Ground-based aerosols/dust observations

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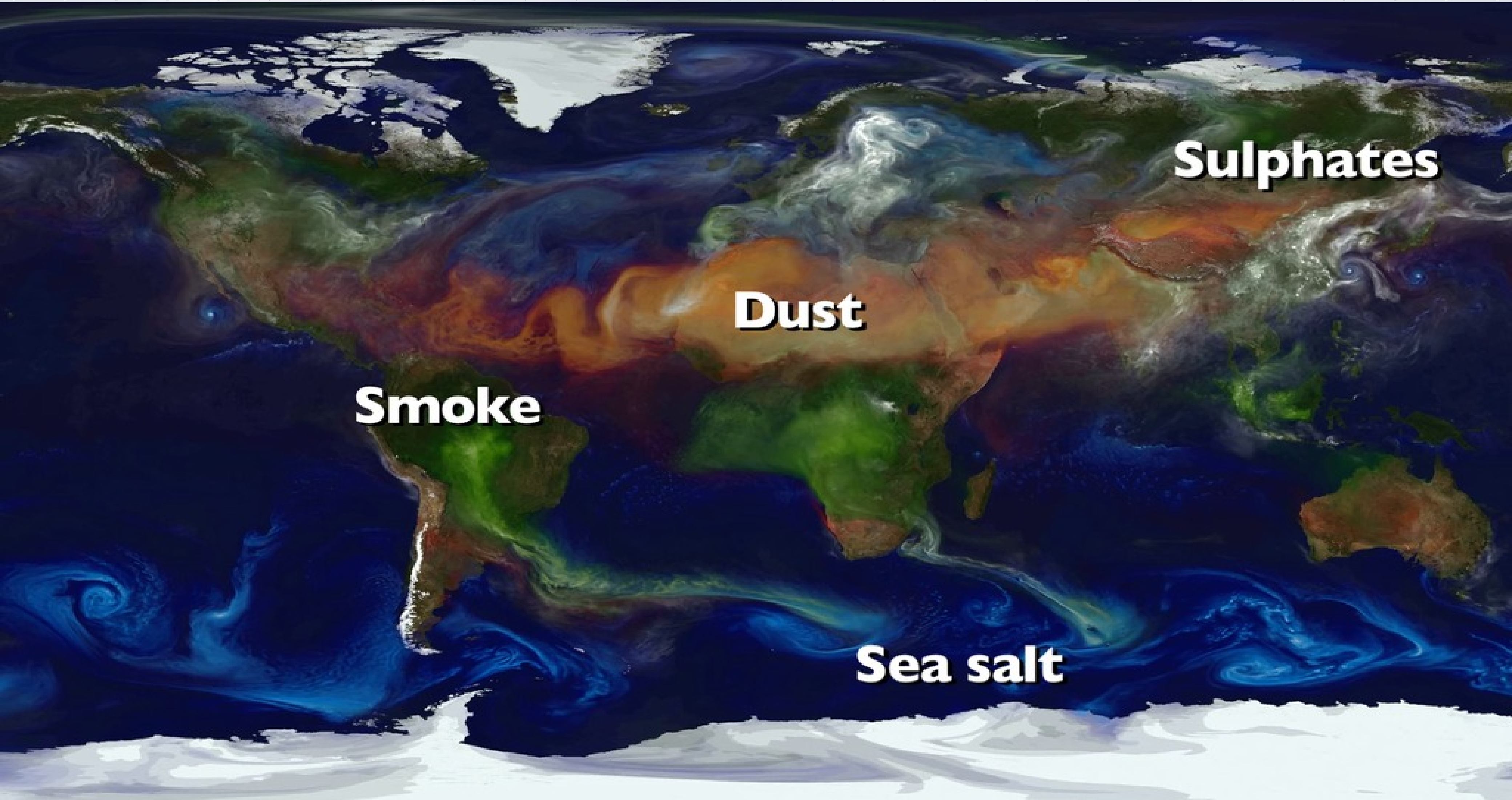
Index

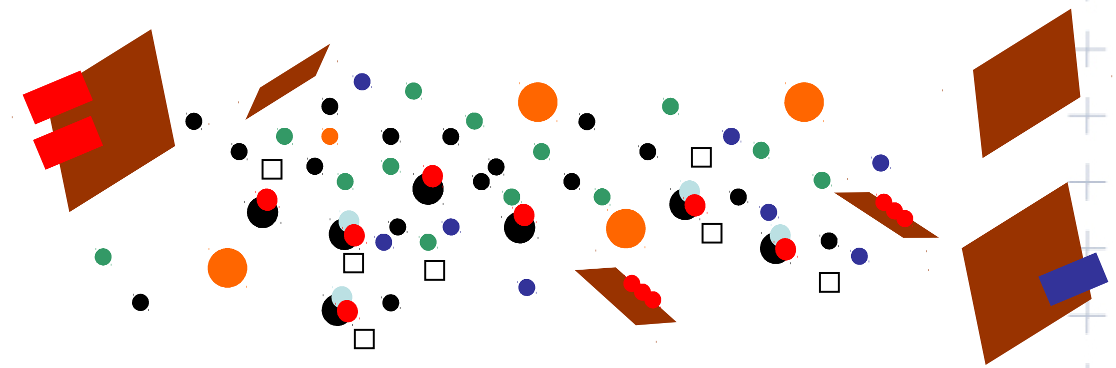
Ground based remote sensing

- Visibility
- In situ techniques
- Photometry


Sulphates
Dust
Smoke
Sea salt

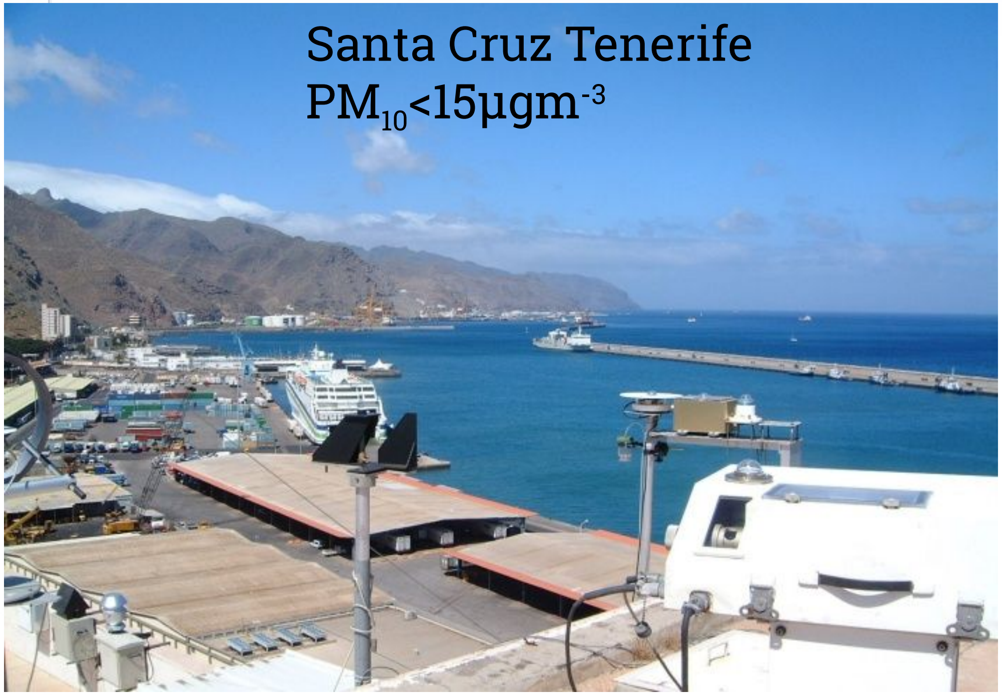
aerosols, a cocktail of chemicals:

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



size: 1 nm (10^{-9} m) to 20 µm (10^{-6} m)

human hair: 70 µm


Santa Cruz Tenerife
PM10<15µgm-3


Santa Cruz Tenerife
PM10>60µgm-3

WMO – visibility

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

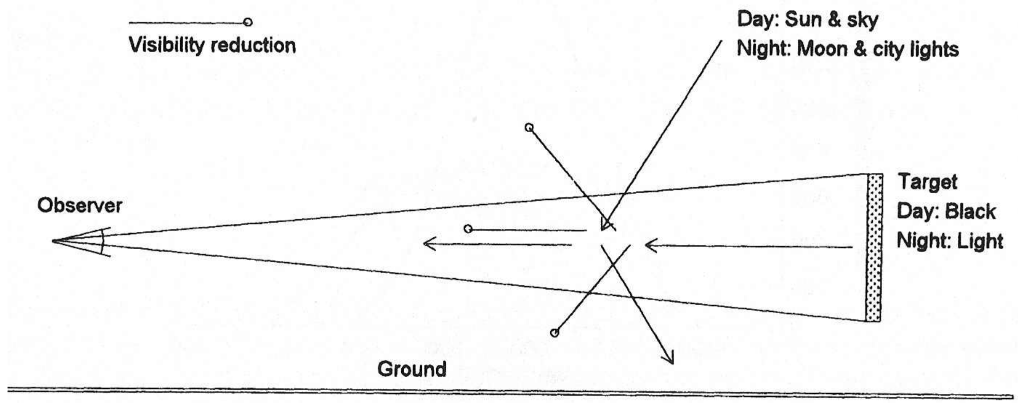


Fig. 11-1 Visibility reduction by scattering.

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 (RVR)

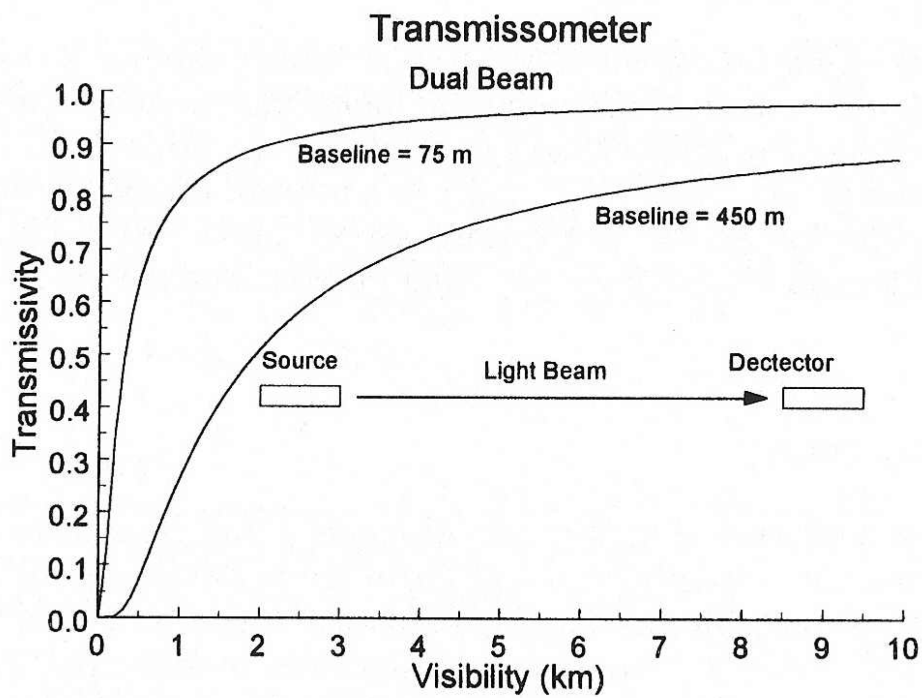
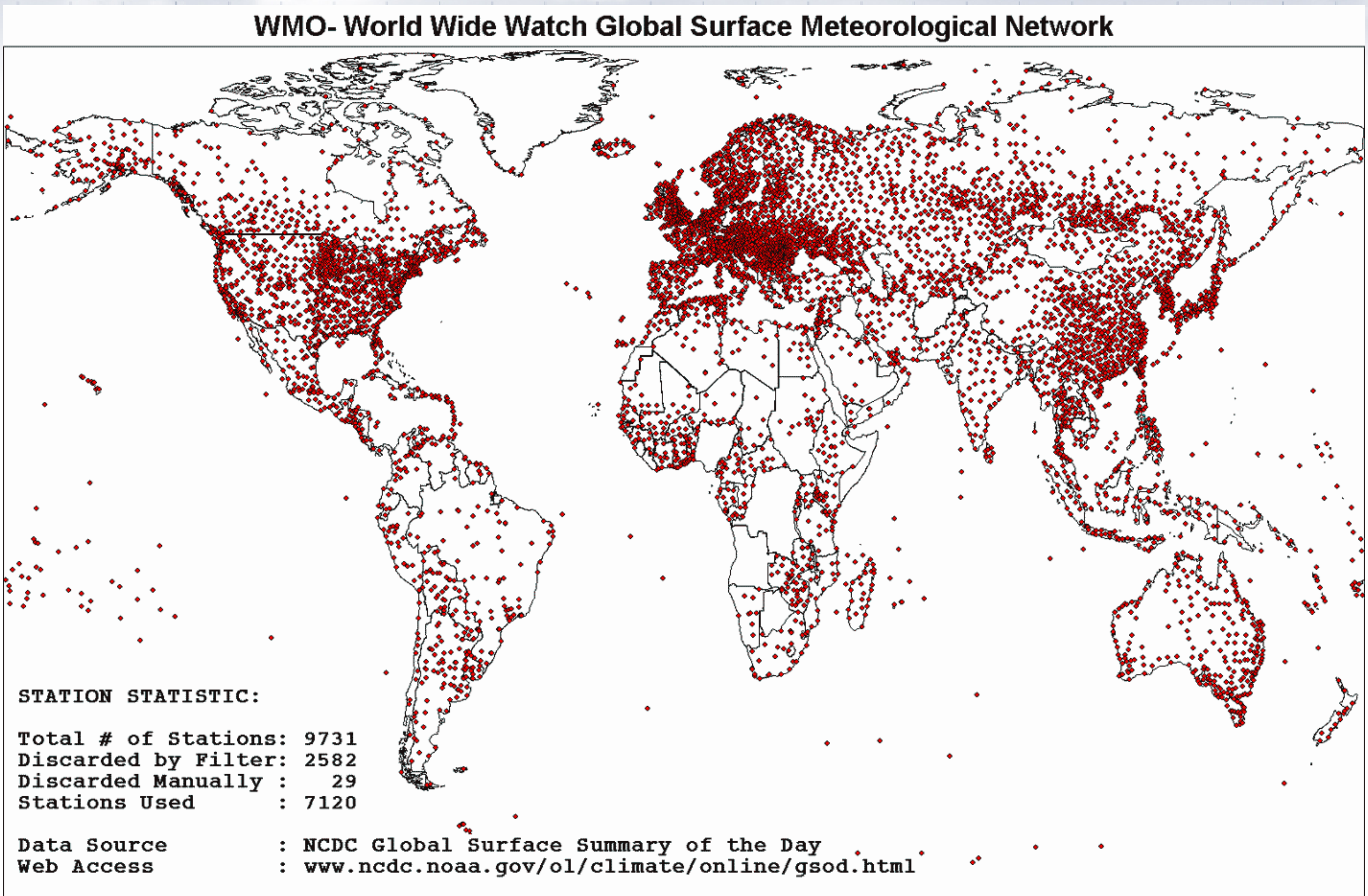
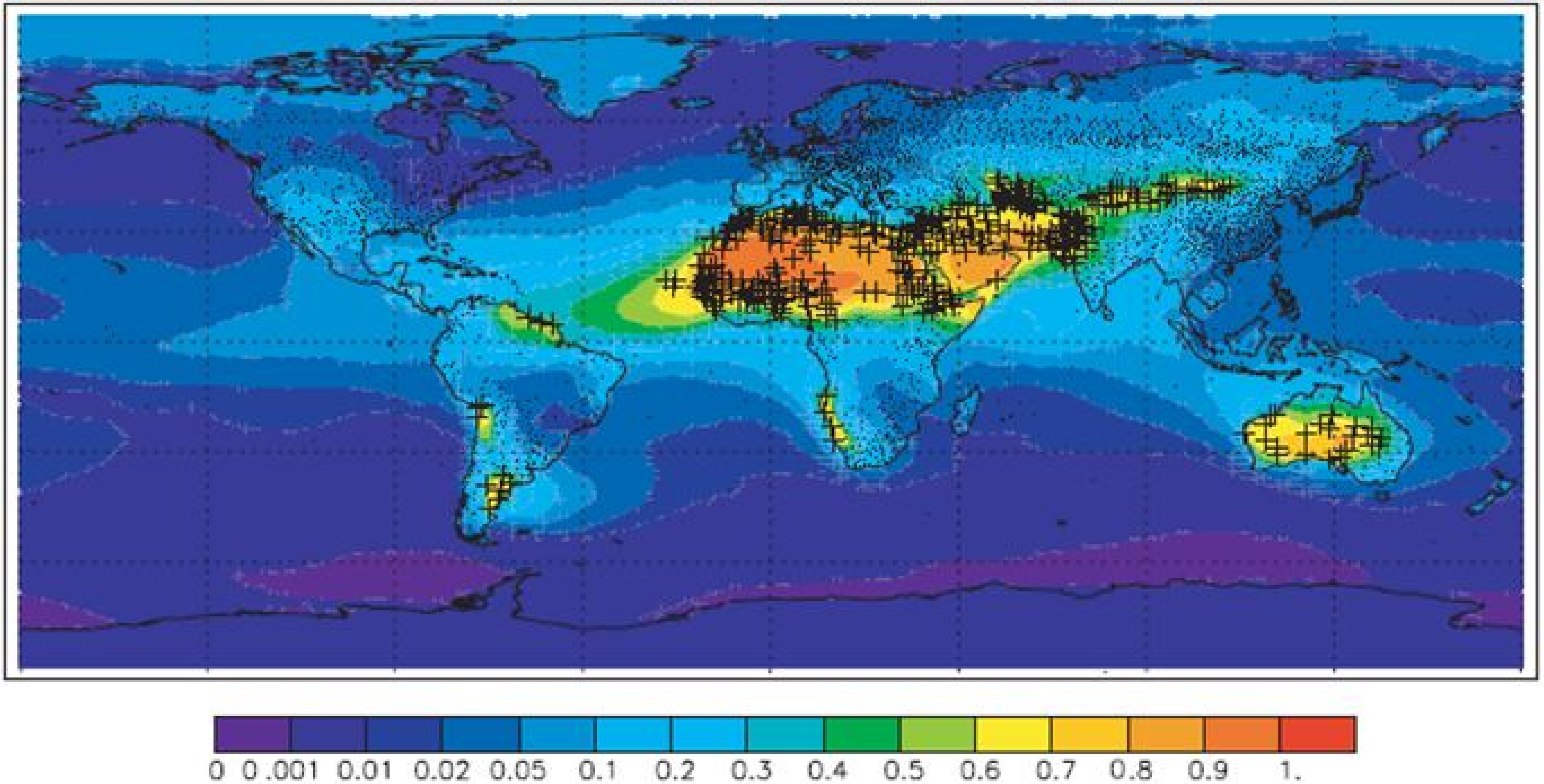


Fig. 11-3 Transfer function for a transmissometer.

Visual range (km) = 3.912 / σ_{ext} (Mm-1)

Visibility

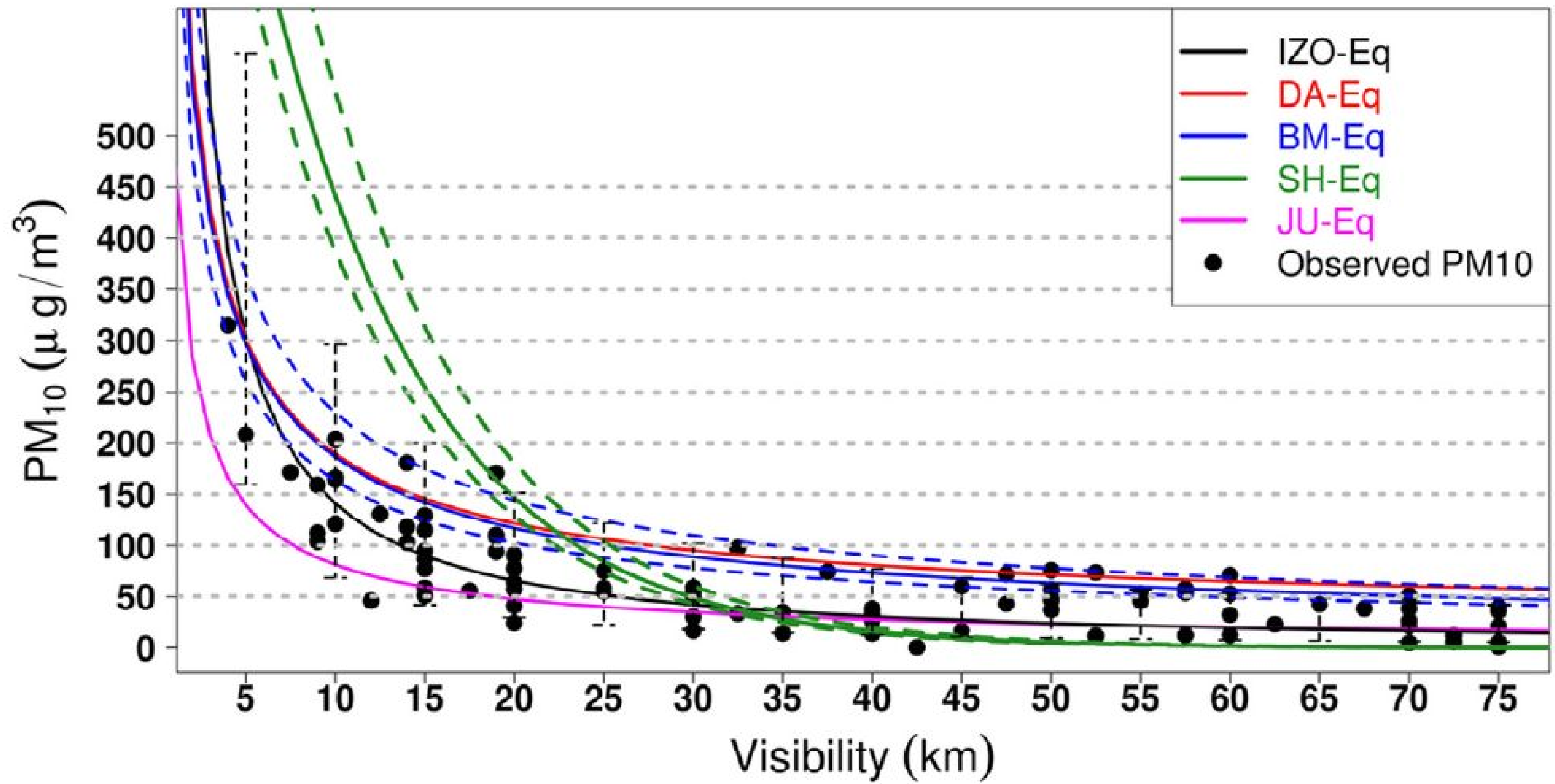

WMO- World Wide Watch Global Surface Meteorological Network
STATION STATISTIC:
Total # of Stations: 9731
Discarded by Filter: 2582
Discarded Manually : 29
Stations Used : 7120
Data Source : NCDC Global Surface Summary of the Day
Web Access : www.ncdc.noaa.gov/ol/climate/online/gsod.html



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

C. Camino et al. / Aeolian Research 16 (2015) 55–68



visibility MOR sensors have a maximum measurement range of 20 km

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 geographic 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

bulk aerosol mass concentration

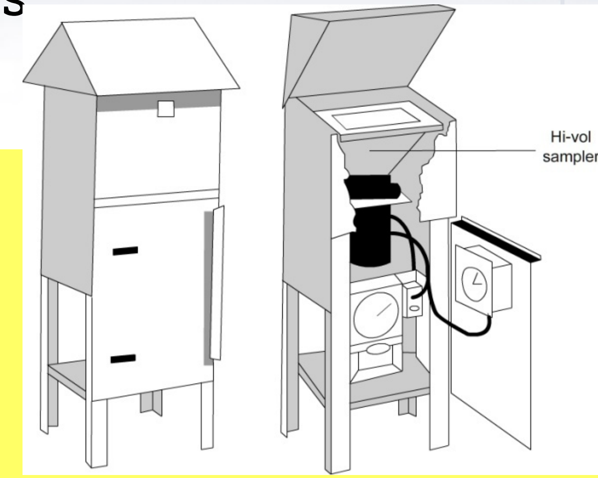
1. Reference method: gravimetric method

2. Automated analyzers

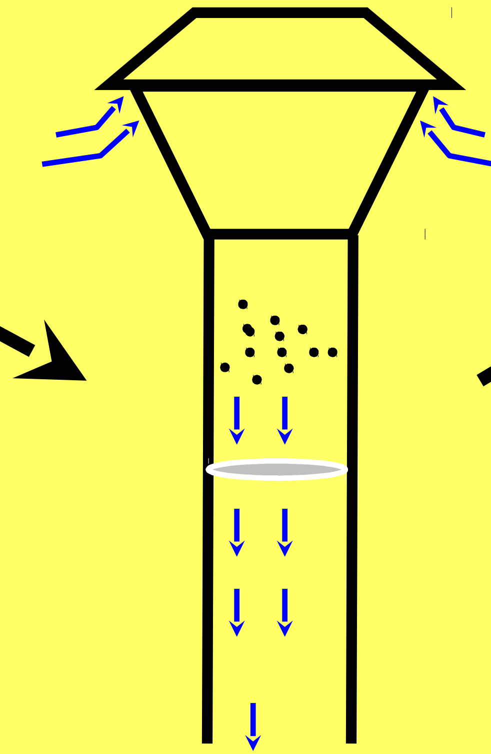
PM_{10} and $PM_{2.5}$ measurements in air quality networks

1. Reference method: gravimetric method

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



Blank filter



Sampled filter

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

- Filter weight (W1)

Pump

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

- Filter weight (W2)

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})

In-situ dust characterization

Micro-Balance room

- 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

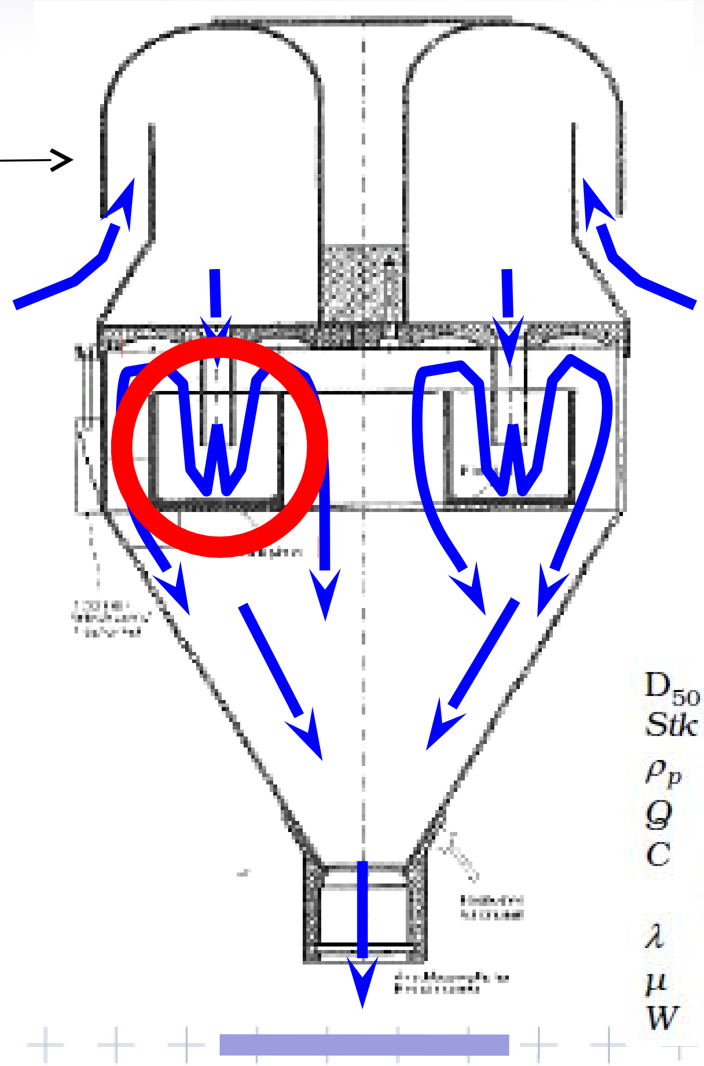
LVS: 2.3 m³/h

HVS: 68 m³/h

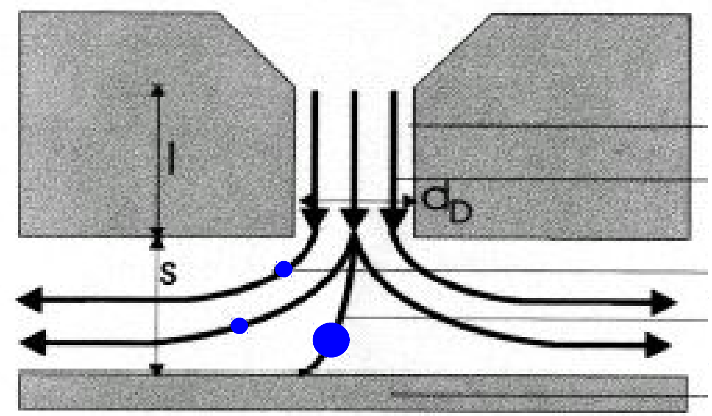
HVS: 30 m³/h

In-situ dust characterization

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•s/cm^2)
W = nozzle diameter (cm)

The Stokes number is a dimensionless parameter that characterizes impaction.

In-situ dust characterization

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

PM_{10}

$PM_{2.5}$

Weight filters conditioned room

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

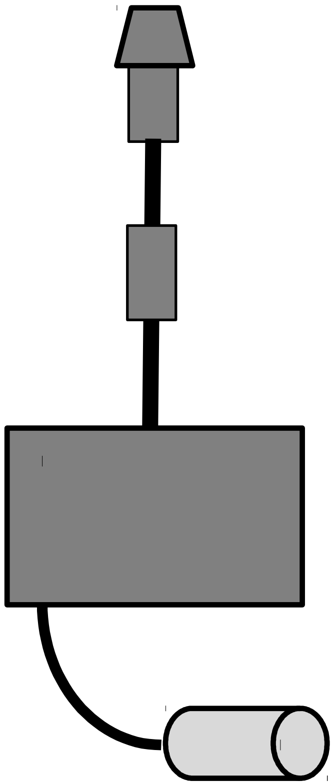
$(Dm / Dt) / (DV / Dt) = mg/m^3$

- Tapered Element Oscillating Microbalance
- Beta (Electron) Attenuation

In-situ dust characterization

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)

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Mass concentration

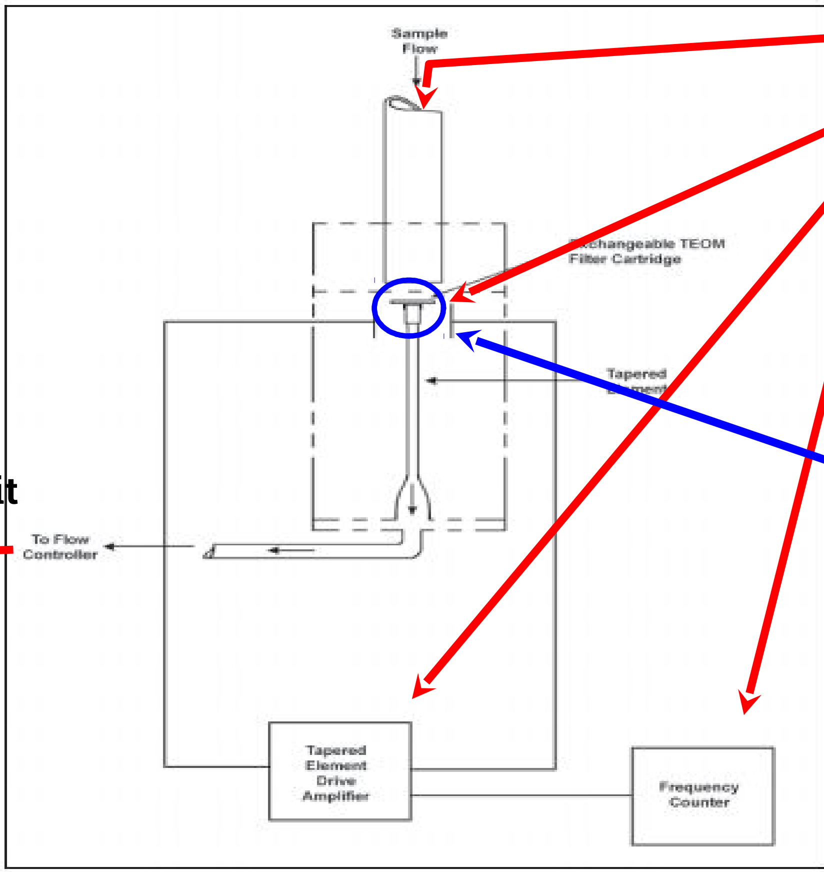
Automatic continuous measurements

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

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Mass concentration

Automatic continuous measurements

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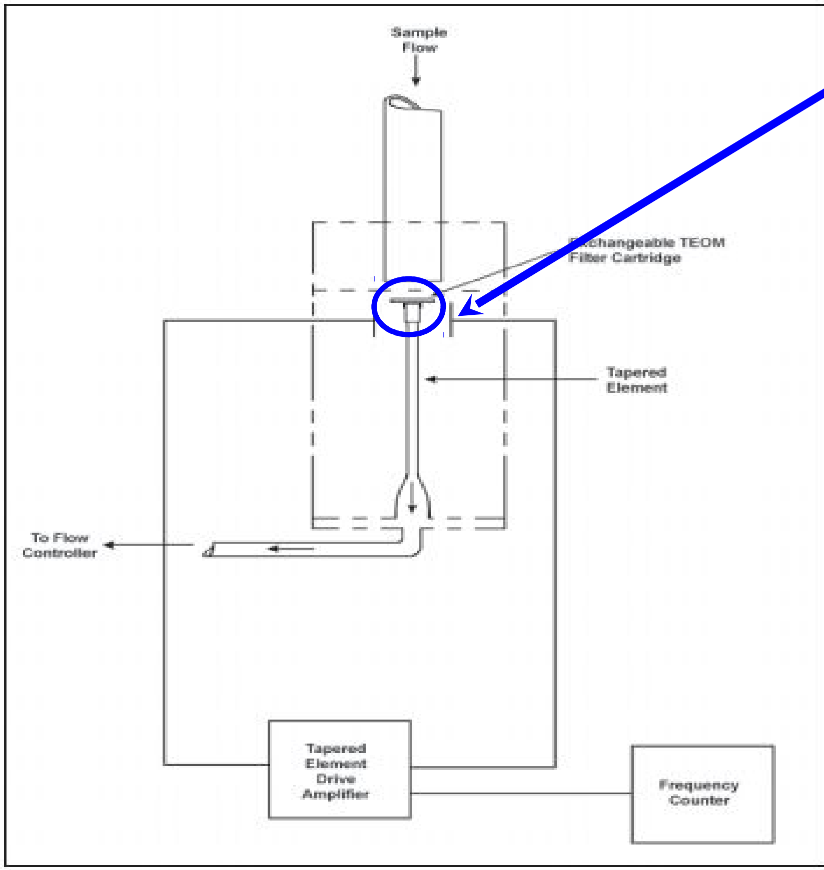


more dust → lower oscillation frequency

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:

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

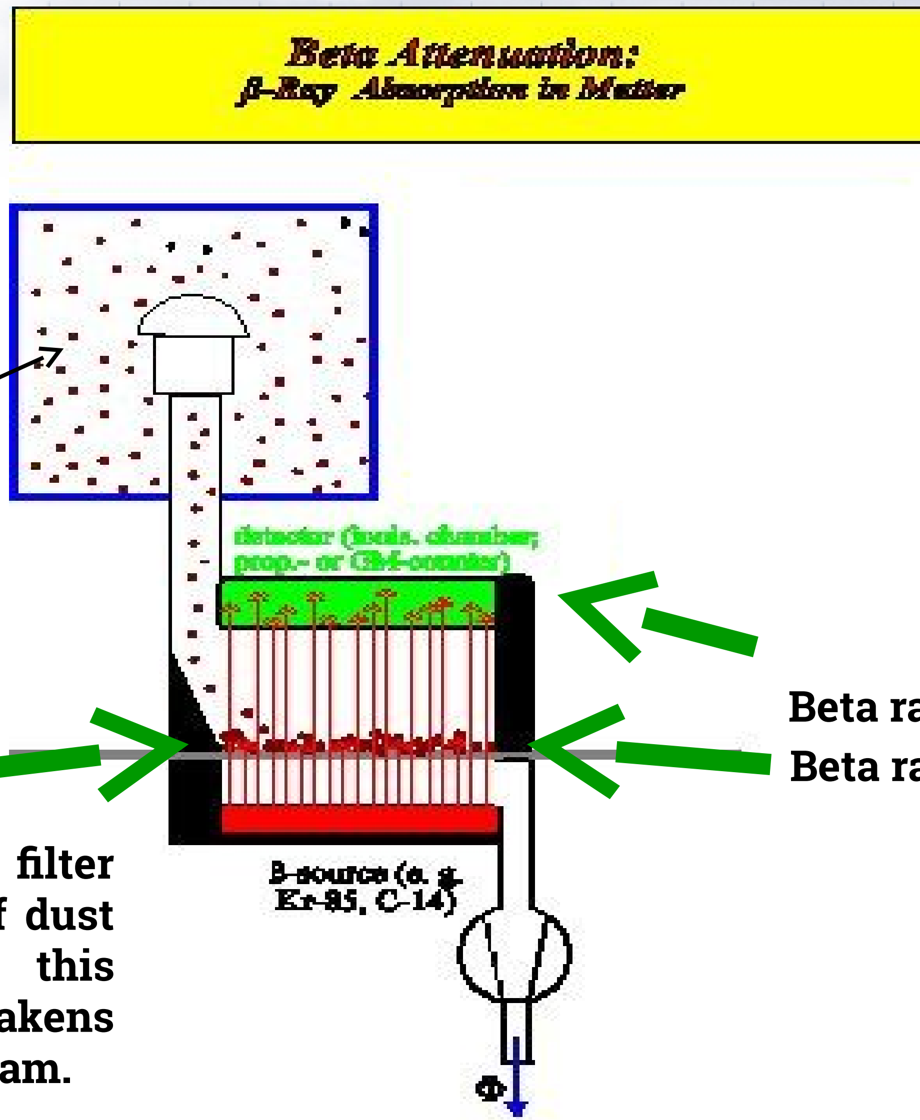
where:

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

Pump and flowmeter

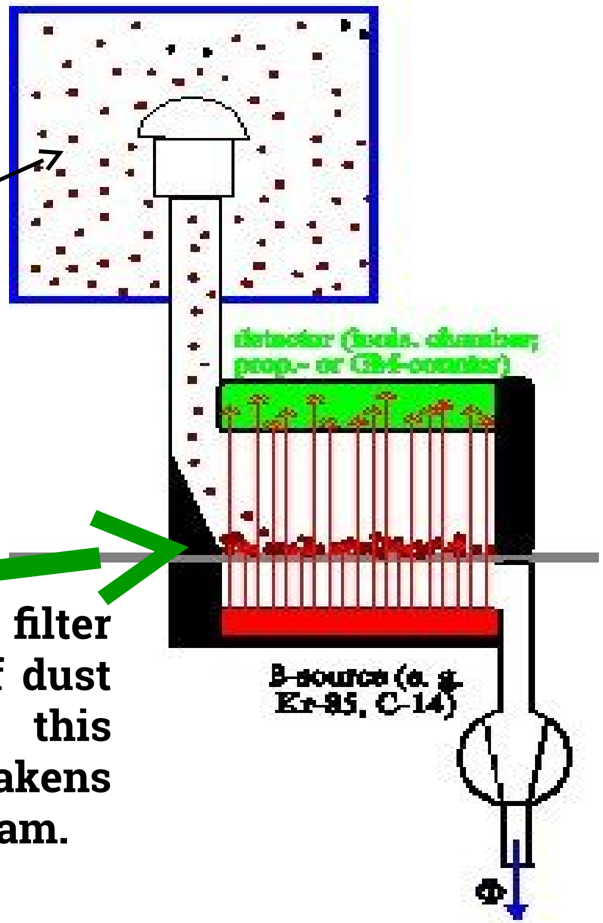
PM with Beta atenuation (1)

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

Ambient air is drawn through the sample system

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.

Beta Attenuation:
β-Ray Absorption in Matter



Pump and flowmeter

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

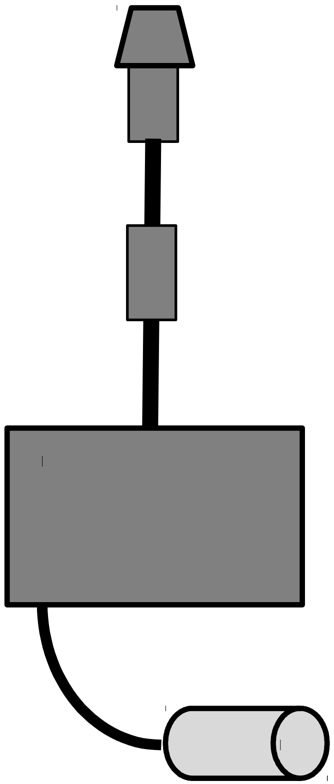
- **m**: increasing particle mass [µg]
- $\mathbf{F_{cal}}$: calibration factor
- $\mathbf{I_0}$ beta ray intensity at empty filter
- **I** beta ray intensity at loaded filter

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)

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

2. Automated analyzers



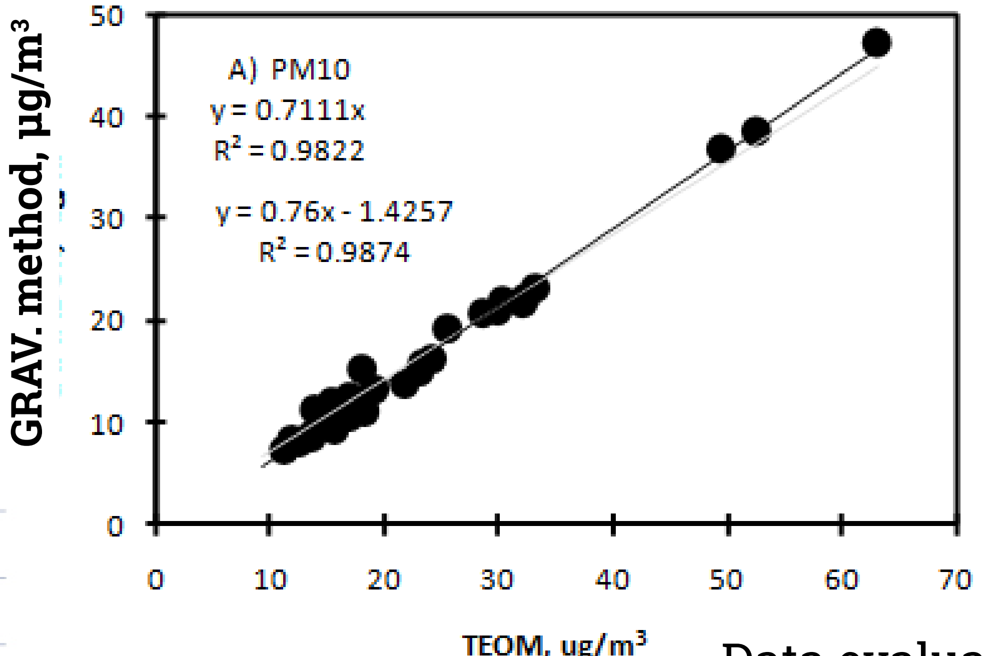
beta

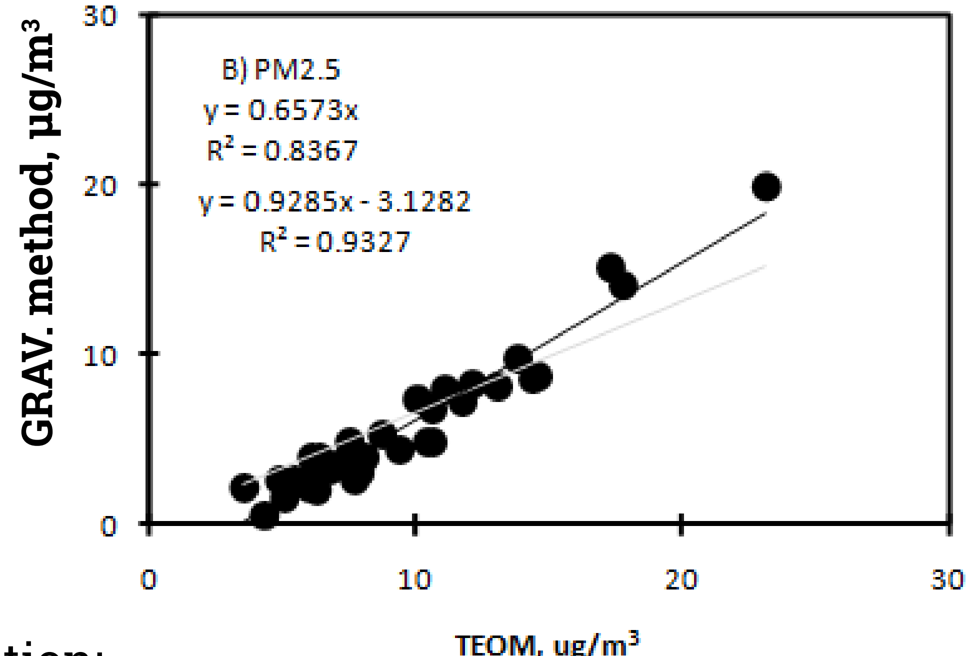
TEOM

Automatic versus the reference gravimetric method

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

Intercomparisons





<u>Data evaluation:</u>

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

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Common Continuous Ambient Aerosol Sampling Techniques

Advantages

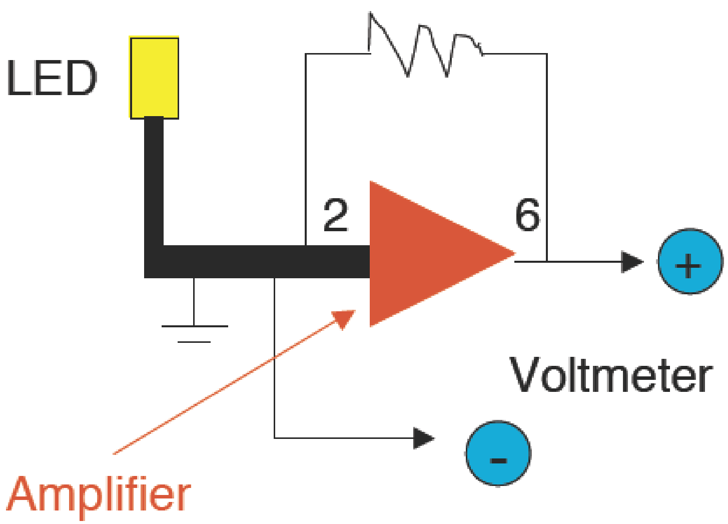
Continuous method
Highly time resolved
High resolution
instantaneous turnaround
Low operational cost

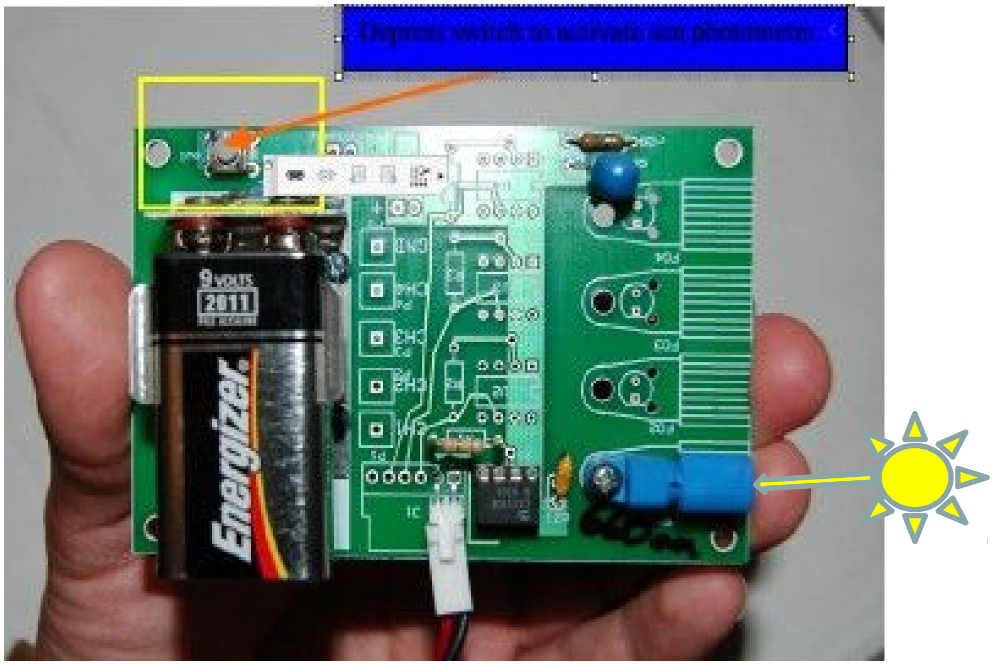
Disadvantages

Temperature dependency:
- Volatile losses
- Seasonal and regional dependencies

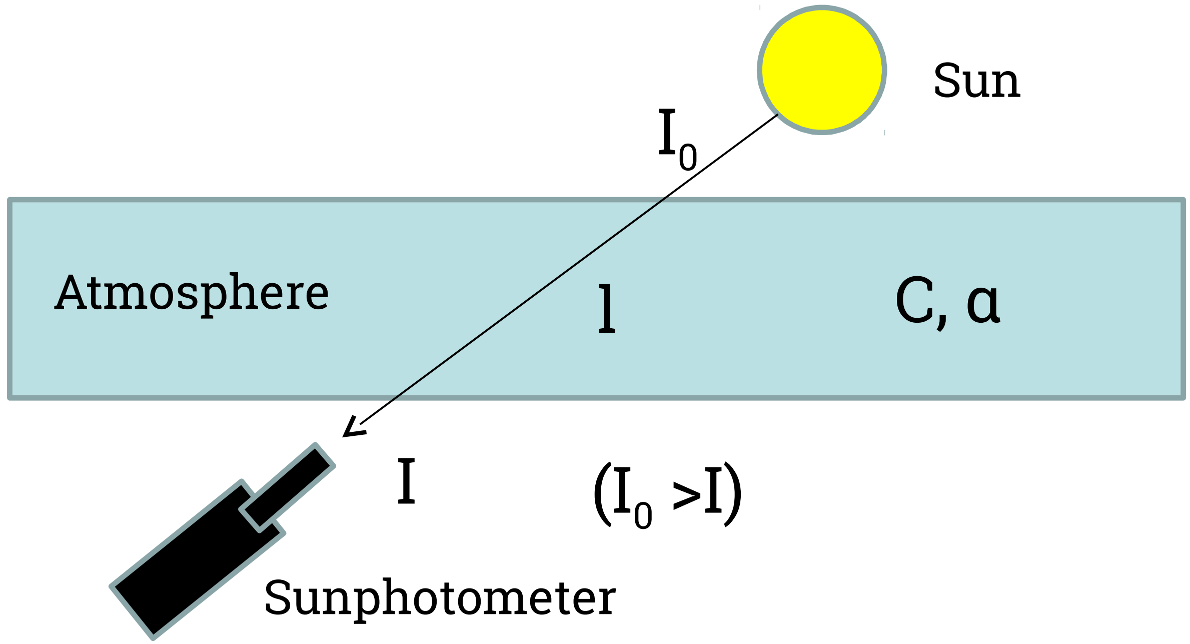
Affected by vibration
Manual filter changes necessary
Complex systems require some skill
X2 or X3 capita cost
Determination of Gravimetric Equivalent concentrations

Sun Photometers measures *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.



Beer's Law

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

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

Langley plot calibration (I_0 determination for each wavelength):

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

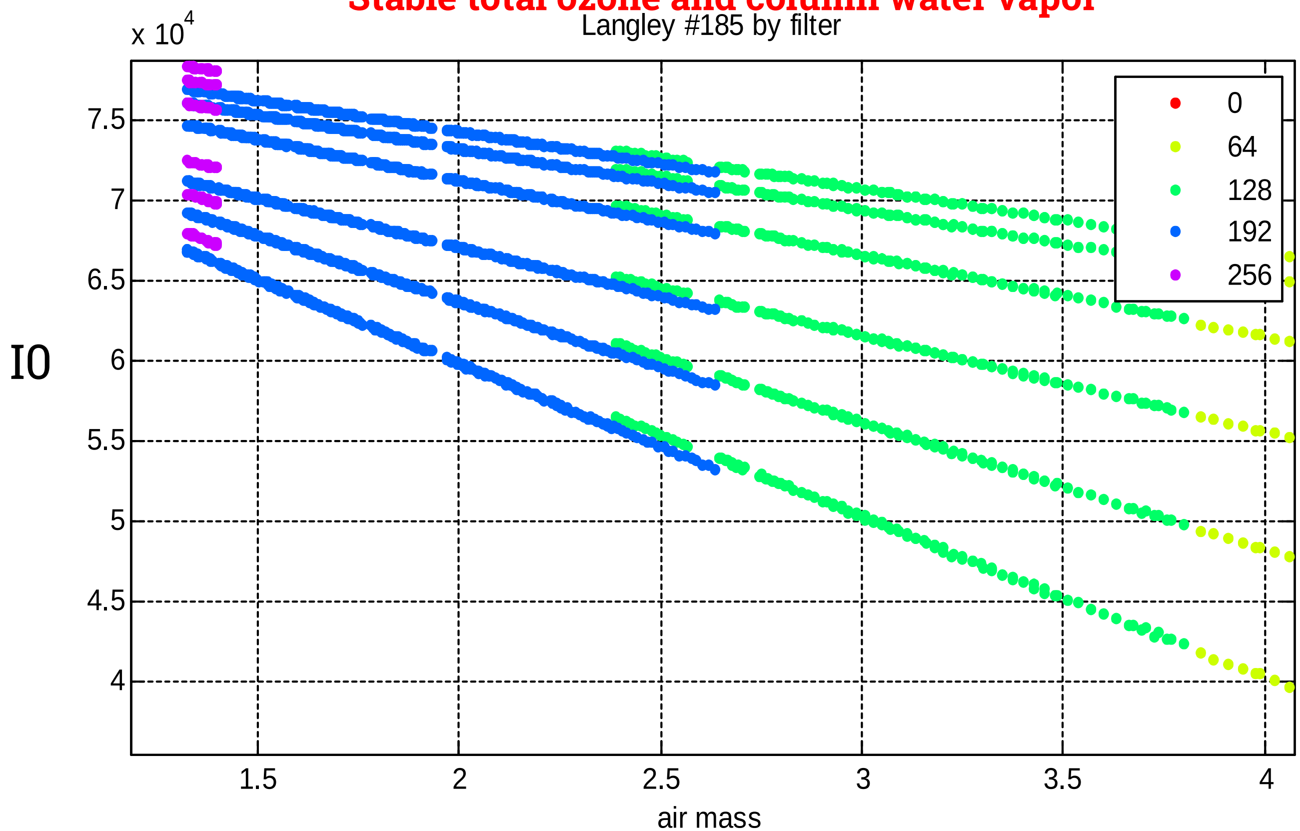
$$LnI = LnI_0 - \sigma_{ext} L$$

If σ_{ext} is constant during the observation → We can determine I_o

Pristine conditions (very low and constant aerosol load)

No clouds

Stable total ozone and column water vapor



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.

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

Typical AOD ranges

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.

CONCEPTS:

Angstrom Exponent (α)

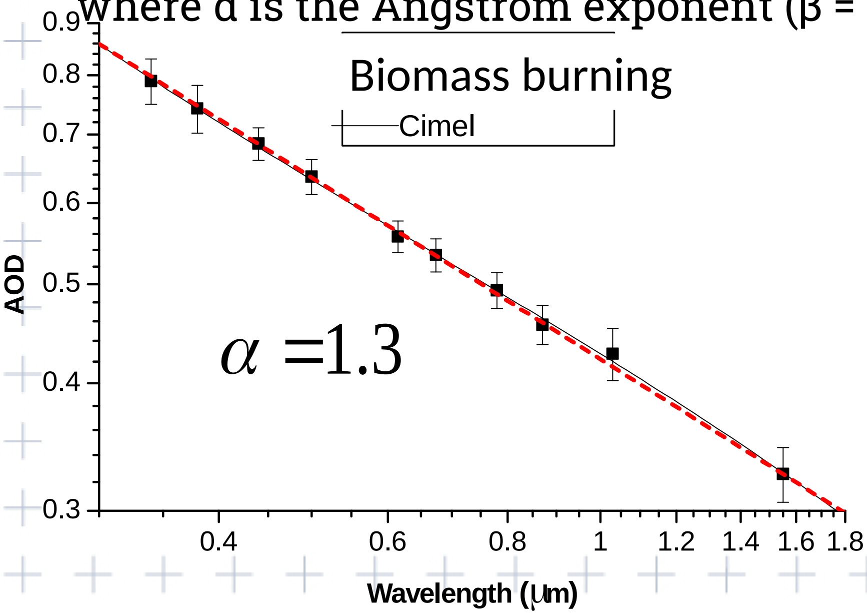
An exponent that expresses the spectral dependence of AOD with the wavelength of incident light (λ). The spectral dependence of aerosol optical thickness can be approximated (depending on size distribution) by:

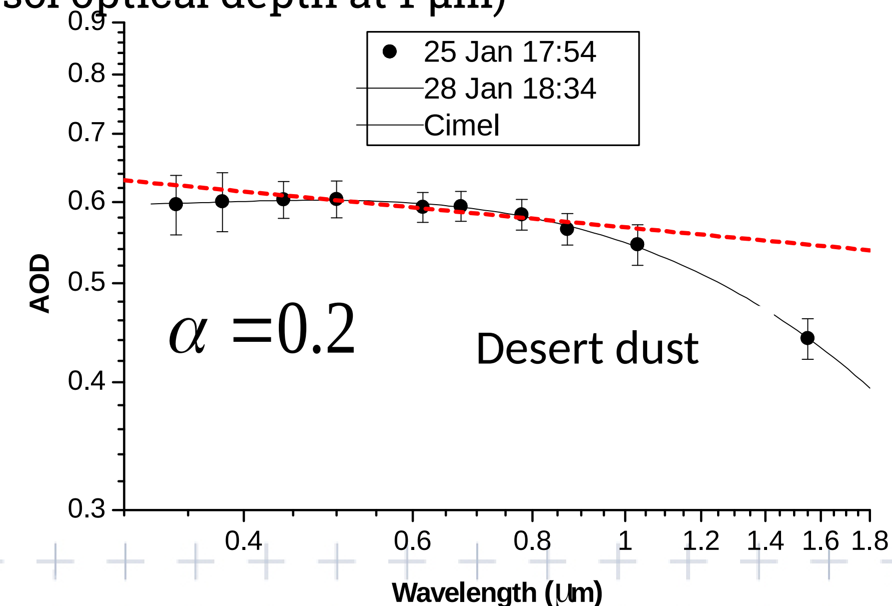
$$AOD = \beta \lambda^{-\alpha} \qquad \tau_a = \beta \lambda^{-\alpha}$$

α >> 0.9 FINE particles

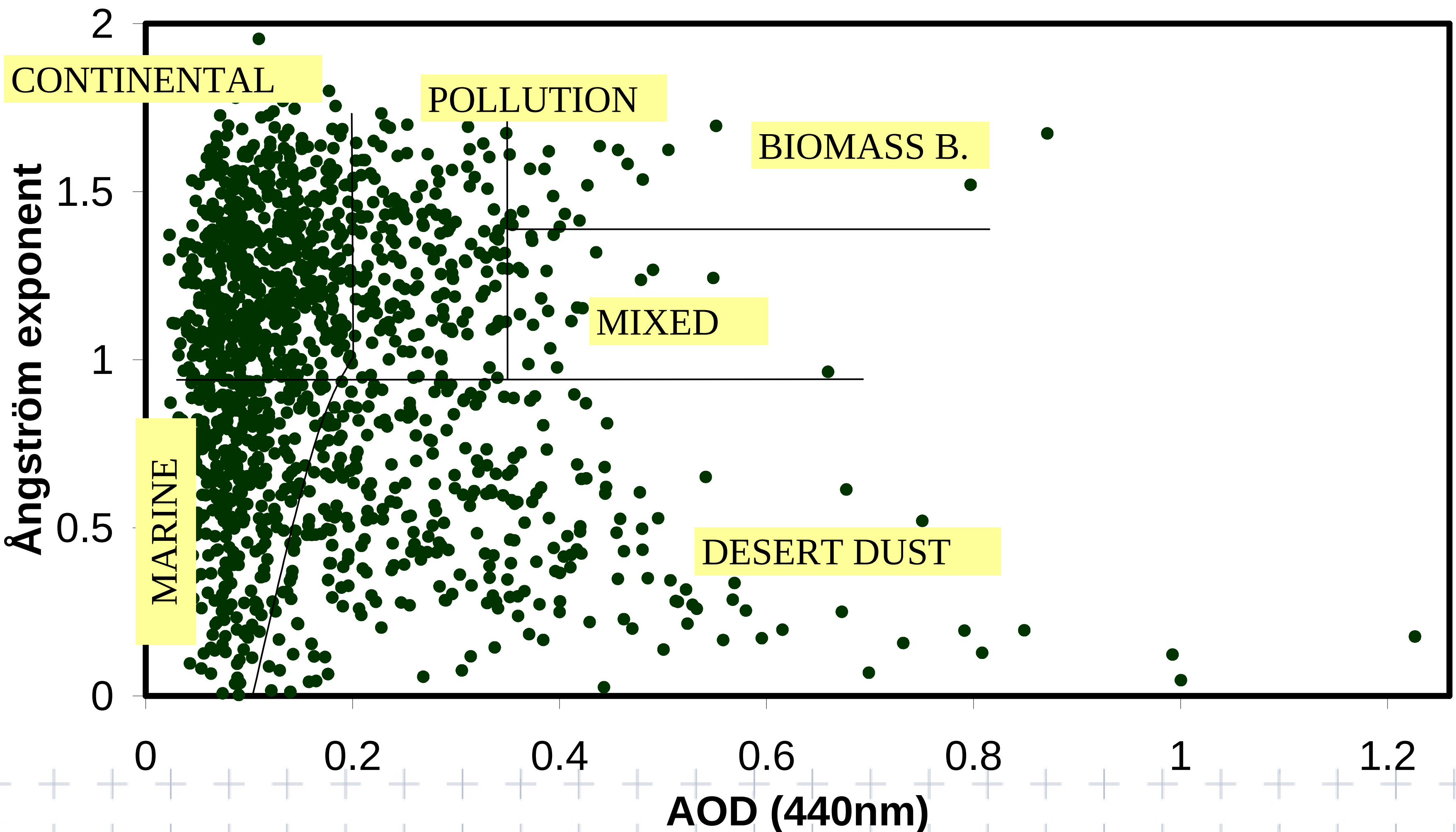
α << 0.7 COARSE particles

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

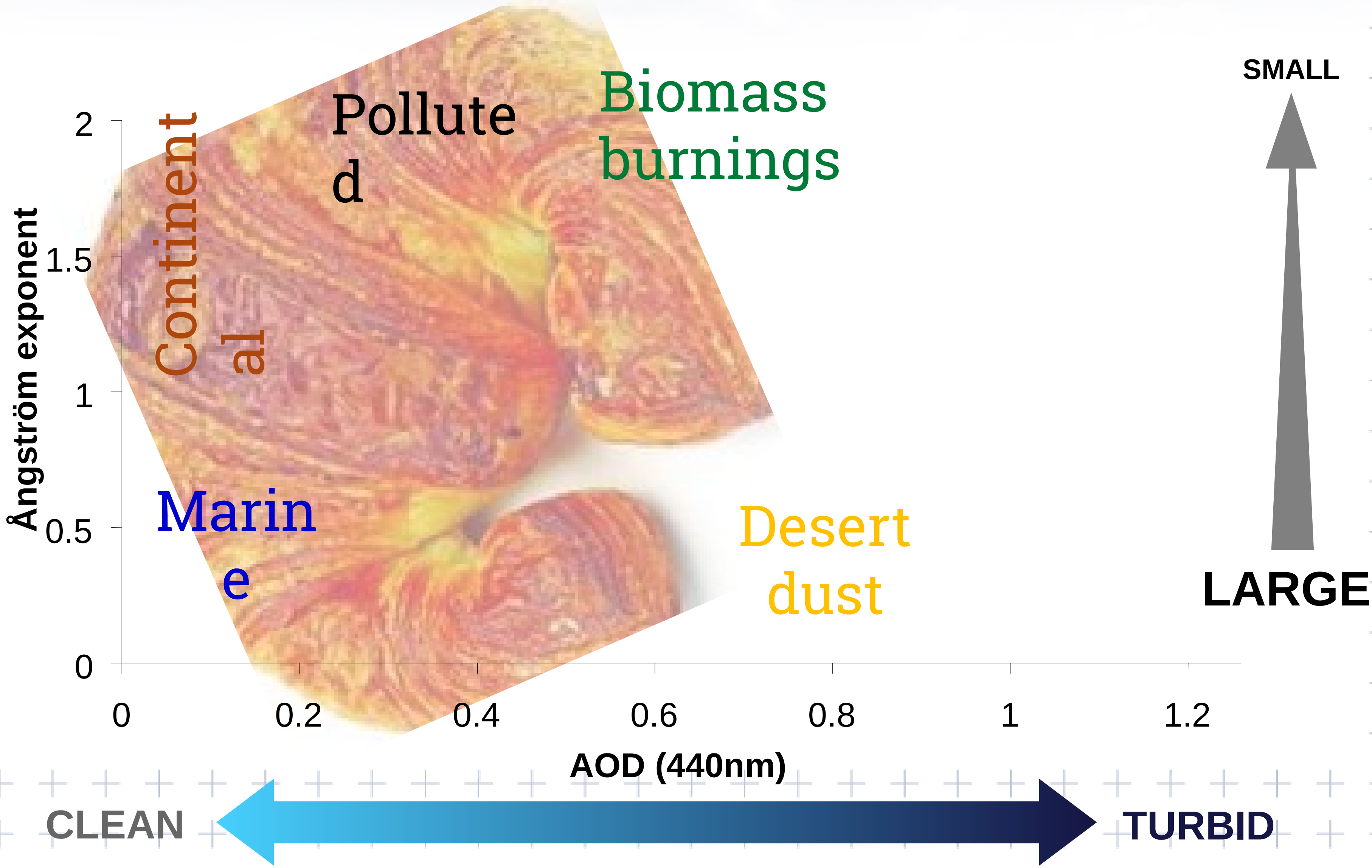




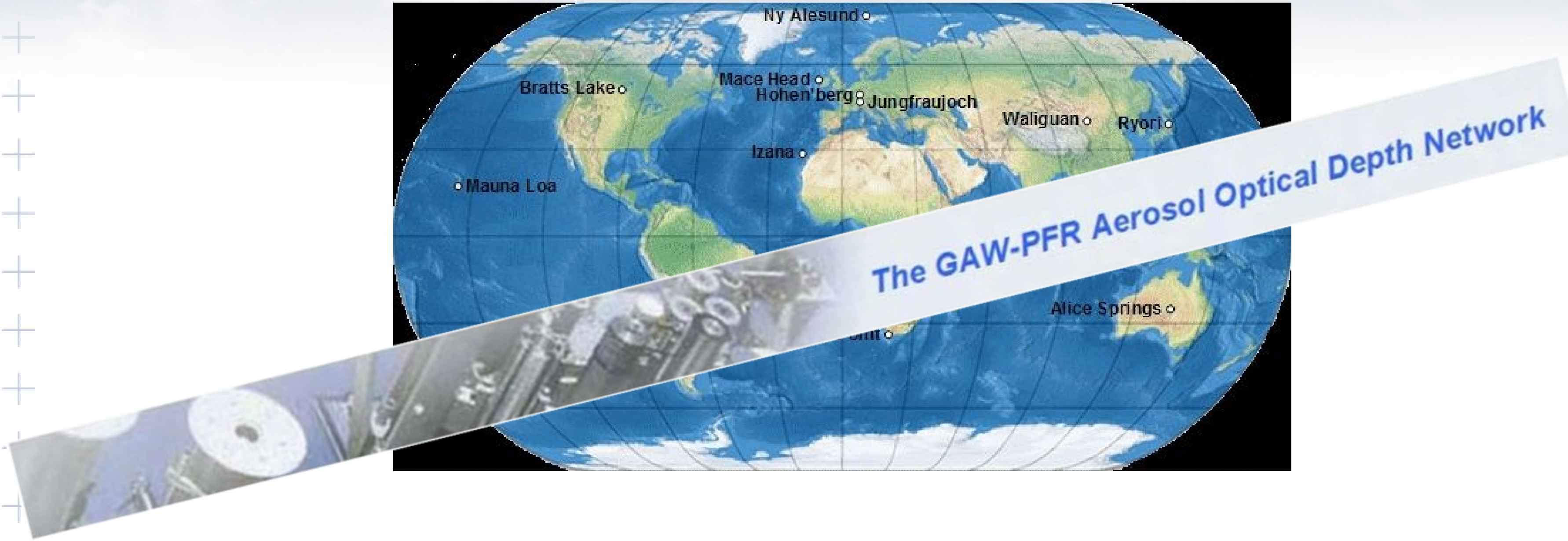
Aerosol Type with diagram AOD-α

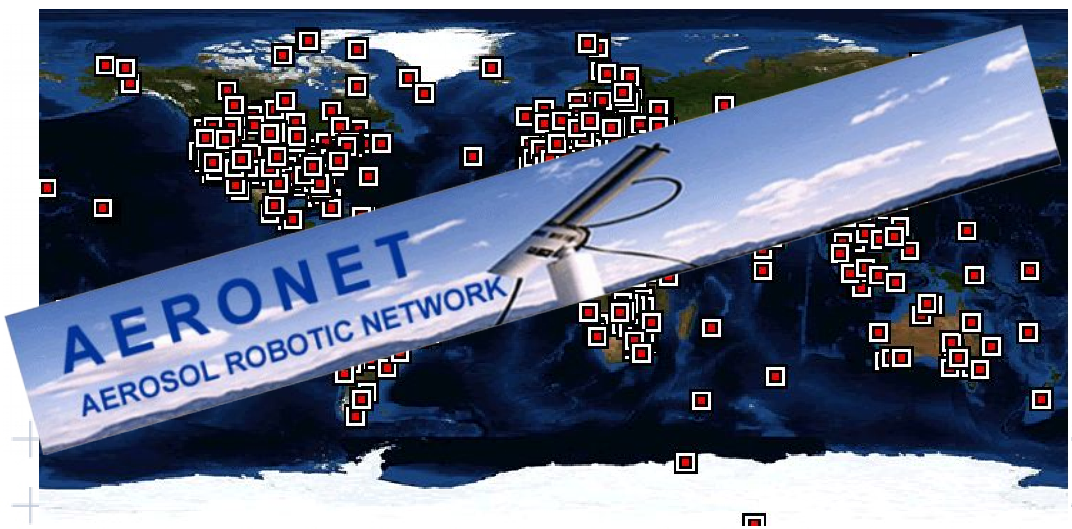


Aerosol Type with diagram AOD-α

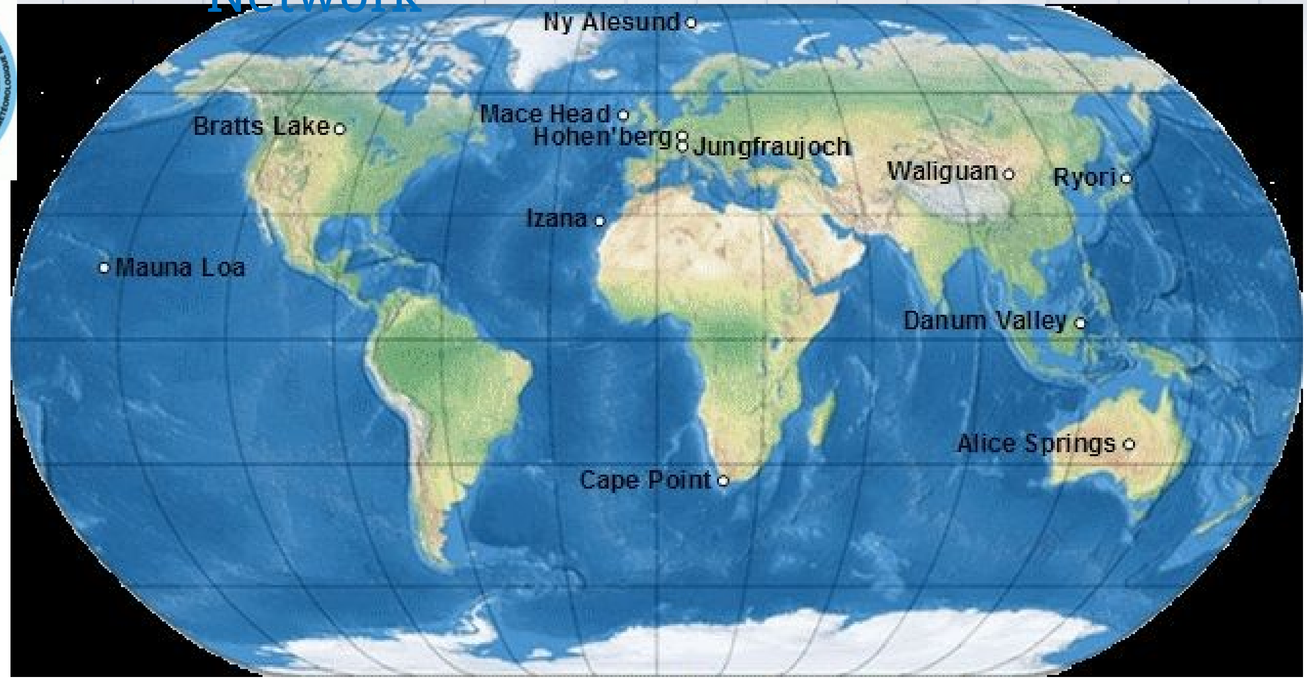


Photometry


The GAW-PFR Aerosol Optical Depth Network
Ny Alesund
Bratts Lake
Mace Head
Hohen'berg
Jungfraujoch
Waliguan
Ryori
Izana
Mauna Loa
Alice Springs

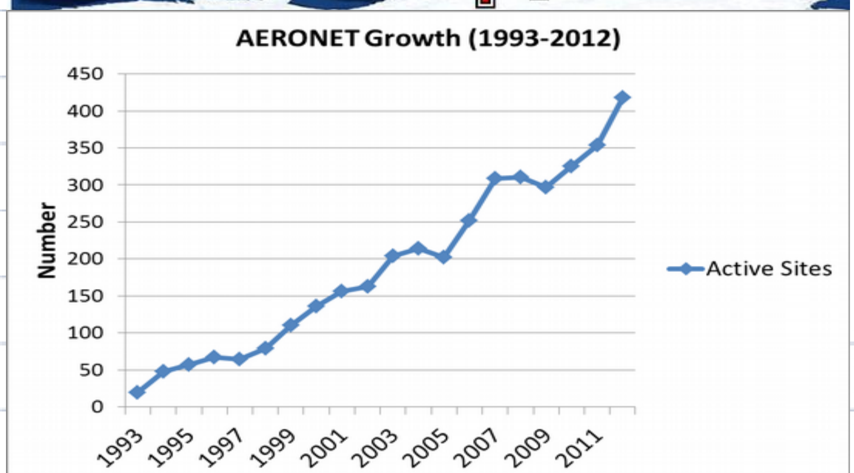

AERONET
AEROSOL ROBOTIC NETWORK

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.

AERONET Aerosol Robotic Network-Twenty Years of Observations and Research



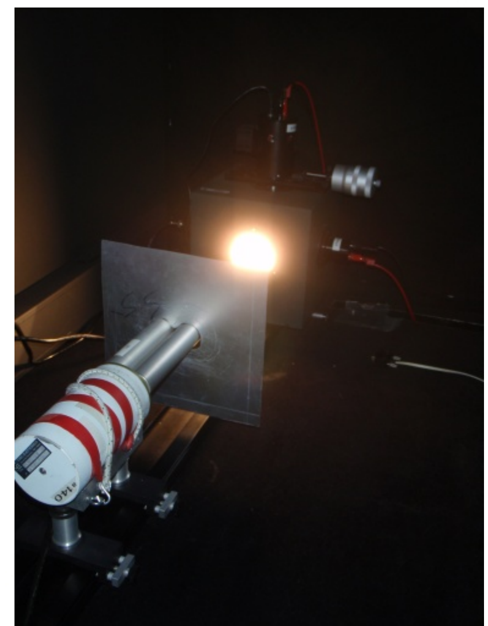
The AERONET program is a federation of ground-based remote sensing aerosol networks established by NASA and LOA-PHOTONS (CNRS) and has been expanded by collaborators from international agencies, institutes, universities, individual scientists and partners.

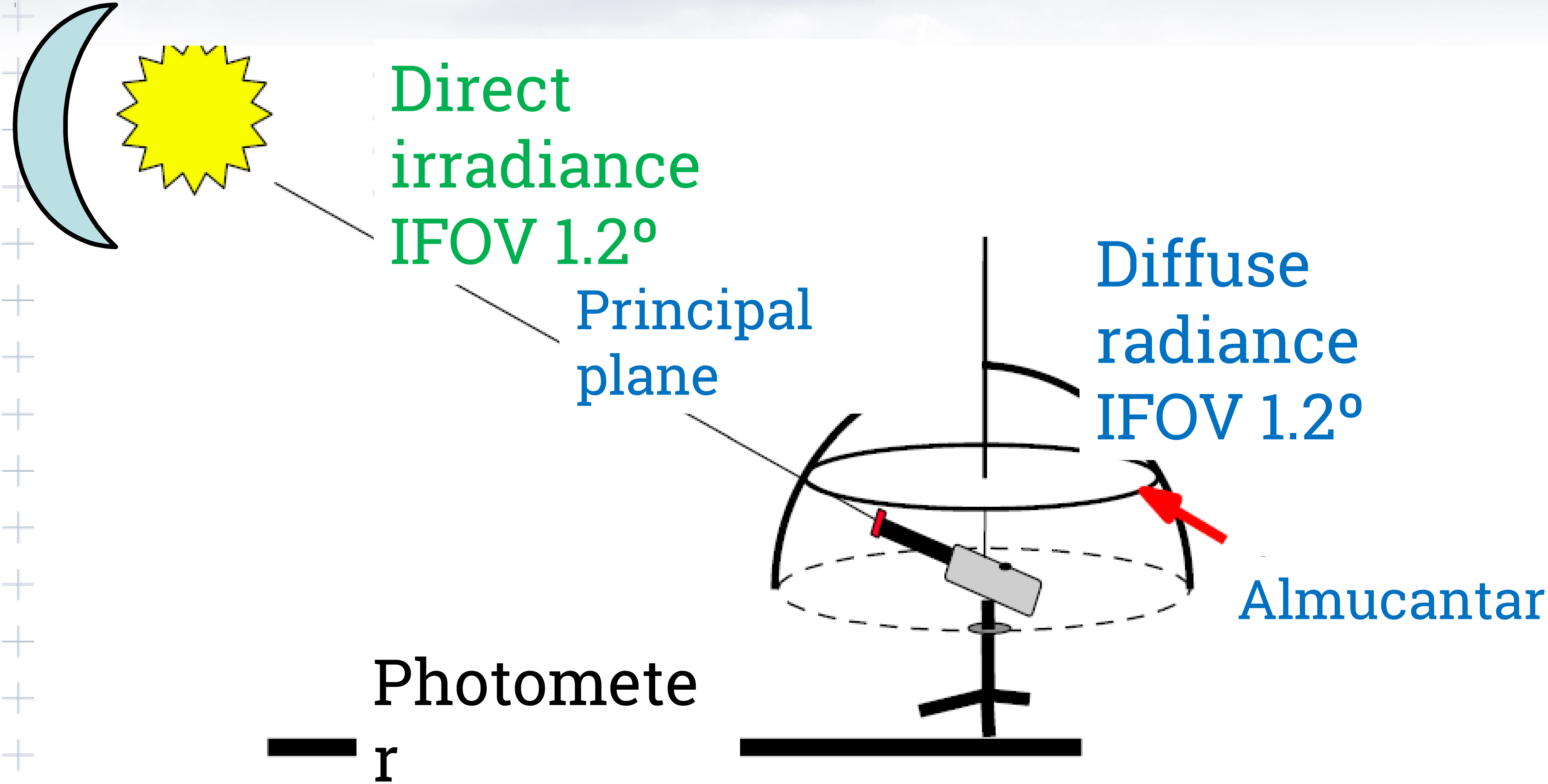
- >7000 citations
- >400 sites
- Over 80 countries
- http://aeronet.gsfc.nasa.gov

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

- 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.

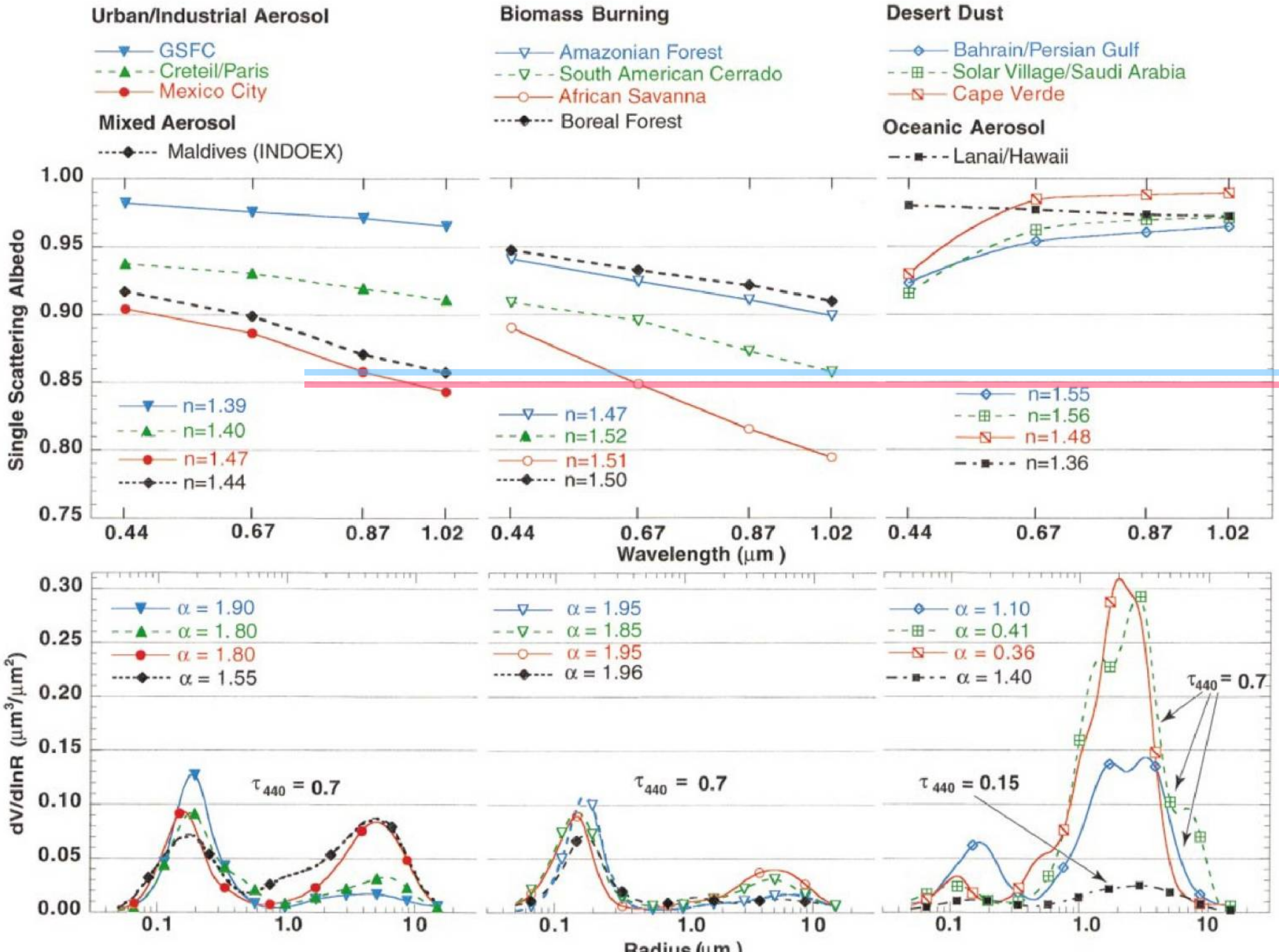




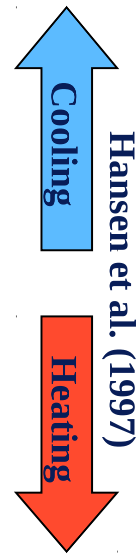
Sun/moon measurements

Sky measurements

Aerosol Climatology from AERONET



$$\omega_0(\lambda) \quad \frac{Scattering\ coefficient(\beta_s)}{Extinction\ coefficient(\beta_s+\beta_a)}$$



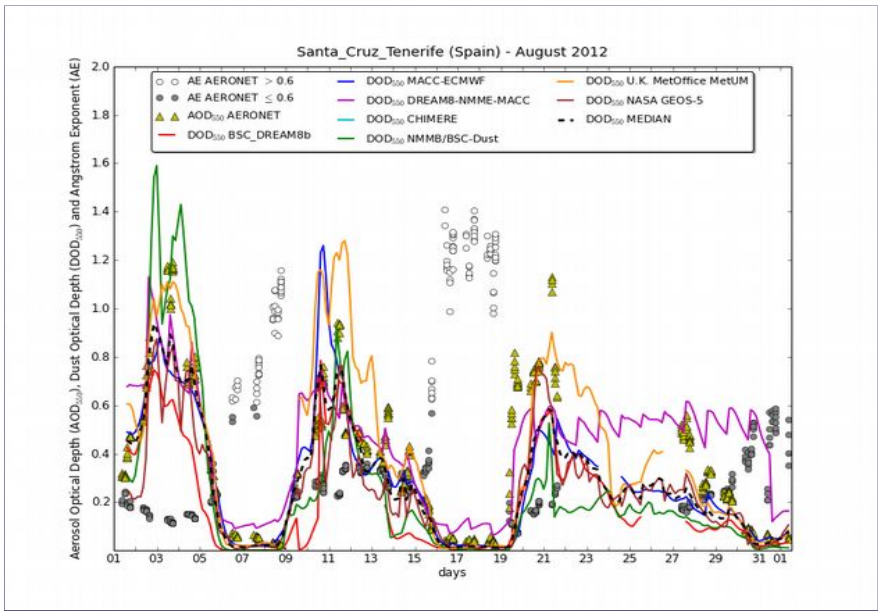
Dubovik, O., B. Holben, T. F. Eck, A. Smirnov, Y. J. Kaufman, M. D. King, D. Tanré, and I. Slutsker, 2002: Variability of absorption and optical properties of key aerosol types observed in worldwide locations. *J. Atmos. Sci.*, **59**, 590–608.

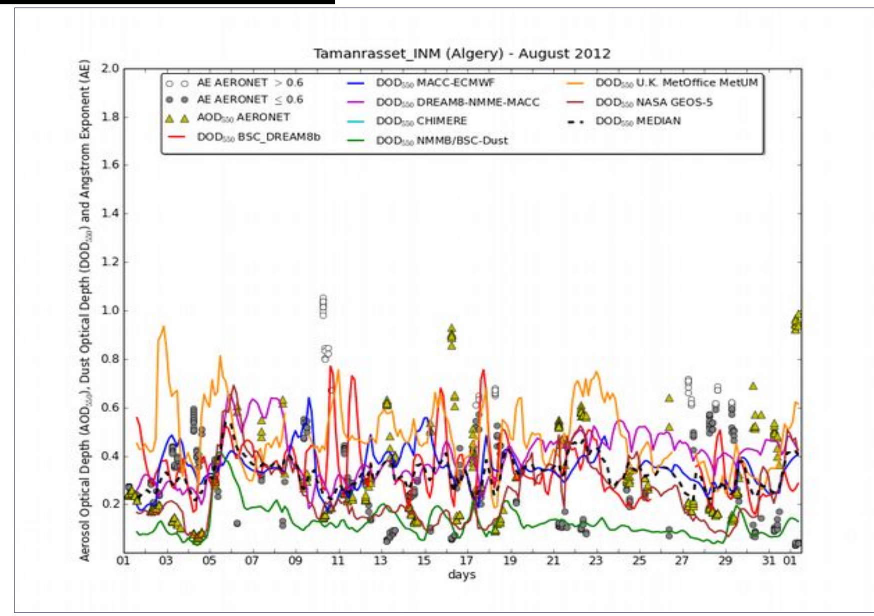
Photometry

NRT evaluation using AERONET data

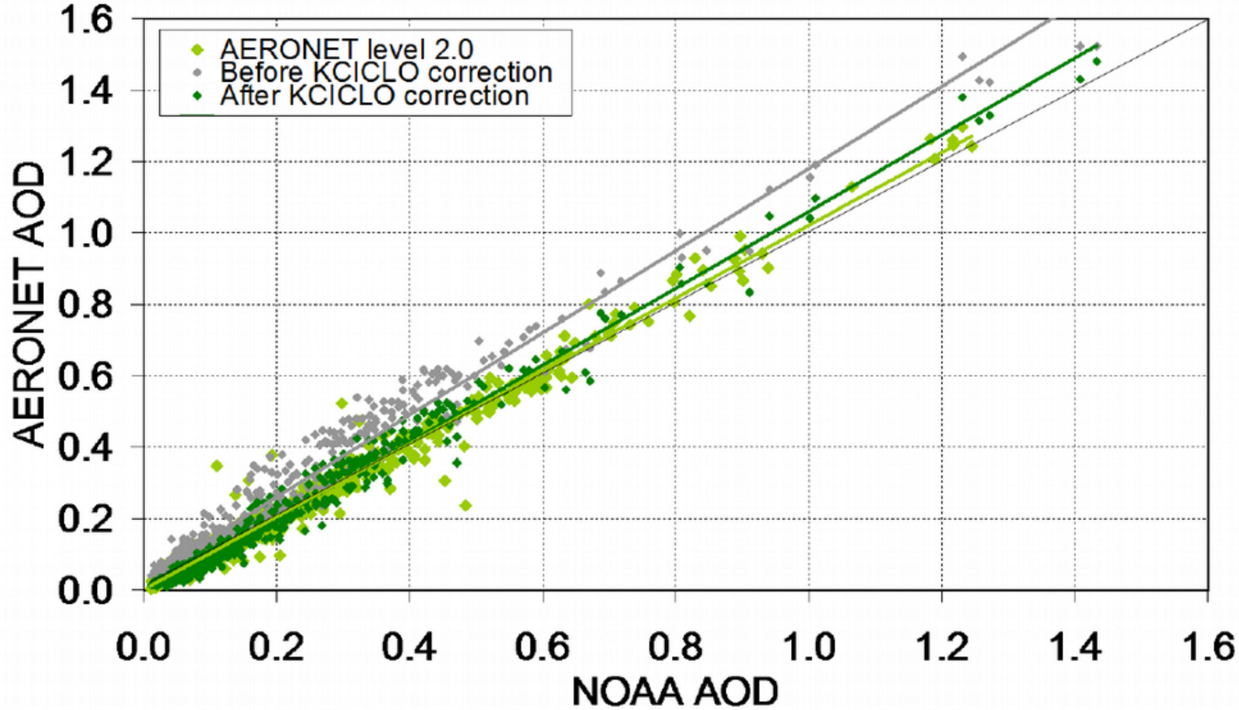
SANTA_CRUZ_TENERIFE

TAMANRASSET_INM





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

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

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

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.

Calitoo handheld sun photometer

AOD @ 465, 540 et 619 nm
Angstrom Exponent

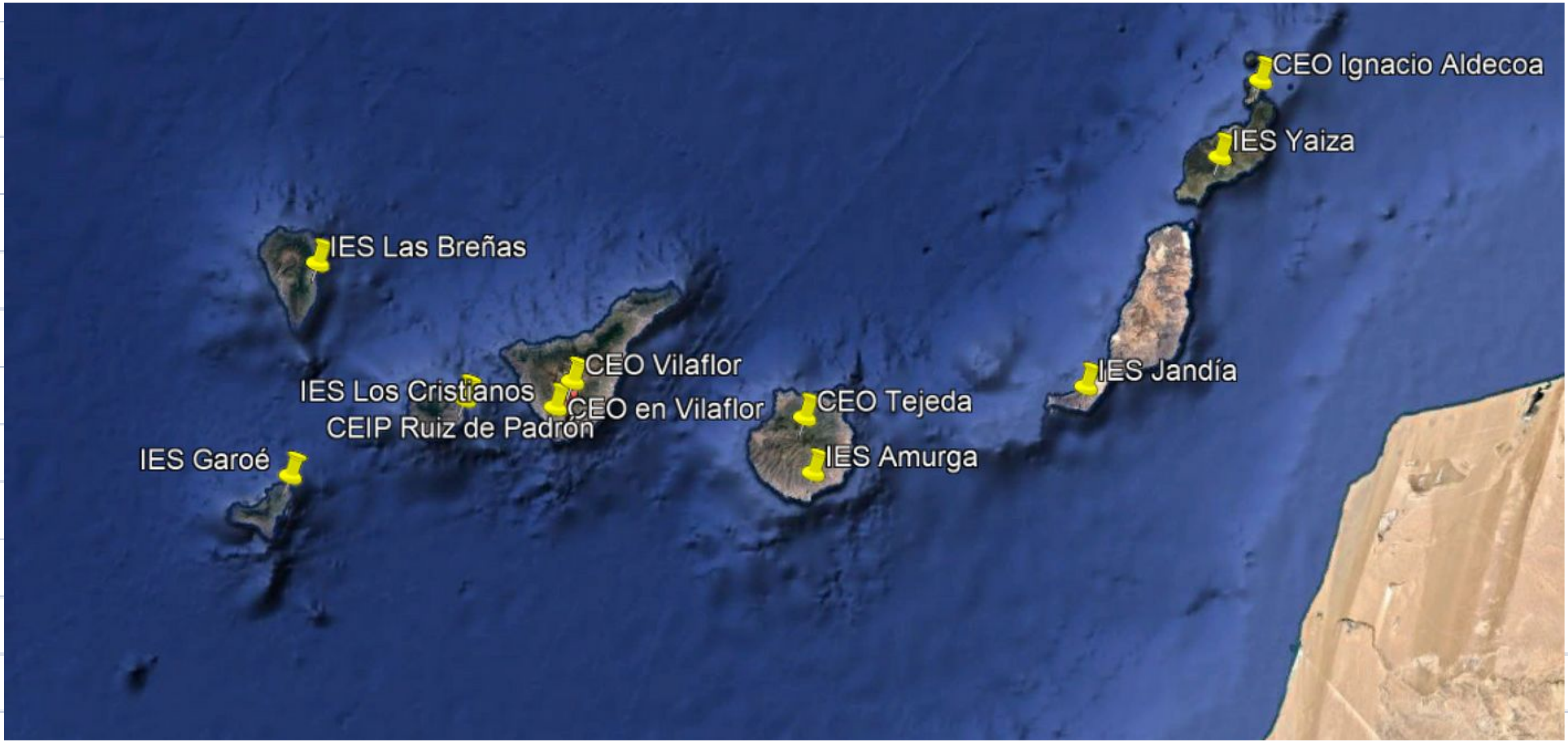
Calibration of hundred Calitoo sun-photometers involved in the GLOBE scientific-educational program at Izaña testbed.

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

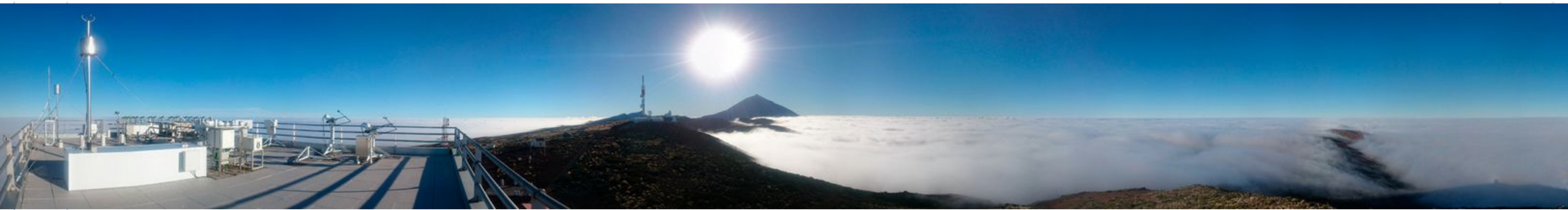
El Hierro - IES Garoe.
La Gomera - CEIP Ruiz de Padrón.
La Palma - IES Las Breñas.
Fuerteventura - IES Jandía
Lanzarote - IES Yaiza
La Graciosa - CEO Ignacio Aldecoa.
Gran Canaria - CEO Tejeda e IES Amurga
Tenerife- IES Los Cristianos y CEO en Vilaflor

http://testbed.aemet.es/calima/

CEIP de la Gomera: ceiprpadron
c31prp4dr0n



Thank you



http://izana.aemet.es