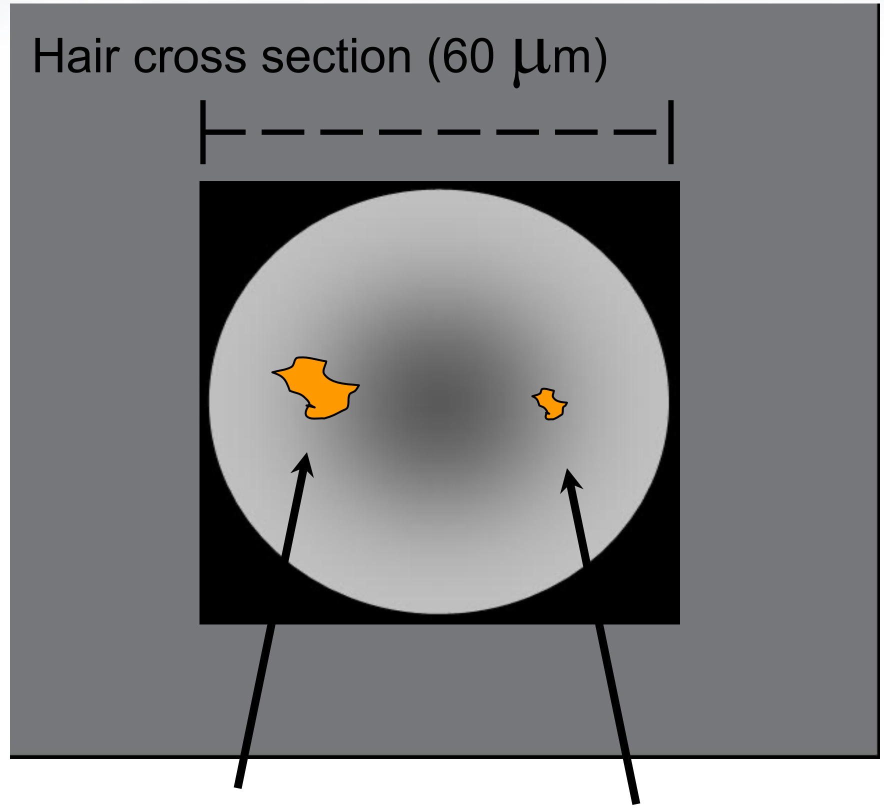




Particles in the Atmosphere: atmospheric residence time Model

Background





Human Hair

(60 µm diameter)

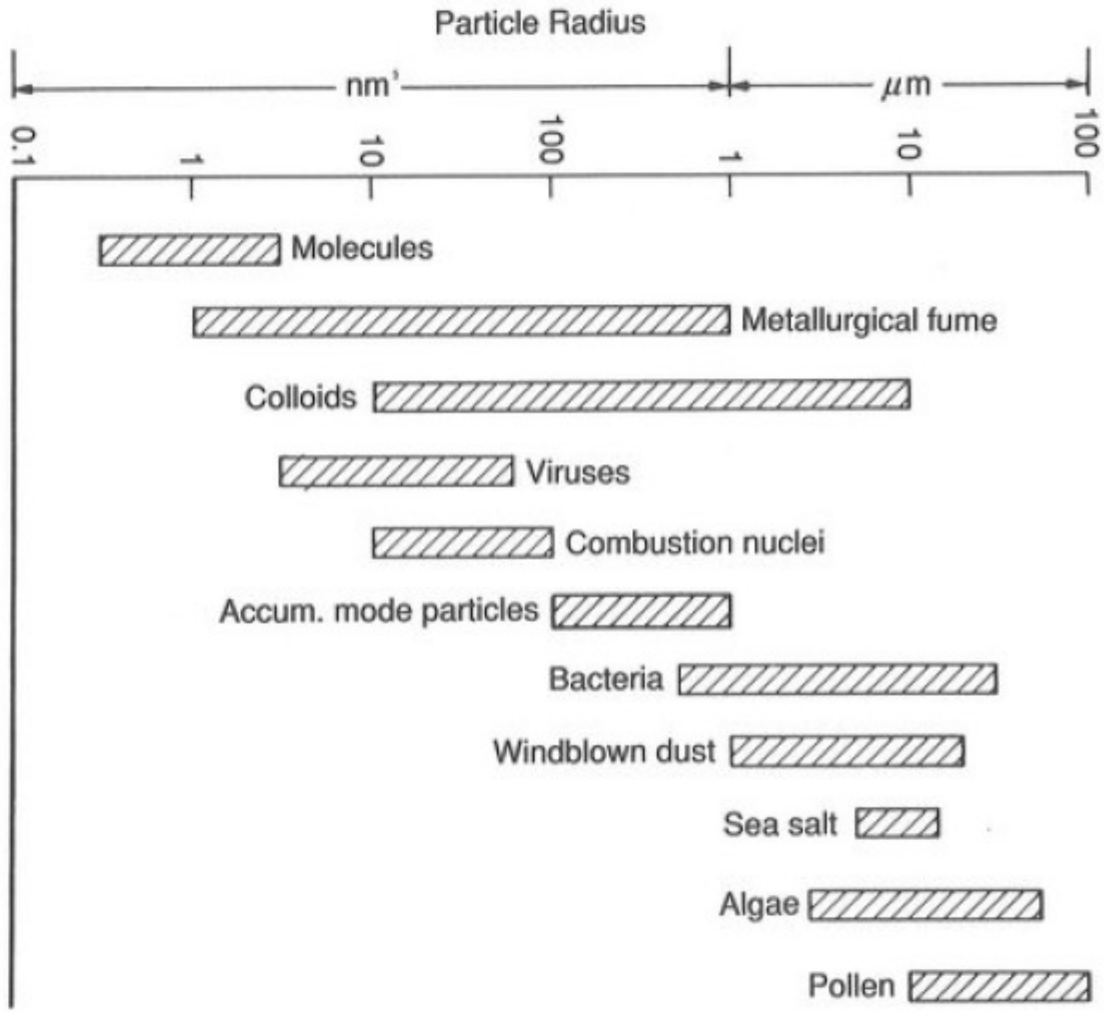
PM_{10}

(10 µm)

$PM_{2.5}$

(2.5 µm)

Background



Size of different atmospheric aerosols, from (Graedel and Crutzen, 1994)

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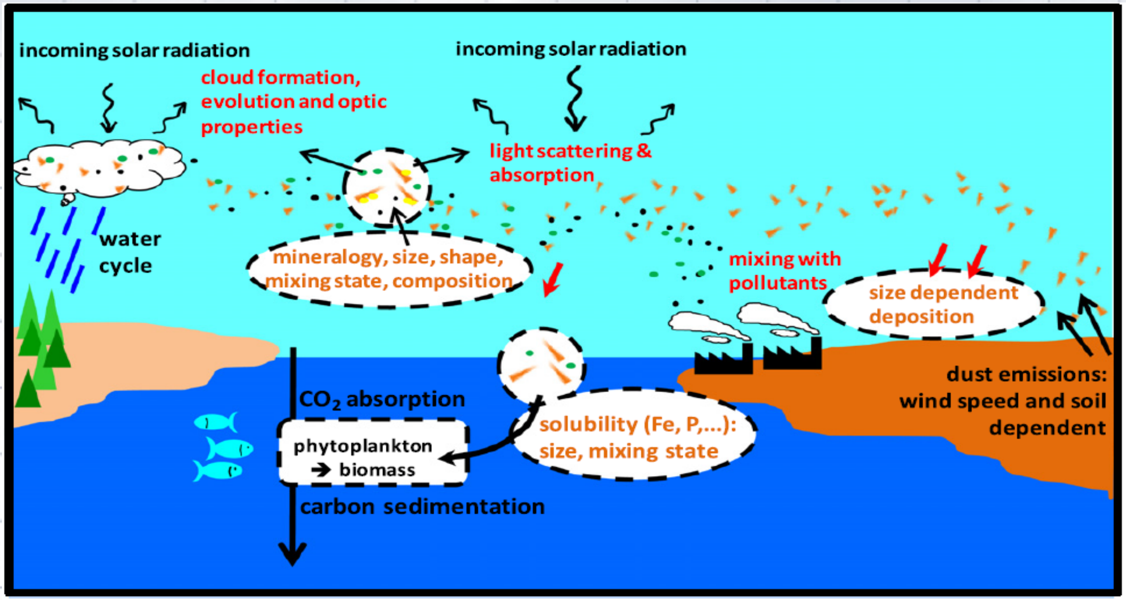
What property of aerosol dust we want to measure ?



number size distribution
mass concentration
chemical composition
mixing state
mineralogy
optical properties

in-situ techniques

Review Article Aeolian Research Aeolian Research 6 (2012) 55–74

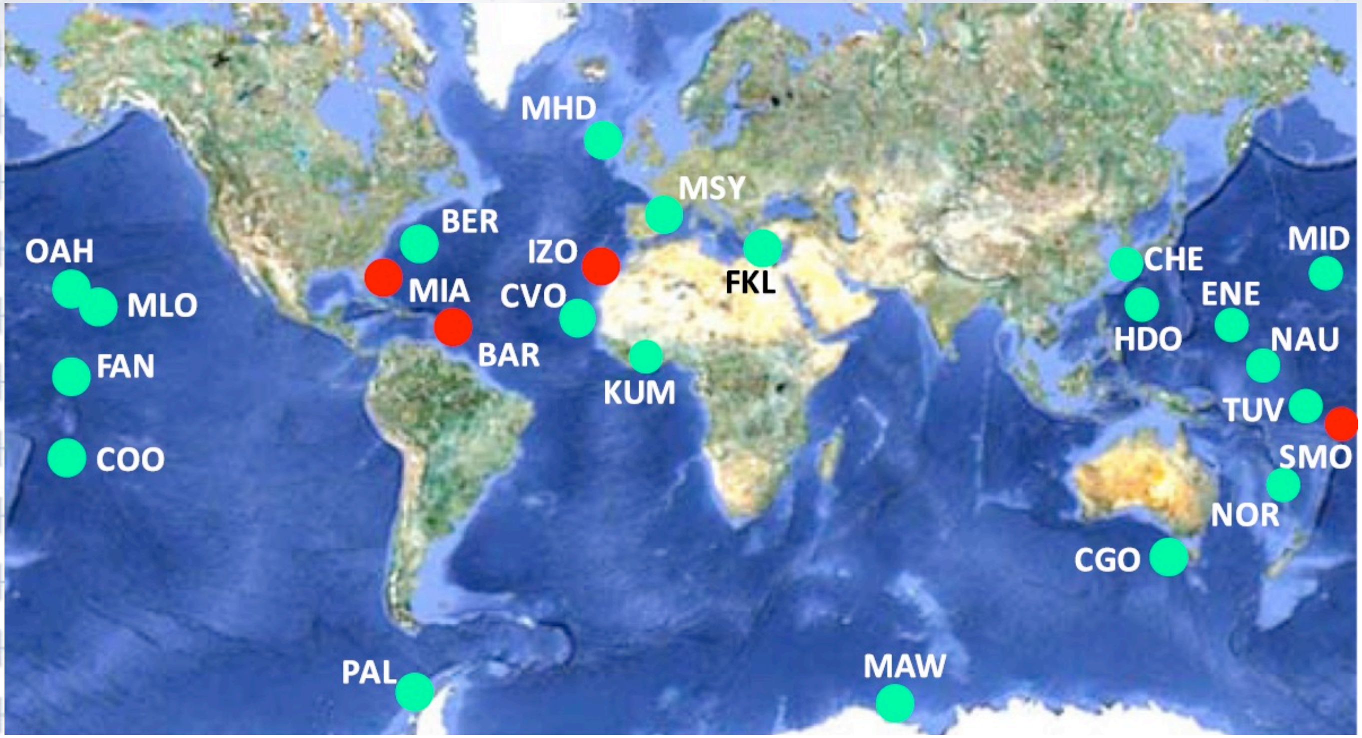
A review of methods for long term in situ characterization of aerosol dust

Sergio Rodríguez [a,*], Andrés Alastuey [b], Xavier Querol [b]

property of aerosol dust:

number size distribution
mass concentration
chemical composition
mixing state
mineralogy
optical properties

Long term monitoring dust background-observatories:



- at least 4 years
- Active during the last 20 years

Review Article

Aeolian Research Aeolian Research 6 (2012) 55–74

A review of methods for long term in situ characterization of aerosol dust

Sergio Rodríguez[a,*], Andrés Alastuey[b], Xavier Querol[b]

Long term monitoring dust observatories:

S. Rodríguez et al. / Aeolian Research 6 (2012) 55–74

Table 1
Observatories where long term dust characterization has been performed during at least 5 years. Elements: elemental composition. Starting date is highlighted in black. See acronyms list.

Observatory	Parameter	Size fraction	Period	Parameter	Technique	Reference
Atlantic Ocean						
Barbados, BAR 13.17°N,59.43°W	Bulk chemistry	Total	1965-on going 48 years	Bulk dust, Al, ($SO_4^{=}$, NO_3^-, Cl^-), Na^+, NH_4^+	Filter: Ash, INAA, IC, FAA, AC	Prospero and Lamb (2003)
Miami, MIA 25.75°N,80.25°W	Bulk chemistry	Total	1972-on going 39 years	Bulk dust, Al, ($SO_4^{=}$, NO_3^-, Cl^-), Na^+, NH_4^+	Filter: Ash, INAA, IC, FAA, AC	Prospero (1999)
Izaña, IZO 28.30°N,16.50°W	Bulk chemistry		1987-on going26 years			
		Total	1987–1999	Bulk dust, Al, ($SO_4^{=}$, NO_3^-, Cl^-), Na^+, NH_4^+	Filter: Ash, INAA, IC, FAA, AC	Prospero et al. (1995)
		Total	2002-on going	Elements, ($SO_4^{=}$, NO_3^-, Cl^-), NH_4^+, (OC, EC)	Filter: (ICP-AES, ICP-MS), IC, ISE, TOR	Rodríguez et al. (2011)
		<10 µm	2005-on going	"	"	"
		<2.5 µm	2002-on going	"	"	"
		<1 µm	2009-on going	"	"	
	Size distribution	10–400 nm	2008-on going	dN/dlogD	SMPS	Rodríguez et al. (2009)
		0.5–20 µm	2007-on going	dN/dlogD	APSTOFS	Rodríguez et al. (2011)
	optical properties	<10 µm	2008-on going	Total and back scattering (3λ	Integrating nephelometer	Andrews et al. (2010)
		<10 µm	2007-on going	Absorption (1λ)	Absorption photometry	Andrews et al. (2010)
Bermudas, BER 32.27°N, 64.87°W	Bulk chemistry	Total	1988-1998 11 years	Bulk dust, Al, ($SO_4^{=}$, NO_3^-, Cl^-), Na^+, NH_4^+	Filter: Ash, INAA, IC, FAA, AC	Prospero (personal communication)
Mace Head, MHD 53.32°N, 9.85°W	Bulk chemistry	Total	1988-1994 7 years	Bulk dust, Al, ($SO_4^{=}$, NO_3^-, Cl^-), Na^+, NH_4^+	Filter: Ash, INAA, IC, FAA, AC	Prospero (personal communication)
Cape Verde, CVO 16.45°N,22.57°W	Bulk chemistry	Total	1991-1994 4 years	Major elements (Si, Al, Ca, K)	Filter: XRF	Chiapello et al. (1995, 1997a)
Kumasi, KUM 6.40°N,1.34°W	Size distribution	0.5–25 µm	1996-2005 10 years	Number size distribution	OPC	Sunnu et al. (2008)

Long term monitoring dust observatories:

S. Rodríguez et al. / Aeolian Research 6 (2012) 55–74

Observatory	Parameter	Size fraction	Period	Parameter	Technique	Reference
Mediterranean						
Montseny, MSY 41.76°N, 2.58°E	Bulk chemistry		2003-on going 10 years			
		<10 µm	2003-on going	Elements, ($SO_4^{=}$, NO_3^-, Cl^-), NH_4^+, (OC, EC)	Filter: (ICP-AES, ICP-MS), IC, ISE, TOR	Querol et al. (2009a,b)
		<2.5 µm	2002-on going	"	"	"
		<1 µm	2009-on going	"	"	"
	Size distribution	10–800 nm	2010-on going	dN/dlogD	SMPS	
	Optical properties	<10 µm	2008-on going	Total and back scattering (3λ	Integrating nephelometer	Pandolfi et al. (2011)
		<10 µm	2009-on going	Absorption (1λ)	Absorption photometry	"
Finokalia, FKL 35.20°N,25.40°E	Bulk chemistry		2004-on going 9 years		Filter: ICP-MS, (IC), TOR	Koulouri et al. (2008)
		<10 µm	2004-on going	Elements, ($SO_4^{=}$, NO_3^-, Cl^-, NH_4^+, K^+, Mg^{+2}, Ca^{+2}), (OC, EC)		
		<1.3 µm	2004-on going	"	"	"
	Size distribution	18–800 nm	2004-on going	dN/dlogD	SMPS	Kalivitis et al. (2008)
	optical properties	<10 µm	2001-on going	Total and back scattering (1λ	Nephelometer	Kalivitis et al. (2011)
		<10 µm	2004-on going	Absorption (3λ)	Absorption photometry	"

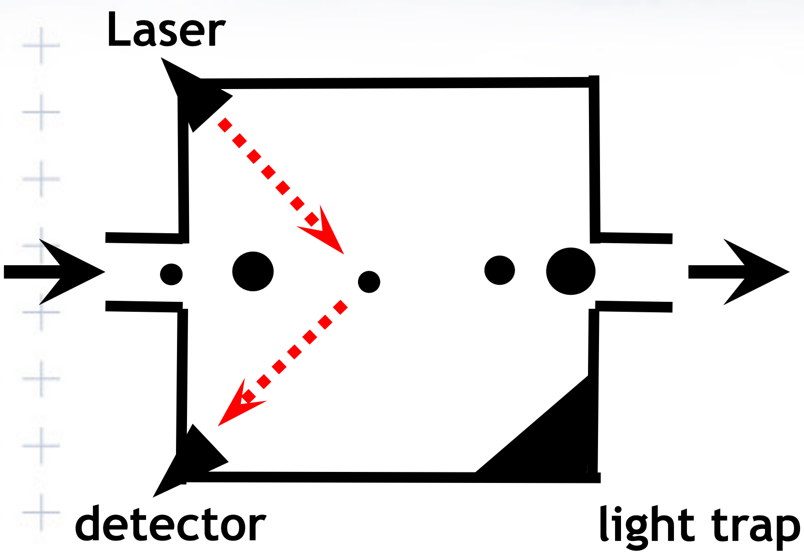
Observatory	Parameter	Size fraction	Period	Parameter	Technique	Reference
Indian Ocean						
CAPE GRIM, CGO 40.68°S,144.68°E	Bulk chemistry	Total	1983-1996 14 years	Bulk dust, Al, ($SO_4^{=}$, NO_3^-, Cl^-), Na^+, NH_4^+	Filter: INAA, IC	Prospero (personal communication)
Antartida						
Mawson, MAW 64.60°S,62.50°E	Bulk chemistry	Total	1987-1995 9 years	Bulk dust, Al, ($SO_4^{=}$, NO_3^-, Cl^-), Na^+, NH_4^+	Filter: INAA, IC	Prospero (personal communication)
Palmer Station, PAL 64.77°S,64.05°W	Bulk chemistry	Total	1990-1996 7 years	Bulk dust, Al, ($SO_4^{=}$, NO_3^-, Cl^-), Na^+, NH_4^+	Filter: INAA, IC	Prospero (personal communication)

property of aerosol dust:

number size distribution
mass concentration
chemical composition
mixing state
mineralogy
optical properties

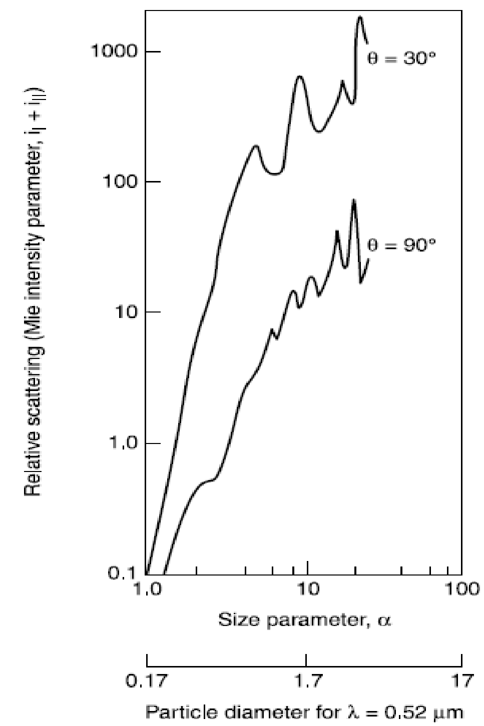
property of aerosol dust: number size distribution

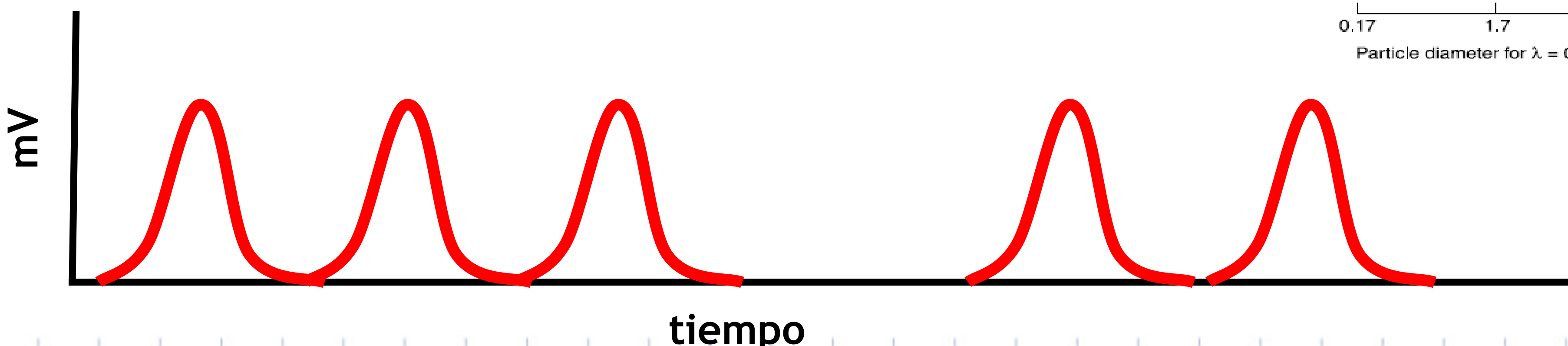
1.Optical Particle Counter OPC: 0.5 - 20 µm



Intensidad del scattering

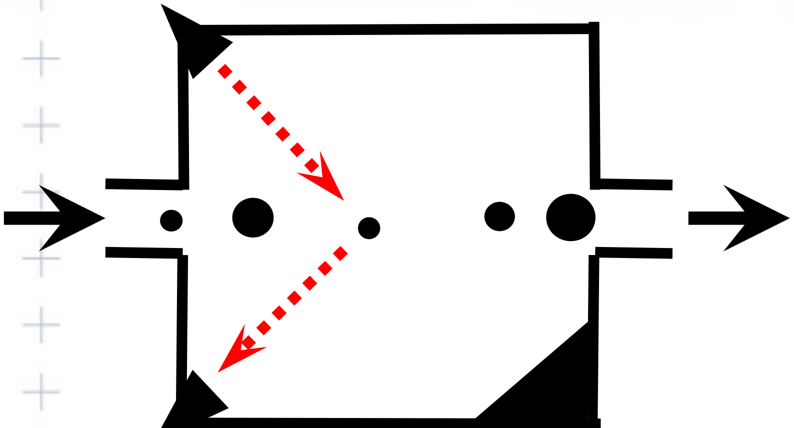
I(dp,θ, λ, m)





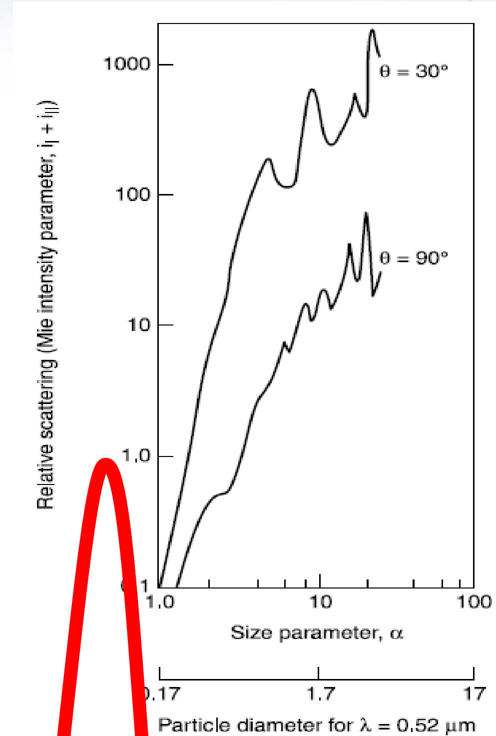
property of aerosol dust: number size distribution

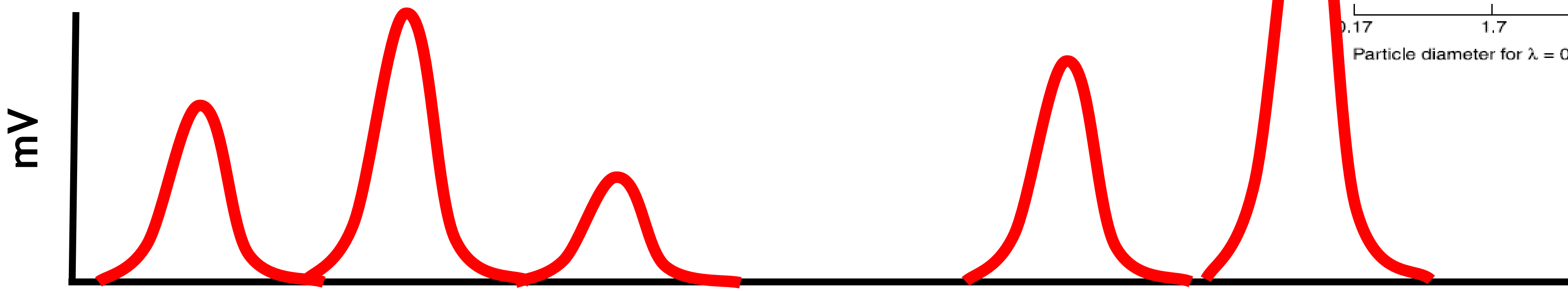
1.Optical Particle Counter OPC: 0.5 - 20 µm



Intensidad del scattering

I(dp,θ, λ, m)





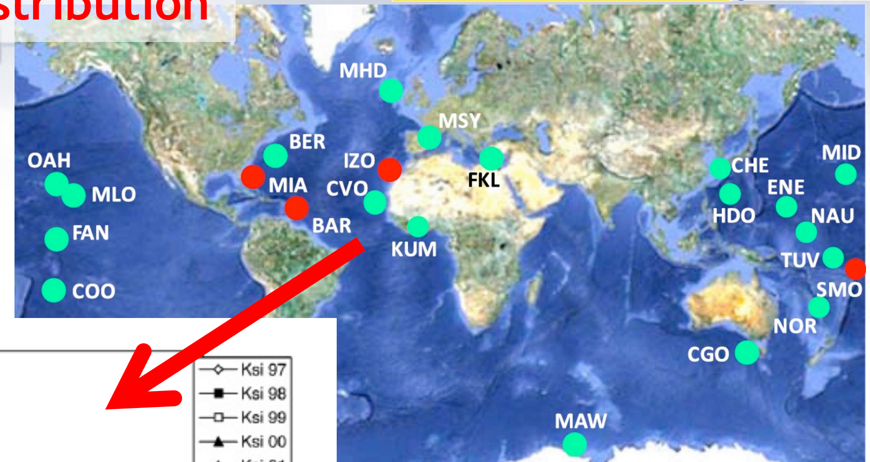
property of aerosol dust: number size distribution

1.Optical Particle Counter OPC: 0.5 - 20 µm

A long-term experimental study of the Saharan dust presence in West Africa

A. Sunnu [a], G. Afeti [a], F. Resch [b,*]

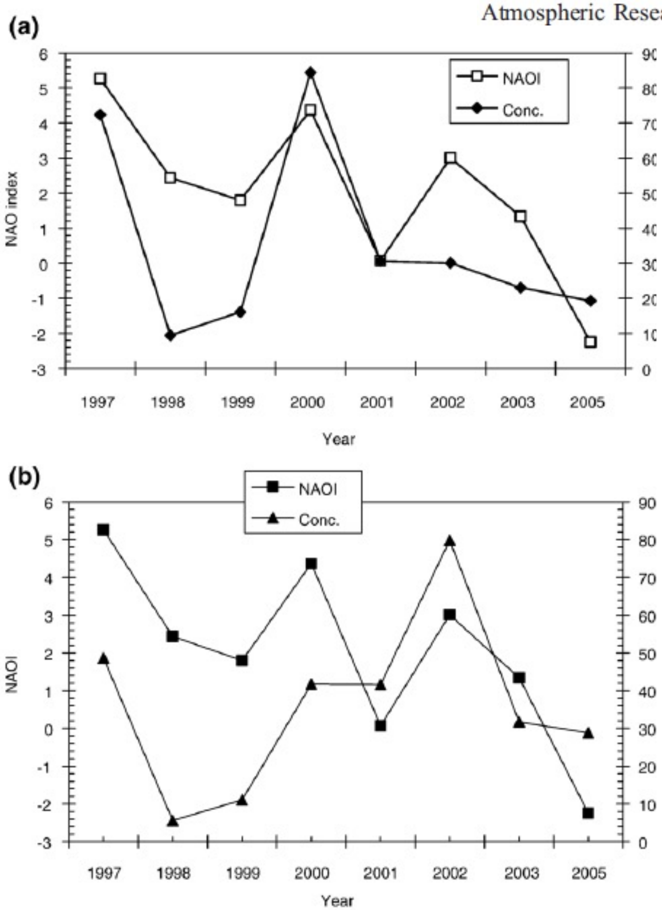
Atmospheric Research 87 (2008) 13 – 26



eview Article Aeolian Research Aeolian Research 6 (2012) 55–74

review of methods for long term in situ characterization of aerosol dust

ergio Rodríguez [a,*], Andrés Alastuey [b], Xavier Querol [b]



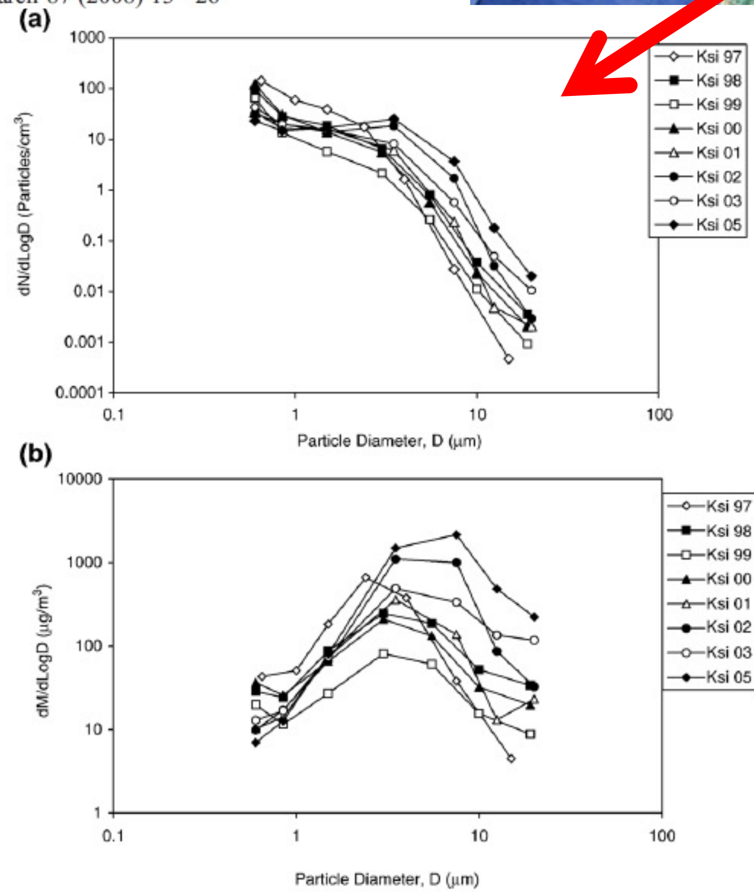


Fig. 3. Inter-annual comparison of number and mass frequency distributions at Kumasi (Ksi).

$$\frac{dV}{d\log D} = \frac{\pi}{6} d^3 \frac{dN}{d\log D}$$

property of aerosol dust: number size distribution

1.Optical Particle Counter OPC: 0.5 - 20 µm

Disadvantage / sources of uncertainties:

Relationship between pulse height (signal in detector) and the size of the particle depends on unknown particle parameters:

refractive index and shape

$m = n + k \cdot i$

e.g. some commercial instruments
$m = 1.5 + 0 \cdot i$

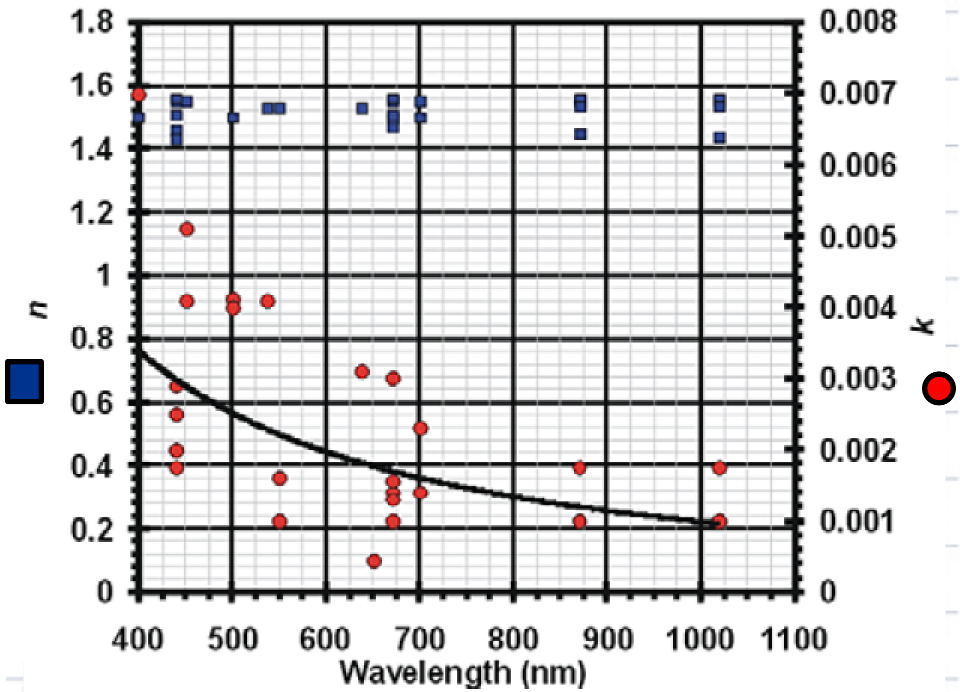
OPC are very useful instruments, but sources of uncertainties should be known:

Particle size (?) → diameter of the calibration polystyrene spheres (PLS)

Light scattering and absorption by wind blown dust: Theory, measurement, and recent data

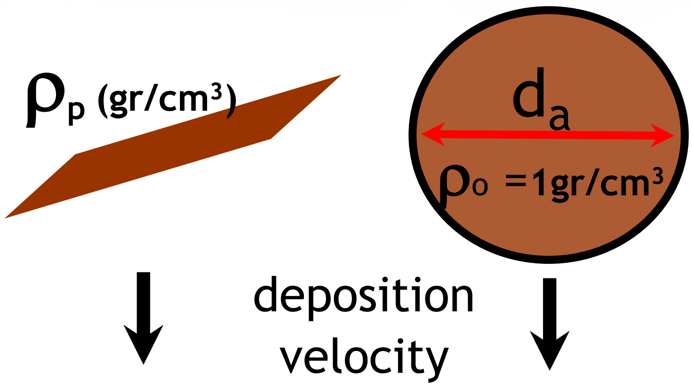
Haley E. Redmond, Kathy D. Dial, Jonathan E. Thompson* Aeolian Research 2 (2010) 5–26

refractive index of dust



property of aerosol dust: number size distribution

1. Optical Particle Counter OPC
2. Aerodynamic Particle Sizer: 0.7 - 20 μm



$$da \cong dp \cdot \left(\sqrt{\frac{\rho_p}{\rho_o}}\right)$$

$\rho_p = 2.6\ g/cm^3$ dust

$\rho_o = 1\ g/cm^3$

1.6

da = 1.6 dp

da > dp

The aerodynamic diameter of a particle is the diameter that would have a particle of density 1 g/cm^3 that settle at the same velocity of our dust - particles

$$V_{TS} = \frac{\rho_p \cdot dp^2 \cdot g}{18\ \eta} = \frac{\rho_o \cdot d_a^2 \cdot g}{18\ \eta}$$

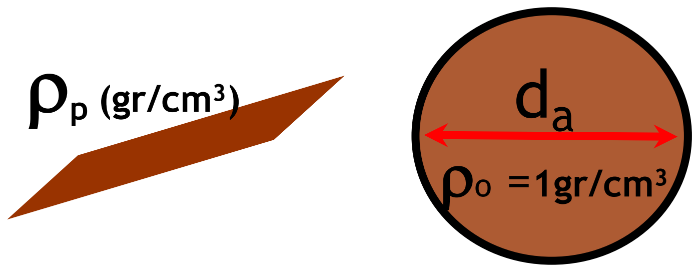
dp = geometric diameter

da = aerodynamic diameter

da, μm	dp, μm
20.0	12.5
10.0	6.25
3.0	1.875
1.0	0.625
0.5	0.3125

property of aerosol dust: number size distribution

1. Optical Particle Counter OPC
2. Aerodynamic Particle Sizer: 0.7 - 20 μm



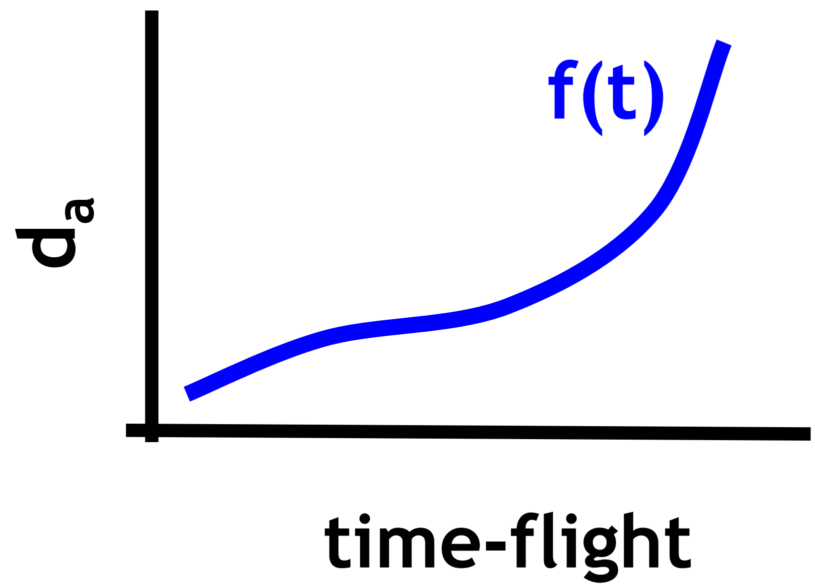
deposition velocity

$$V_{TS} = \frac{\rho_p \cdot dp^2 \cdot g}{18\,\eta} = \frac{\rho_o \cdot d_a^2 \cdot g}{18\,\eta}$$

$$\rho_p \cdot d^2 = \frac{s \cdot t \cdot 18 \cdot \eta}{a} = \rho_o \cdot d_a^2$$

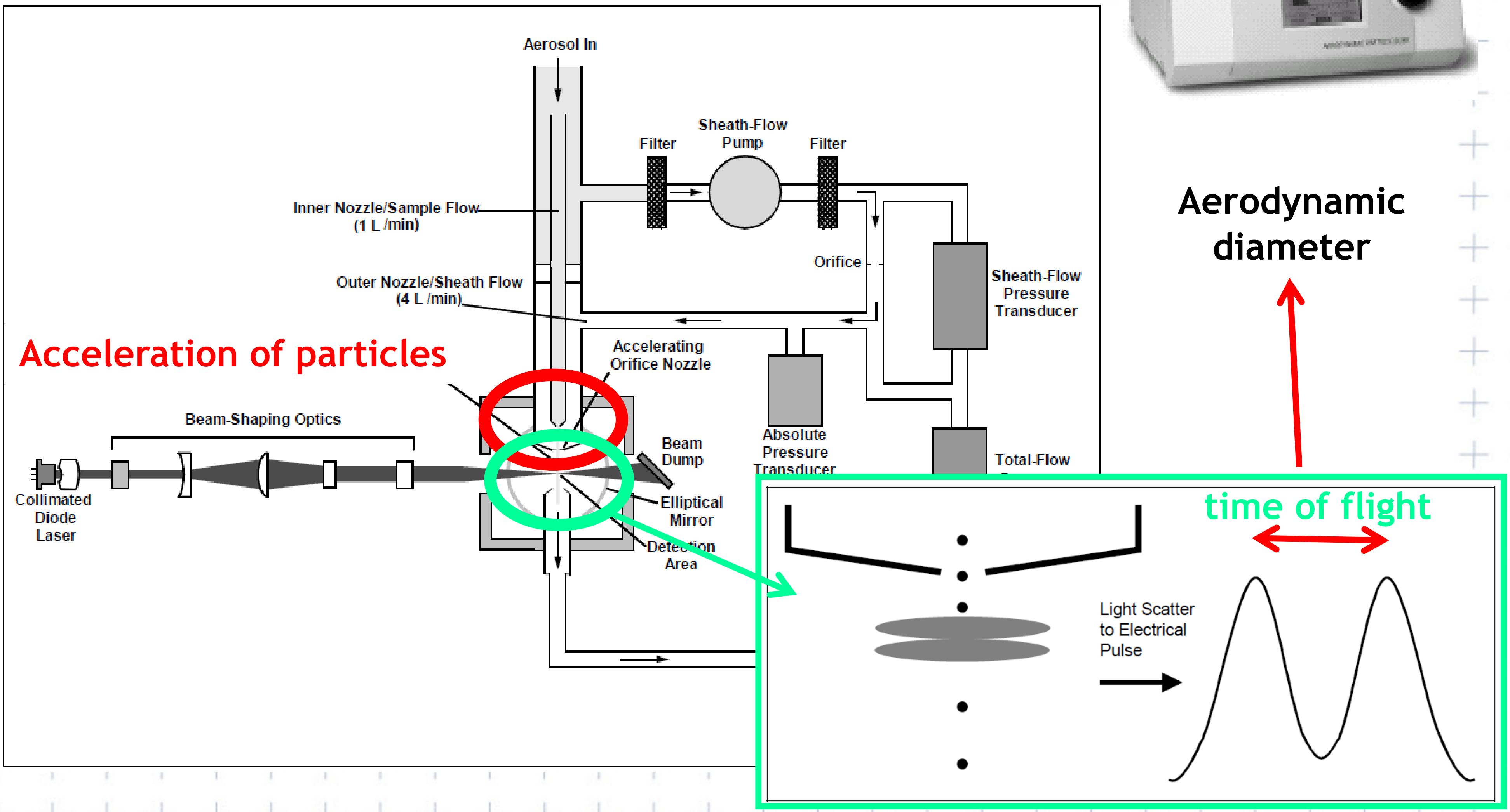
calibration
$t=f(\rho p,d)$

measurement
$da=f(t)$



property of aerosol dust: number size distribution

1. Optical Particle Counter OPC
2. Aerodynamic Particle Sizer: 0.7 - 20 µm



Aerodynamic diameter

property of aerosol dust: number size distribution

1. Optical Particle Counter OPC
2. Aerodynamic Particle Sizer: 0.7 - 20 µm

Potential sources of uncertainties:

Deviations in the sheath / sample flows ➔ inaccuracies in sizing

Characterization of TSP 3321 model, with PLS:

- a counting efficiency of 85% at 0.8 µm, 99% at 3.0 µm, 99% at 5.1 µm and 90% at 9.4 µm (Volckens and Peters, 2005).
- a sizing accuracy of 2 and 3% when measuring spheres of 0.65 µm and 0.96 µm diameter, respectively (Peters and Leith, 2003).
- a 15% instrument-to-instrument variability when sizing 1 µm spheres (Volckens and Peters, 2005).

property of aerosol dust: number size distribution

1. Optical Particle Counter OPC: 0.5 - 20 µm
2. Aerodynamic Particle Sizer: 0.5 - 20 µm
3. Scanning Mobility Particle Sizer: 3 nm - 1µm

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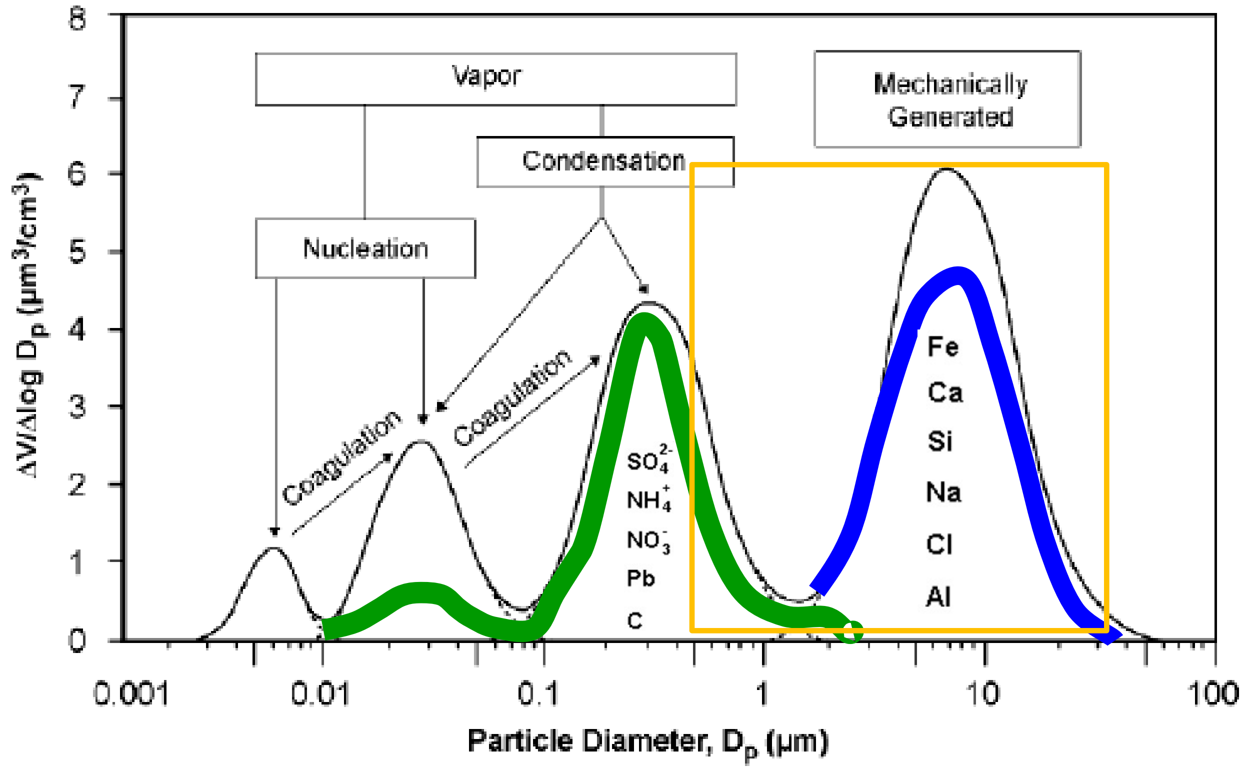
PM$_{10}$ (diameter <10 microm)

PM$_{2.5}$

PM$_{2.5-10}$



ultrafine <0.1 µm

accumulation 0.1 – 1 µm

Coarse 1 - 10 µm

Mineral dust :

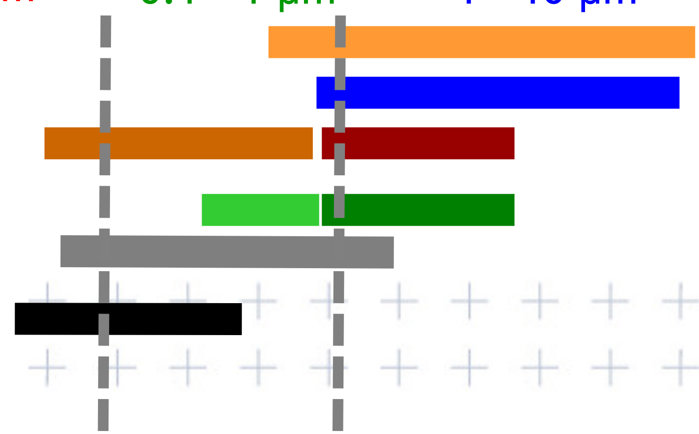
Marine salt:

Sulfate:

Nitrate:

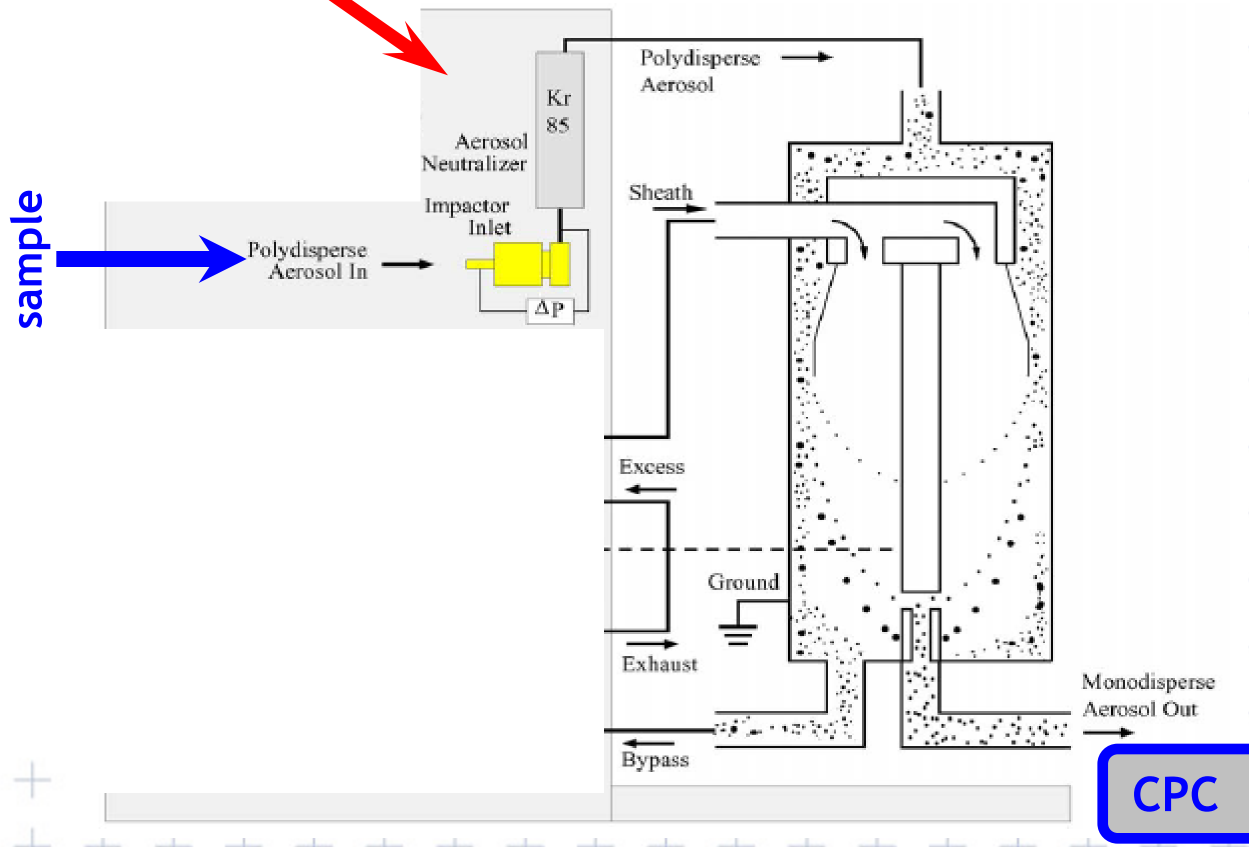
Organic aerosol:

black carbon:



Scanning Mobility Particle Sizer: 3 nm - 1μm

1. Neutralizer: known charge distribution



Scanning Mobility Particle Sizer: 3 nm - 1µm

1. Neutralizer: known charge distribution
2. Electrical mobility and selection of particles by size

$$Z_p = \frac{neC}{3\pi\mu D_p}$$

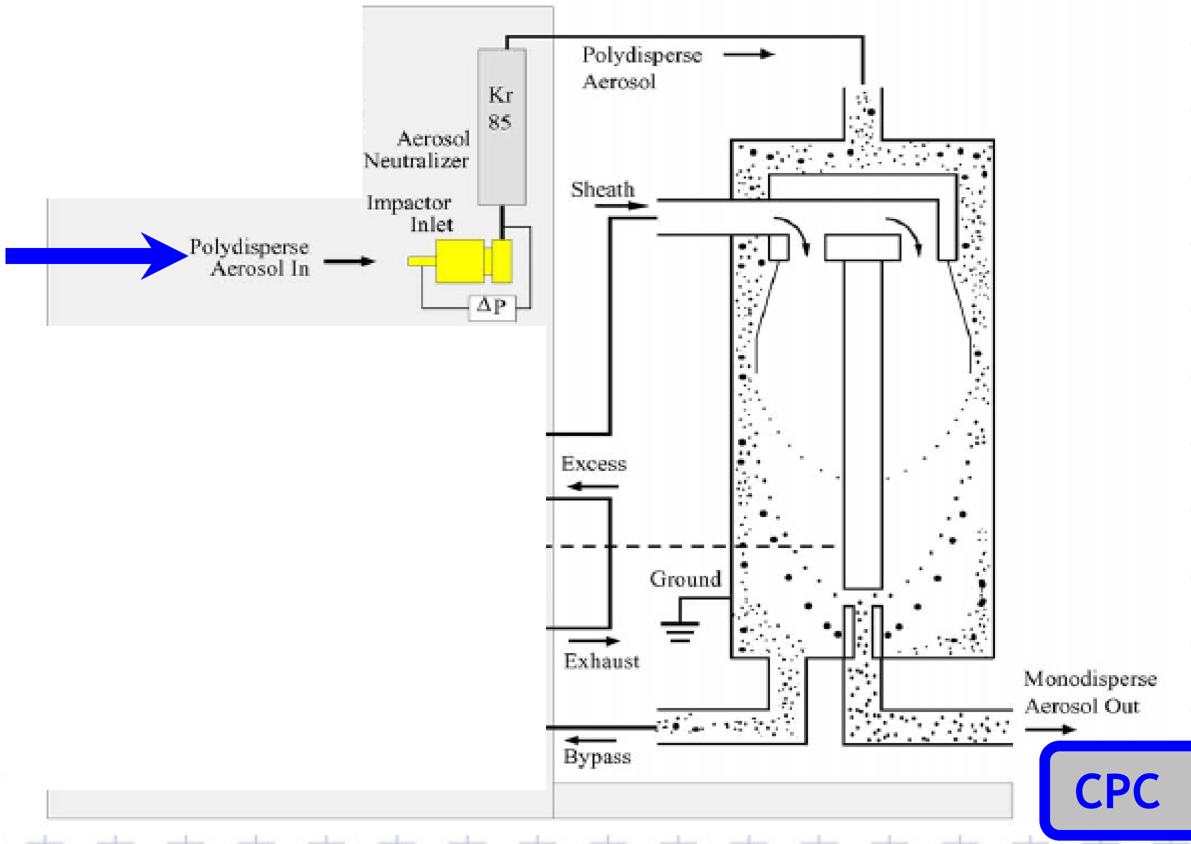
n = number of elementary charges on the particle
e = elementary charge (1.6×10^{-19} Coulomb)
C = Cunningham slip correction = $1+Kn[\alpha+\beta \exp(-\gamma/Kn)]$
α = 1.142, β = 0.558, γ = 0.999 (Allen & Raabe, 1985)
Kn = Knudsen Number = $2\lambda/D_p$
λ = gas mean free path =

$$\lambda_r \left(\frac{P_r}{P}\right)\left(\frac{T}{T_r}\right)\left(\frac{1+S/T_r}{1+S/T}\right)$$

μ = gas viscosity (dyne • s/cm²) poise =

$$\mu_r \left(\frac{T_r+S}{T+S}\right)\left(\frac{T}{T_r}\right)^{\frac{3}{2}}$$

D_p = particle diameter (cm)
S = Sutherland constant [K]
T = temperature [K]
T_r = reference temperature [K]



Scanning Mobility Particle Sizer: 3 nm - 1µm

1. Neutralizer: known charge distribution
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S = Sutherland constant [K]
T = temperature [K]
T_r = reference temperature [K]

$$Z_p^* = \frac{q_{sh}}{2\pi VL}\ln\left(\frac{r_2}{r_1}\right)$$

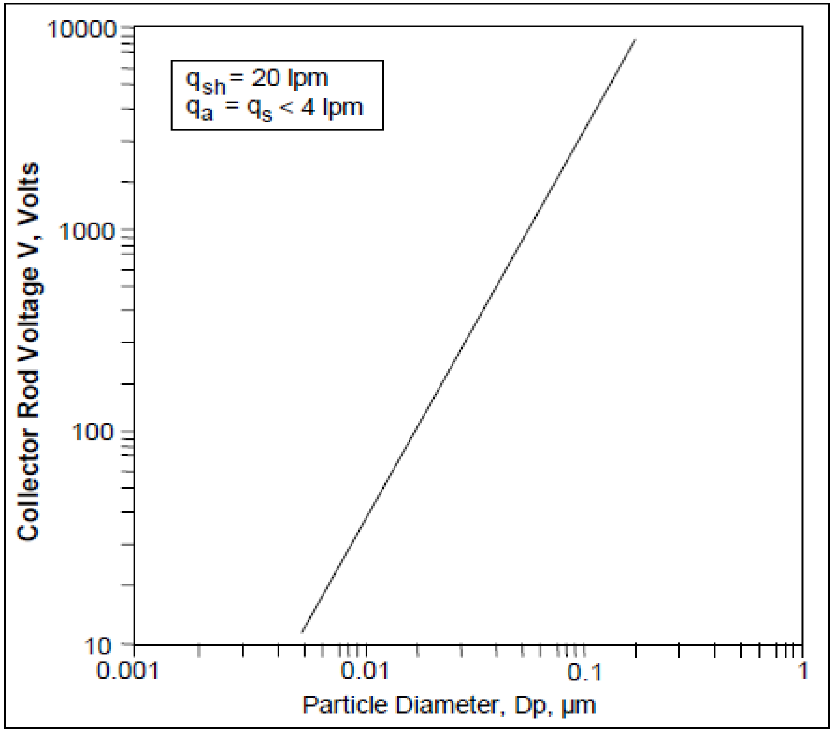
where:
Z_p^* = set mobility
q_a = aerosol flow rate through the DMA ($q_a = q_s = q_p$; for closed-loop setup of sheath and excess flow rate)
q_s = monodisperse flow rate
q_p = polydisperse flow rate
q_{sh} = sheath air flow rate (equal to excess air flow rate)
r_2 = outer radius of annular space
= 1.961 cm (for Long DMA)
= 1.905 cm (for Nano DMA)
r_1 = inner radius of the annular space
= 0.937 cm (for Long DMA)
= 0.937 cm (for Nano DMA)
$\overline{V}$ = average voltage on the inner center rod (volts)
L = length between exit slit and polydisperse aerosol inlet
= 44.369 cm (for Long DMA*)
= 4.987 cm (for Nano DMA)

Scanning Mobility Particle Sizer: 3 nm - 1µm

1. Neutralizer: known charge distribution
2. Electrical mobility and selection of particles by size

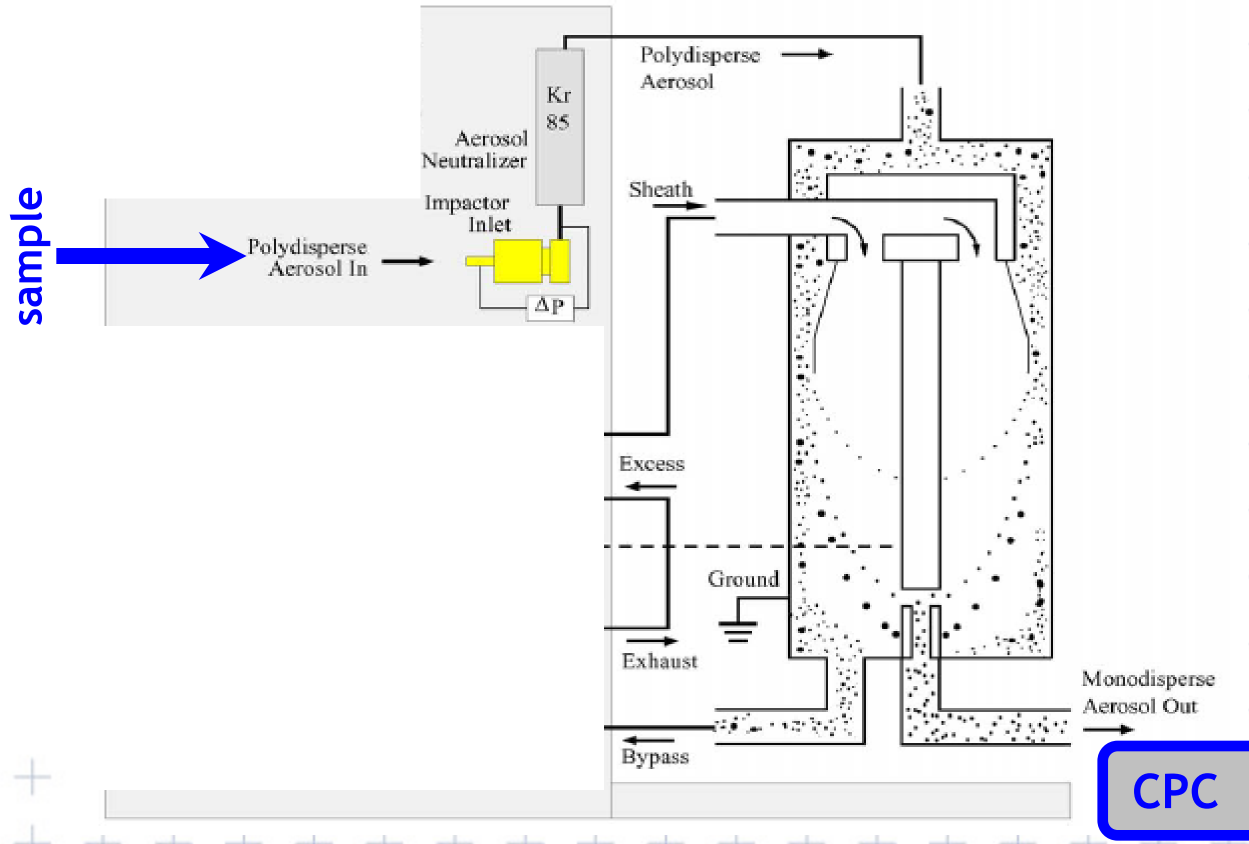
$$Z_p = \frac{neC}{3\pi\mu D_p}$$

$$Z_p^* = \frac{q_{sh}}{2\pi VL}\ln\left(\frac{r_2}{r_1}\right)$$



Scanning Mobility Particle Sizer: 3 nm - 1µm

1. Neutralizer: known charge distribution
2. Electrical mobility and selection of particles by size
3. Counting of monodisperse particles



Scanning Mobility Particle Sizer: 3 nm - 1µm

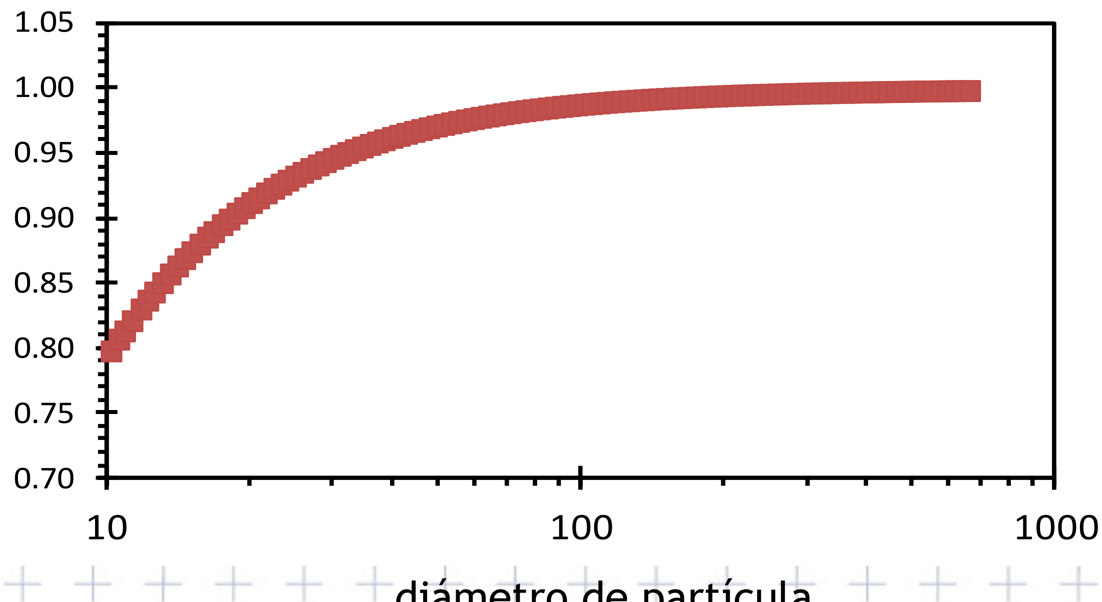
1. Neutralizer: known charge distribution
2. Movilidad eléctrica y selección de tamaño de partículas
3. Counting of monodisperse particles
4. Diffusion looses correction

Penetration; difusion looses
HINDS (Eq 7.29, pag.146)
BARON (Eq 19-20, 19-21, pag.580)

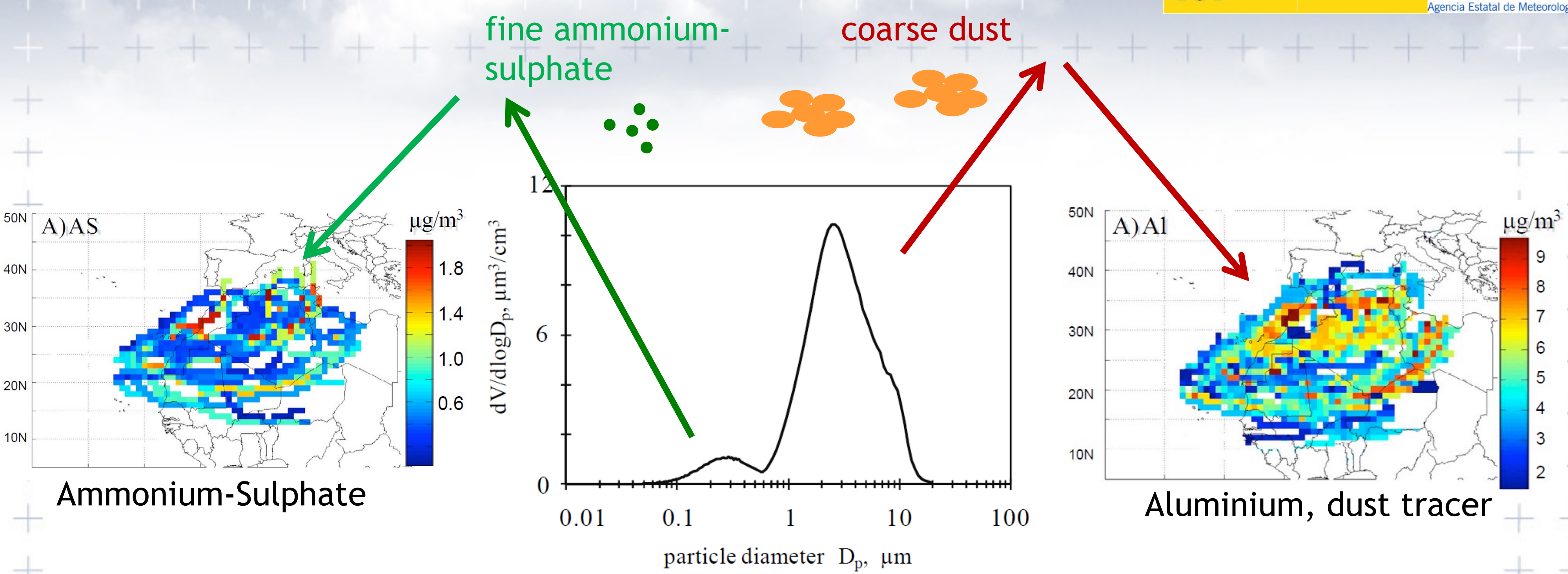
$$P = 0.81905\exp(-3.6568\mu) + 0.09753\exp(-22.305\mu) + 0.0325\exp(-56.961\mu) + 0.01544\exp(-107.62\mu) \quad \text{for} \quad \mu > 0.02 \qquad (19\text{–}20)$$

$$P = 1.0 - 2.5638\mu^{2/3} + 1.2\mu + 0.1767\mu^{4/3} \quad \text{for} \quad \mu \le 0.02 \qquad (19\text{–}21)$$

$$P = \frac{N_{out}}{N_{in}}$$



Scanning Mobility Particle Sizer: 3 nm - 1μm



Scanning Mobility Particle Sizer Aerodynamic Particle Sizer

Disadvantage of particle sizers (OPC, APS SMPS): cannot differentiate dust from other particles

property of aerosol dust:

number size distribution
mass concentration
chemical composition
mixing state
mineralogy
optical properties

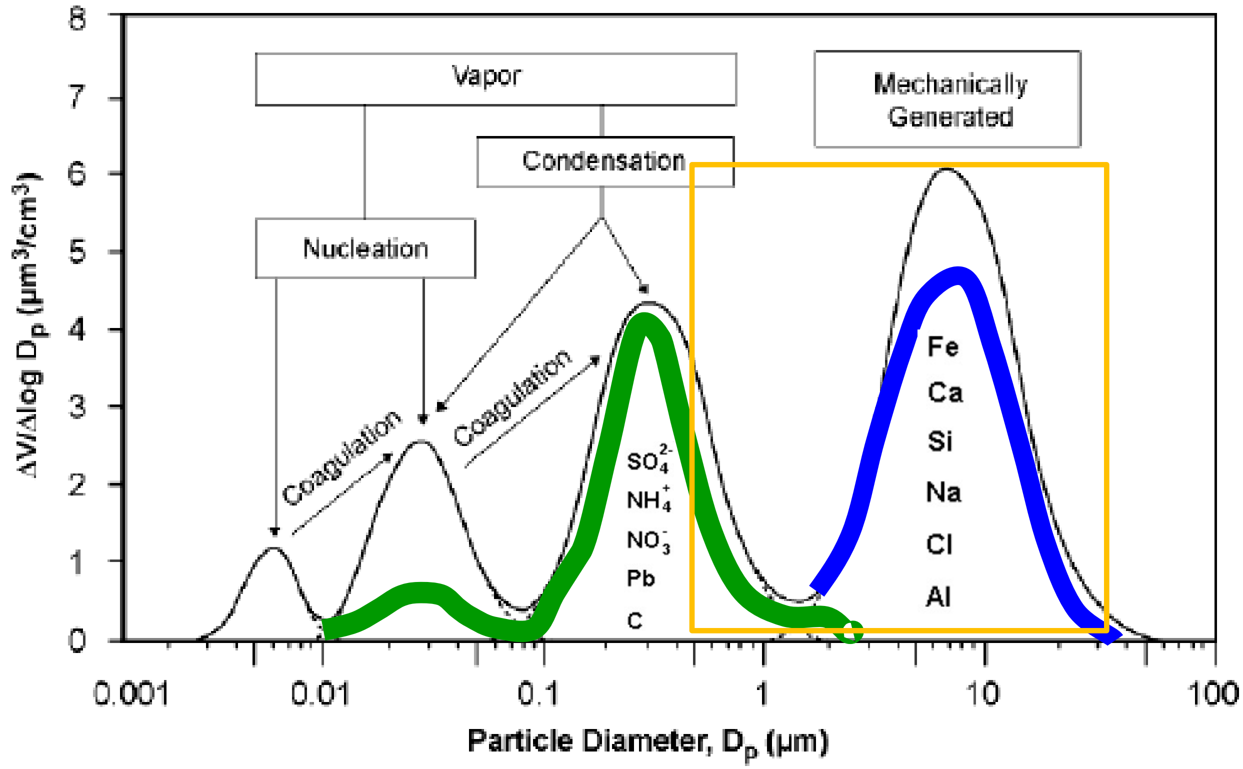
property of aerosol dust: mass concentration

bulk aerosol mass concentration

PM_{10} (diameter <10 microm)

$PM_{2.5}$

$PM_{2.5-10}$



ultrafine
<0.1 µm

accumulation
0.1 – 1 µm

Coarse
1 - 10 µm

Mineral dust :
Marine salt:
Sulfate:
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Organic aerosol:
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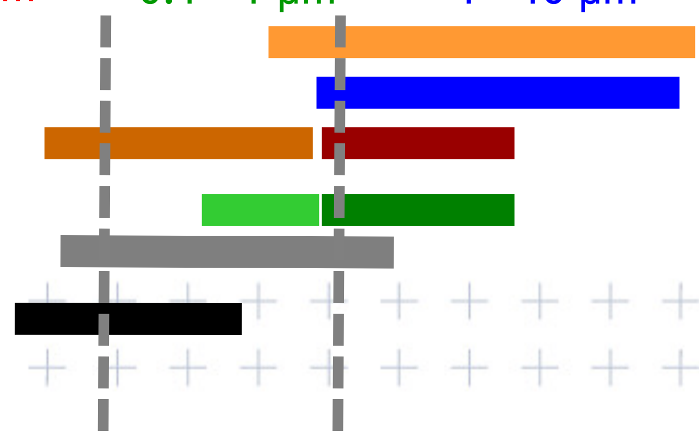


property of aerosol dust: mass concentration

bulk aerosol mass concentration

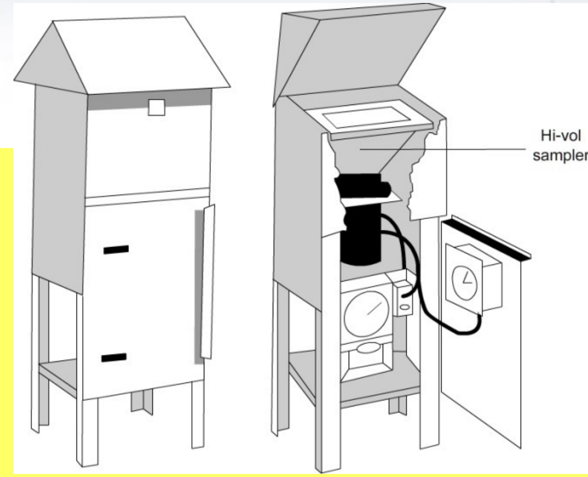
1. Reference method: gravimetric method

2. Automated analyzers

PM_{10} and $PM_{2.5}$ measurements in air quality networks

1. Reference method: gravimetric method

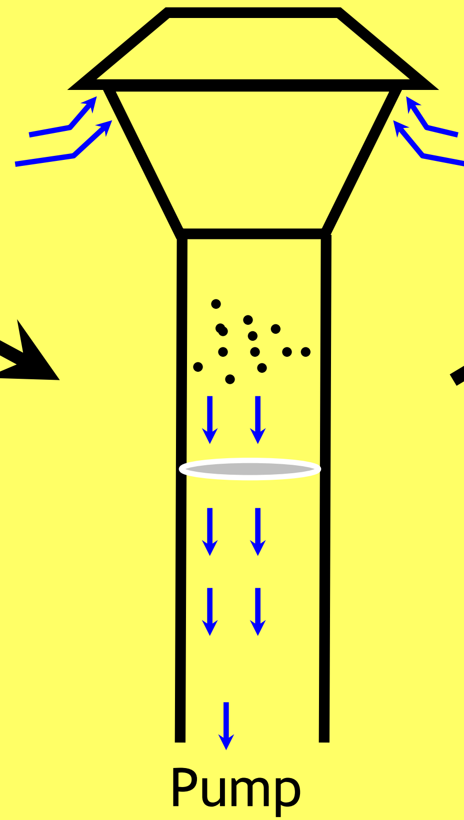
$$PM = \frac{(W2 - W1)}{Volume} \ \mu g/m^3$$



Blank filter

Conditioning
RH (50±5%) y T(20±1°C) 24-h

- Filter weight (W1)



Sampled filter

Conditioning
RH (50±5%) y T(20±1°C) 24-h

- Filter weight (W2)

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Common Gravimetric Ambient Aerosol Sampling Techniques

- High volume methods: TSP, PM_{10}, $PM_{2.5}$
- Low volume methods: (PM_{10}, $PM_{2.5}$, PM_{Coarse})

Micro-Balance room

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- Filters conditioning 48-h, HR=50±5 % and T=20±1ºC
- balance, LVS resolution >= 5 digits (0.00001g)
-balance, HVS resolution >= 6 digits (0.000001g)

This sample filter is equilibrated at some set of thermodynamic conditions for a period of time before and after sampling. Through the use of a laboratory gravimetric balance, the difference in pre- and post-sample weights yields the PM mass collected. Knowing the volume of air passed through the filter allows the determination of the PM mass concentration.

PM_{10} and $PM_{2.5}$ measurements in air quality networks

1. Reference method: gravimetric method

Low Volume Sampler

High Volume Sampler

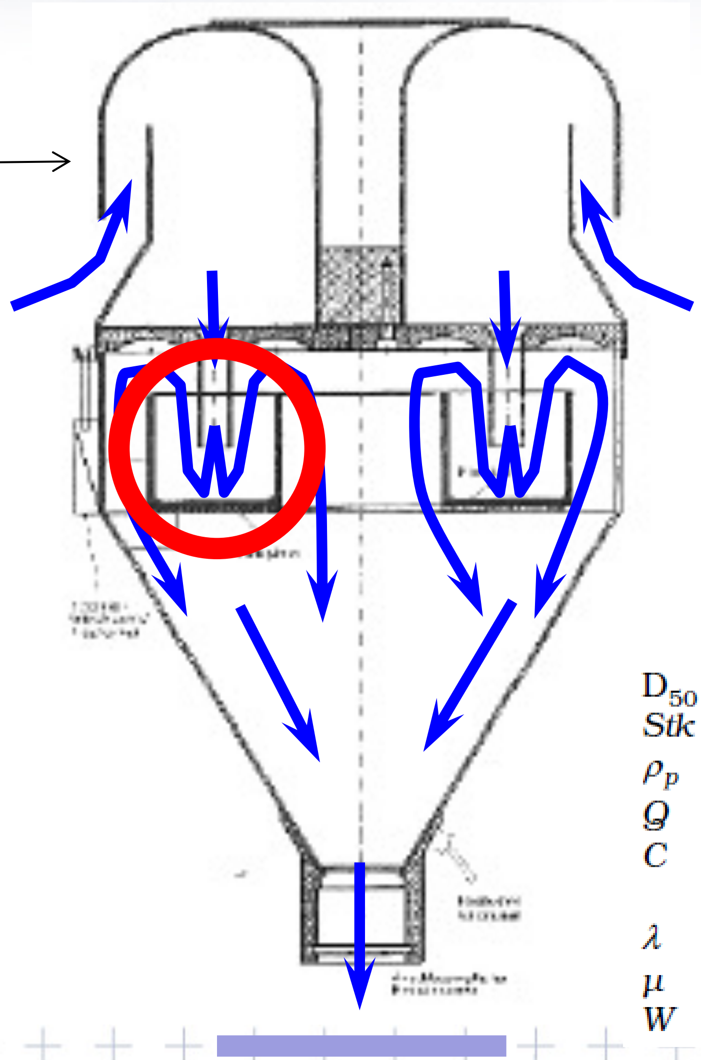
LVS: $2.3\ m^3/h$

HVS: $68\ m^3/h$

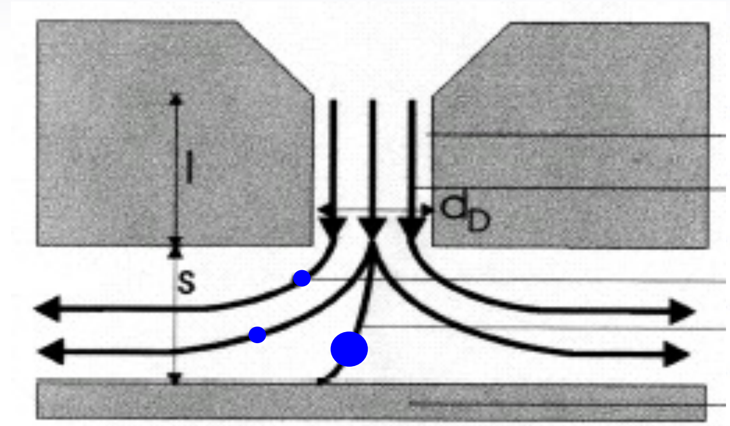
HVS: $30\ m^3/h$

In-situ measurements (PM)

TSP, PM_{10}, $PM_{2.5}$, PM_1: aerodynamic diameter (as the APS)



Filter



$$D_{50} = \sqrt{\frac{9\pi Stk\,\mu W^{3}}{4\rho_p C Q}}$$

D_{50} = particle cut-point diameter centimeter
Stk = Stokes number = 0.23
ρ_p = particle density (g/cm^3)
Q = volumetric flow rate (cm^3/s)
C = Cunningham slip correction
= $1 + 2.492\,\lambda/D_{50} + 0.84\,\lambda/D_{50}\,\exp(-0.435\,D_{50}/\lambda)$
λ = gas mean free path
μ = gas viscosity ($dyne\bullet s/cm^2$)
W = nozzle diameter (cm)

The Stokes number is a dimensionless parameter that characterizes impaction.

In-situ measurements (PM)

Complete PM gravimetric method set-up at Izana Atmopsheric Research Center

PM_{10}

$PM_{2.5}$

Weight filters conditioned room

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Common Gravimetric Ambient Aerosol Sampling Techniques

- Advantages: Recognized reference method, low capital cost
- Disadvantages: Limited time resolution (typically 24-hr), long turnaround times, labor intensive, and gravimetric lab maintenance/cost

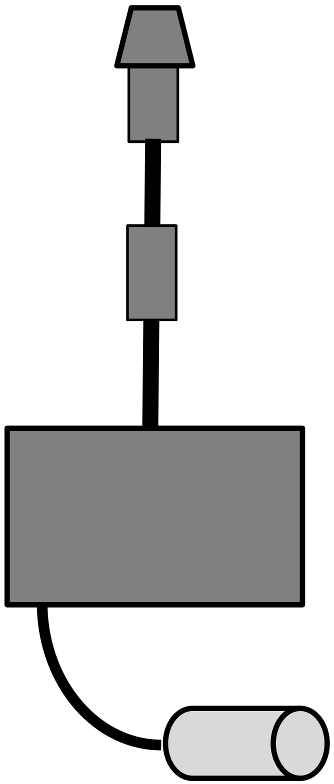
Common Continuous Ambient Aerosol Sampling Techniques

$(Dm / Dt) / (DV / Dt) = mg/m^3$

- Tapered Element Oscillating Microbalance
- Beta (Electron) Attenuation

PM_{10} and $PM_{2.5}$ measurements in air quality networks

2. Automated analyzers



1. Impactor PM_{10} / $PM_{2.5}$
2. RH reductor / heater
3. Sensor (Beta radiation attenuation or Tapered Oscillating microbalance-TEOM-) → instead of weighting filters
4. Pump / Flow meter

Continuous measurements of PM (PM_{10}, $PM_{2.5}$, PM_1 or TSP)

Mass concentration

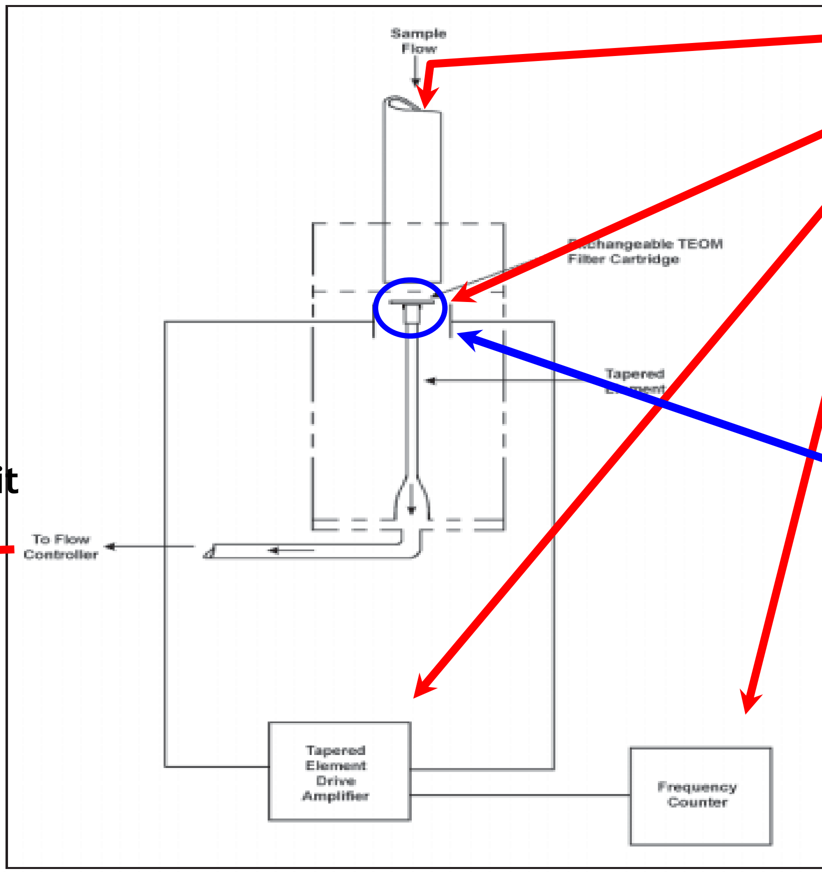
medidas automáticas en continuo

TEOM :Tappered Element Oscillating Microbalance

1. TEOM mod.1400a

mass=function (frequency)

sensor



Flow exit

Sampling flow rate (16.67 l/m)

Sample accumalated in the filter

Micro-oscilation of constante amplitue GENERATOR

Frequency sensor

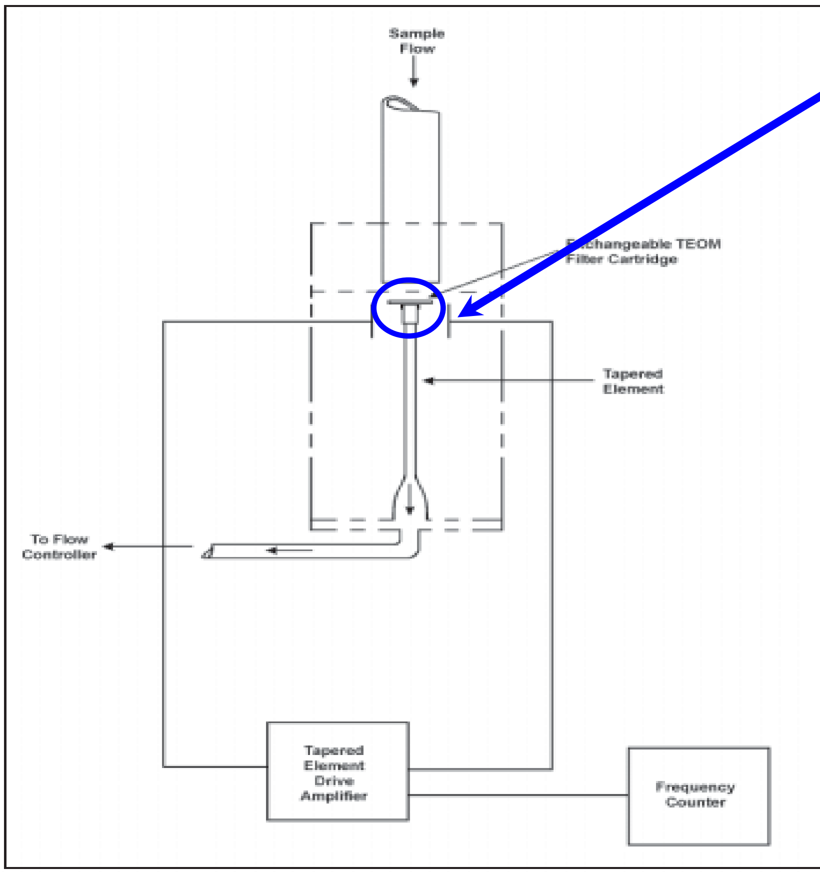
An increase in the amount of sample (dust) accumulated in the filter ➔ decrease in the oscillation frequency

Concentración en masa
medidas automáticas en continuo

TEOM-Microbalanza Oscilante
TEOM :Tappered Element Oscillating Microbalance

1. TEOM mod.1400a

sensor



mass=function (frequency)

more dust ➔ lower oscillation frequency

In a spring-mass system the frequency follows the equation:

$$f = (K / M)^{0.5}$$

where:

f = frequency (radians/sec)
K = spring rate
M = mass

K and M are in consistent units. The relationship between mass and change in frequency can be expressed as:

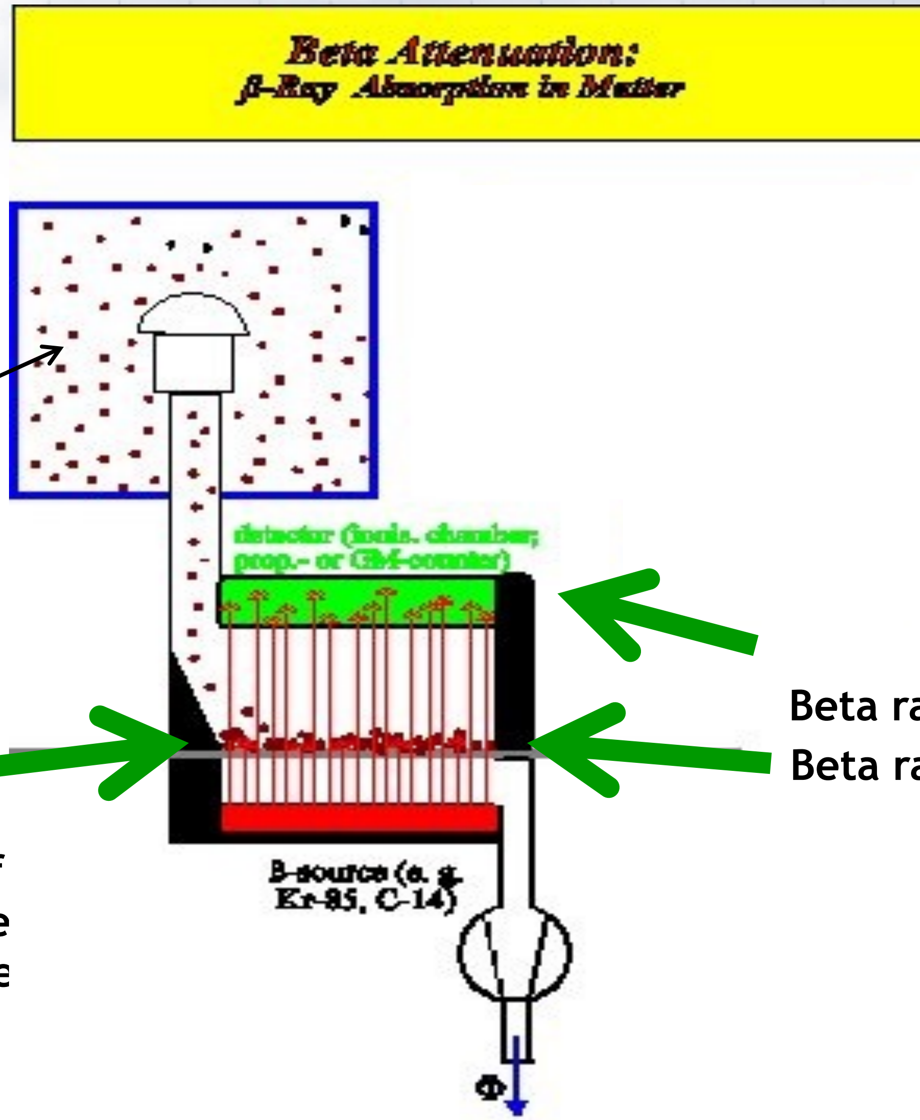
$$dm = K_0 \left(\frac{1}{f_1^2} - \frac{1}{f_0^2} \right) \qquad (2)$$

where:

dm = change in mass
K_0 = spring constant (including mass conversions)
f_0 = initial frequency (Hz)
f_1 = final frequency (Hz)

PM with Beta atenuation (1)

Krypton-85 or Carbon-14 is used as source of beta radiation (emitted by electrons during the nuclear decay of radioactive elements).



Ambient air is drawn through the sample system

Beta rays detector

Beta rays source (Kr-85)

Dust is deposited on a continuously. The layer of is building up and this incre dust mass weakens the inte of the beta beam.

Pump and flowmeter

PM with Beta atenuation (1)

Krypton-85 or Carbon-14 is used as source of beta radiation (emitted by electrons during the nuclear decay of radioactive elements).

Beta Attenuation:
β-Ray Absorption in Matter

$$I = I_0 e^{-\mu_\beta \cdot x}$$

μ_β is the mass absorption coefficient for beta radiation

x mass thickness of the sample

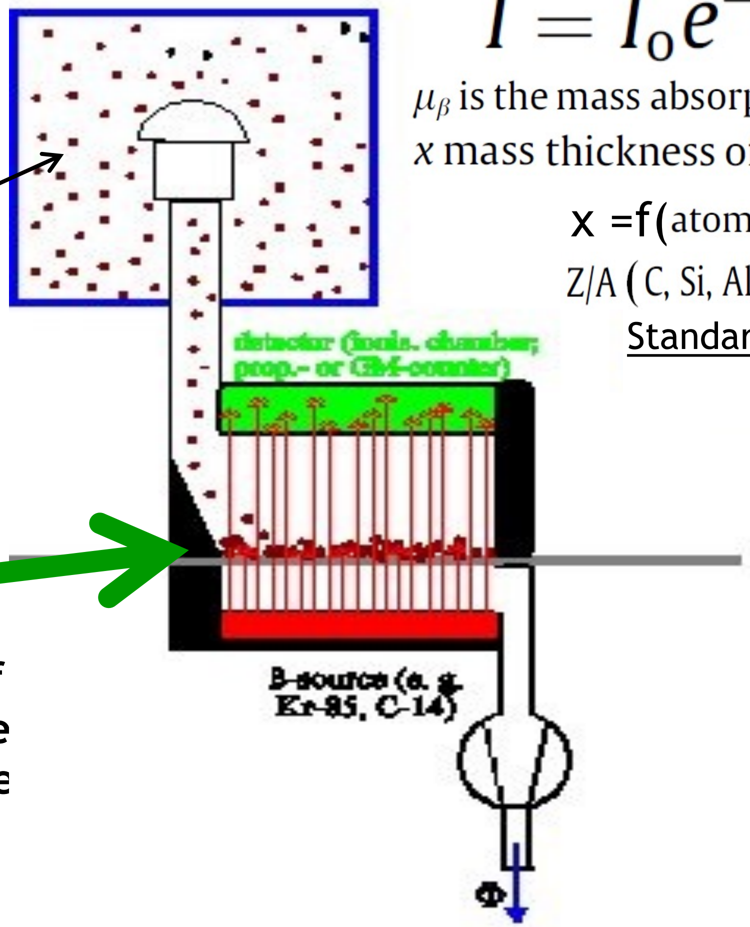
x =f(atomic number to atomic mass ratio (Z/A))

Z/A (C, Si, Al, Ca, Fe, Mg, K, Cl, Na, N, O and S) 0.47–0.50

Standard foil calibration

typical elements of aerosols; fixed Z/A ratio: error of about 10%

Ambient air is drawn through the sample system



Dust is deposited on a continuously. The layer of is building up and this incre dust mass weakens the inte of the beta beam.

Pump and flowmeter

PM with Beta atenuation (2)

$$m = F_{cal} ln\left(\frac{I_0}{I}\right)$$

- **m:** increasing particle mass [µg]
- **F_{cal}**: calibration factor
- **I_0** beta ray intensity at empty filter
- **I** beta ray intensity at loaded filter

The intensities I_0 and I are measured with the detector system. F_{cal} has to be measured directly during the calibration procedure. This is accomphished by replacing the filter with the element having a known mass (mass calibration kit)

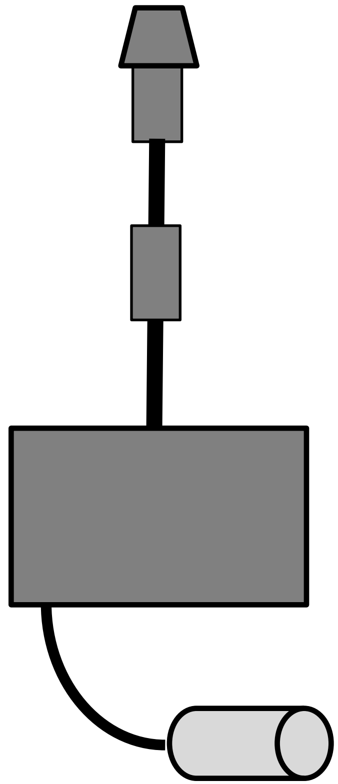
The mass concentration is calculated from:

$$c = \frac{m}{Ft}$$

Where:
c: concentration [µg/m^3]
F: measured air flow [m^3/h]
t: time [h]

PM_{10} and $PM_{2.5}$ measurements in air quality networks

2. Automated analyzers



beta

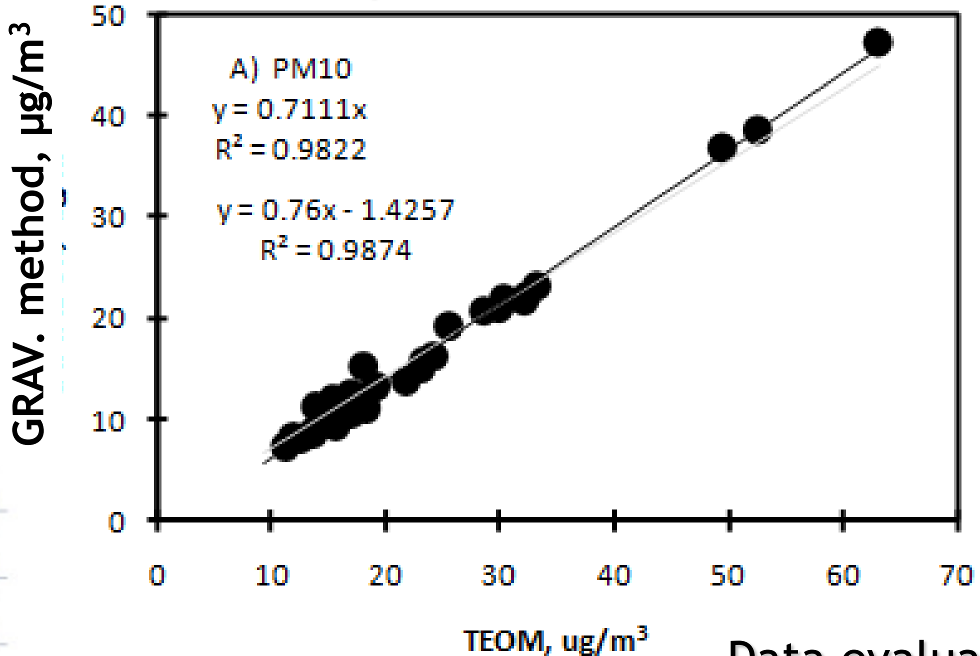
TEOM

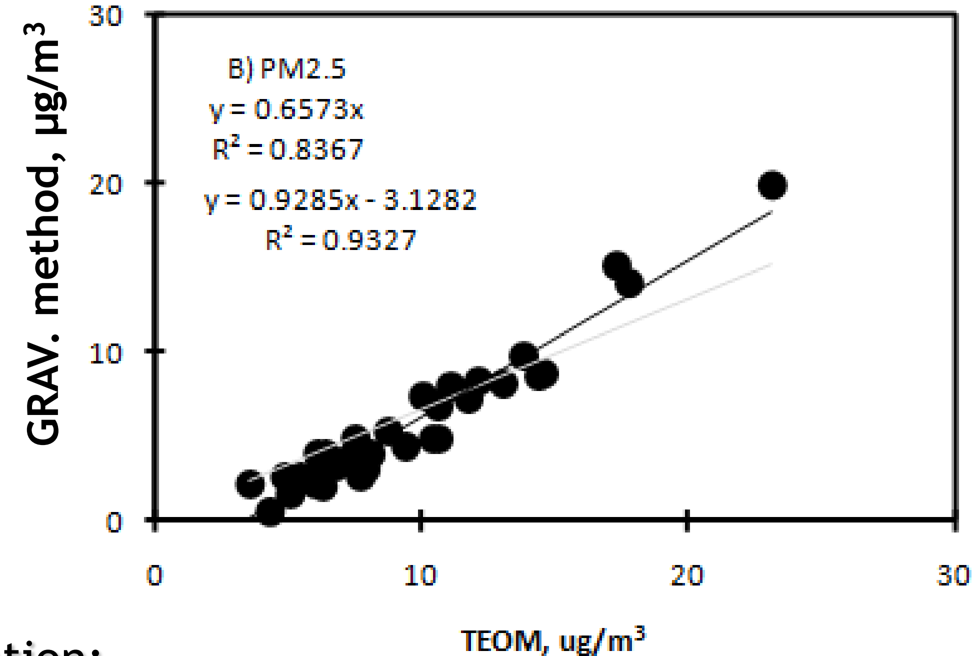
In-situ measurements (PM)

automatic versus the reference gravimetric method

Convertion of the 'automatic PM_{10} and $PM_{2.5}$ ' data to GRAVIMETRIC EQUIVALENT data

Intercomparisons





Data evaluation:

Data from continuous analyzer are valid if they fit A or B:

A) $Y = a \cdot X$; $r^2 \geq 0.8$

B) $Y = a \cdot X + b$; $r^2 \geq 0.8$; $abs(b) < 5$

Y= Reference Method (gravimetric method),
X= Automatic analyzer

Common Continuous Ambient Aerosol Sampling Techniques

$$(Dm / Dt) / (DV / Dt) = mg/m^3$$

Advantages

Continuous method
Highly time resolved
High resolution
instantaneous turnaround
Low operational cost

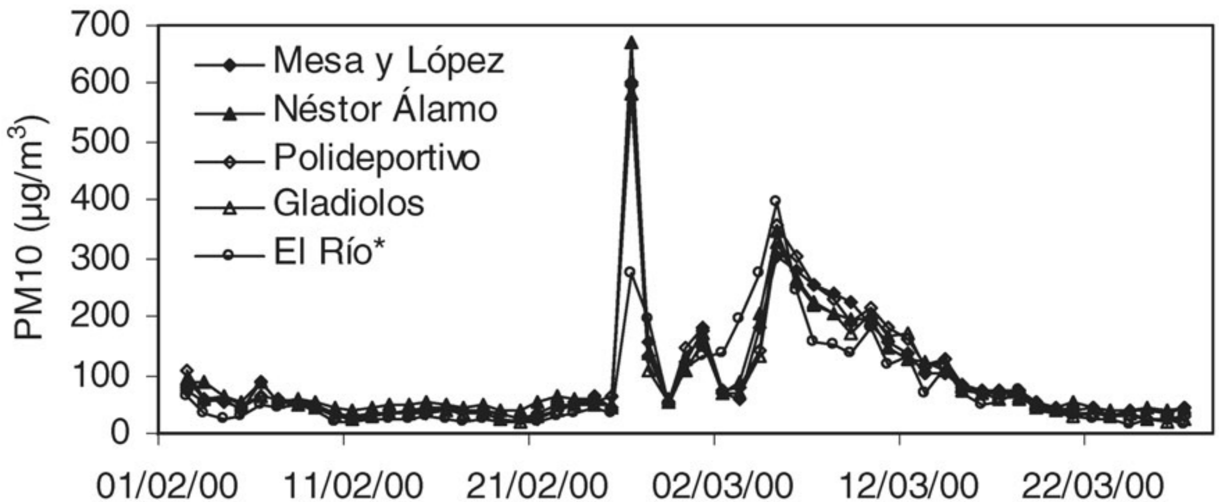
Disadvantages

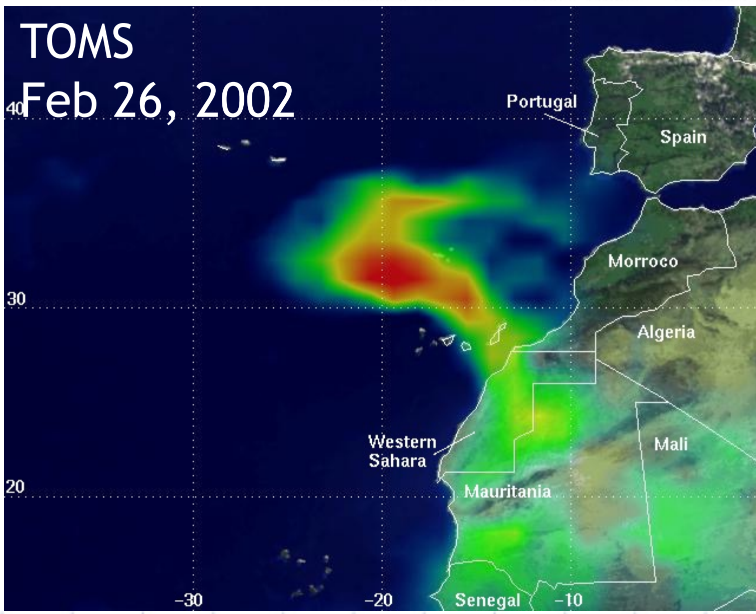
Temperature dependency:
- Volatile losses
- Seasonal and regional dependencies

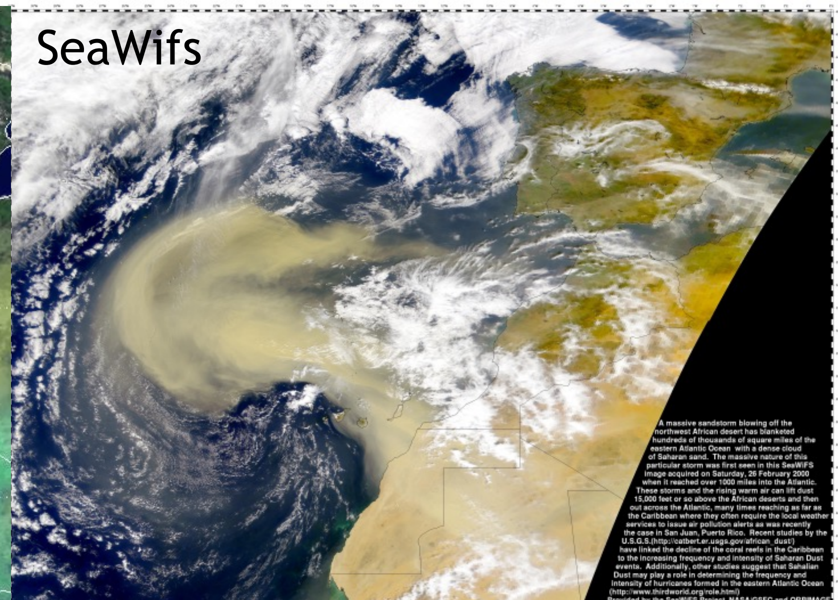
Affected by vibration
Manual filter changes necessary
Complex systems require some skill
X2 or X3 capita cost
Determination of Gravimetric Equivalent concentrations

In-situ measurements (PM)

Air quality stations at Tenerife Island

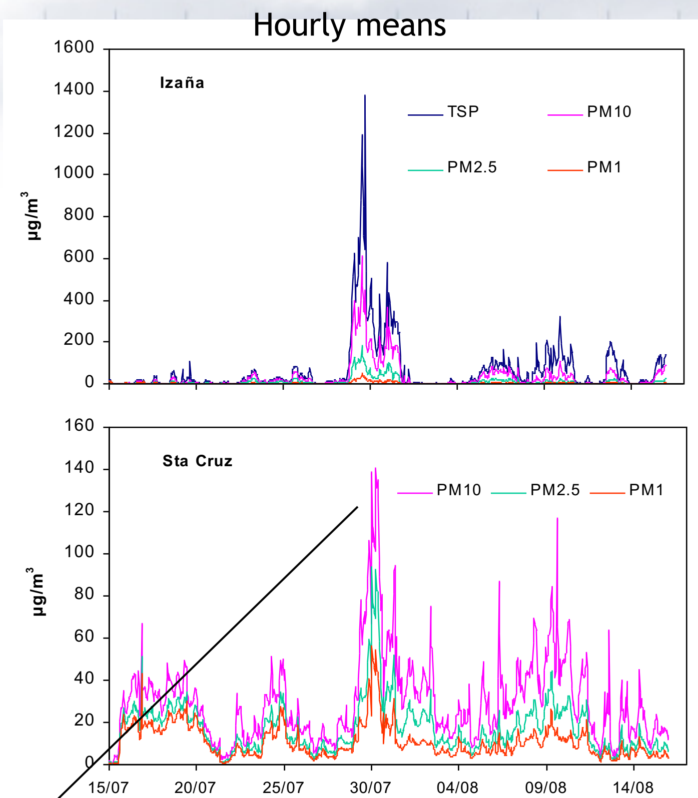


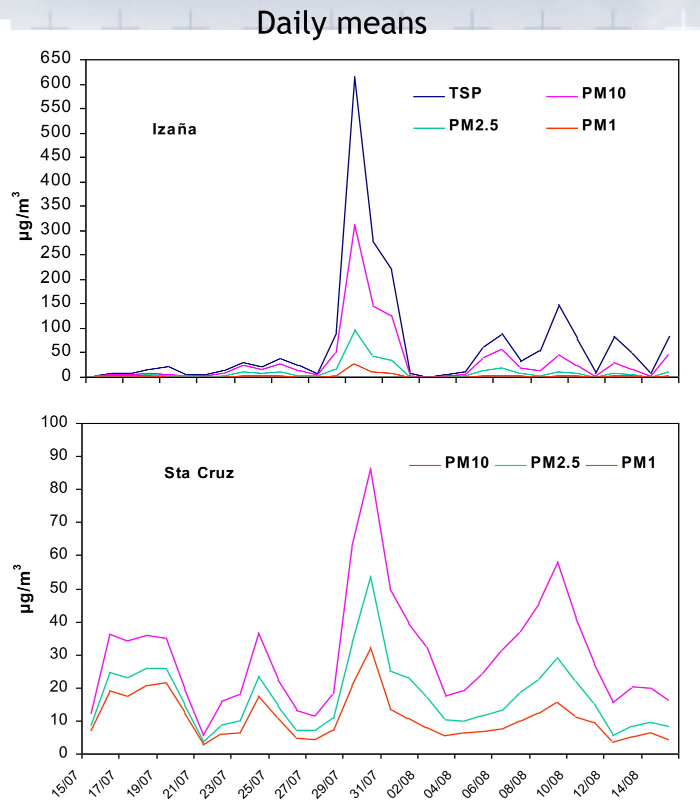




Viana et al., Atmospheric Environment , 2002

In-situ measurements (PM)





property of aerosol dust: mass concentration

bulk aerosol mass concentration

bulk dust mass concentration

bulk dust mass concentration

method-1 : filter ash (J.M. Prospero)

step-1: samples collected on filters are extracted with de-ionized water and the extracts are analyzed for major soluble inorganic ions:

- Na^+ by flame atomic absorption
- Cl^-, NO_3^- and $SO_4^=$ by suppressed ion chromatography
- NH_4^+ by automated colorimetry

step-2: then, non sea salt sulfate is calculated using the $SO_4^=$/Na+ ratio in bulk sea water (0.2517).

sea salt = Na^+ + ss-$SO_4^=$ (0.2517·Na^+)

step-3: the extracted filters are then placed in a muffle furnace for 14-h (overnight) at 500º C. The ash residue weight.

$$\text{bulk dust} = \frac{\text{weight ash reside}}{\text{volume of sampled air}} \times 1.3$$

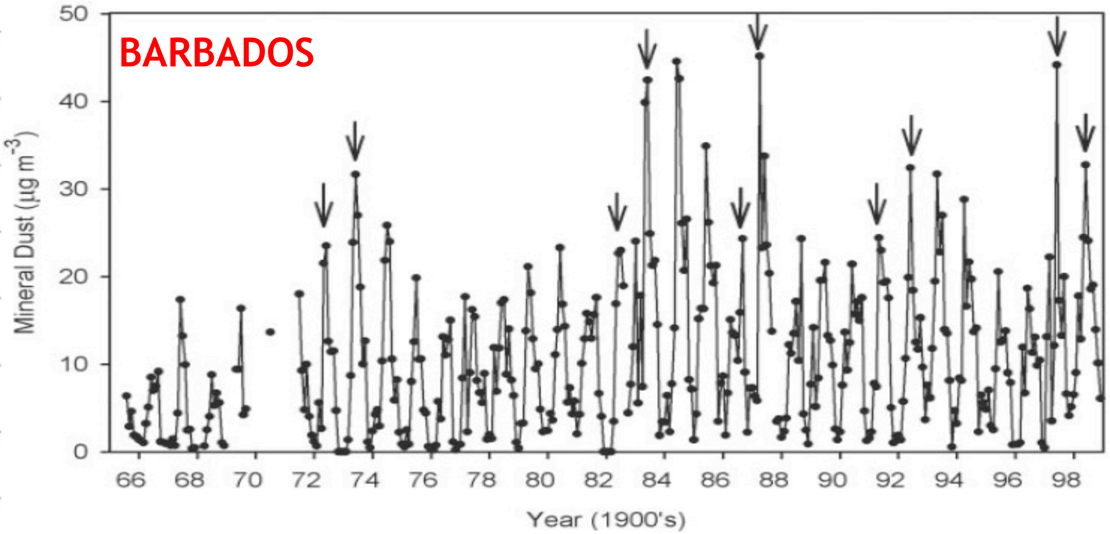
normalization: Al accounts for 8% of dust

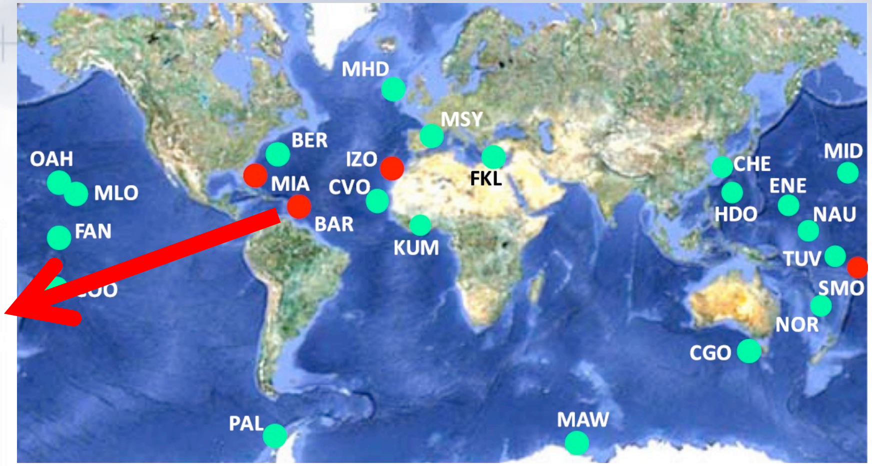
this technique may underestimate dust concentrations because of the loss of soluble minerals (carbonates, halides).

-standard error is considered: ± 0.1 μg/m³ for concentrations <1 μg/m³
10% for higher concentrations.

<u>method-1 : filter ash</u> (J.M. Prospero)

Longest records of dust: since 1964





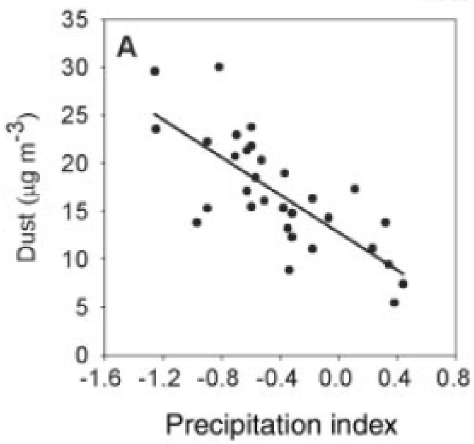
Review Article

Aeolian Research

Aeolian Research 6 (2012) 55–74

A review of methods for long term in situ characterization of aerosol dust

Sergio Rodríguez [a,*], Andrés Alastuey [b], Xavier Querol [b]



(A) Dust plotted against the prior-year

African Droughts and Dust Transport to the Caribbean: Climate Change Implications

Joseph M. Prospero[1*] and Peter J. Lamb[2]

7 NOVEMBER 2003 VOL 302 SCIENCE

bulk dust mass concentration

method-2: tracer analysis

In a filter with the dust sample, one or more dust tracer are analysed by chemical methods, and then total dust is calculated using the mean proportion of that element in dust:

Al (8% of soil) → dust= Al·(100/8) Eq-1

Si (33% of soil) → dust= Si·(100/33) Eq-2

ratio element / oxide

Na2O	0.47
MgO	0.43
Al2O3	1.89
SiO2	5.98
K2O	0.38
CaO	0.62
TiO2	0.09
Fe2O3	0.88

stoichiometry

dust= 0.47·Na+0.43·Mg+1.89·Al+5.98·Si+0.38·K+0.62·Ca+0.88·Fe+0.09·Ti Eq-3

Can be applied with elements with low enrichment factors!!!!

bulk dust mass concentration
method-2: tracer analysis

Mean ratio to Al in soil

	Mason (1966)	Taylor (1964)
Na	0.34809	0.28676
Mg	0.25707	0.28311
Al	1.00000	1.00000
Si	3.40959	3.42041
K	0.31857	0.25395
Ca	0.44649	0.50425
Ti	0.05412	0.06926
Fe	0.61501	0.68408
P	0.01292	0.01276
Mn	0.01169	0.01154
Sr	0.00456	0.00461
S	0.00316	0.00320
V	0.00166	0.00164
Cl	0.00160	0.00158
Cr	0.00123	0.00122
Ni	0.00092	0.00091
Zn	0.00086	0.00085
Cu	0.00068	0.00067

$$\text{EF- Enrichment Factor (X)} = \frac{(X\ /\ Al)_{sample}}{(X\ /\ Al)_{soil}}$$

EF (X) = 1 → element X is due to soil emissions

EF (X) >> 1 → there is an additional contribution to element X from other sources. Then, do not include X in Eq-3.

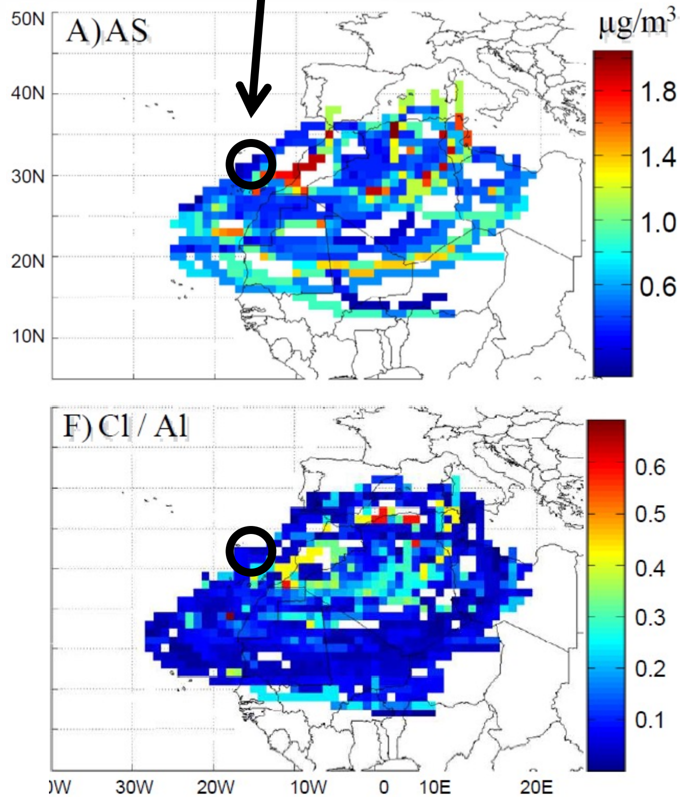
bulk dust mass concentration

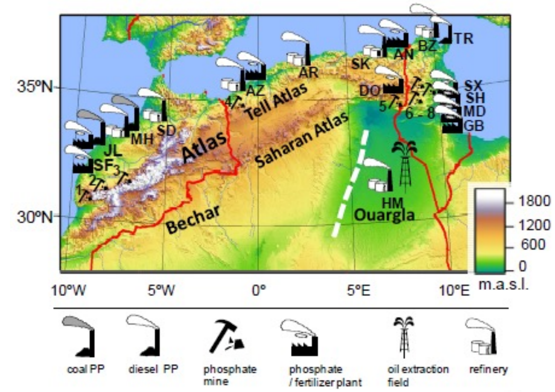
method-2: tracer analysis

Izaña - Tenerife

	EF
Al	1.00
Ca	0.97
K	0.72
Na	0.31
Mg	0.78
Fe	0.85
S	35.71
Cl	77.70
P	0.70
Ni	0.56

Izaña: measurement site





S and Cl⁻ emitted by industry mixed with dust

Transport of desert dust mixed with North African industrial pollutants in the subtropical Saharan Air Layer

S. Rodríguez[1], A. Alastuey[2], S. Alonso-Pérez[1,2], X. Querol[2], E. Cuevas[1], J. Abreu-Afonso[1], M. Viana[2], N. Pérez[2], M. Pandolfi[2], and J. de la Rosa[3]

Atmos. Chem. Phys., 11, 6663–6685, 2011
www.atmos-chem-phys.net/11/6663/2011/
doi:10.5194/acp-11-6663-2011
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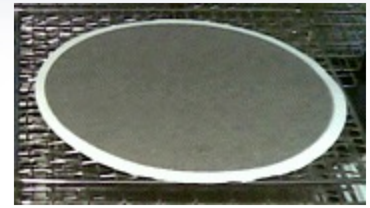
property of aerosol dust:

number size distribution
mass concentration
chemical composition
mixing state
mineralogy
optical properties

bulk chemical composition

Saharan dust

Urban particles



PM samples:
- fine + coarse (TSP, PM_{10})
- fine ($PM_{2.5}$, PM_1)

PM ($\mu g/m^3$)= dust + **ions ($SO_4^=$, NO_3^-, NH_4^+, Na^+, Cl-)** + OC + EC + trace elements

Elemental Composition: Major elements (Al, Si, Ca, K, Na, Mg) + trace elements (P, Li , Be , Sc , Ti , V , Cr , Mn , Co , Ni , Cu , Zn , Ga , Ge , As , Se , Rb , Sr , Y , Zr , Nb , Mo, Cd , Sn , Sb, Cs , Ba , La , Ce , Pr , Nd , Sm , Eu , Gd , Tb , Dy , Ho , Er , Tm , Yb , Lu , Hf , Ta, W, Tl , Pb , Bi , Th , U)

ICP-AES, IPC-MS : destructive techniques
XRF, PIXE, INAA: none destructive techniques

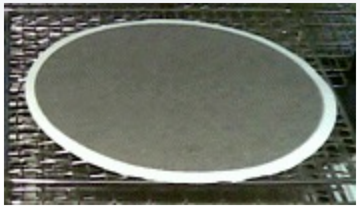
Ions: $SO_4^=$, NO_3^-, NH_4^+, Na^+, Cl^-: Ion Chromatography, ICP-AES, ICP-MS, selective electrodes and colorimetry : destructive techniques

OC , EC: TOR or TOT : destructive techniques

bulk chemical composition

Saharan dust

Urban particles



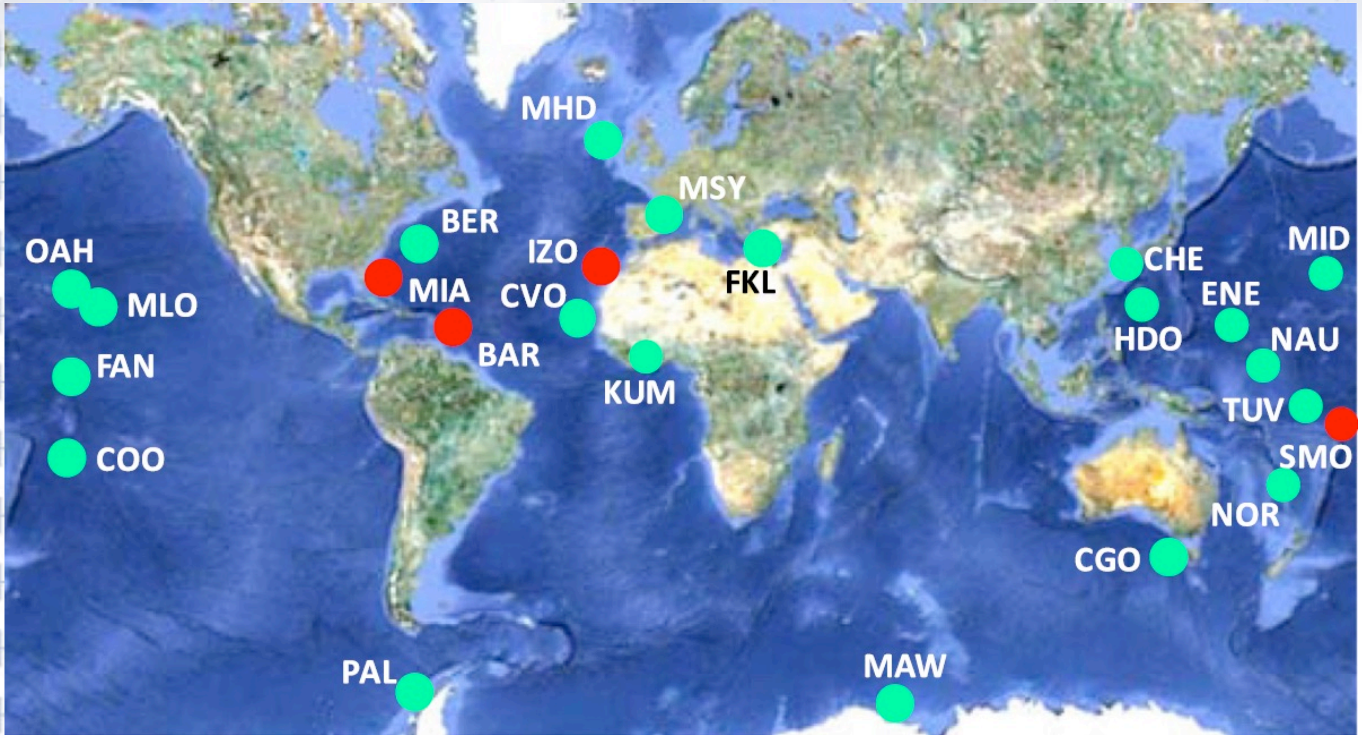
PM samples:
- fine + coarse (TSP, PM_{10})
- fine ($PM_{2.5}$, PM_1)

PM ($\mu g/m^3$)= dust + ions ($SO_4^=$, NO_3^-, NH_4^+, Na^+, Cl-) + OC + EC + trace elements

bulk chemical composition is the most reliable technique for quantifying the concentration of dust and other species (if present, e.g. pollutants, sea salt).

This is considered a reference method for the quantification of dust.

Other analytical techniques are available. Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) coupled with Energy Dispersive X-ray analysis (EDX) allows individual particle characterization for size, morphology, chemical and mineral composition.



at least 4 years

Active during the last 20 years

Review Article

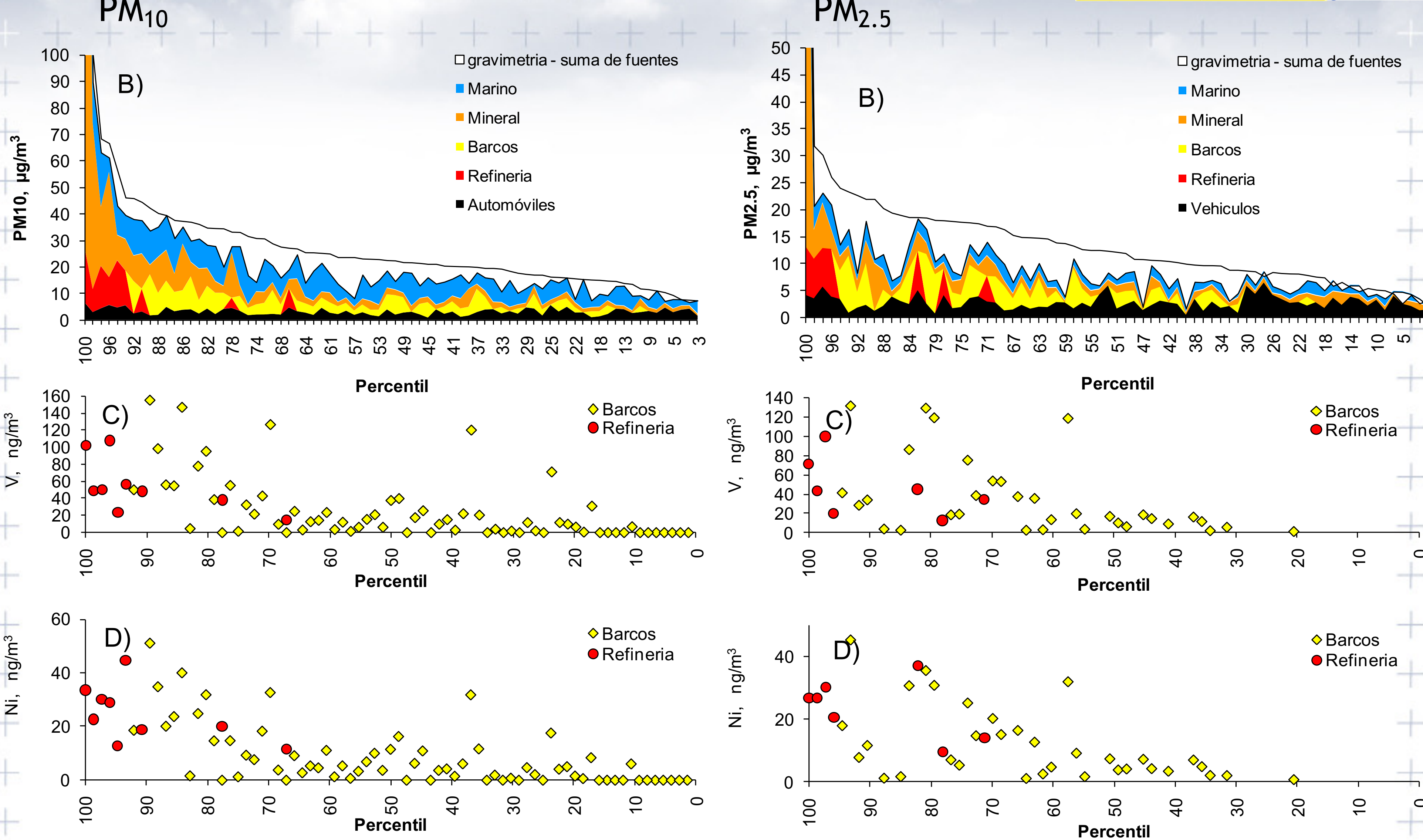
Aeolian Research Aeolian Research 6 (2012) 55–74

A review of methods for long term in situ characterization of aerosol dust

Sergio Rodríguez [a,*], Andrés Alastuey [b], Xavier Querol [b]

bulk chemical composition **reference method for the quantification of dust.**

In-situ measurements (PM)



Santa Cruz de Tenerife source apportionment study by receptor modeling

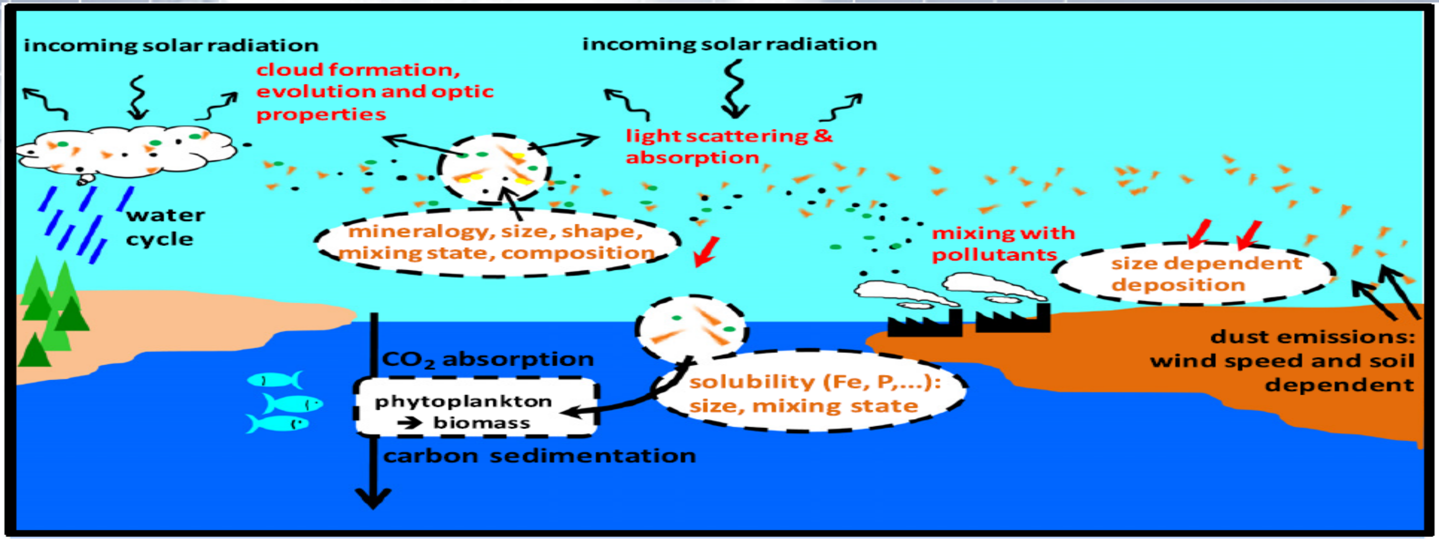
Rodríguez et al., 2009

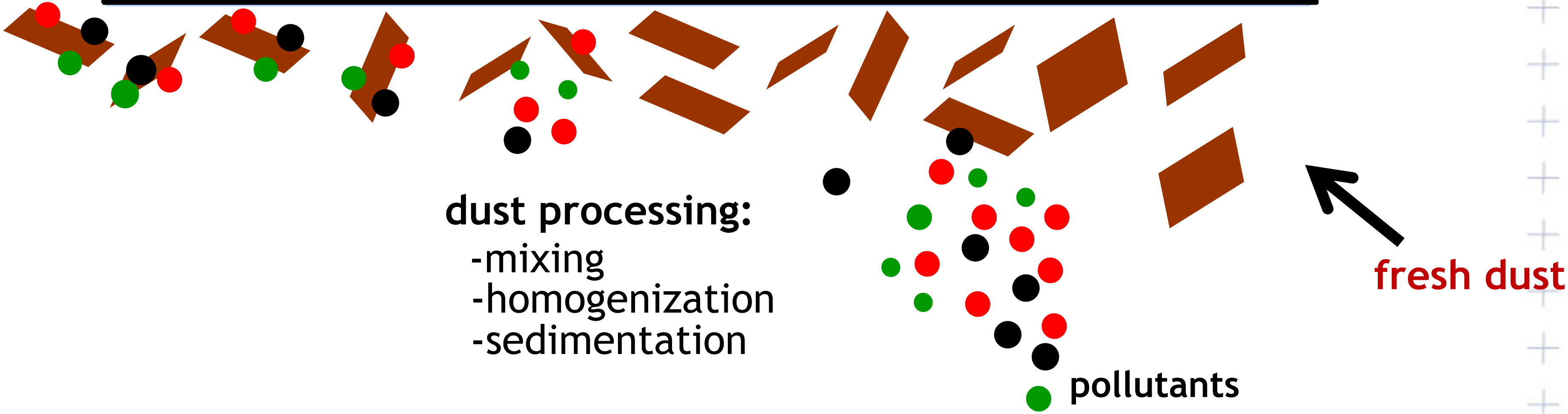
property of aerosol dust:

number size distribution
mass concentration
chemical composition
mixing state
mineralogy
optical properties

MINISTERIO DE MEDIO AMBIENTE Y MEDIO RURAL Y MARINO

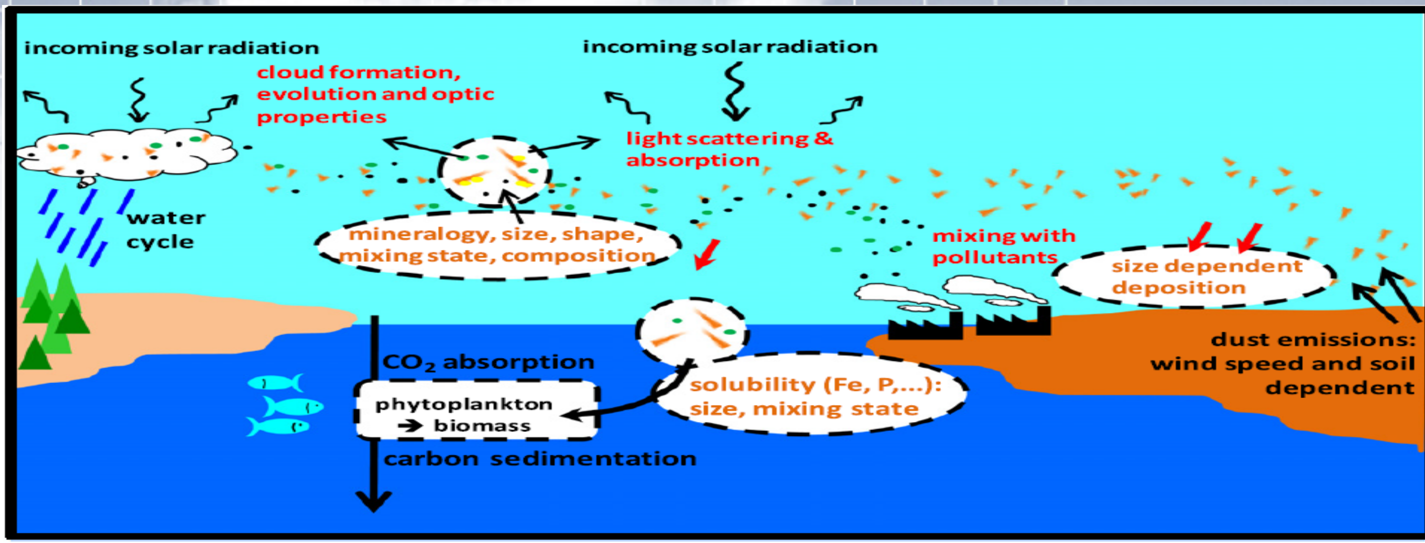
AEMet Agencia Estatal de Meteorología

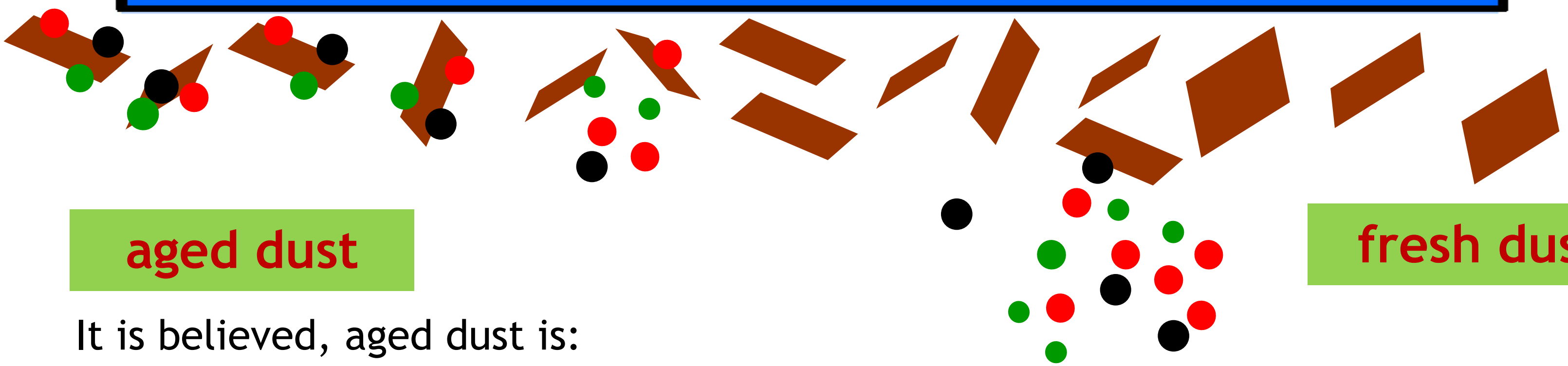




internal mixing:
all particles the same composition (same mixing)

external mixing:
each particle different chemical composition





aged dust

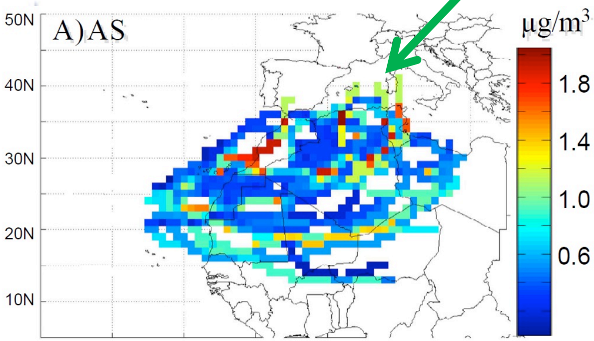
fresh dust

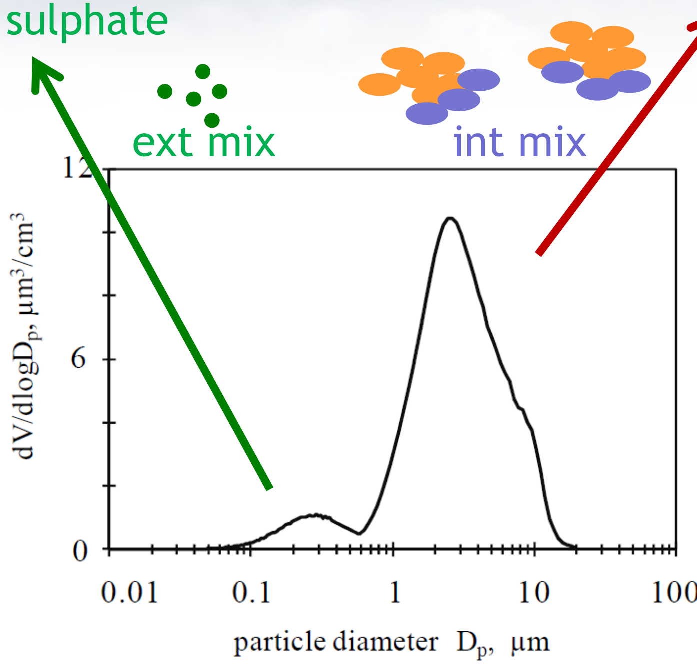
It is believed, aged dust is:

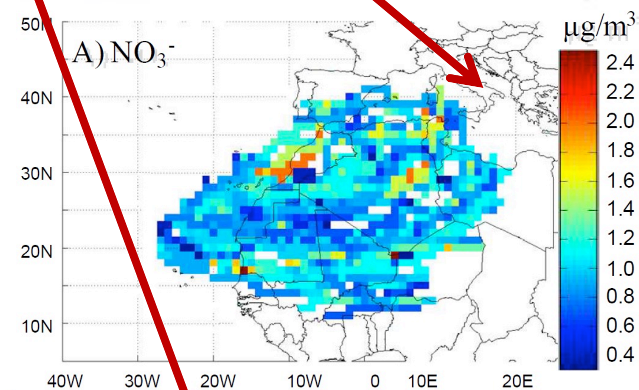
-more soluble
-different refractive index

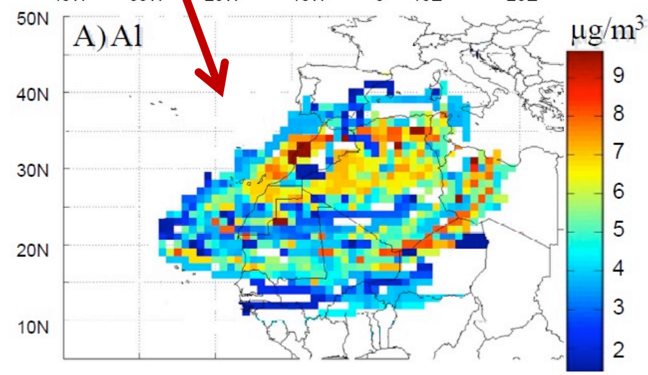
fine ammonium-sulphate

coarse dust + coated by nitrate









Mass spectrometry !!!!

Transport of desert dust mixed with North African industrial pollutants in the subtropical Saharan Air Layer

S. Rodríguez[1], A. Alastuey[2], S. Alonso-Pérez[1,2], X. Querol[2], E. Cuevas[1], J. Abreu-Afonso[1], M. Viana[2], N. Pérez[2], M. Pandolfi[2], and J. de la Rosa[3]

Atmos. Chem. Phys., 11, 6663–6685, 2011
www.atmos-chem-phys.net/11/6663/2011/
doi:10.5194/acp-11-6663-2011
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Atmospheric Environment 44 (2010) 3135–3146

Variation of the mixing state of Saharan dust particles with atmospheric transport

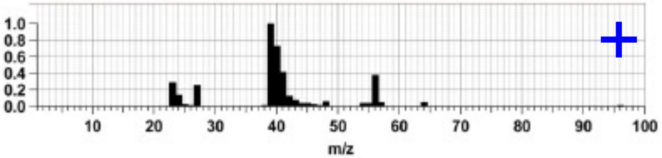
Manuel Dall'Osto[a,b], Roy M. Harrison[a,*], Eleanor J. Highwood[c], Colin O'Dowd[b], Darius Ceburnis[b], Xavier Querol[d], Eric P. Achterberg[e]

Aerosol Time Of Flight Mass Spectrometer (**ATOFMS**)

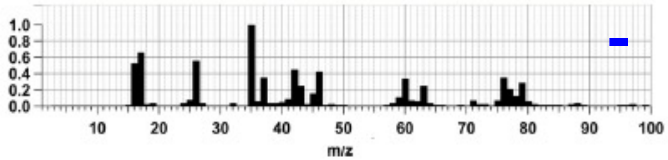
-aerodynamic size of particles (0.3 – 1 µm)

-chemical composition of individual particles

➔ positive and negative ion mass spectrums of a single particle.



m/z: 27 (Al), 40 and 56 (Ca)…………………



m/z: -97 (HSO_4^-), -80 (SO_3^-) , -62 (NO_3^-)…………..

The mass spectrum is qualitative in that the intensities of the mass spectral peaks are not directly proportional to the component mass but are dependent on the particle matrix.

Not for long term measurements

The ATOFMS can supply quantitative information on particle number as a function of composition , providing measurements of all the particle components (including OC, EC, sulfate, nitrate, dust and sea salt)

property of aerosol dust:

number size distribution

mass concentration

chemical composition

mixing state

mineralogy

optical properties

optical properties

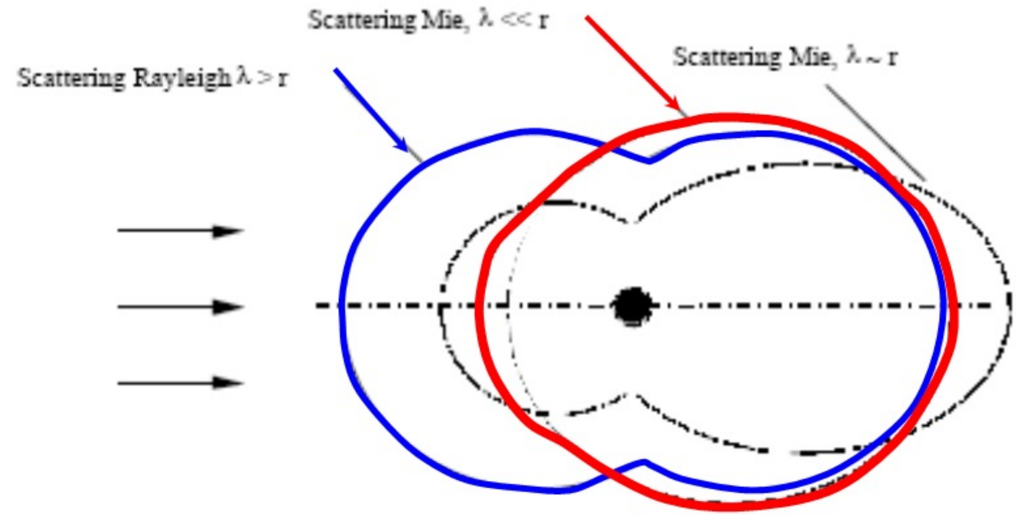
Redistribution of radiation depends on:

-<u>particle size</u>

forward scattering increase with particle size

-<u>composition and mineralogy</u>

mixing with pollutants
absorbing minerals (iron oxides)



optical properties

2 basic optical properties:

scattering and backscattering coefficient (several λ)

absorption coefficient (several λ)

$$I = I_o \cdot e^{-\sigma_{ep} \cdot L}$$

$$\sigma_{ep} = \sigma_{ap} + \sigma_{sp}$$

σ_{ep} aerosol extinction coeficient

σ_{ap} aerosol absorption coefficient : Absorption Photometer

(MAAP, Aethalometer, PSAP)

σ_{ap} aerosol scattering coefficient: NEPHELOMETER

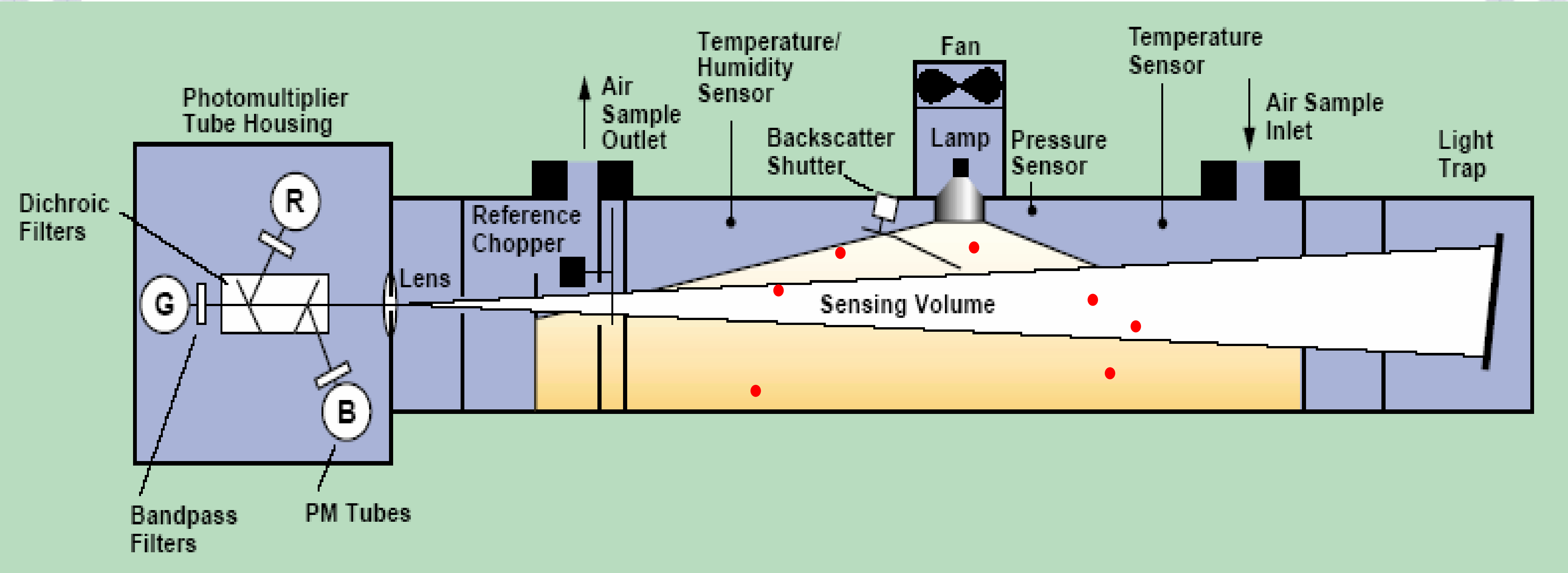
optical properties

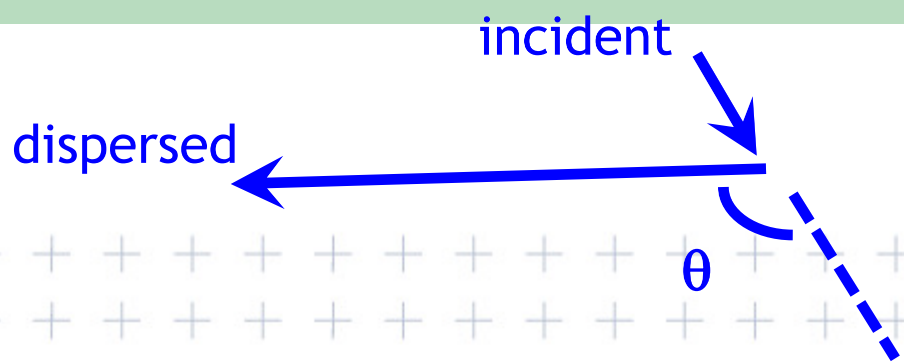
2 basic optical properties:

scattering (σ_{sp}) and backscattering coefficient (several λ)

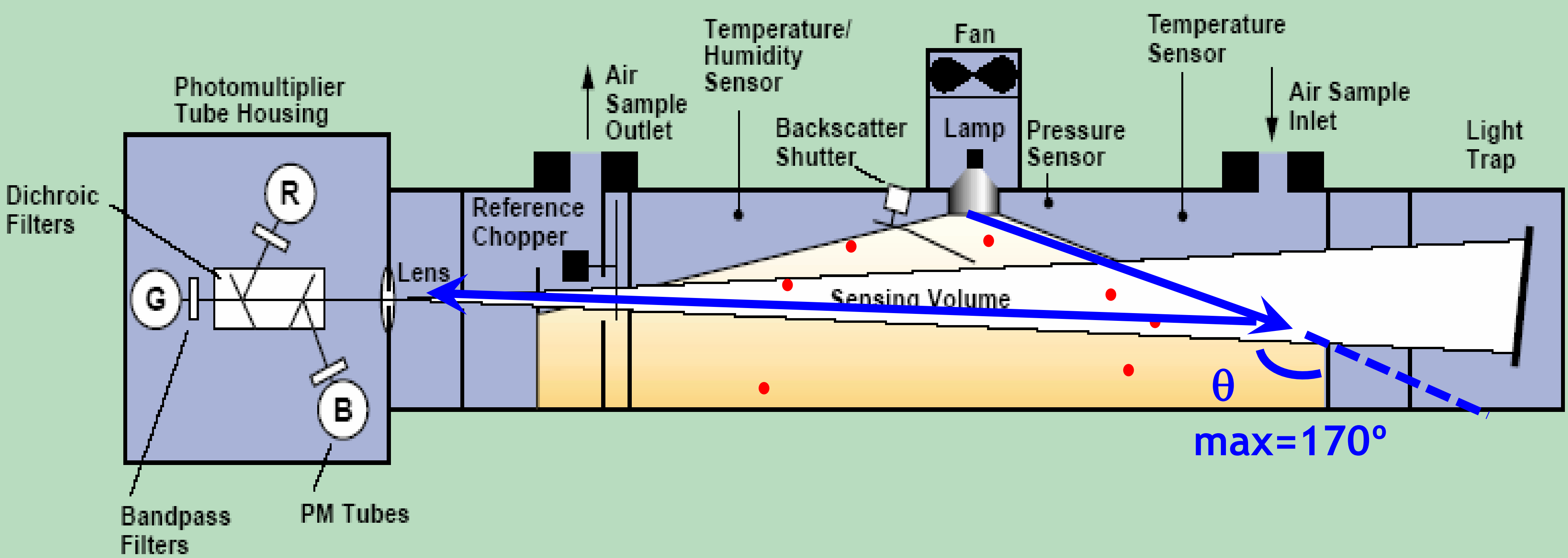
absorption coefficient (several λ)

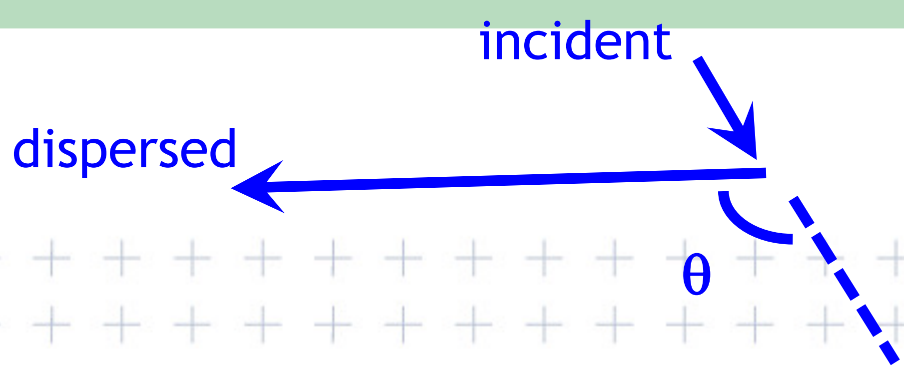
Integrating Nephelometer coeficiente de scattering



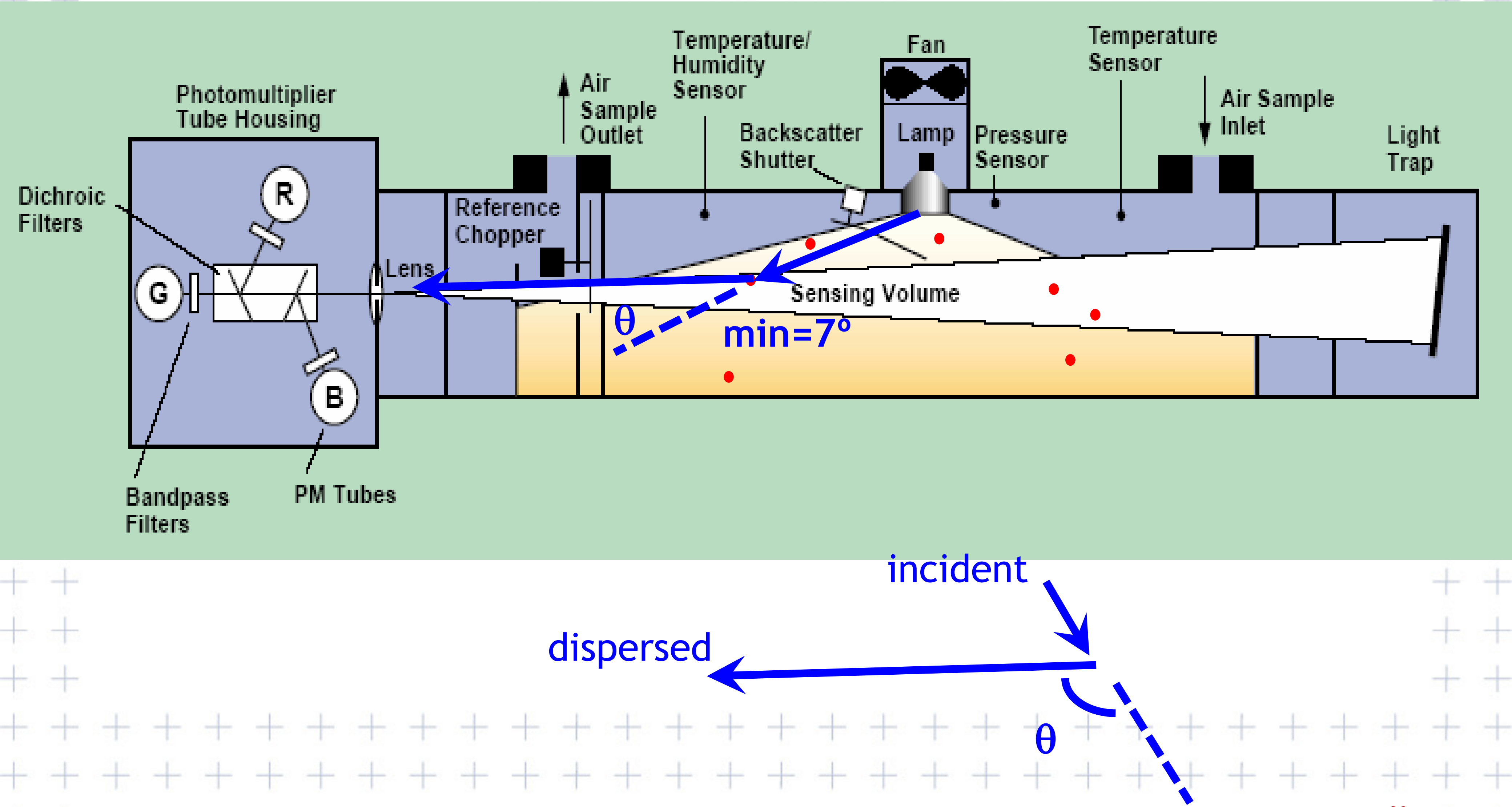


Integrating Nephelometer coeficiente de scattering

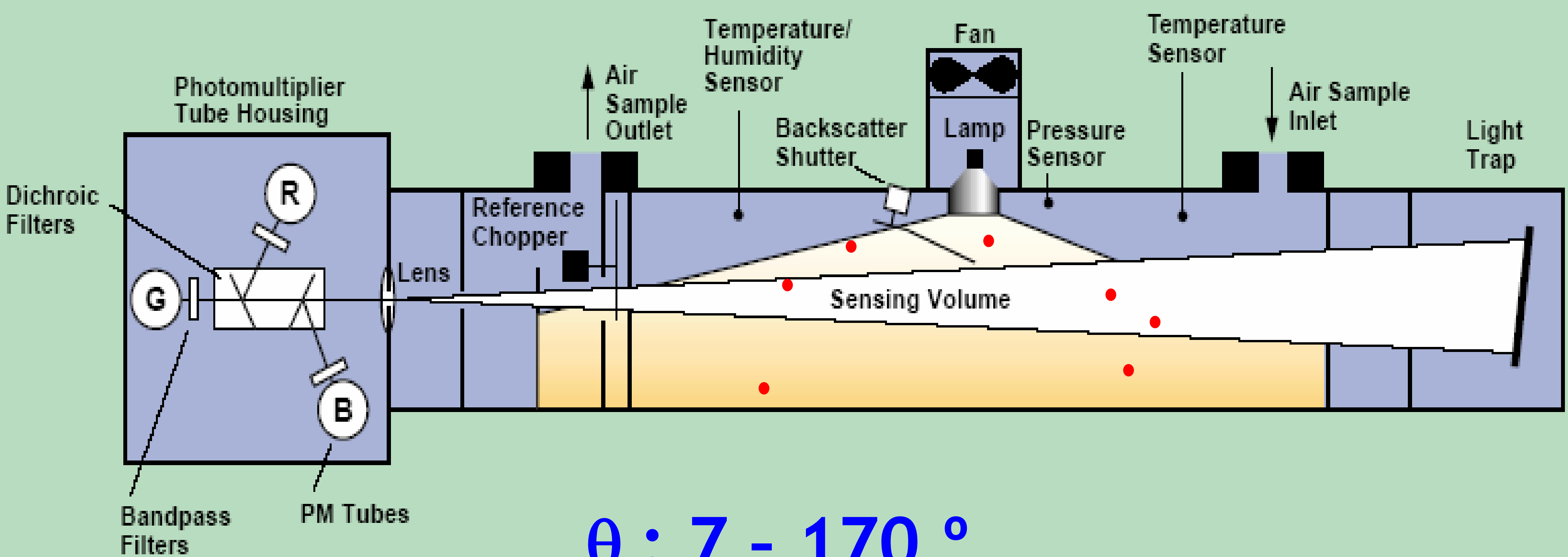




Integrating Nephelometer   coeficiente de scattering



Integrating Nephelometer coeficiente de scattering

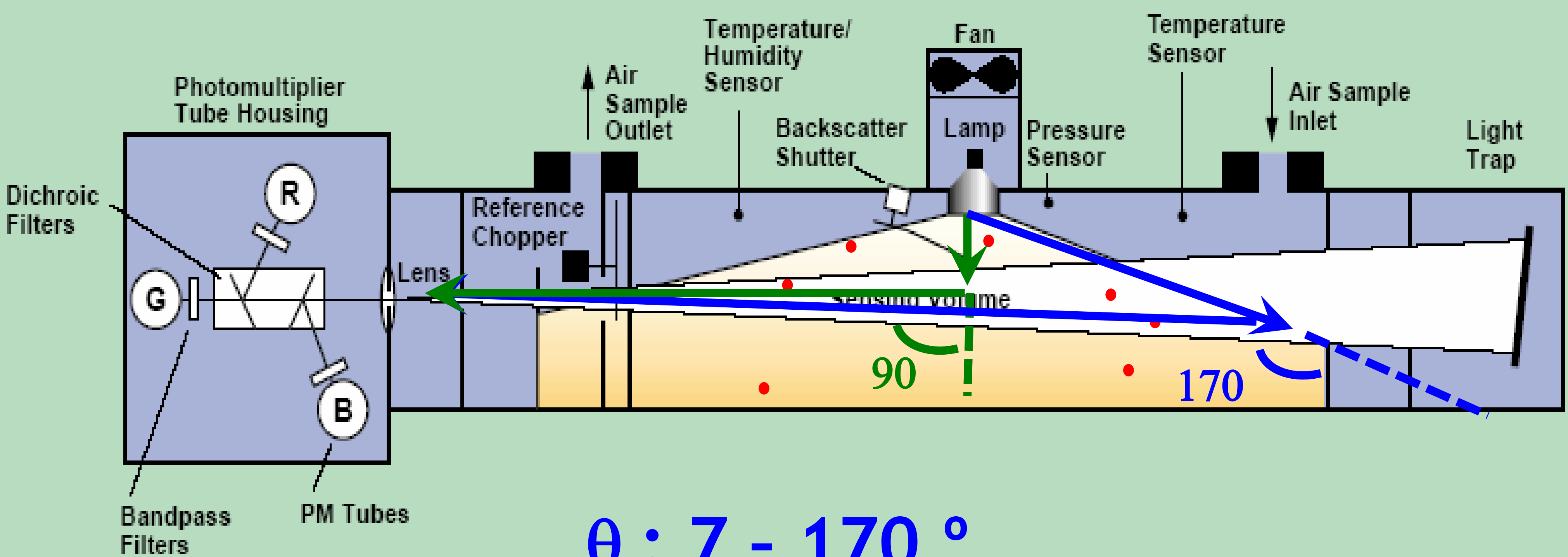


θ : 7 - 170 °

Integrating nephelometer

Scattering Coeficiente 7 - 170 º

Integrating Nephelometer coeficiente de scattering



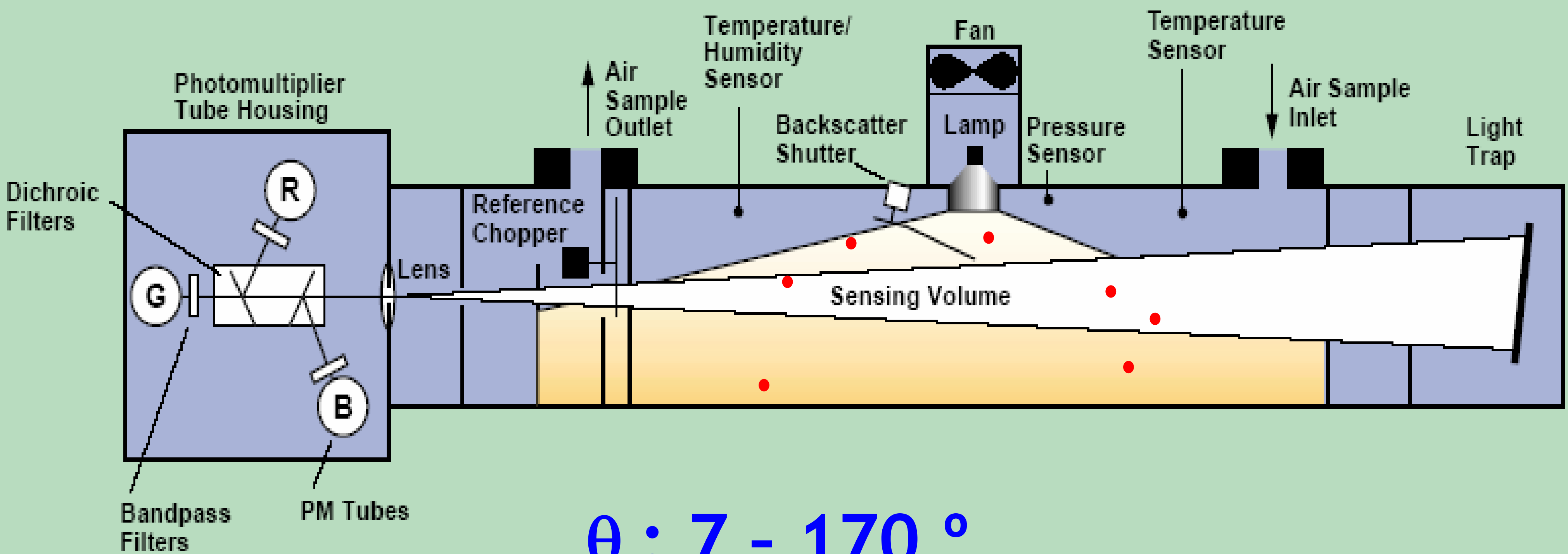
θ : 7 - 170 °

Integrating nephelometer

Coeficiente scattering total 7 - 170 °

Coeficiente backscattering total 90 - 170 °

Integrating Nephelometer coeficiente de scattering



θ : 7 - 170 º

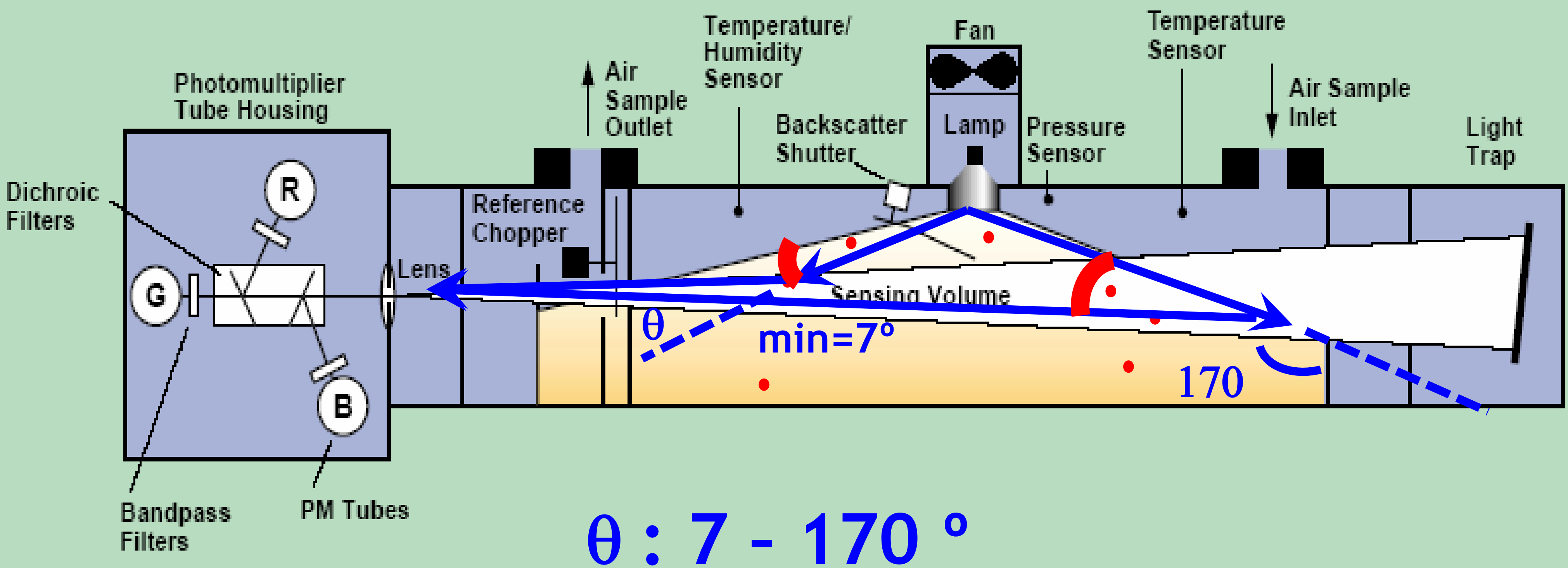
Integrating nephelometer

Coeficiente scattering total 7 - 170 º

Coeficiente backscattering total 90 - 170 º

λ = 450, 550, 700 nm

Integrating Nephelometer: CORRECCIÓN POR TRUNCAMIENTO



coeficiente scattering total 7 - 170 º

Truncation error: light dispersed within the angles 0-7º y 170-180º is not measured

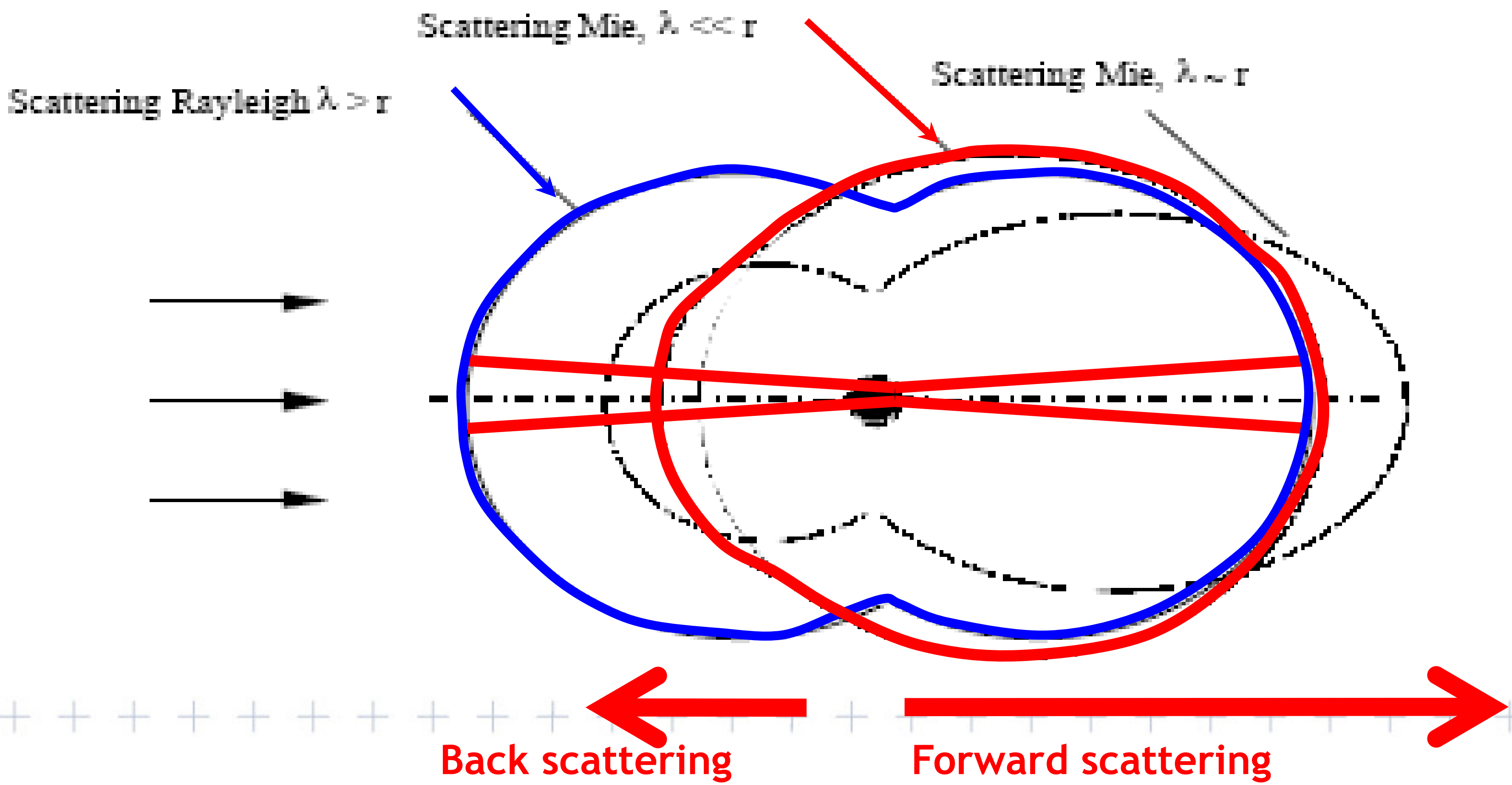
Forward scattering increase with particle size.

Coarse dust particles ➔ TRUNCATION ERROR

TRUNCATION CORRECTION IS IMPORTANT FOR DUST

Correction scheme ➔ Anderson y Ogren (1998).

Anderson, T.L., Ogren, J.A., 1998. Determining aerosol radiative properties using the TSI 3563 Integrating Nephelometer. Aerosol Science and Technology, 29, 57-69.



Forward scattering increase with particle size.

Coarse dust particles ➔ TRUNCATION ERROR

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Anderson, T.L., Ogren, J.A., 1998. Determining aerosol radiative properties using the TSI 3563 Integrating Nephelometer. Aerosol Science and Technology, 29, 57-69.

$$C = \frac{\sigma_{true}}{\sigma_{neph}},$$

$$C = a + b^{*}Å^{b}$$

$$Å(\lambda_1/\lambda_2) = -\frac{\log(\sigma_{sp}^{\lambda_1}/\sigma_{sp}^{\lambda_2})}{\log(\lambda_1/\lambda_2)}.$$

b) Correction factors for total scatter as a linear function of Ångström exponent using $C = a + b^{*}Å^{b}$

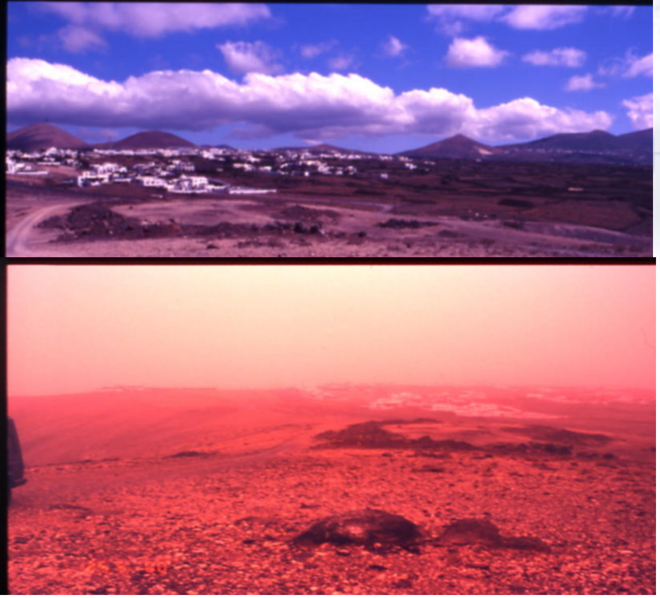
	450 nm		|residual|		550 nm		|residual|		700 nm		|residual|	
	a	b	mean	max	a	b	mean	max	a	b	mean	max
No cut	1.365	−.156	0.050	0.22	1.337	−.138	0.046	0.21	1.297	−.113	0.042	0.17
Sub-μm	1.165	−.046	0.010	0.031	1.152	−.044	0.007	0.022	1.120	−.035	0.004	0.014

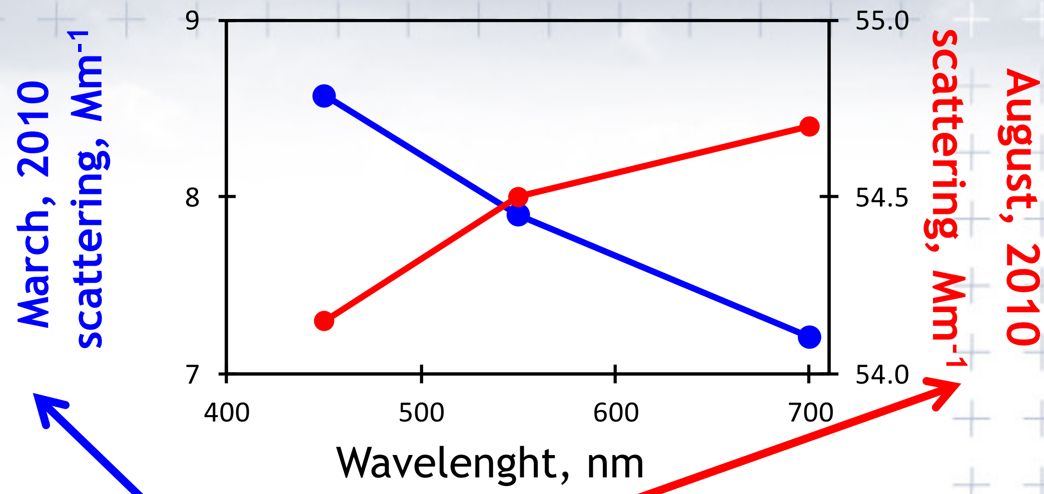
[a] Bimodal, lognormal size distributions with ranges of volume mean diameters and refractive indices given in text. The range of fine mode mass fraction is 0.9 to 0.1.
[b] Å-values for input to this formula are calculated from Eq. (11) using uncorrected nephelometer measurements of σ_{sp} at two wavelengths; Å(450/550) at 450 nm, Å(450/700) at 550 nm, and Å(550/700) at 700 nm.

Ångstrom exponent high values (e.g. > 0.7) fine particles

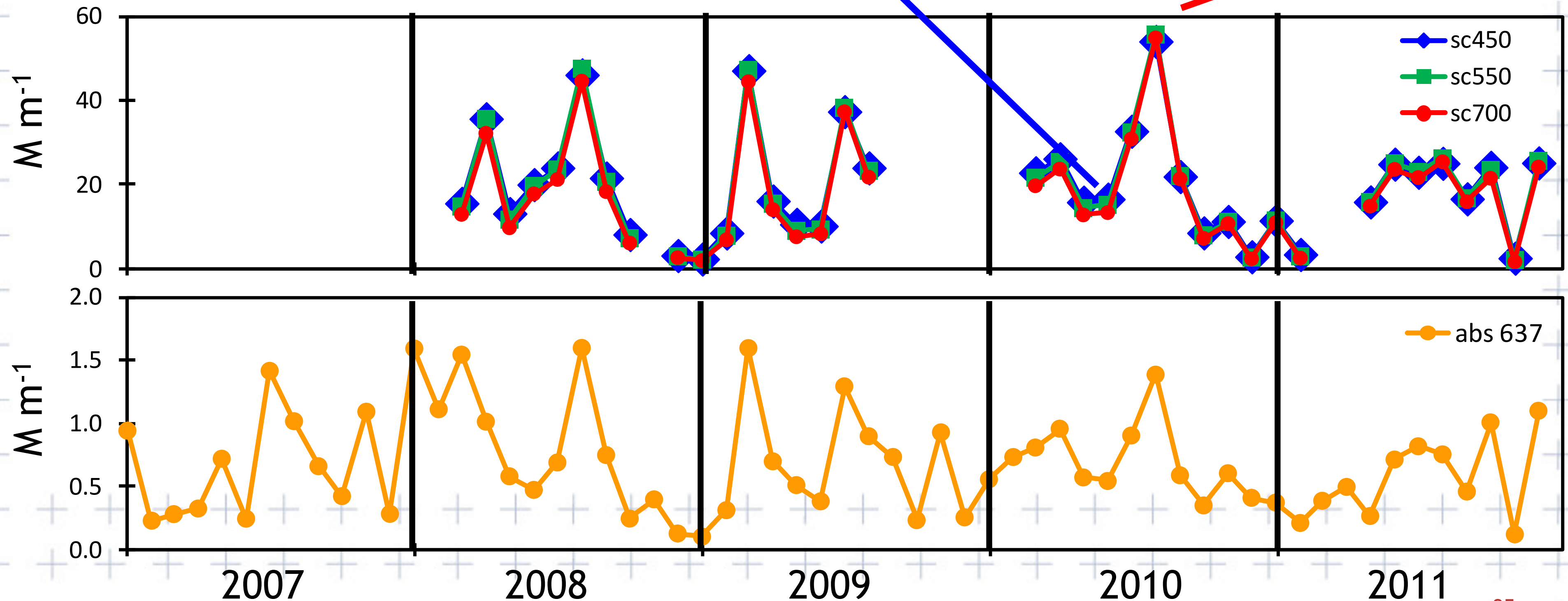
Ångstrom exponent high values (e.g. < 0.7) coarse particles, **DUST**

If correction is not applied, the total scattering is underestimated by between 5-15% for submicron particles and by 40-60% for coarse particles





Optical properties: scattering and absorption



optical properties

2 basic optical properties:

scattering (σ_{sp}) and backscattering coefficient (several λ)

absorption coefficient (several λ)

PSAP: Particle Soot Absorption Photometer

MAAP: Multi-Angle Absorption Photometer

Aethalometer

3λ

5–7 λ

λ=670nm

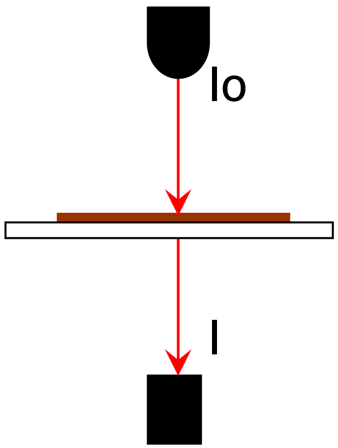
optical properties

2 basic optical properties:

scattering (σ_{sp}) and backscattering coefficient (several λ)

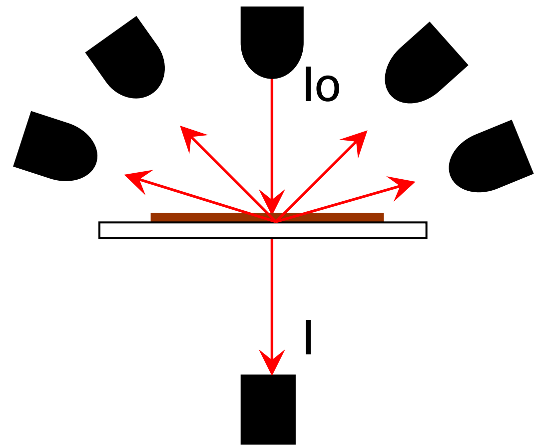
absorption coefficient (several λ)

$$I = I_o \cdot e^{-\sigma_{ep} \cdot m}$$



Aethalometer and PSAP

$$I = I_o \cdot e^{-\sigma_{ap} \cdot m}$$



MAAP: MultiAngle Absorption Photometer

Coef. Abs (aethamoletro-PSAP) > **Coef. Abs** (MAAP)

CORRECTION ALGORITHMS

PSAP: Particle Soot Absorption Photometer

Correction for loading: 2 algorithms

Bond, T. C., Anderson, T. L., and Campbell, D.: Calibration and intercomparison of filter-based measurements of visible light absorption by aerosols, Aerosol Sci. Tech., 30, 582–600, 1999.

Virkkula, A.: Correction of the Calibration of the 3-wavelength Particle Soot Absorption Photometer (3 □□ PSAP), Aerosol Science and Technology, 44, 706–712, doi:10.1080/02786826.2010.482110, 2010.

Virkkula, A., Ahlquist, N. C., Covert, D. S., Arnott,W. P., Sheridan, P. J., Quinn, P. K., and Coffmann, D. J.: Modification, calibration and a field test of an instrument for measuring light absorption by particles, Aerosol Science and Technology, 39, 68–83, 2005.

3λ

CORRECTION ALGORITHMS

Aethalometer

Correction for 'loading': 5 algoritmos

Weingartner, E., Saathoff, H., Schnaiter, M., Streit, N., Bitnar, B., and Baltensperger, U., 2003. Absorption of light by soot particles, 2003. Determination of the absorption by means of aethalometers, Journal of Aerosol Science, 34, 1445–1463.

Arnott, W. P., Hamasha, K., Moosmüller, H., Sheridan, P. J., Ogren, J. A., 2002. Towards aerosol light-absorption measurements with a 7-wavelength aethalometer: Evaluation with a photoacoustic instrument and 3-wavelength nephelometer, Aerosol Sci. Tech., 39, 17–29.

Schmid, O., Artaxo, P., Arnott,W. P., Chand, D., Gatti, L. V., Frank, G. P., Hoffer, A., Schnaiter, M., and Andreae, M. O., 2006. Spectral light absorption by ambient aerosols influenced by biomass burning in the Amazon Basin. I: Comparison and field calibration of absorption measurement techniques, Atmos. Chem. Phys., 6, 3443–3462, doi:10.5194/acp-6-3443-2006.

Virkkula, A., Mäkelä, T., Yli-Tuomi, T., Hirsikko, A., Koponen, I. K., Hämeri, K., and Hillamo, R.: A simple procedure for correcting loading effects of aethalometer data, J. Air Waste Manage., 57, 1214–1222, doi:10.3155/1047-3289.57.10.1214, 2007.

Collaud Coen, M., Weingartner, E., Apituley, A., Ceburnis, D., Fierz-Schmidhauser, R., Flentje, H., Henzing, J. S., Jennings, S. G., Moerman, M., Petzold, A., Schmid, O., and Baltensperger, U., 2010. Minimizing light absorption measurement artifacts of the Aethalometer: evaluation of five correction algorithms, Atmos. Meas. Tech., 3, 457–474, doi:10.5194/amt-3-457-2010.

Scattering Coefficient is necessary for applying these corrections

CORRECTION ALGORITHMS

MAAP: Multi-Angle Absorption Photometer

No correction necessary:

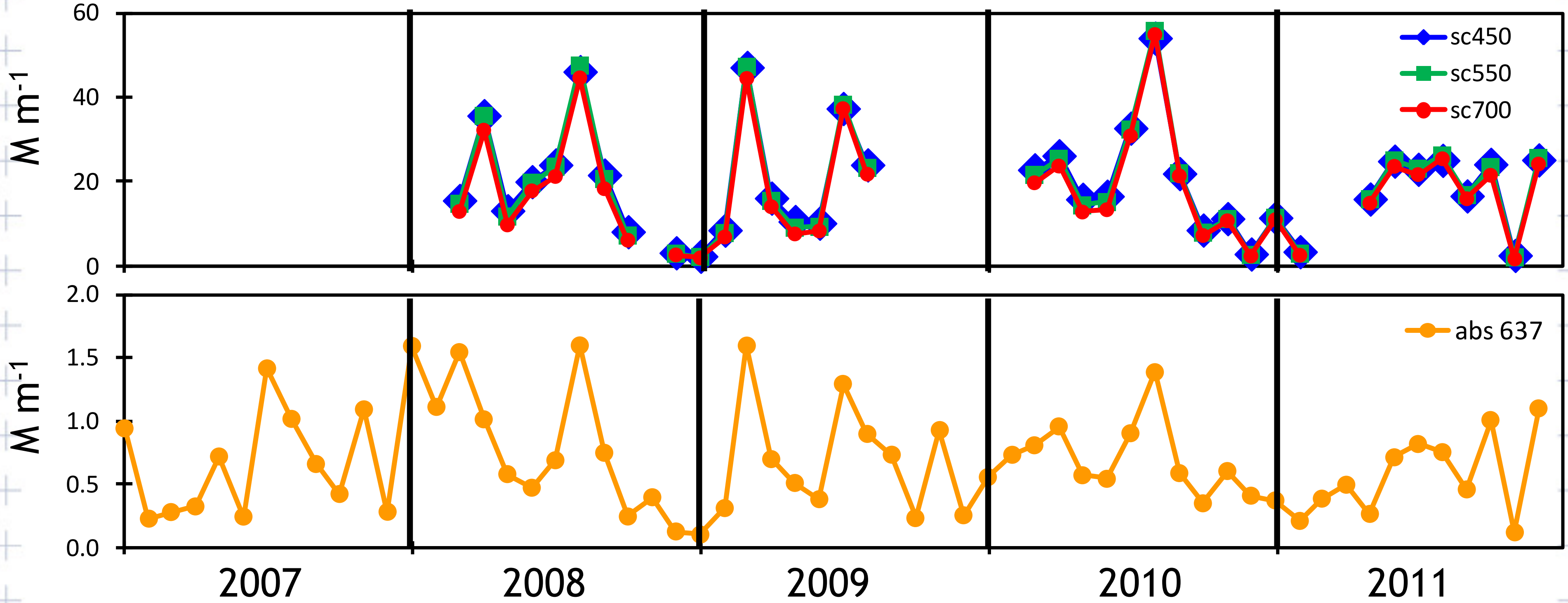
Manufacturer: 670nm

Experimental: 637nm

Coef. de Abs. x 1.05

Müller and other 38 authors, 2011. Characterization and intercomparison of aerosol absorption photometers: result of two intercomparison workshops, Atmospheric Measurements Techniques, 4, 245-268. doi:10.5194/amt-4-245-2011.

Long term monitoring of optical properties with simultaneous chemical and mineralogical characterization allows to understand potential changes in the optical properties due to changes in the dust and pollutants mixing or changes in the dust-sources



property of aerosol dust:

number size distribution
mass concentration
chemical composition
mixing state
mineralogy
optical properties

Dust is a mixing of different minerals:

		uma-->
type	common name	formula empirica
clay	Montmorillonite	$Na_{0.2}Ca_{0.1}Al_2Si_4O_{10}(OH)_2(H_2O)_{10}\cdot n(H_2O)$
clay	Smectite	$(Na, Ca)Al_4(Si, Al)_8O_{20}(OH)_4\cdot 2(H_2O)$
clay	Chlorite	$Na_{0.5}(Al, Mg)_6(Si, Al)_8O_{18}(OH)_{12}\cdot 5(H_2O)$
Ca rich	calcite	$CaCO_3$
Ca rich	dolomite	$CaMg(CO_3)_2$
Ca rich	gypsum	$CaSO_4\cdot 2(H_2O)$
Ca rich	anhydrite	$CaSO_4$
SiO2	quartz	SiO_2
Feldspars	mocricline	$KAlSi_3O_8$
Plagioclase feldspar	Var oligoclase	$(Na,Ca)(Si,Al)_4O_8$
Plagioclase feldspar	Var albite	$NaAlSi_3O_8$
Plagioclase feldspar	Var anorthite	$CaAl_2Si_2O_8$
Oxides	hematite	Fe_2O_3
Oxides	goethite	$FeO(OH)$
Oxides	gibbsite	$Al(OH)_3$
Oxides	rutile	TiO_2
Salt	halite	$NaCl$

close chemical composition,
but different mineralogy

different optical properties

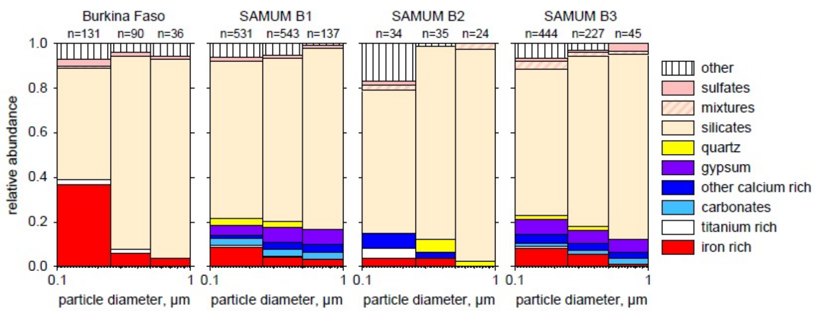
Dust is a mixing of different minerals:

Techniques for the identification of different minerals:

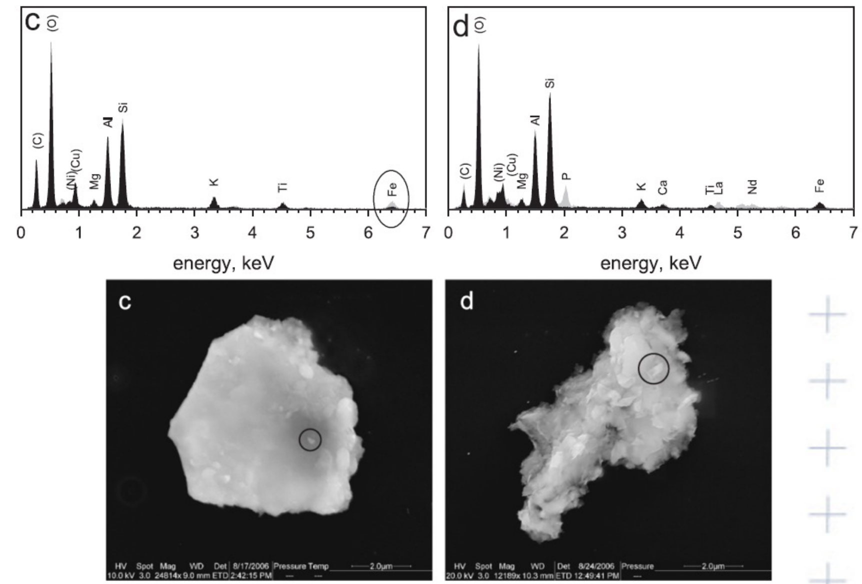
X-Ray diffraction

Scanning Electron Microscopy (SEM) and **Transmission Electron Microscopy** (TEM) individual particle characterization for size, morphology, chemical and mineral composition.

not for long term monitoring



Component	Burkina Faso	SAMUM B1	SAMUM B3
"Quartz"	0.004	0.012	0.006
"Hematite"	0.027	0.016	0.011
"Calcite"	0.001	0.092	0.055
"Average Silicate"	0.949	0.842	0.867
"Sulphate"	0.019	0.037	0.061



Complex refractive indices of Saharan dust samples at visible and near UV wavelengths: a laboratory study

R. Wagner[1], T. Ajtai[2], K. Kandler[3], K. Lieke[3], C. Linke[1], T. Müller[4], M. Schnaiter[1], and M. Vragel[1]

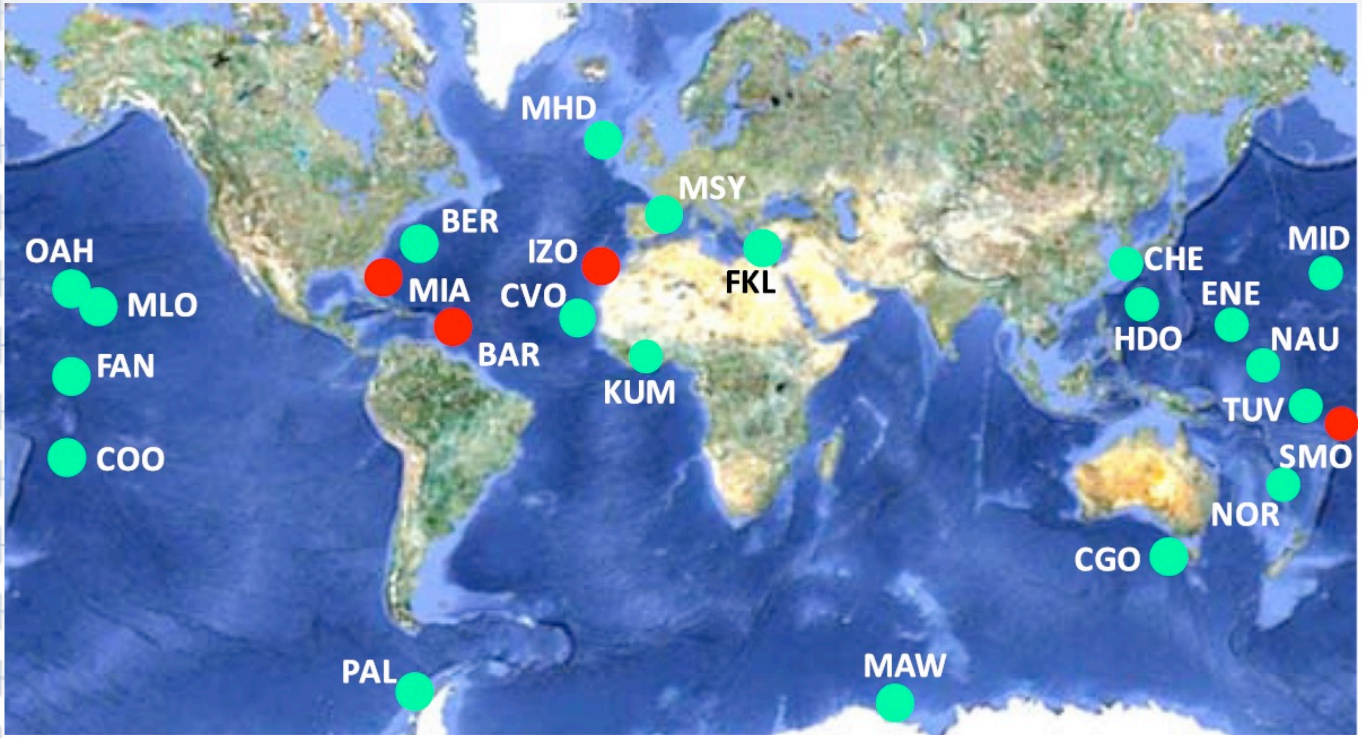
Atmos. Chem. Phys., 12, 2491–2512, 2012

Chemical composition and complex refractive index of Saharan Mineral Dust at Izaña, Tenerife (Spain) derived by electron microscopy

Konrad Kandler[a,*], Nathalie Benker[a], Ulrich Bundke[b], Emilio Cuevas[c], Martin Ebert[a], Peter Knippertz[d], Sergio Rodríguez[c,e], Lothar Schütz[d], Stephan Weinbruch[a]

Atmospheric Environment 41 (2007) 8058–8074

Long term monitoring dust background-observatories:



at least 4 years

Active during the last 20 years

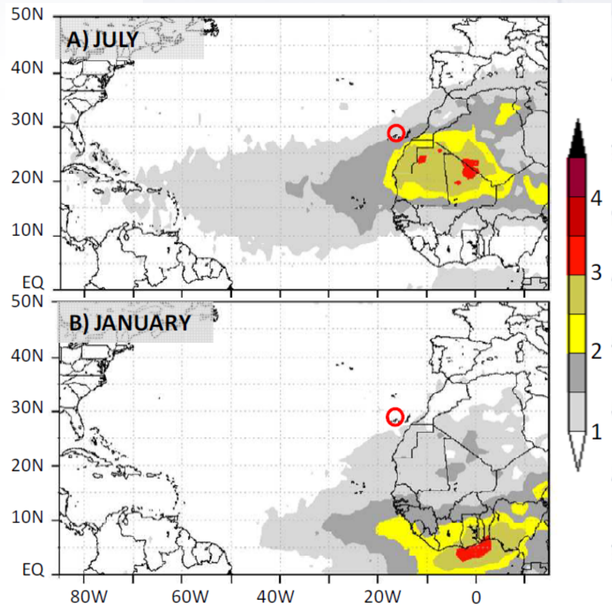
Review Article

Aeolian Research Aeolian Research 6 (2012) 55–74

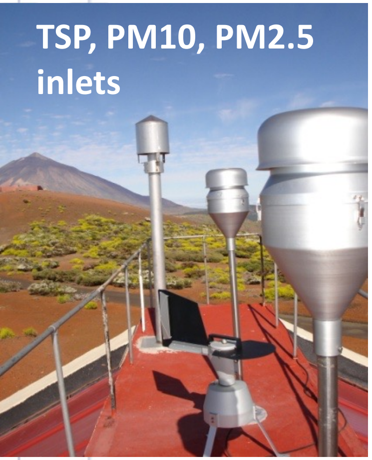
A review of methods for long term in situ characterization of aerosol dust

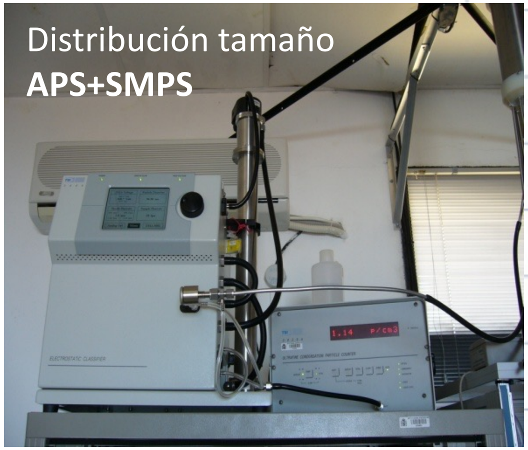
Sergio Rodríguez [a,*], Andrés Alastuey [b], Xavier Querol [b]

Example of
long term monitoring dust background-observatories, Izaña (Tenerife, Canary Islands)



In-situ aerosols GAW program:





Chemical composition, TSP: 1987, $PM_{2.5}$: 2002, PM_{10}: 2005 …

Ultrafine particles (CPC 3025A): 1997 – 2009

Size distribution of fine and ultrafine particles (SMPS): 2008 - …

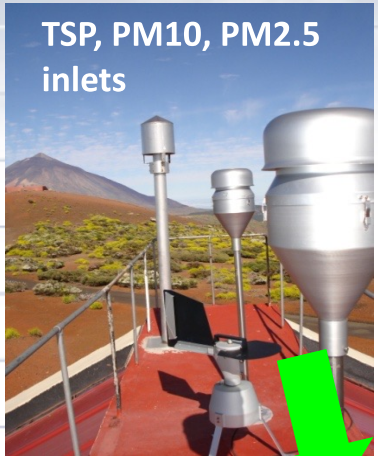
Size distribution of coarse particles (APS): 2006 - …

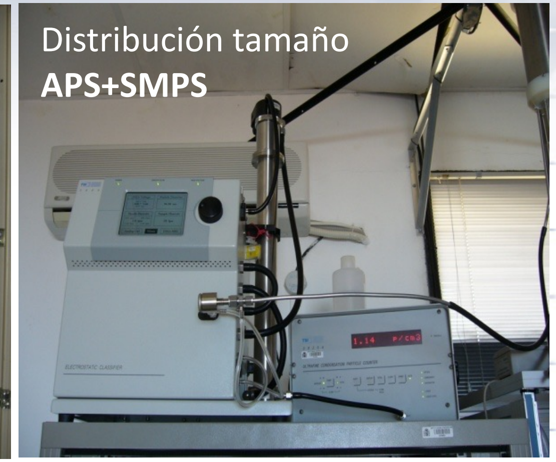
Scattering and backscattering (nephelometer): 2008 - …

Absorption coefficient (1 λ): 2006 - …

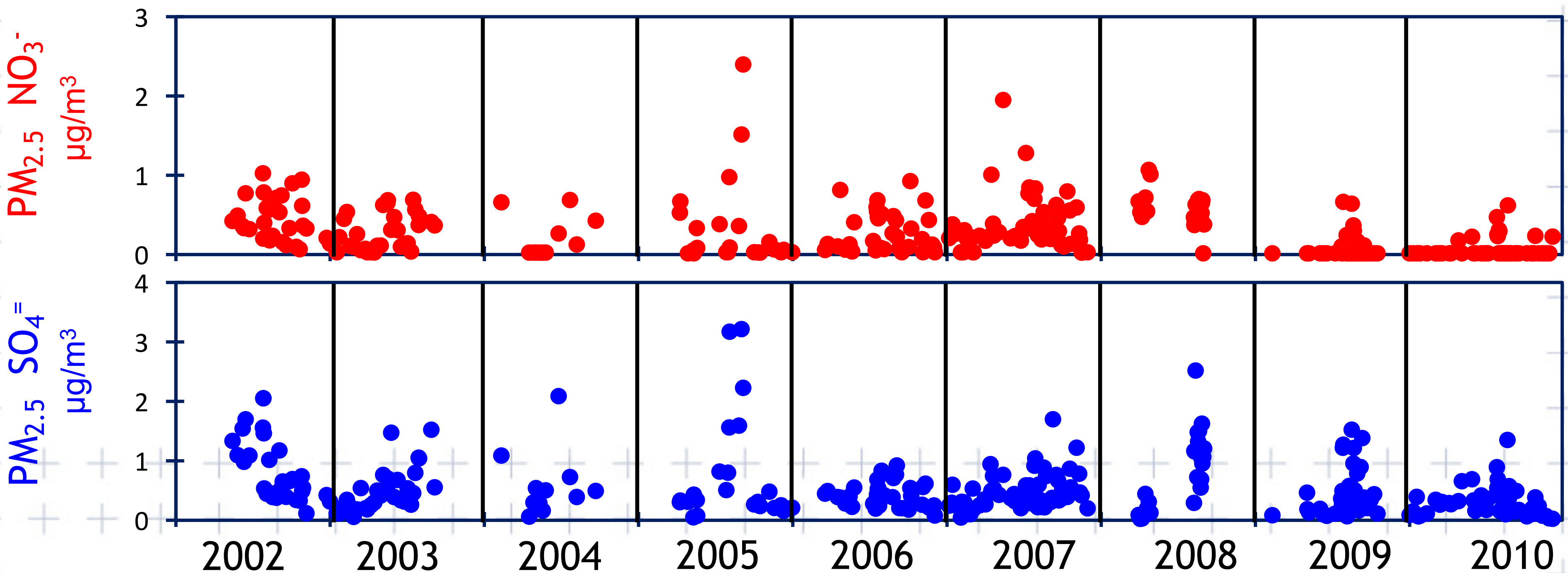
Absorption coefficient (7 λ): 2012 - …

GAW program:

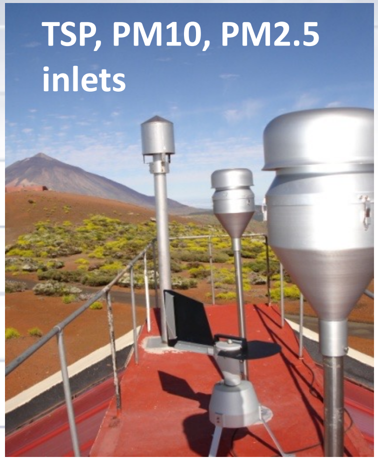


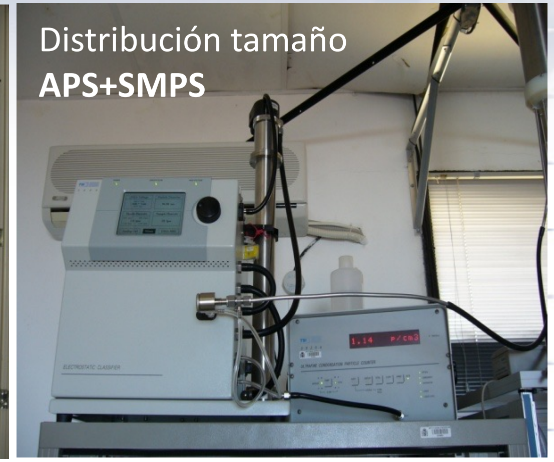


Chemical composition (TSP, PM_{10}, $PM_{2.5}$): elemental (ICP-AES+ICP-MS) , ions ($SO_4^=$, NO_3^-, NH_4^+), OC, EC

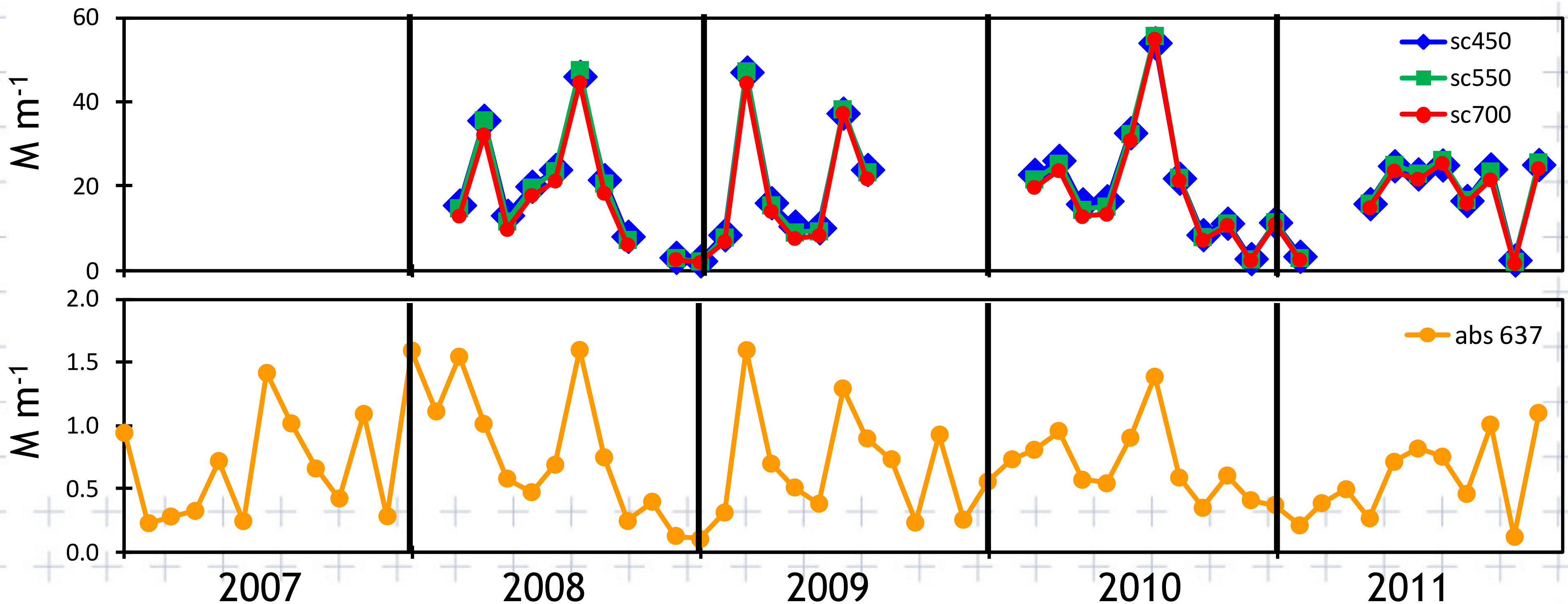


GAW program:

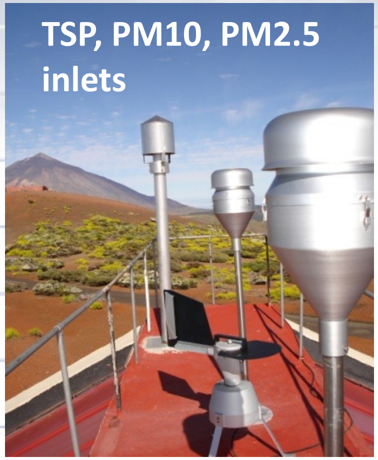


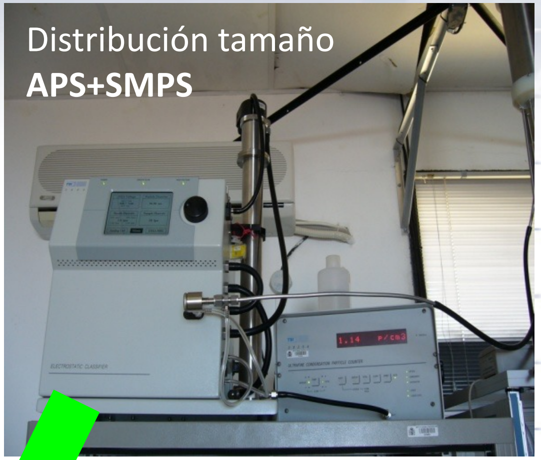


Optical properties: scattering and absorption

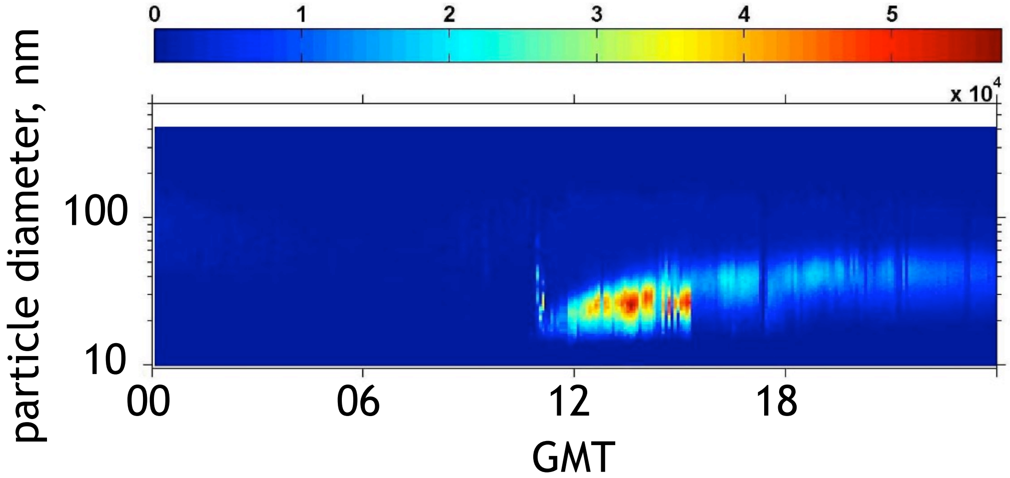


GAW program:





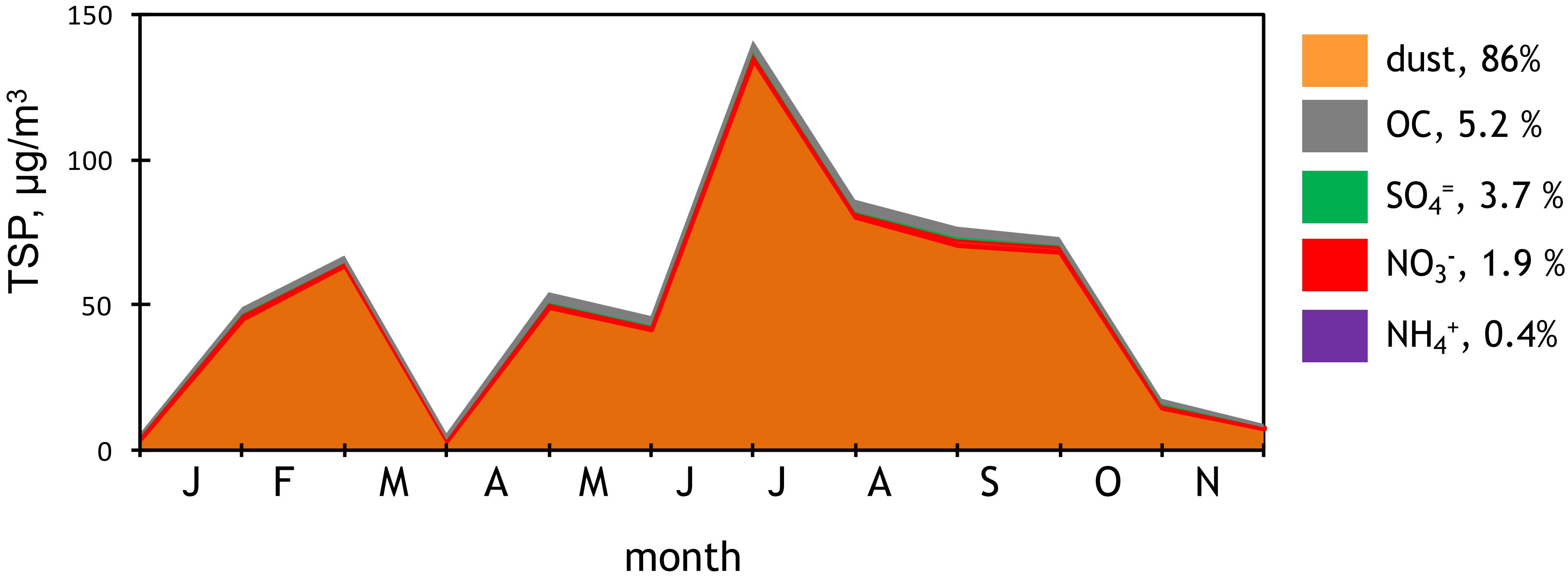
Size distribution: 10-500 nm (SMPS) + 0.5-20 μm (APS)



Example: new particle formation by nucleation

POLLUTANTS mixed with dust

Saharan dust is the most abundant aerosol we detect !!!!!!



From ground observations…

to ground estimations…

Visibility

Index

- Aerosols and dust background
- In-situ dust characterization
- In-situ dust estimations (Visibility)
- Ground based remote sensing
- Summary

WMO - visibility

The greatest distance that a black object of "suitable dimensions," situated near the ground, can be seen and recognized when observed against a background of fog

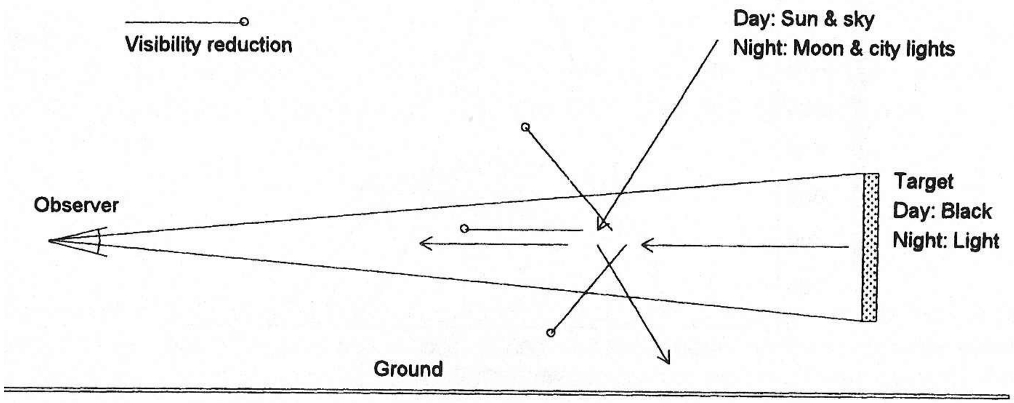


Fig. 11-1 Visibility reduction by scattering.

aerosols are the main cause of visibility reduction

- **Operational surface synoptic weather station reports from Global Telecommunication System (GTS)**
- **Station reports include past & present weather, visibility (km), temperature (°C), dew point temperature, wind direction (°), and speed (knots)**

62733	15.32	35.60	02040818	Dust, not at time of obs.		6	0		18	22	320	2	35.5
62733	15.32	35.60	02041015	Dust, raised at time of obs.		7	0		99.	30	320	6	34.5
62733	15.32	35.60	02041121		-9	-9	-9	-9	20	23	320	2	26.0
62733	15.32	35.60	02041212		-9	-9	-9	-9	20	34	340	3	37.5

In-situ estimations

Measurement of visibility – **transmissometer & scatemeter**

- A light source with one or two light detectors at fixed distances from the source
- Detectors are designed to receive light only from the source direction
- Often located along and parallel to a runway (**runway visual range; RVR**)

transmissometer

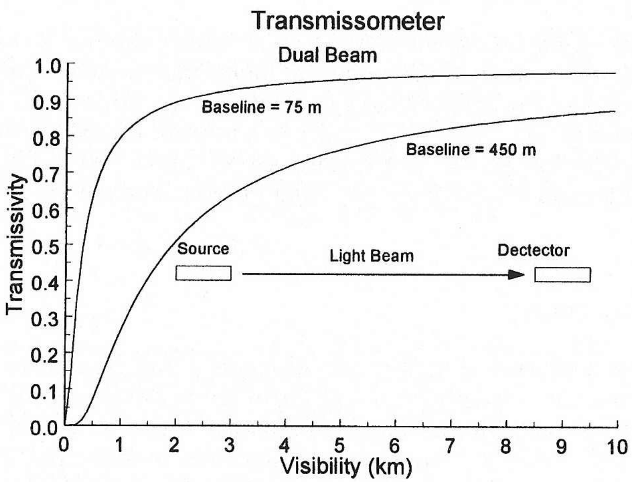


Fig. 11-3 Transfer function for a transmissometer.

scatemeter

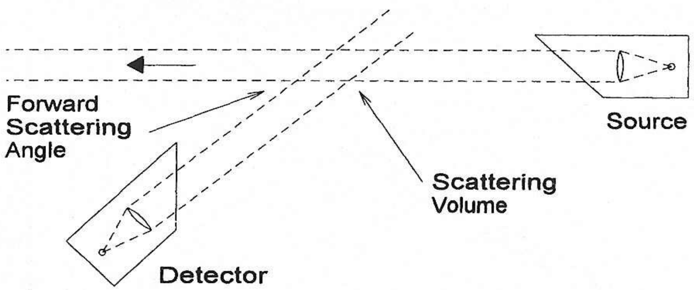
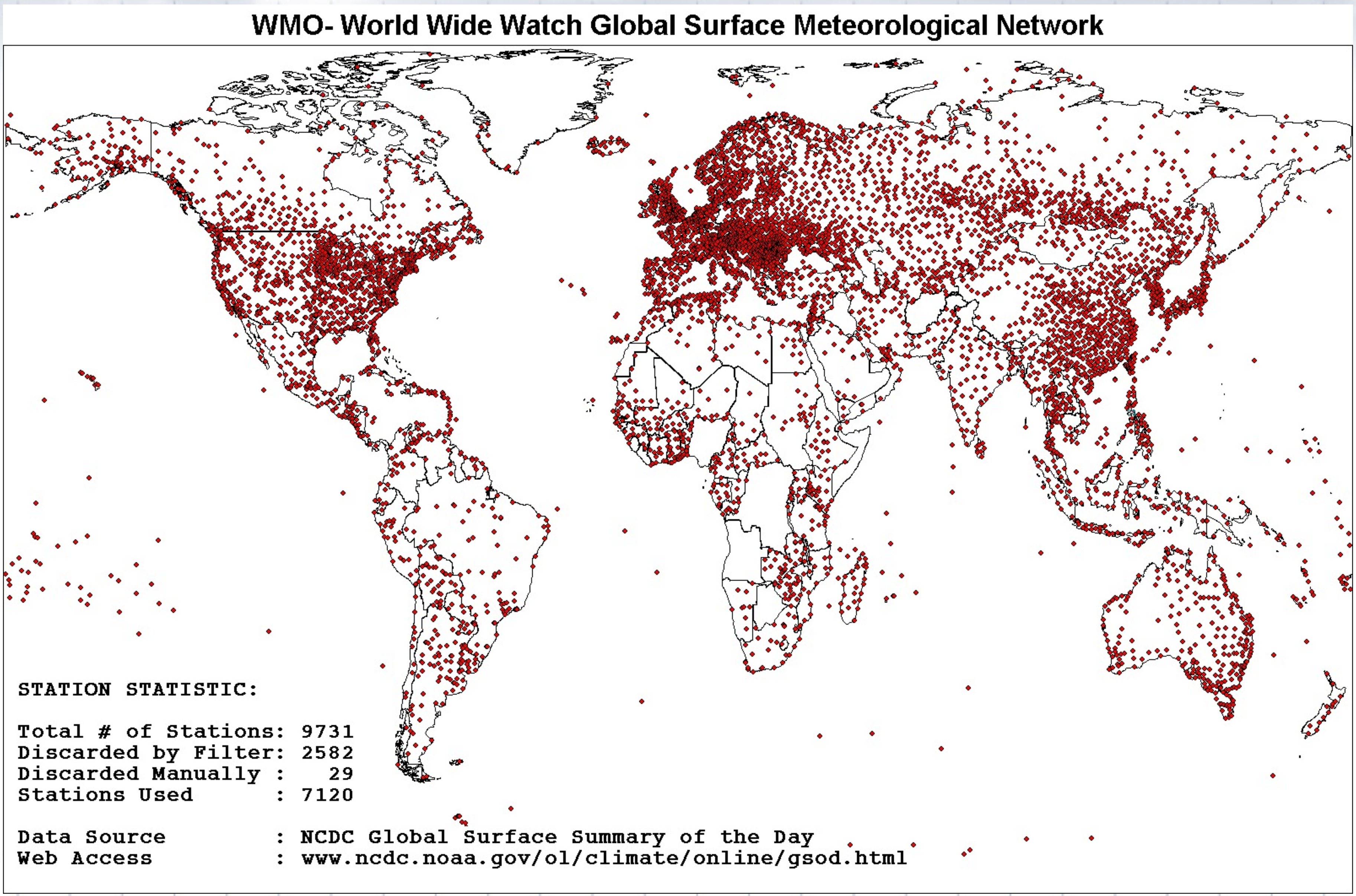


Fig. 11-4 A forward scatter visibility meter.

In-situ estimations



Relation between horizontal visibility and TSP or PM10

Very few studies on the relation between horizontal visibility and TSP or PM10 levels of mineral dust mass concentration have been carried out in Africa.

$C_{TSP} = 1339.84\ VV^{-0.67}$ Ben Mohamed et al. (1992)

$C_{PM10} = 914.06 VV^{-0.73} + 19.03$ D'Almeida's (1986)

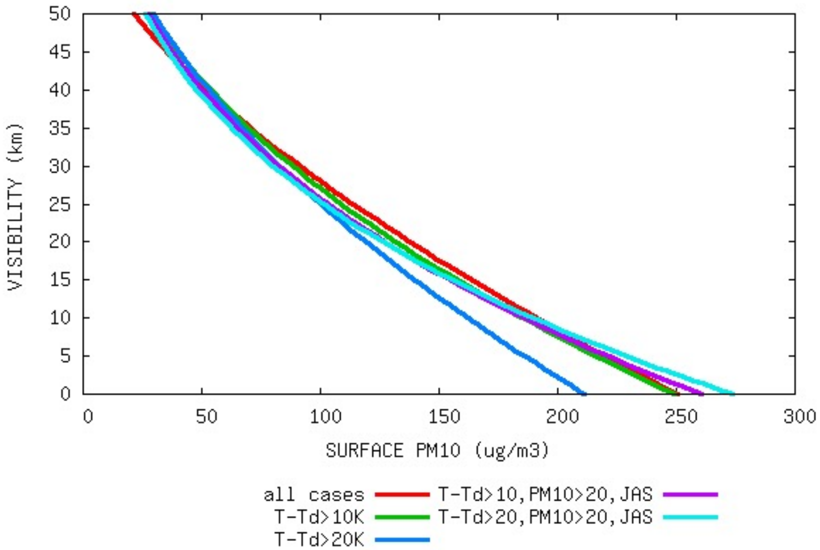
where *C is the TSP concentration in* μgm^{-3} *and VV* is the horizontal visibility in km

E. Terradellas

$Vis = 63023 - 1838(PM_{10}^{0.64})$

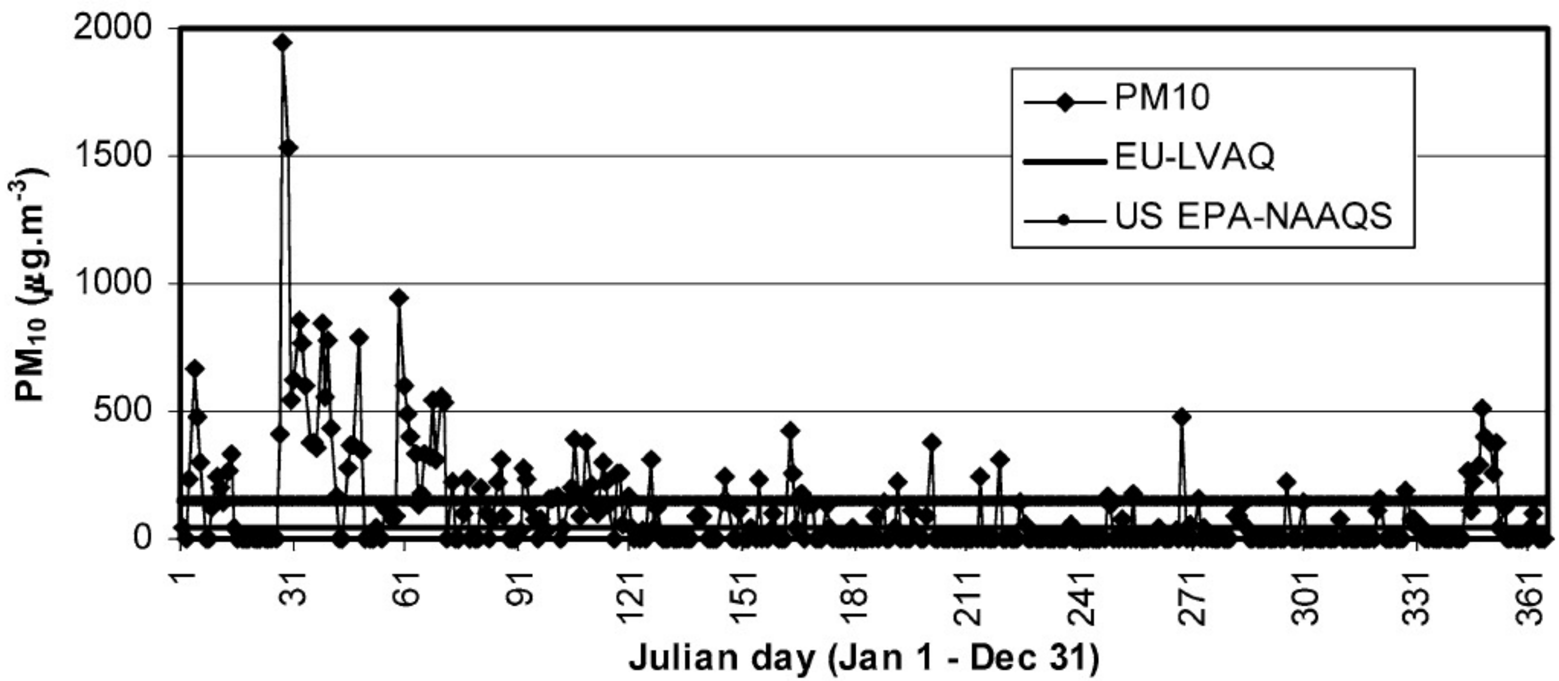
PM_{10} at Izaña

Visibility from SYNOP-Izaña



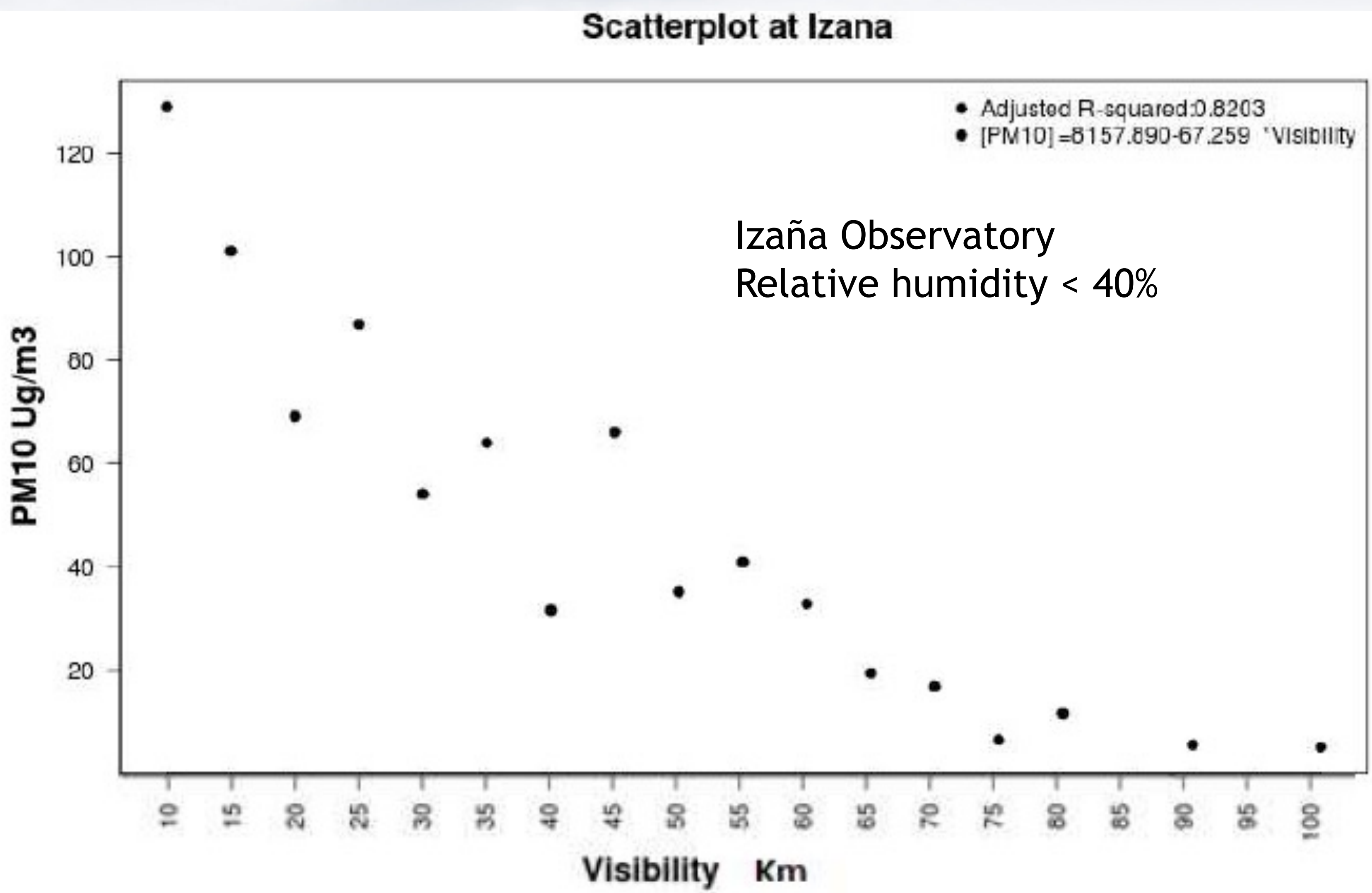
Identify surface station visibility reports that may be used in simple regression model for estimate ground PM10 or TSP

Variations of estimated daily mean concentrations of TSP and PM10 (μgm^{-3}) *due to* Saharan dust events at Nouakchott, Mauritania, in 2000



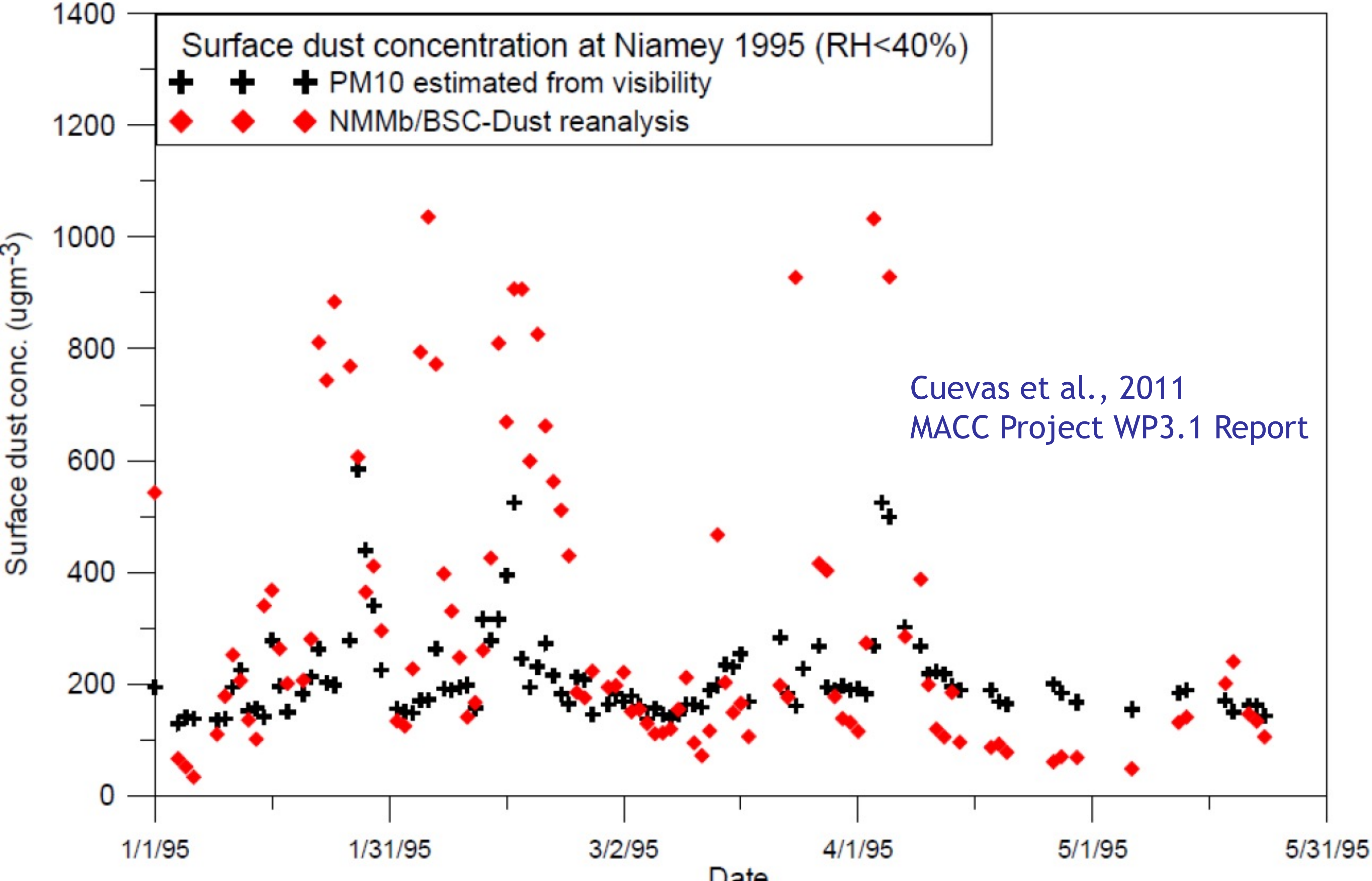
Ozer et al., (2006): Estimation of air quality degradation due to Saharan dust at Nouakchott, Mauritania, from horizontal visibility data

In-situ estimations



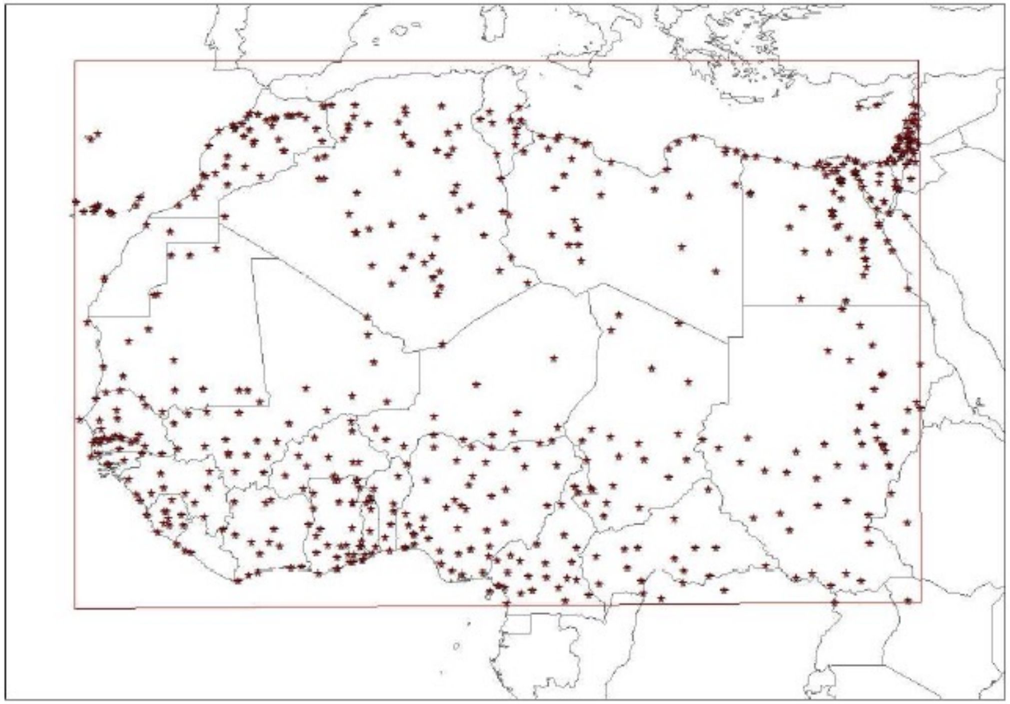
Izaña Observatory
Relative humidity < 40%

In-situ estimations



Cuevas et al., 2011
MACC Project WP3.1 Report

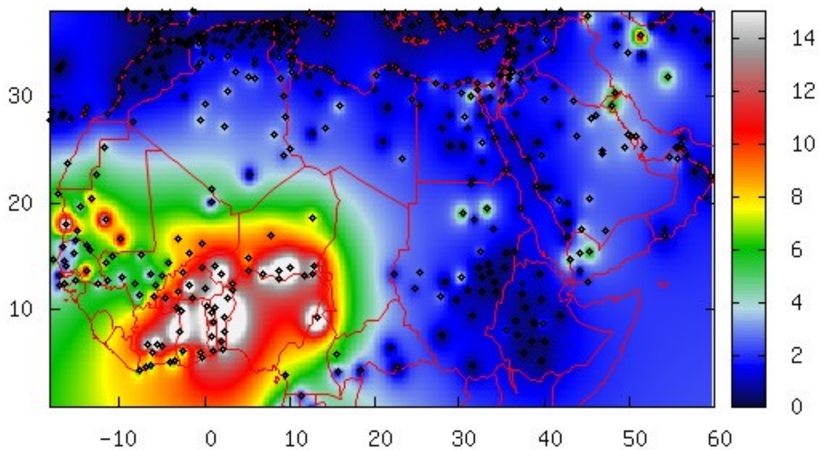
In-situ estimations



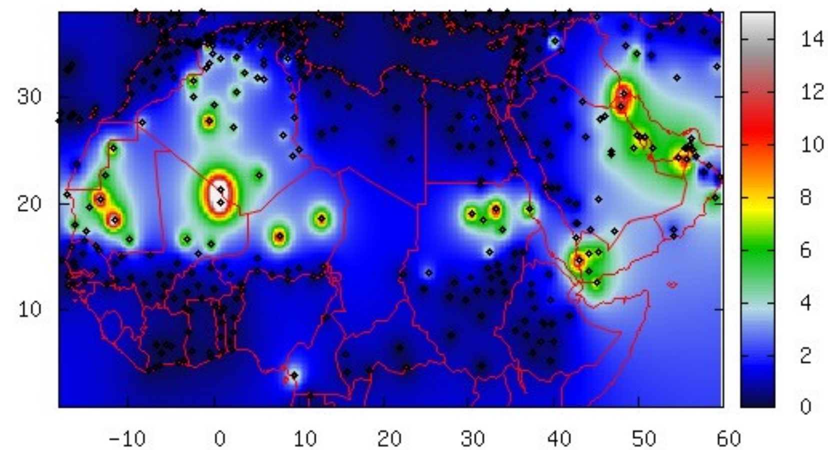
Synop and Metar reports from Met stations

Provided by Enric Terradellas

WINTER



SUMMER



a Est

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Problems with station visibility estimates

1. Human observations are inherently subjective.
2. No all reductions of visibility are due to dust (fog, biomass burning…)
3. Coarse reporting bins
4. Judgment in distinguishing visibility beyond 10 km

Main advantages

1. Reports are abundant and widespread over land. There is information in remote areas (deserts)
2. There are *some* standards
3. Human detected visibility has been correlated well with surface extinction analyses (Husar et al., 2000)
4. Estimations of PM are possible

From ground observations…

to total atmospheric column observations

Sunphotometers

Index

- Aerosols and dust background
- In-situ dust characterization
- In-situ dust estimations (Visibility)
- Ground based remote sensing
- Summary

Ground-based remote sensing

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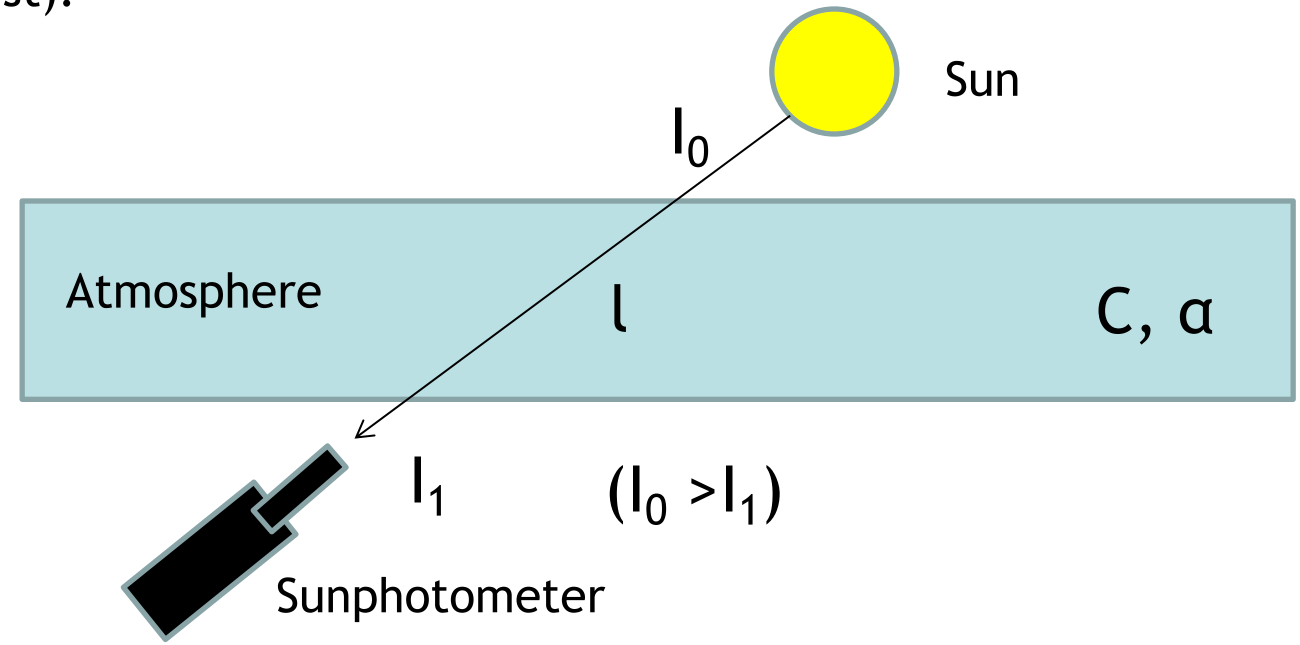
Knowing the sunlight's energy at the top of the atmosphere, the thickness of the atmosphere, and the amount of sunlight transmitted to the earth's surface and can allows us to determine the amount of scattering, and thus, the amount of aerosols (dust).

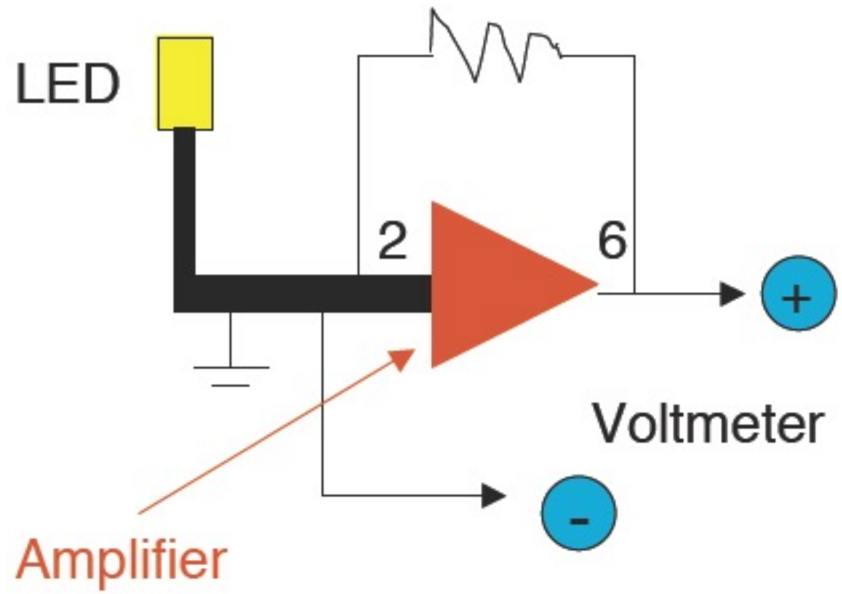


Beer's Law

$$T = I_1/I_0 = 10^{-\alpha l} = 10^{-\varepsilon l c}$$

Transmissivity (T)
Extinction coefficient (α)
path length (ι)
molar absorptivity of the absorber (ε)
concentration of absorbing species in the material (c)
extintion cross section (σ)
density of absorbers (N)

Sun Photometers absorb *direct* sunlight energy with a LED light and convert the intensity into a quantified voltage to measure aerosols in the atmosphere.



The intensity of sunlight at the top of the earth's atmosphere is constant. While the sunlight travels through the atmosphere, aerosols can dissipate the energy by scattering (Rayleigh and Mie) and absorbing the light. More aerosols in the atmosphere cause more scattering and less energy transmitted to the surface.

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ASSESSMENT OF OBSERVATIONS CONSISTENCY

Langely plot calibration (I00 determination for each wavelenght):

Beer's Law

$$T = I_1/I_0 = 10^{-\alpha\iota}$$

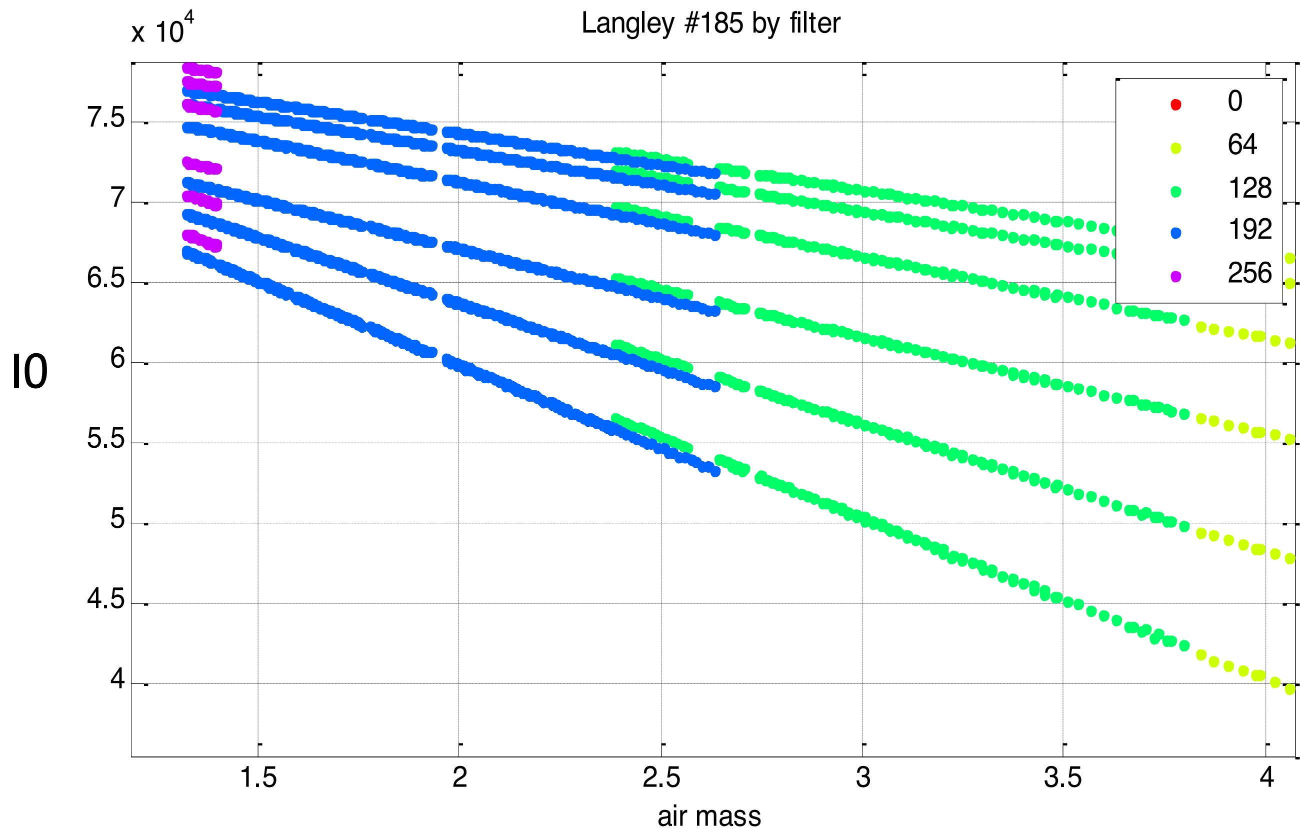
$$LnI = LnI_0 - \alpha\iota$$

Pristine conditions

No clouds

Stable total ozone and column water vapor

If α is constant during the observation → Determine I_0



CONCEPTS:

Aerosol Extinction: A measure of attenuation of the light passing through the atmosphere due to scattering and absorption by aerosol particles.

Extinction coefficient is the fractional depletion of radiance per unit path length (also called attenuation). It has units of km^{-1} .

Aerosol Mass Load: The columnar aerosol mass concentration ($\mu gm/cm^2$) is the total aerosol mass in a vertical column of atmosphere.

CONCEPTS:

Aerosol Asymmetry Factor A measure of the preferred scattering direction (forward or backward) for light encountering aerosol particles.

$$g = \frac{1}{2}\int_{-1}^{+1} \cos\Theta \, P(\cos\Theta) \; d\cos\Theta$$

$$P(\cos\Theta) = \frac{1-g^2}{\left(1+g^2-2g\,\cos\Theta\right)^{3/2}}$$

In general, **g=0 indicates scattering directions evenly distributed** between forward and backward directions, i.e. **isotropic scattering** (e.g. scattering from small particles)

g<0 scattering in the backward direction (i.e scattering angle > 90 deg.), often referred to as backscattering, is **scattering at 180 deg**.

g>0 scattering in the forward direction (i.e scattering angle < 90 deg.), often referred to as forward-scattering, is **scattering at 0 deg**. **For larger size or Mie particles, g is close to +1.**

CONCEPTS:

Aerosol Optical Depth (or Thickness)

"Aerosol Optical Depth“ (AOD) is the degree to which aerosols prevent the transmission of light. The aerosol optical depth or optical thickness (τ) is defined as the integrated extinction coefficient over a vertical column of unit cross section.

$$\tau_{ext} = \int_{z=0}^{z=toa} K_{ext}(z)dz$$

Angstrom Exponent (α)

An exponent that expresses the spectral dependence of Aerosol Optical Depth (τ) with the wavelength of incident light (λ). The spectral dependence of aerosol optical thickness can be approximated (depending on size distribution) by:

$$\tau_a = \beta \lambda^{\alpha}$$

α >> 0.9 FINE particles

α << 0.7 COARSE particles

where α is the Angstrom exponent (β = aerosol optical depth at 1 μm)

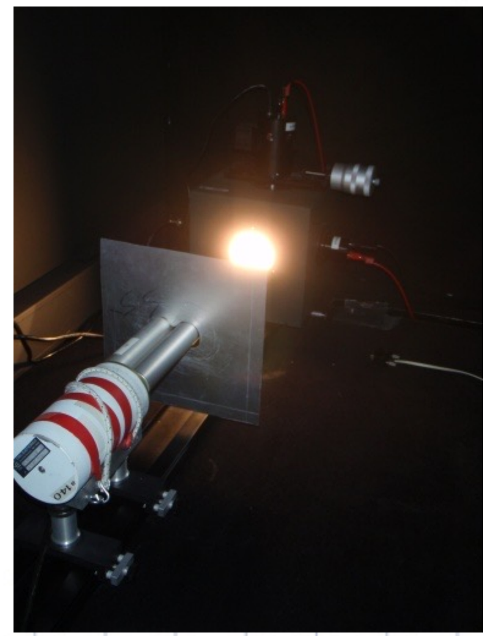
i.e. If AOD >~ 0.2 and α<0.7 then we are observing dust (aprox.)

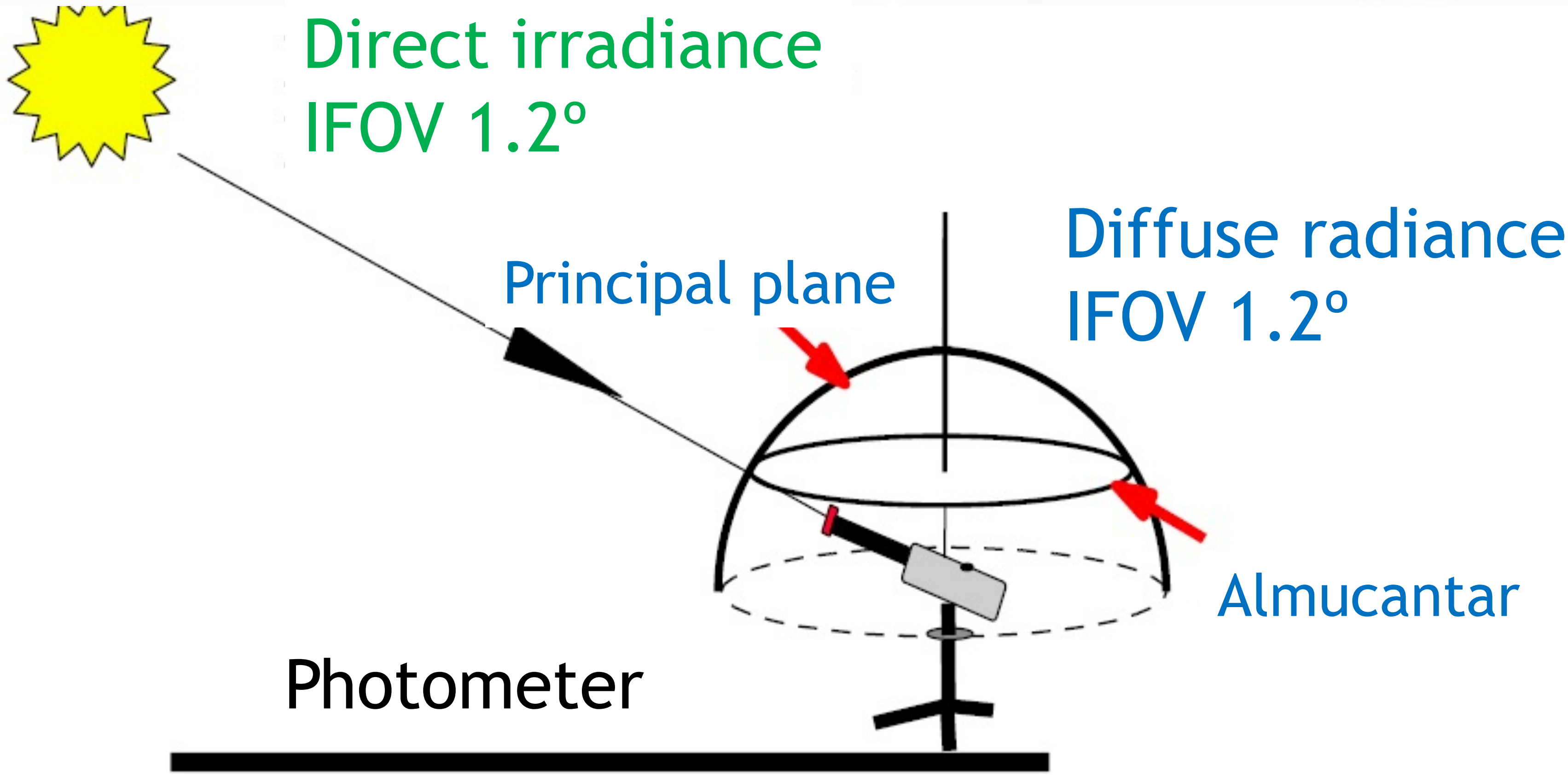
Ground-based remote sensing

- The **Cimel Electronique 318** spectral radiometer is a solar-powered, weather-hardy, robotically-pointed sun and sky spectral sun photometer.

- A sensor head points the sensor head at the sun according to a preprogrammed routine.

- The Cimel controller, batteries, and the optional Vitel **satellite transmission** equipment are usually deployed in a weatherproof plastic case.





Sun measurements

Sky measurements

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AERONET Data Flows

http://aeronet.gsfc.nasa.gov

Holben et al.
RSE, 1998
Holben et al.
JGR, 2001

Eck et al.
JGR, 1999

Smirnov et al.
RSE, 2000

Dubovik and King
JGR, 2000
Dubovik et al.
JGR, 2000
GRL, 2002

Flux measurements

Direct - l=340, 380, 440, 500, 670, 870, 940, 1020 nm
Diffuse - l=440, 670, 870, 1020 nm (alm, pp, pol)

Calibration and processing information

Mauna-Loa and Izaña
CNRS-University of Lille and University of Valladolid

Aerosol optical depth and precipitable water computations

Cloud screening and quality control

Inversion products

Volume size distribution (0.05 < size <15 μm), refractive index, single scattering albedo (l=440, 670, 870, 1020 nm)

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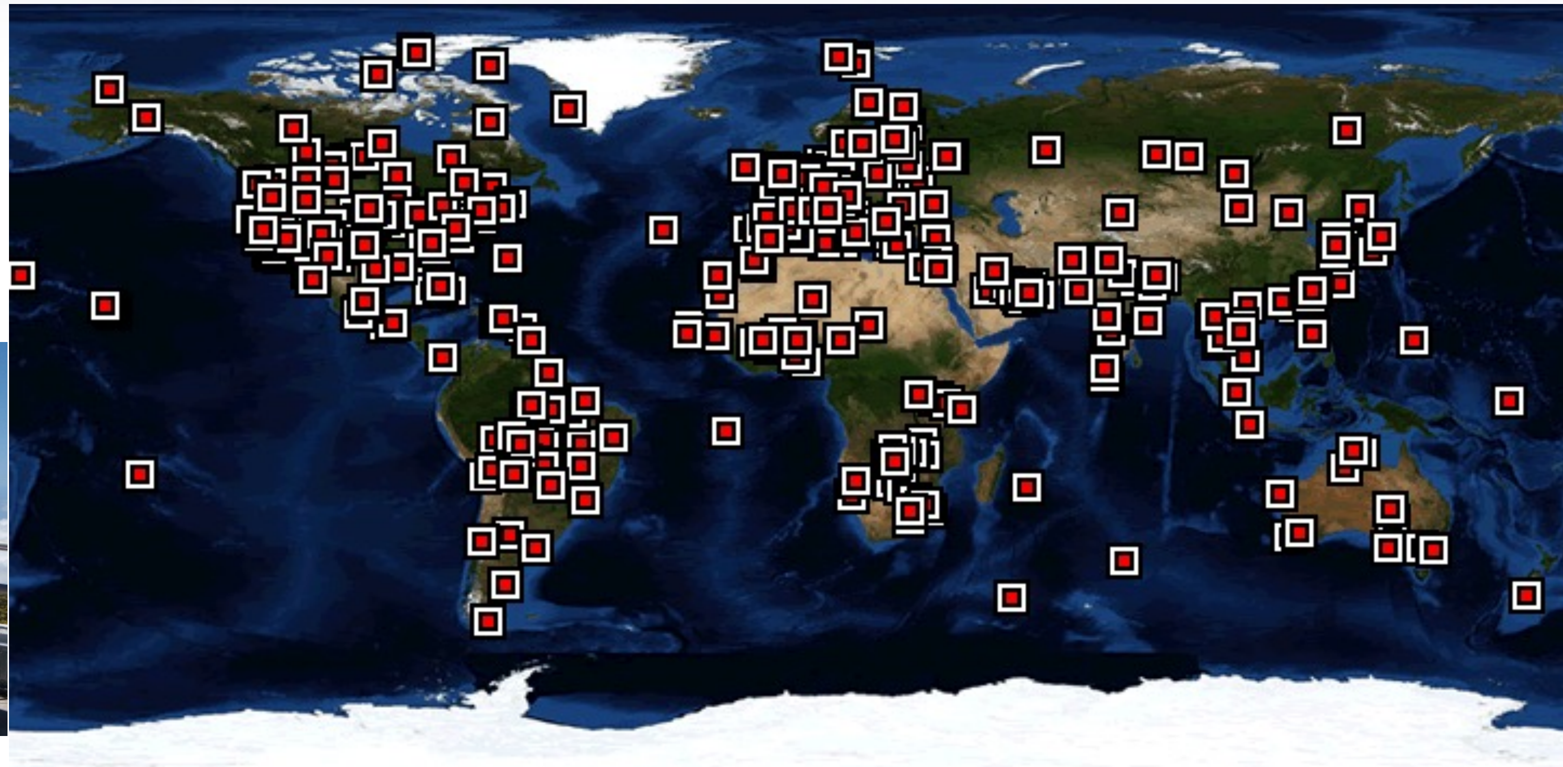
AERONET (AErosol RObotic NETwork)- http://aeronet.gsfc.nasa.gov

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE



An internationally Federated Network

- Characterization of aerosol optical properties
- Validation of satellite aerosol retrieval
- Near real-time acquisition; long term measurements

AERONET provides:

- global Aerosol Optical Depth of Dust in near real-time
- robust optical properties of Dust: size distribution, ref. Index, etc. (e.g. Asian Dust has stronger and less spectral dependent absorption than Saharan Dust)
- climatological models that reproduce observed optical properties of aerosol (useful for satellite retrievals)

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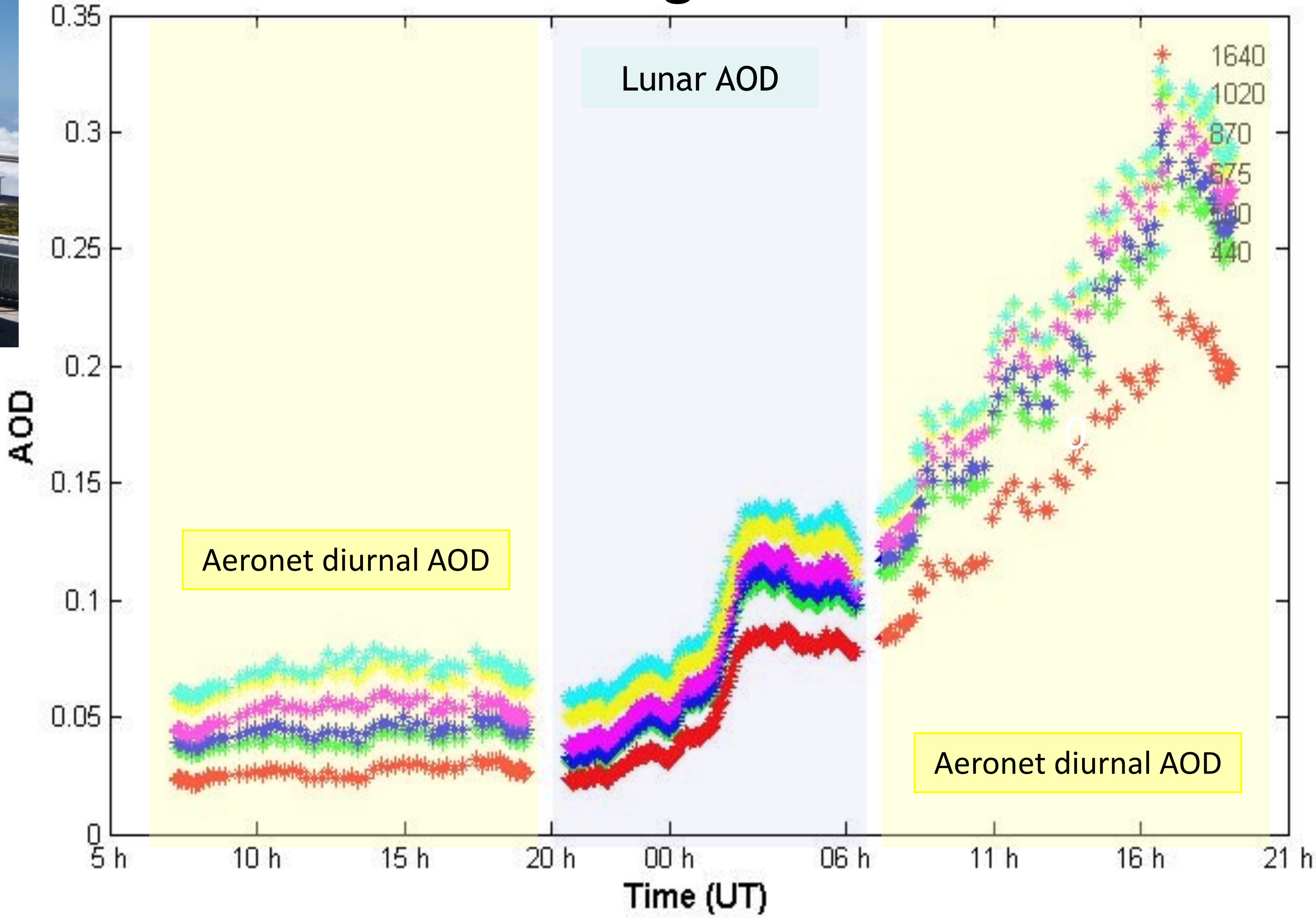
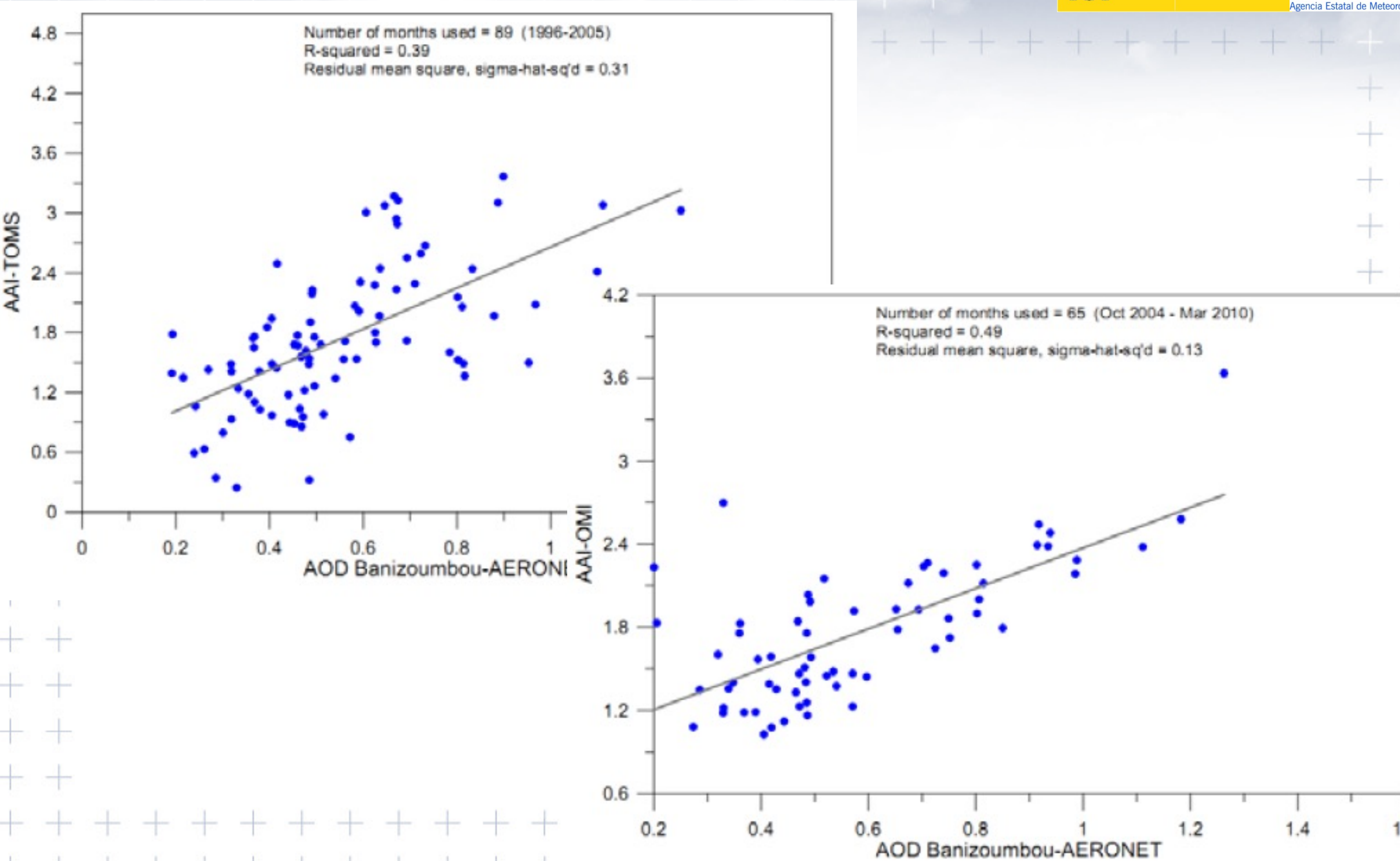
AOD 14 August 2011

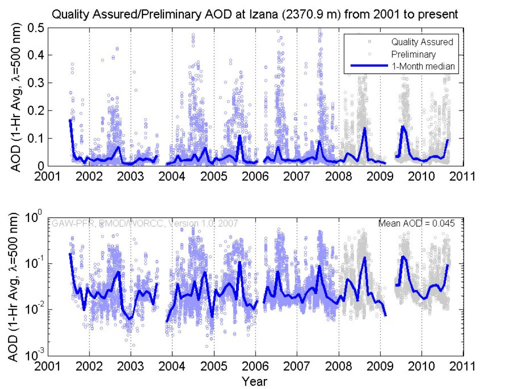


August 13

August 14


Number of months used = 89 (1996-2005)
R-squared = 0.39
Residual mean square, sigma-hat-sq'd = 0.31
AAI-TOMS
AOD Banizoumbou-AERONET
Number of months used = 65 (Oct 2004 - Mar 2010)
R-squared = 0.49
Residual mean square, sigma-hat-sq'd = 0.13
AAI-OMI
AOD Banizoumbou-AERONET

GAW-PFR AOD Network



- Classic extinction measurements at the recommended 4 WMO wavelengths 368, 415, 500 and 862 nm using Precision Filter Radiometers (PFRs).
- Continuous sampling at a 1- minute frequency by automated systems.
- Data products: AOD and the Angström coefficients alpha and beta (no inversions).
- Hourly mean AOD archived at the World Data Center for Aerosols (WDCA). Data with a 1-minute resolution are available from WORCC upon request.

GAW-PFR provides:

- long-term high-accuracy AOD and Angström Coefficients
- GAW-PFR provides AOD Dust in near real-time

Ground-based remote sensing

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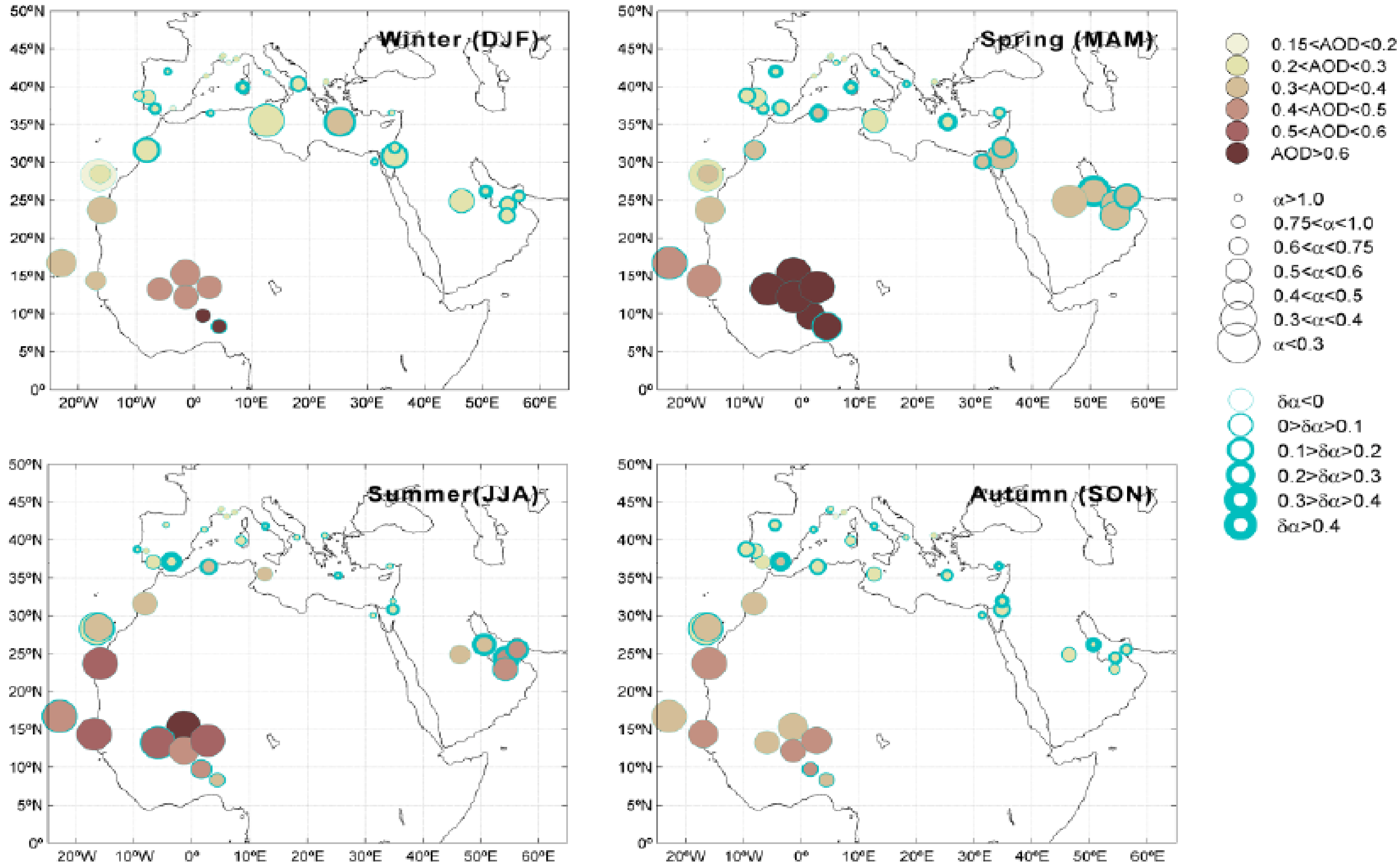
Aerosol characterization in Northern Africa, Northeastern Atlantic, Mediterranean Basin and Middle East from direct-sun AERONET observations

S.Basart, C. Pérez, E. Cuevas, J.M. Baldasano, and G.P. Gobbi

(**Atmos. Chem. Phys.** October-2009)



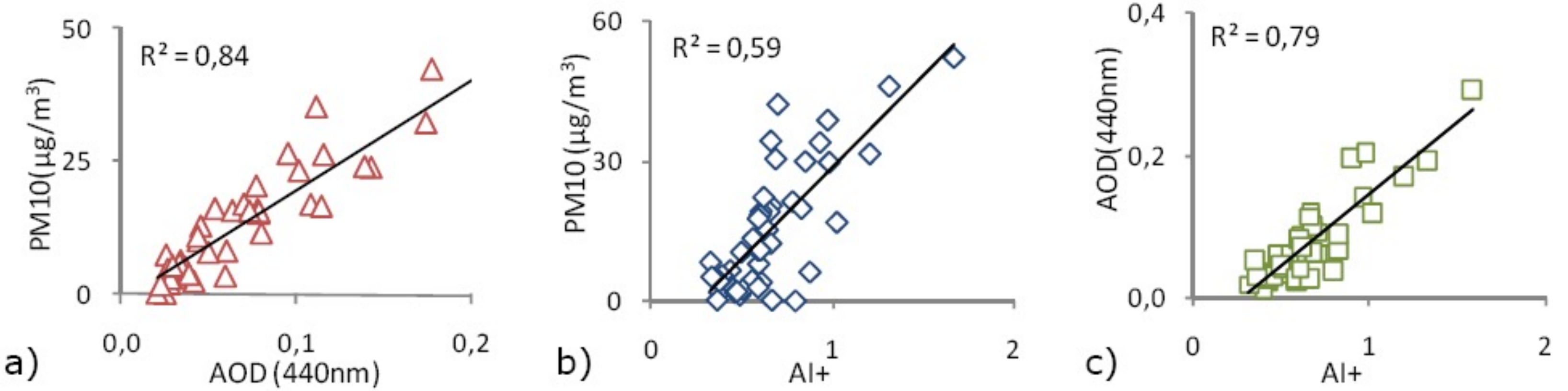


Figure 1. Scatterplot of monthly means of a) AOD vs PM_{10}; b) AI positive values vs PM_{10}; c) AI positive values vs AOD.

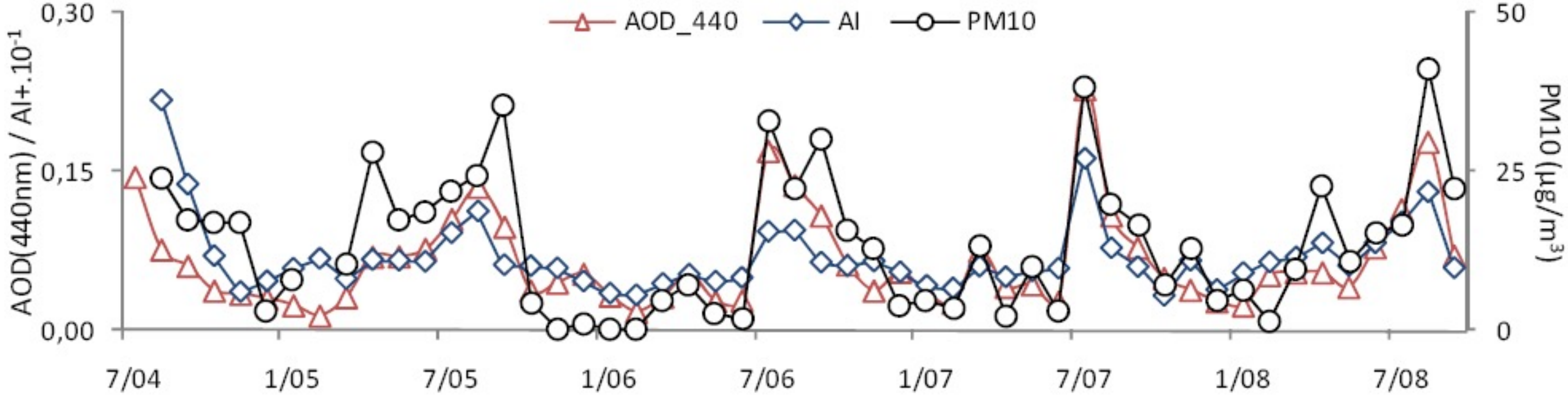
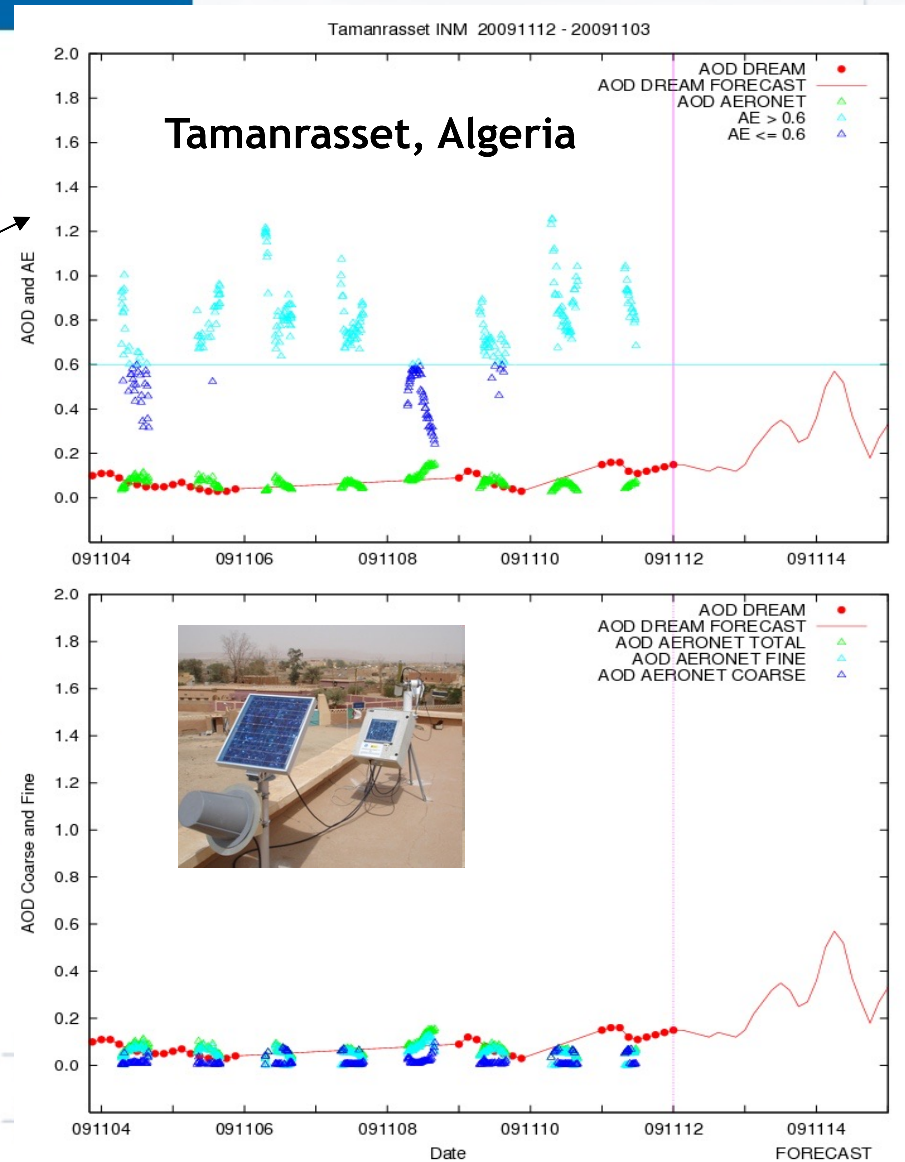


Figure 2. Monthly means of PM_{10} (µg/m³), AOD and AI positive values.

Adam et al., 2010 (ACP-Interlaken): Detection of the Saharan dust air layer in the North Atlantic free troposphere with AERONET, OMI and in-situ data at Izaña Atmospheric Observatory

Ground-based remote sensing



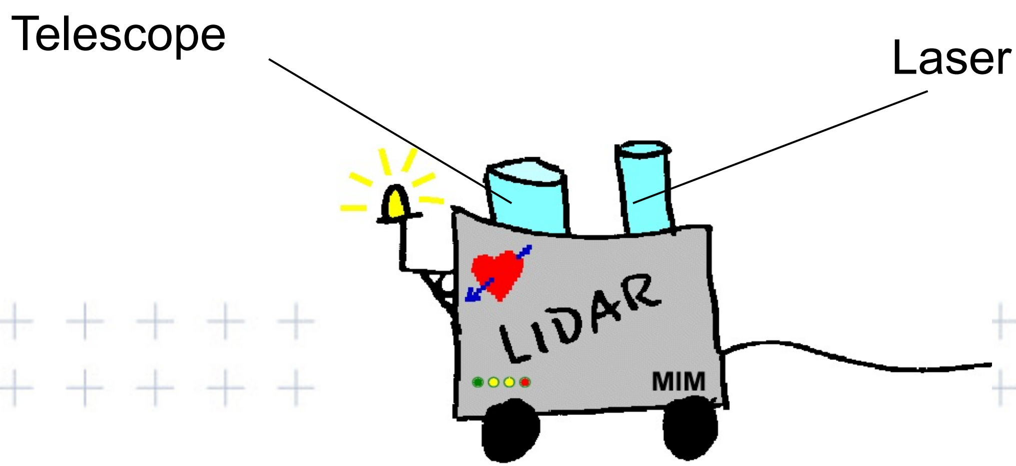
Near real time model verification against AERONET data

From total column observations…

to vertical resolved observations

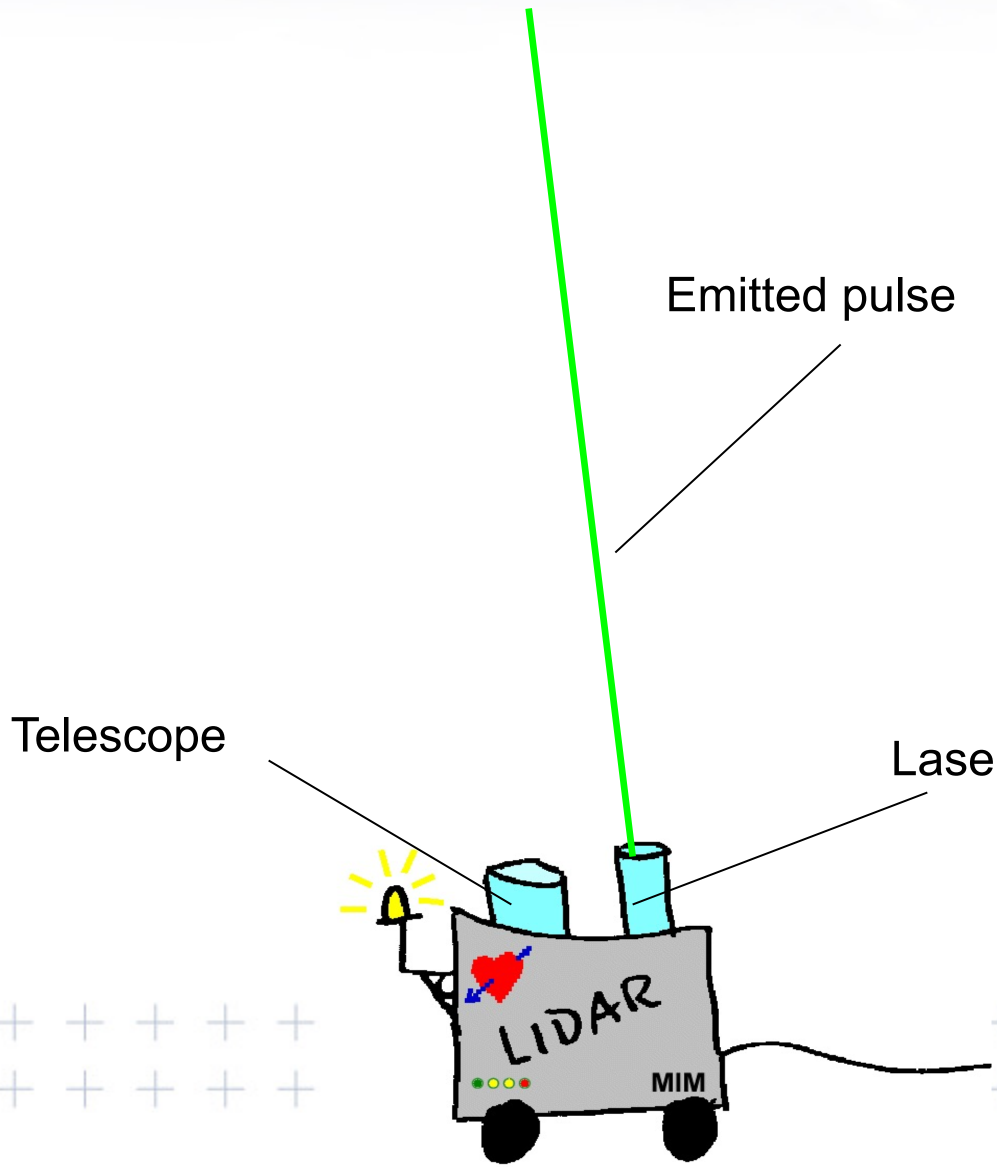
Lidars

Ground-based remote sensing

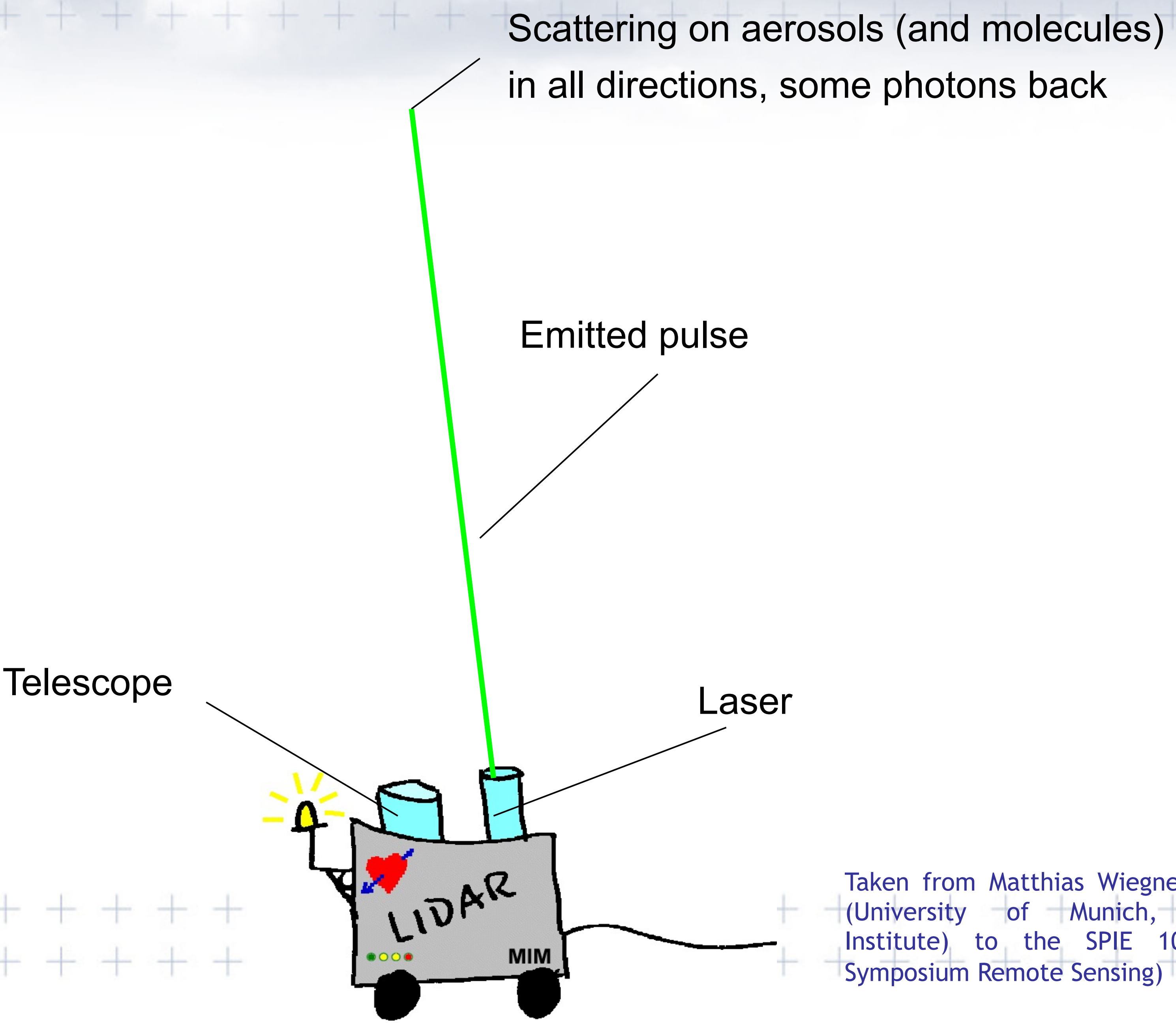


Taken from Matthias Wiegner's presentation (University of Munich, Meteorological Institute) to the SPIE 10 (International Symposium Remote Sensing)

GOBIERNO DE ESPAÑA MINISTERIO DE MEDIO AMBIENTE Y MEDIO RURAL Y MARINO AEMet Agencia Estatal de Meteorología



Taken from Matthias Wiegner's presentation (University of Munich, Meteorological Institute) to the SPIE 10 (International Symposium Remote Sensing)



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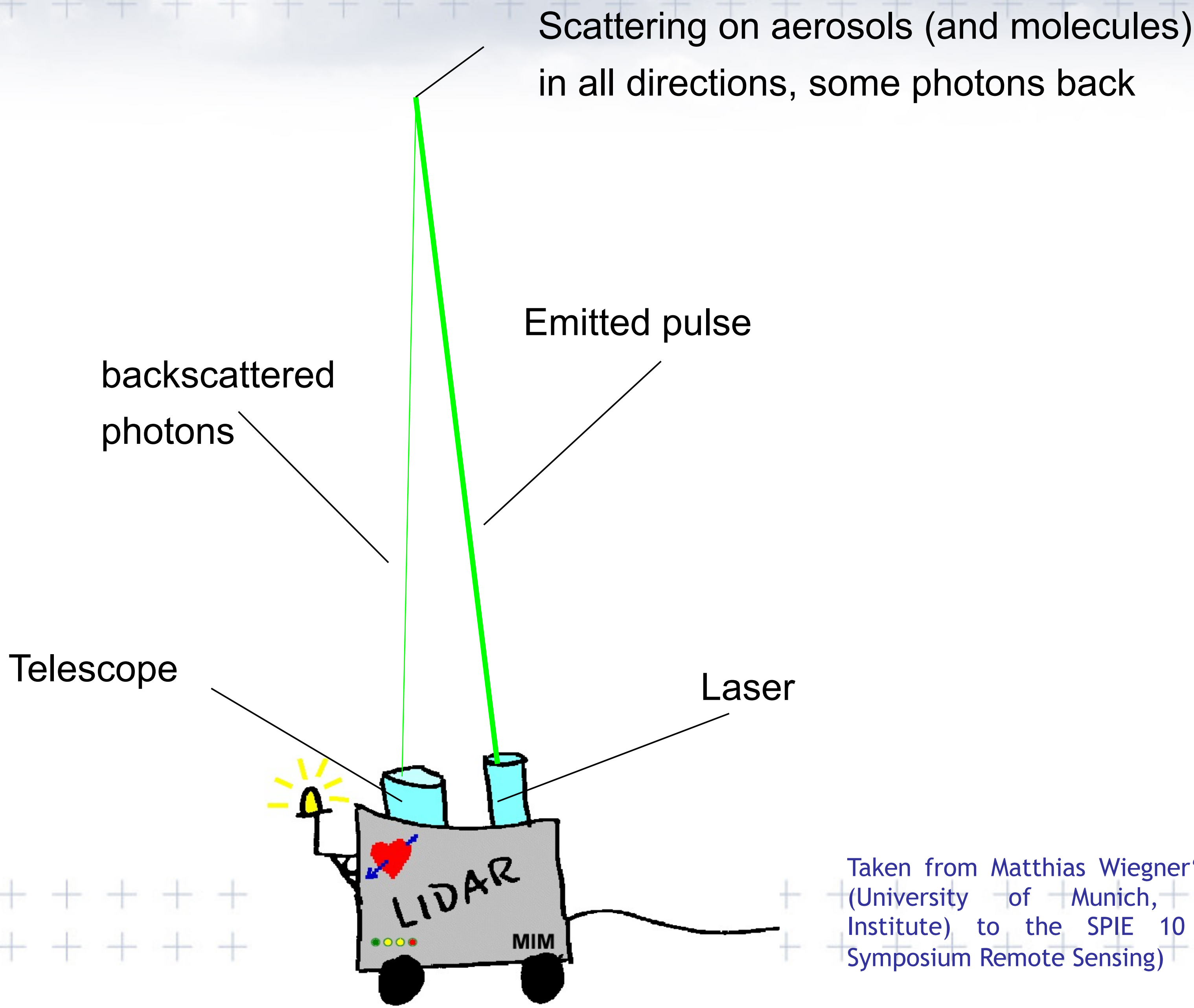
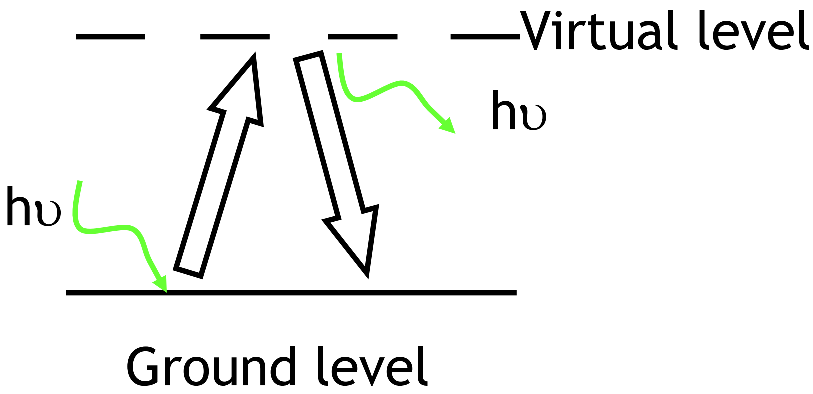


Taken from Matthias Wiegner's presentation (University of Munich, Meteorological Institute) to the SPIE 10 (International Symposium Remote Sensing)

Ground-based remote sensing

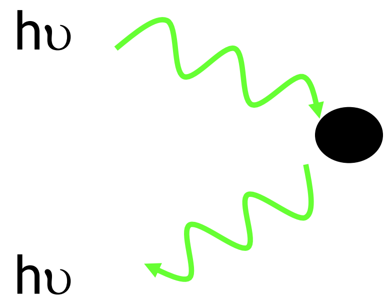
- **Rayleigh Scattering**

  "Laser radiation elastically scattered from atoms or molecules is observed with no change of frequency"



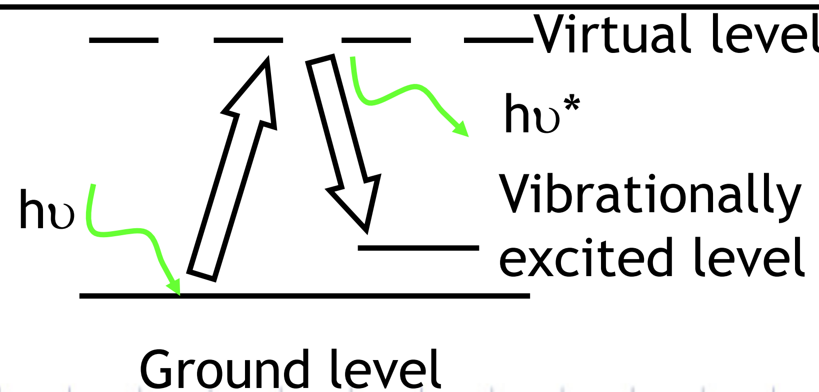
- **Mie Scattering**

  "Laser radiation elastically scattered from small particulates or aerosols (of size comparable to wavelength of radiation) is observed with no change in frequency"



- **Raman Scattering**

  "Laser radiation inelastically scattered from molecules is observed with a frequency shift characteristic of the molecule ($h\nu$ - $h\nu^*$ = E)"



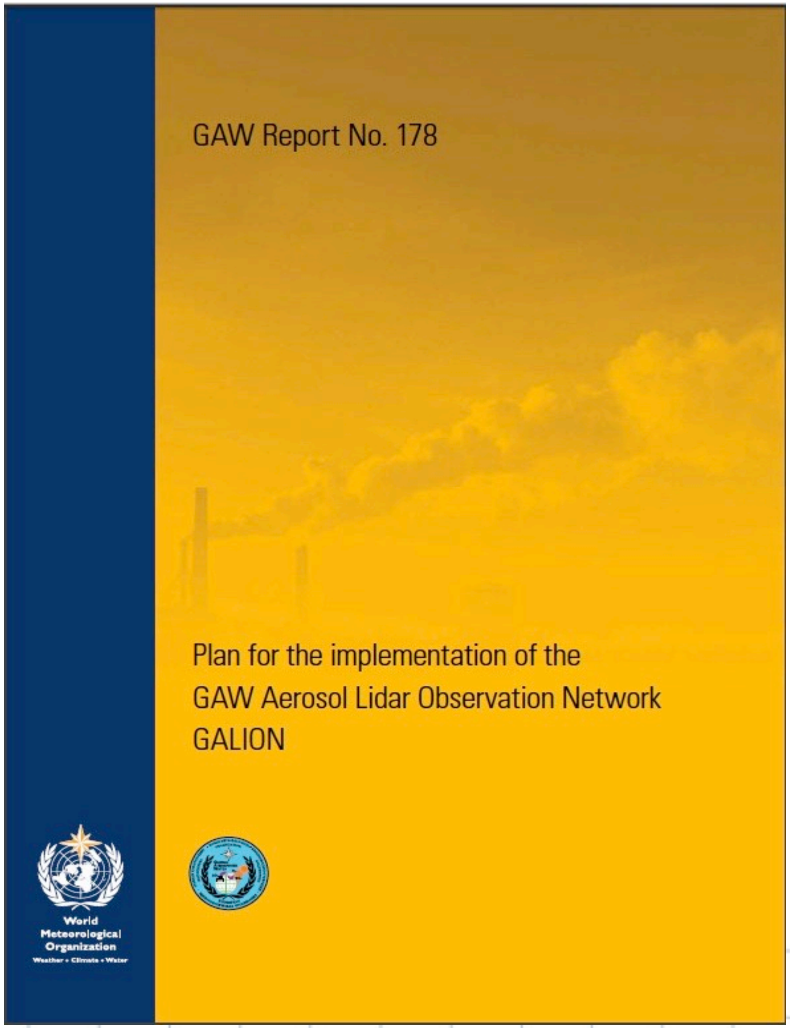
Taken from Laser Remote Sensing Fundamentals and Applications by Raymond M. Measures (pgs 206-207)

Ground-based remote sensing

Lidar-Barcelona (UPC)
Raman Lidar
EARLINET-SPALINET

Lidar-Tenerife (INTA-AEMET); Elastic lidar
MPLNET

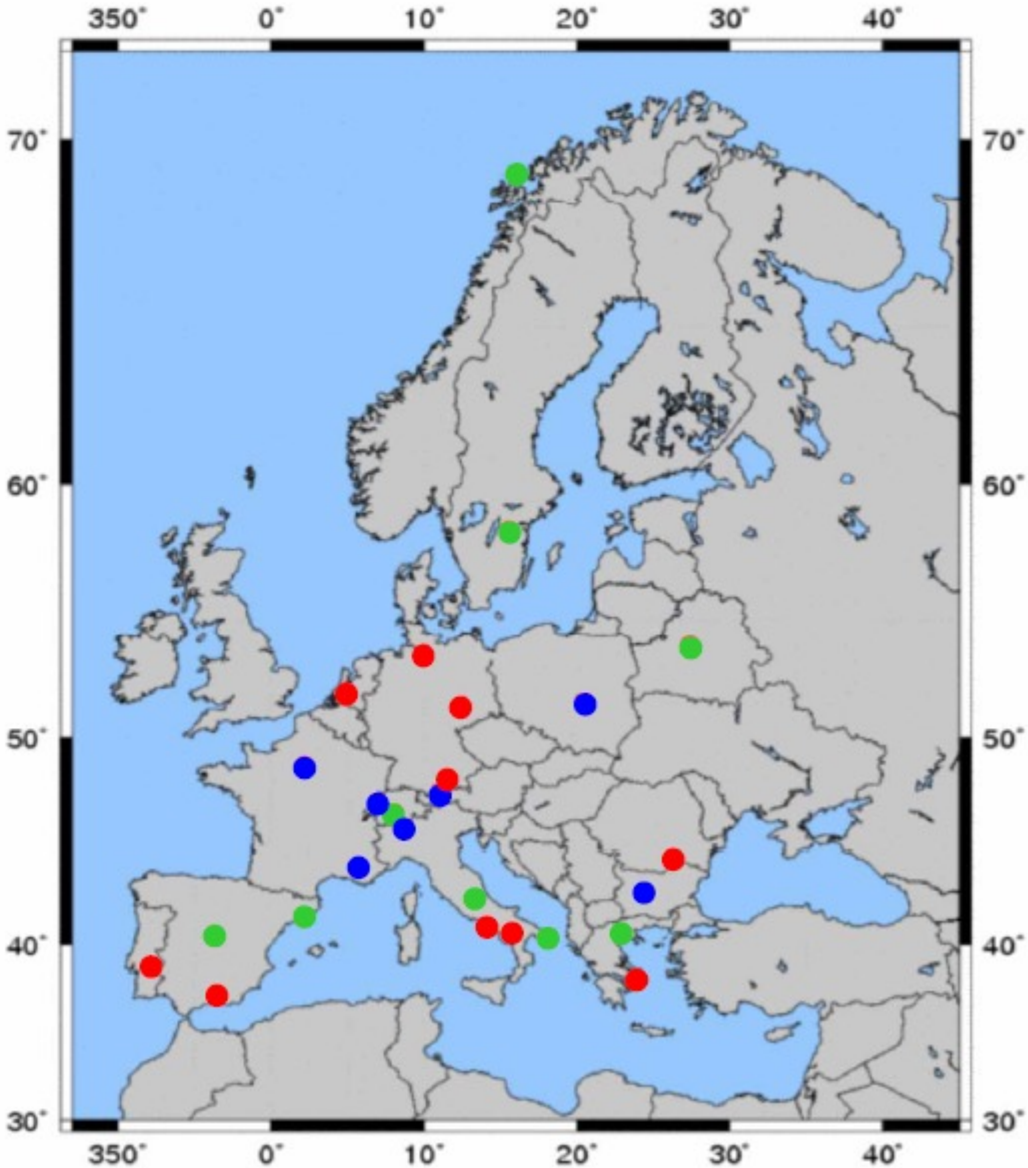
GAW Atmospheric Lidar Network (GALION)


GAW Report No. 178

Plan for the implementation of the
GAW Aerosol Lidar Observation Network
GALION

World Meteorological Organization
Weather • Climate • Water

ftp://ftp.wmo.int/Documents/PublicWeb/arep/gaw/gaw178-galion-27-Oct.pdf



EARLINET

EARLINET (**European Aerosol Research LIdar NETwork**) is a network of advanced lidar stations distributed over Europe with the main goal to provide a comprehensive, quantitative, and statistically significant data base for the aerosol distribution on a continental scale. EARLINET provides independent measurements of aerosol extinction and backscatter, and retrieval of aerosol microphysical properties.

10 EARLINET stations are equipped also with sunphotometers (they are part of AERONET).

26 lidar stations

- 10 multiwavelength Raman lidar stations

backscatter (355, 532 and 1064 nm) + extinction (355 and 532 nm) + depol ratio (532 nm)

- 9 Raman lidar stations

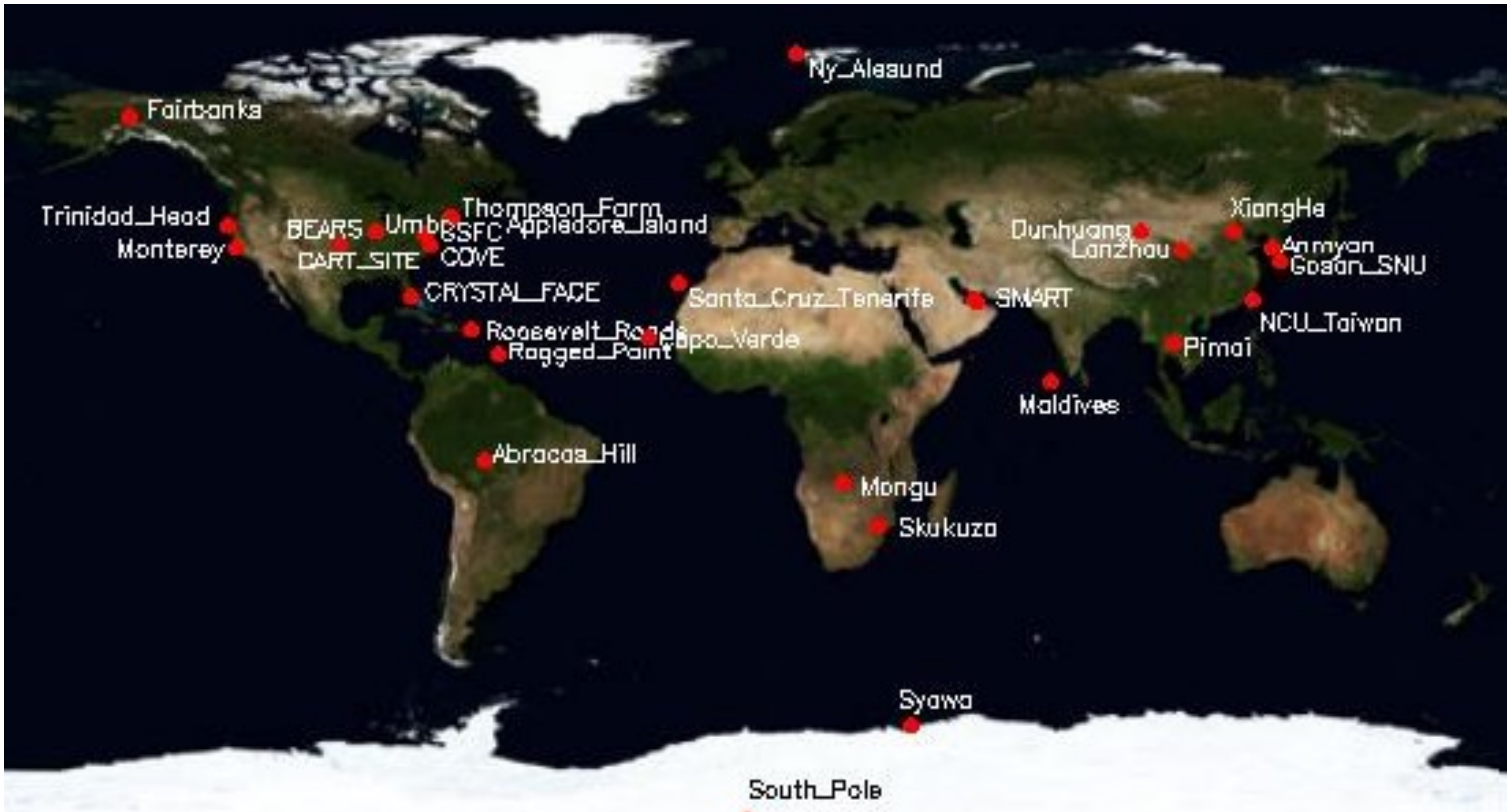
- 7 single backscatter lidar stations

Ground-based remote sensing

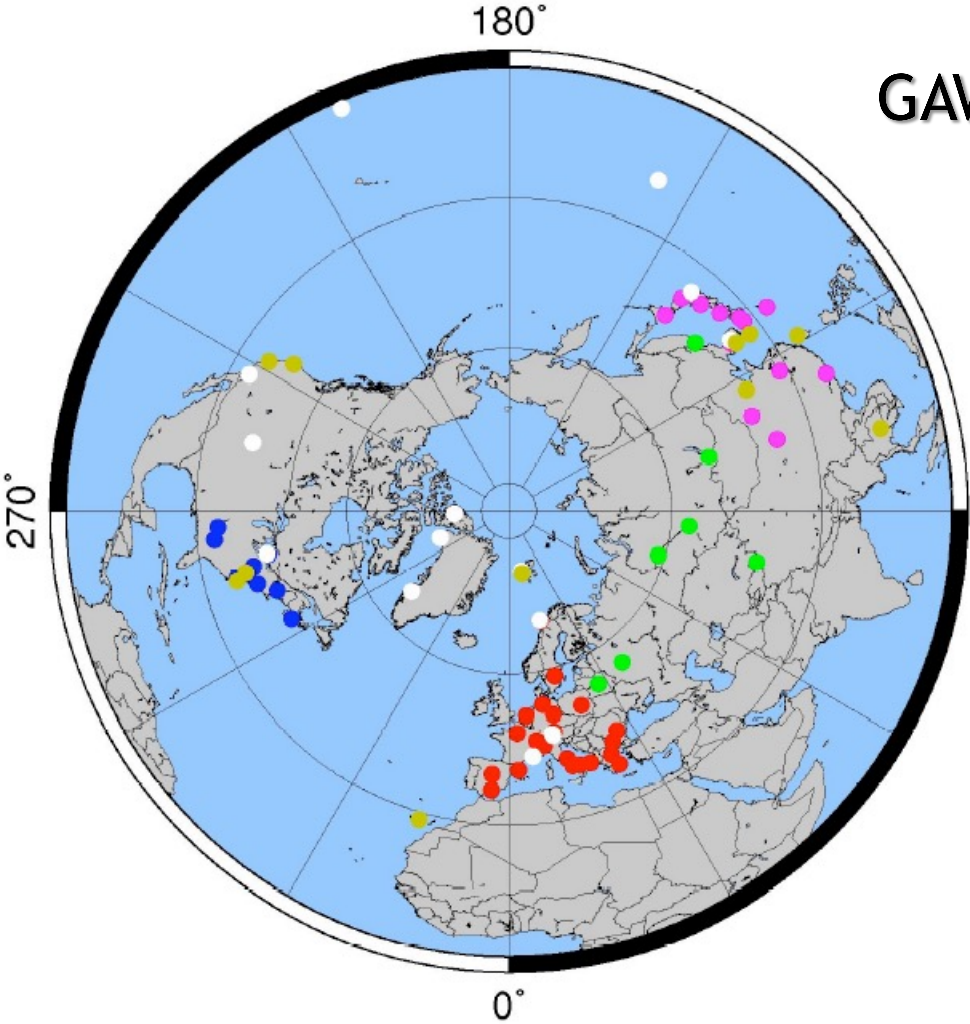
Aerosol lidar (MPLNet)

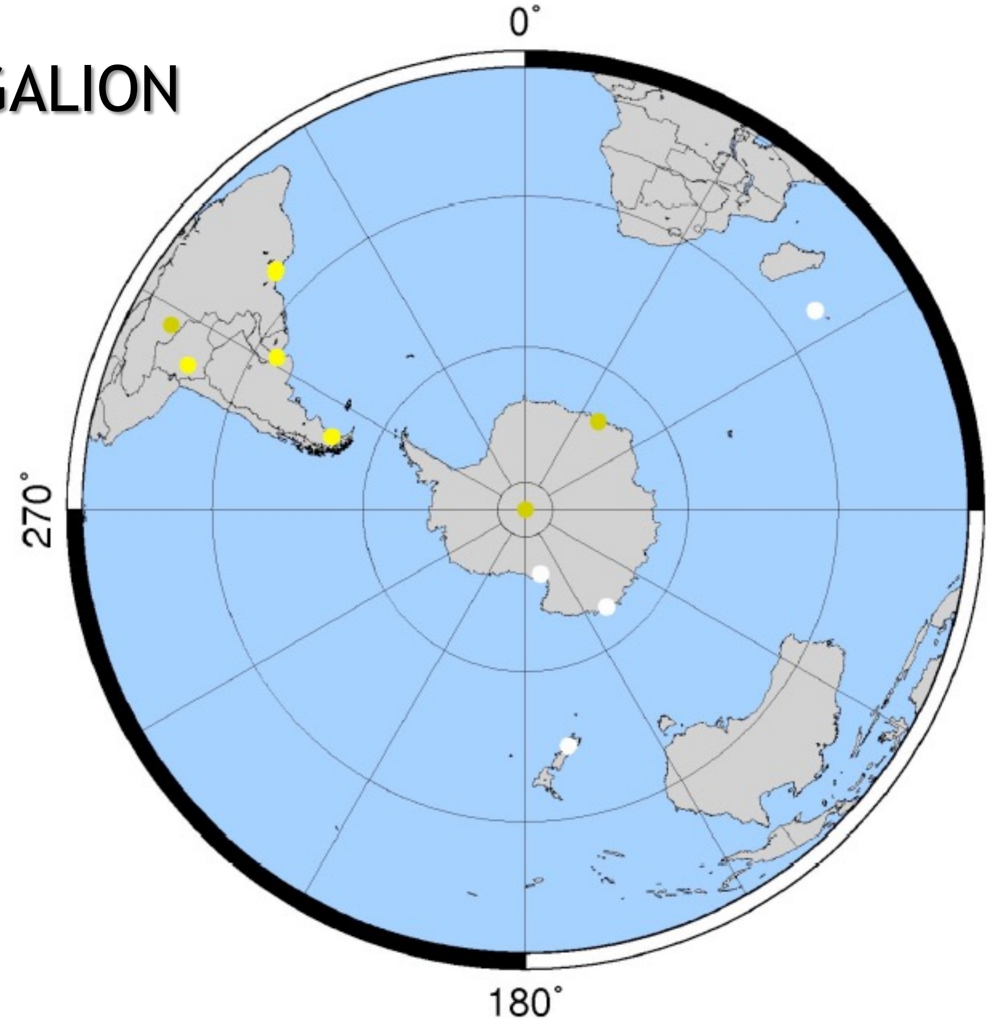
http://mplnet.gsfc.nasa.gov/

523 nm MPLNET
Automatized since July 2005



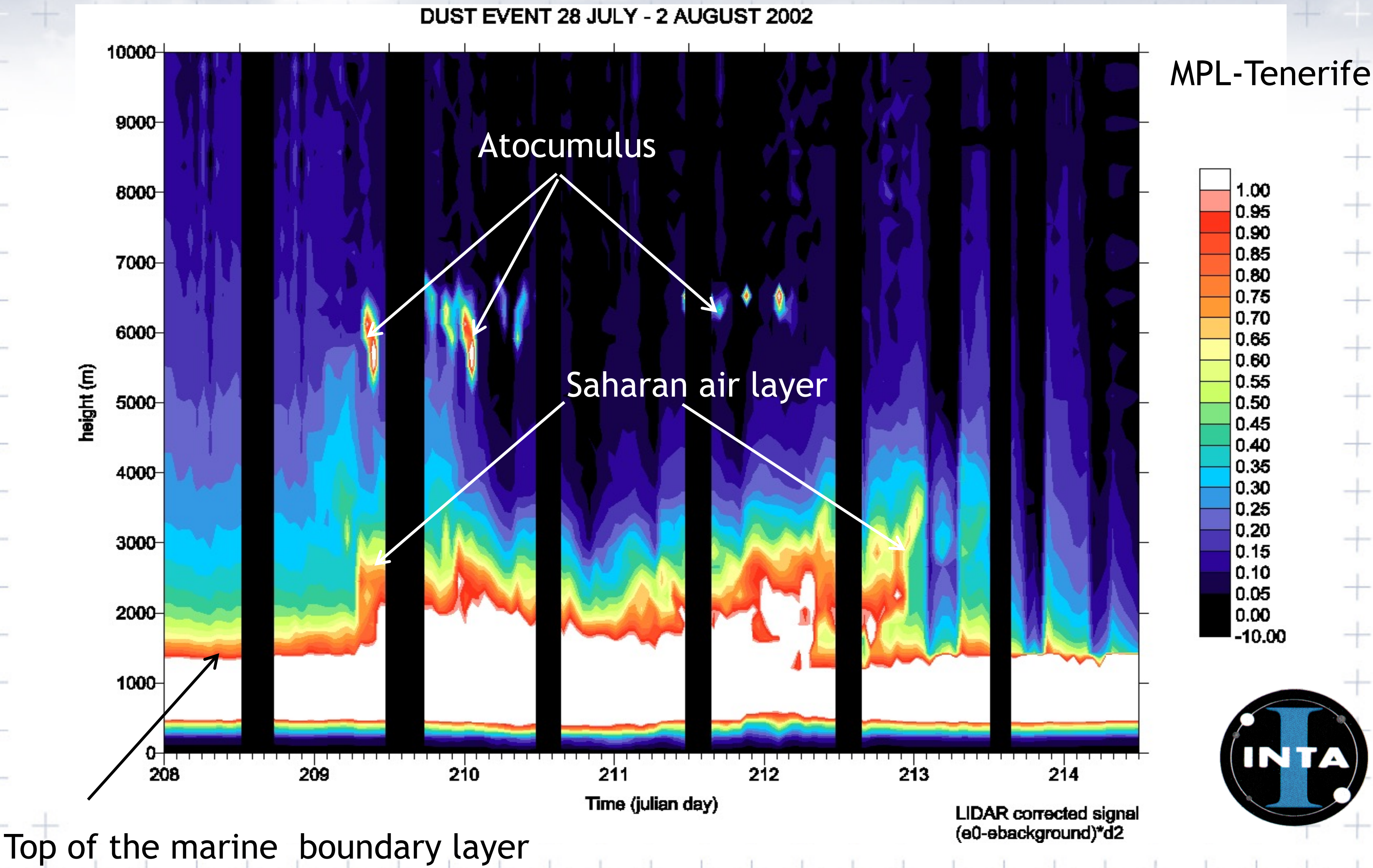
GAW-GALION





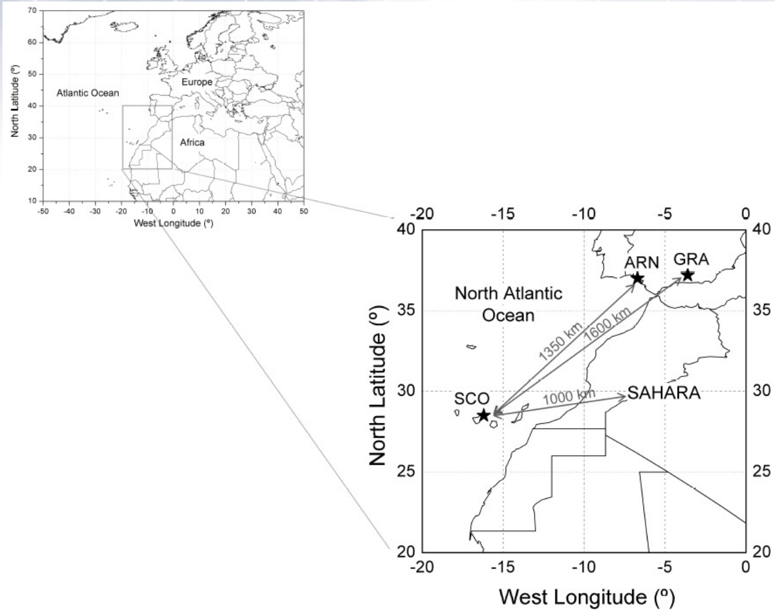
Distribution of stations as available through the cooperation between existing networks: AD-NET , ALINE , CISLiNet , EARLINET , MPLNET , NDACC , REALM .

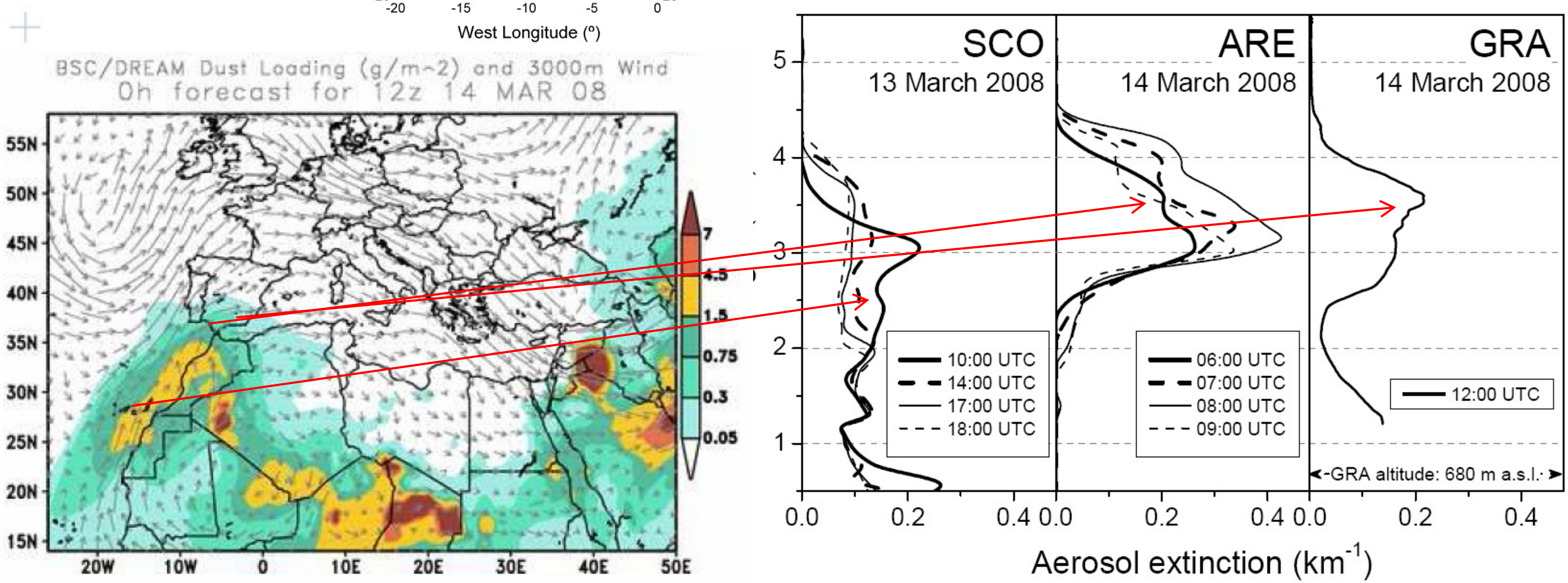
Ground-based remote sensing



A case study of dust transport from Canary Islands to Iberian Peninsula

Córdoba-Jabonero et al., ACP Discuss., 2010





Ground-based remote sensing

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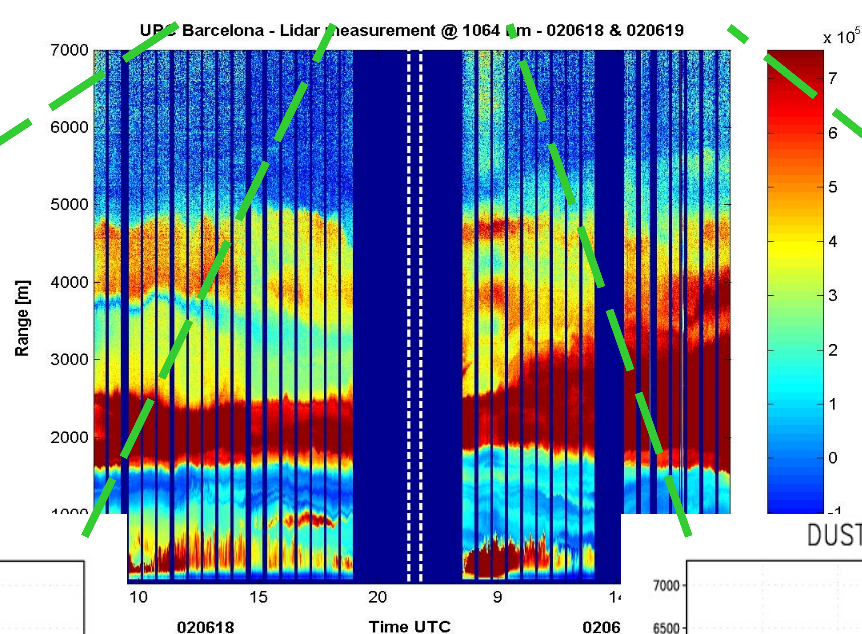
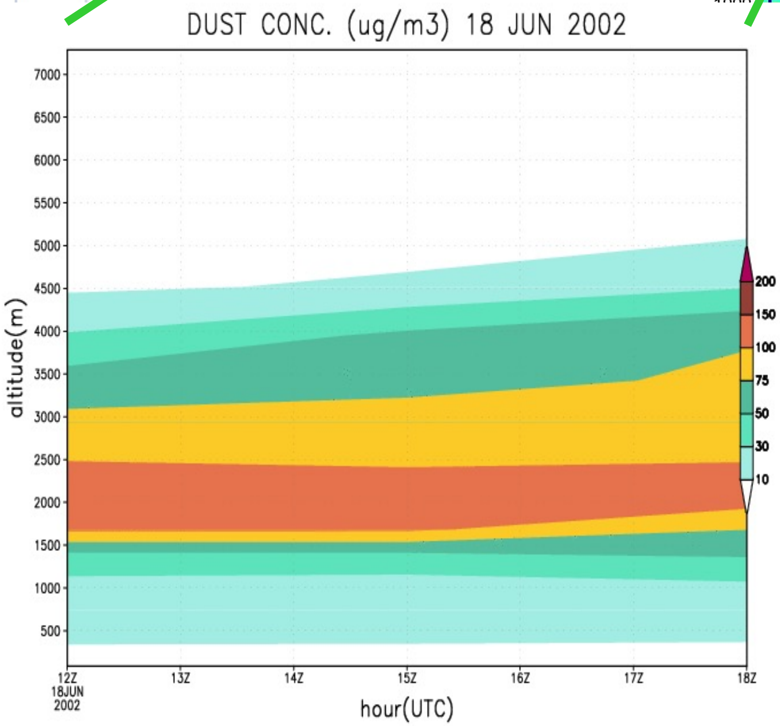
Barcelona lidar vs DREAM BSC



EARLINET: Lidar-UPC, Barcelona

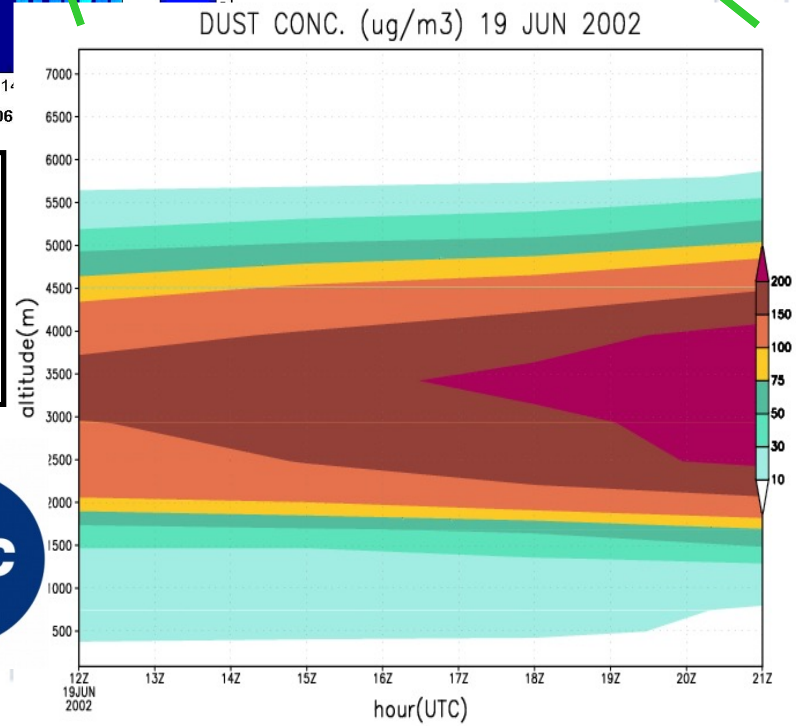
18-19 June 2002



Vertical dust distribution validation: AIRLINET-DREAM

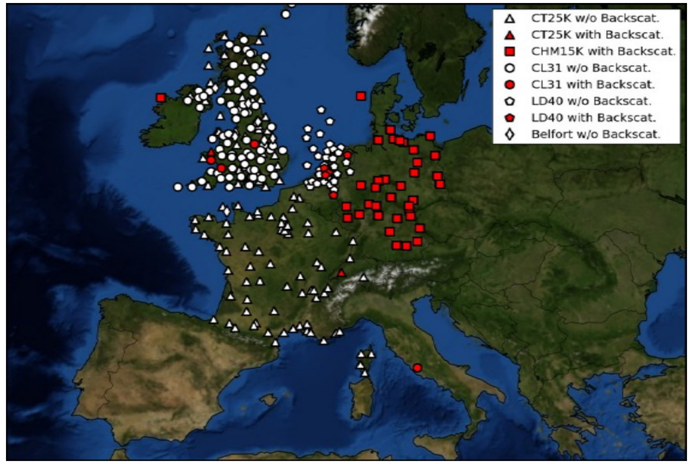
UPC

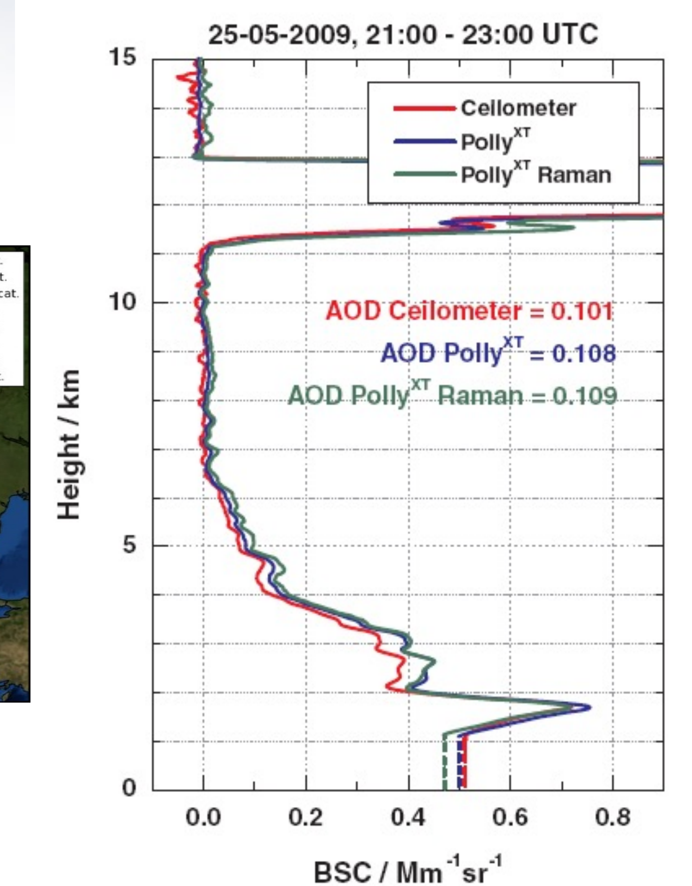
BSC



Ceilometer network

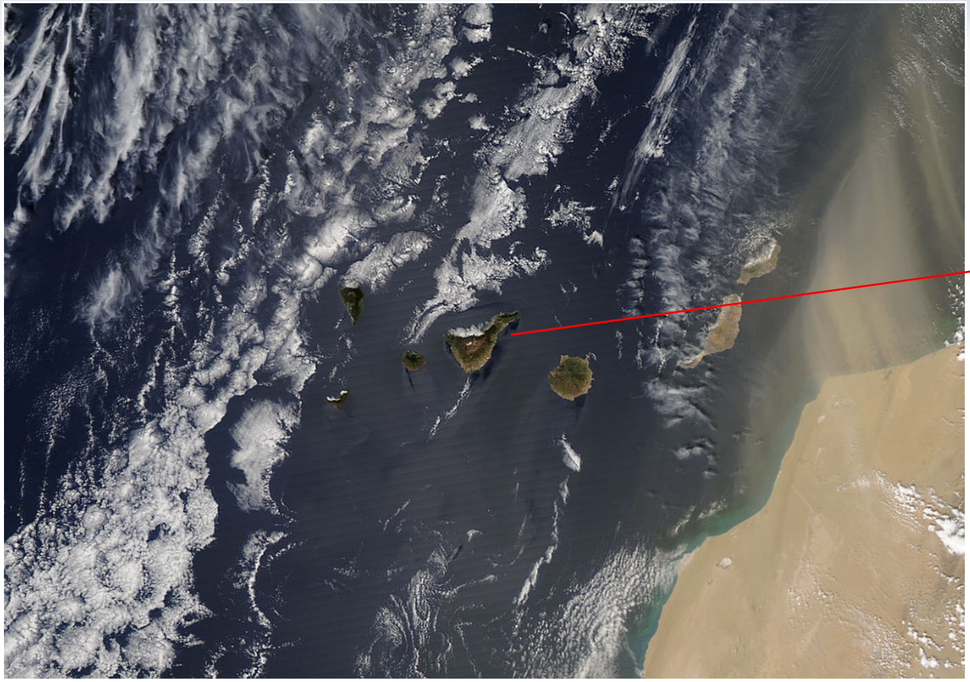
Met Services are replacing **cloud-base** ceilometer networks by **aerosol backscatter profiling ceilometers** (**IR wavelenght**).
Objective: To monitor MLD (Mixing Layer Depth) based on **several hundred profiling ceilometers (100km sampling)**





Heese et al., Atmos. Mes. Tech. 2010, Ceilometer-lidar inter-comparison: backscatter coefficient retrieval and signal-to-noise ratio determination

Optimal for desertic areas !!



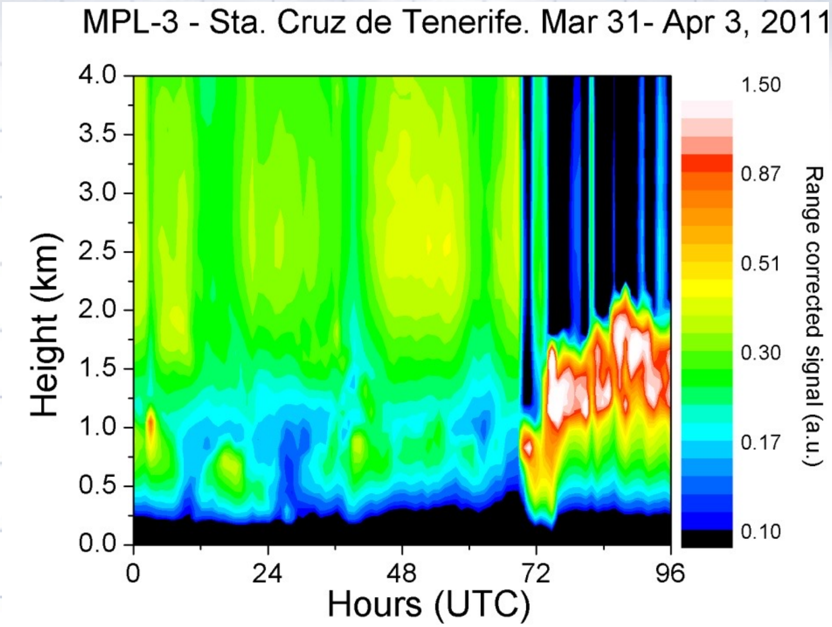
Viasala Ceilometer CL-51

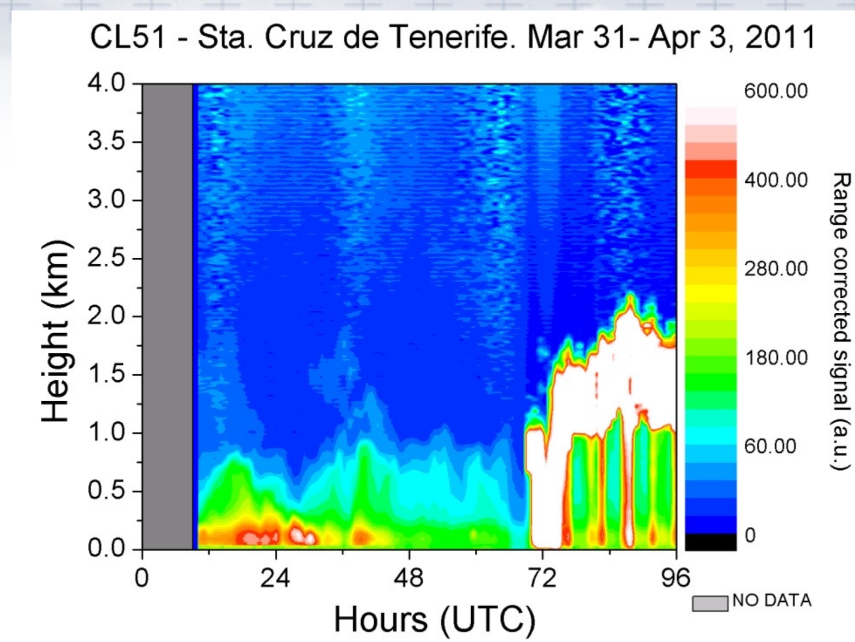
MicroPulse Lidar and Ceilometer inter-comparison during Saharan dust intrusions over the Canary Islands

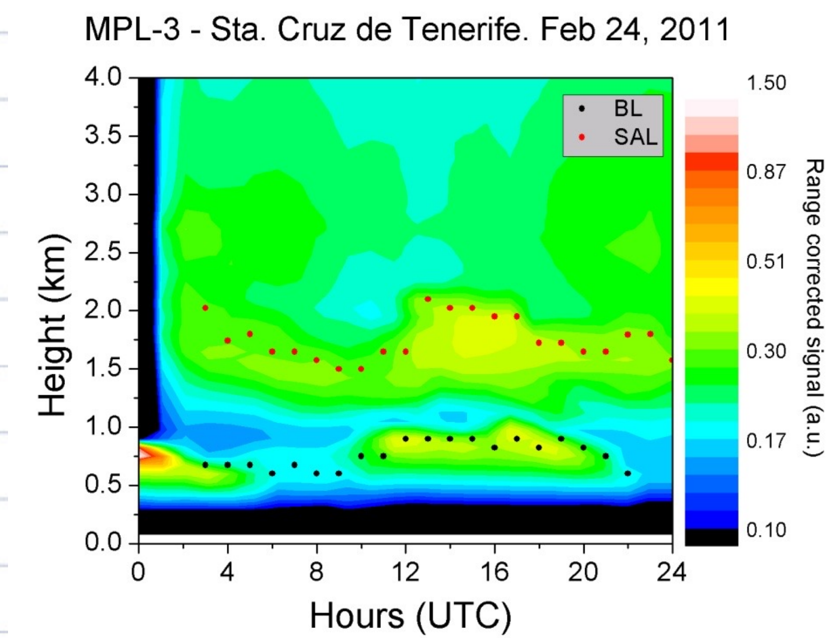
Y. Hernández, S. Alonso-Pérez, E. Cuevas, C. Camino, R. Ramos, J. de Bustos, C. Marrero, C. Córdoba-Jabonero and M. Gil (2011)

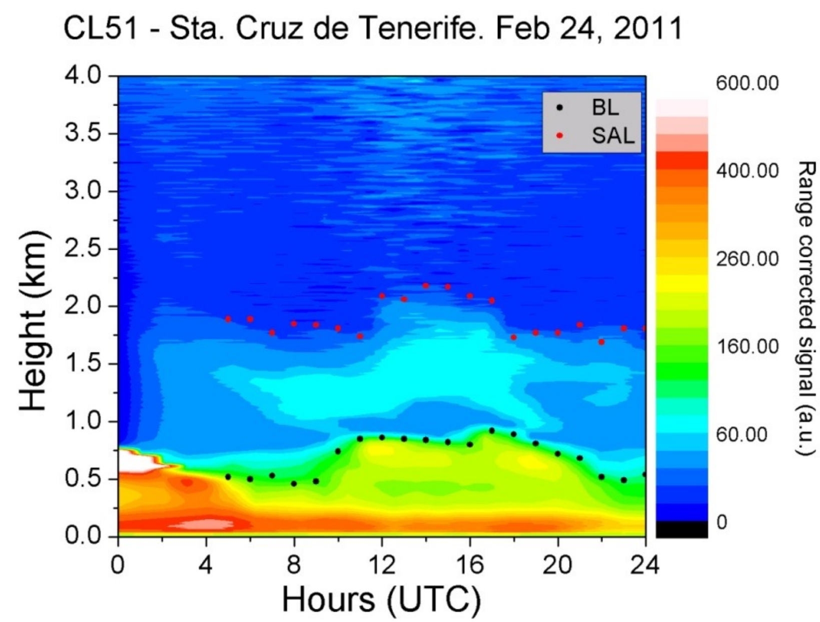
Campaign performed from January to March 2011 in Tenerife island

Ground-based remote sensing









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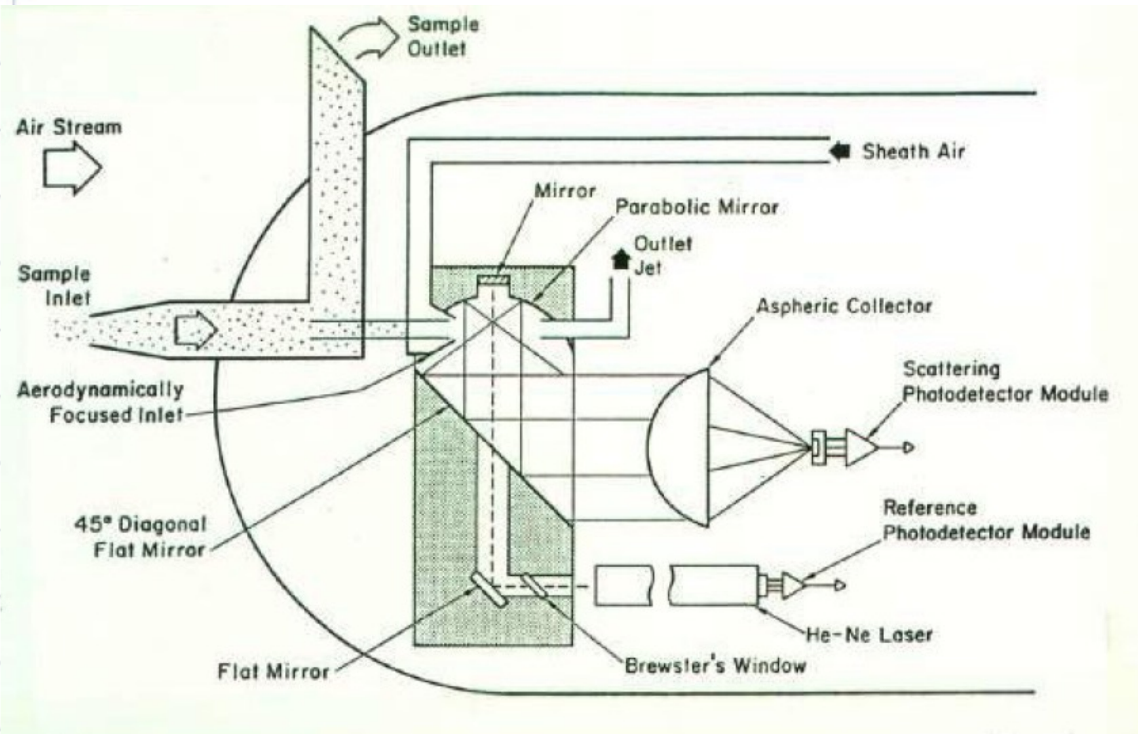
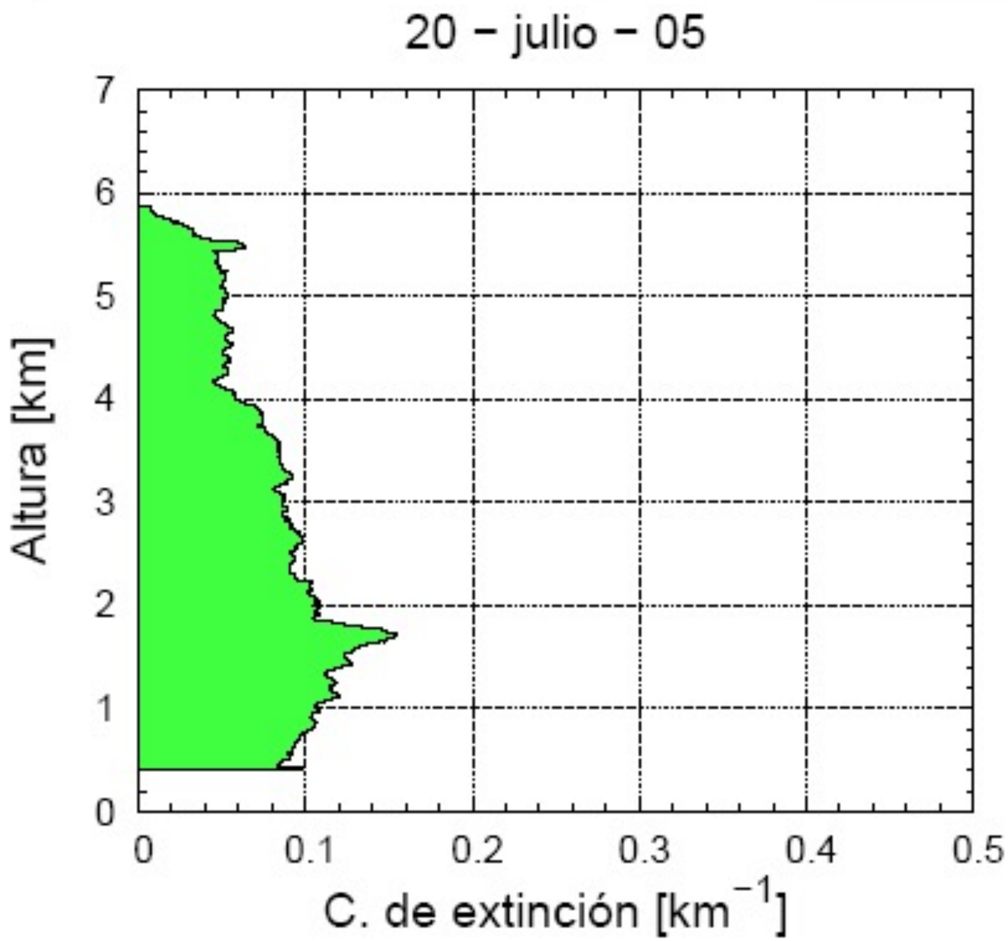
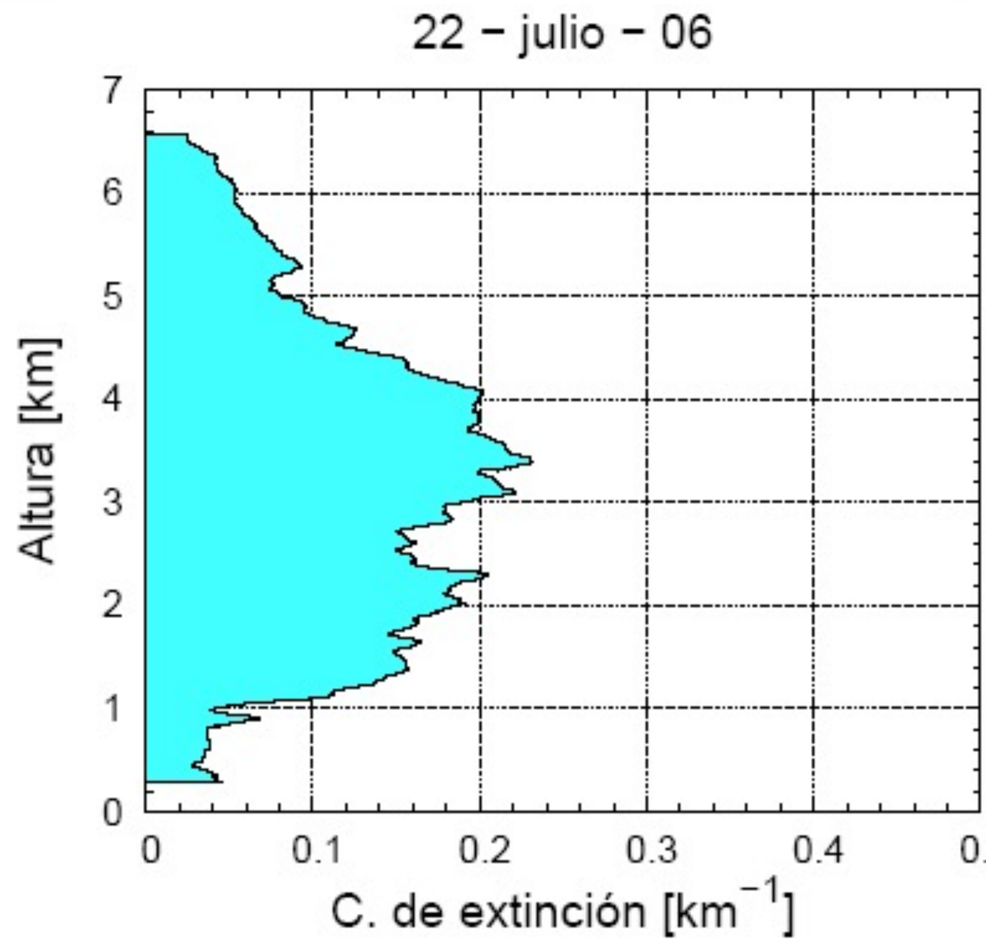


PCASP-100X sonde

Optical counter
0.1 - 3.0 um en 15 channels
Up to 20,000 particles /s
A size distribution /s

Airborne in-situ measurements





Andrey, 2011 (PhD)

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In-situ measurements and surface remote sensing compared to satellite

	Advantages	Disadvantages
In-situ measurements		
Ground-based remote sensing		
Satellite remote sensing		

Summary

In-situ measurements and surface remote sensing compared to satellite

	Advantages	Disadvantages
In-situ measurements	- very straightforward; - unique dust physical and chemical information; - universal applicability (no sky conditions dependent) - Time high resolution (minutes)	- intrusive measurements; - local coverage in some sites
Ground-based remote sensing	- high information on dust (transmitted light dominates over reflected); - non-intrusive measurements; - easy access to equipment; - column dust information	- local coverage; - indirect measurements; - very limited capability in presence of clouds (Photom.)
Satellite remote sensing	- global coverage; (global dust) - non-intrusive measurements	- limited on information aerosol (aerosol and surface effects to be separated); - no access to equipment

Summary

Ground-based dust observations are essential for:

- High-accuracy optical and chemical characterization of dust
- Dust model verification, validation and assimilation
- Dust satellite-based products validation

Ground based 'supersites' equipped with complete high-quality dust observation programs (in-situ and remote sensing) constitute unique platforms for satellite-based dust observations and dust models quality assurance

In-situ observations & long term monitoring:

mass concentration:

bulk aerosol mass (TSP, PM_{10}, $PM_{2.5}$)

bulk dust mass (total dust, $dust_{10}$, $dust_{2.5}$): 1 or more tracers methods

chemical composition

bulk aerosol = dust, pollutants ($SO_4^{=}$, NO_3^-, NH_4^+), sea-salt + trace metals, OC, EC

number size distribution

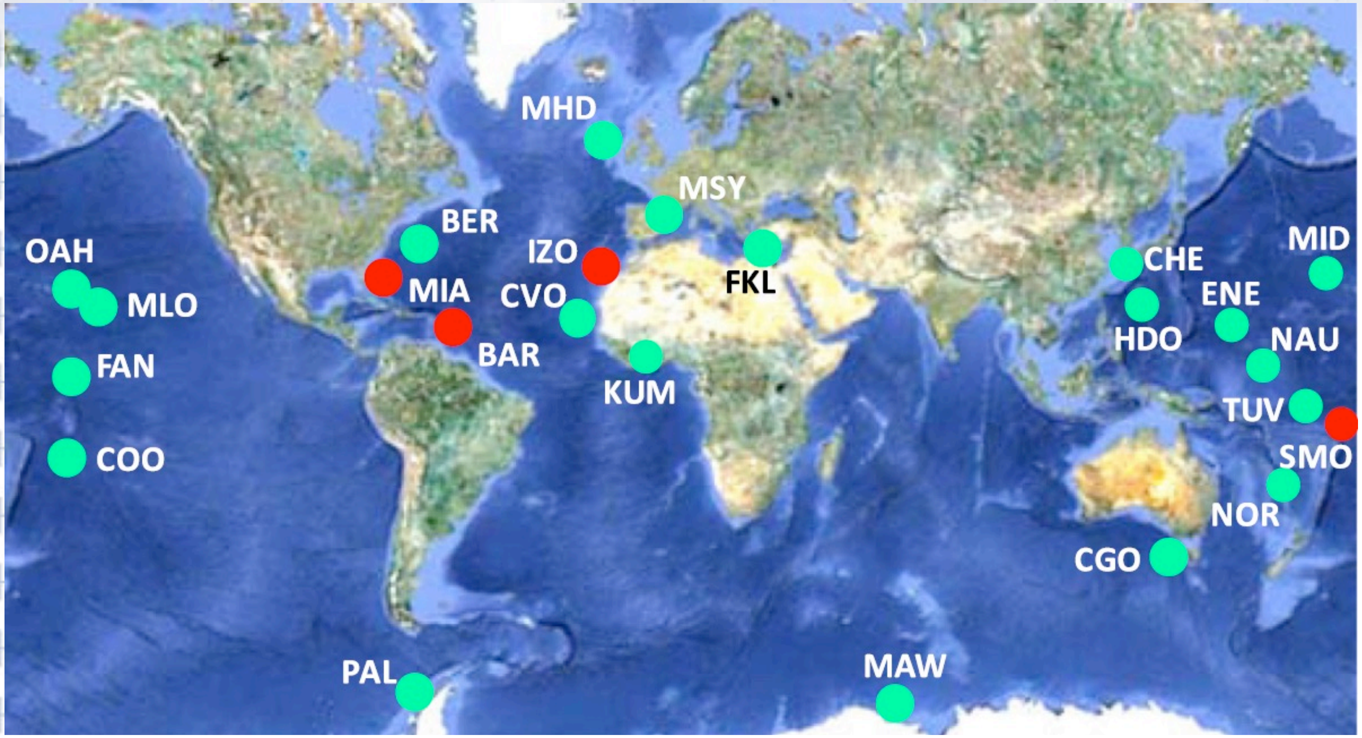
10nm - 500nm + 0.5 - 20 µm (no distinction between dust and other aerosols)

optical properties

scattering and absorption coefficients

complementary measurements: mixing state, mineralogy, isotopic characterization, etc...

Long term monitoring dust background-observatories:



at least 4 years

Active during the last 20 years

Review Article

Aeolian Research Aeolian Research 6 (2012) 55–74

A review of methods for long term in situ characterization of aerosol dust

Sergio Rodríguez [a,*], Andrés Alastuey [b], Xavier Querol [b]

II Lectures on Atmospheric Mineral Dust
5-9 November 2012, Barcelona - Spain

World Meteorological Organization

ground observations of mineral dust

Sergio Rodríguez [srodriguezg@aemet.es]

www.izana.org

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