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AEMet Agencia Estatal de Meteorología

WMO

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inDust

BSC Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Dust Ground Observation

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AEMET

9th December 2019

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Brief introduction about aerosols and dust
(to better understand why and how)

Ground based observations

- In-situ dust estimations (Visibility)
- In-situ dust measurements
- Ground base remote sensing of dust
- Summary

Aerosols exist in the atmosphere as a natural origin

Without aerosols there would no be clouds!

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Aerosol

"Solid and liquid matter suspended in a gas"

exemple: spray (l+g), dust (s+g), smoke (s+g), vapor (l+g)

Atmospheric aerosol

"Solid and liquid matter suspended in the atmosphere"

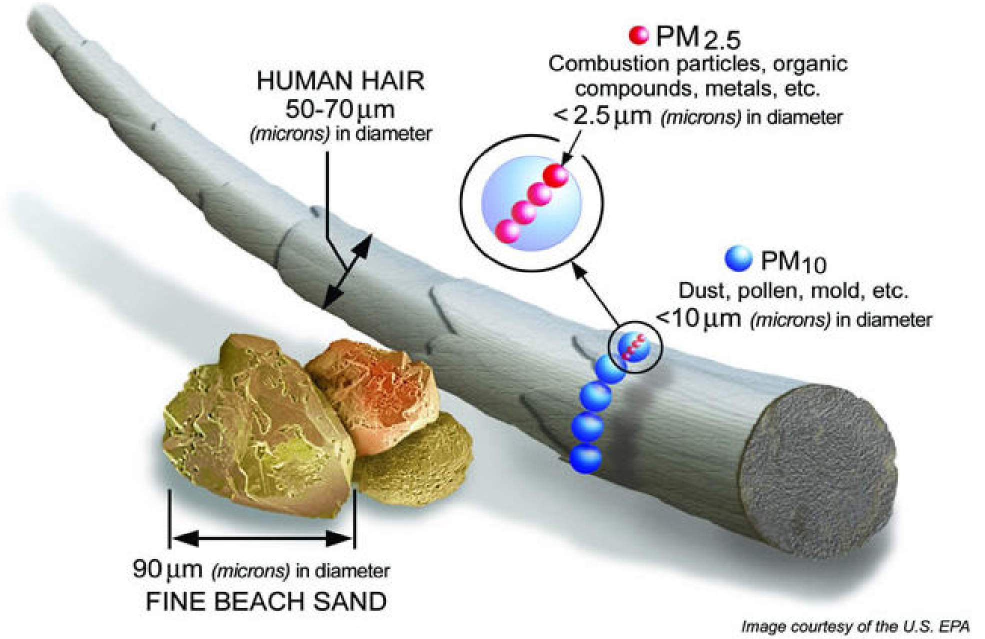
exemple: atmosphere (g+l+s), cloud (l+g),….

Size: 1nm - 100µm (10^{-9} - 10^{-4} m)

< 1nm: ➔ Å

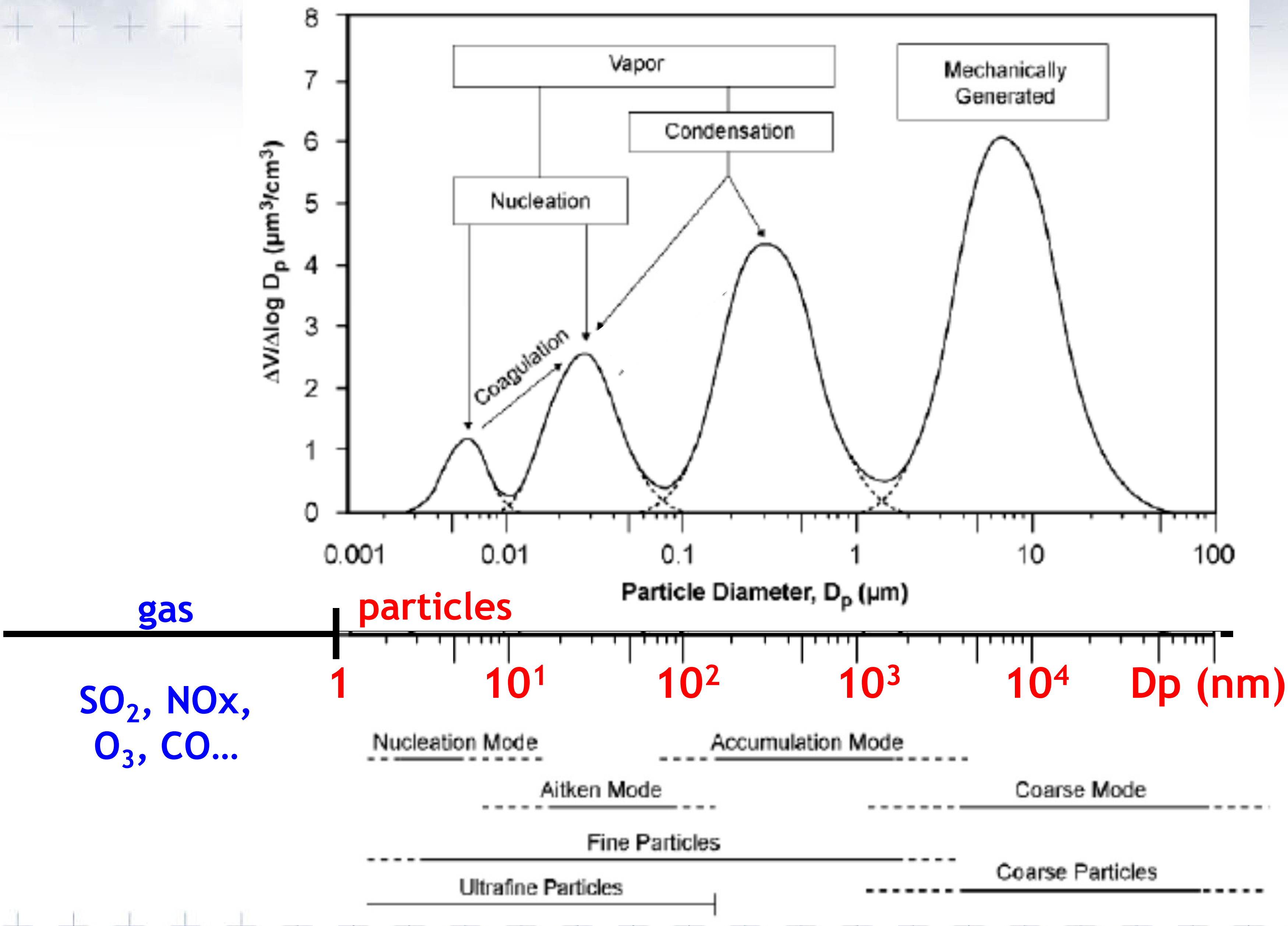
> 100µm: ➔ does not remain in suspension

In terms of Air Quality:→ Particulate Matter PM



PM10 mass concentration (µg/m3) of all aerosols smaller than 10 µm (particles with Ø < 10 µm)

PM2.5 mass concentration (µg/m3) of all aerosols smaller than 2,5 µm (particles with Ø < 2,5 µm)


Vapor
Mechanically Generated
Condensation
Nucleation
Coagulation
ΔV/Δlog D_p (μm³/cm³)
0.001
0.01
0.1
1
10
100
Particle Diameter, D_p (μm)
gas
particles
1
10^1
10^2
10^3
10^4
Dp (nm)
SO_2, NOx, O_3, CO…
Nucleation Mode
Accumulation Mode
Aitken Mode
Coarse Mode
Fine Particles
Coarse Particles
Ultrafine Particles

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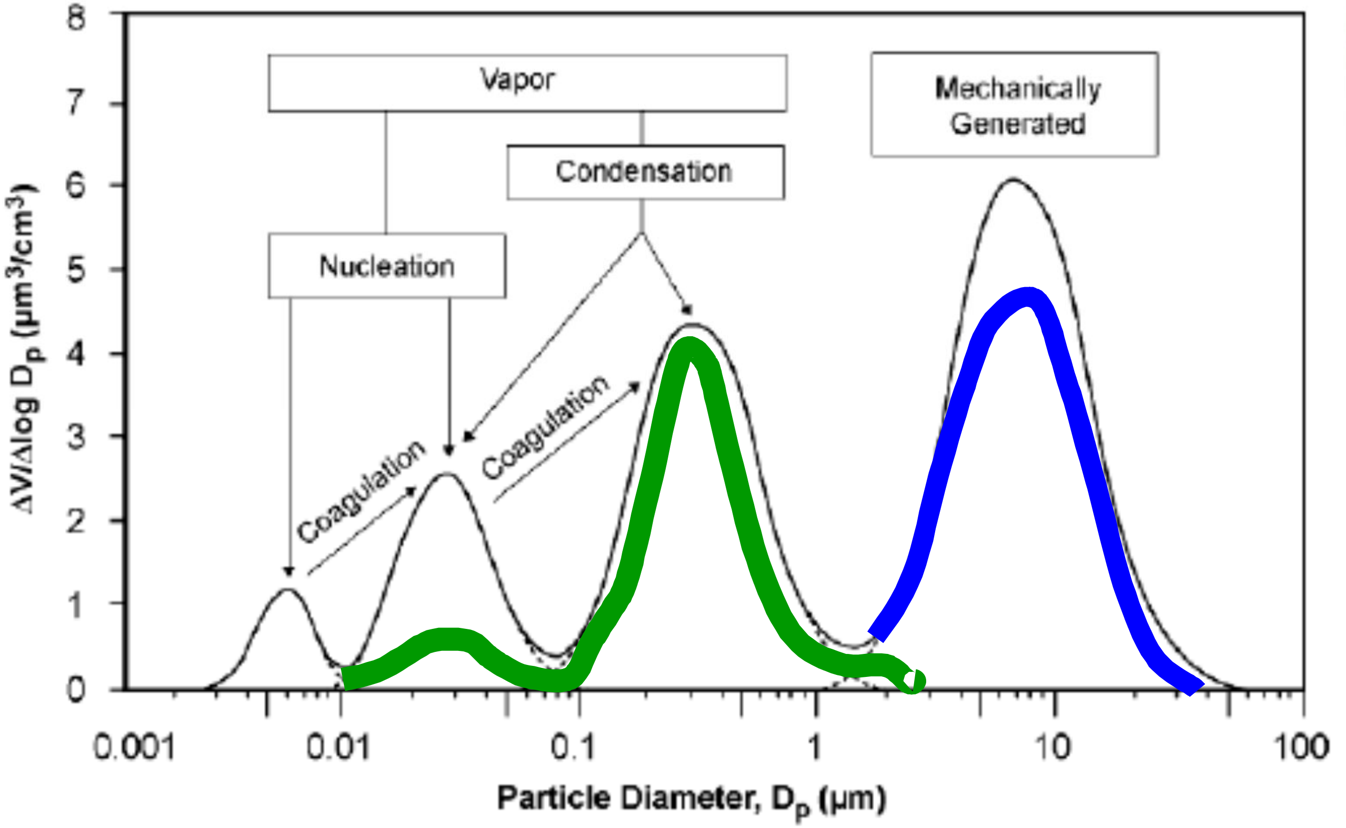
$PM_{2.5}$ → fine particles

$PM_{2.5-10}$ → coarse part.

PM_{10}



ultrafine <0.1 μm

acumulation 0.1 - 1 μm

coarse 1 - 100 μm

mineral:

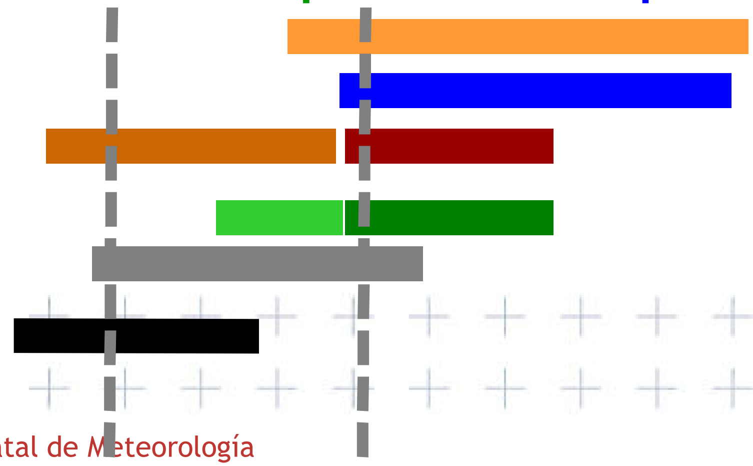
sea salt:

sulphate:

nitrate:

organic matter:

black carbon:



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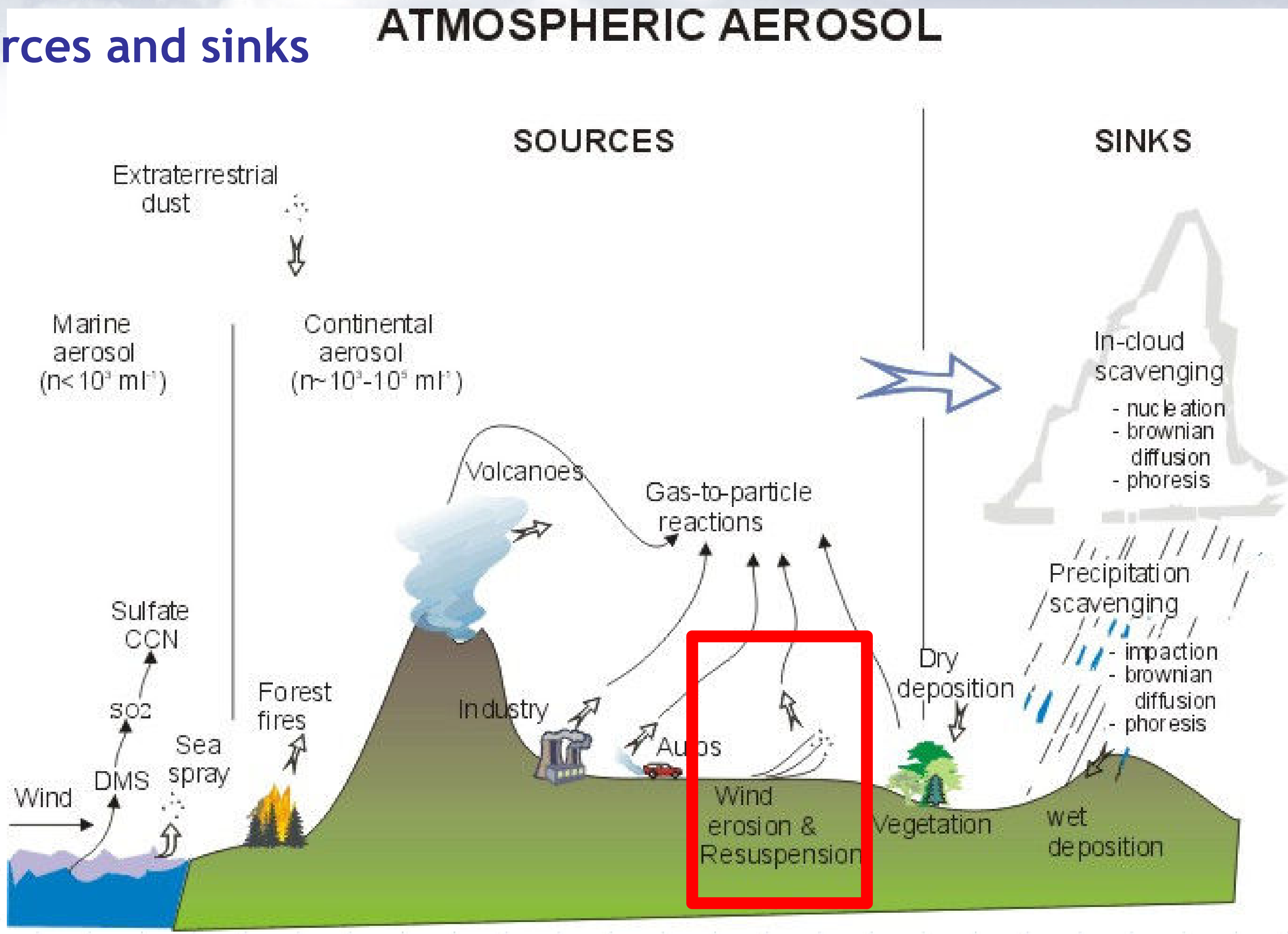
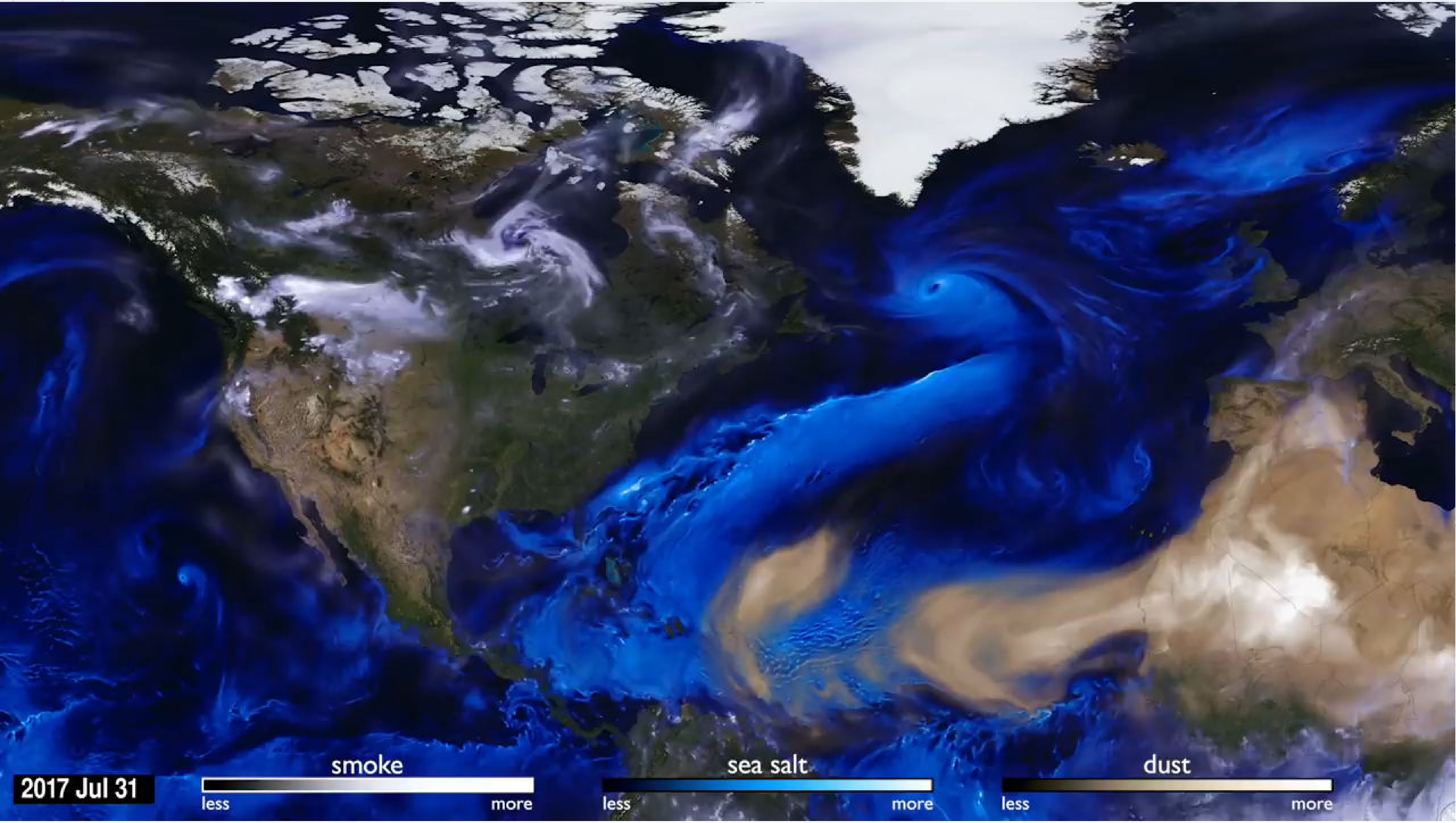
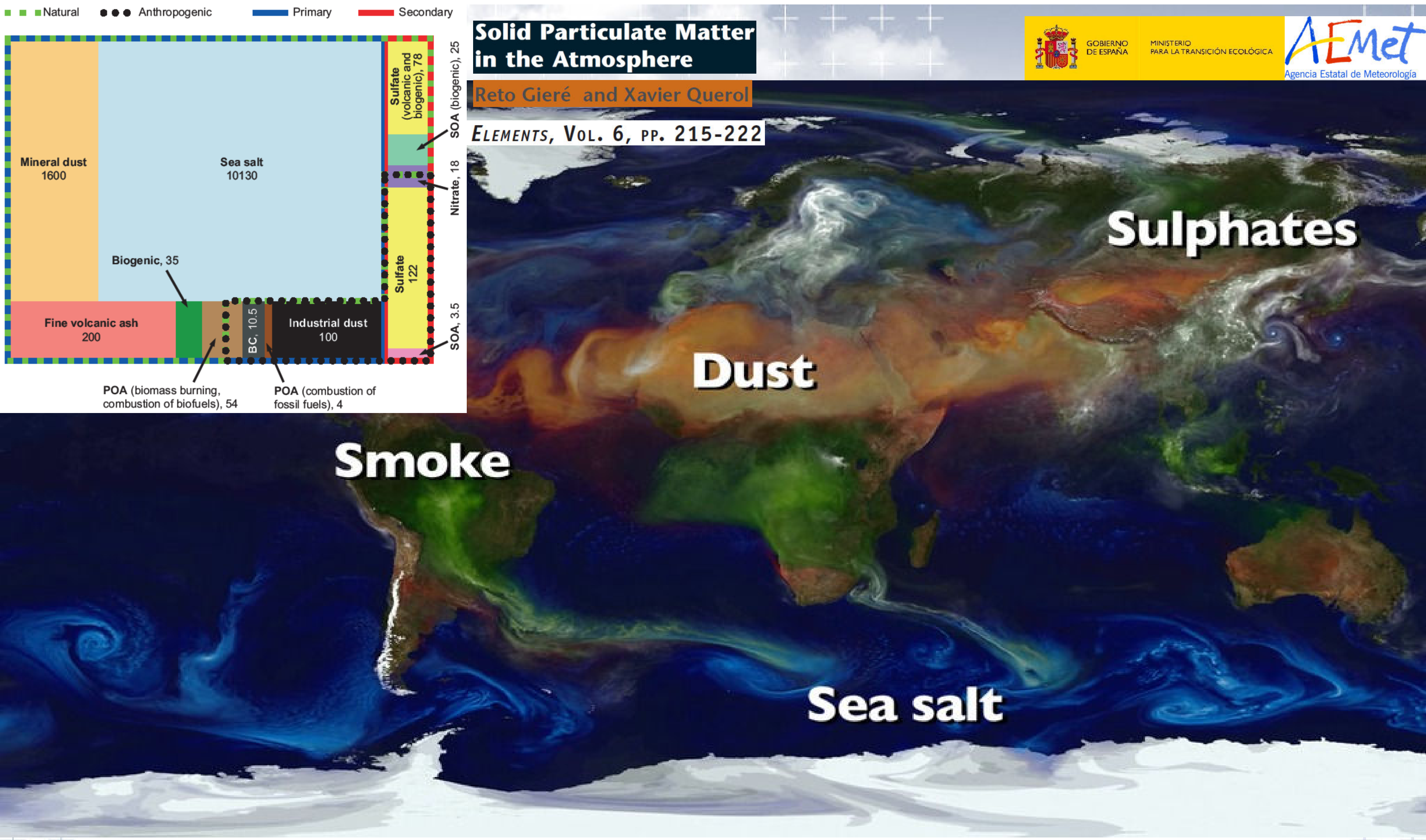
Sources and sinks



Sources and skins





Solid Particulate Matter in the Atmosphere

Reto Gieré and Xavier Querol

ELEMENTS, VOL. 6, PP. 215-222

Absorbing components:

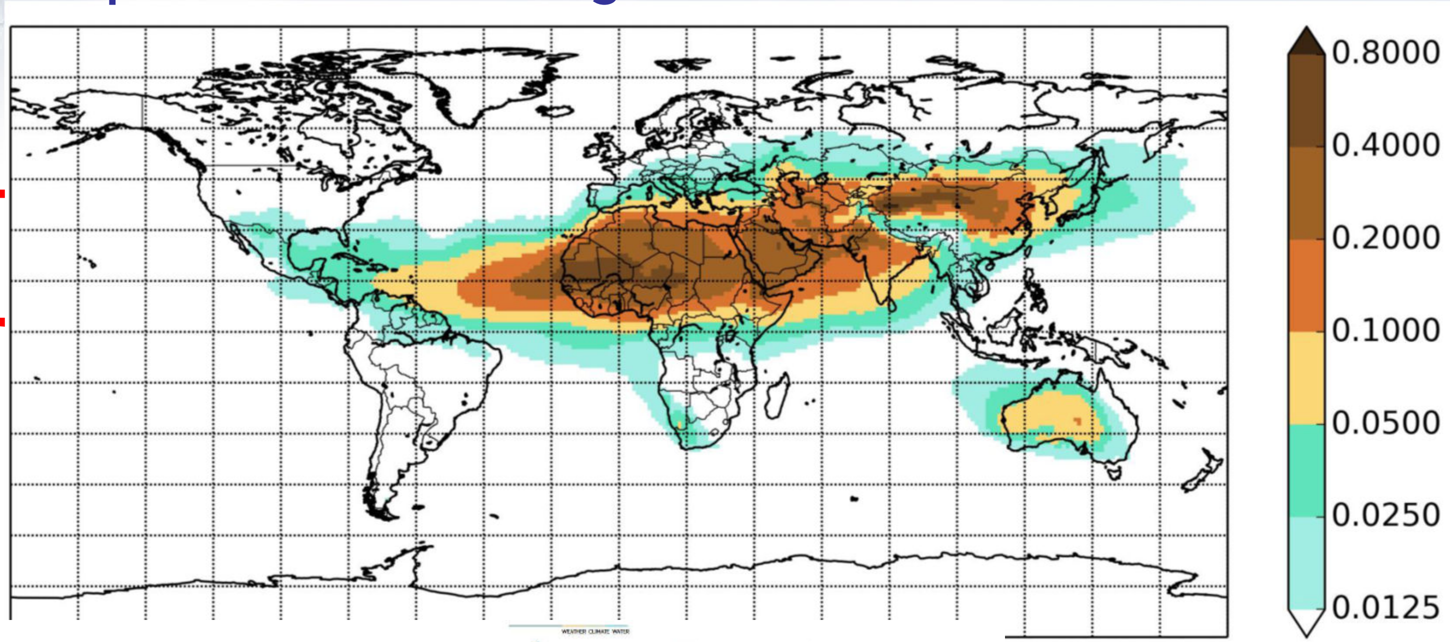
- Smoke (partially Black Carbon)
- Dust

Non-absorbing components:

- Sea salt
- Sulphates

Dust optical depth at 550 nm. Avergae value 2003-2015

dust belt

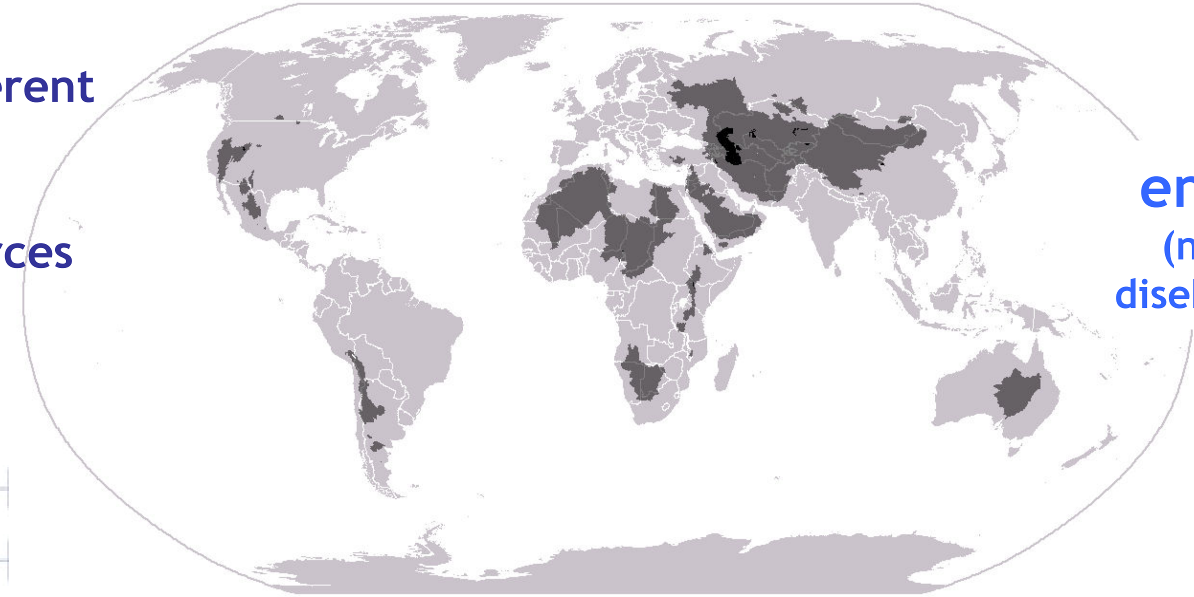


Data: CAMS reanalysis
Picture: WMO SDS-WAS

WMO AIRBORNE DUST

Ratio between different chemical components:

key for studing dust sources



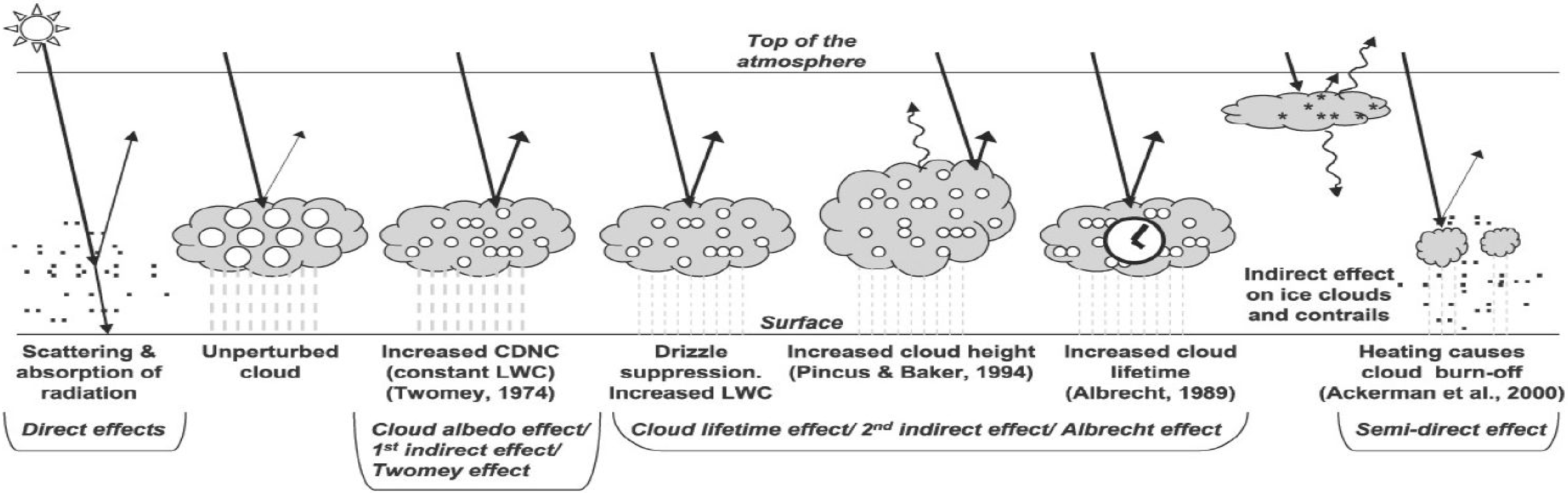
endorheic basins
(no conection to sea, disekated lakes and rivers)

Introduction

Not only natural dust sources (deserts), but also anthropogenic sources:

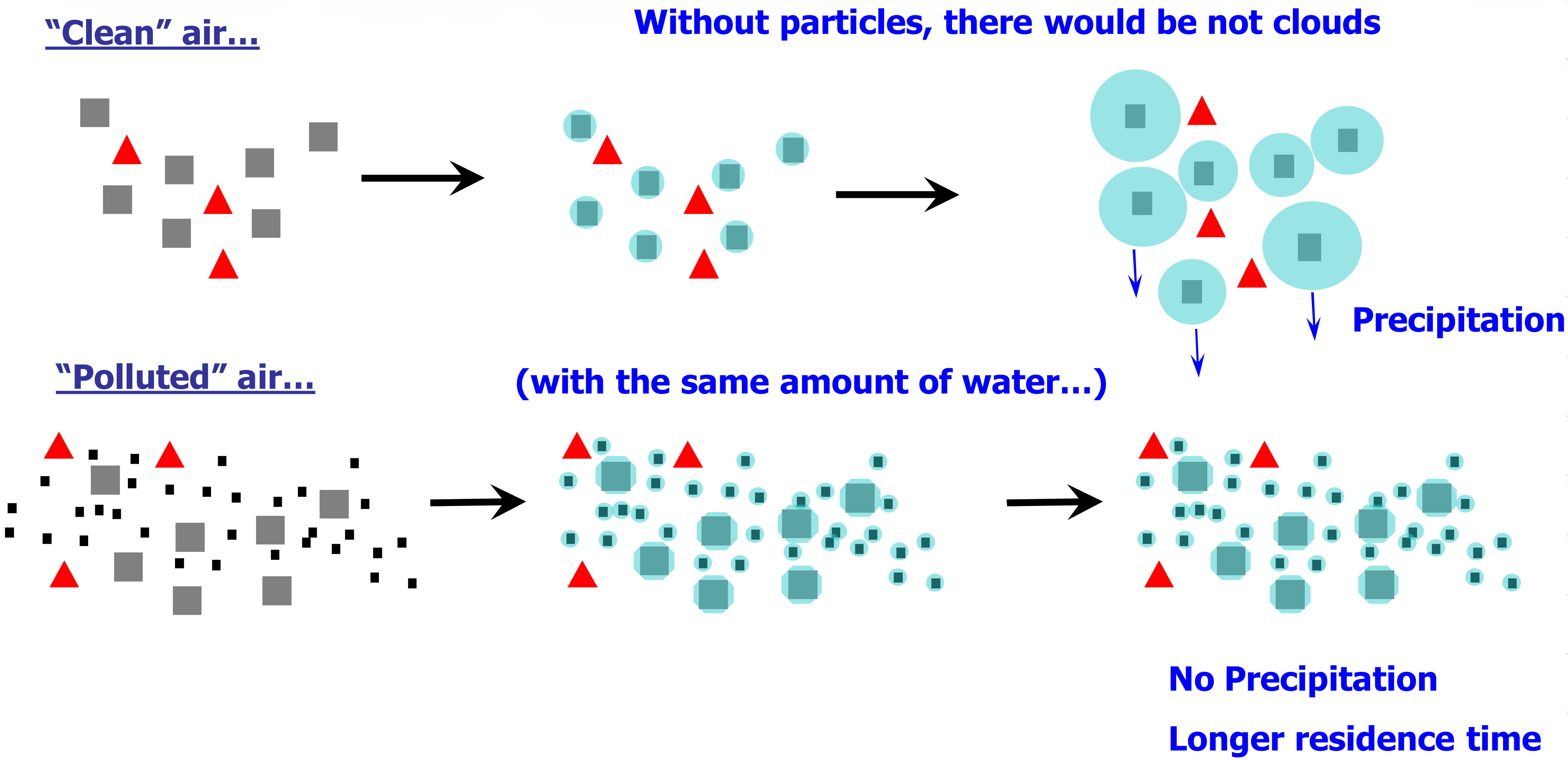
- From unpaved road
- From crop land
- From industry
- …

Effects of Aerosols on Climate Change



IPCC report, 2007

Aerosol-cloud interaction (extension)

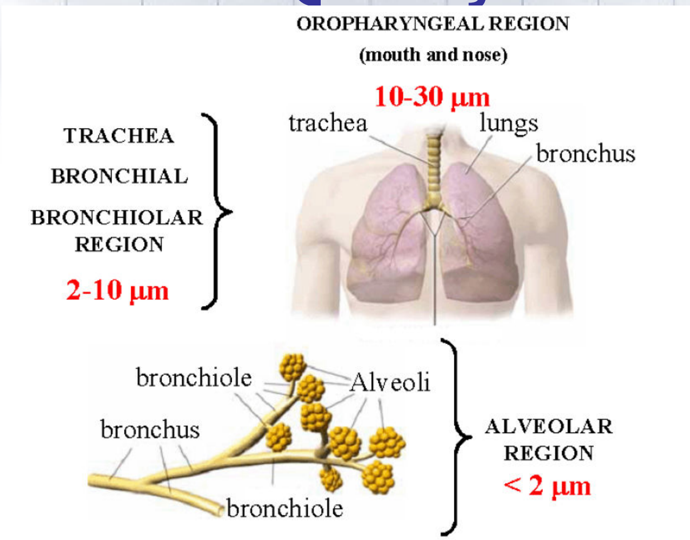


Influencen on radiative forcing

the presence of particles decreases the size of the drops of the clouds and increases the life of these

Effects of Aerosols on Air Quality

Health effects:



- Asthma
- Pulmonary inflammation
- Hay fever
- Eyes infection
- Respiratoyr symptoms
- Skin allergy
- …

→ Dust impact on health by Aurelio Tobías on Wednesday…

Visibility effects: could lead in cancellation of flight operations

WMO OMM Global Atmospheric Watch Programme

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As the WMO/GAW indicate, "*knowledge of aerosol radiative properties is needed for the evaluation of effects of aerosol particles on climate and air quality (visibility)*"

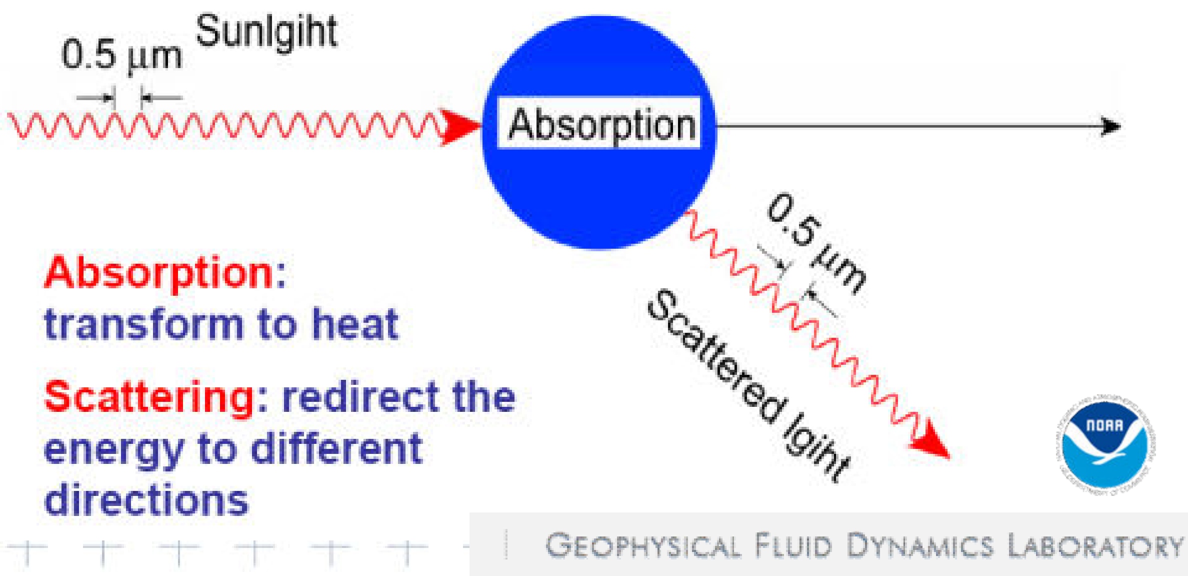
"The fundamental quantity of interest for these applications is the aerosol particles cross-section for light extinction per unit volume of air"

⇩

Ext=Abs+Sct

(aerosol) particle light extinction coefficient σ_{ep}

In the atmosphere: aerosol particles can scatter and absorb solar and infrared radiation altering air temperature and the rates of photochemical reactions.



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WMO - visibility

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

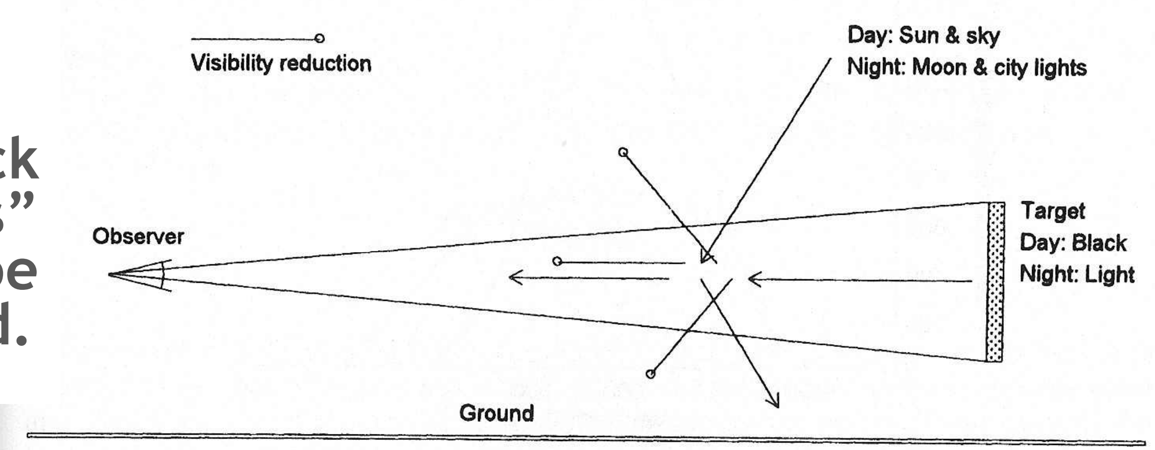


Fig. 11-1 Visibility reduction by scattering.

- 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 (°C), 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

Measurement of visibility – transmissometer

- 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)

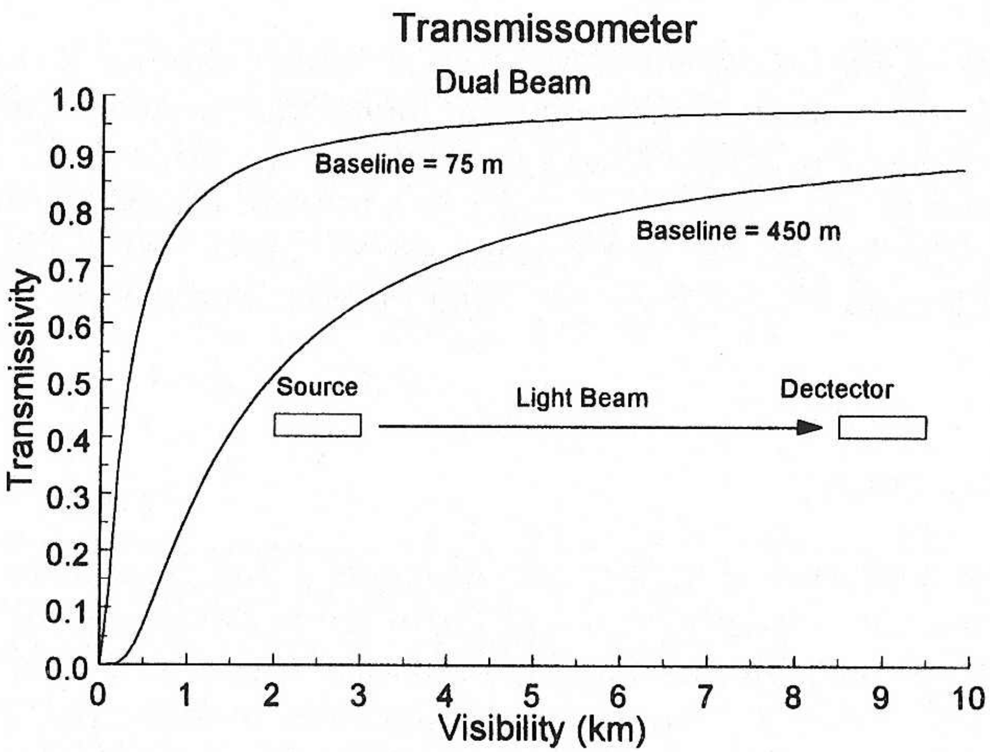
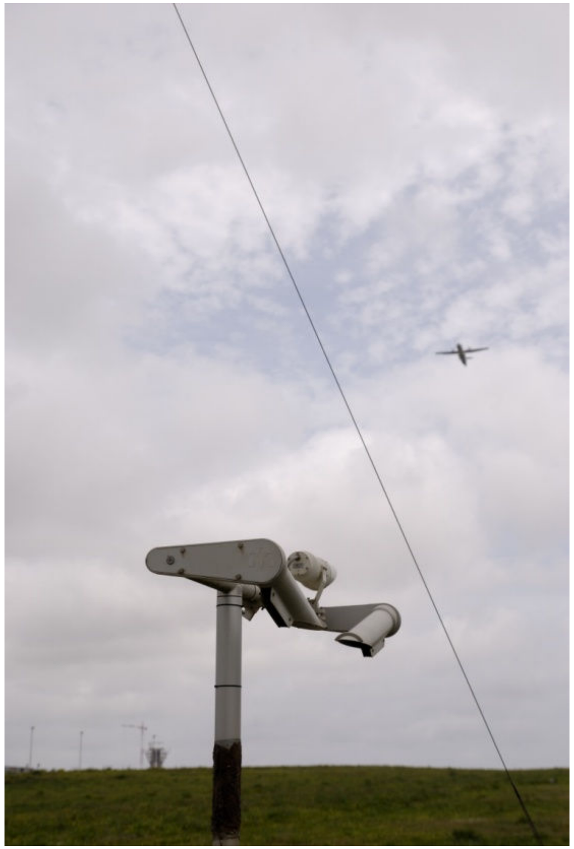


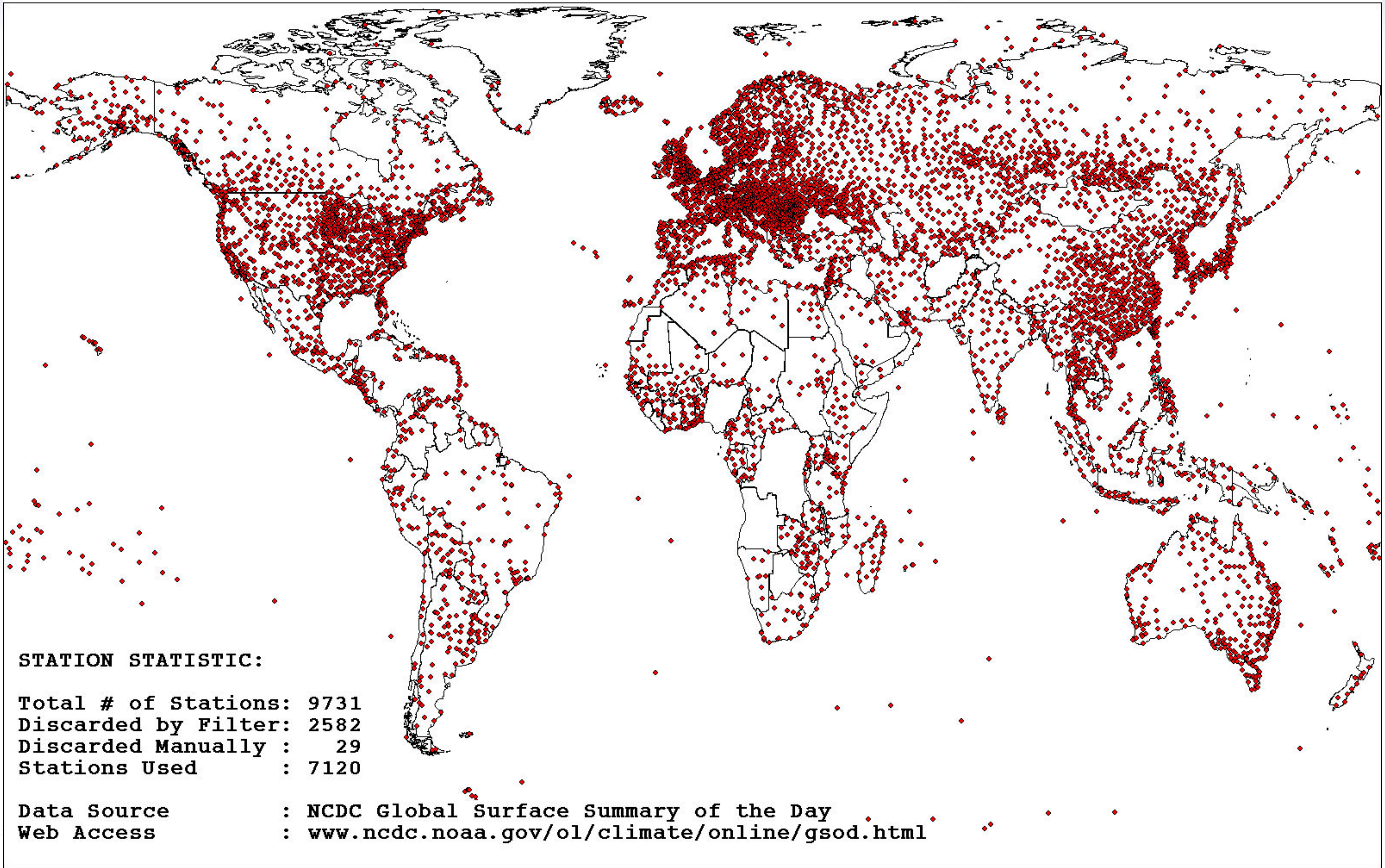
Fig. 11-3 Transfer function for a transmissometer.



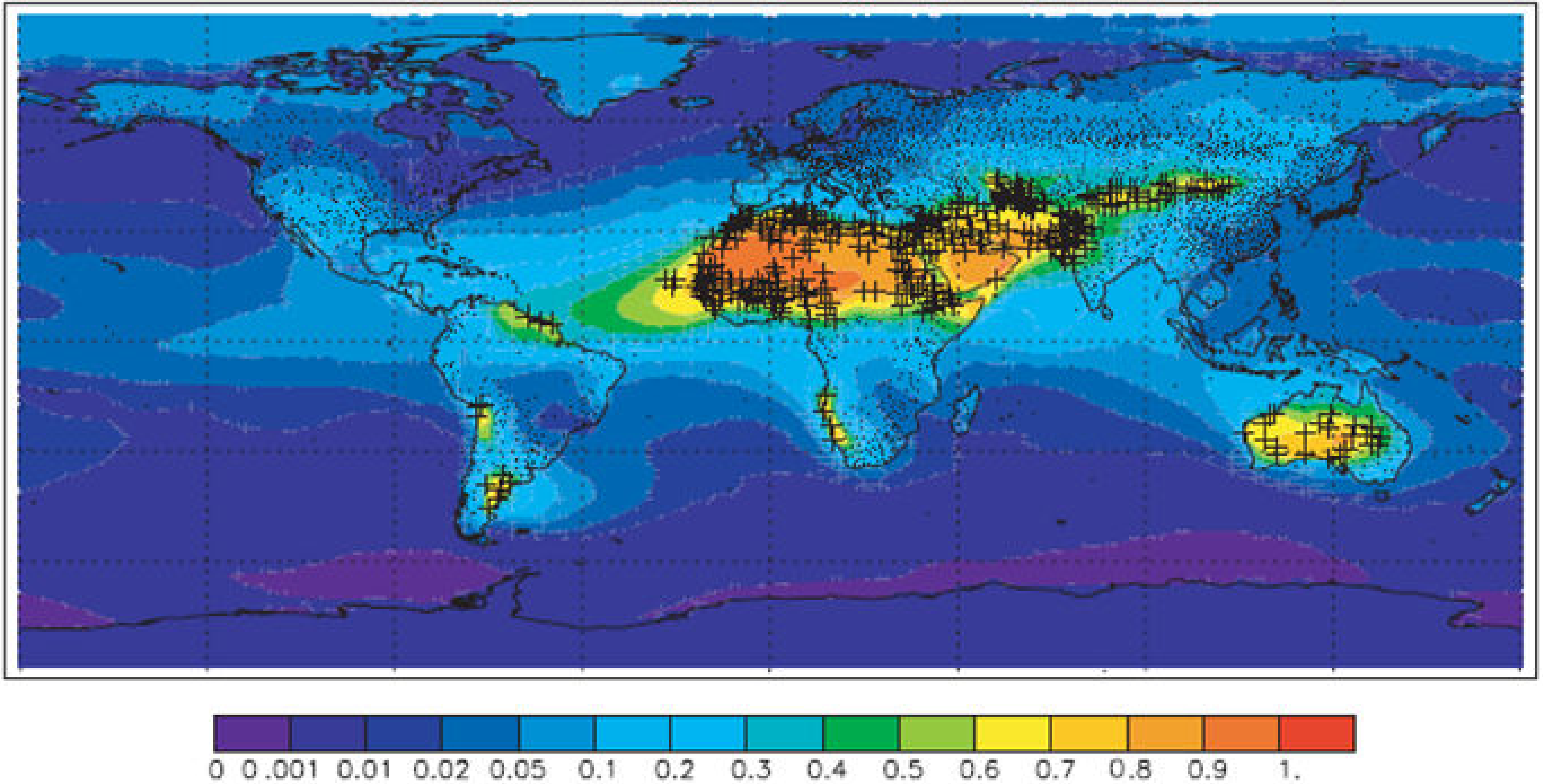
Visual range (km) = 3.912 / σ ext (Mm-1)

Koschmieder (1924) relationship (TOTAL AMBIENT light extinction coefficient)

WMO- World Wide Watch Global Surface Meteorological Network



Visibility



Mahowald et al. (2007) Atmos. Chem. Phys.; Global trends in visibility: implications for dust sources

Location of visibility stations with more than 30 years of data
Coloured contours show the fraction of surface extinction from desert dust
+ show stations dominated by desert dust
· show other locations

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Camino et al. (2015) Aeolian Res.; An empirical equation to estimate mineral dust concentrations from visibility observations in Northern Africa

Empirical equations to estimate dust concentration (PM10 or TSP in μg/m3) using visibility (V in km) obtained by several authors within the dust belt.

Authors	Code	Empirical equation	Dust concentrations and visibility data reported from SYNOP station
D'Almeida (1986)	DA-Eq	$PM_{10} = 914.0\,V^{-0.73} + 19.03$	Turbidity network of eleven stations set up over the Sahara and the Sahelian belt PM_{10} field campaign at Agadez (Niger) with visibility ranges from 0.2 to 40 km
Ben Mohamed et al. (1992)	BM-Eq	$TSP = 1339.84\,V^{-0.67}$	TSP field campaign at Niamey (Niger) with visibility ranges from 0.1 to 20 km
Shao and Wang (2003)	SH-Eq	$TSP = 3802.29\,V^{-0.84}$; $V < 3.5$ km $TSP = e^{-0.11V+7.62}$; $V \geq 3.5$ km	TSP measured at twelve monitoring sites located in China, Japan and Korea Visibility data disaggregated in weak dust events and strong dust events
Dayan et al. (2008)	DAY-Eq	$PM_{10} = -505\ln(V) + 2264$	PM_{10} monitoring site located at Negev Desert. Visibility ranges from 1 to 5 km at Hazerim airport (Israel)
Jugder et al. (2014)	JU-Eq	$PM_{10} = 485.67V^{-0.776}$	PM_{10} and visibility data were observed at Zamyn-Uud site in the Gobi desert. $PM_{10} \geqslant 50\ \mu g/m^3$ threshold was established for hazy atmospheric conditions Visibility MOR sensors have a maximum measurement range of 20 km

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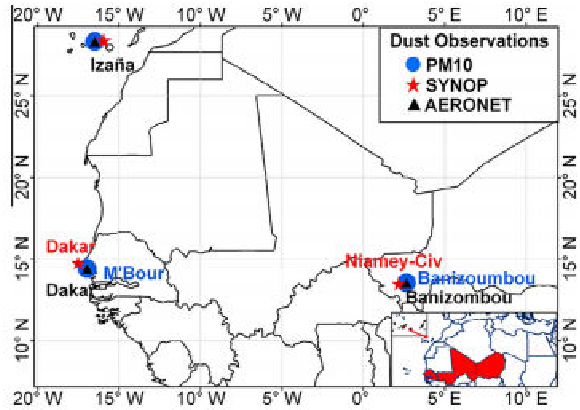
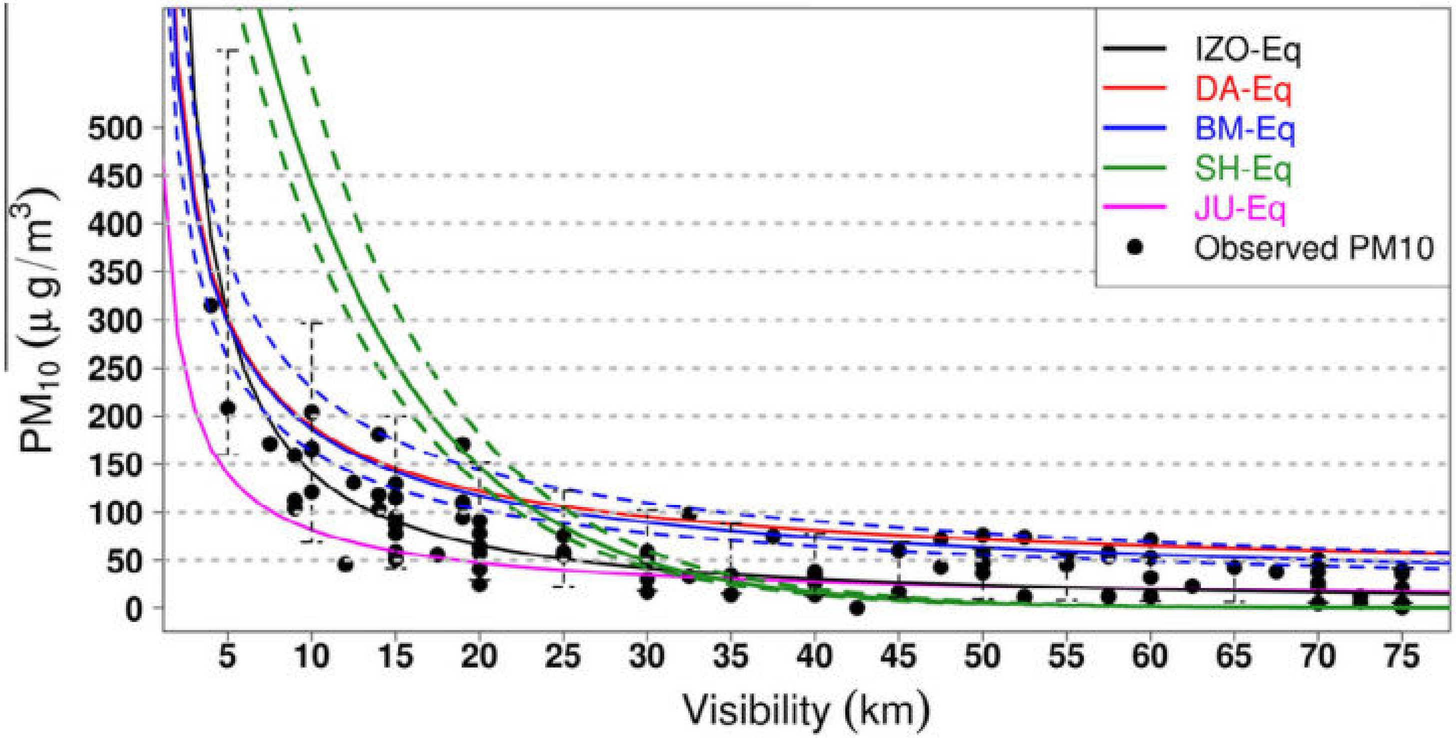


Camino et al. (2015)

IZO-Eq $PM_{10} = 1772.24\ V^{-1.1}$



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. Judgment in distinguishing visibility beyond 10 km / lack of geographical references
4. No obligation to report when reduced-visibility is reduced is > 10km.

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

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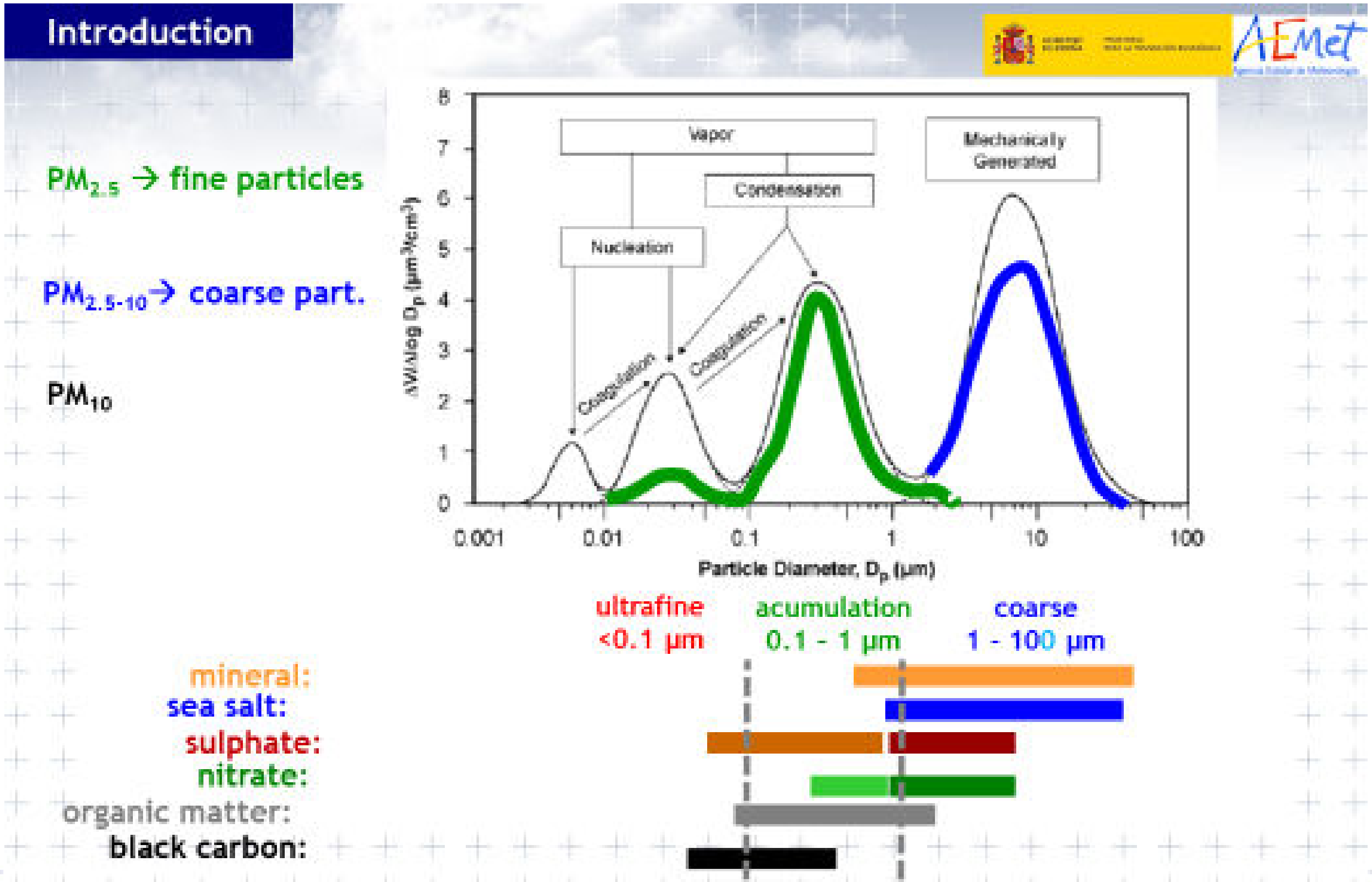
From estimation of dust concentration from visibility information to dust concentration observations… → **In-Situ techniques**

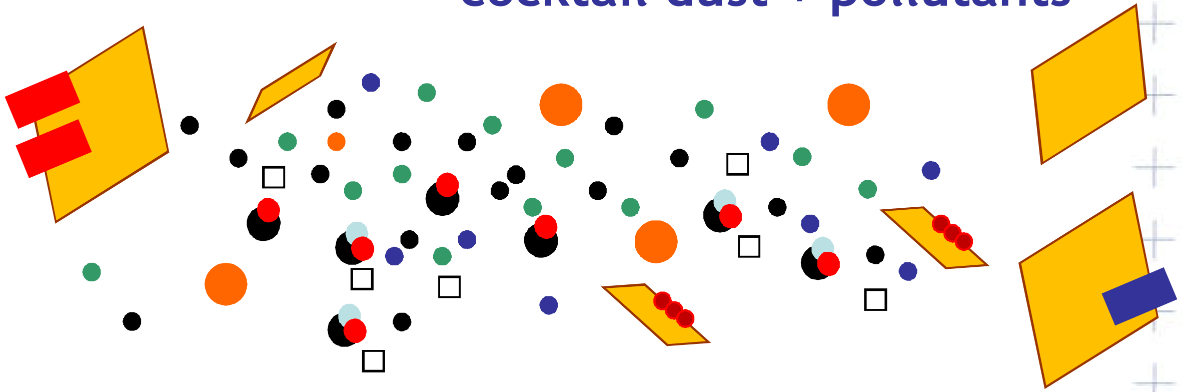
- **How can we measure dust concentration….?**

Because what we have in fact is a mixture of dust and others…



people live in cities and breath a cocktail dust + pollutants

aerosols, a cocktail of chemicals:



- dust (mineral)
- sulphate
- nitrate
- organic mater
- black carbón (soot)
- metals (Ni, As, Cd, V, Co...)
- sea salt

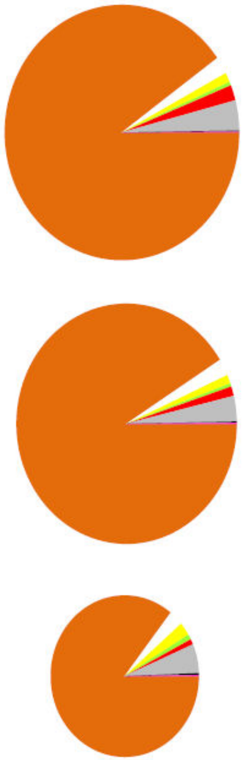
In air quality, aerosols:

- PM_{10}: mass concentration ($\mu g/m^3$) of all aerosols smaller than 10 µm → inhalable particles
- $PM_{2.5}$: mass concentration ($\mu g/m^3$) of all aerosols smaller than 2.5 µm → alveolar particles

PM_{10}: dust + sea salt + (sulphate + nitrate + organic matter + black carbon +metals) ...

$PM_{2.5}$: dust + sea salt + (sulphate + nitrate + organic matter + black carbon +metals) ...

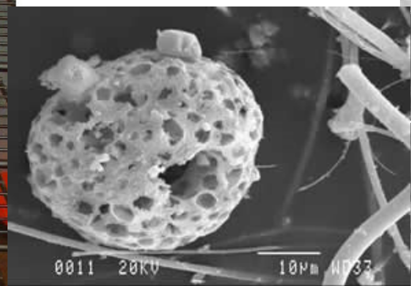
PM_x composition in the SAL (Saharan Air Layer)



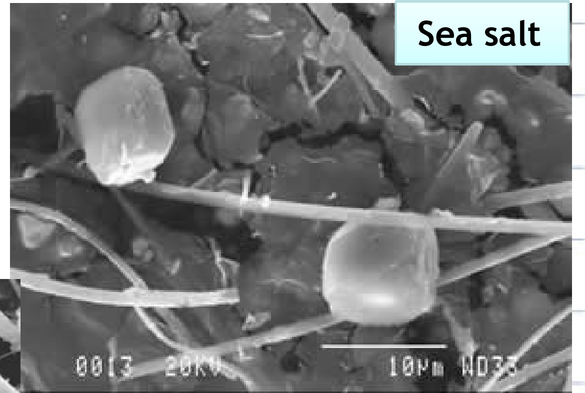
PM_T	47.3 $\mu g/m^3$	
91%	42.6	dust (Al, Fe, Ca, Ti..)
2.2%	1.0	none ammonium-sulfate
1.2%	0.5	ammonium-sulfate
0.4%	0.2	ammonium
1.9%	0.9	nitrate
3.8%	1.8	organic matter
0.2%	0.0 7	elemental carbon

PM_{10}	42.0 $\mu g/m^3$	
91%	38.3	dust
2.2%	0.9	none ammonium-sulfate
1.2%	0.5	ammonium-sulfate
0.4%	0.2	ammonium
1.3%	0.6	nitrate
3.4%	1.4	organic matter
0.2%	0.0 7	elemental carbon

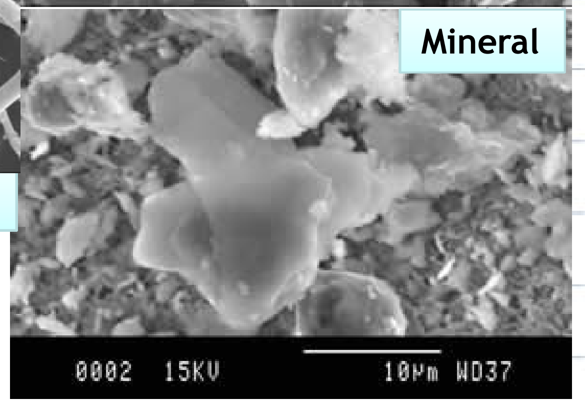
$PM_{2.5}$	18.5 $\mu g/m^3$	
85%	15.8	dust
3.0%	0.6	none ammonium-sulfate
2.7%	0.5	ammonium-sulfate
1.0%	0.2	ammonium
1.1%	0.2	nitrate
5.8%	1.1	organic matter
0.4%	0.0	elemental carbon



Combustion



Sea salt



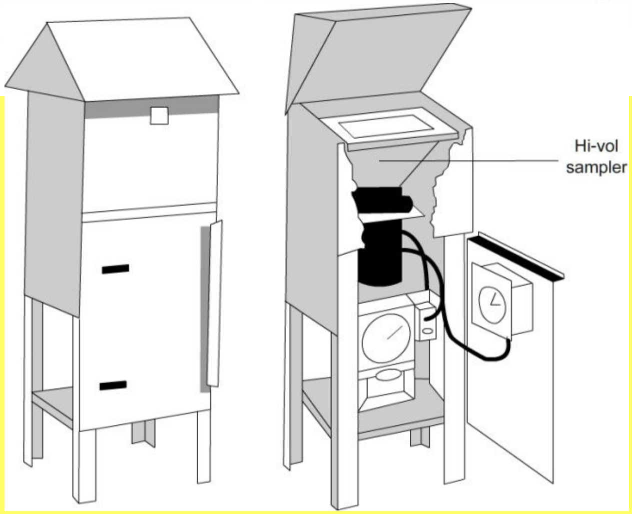
Mineral

Images courtesy from "Grupo de Geoquímica Ambiental del Instituto de Diagnóstico Ambiental y Estudios del Agua", CSIC

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

1. Reference method: gravimetric method

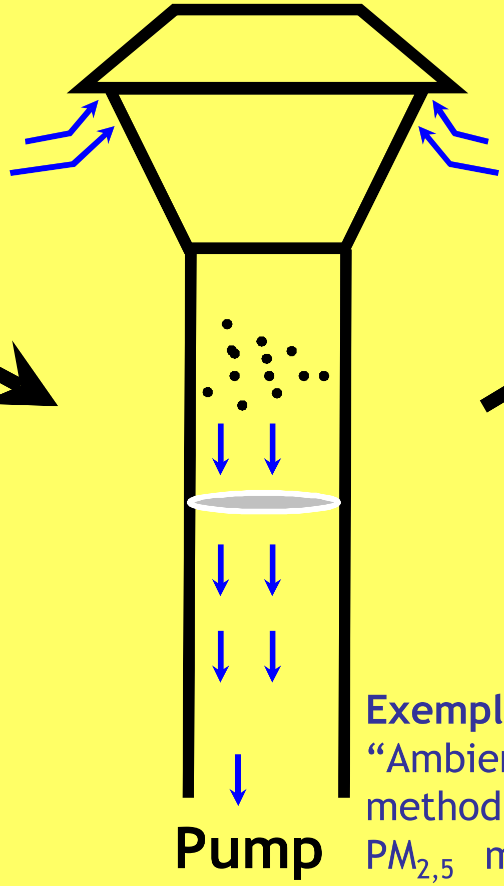
$$PM = \frac{(W2-W1)}{Volume} \quad \mu g/m^3$$



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)

Exemple of reference method: EN 12341:2014
"Ambient air. Standard gravimetric measurement method for the determination of the PM_{10} or $PM_{2,5}$ mass concentration of suspended particulate matter"

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

Low Volume Sampler

LVS: 2.3 m^3/h

High Volume Sampler

HVS: 68 m^3/h

HVS: 30 m^3/h

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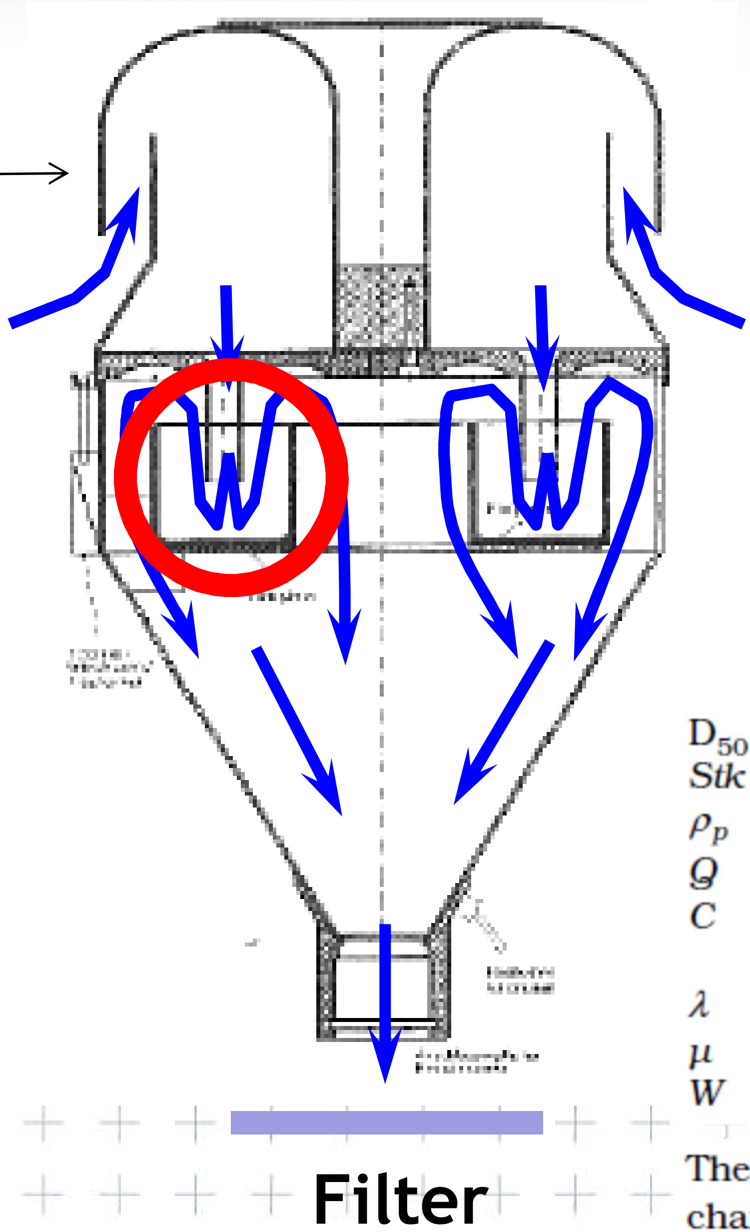
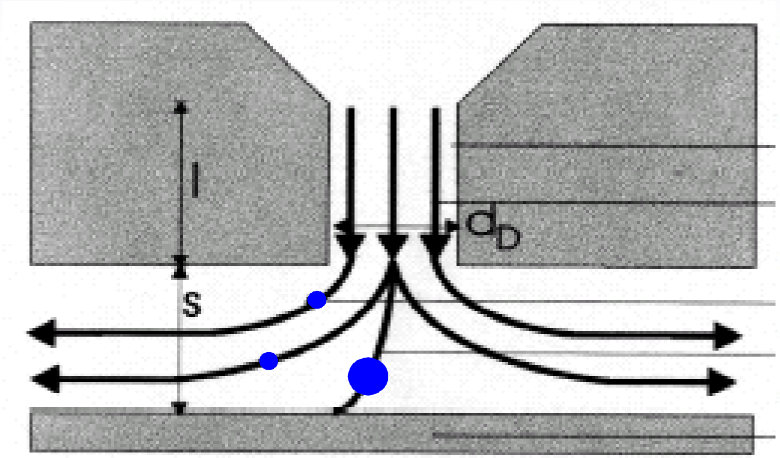
TSP, PM_{10}, $PM_{2.5}$, PM_1: aerodynamic diameter



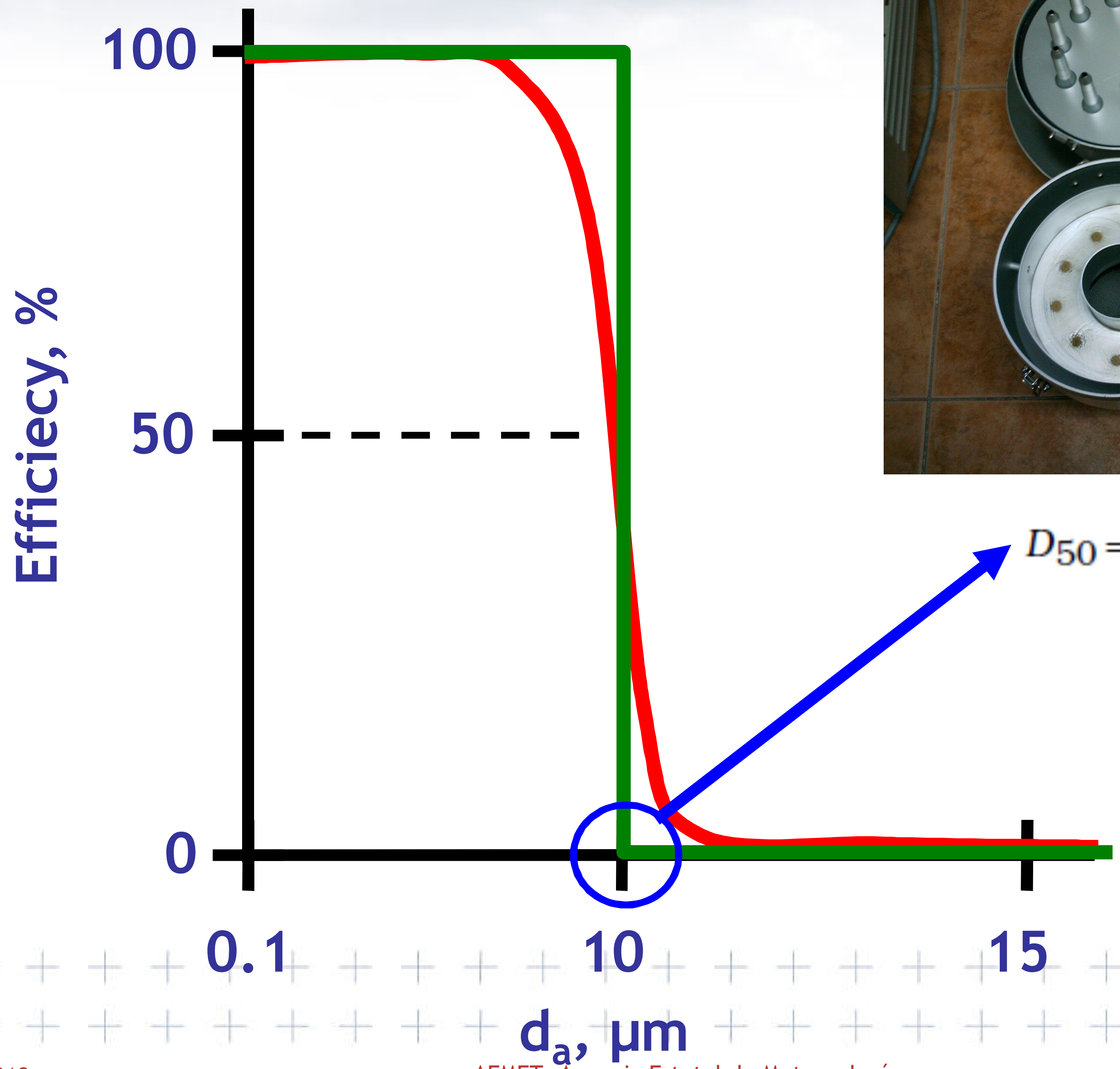


$$D_{50} = \sqrt{\frac{9\pi Stk\,\mu W^3}{4\rho_p C Q}}$$

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•s/cm^2)
W = nozzle diameter (cm)

The Stokes number is a dimensionless parameter that characterizes impaction.

Impactor efficiency



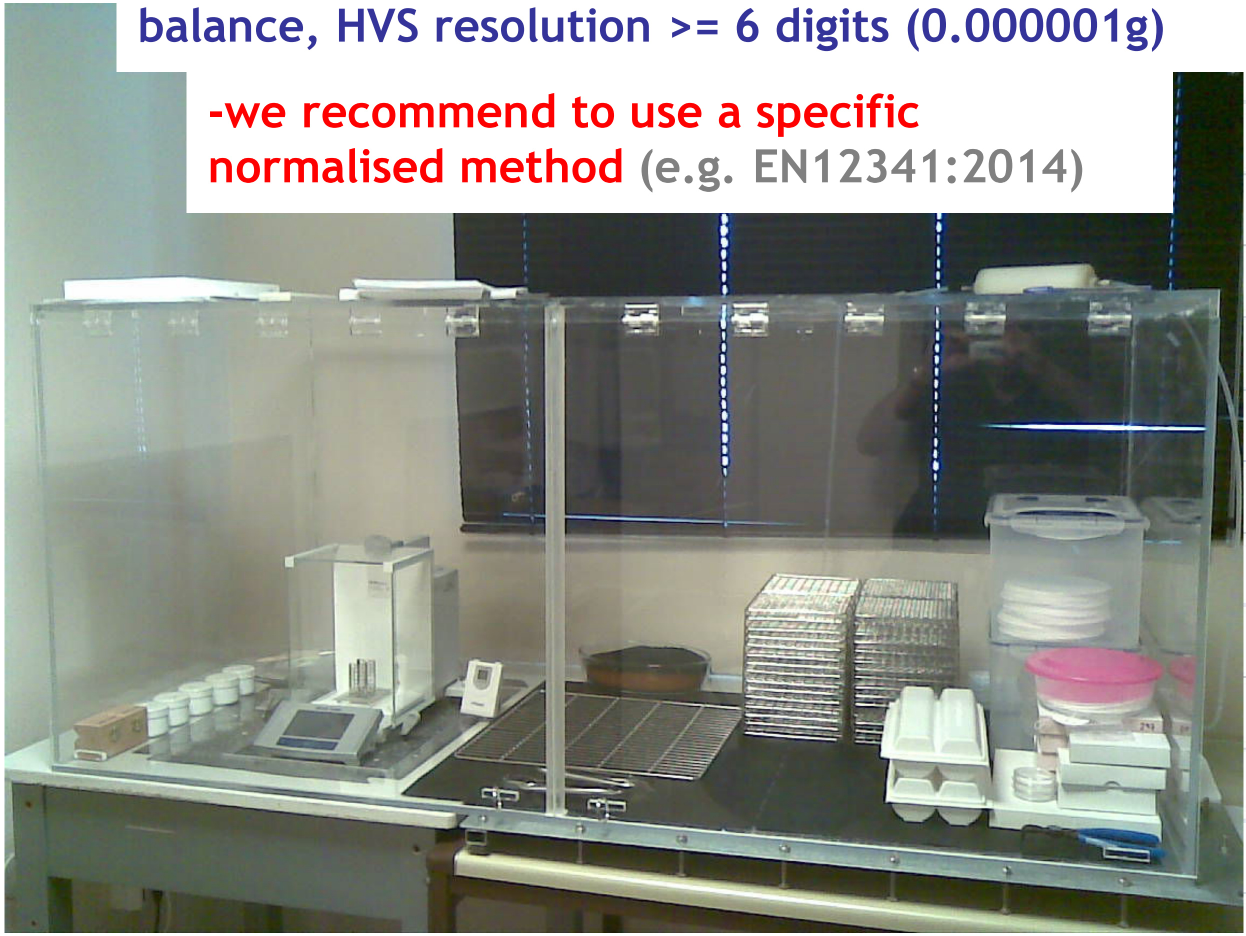
$$D_{50} = \sqrt[3]{\frac{9\pi Stk\,\mu W}{4\rho_p C Q}}$$

In-Situ techniques

Room for weighting the filters:
RH =50% (30 %) and 20°C

balance, LVS resolution >= 5 digits (0.00001g)
balance, HVS resolution >= 6 digits (0.000001g)

-we recommend to use a specific normalised method (e.g. EN12341:2014)



PM_{10} $PM_{2.5}$

24h pre and post conditioning
No data available until some days…

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PM_{10}
Blank filter

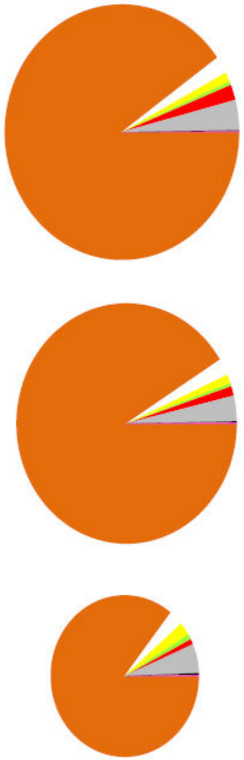
PM_{10}
sample urban air

PM_{10}
sample in dust days

Filters: Quartz, Teflon, Cellulose
(depending on the use after collect it...)

Bulk dust mass concentrations

PM_x composition in the SAL (Saharan Air Layer)



PM_T		47.3 µg/m³	
91%	orange	42.6	dust (Al, Fe, Ca, Ti..)
2.2%	white	1.0	none ammonium-sulfate
1.2%	yellow	0.5	ammonium-sulfate
0.4%	green	0.2	ammonium
1.9%	red	0.9	nitrate
3.8%	grey	1.8	organic matter
0.2%	black	0.07	elemental carbon

PM_{10}		42.0 µg/m³	
91%	orange	38.3	dust
2.2%	white	0.9	none ammonium-sulfate
1.2%	yellow	0.5	ammonium-sulfate
0.4%	green	0.2	ammonium
1.3%	red	0.6	nitrate
3.4%	grey	1.4	organic matter
0.2%	black	0.07	elemental carbon

$PM_{2.5}$		18.5 µg/m³	
85%	orange	15.8	dust
3.0%	white	0.6	none ammonium-sulfate
2.7%	yellow	0.5	ammonium-sulfate
1.0%	green	0.2	ammonium
1.1%	red	0.2	nitrate
5.8%	grey	1.1	organic matter
0.4%	black	0.0	elemental carbon

Bulk chemical characterization is the most widely used technique for identifying and quantifying the presence of dust.

Typical mineral elements are Si, Al, Ca, K, Na, Mg, Fe, K and P (as major elements) and Ti, V, Cr, Mn, Co, Ni, Cu, Zn, As, Sr, Cd, Sn, Sb and Pb as trace elements.

Variability in dust composition is often used to identify dust sources.

Al is included as soil dust tracer (clay mineral). → ratio of each element (X) to Al (X/Al) is used to know the potential source contribution (for exemple Ca/Al, Fe/Al, etc.)

-Rodriguez et al. (2012) A review of methods for long term in situ characterization of aerosol dust (http://dx.doi.org/10.1016/j.aeolia.2012.07.004)
-Rodriguez et al. (2019) Rapid changes of dust geochemistry in the Saharan Air Layer linked to sources and meteorology (https://doi.org/10.1016/j.atmosenv.2019.117186)

1. Reference method: gravimetric method

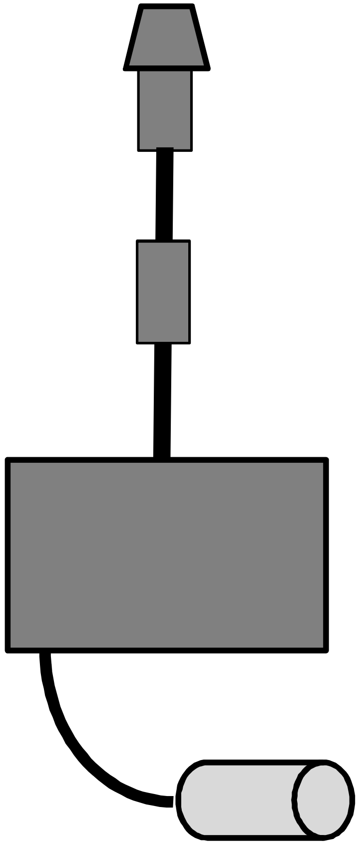
- **Advantages:**
  - Recognized reference method
  - Low capital cost
  - Possibility to "identified" different types of Aerosols in terms of chemical composition… (bulk dust mass concentration)

Alternative…

2. Automatic Methods

- **Disadvantages:**
  - Limited time resolution (typically 24-hr)
  - Long turnaround times (pre&post-conditioning)
  - Labor intensive
  - Gravimetric lab maintenance/cost

2. Automatic Methods



1. Impactor PM_{10} / $PM_{2.5}$ → same as gravimetric method

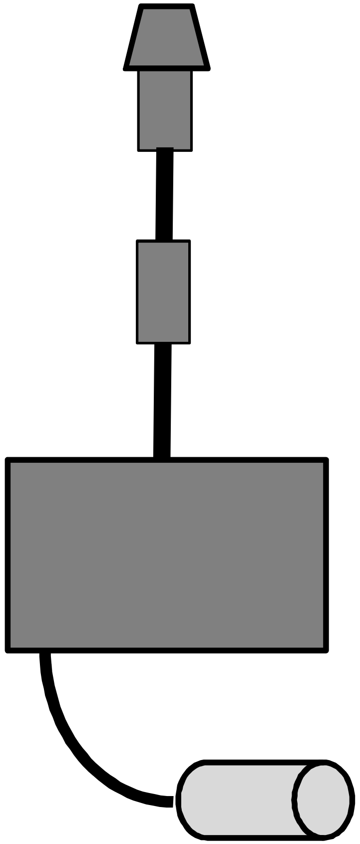
2. RH reductor / heater

3. Sensor (Beta-radiation Attenuation Method -BAM or Tapered Element Oscillating Microbalance-TEOM) → instead of weighting filters

4. Pump / Flow meter → same as gravimetric method

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

2. Automatic Methods



BAM

TEOM

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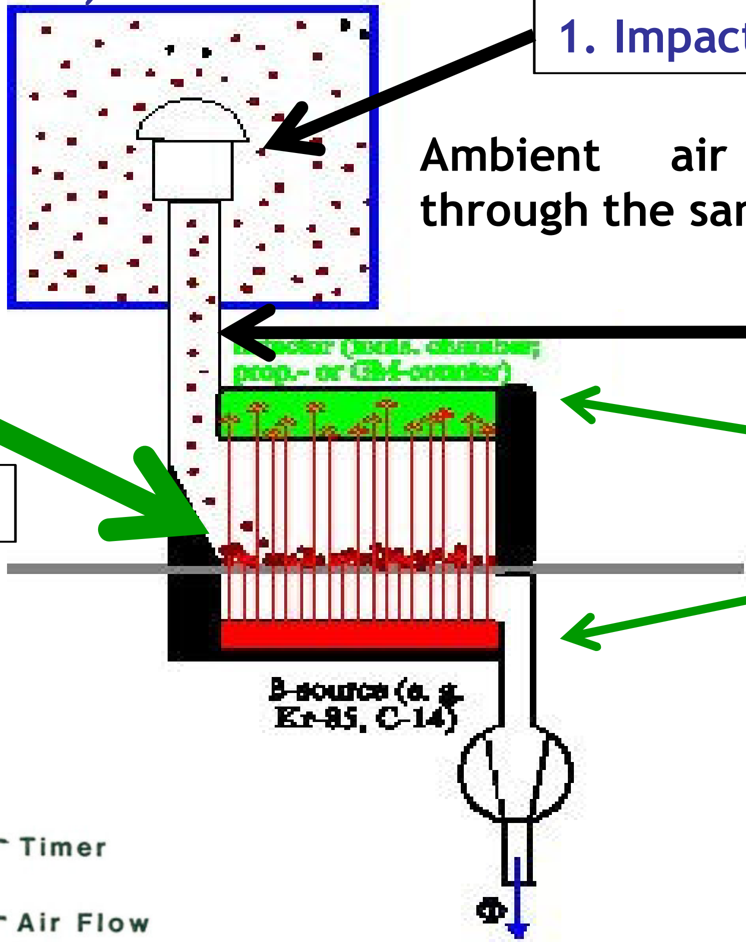
Beta Attenuation:
β-Ray Absorption in Matter

2. Automatic Methods: BAM (Beta)

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



1. Impactor $PM_{10}/PM_{2.5}$

Ambient air is drawn through the sample system

2. RH reductor / heater

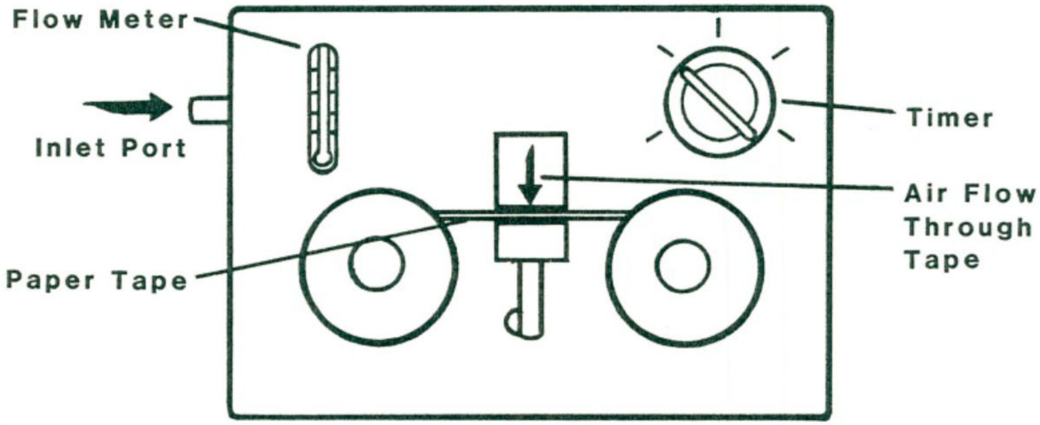
β-rays detector

3. Sensor

β-rays source(Kr85)

4. Pump and flowmeter

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



2. Automatic Methods: BAM (Beta)

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

- 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 accomplished by replacing the filter with the element having a known mass (mass calibration kit)

The mass concentration is calculated from:

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

Where:
c: concentration [µg/m³]
F: measured air flow [m³/h]
t: time [h]

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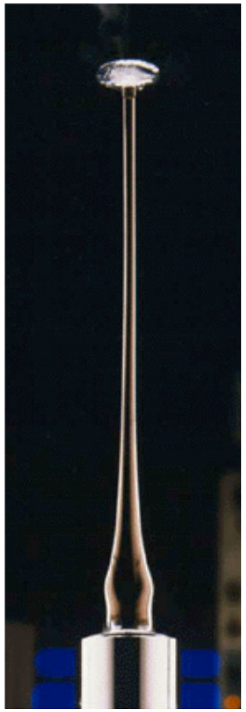
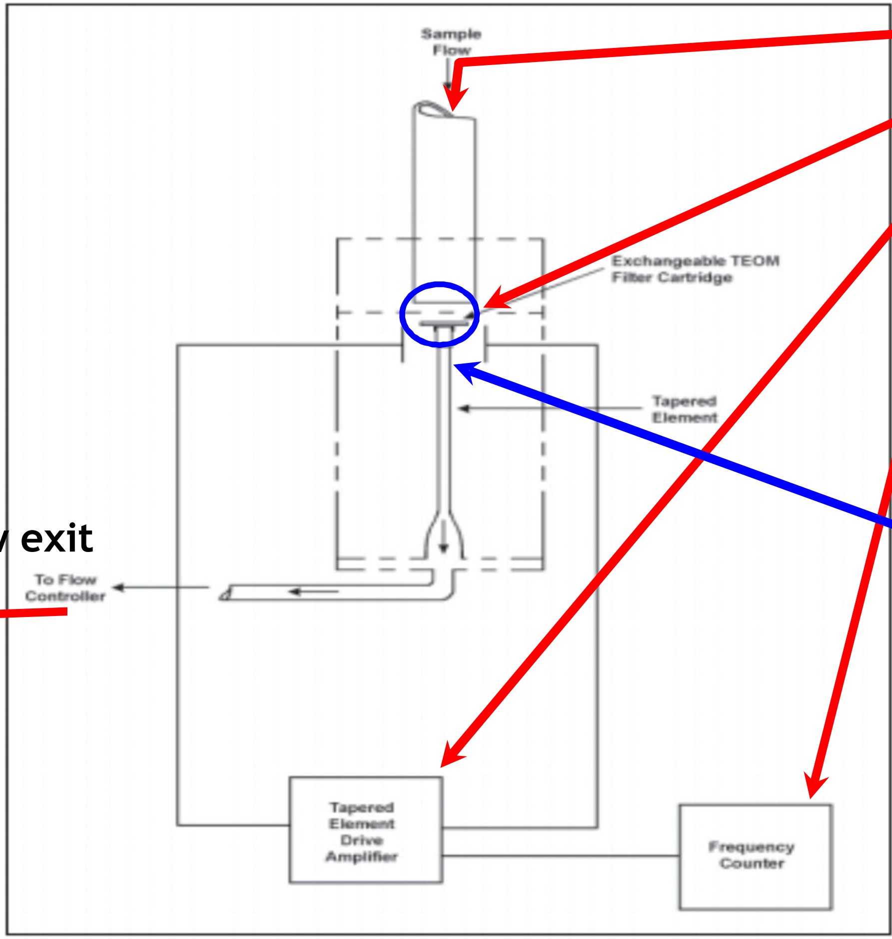
2. Automatic Methods: TEOM Tappered Element Oscillating Microbalance





Sampling flow rate (16.67 l/m)

Sample accumalated in the filter

Micro-oscilation of constante amplitue GENERATOR

Frequency sensor

•Flow exit

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

mass=function (frequer

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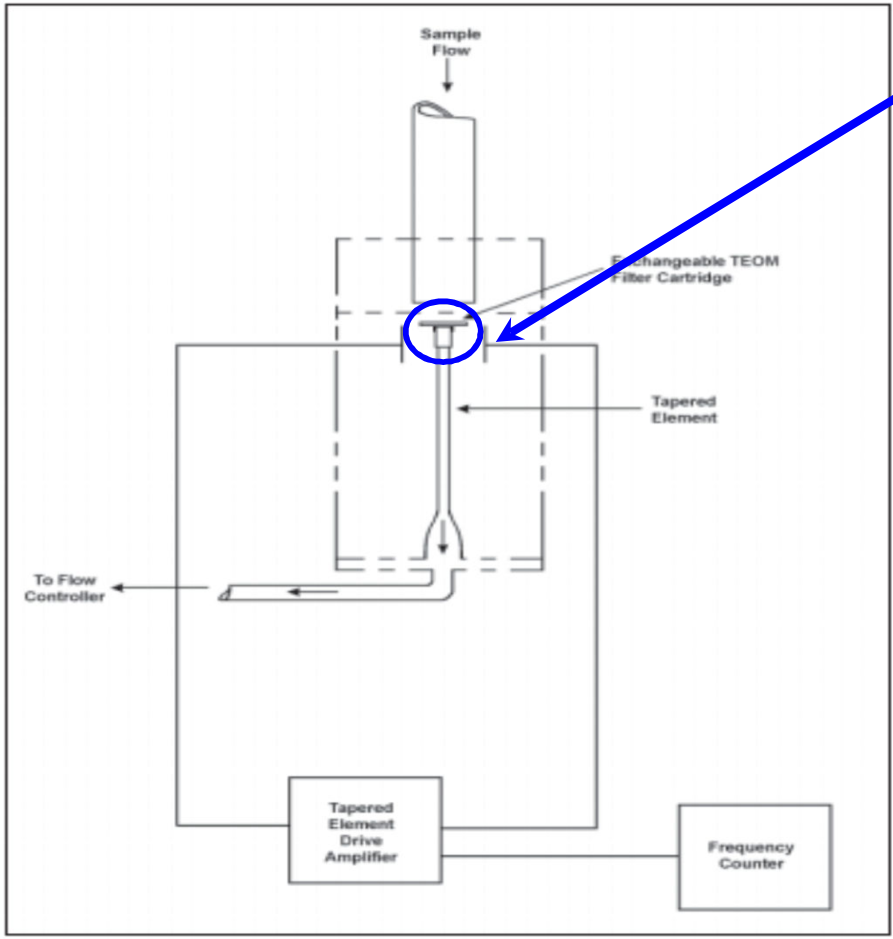
2. Automatic Methods: TEOM

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:

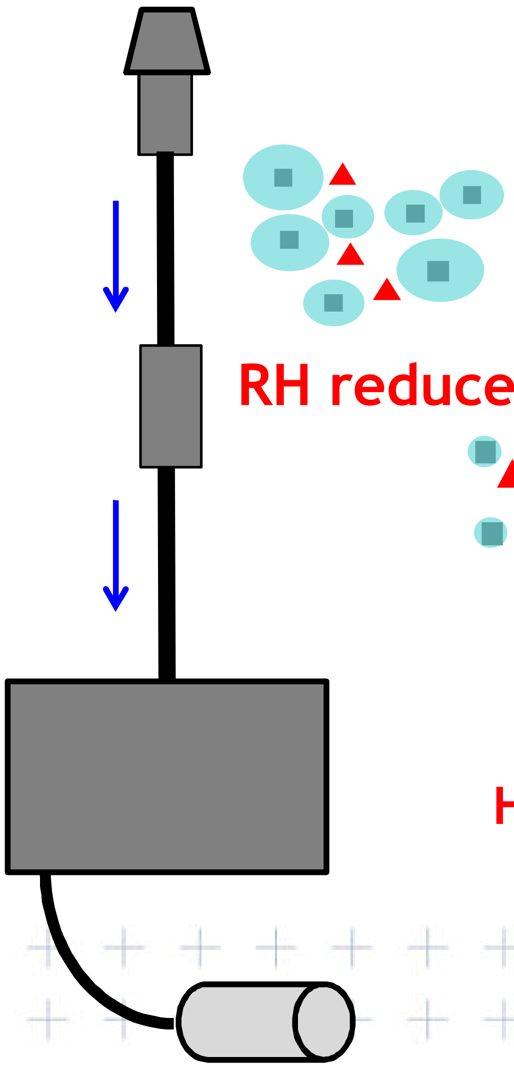
$$dm = K_0 \left(\frac{1}{f_1^2} - \frac{1}{f_0^2} \right) \qquad (2)$$

where:

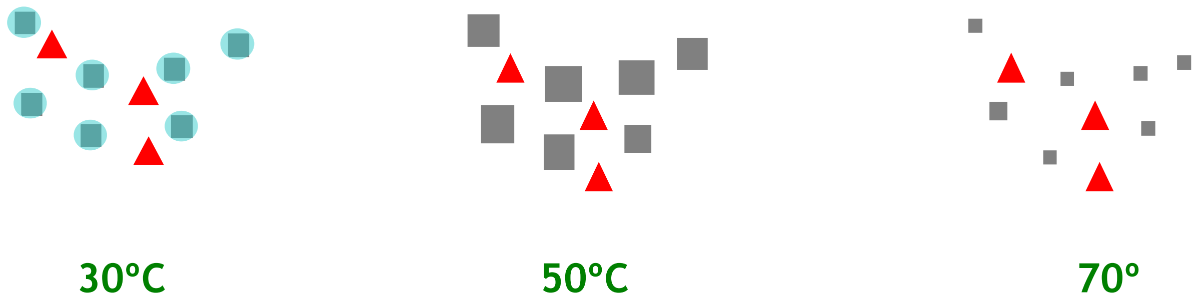
dm	=	change in mass
K_0	=	spring constant (including mass conversions)
f_0	=	initial frequency (Hz)
f_1	=	final frequency (Hz)

2. Automatic Methods: BAM (Beta) - TEOM

drying of the sample in automatic equipment



RH reduce/ heater



Heating of the sample can cause evaporation losses of semi-volatile species

organic compounds
ammonium nitrate

2. Automatic Methods: TEOM (FDMS Filter Dynamics Measurements System)

base flow mode: 6 min. → "Provisional" PM10 concentration PM10'

reference flow mode: 6 min. → Evaluation of changes in concentration when filter expose to ambient air without particles, and determine such chages ΔPM10.

The PM10 final concentration will be then:

$$PM10 = PM10' - \Delta PM10$$

If $\Delta PM10 > 0$ → Positive artifact for gas reacting over particles on filter

$PM10 < PM10'$

If $\Delta PM10 < 0$ → Negative artifact due to volatilization of particles on filter

$PM10 > PM10'$

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2. Automatic Methods: BAM (Beta) - TEOM

- Advantages:
  - On-line measurements
  - Long time stability (> 1 year)
  - Good correlation with gravimetric method
  - US-EPA has adopted it has reference method

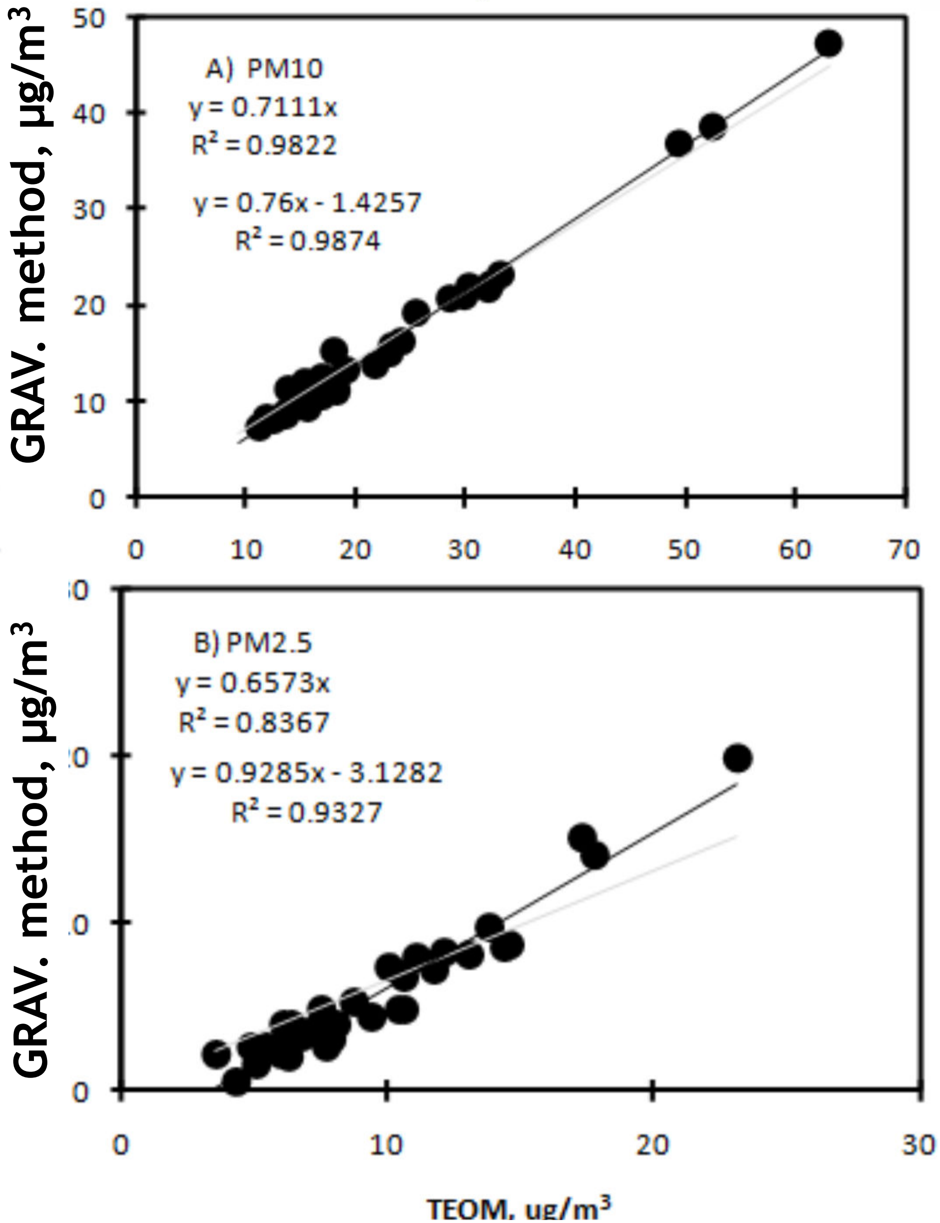
- Disadvantages:
  - Possible dependency of the aerosol chemical composition (BAM)
  - Filters not useful for later chemical analysis (not possible to identified dust composition)
  - Use of radiative sources could need special permission in some countries (BAM)
  - Temperature dependency (volatile losses; seasonal and regional dependencies)

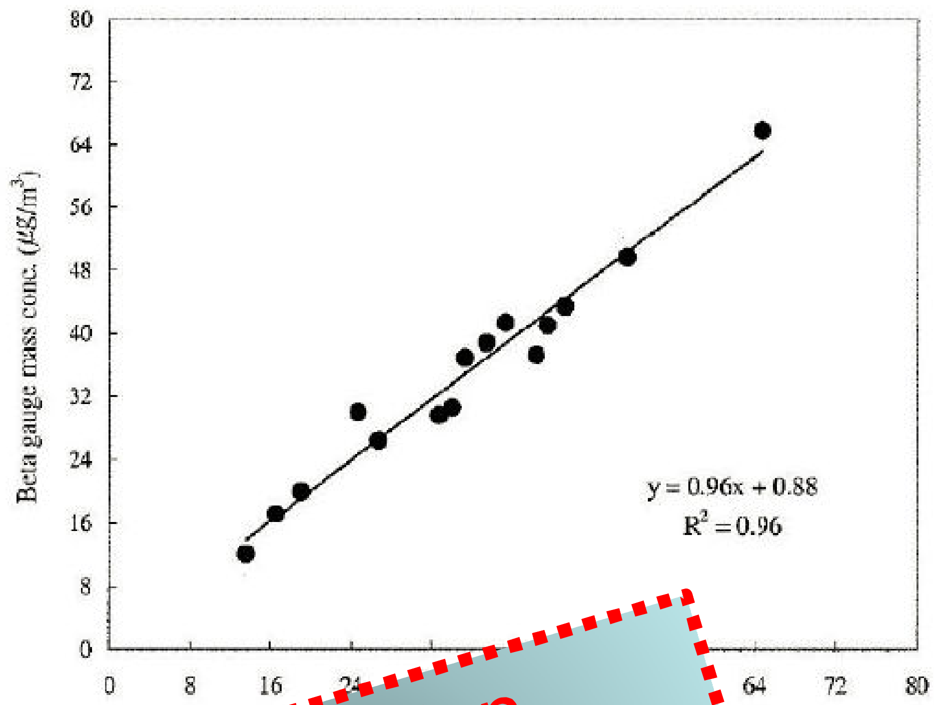
(not in the case of a TEOM-DFMS)

Automatic versus the reference gravimetric method

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

- Intercomparisons





Park et al., 2001

Standardization…
… for traceability and intercomparability

2. Automatic Methods: Low-Cost Sensor (EXPERIMENTAL!!!)

Low-cost sensors for the measurement of atmospheric composition: overview of topic and future applications (WMO, 2018)

Review of sensors for air quality monitoring (JRC-EC, 2019)

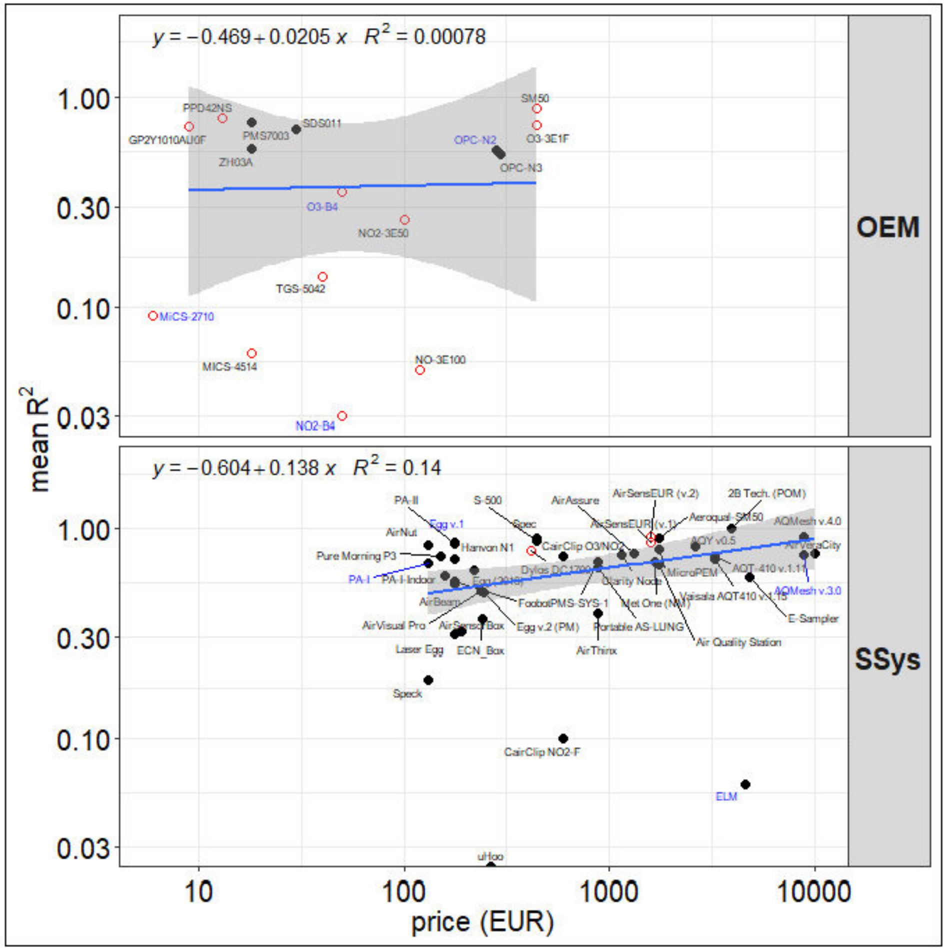
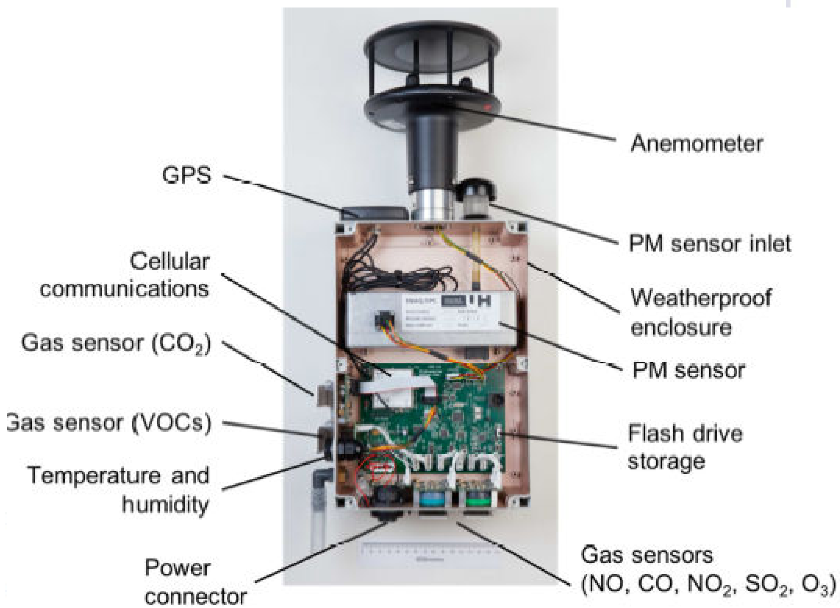


Figure 7. Relation between prices of OEMs/Sensor Systems (SS) and R^2 for field test only. Logarithmic scale has been set for both axis. Open source and black box models are indicated with open and full circles, respectively. Names of 'living' and 'non-living' sensors are indicated in black and blue colour, respectively. R^2 refers to data averaged over 1 hour. Grey shade in the fit plots indicate a pointwise 95% confidence interval on the fitted values.

TEOM ~ 40.000€
BAM(BETA) ~ 20.000€
… and high qualified operator for maintenance

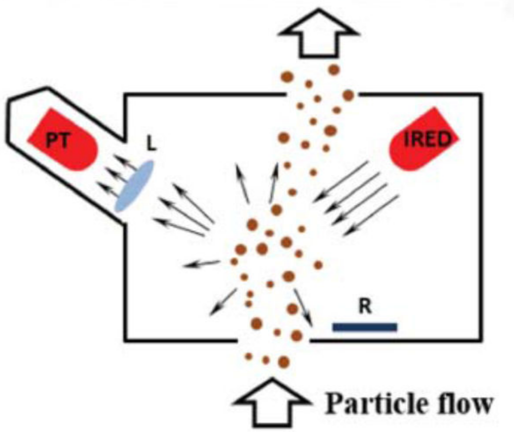
Common core components and functions may include:

- The sensing element or detector
- Sampling capability, e.g. pump or passive inlet
- Power systems, including batteries and voltage/power stabilization
- Sensor signal processing
- Local data storage
- Data transmission capability (WiFi, GPRS, 3/4G etc)
- Server-side software for data treatment
- Housing and weatherproofing

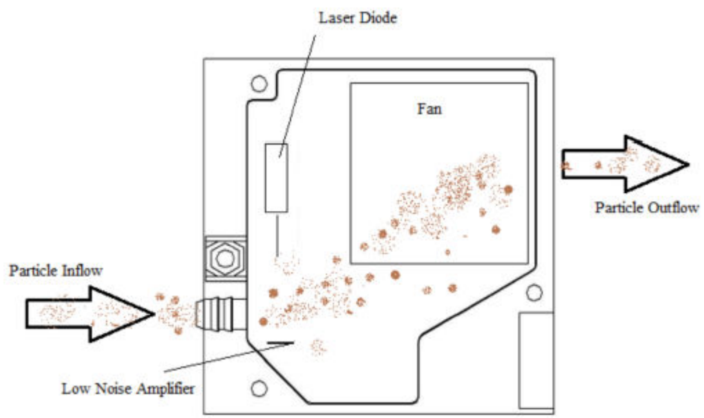


2. Automatic Methods: Low-Cost Sensor (EXPERIMENTAL!!!)

optical technique for low-cost sensing due to its low cost and power requirements and quick response times



Wang et al. - 2015



Genikomsakis et al. - 2018

A number of different approaches and locations are needed to evaluate the applications and capacities where low-cost sensors can be successfully implemented.

Concentration is proportional to the scattered light intensity and a particle density and size distribution is usually assumed

In “field-measurements” → changing conditions of particle compositions, sizes, and environmental factors such as humidity and temperature

http://aqicn.org/map/

Could be a help for increase space coverage

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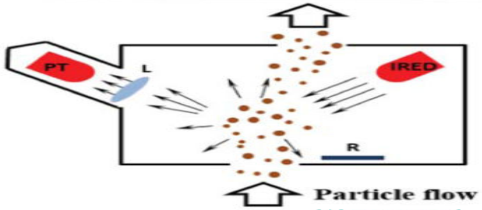
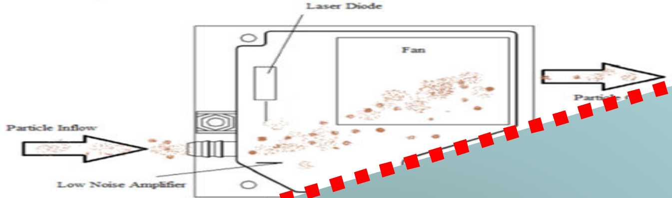
2. Automatic Methods: Low-Cost Sensor (EXPERIMENTAL!!!)

optical technique for low-cost sensing due to its low cost and power requirements and quick response times



Wang et al. - 2015



A number of diff[...]nt approaches [...]ations are [...] to evaluate [...]lications and [...]es where [...] sensors can [...]ssfully [...]nted.

Concentration is proporti[...] and a particle density[...]

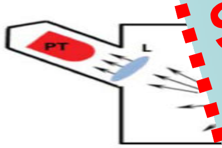
In "field-measurements" → [...] factors such as humid[...]

C[...]

The suitability of such low-cost sensors for long term monitoring of PM is yet to be explored by the scientific community.

2. A[...]

optical [...] power r[...]



[...]al. - 2018

[...]ches [...]re [...] evaluate [...]plications and [...]pacities where low-cost sensors can be successfully implemented.

Concentrati[...] [...]attered light intensity and a partic[...] [...]ribution is usually assumed

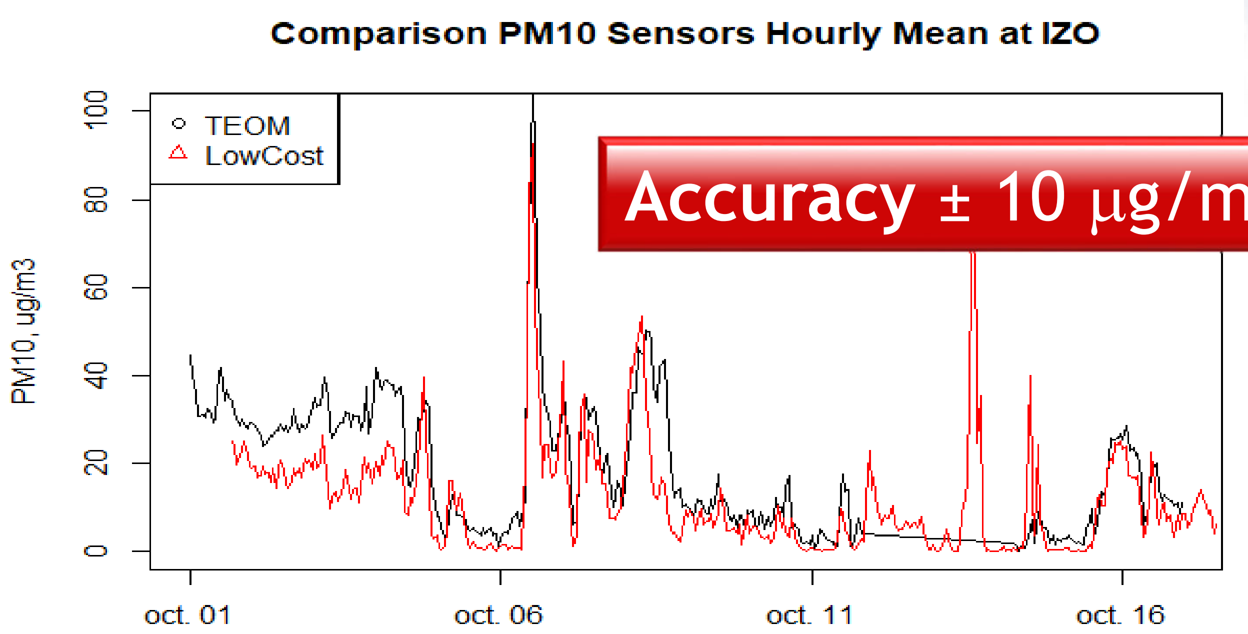
In "field-measurem[...] [...] of particle compositions, sizes, and environmental factors such as hum[...]

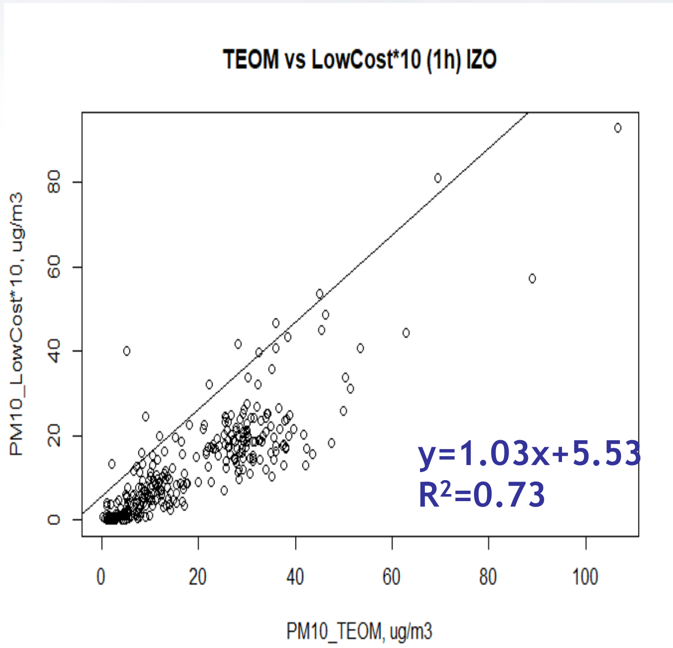
http://aqicn.org/map/

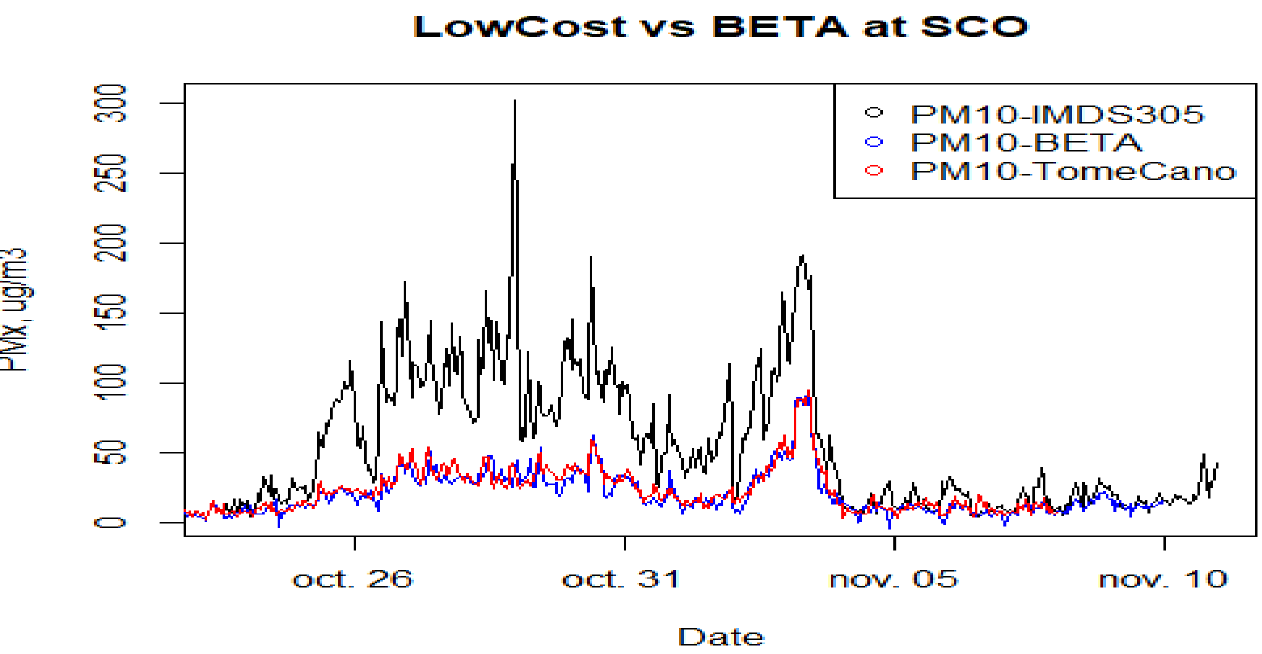
Could be a help for increase space coverage

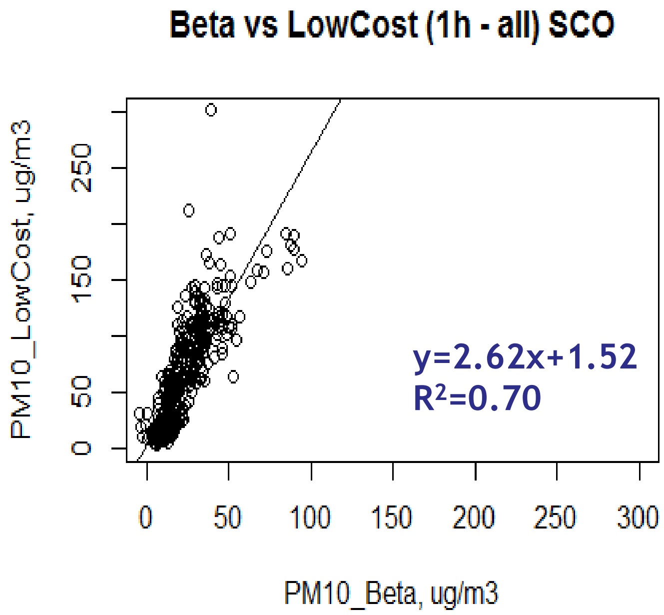
2. Automatic Methods: Low-Cost Sensor (EXPERIMENTAL!!!)

Accuracy ± 10 μg/m³









• Index

Brief introduction about aerosols and dust
(to better understand why and how)

Ground based observations

- In-situ dust estimations (Visibility)
- In-situ dust measurements
- Ground base remote sensing of dust
- Summary

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From in-situ dust observations to ground base remote sensing…

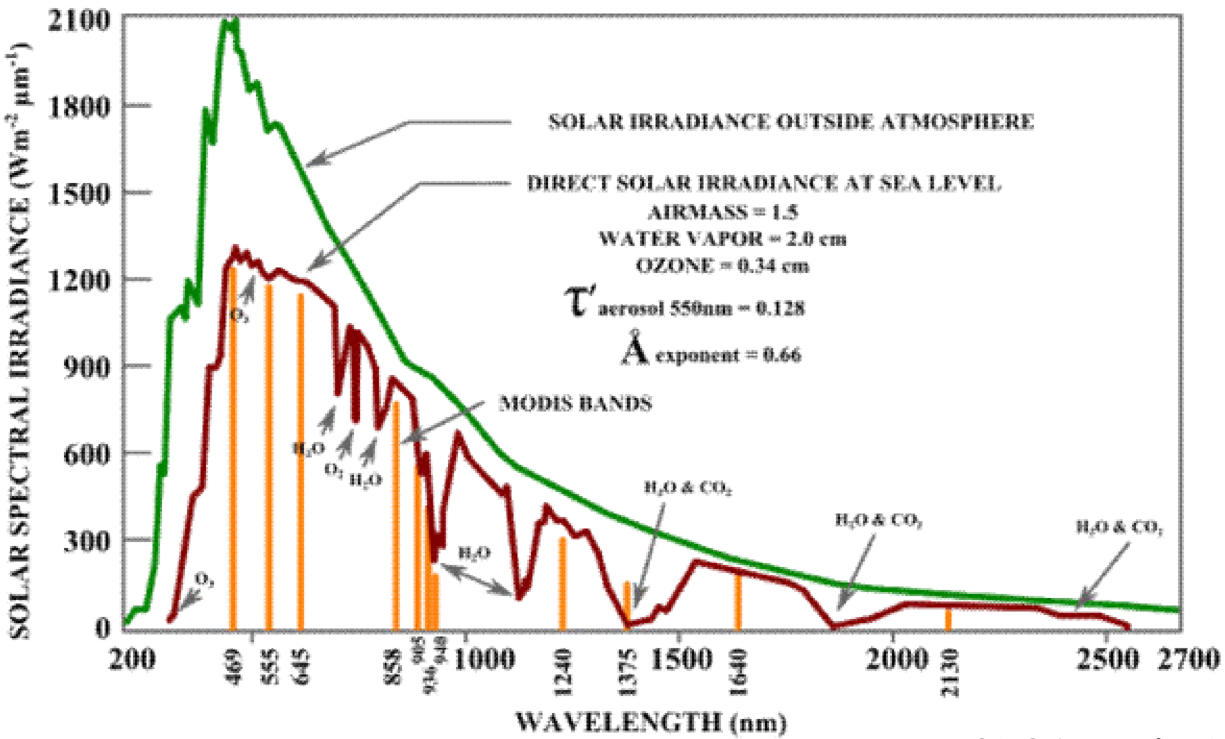
… total atmospheric column observations
(passive remote sensing, based on photometry techniques)

… vertical resolved observations
(active remote sensing, based on lidar techniques)

1. Photometry

The intensity of sunlight at the top of the earth's atmosphere is constant.

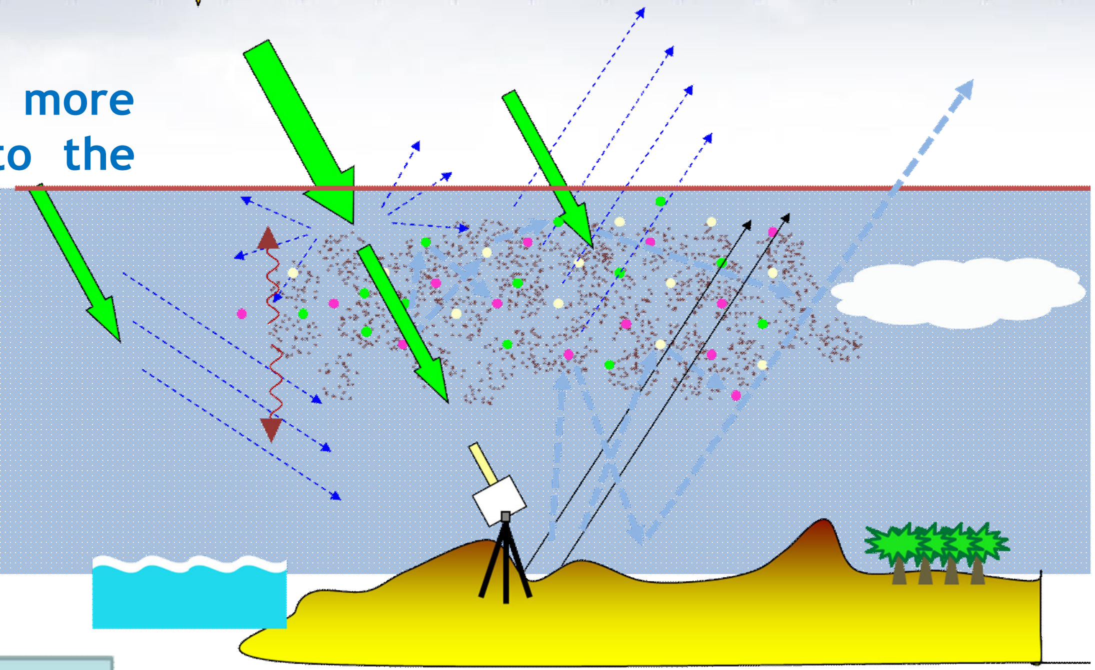
While the sunlight travels through the atmosphere, aerosols can dissipate the energy by scattering (Rayleigh and Mie) and absorbing the light. More aerosols in the atmosphere cause more extinction and less energy transmitted to the surface.



From MODIS ATM solar irradiance.svg

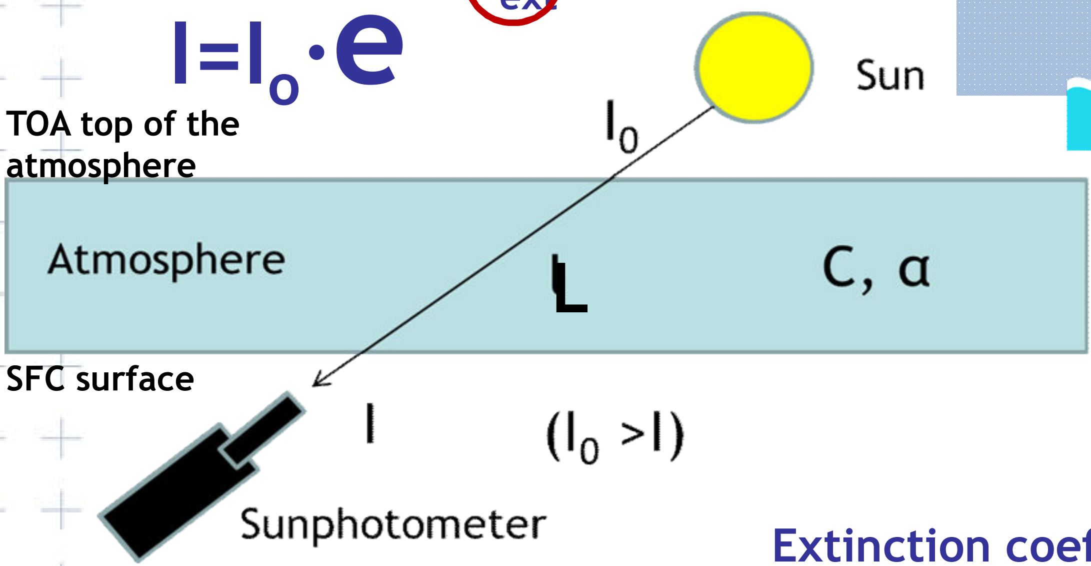
1. Photometry

More aerosols in the atmosphere cause more extinction and less energy transmitted to the surface.



Beer's Law

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



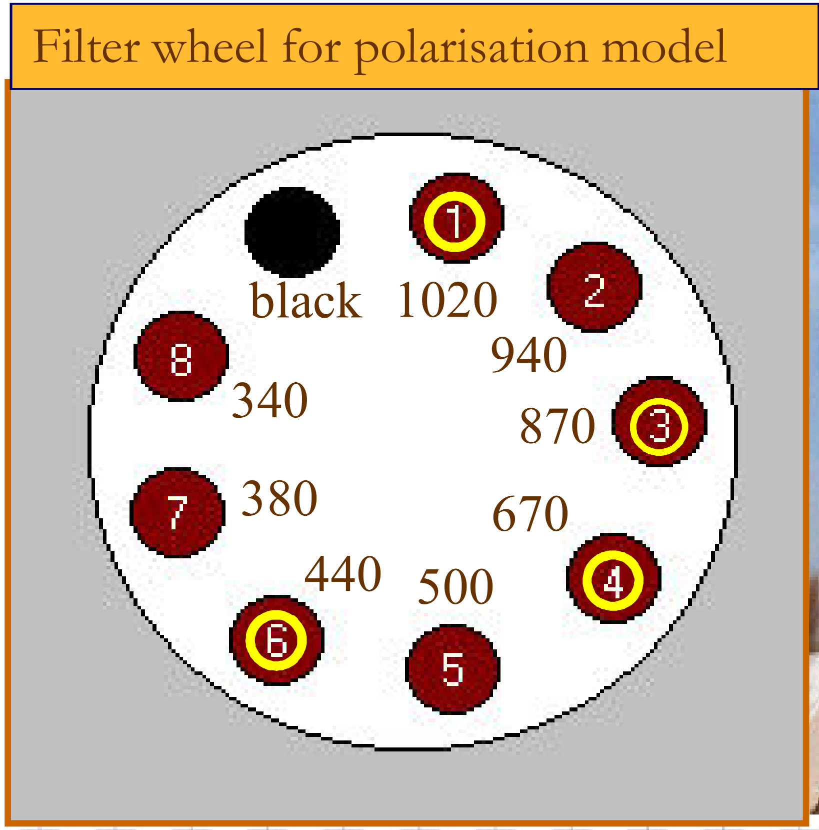
aerosol particles cross-section for light extinction per unit volume of air

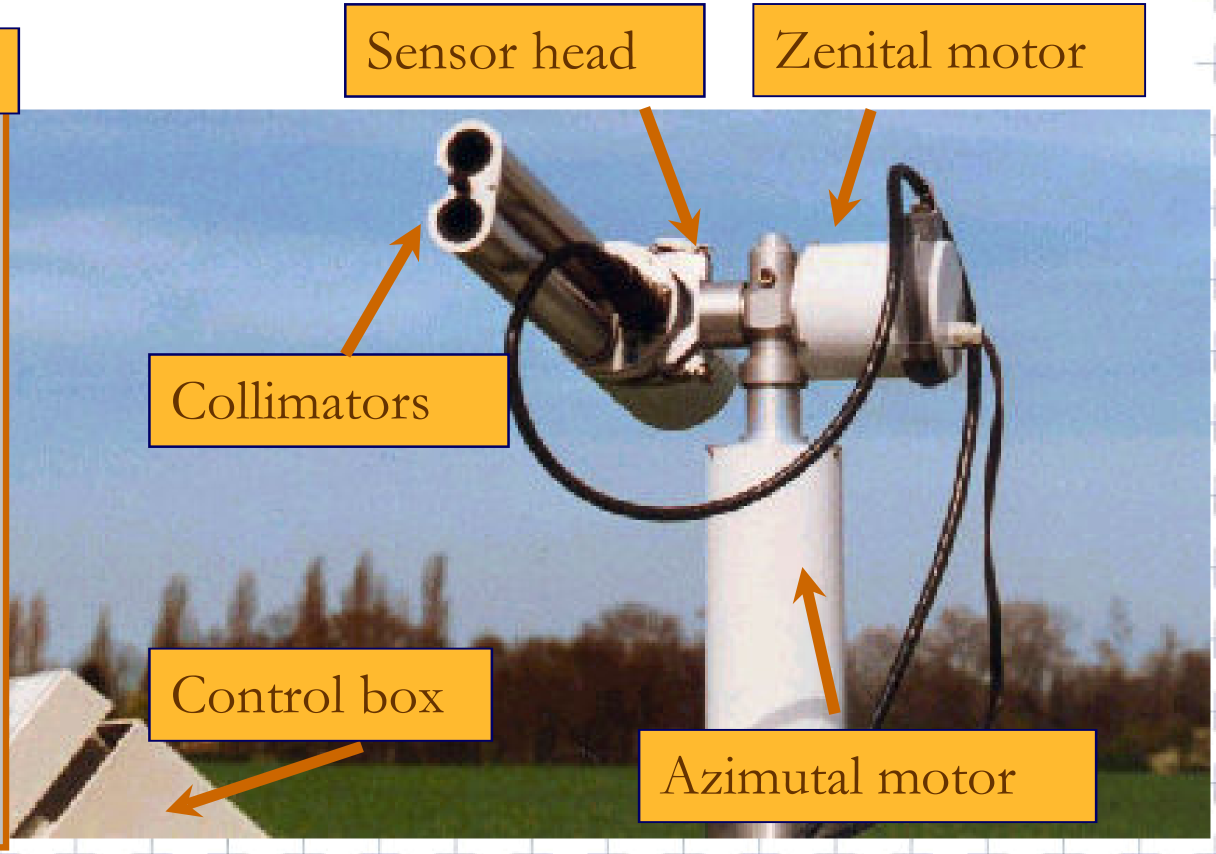
Extinction coefficient (σext): εC
Path length (L)
molar absorptivity of the absorber (ε)
concentration of absorbing species in the material (C)

1. Photometry

Sun Photometers measures *direct* sunlight energy with photodetectors (passing a interference filter with a certain bandwidth), convert the intensity into a quantified voltage ➔ to measure aerosols in the atmosphere.

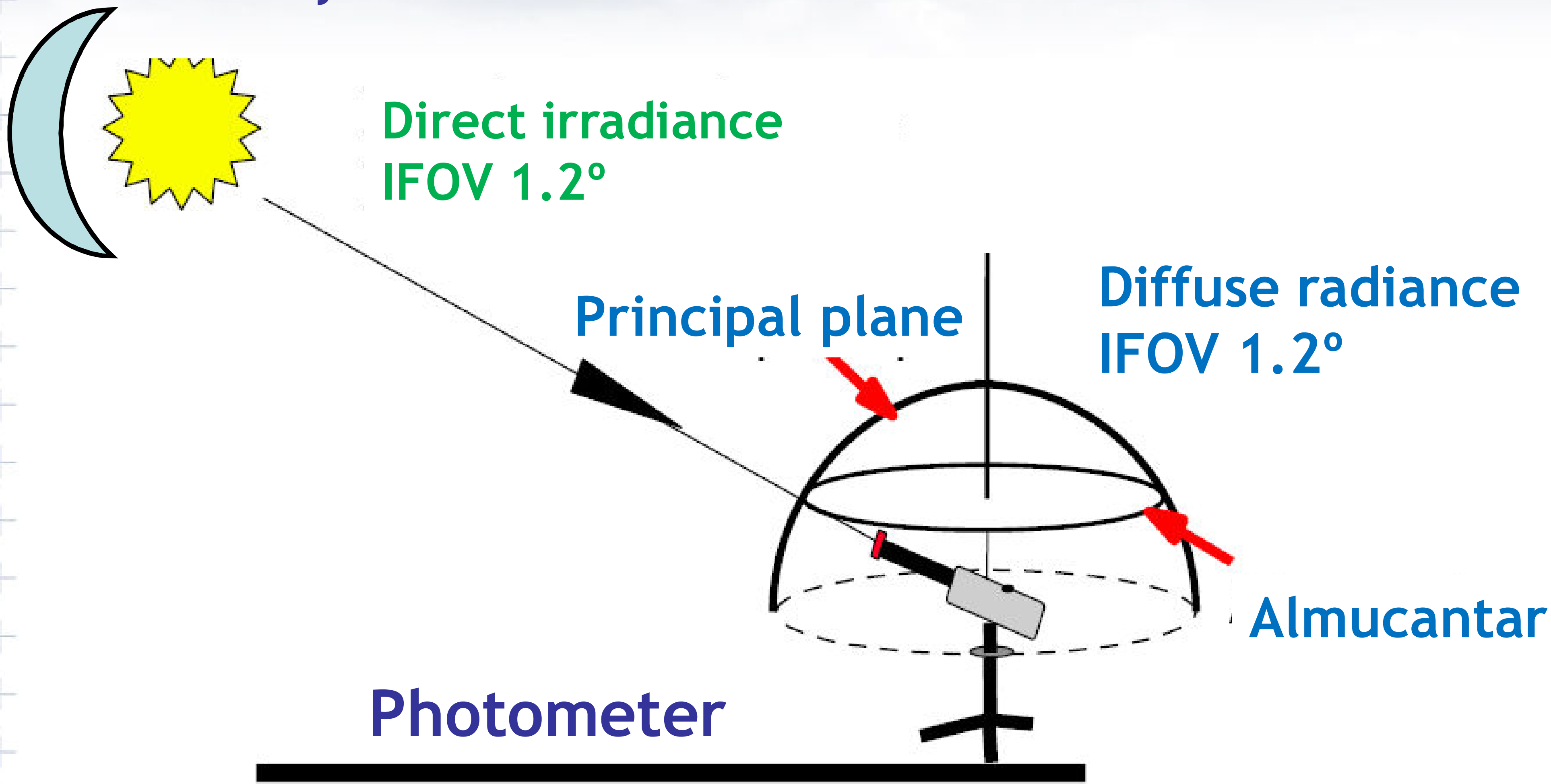
Exemple: Cimel T318





More info: http://pages.usherbrooke.ca/cimel/index.php/Accueil

1. Photometry

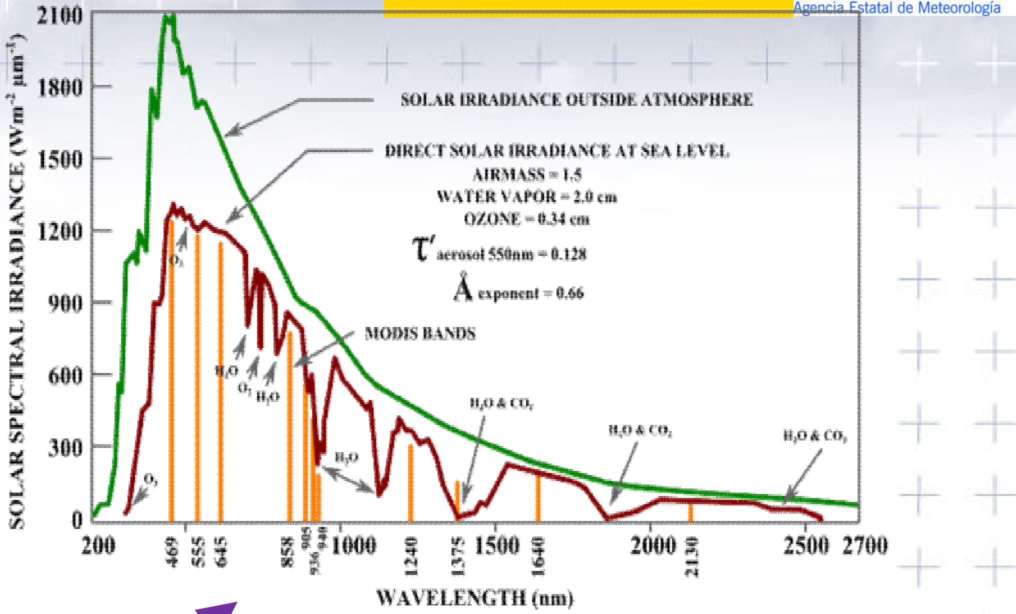


Sun/moon measurements

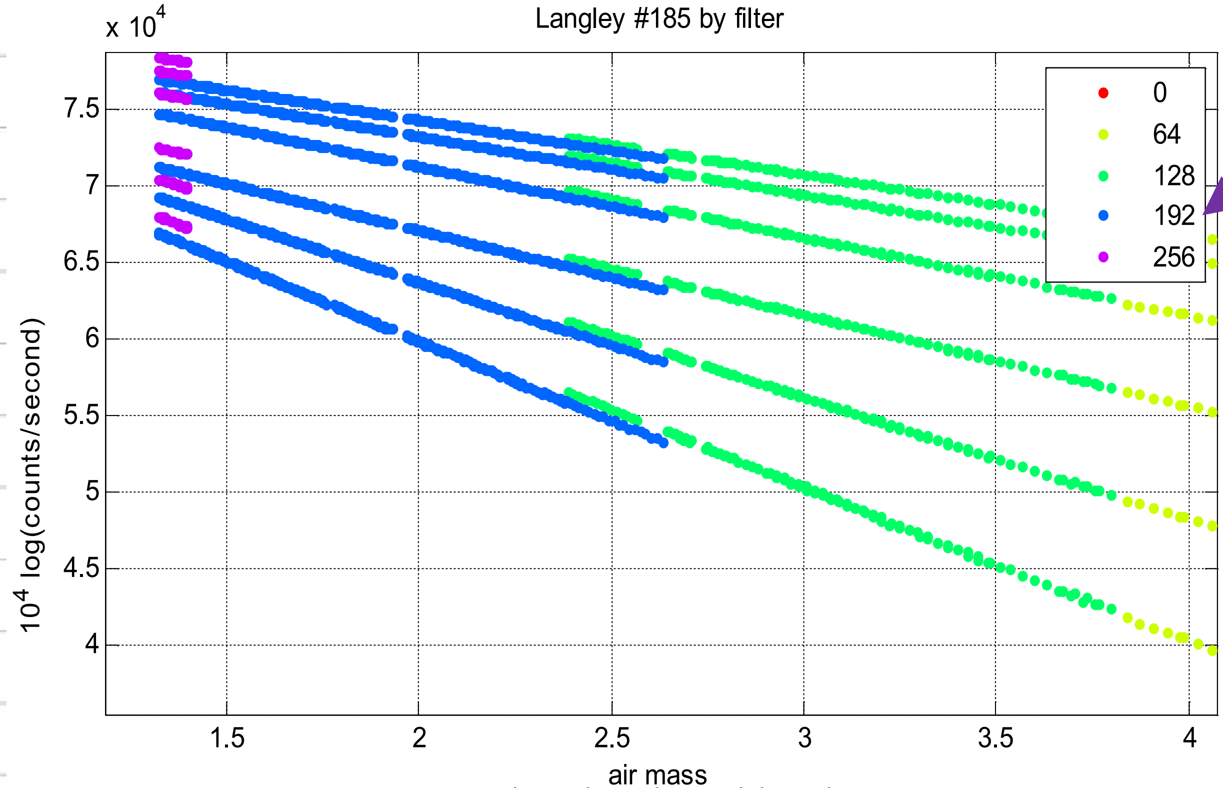
Sky measurements

1. Photometry

Langley plot calibration
(I_0 determination for each wavelength):



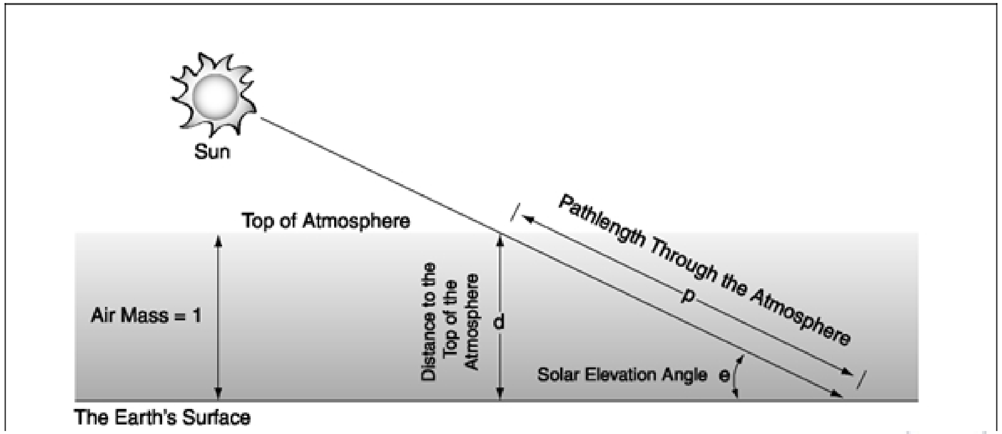
From MODIS ATM solar irradiance.svg



(air mass related with pathlenght L)

For each wavelengh

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

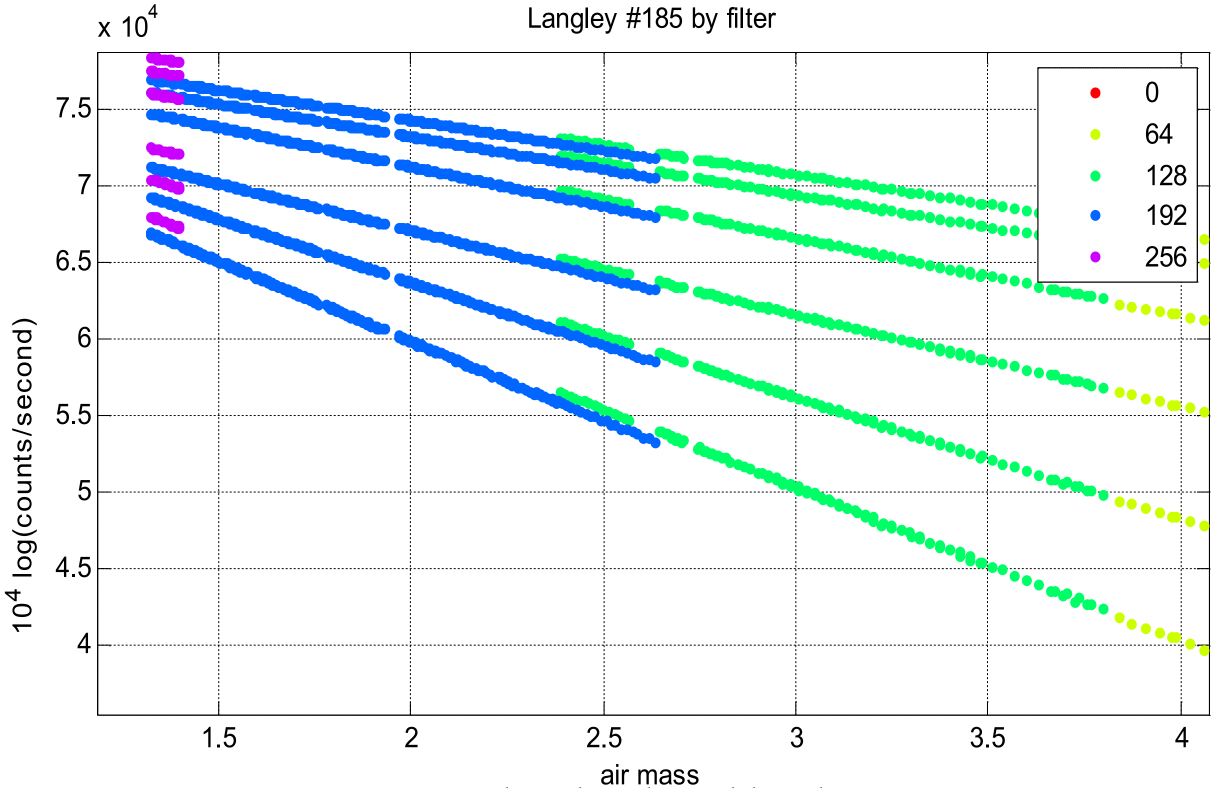


1. Photometry

$$I = I_0 \cdot e^{-\sigma_{ext} \cdot L}$$

$$\ln I = \ln I_0 - \sigma_{ext} L$$

Langley plot calibration
(I_0 determination for each wavelength):



(air mass related with pathlenght L)

If σ_{ext} is constant during the observation

- Pristine conditions (very low and constant aerosol load)
- No clouds
- Stable total ozone and column water vapor

We can determine I_0

1. Photometry

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 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.

$$AOD = \int_{z=0}^{z=toa} \sigma_{ext}(z)\,dz$$

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

1. Photometry

Typical AOD

Sky conditions	Green channel	Red channel
Extremely clear (pristine)	0.03 - 0.05	0.02 - 0.03
Clear	0.05 - 0.10	0.03 - 0.07
Somewaht hazy	0.10 - 0.25	0.07 - 0.20
Hazy	0.25 - 0.5	0.20 - 0.40
Extremly hazy	> 0.5	> 0.4

Note that red AOD values are typically less than green AOD values. This is due to the fact that typical aerosols scatter green light more efficiently than red light.

1. Photometry

CONCEPTS:

Angstrom Exponent (α)

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

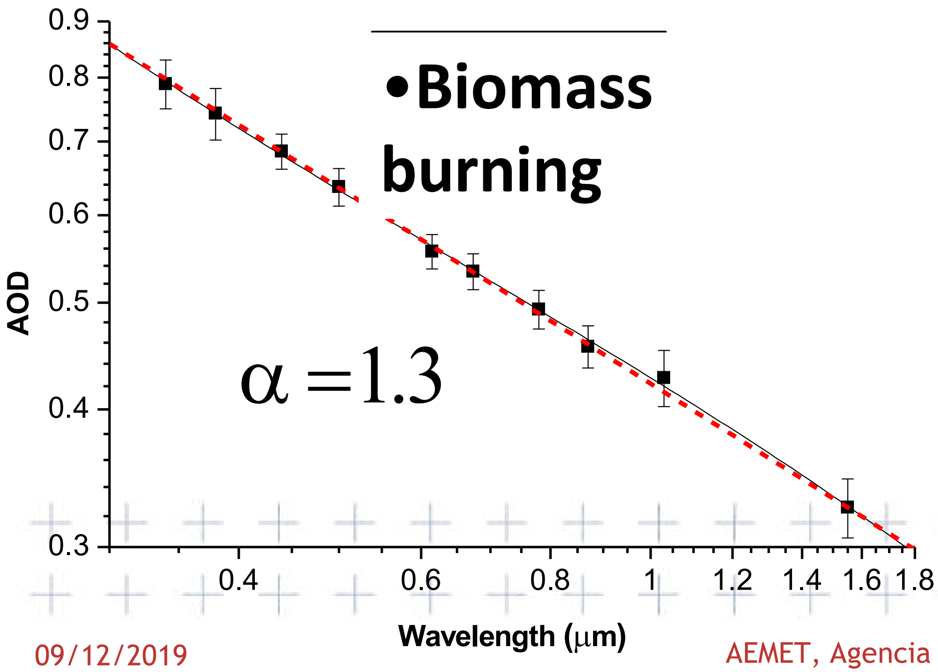
AOD → τ_a

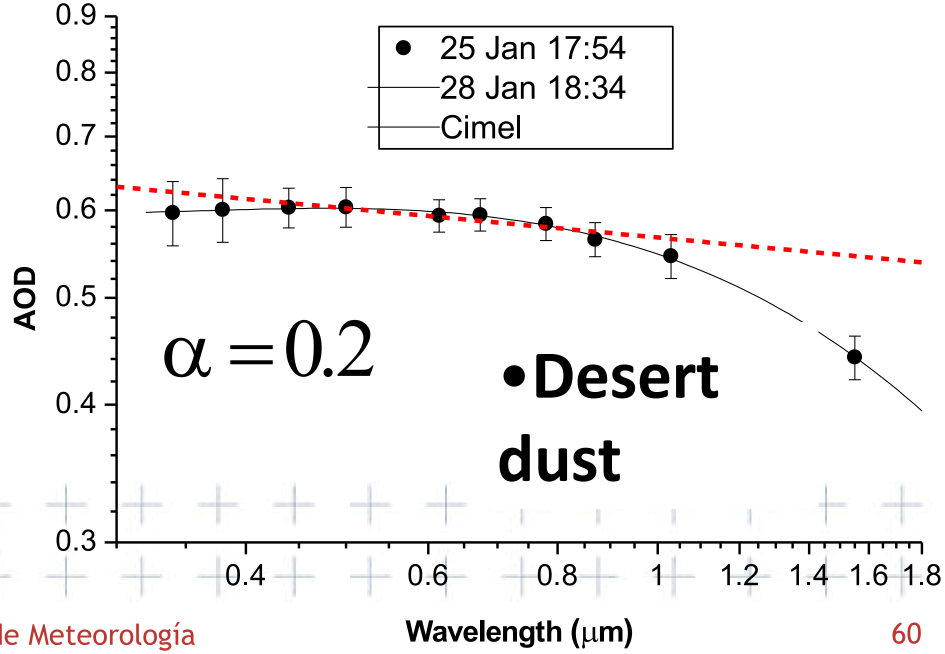
$$\tau_a = \beta \cdot \lambda^{-\alpha}$$

α >> 0.9 FINE particles

α << 0.7 COARSE particles

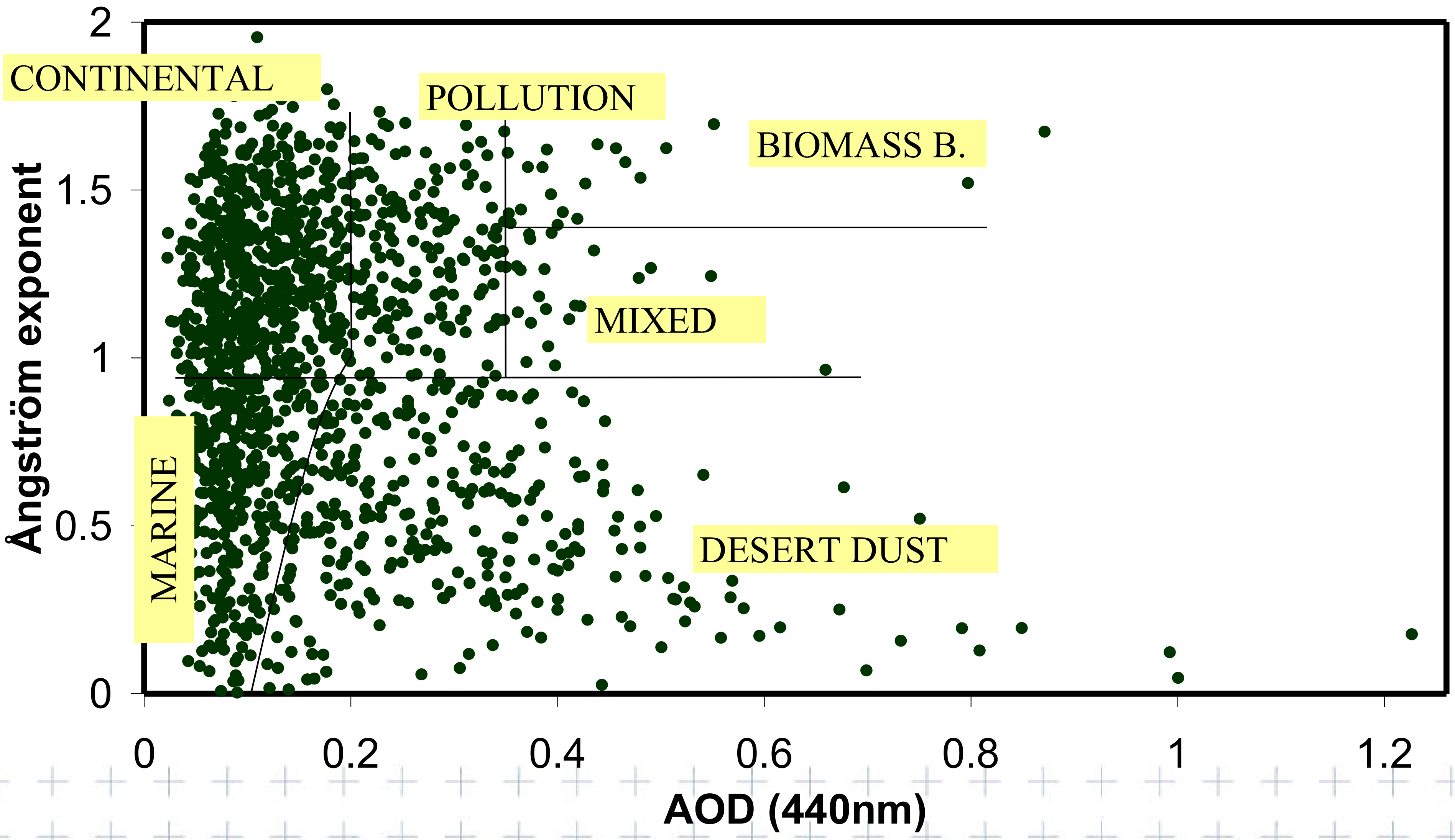
where α is the Angstrom exponent (β = aerosol optical depth at 1 µm)





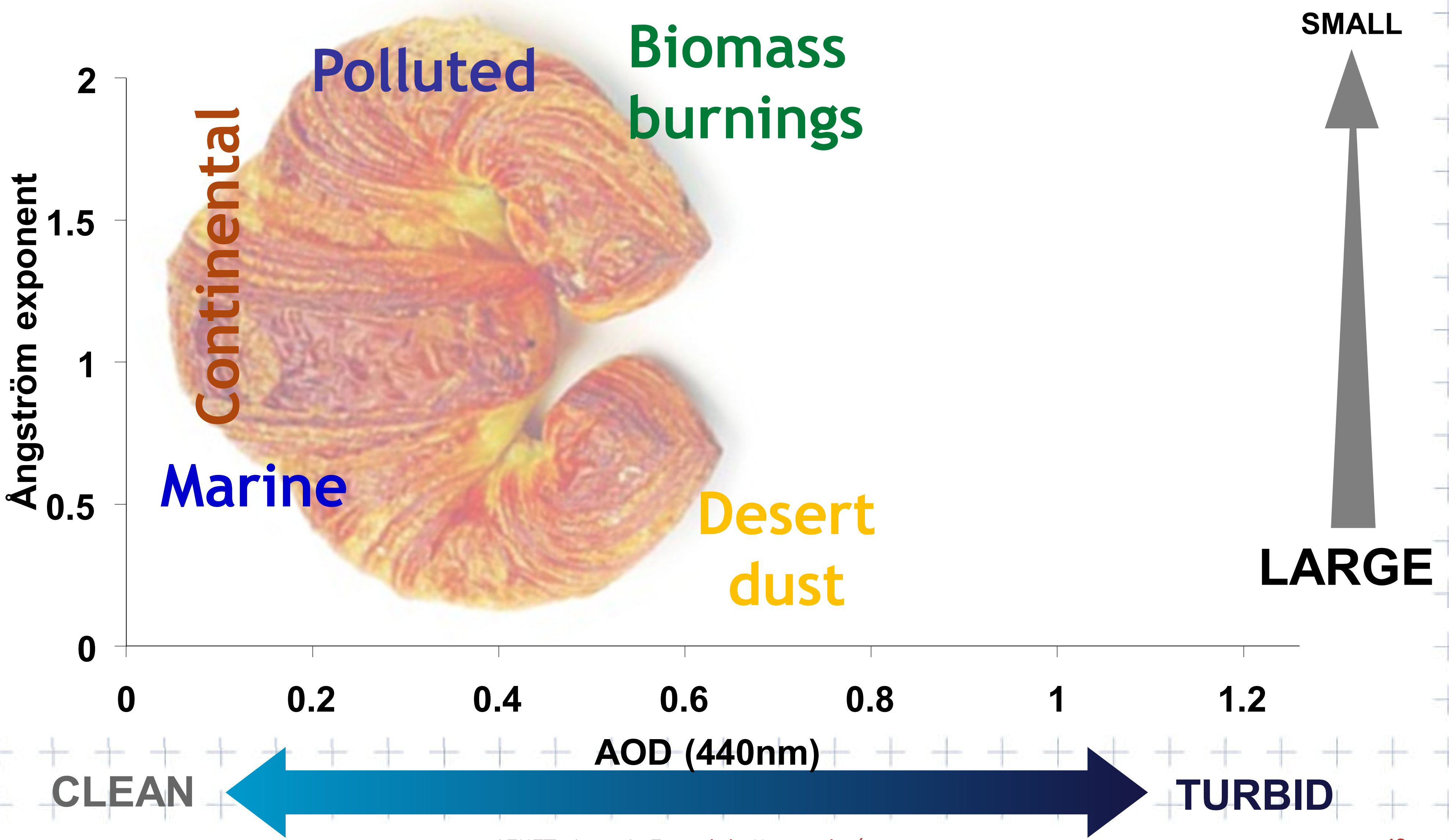
1. Photometry

Aerosol Type with diagram AOD-α



1. Photometry

Aerosol Type with diagram AOD-α



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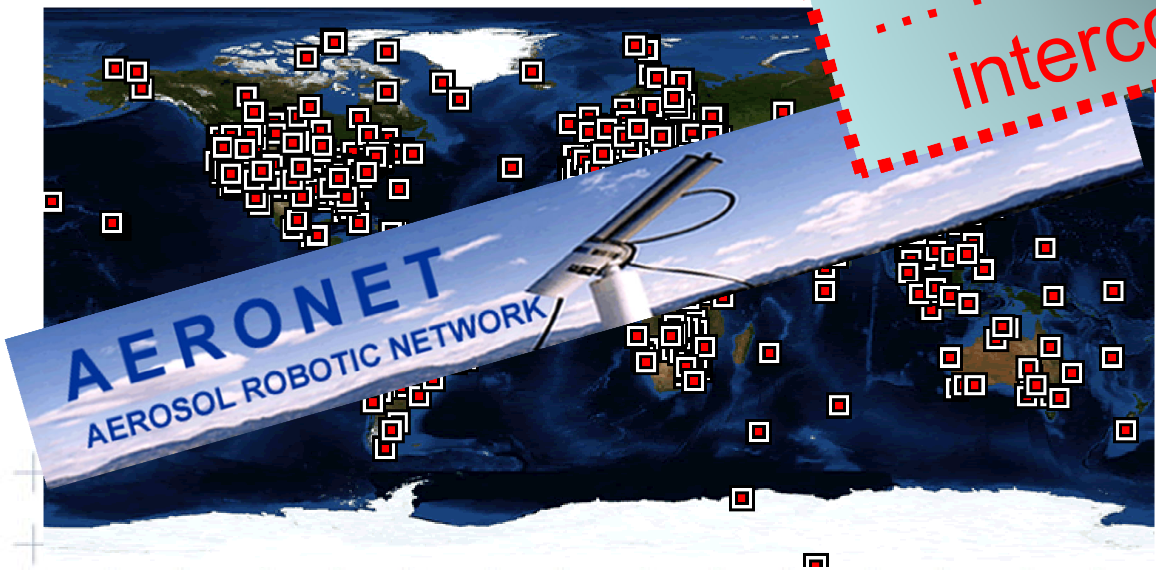
1. Photometry

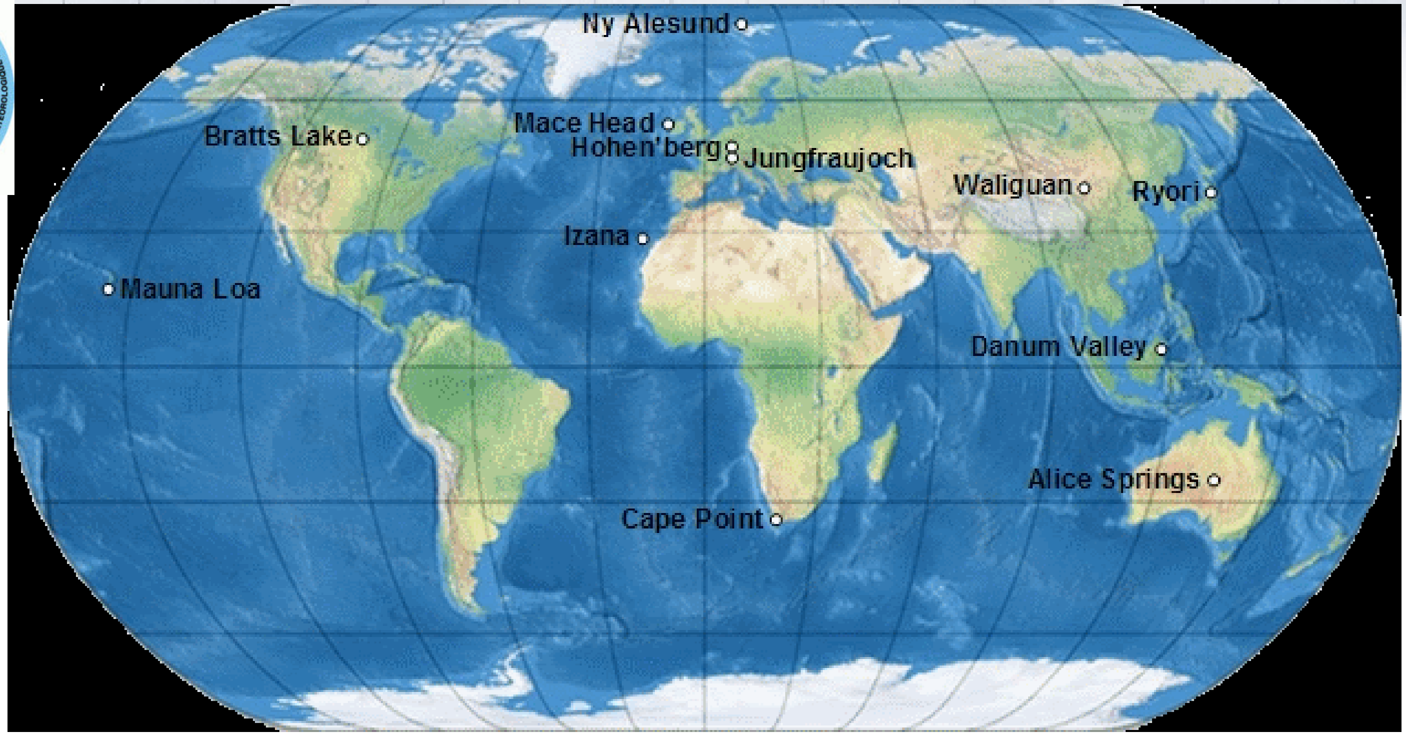
https://sds-was.aemet.es/forecast-p

Standardization…
… for traceability and intercomparability



Ground base remote sensing

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.

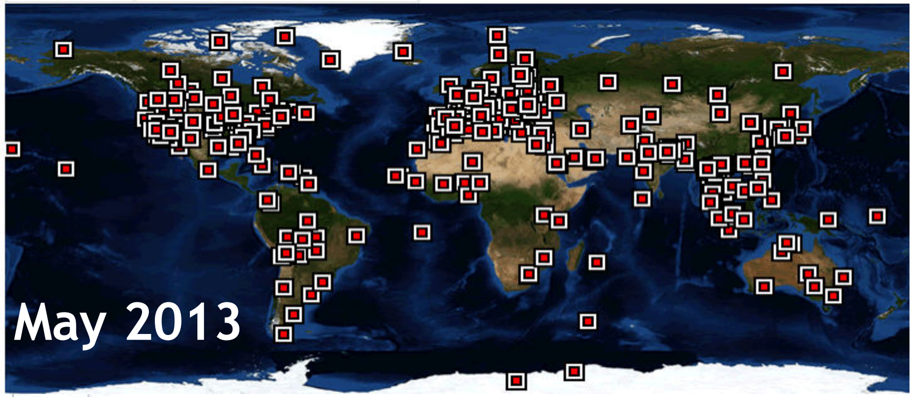
1. Photometry

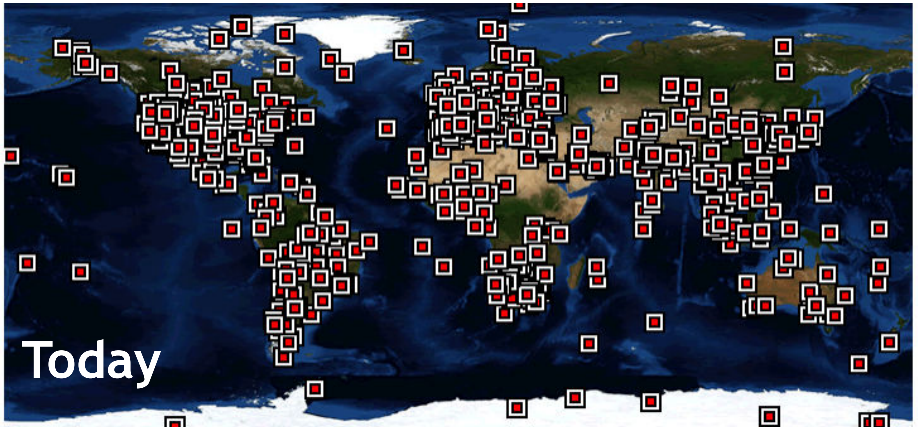
GAW-PFR provides:

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

Ground base remote sensing

AERONET Aerosol Robotic Network- More than 25 Years of Observations and Research





The AERONET program is a federation of ground-based remote sensing aerosol networks established by NASA and LOA-PHOTONS (CNRS) and has been expanded by collaborators from international agencies, institutes, universities, individual scientists and partners.

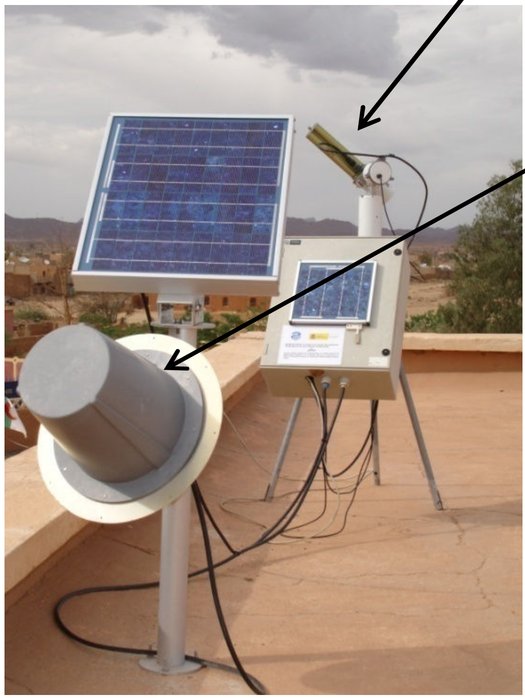
>7000 citations
>400 sites
Over 80 countries
http://aeronet.gsfc.nasa.gov

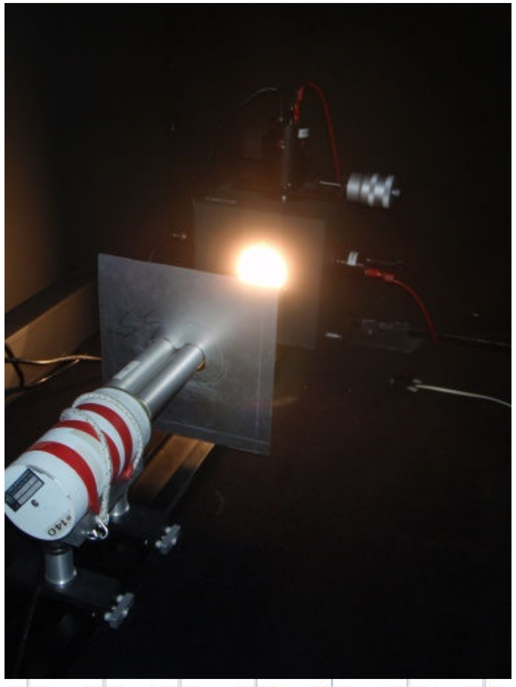
AERONET provides a long-term, continuous public database of aerosol optical, microphysical, and radiative properties for aerosol research and characterization, validation of satellite measurements, and synergism with other databases.

AERONET

1. Photometry

- The Cimel Electronique 318-T spectral radiometer is a solar-powered, weather-hardy, robotically-pointed sun, moon and sky spectral photometer.
- A sensor head points the sensor head at the sun/moon according to a preprogrammed routine.
- The Cimel controller, batteries, and the optional Vitel satellite transmission equipment are usually deployed in a weatherproof plastic case.



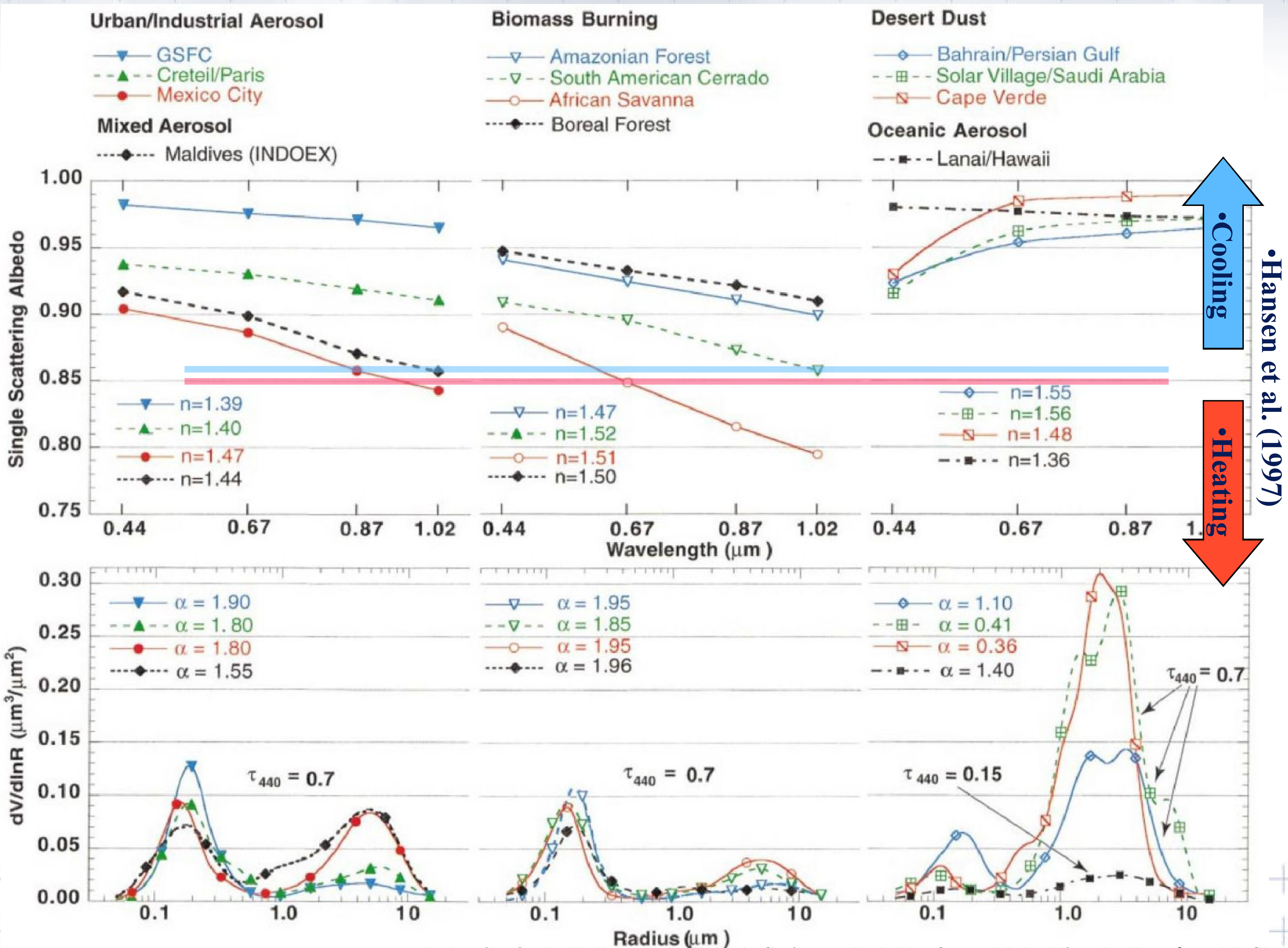


Ground base remote sensing

1. Photometry: AERONET

Aerosol Climatology from AERONET

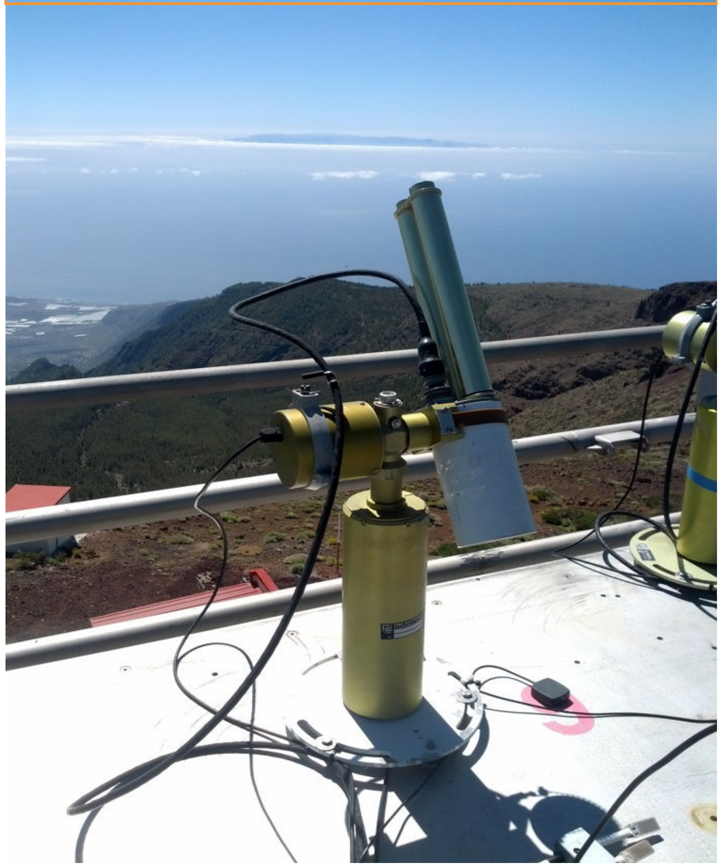
GOBIERNO DE ESPAÑA · MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA · AEMet Agencia Estatal de Meteorología



•Dubovik, O., B. Holben, T. F. Eck, A. Smirnov, Y. J. Kaufman, M. D. King, D. Tanré, and I. Slutsker, 2002: Variability of absorption and optical properties of key aerosol types observed in worldwide locations. *J. Atmos.*

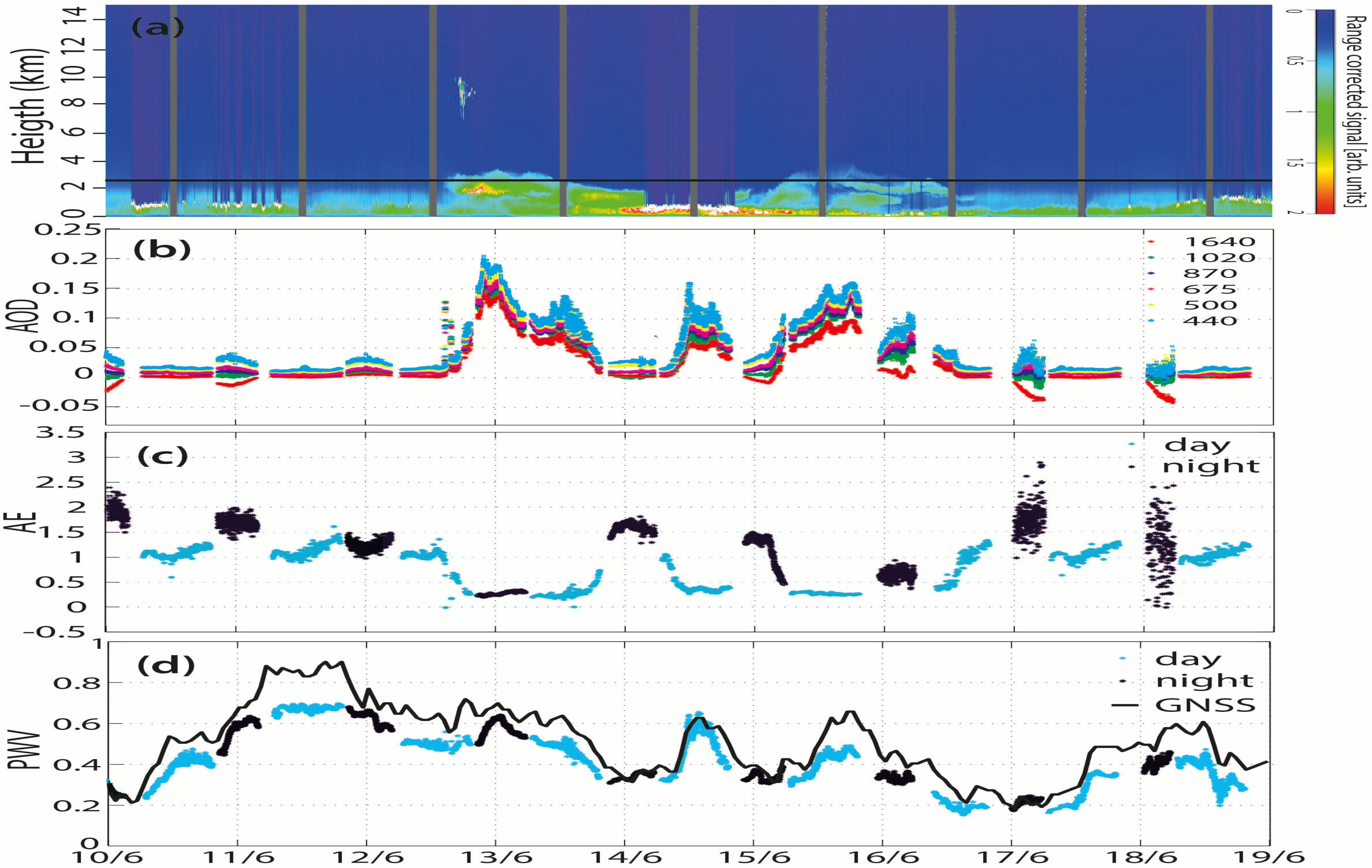
1. Photometry: CE318T

DAYTIME.



NIGHTTIME

1. Photometry: 318-T



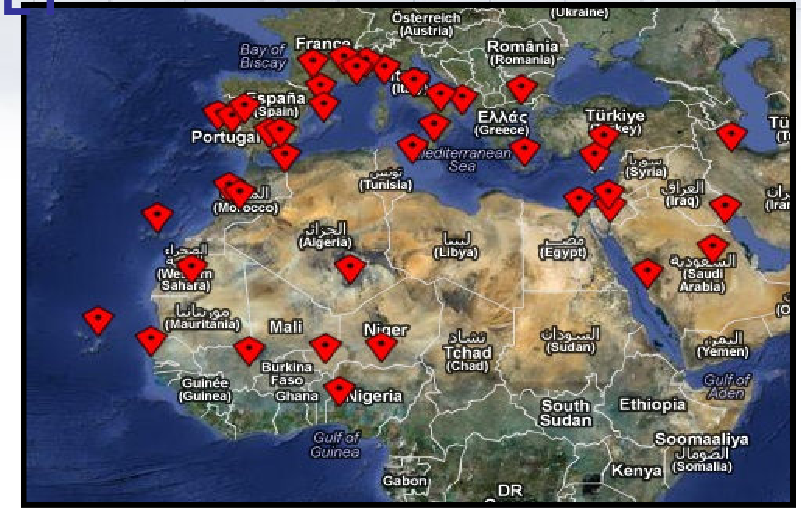
NRT evaluation using AERONET data

GOBIERNO DE ESPAÑA MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA

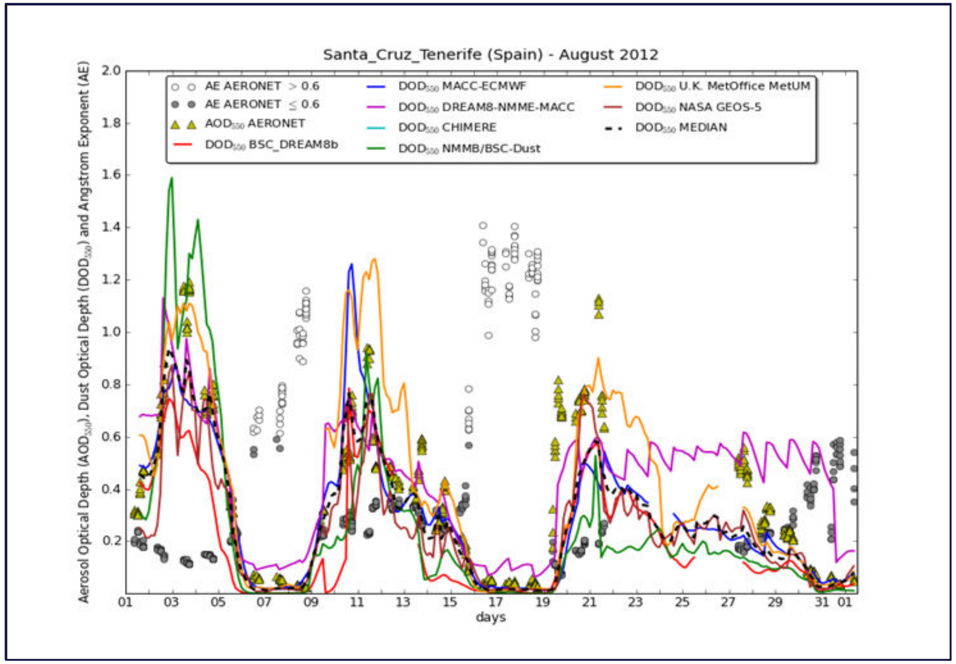
AEMet Agencia Estatal de Meteorología

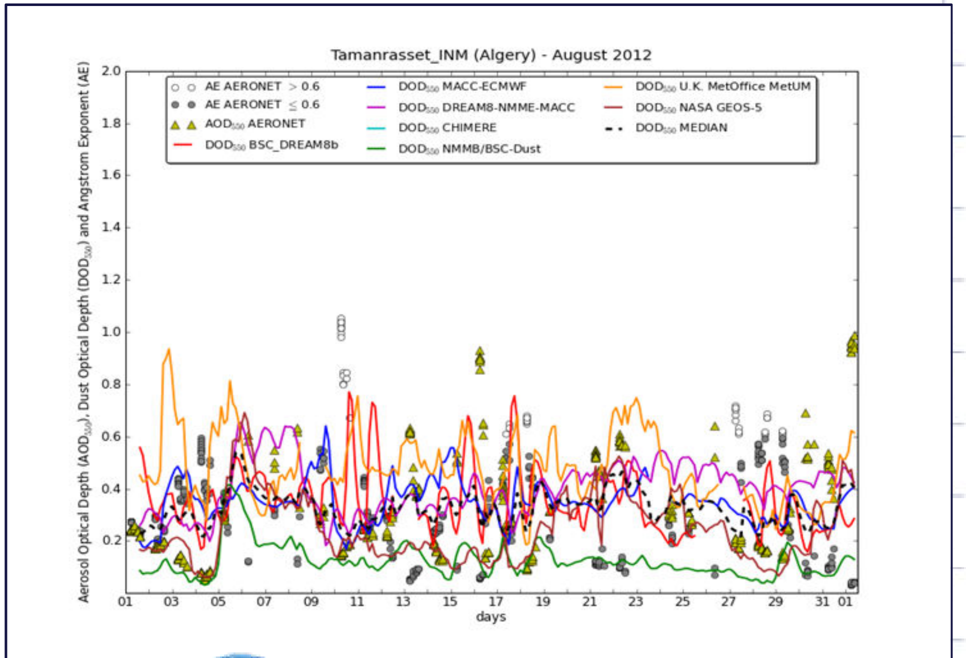
1. Photometry: AERONET

SANTA_CRUZ_TENERIFE



TAMANRASSET_INM





NORTHERN AFRICA-MIDDLE EAST-EUROPE (NA-ME-E) REGIONAL CENTER

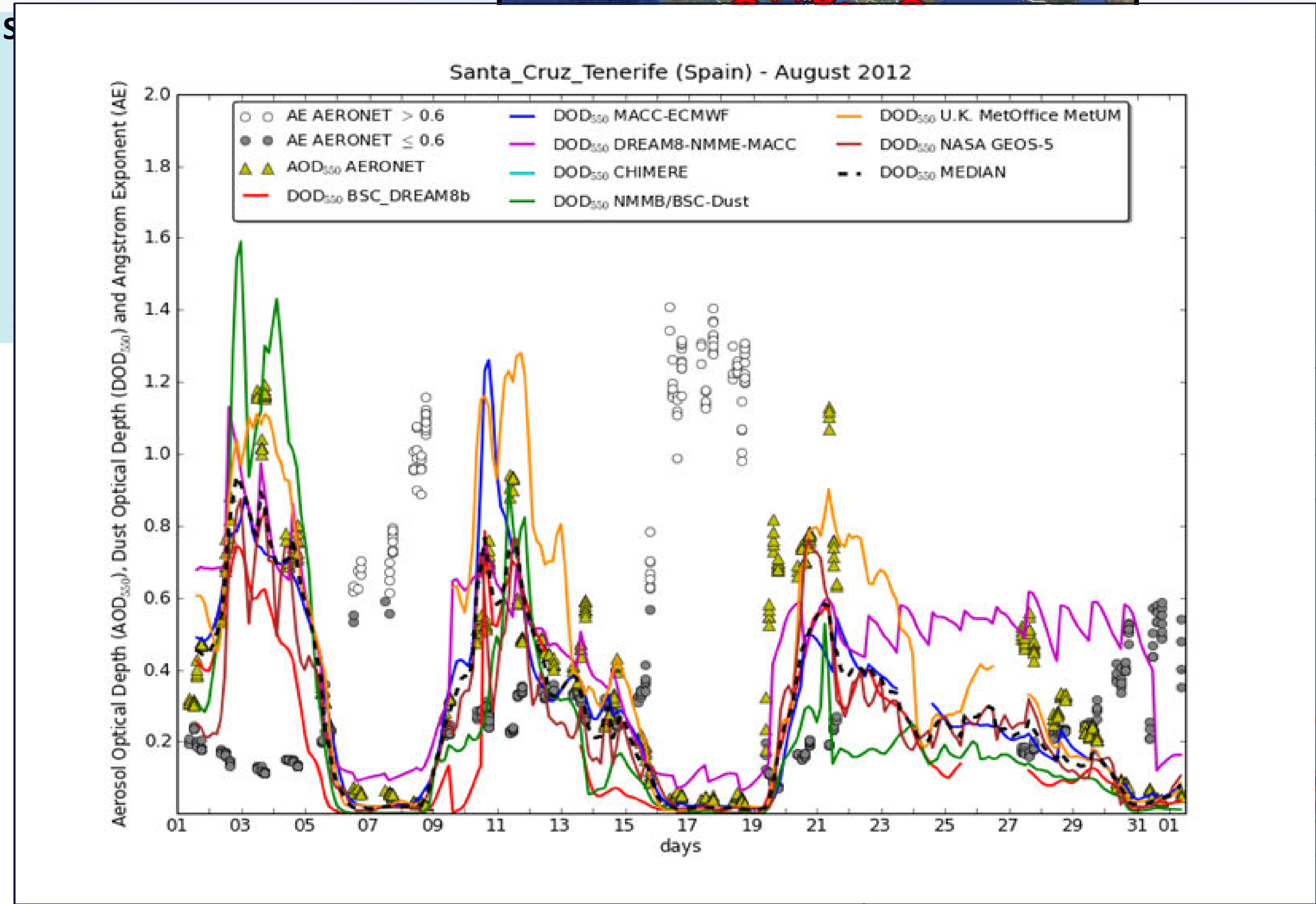
WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS)

WMO SDS WAS || Asia Regional Center || America Regional Center

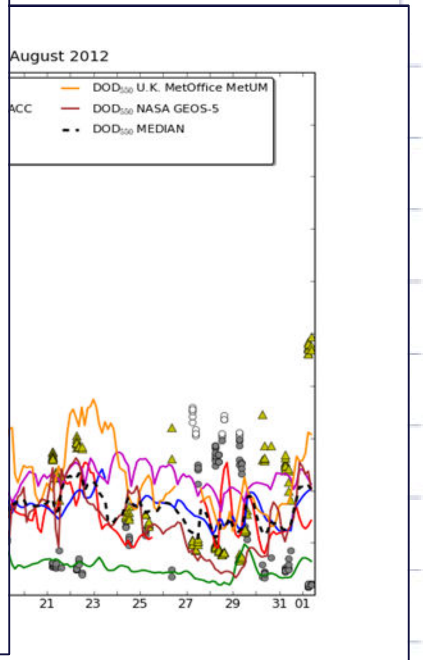
Copernicus Europe's eyes on Earth

NRT evaluation using AERONET data

1. Photometry: AERONET



TAMANRASSET_INM



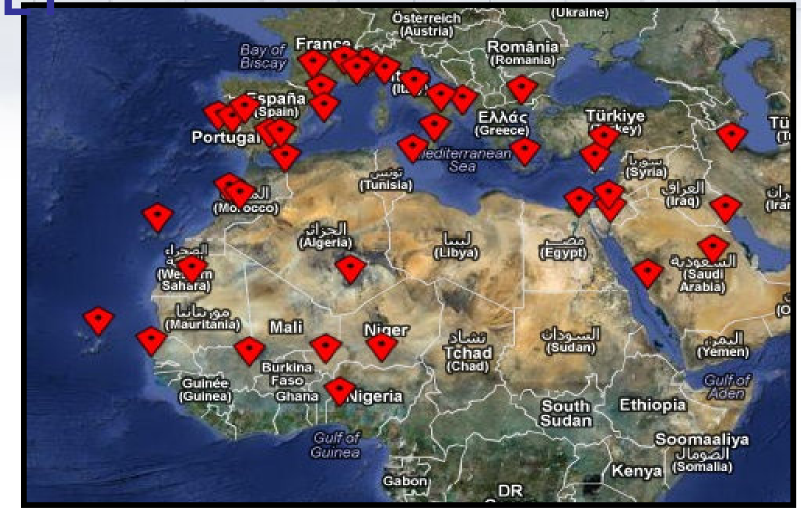
Copernicus
Europe's eyes on Earth

Ground base remote sensing

NRT evaluation using AERONET data

1. Photometry: AERONET

SANTA_CRUZ_TENERIFE



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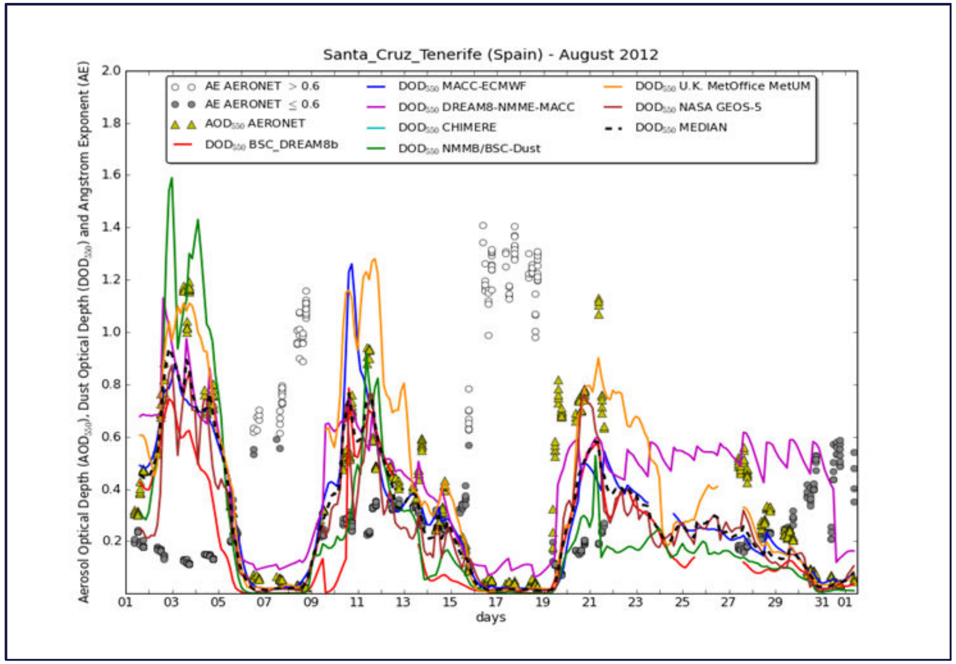

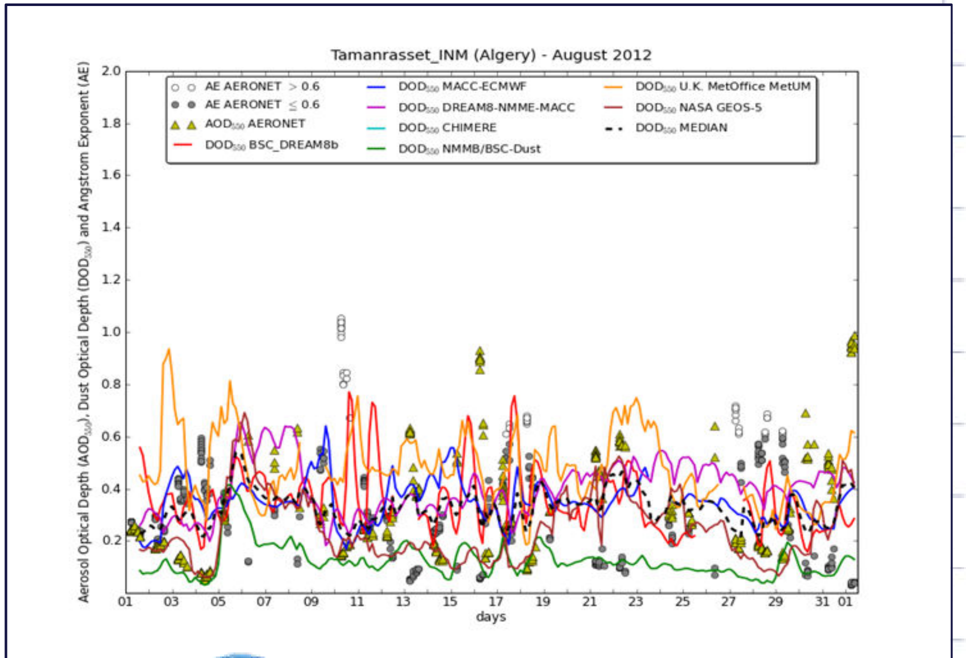

NORTHERN AFRICA-MIDDLE EAST-EUROPE (NA-ME-E) REGIONAL CENTER

WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS)

WMO SDS WAS || Asia Regional Center || America Regional Center

Copernicus — Europe's eyes on Earth

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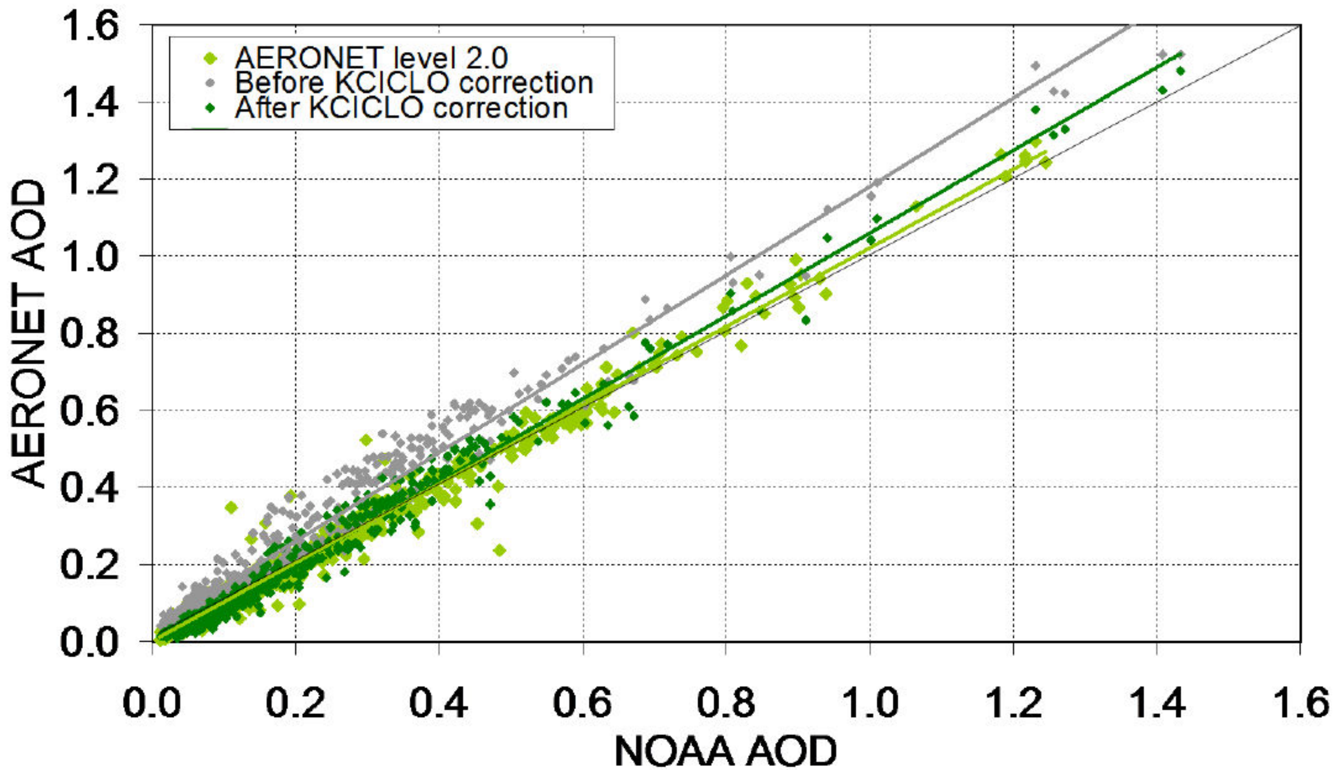
1. Photometry



Correlation between AERONET AOD@440 nm and NOAA AOD@500 nm (since 1994) for time coincident data (within 15 minutes) at Tamanrasset GAW Station (Algeria). The AERONET level 2.0 data (light green) cover the period from October 2006 to February 2009.
Correlation coefficient= 0.981
(Guirado et al., 2014)
Stable for, at least, 8 years

1. Photometry: Calitoo handheld sun photometer

Reconsidering hand-held sunphotometers for reporting dust AOD?

Microtops-II, Calitoo-Tenum...

Many observations at airports (even in remote regions)
Operated by meteorological observers
Easy data transmission through WMO GTS/WIS communication system

NRT data for model evaluation and data assimilation
NRT data for satellite evaluation
NRT data for dust nowcasting

1. Photometry: Calitoo handheld sun photometer

Technicals characteristics:

- Light channels: 465, 540 and 619 nm
- Possible 999 measures stored in memory
- AOD calculated in real-time
- USB data download
- Free software on web site.
- Supply : 4 batteries AA (1,5V)
- Dimensions : 210 x 100 x 35 mm
- Weight : 400 g (With batteries)
- Operating temperature : -20°C to 55°C

http://www.calitoo.com

1. Photometry: Calitoo handheld sun photometer

Measurements

The measurement principle is to point the Sun and search for the maximum flow. The photometer keeps only the maximum measured and then calculated the optical depth.

The Sun alignment is done manually. It is facilitated by the sighting device located above the display of the Calitoo.

The calculation of optical depth use raw brightness measurements, calibration coefficients, date and GPS position as well as atmospheric pressure.

1. Photometry: Calitoo handheld sun photometer

AOD @ 465, 540 et 619 nm
Angstrom Exponent

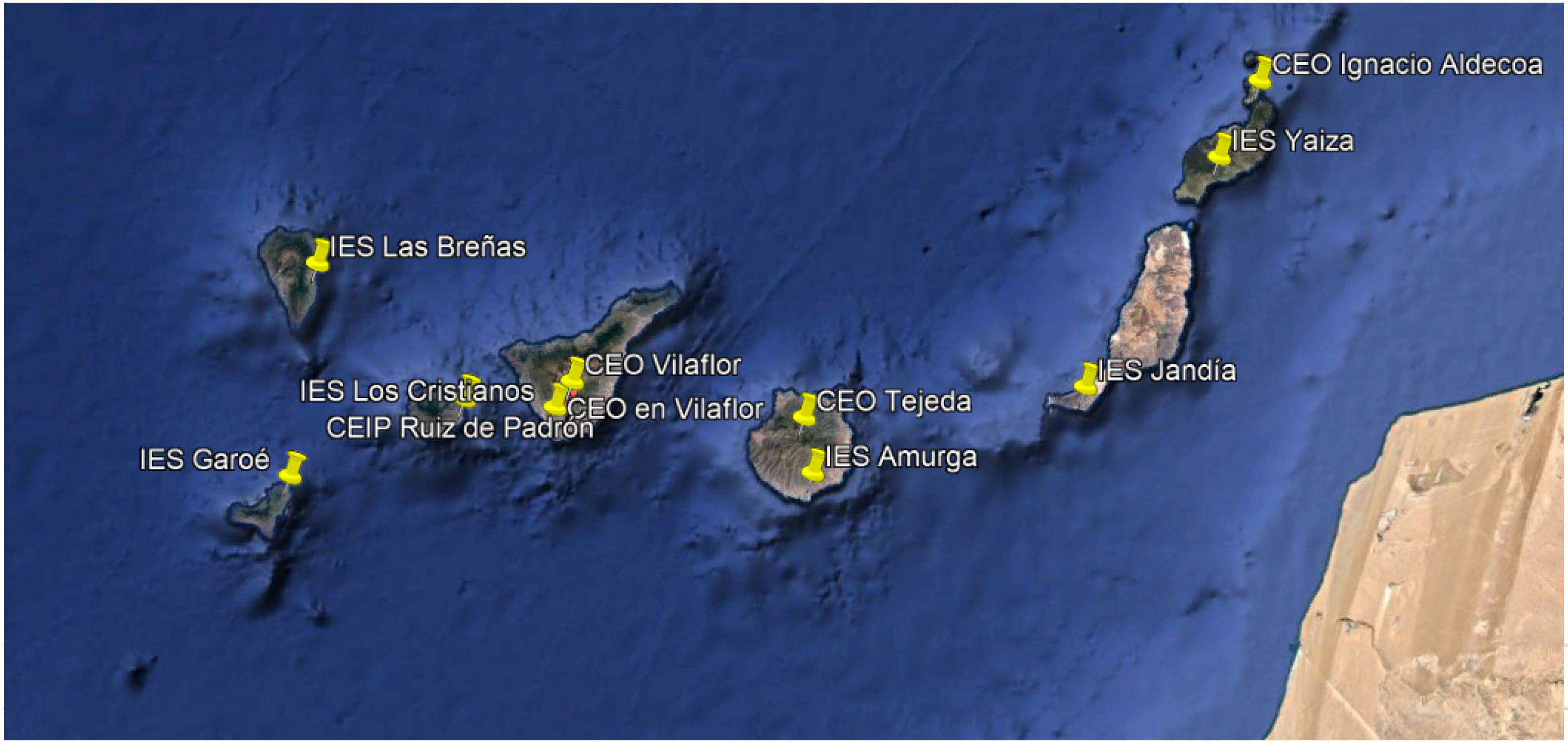
Calibration of hundred Calitoo sun-photometers involved in the GLOBE scientific-educational program **at Izaña testbed.**

Pilot experiments at:
Tamanrasset GAW Station (Algeria)
Tehran (Iran)
Aminabad Mt. Firoozkoh GAW station (Iran)

1. Photometry: Calitoo handheld sun photometer

El Hierro - IES Garoe.
La Gomera - CEIP Ruiz de Padrón.
La Palma - IES Las Breñas.
Fuerteventura - IES Jandía
Lanzarote - IES Yaiza
La Graciosa - CEO Ignacio Aldecoa.
Gran Canaria - CEO Tejeda e IES Amurga
Tenerife- IES Los Cristianos y CEO en Vilaflor

http://testbed.aemet.es/calimaview/



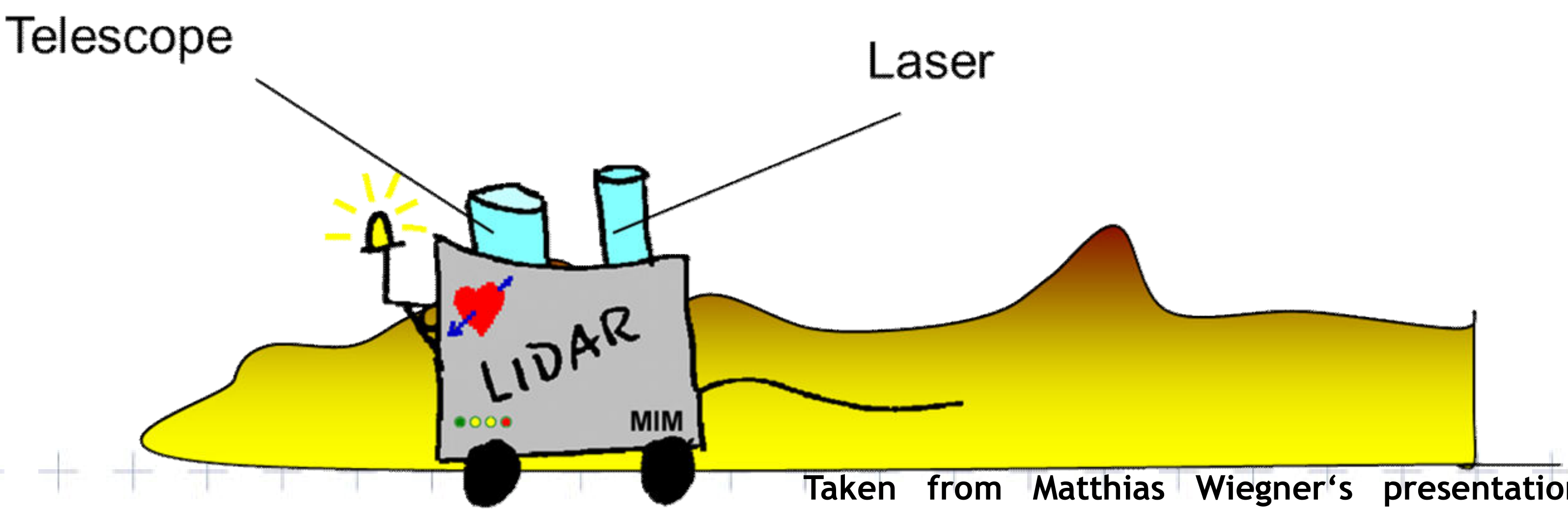
From in-situ dust concentration observations to ground base remote sensing…

… total atmospheric column observations
(passive remote sensing, based on photometry techniques)

… vertical resolved observations
(active remote sensing, based on lidar techniques)

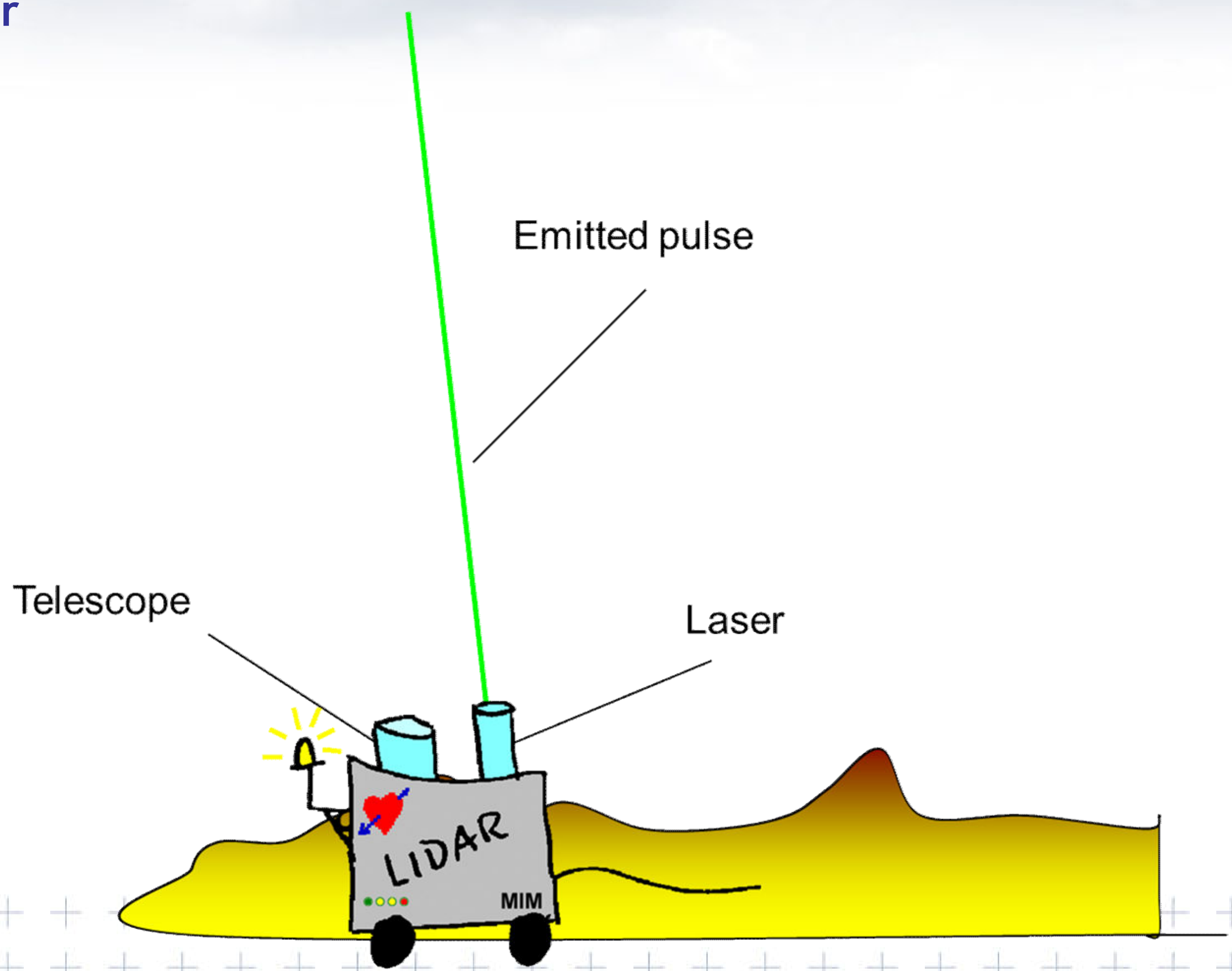
2. Lidar

Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth

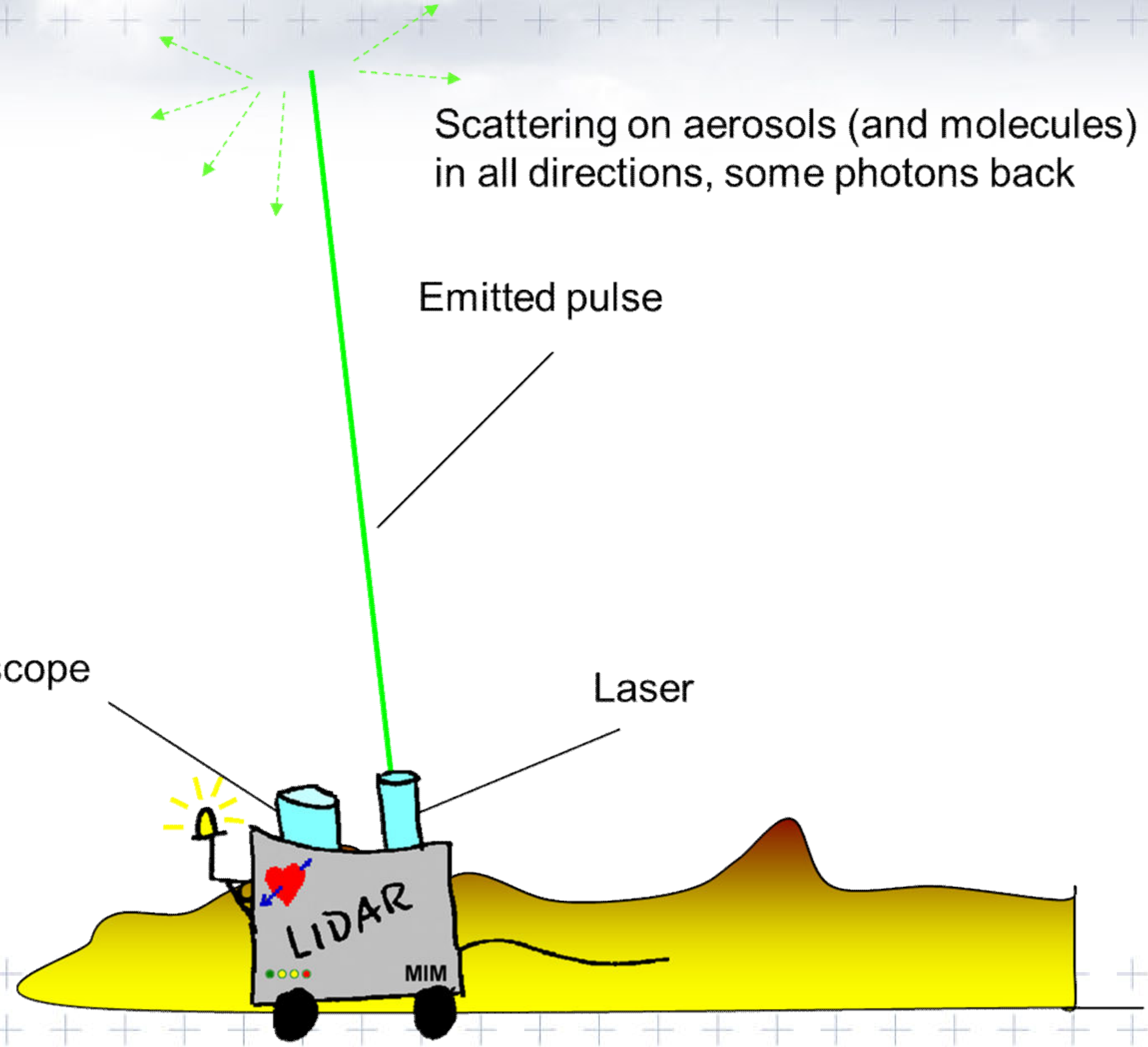


Taken from Matthias Wiegner's presentation (University of Munich, Meteorological Institute) to the SPIE 10 (International Symposium Remote Sensing)

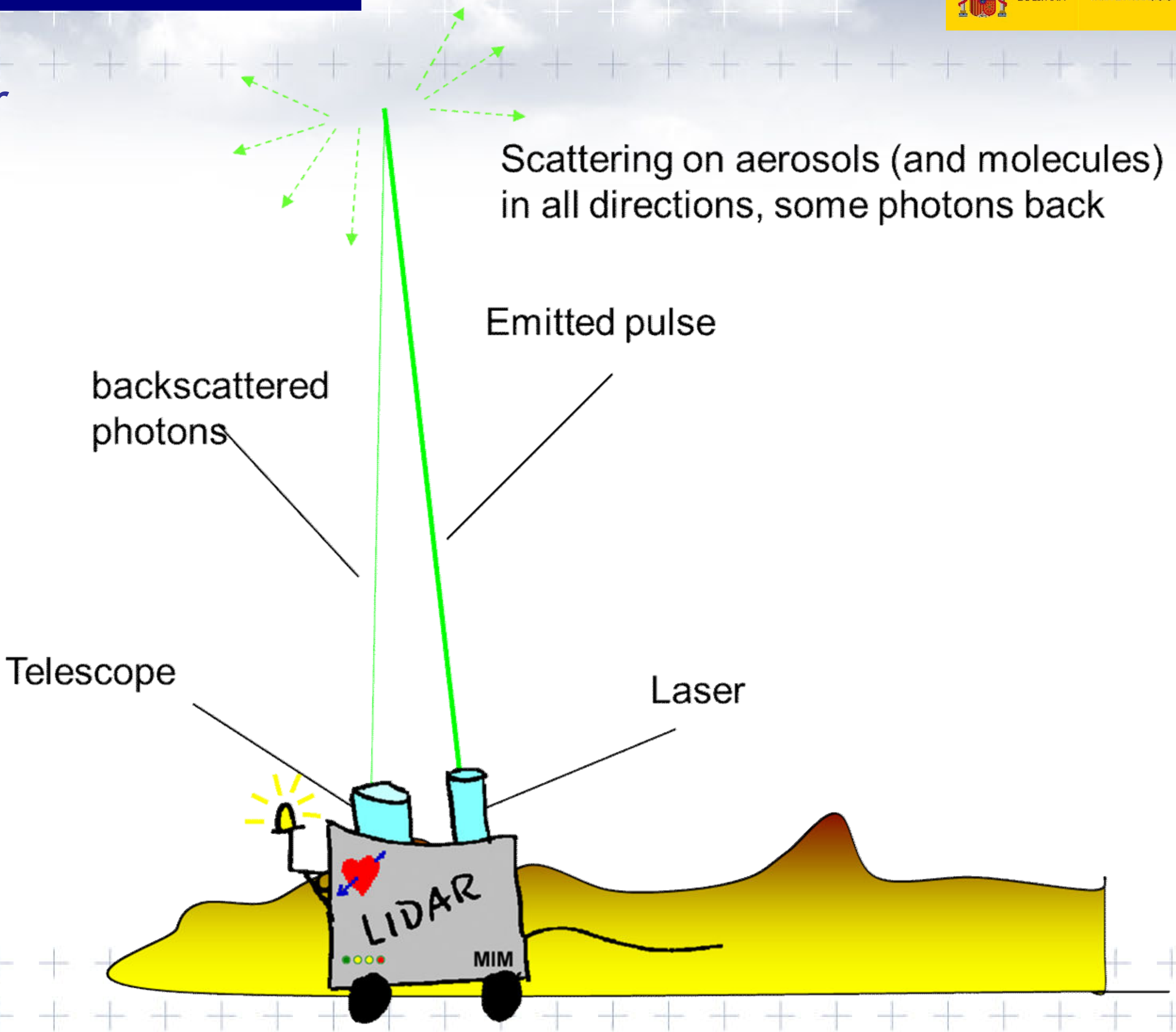
2. Lidar



2. Lidar


Scattering on aerosols (and molecules)
in all directions, some photons back
Emitted pulse
Telescope
Laser
LIDAR
MIM

2. Lidar


Scattering on aerosols (and molecules)
in all directions, some photons back
Emitted pulse
backscattered
photons
Telescope
Laser
LIDAR
MIM

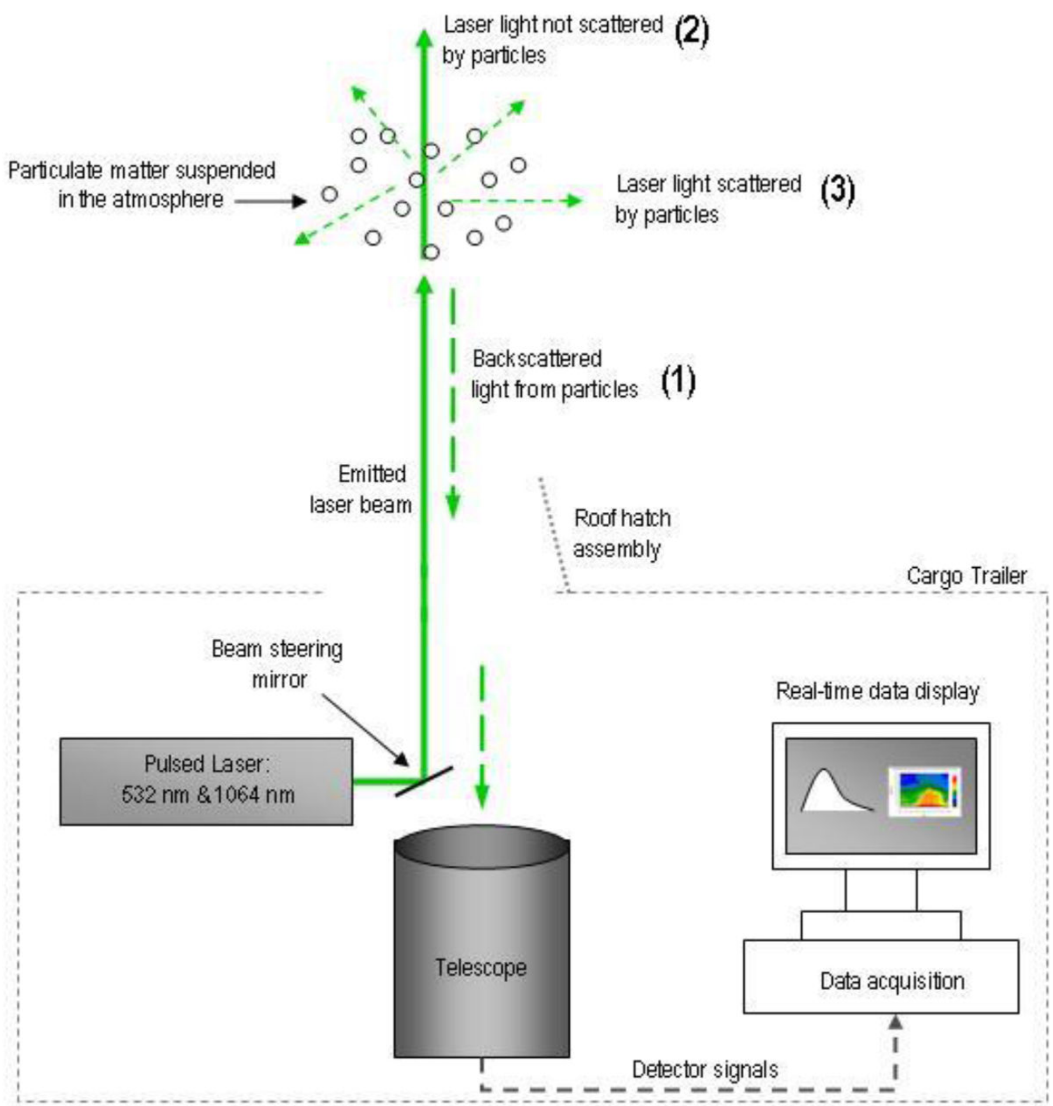
2. Lidar

Lidar-Barcelona (UPC)
Raman Lidar
EARLINET

Lidar-Tenerife (INTA-AEMET)
Elastic lidar
MPLNET

ALOMAR (69ºN)

2. Lidar



University of British Columbia

Lidar systems retrieve vertical profiles of aerosol optical properties

They measure backscatter and need the lidar ratio (S) to obtain extinction profiles.

(S → gives an estimation of the ratio between light backscattered by particles and the extinction of the atmosphere)

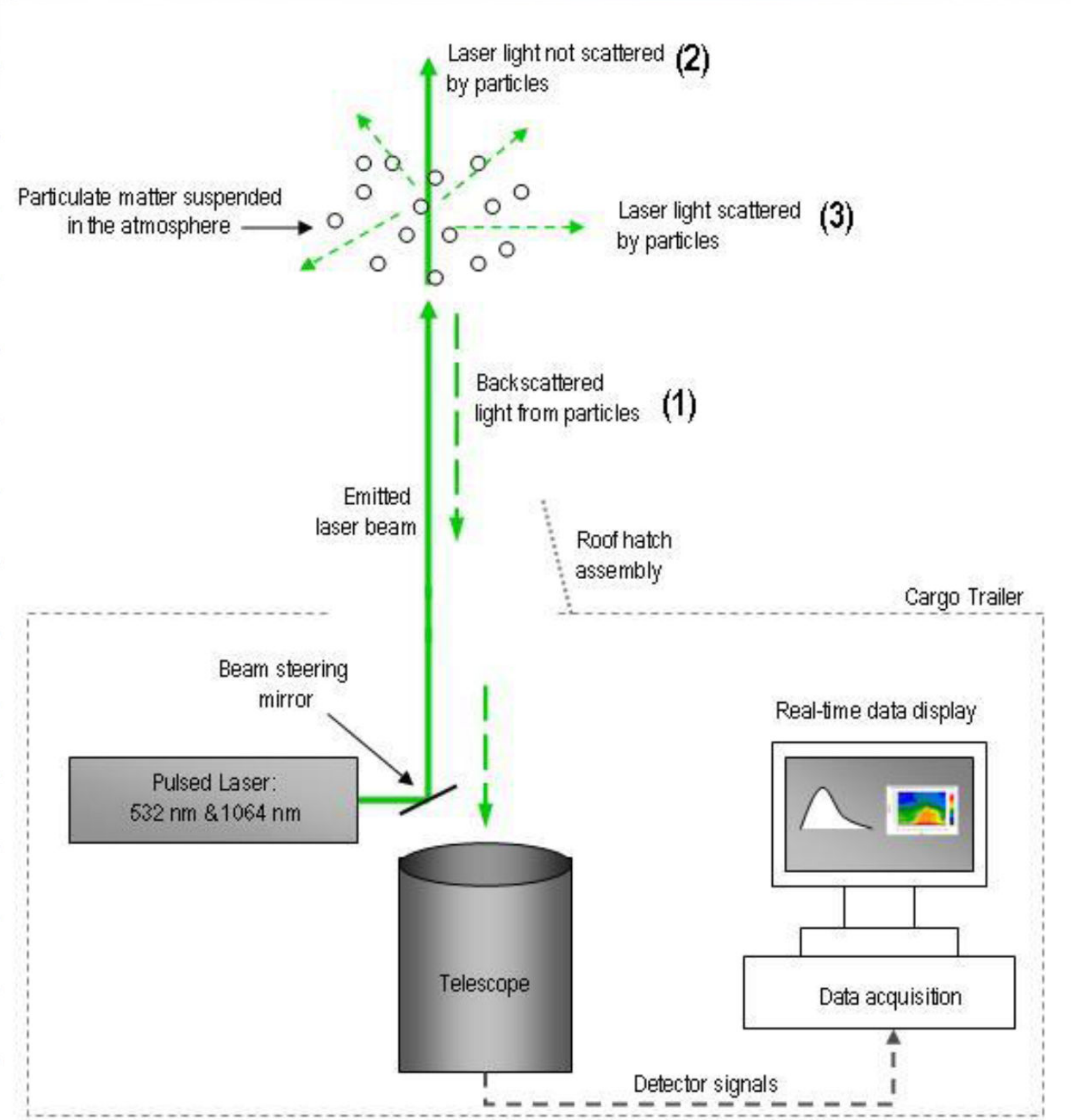
Elastic lidars:

Assuming a S constant along the column (determine through photometry or assuming a type of aerosol…)

Raman lidars:

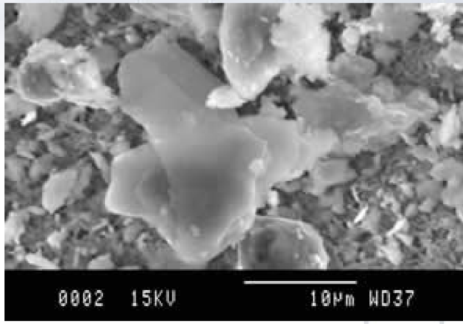
Able to determine S because a more sophisticated systems (more expensive, more power consuming, more technical requirements…)

2. Lidar



University of British Columbia

Mineral



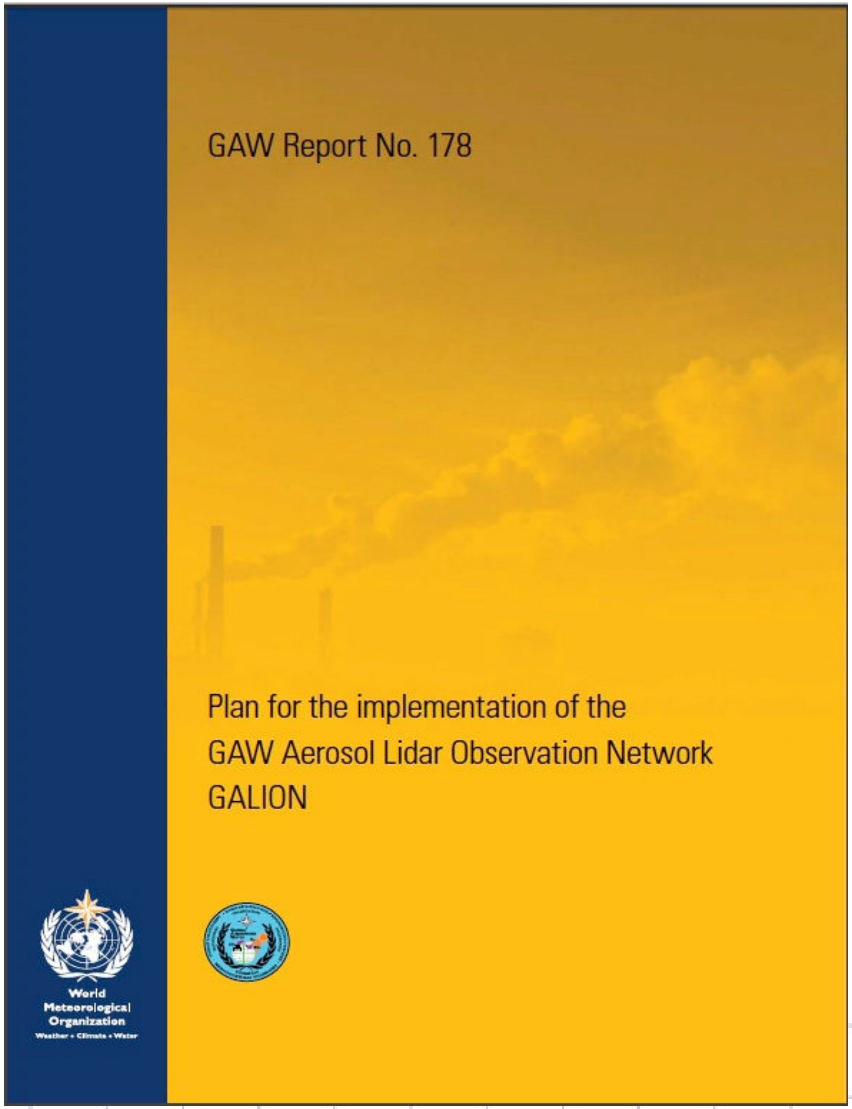
Elastic lidars:
Depolarization ratio provides information on sphericity → dust layers

Raman lidars:
provide better estimations of extinction.

Ceilometer:
(more robust and less expensive) can potentially be installed in remote sites.

2. Lidar

GAW Atmospheric Lidar Network (GALION)



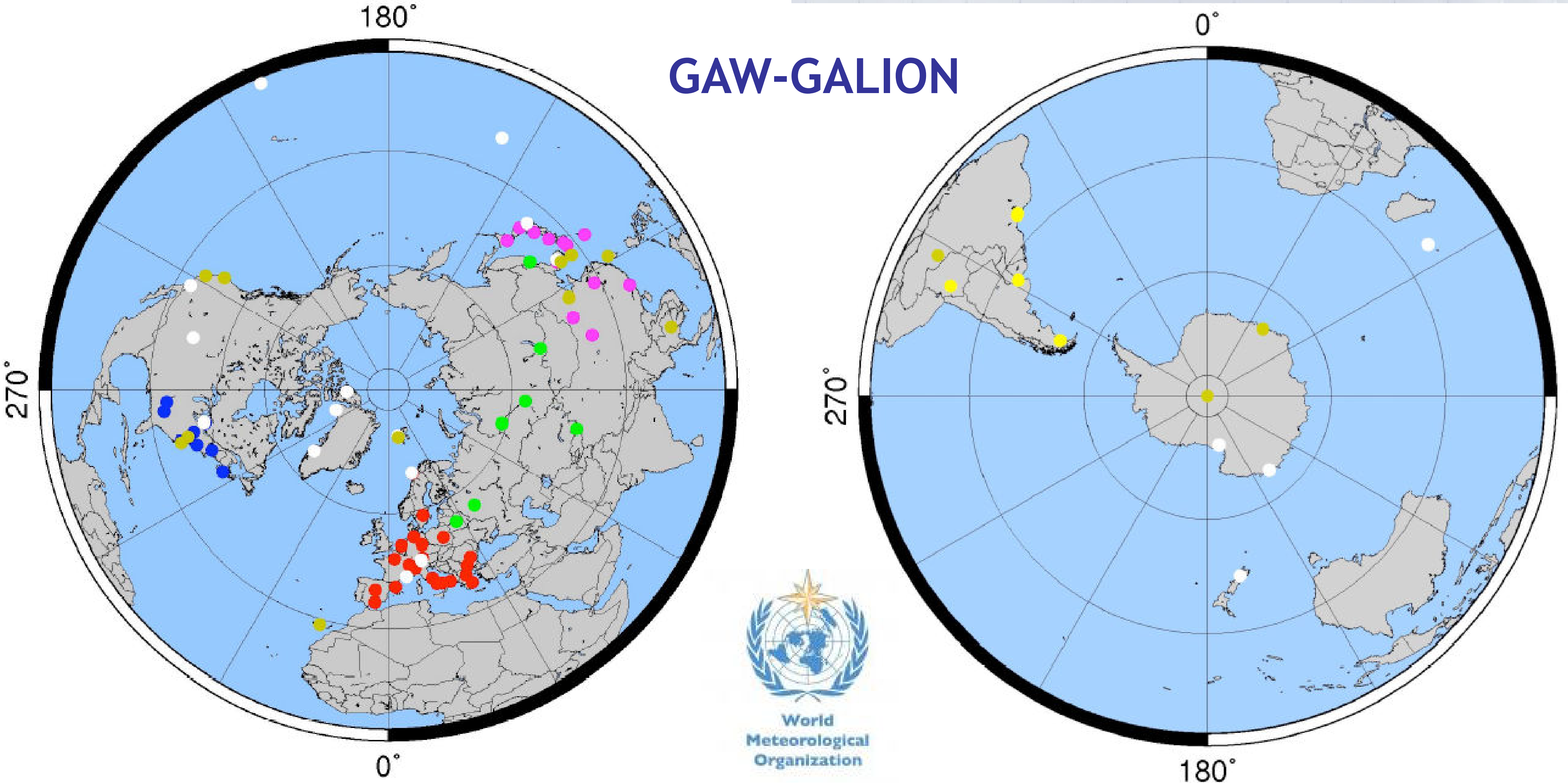
https://www.wmo.int/pages/prog/arep/gaw/documents/gaw178-galion-27-Oct.pdf

Ground base remote sensing

GOBIERNO DE ESPAÑA MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA

AEMet Agencia Estatal de Meteorología

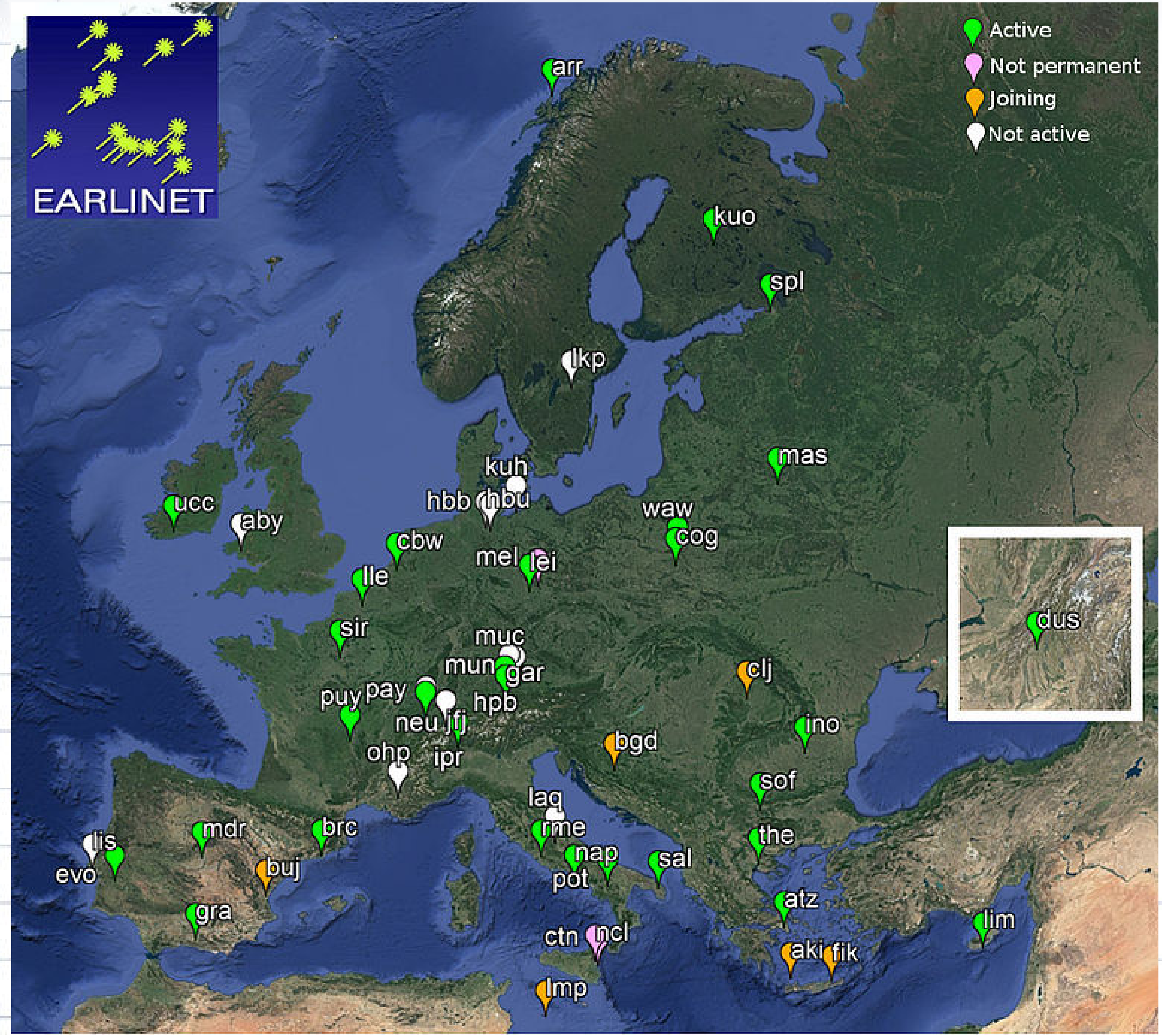
GAW-GALION



World Meteorological Organization

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

2. Lidar



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.

Some of the EARLINET stations are equipped also with sunphotometers (they are part of AERONET)→ synergy.

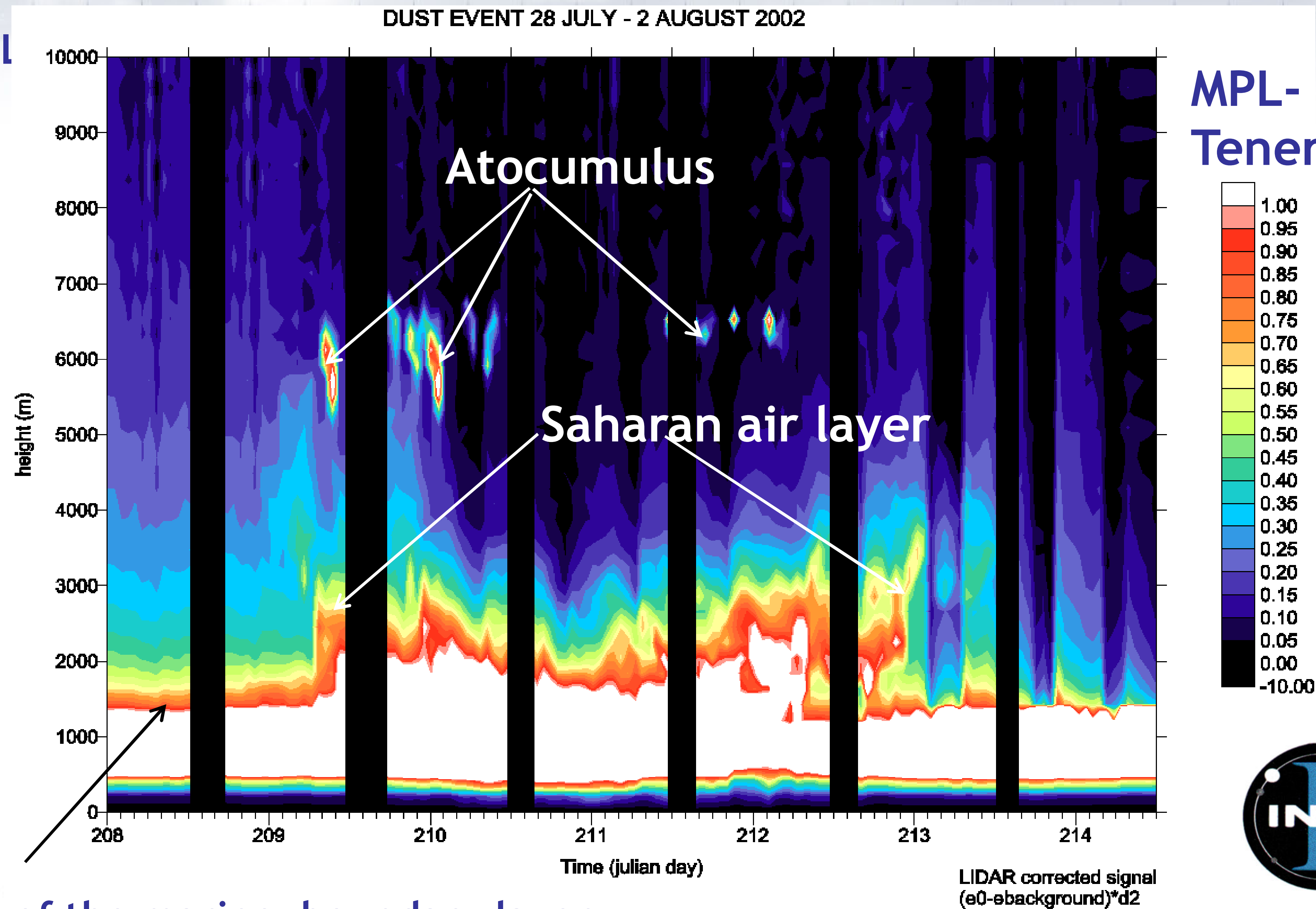
Raman lidars

2. Lidar

MPLNet: MicroPulse Lidar Network

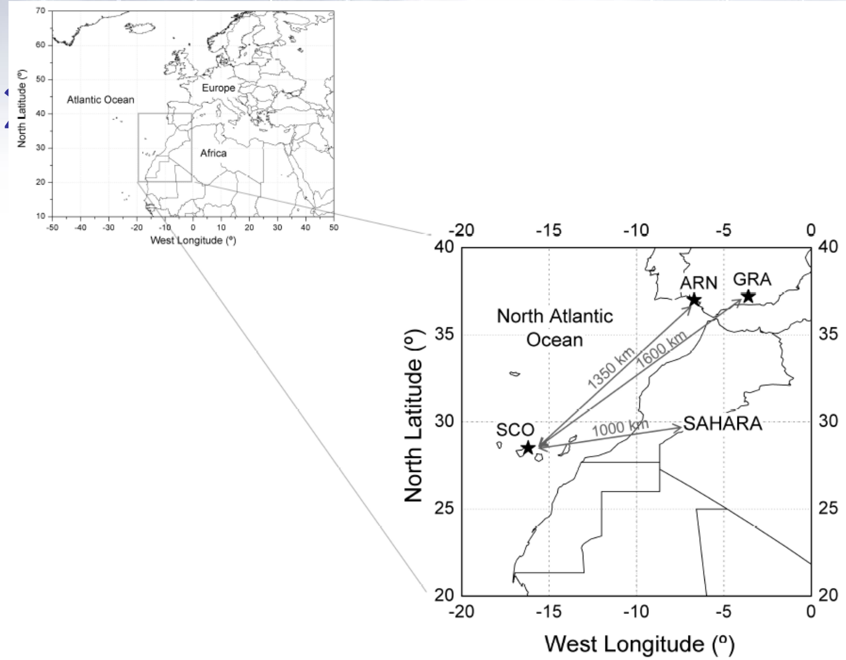
523 nm MPLNET (elastic lidars)
Automatized since July 2005

2. L



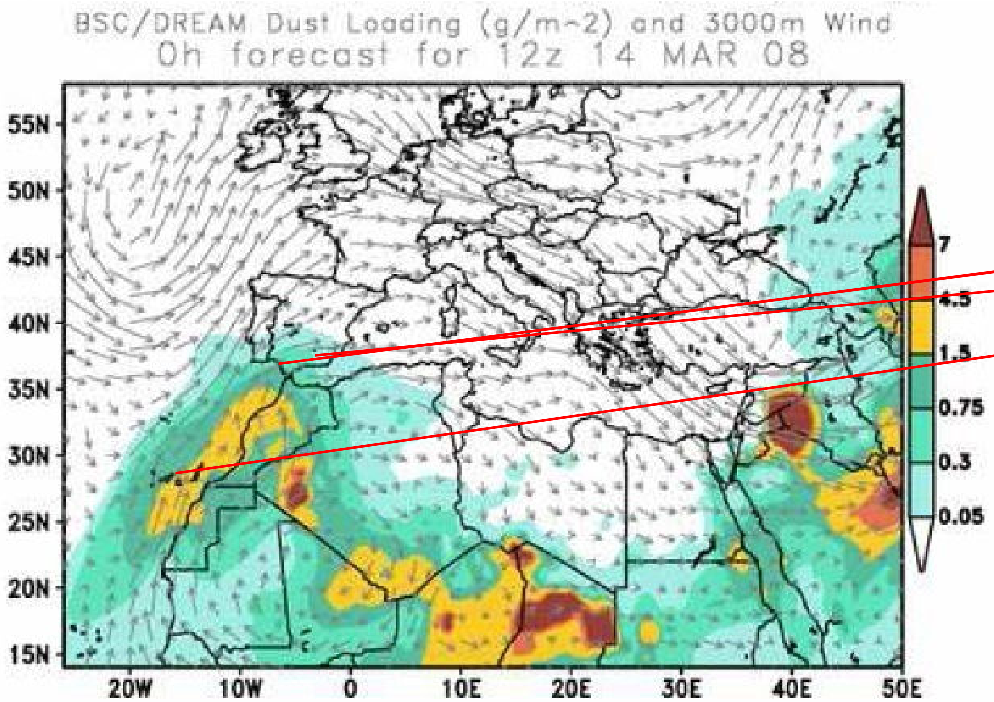
MPL-Tenerife

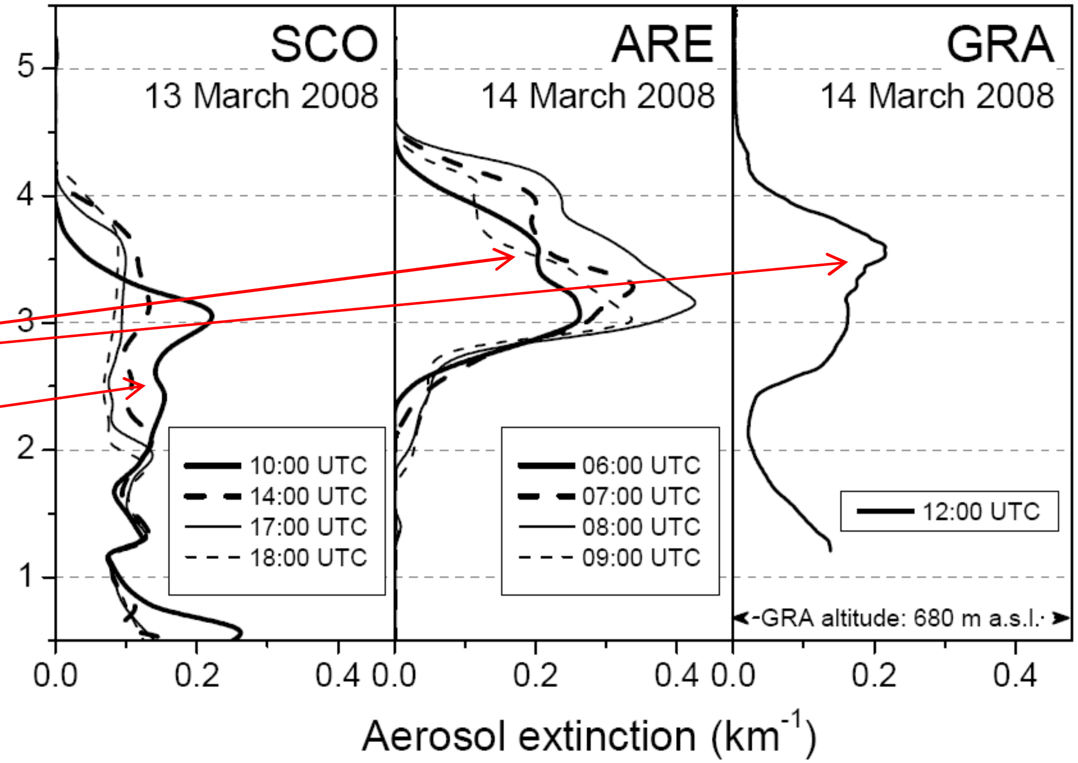
Top of the marine boundary layer



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

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



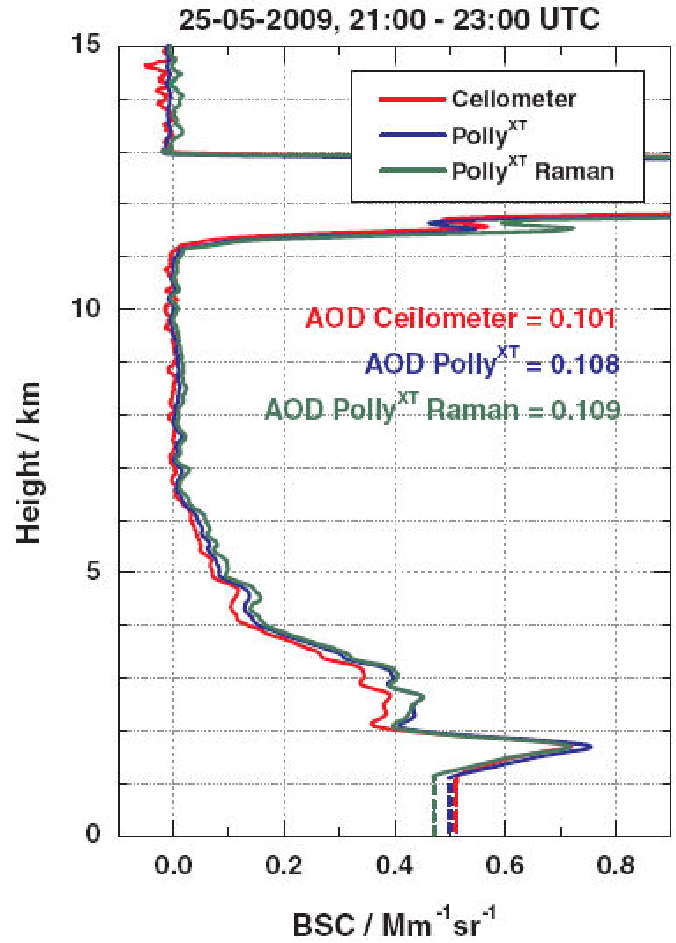


2. Lidar: Ceilometer

Ceilometers are built to detect clouds.

They work in NIR wavelenght for trying to have neglibigle signal of aerosol (in principle, for ceilometers areosols are a perturbation in clouds measurements).

Nonetheless, this low signal could be use to retrieve aerosol properties,…

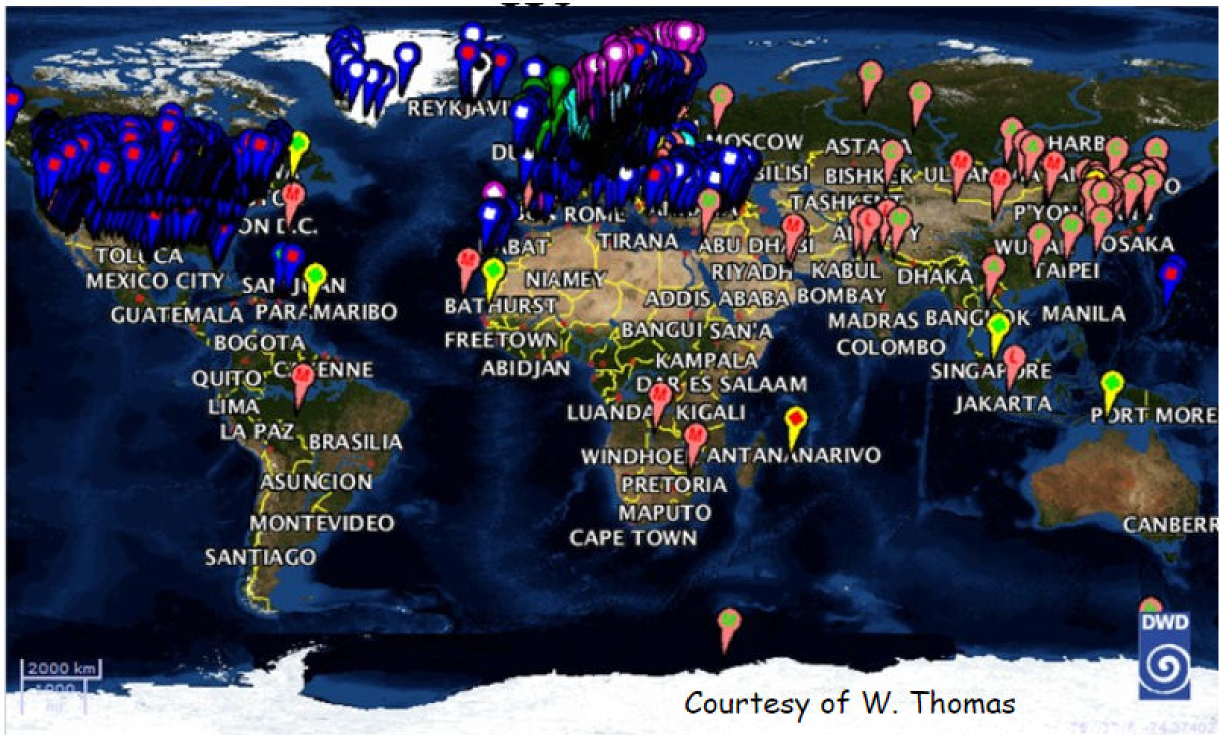


Heese et al., Atmos. Mes. Tech. 2010, Ceilometer-lidar inter-comparison: backscatter coefficient retrieval and signal-to-noise ratio determination

Desirable for desert regions !!

2. Lidar: Ceilometer

Ceilometers for aerosol profiling: potential world ceilometer network



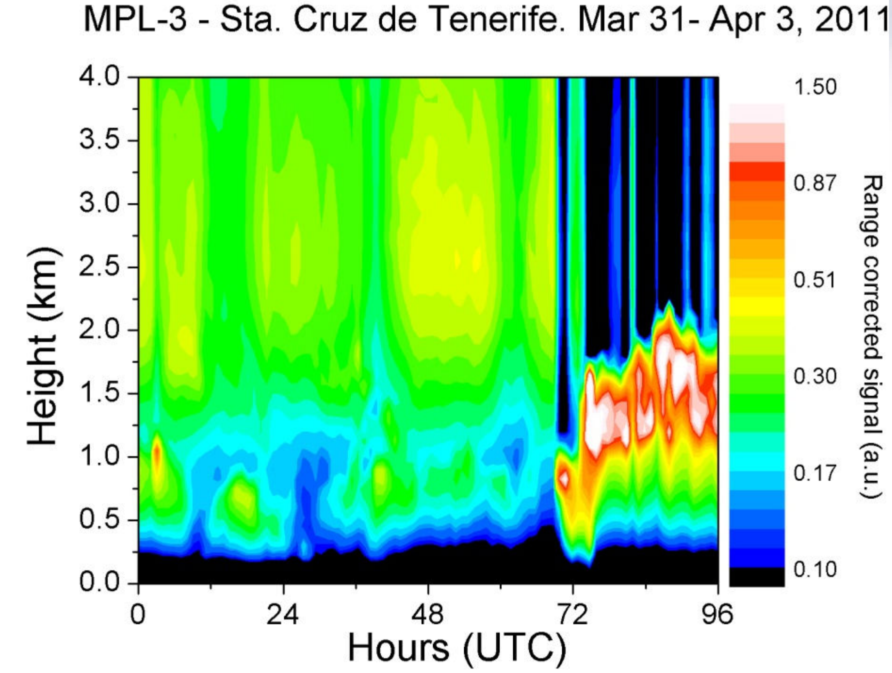
Higher density of observations, despite greater uncertainty

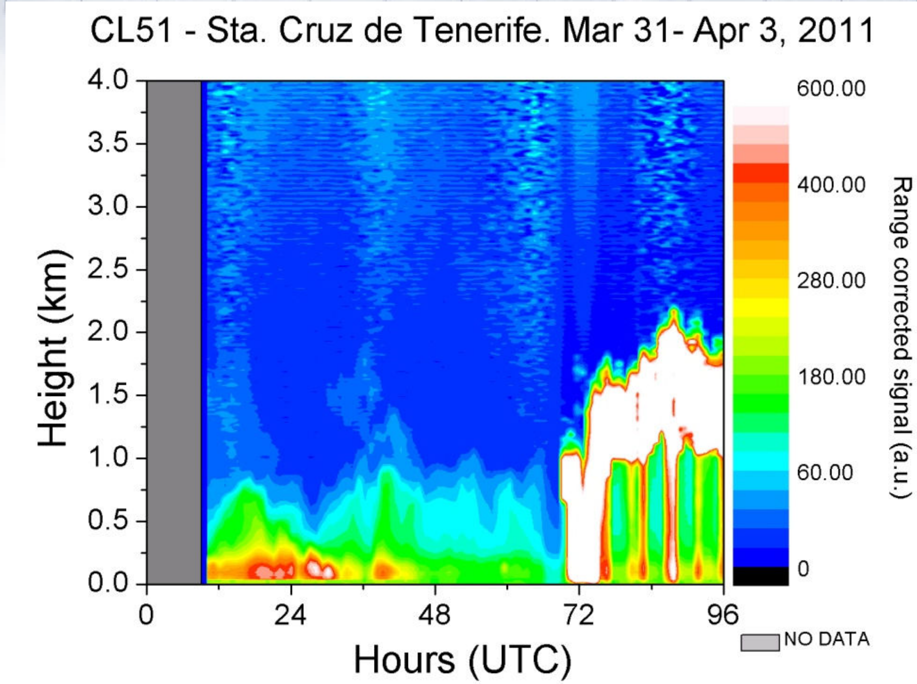
Met Services are replacing cloud-base ceilometer networks by aerosol backscatter profiling ceilometers (IR wavelenght).

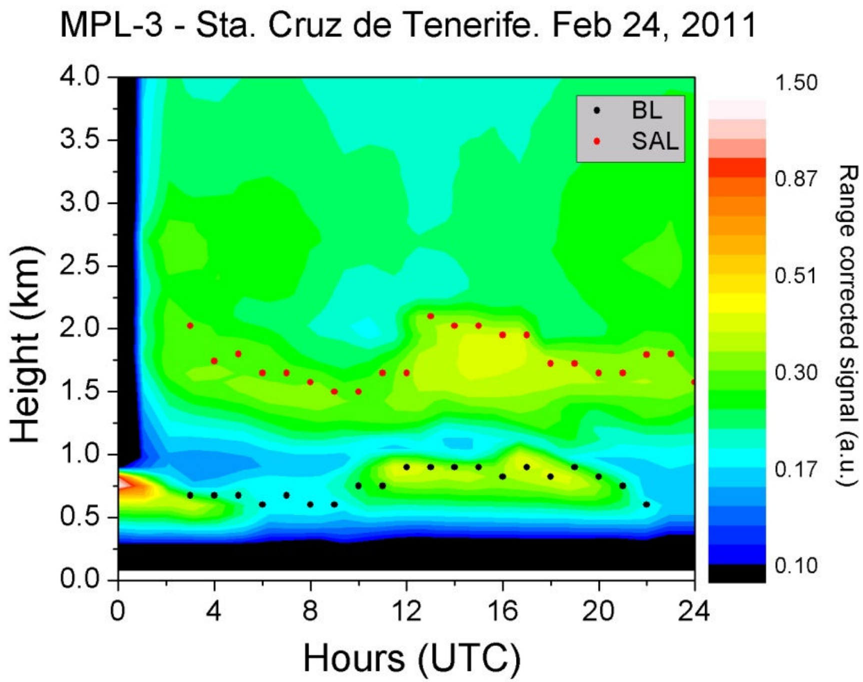
Objective: To monitor MLD (Mixing Layer Depth) based on several hundred profiling ceilometers

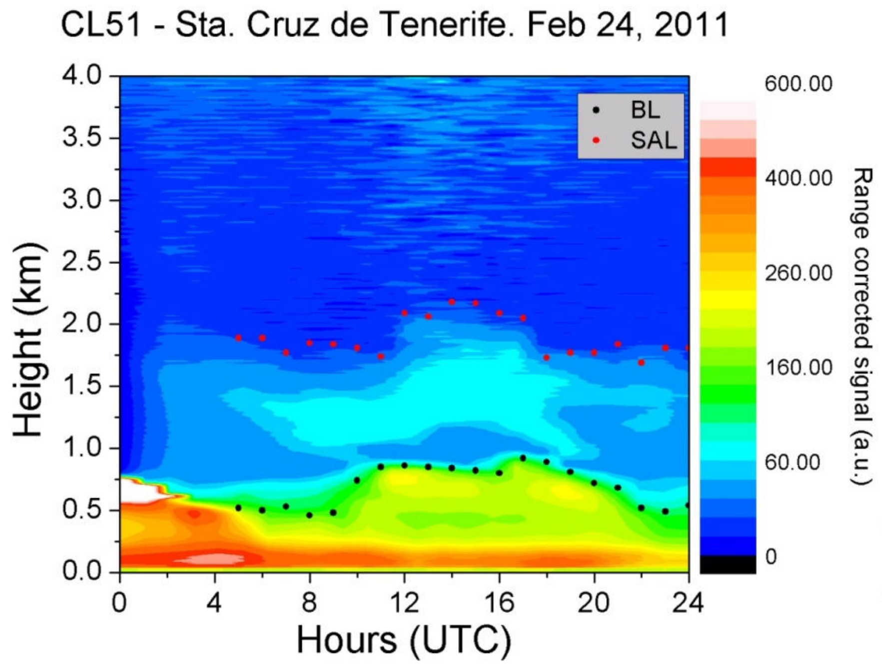
Ground base remote sensing

2. Lidar: Ceilometer









• Index

Brief introduction about aerosols and dust (to better understand why and how)

Ground based observations

- In-situ dust estimations (Visibility)
- In-situ dust measurements
- Ground base remote sensing of dust
- Summary

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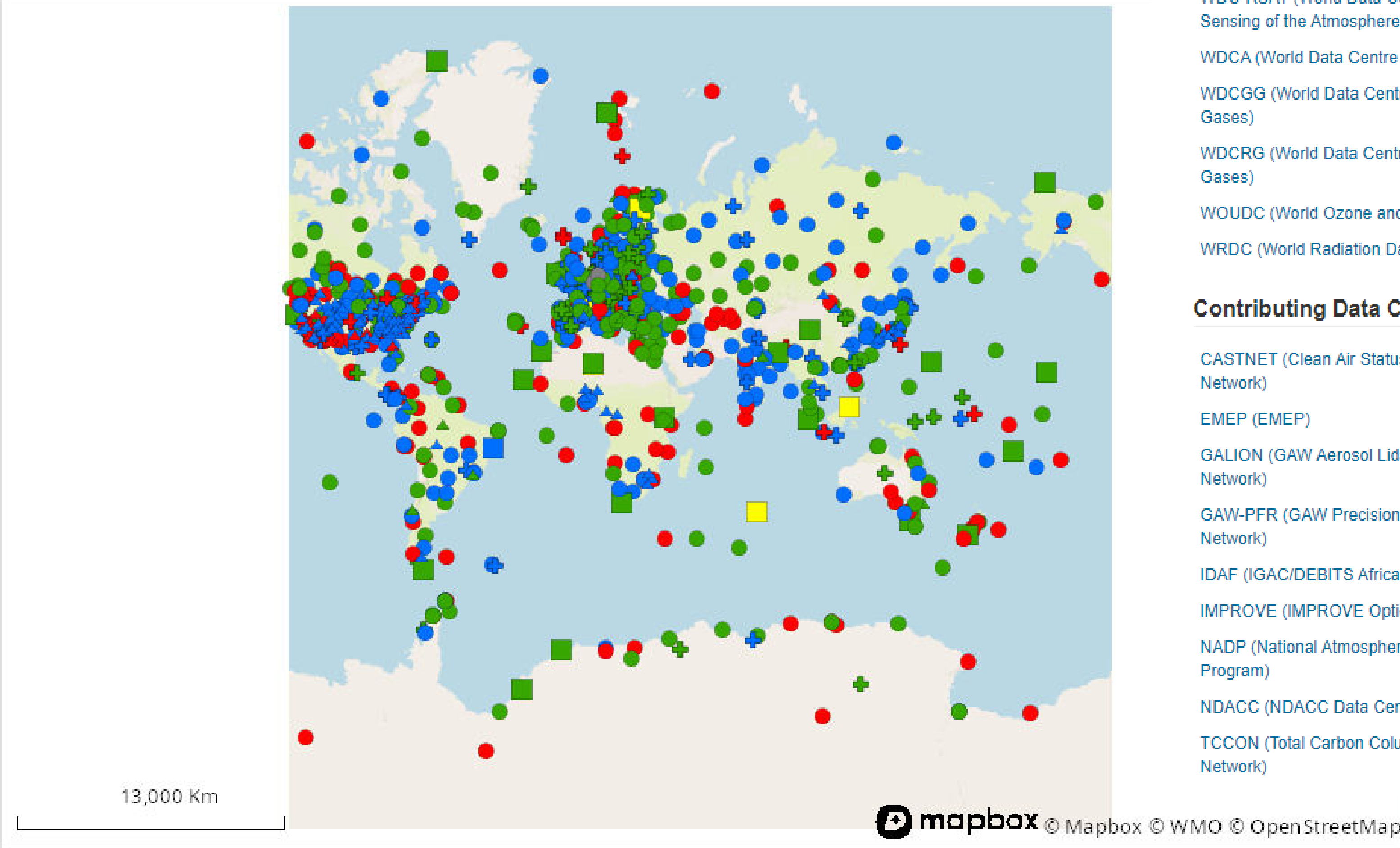
https://gawsis.meteoswiss.ch/GAWSIS/#/



GAW World Data Centres

- WDC-RSAT (World Data Center for Remote Sensing of the Atmosphere)
- WDCA (World Data Centre for Aerosols)
- WDCGG (World Data Centre for Greenhouse Gases)
- WDCRG (World Data Centre for Reactive Gases)
- WOUDC (World Ozone and UV Data Centre)
- WRDC (World Radiation Data Centre)

Contributing Data Centres

- CASTNET (Clean Air Status and Trends Network)
- EMEP (EMEP)
- GALION (GAW Aerosol Lidar Observation Network)
- GAW-PFR (GAW Precision Filter Radiometer Network)
- IDAF (IGAC/DEBITS Africa)
- IMPROVE (IMPROVE Optical Aerosol)
- NADP (National Atmospheric Deposition Program)
- NDACC (NDACC Data Center)
- TCCON (Total Carbon Column Observing Network)

World Meteorological Organization Weather-Climate-Water

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss

Global	■	Operational (green)
Regional	●	Partly operational (yellow)
Contributing networks	▲	Non-reporting (blue)
Local	★	Closed (red)
Other networks	✚	Planned (grey)
		Pre-operational (grey)
		Stand-by (grey)

Aerosol, Clouds and TRace gases Research Infraestructure

https://www.actris.eu/Home.aspx

OBJECTIVES:

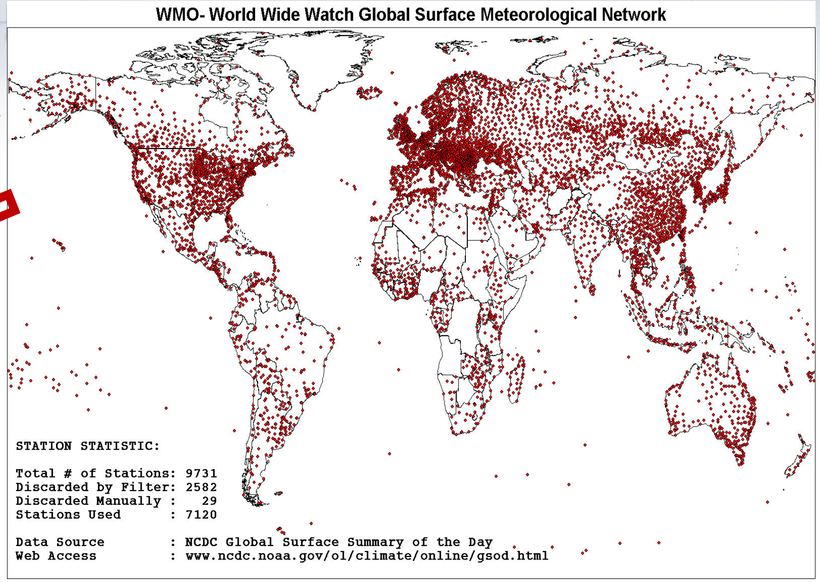
- To provide the 4D-variability of clouds and of the physical, optical and chemical properties of short-lived atmospheric species (required level of precision, coherence and integration)
- To provide effective access to this information…
- To raise level of technology and quality of services…
- To promote training of operators and users…

Standardization…
… for traceability and intercomparability

Summary

Visibility:
- human eye
- transmissometer

PMx concentrations:
- empirical from visibility



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Visibility:

- human eye
- transmissometer

PMx concentrations:

- empirical from visibility → widespread but empirical
- Gravimetry (reference)
- automathic “standarized” (BAM & TEOM)

} → low density/coverage

- PMx LowCost Sensors →

Expand coverage
QUALITATIVE!!!
The suitability of such low-cost sensors for long term monitoring of PM is yet to be explored by the scientific community.

Summary

Visibility:
- human eye
- transmissometer

PMx concentrations:
- empirical from visibility → widespread but empirical
- Gravimetry (reference)
- automathic "standarized" (BAM & TEOM)

(Gravimetry and automathic) → low density/coverage

- PMx LowCost Sensors → EXPERIMENTAL!!!

Extinction (column): AOD-Alpha
- reference photometry (Cimel, PFR) → Well stablish, not enough coverage (particularly in desert regions)
- lowCost photometers (Calitoo) → In progress (promising)

Extinction (profile):
- high and low power lidars (GALION) → Well stablish, not enough coverage (particularly in desert regions)
- ceilometers → In progress (promising)

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- human eye
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- high and low power lidars (GALION)
- ceilometers

Standardization…
… for traceability and intercomparability

Thank you!

http://izana.aemet.es

npratsp@aemet.es

Agencia Estatal de Meteorología

Definitions from WMO-GAW referring to three key technical descriptors, “reference instruments”, “sensors”, and “sensor systems” (although there is no single internationally agreed definition of these terms, but for clarity we define these here as:

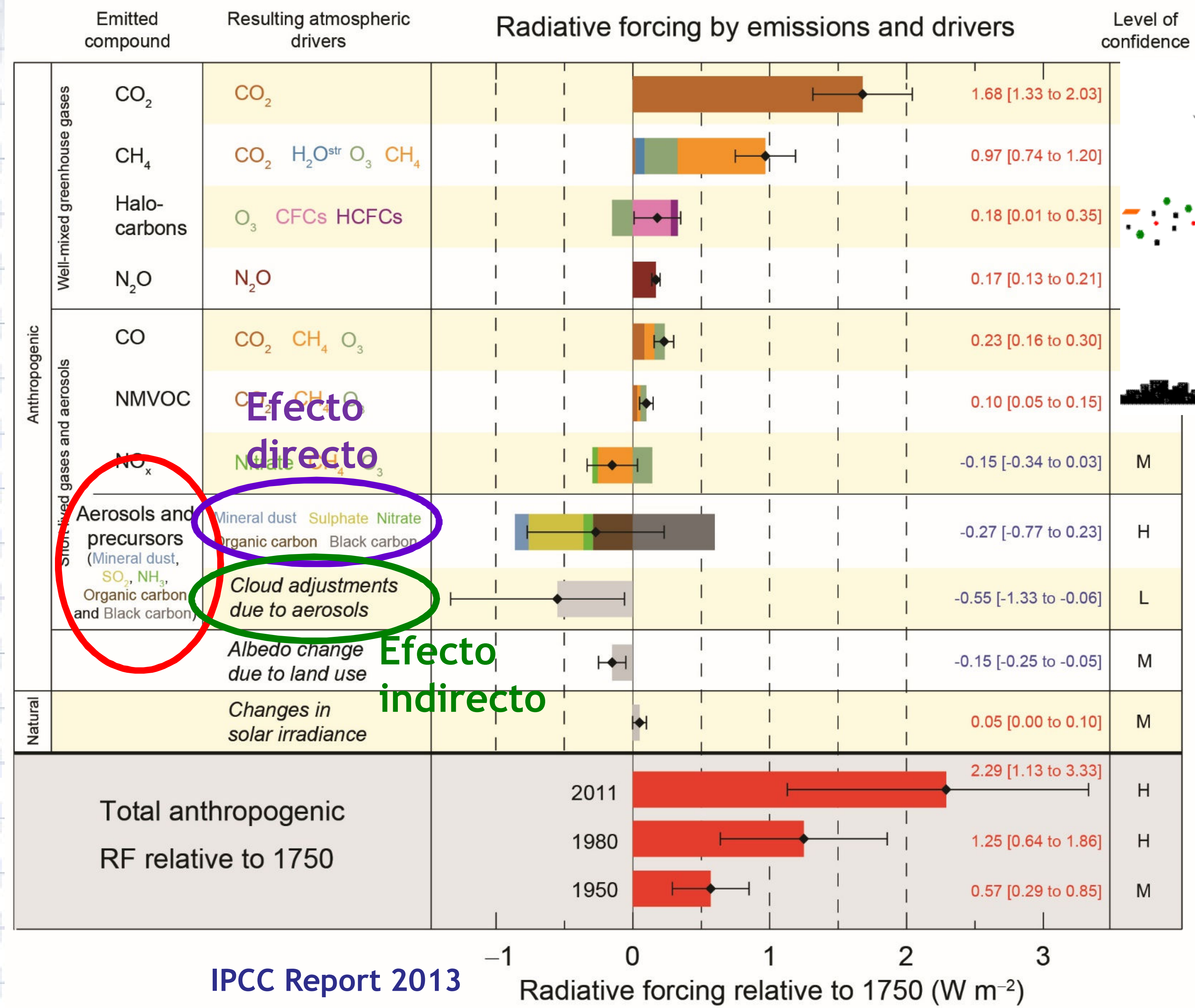
Reference instrument: in an air pollution context, a reference instrument is most commonly understood to be one with a certification that comes from an official regulating body and can be associated with a reference method notified in legal drivers. For example, instruments to measure air pollutants for regulatory compliance purposes must be approved by the Environmental Protection Agency (EPA) for use in the USA or nominated for type testing according to European Committee for Standardization (CEN) for use in the European Union. Reference instruments measure specific air pollutants to predefined criteria, such as precision, accuracy, drift over time and so on, to provide data that meets regulatory requirements. In extremis reference data on air quality can have validity in courts of law. In the context of this report we also consider as reference instruments any instrument with well- established prior art, for example where the analytical methodologies have been rigorously tested and reported through peer-reviewed literature and where suitable reference materials are available to calibrate such instruments. Any instrument that has been demonstrated to meet the data quality and traceability requirements of international programmes such as WMO/GAW, for example, would be considered a reference instruments in this context.

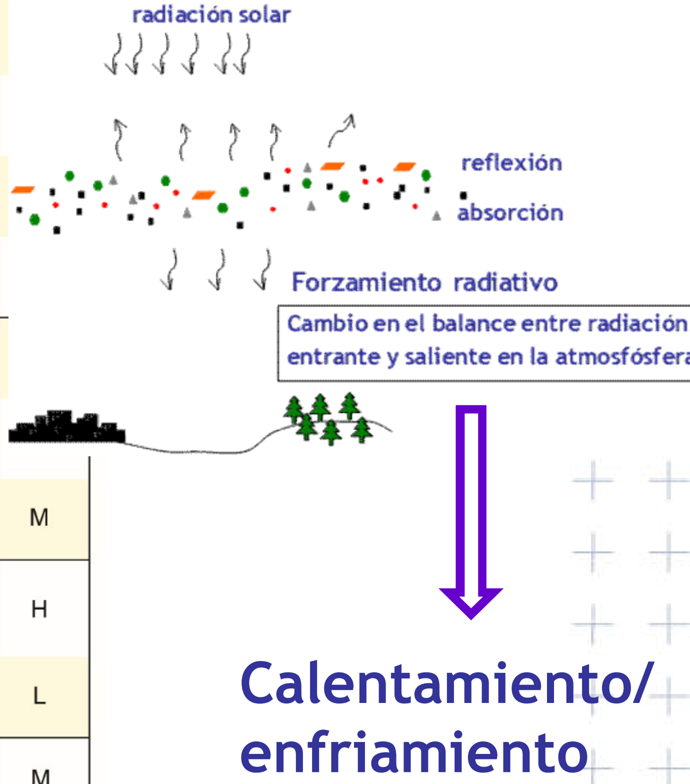
Sensor: the basic sub-component technology that actually makes the analytical measurement of a greenhouse gas or an air pollutant. The presence of a relevant gas or particle is typically converted into an electrical signal where the relative magnitude of that signal is related to the atmospheric concentration. Examples include low-cost sensors for temperature and pressure, capacitive sensors, electrochemical sensors, metal oxide sensors, or self-contained optical sensors including ultra-violet (UV) or nondispersive infrared sensor (NDIR) absorption cells or optical light scattering sensors.

Sensor system: an integrated device that comprises one or more sensor subcomponents and other supporting components needed to create a fully functional and autonomous detection system. A sensor system can include components that reside remotely from the physical sensor and include remote data transfer and data processing steps.

Low-cost: in the context of this work, “low-cost” refers to the initial purchase cost of a single functional sensor system when compared against the purchase cost of a single reference instrument measuring the same or similar atmospheric parameter(s).

2. Efectos de la contaminación por aerosoles atmosféricos





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