AEROSOL
MAGEE SCIENTIFIC

Demonstration of the new Aethalometer model AE36 performance

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Outline

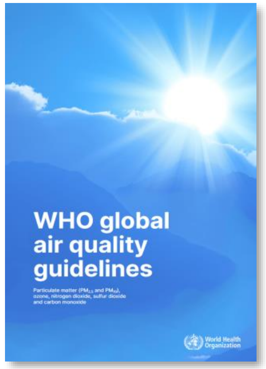
- Fine Particulate Matter ($PM_{2.5}$) and Carbonaceous Aerosols – introduction, terminology, sources, motivation.
- Instrumentation: **new Aethalometer AE36.**
- AE36 – Demonstration of performance.
- **Black Carbon Index.**
- Conclusions.

Aethalometer model AE36.

Fine Particulate matter ($PM_{2.5}$)

- Clean air is fundamental to health.
- Air pollution is now recognized as the single biggest environmental threat to human health.

WHO, 2021



Recommended AQ guidelines

Pollutant	Averaging time	AQG level
$PM_{2.5}$, µg/m³	Annual	5
	24-hour[a]	15
PM_{10}, µg/m³	Annual	15
	24-hour[a]	45

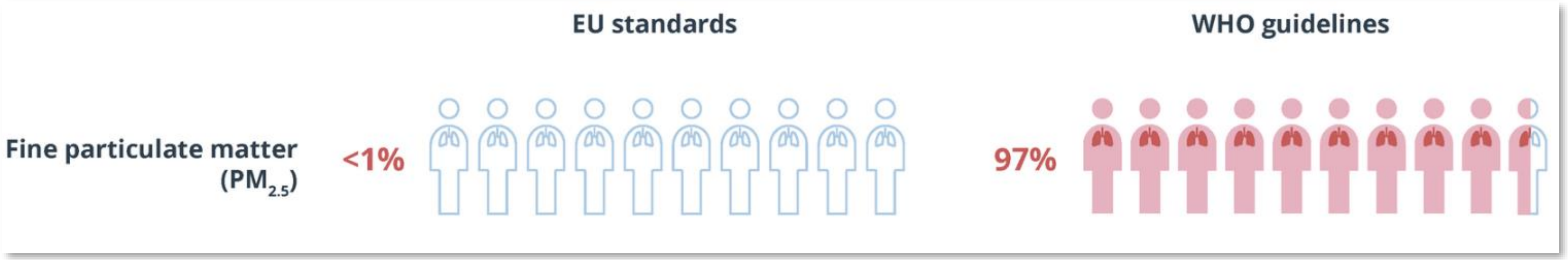
new directives

US EPA 2024

Pollutant	Averaging time	AQG level
$PM_{2.5}$, µg/m³	Annual, primary	9
	24-hour[a]	35
PM_{10}, µg/m³	Annual	/
	24-hour[a]	150

$PM_{2.5}$ → Carbonaceous Aerosols

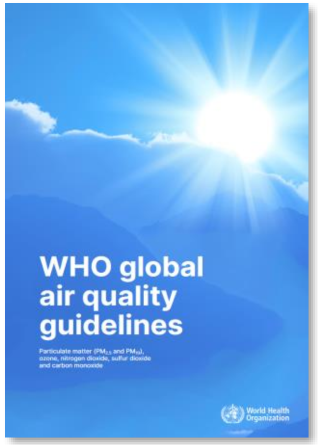
- Under the extant standards in Europe, less than 1% of the population is exposed to air with PM2.5 concentrations exceeding the prescribed limits. However, this proportion escalates to 97% when evaluated against the WHO guidelines.



- To be able to further decrease PM2.5 concentrations, mitigation strategies must be targeted to specific sources, and source apportionment needs to be implemented in monitoring networks.
- Carbonaceous aerosols (Black Carbon – BC, Organic Aerosols – OA) is the largest and often dominant fraction of PM2.5

Particulate matter (PM) → Carbonaceous Aerosols

WHO, 2021



Good practice statements

BC/EC

1. Make systematic measurements of black carbon and/or elemental carbon. Such measurements should not replace or reduce existing monitoring of those pollutants for which guidelines currently exist.
2. Undertake the production of emission inventories, exposure assessments and source apportionment for BC/EC.
3. Take measures to reduce BC/EC emissions from within the relevant jurisdiction and, where appropriate, develop standards (or targets) for ambient BC/EC concentrations.

new directives? →

BC limit

CA limit

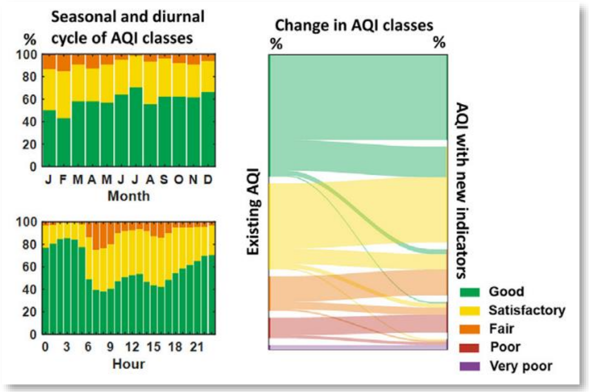
POA, SOA limit

AQI for Ozone and PM

AQI Basics for Ozone and Particle Pollution

Levels of Concern	Values of Index	Description of Air Quality
Good	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Moderate	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Unhealthy	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 to 300	Health alert: The risk of health effects is increased for everyone.
Hazardous	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

AirNow

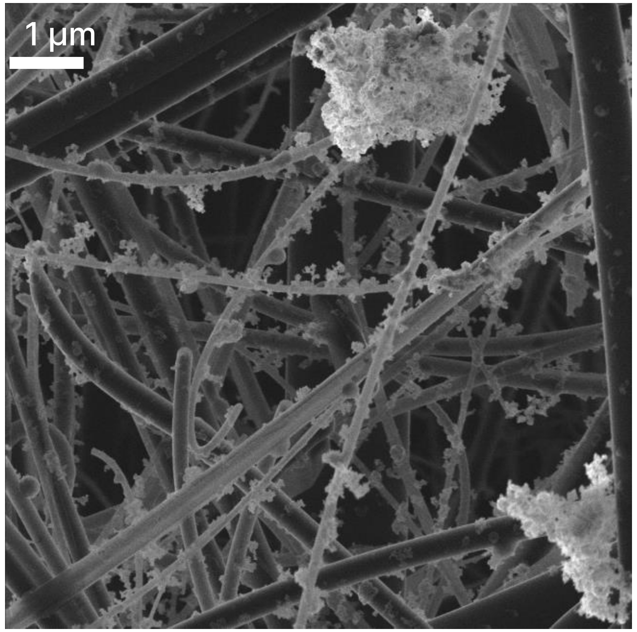


Comparison of existing AQI and new AQI with BC indicator.

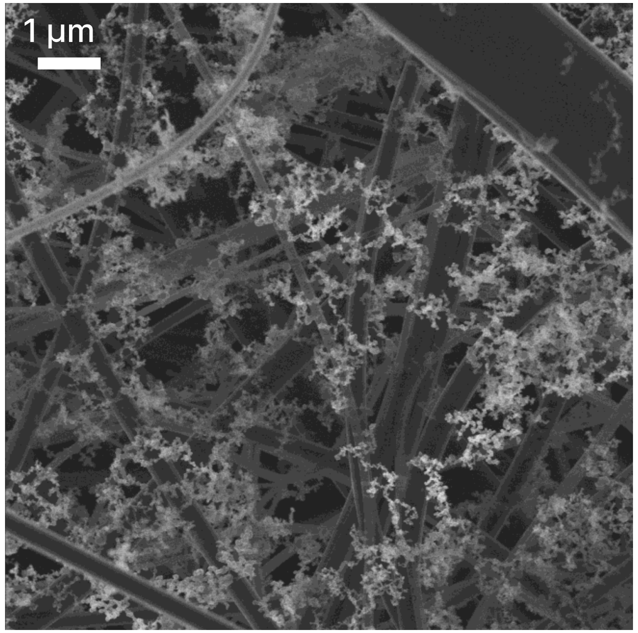
Source: Fung et al., Science of the Total Environment, 844, 2022.

Carbonaceous Aerosol

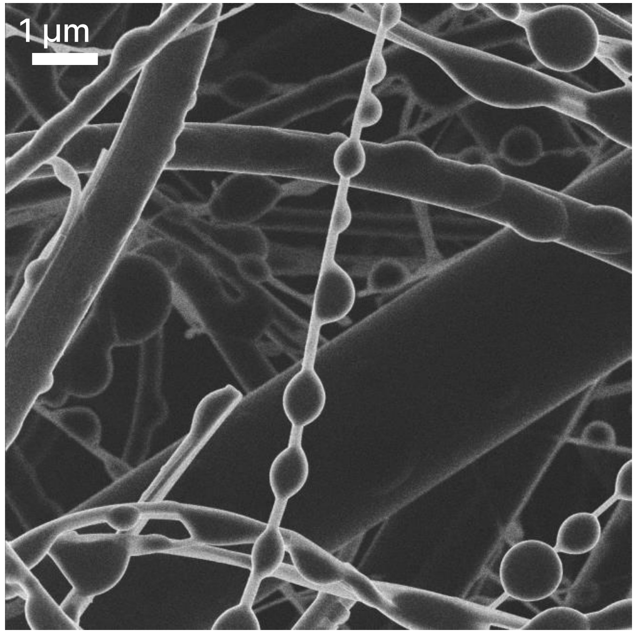
Diesel



Wood flaming (beech)



Wood smouldering (orange)



Rigler et al., Demonstration of the new Aethalometer model AE36 performance

New Aethalometers AE36 and AE36s

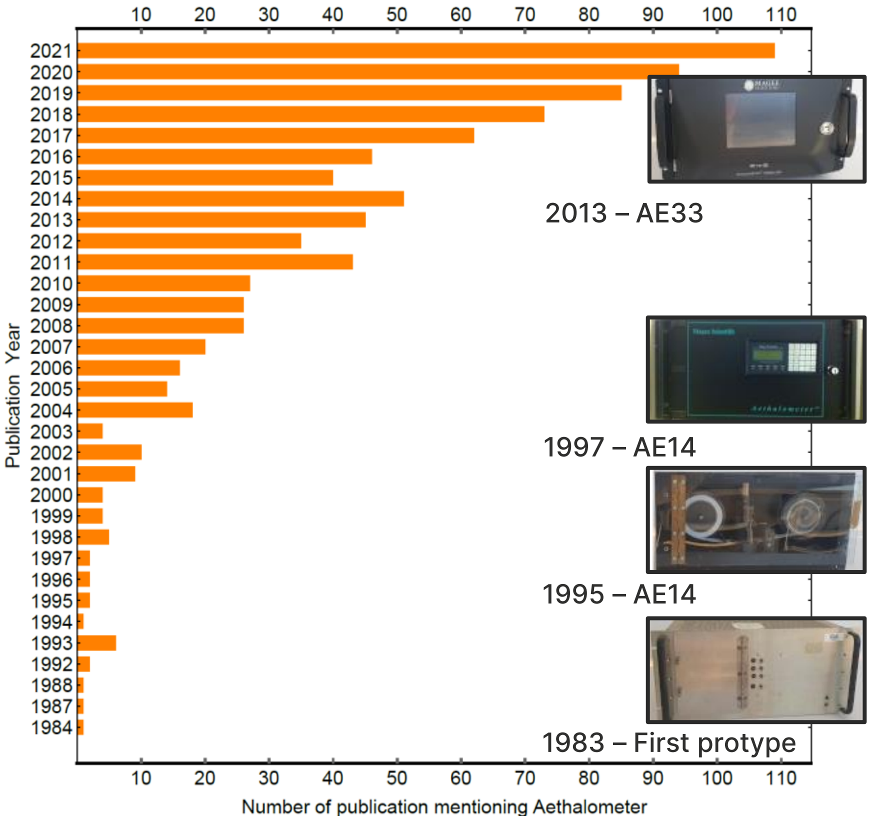
- 9-wavelength, 340 – 950 nm, characterization of light-absorbing aerosols for AE36s.
- Real-time Brown Carbon analyses using two new wavelengths, 340 and 400 nm.
- **Robustness to relative humidity changes.**
- **Improved Limit of detection.**
- **20 m filter tape, self-cleaning procedure.**
- **Automatic data validation.**
- **Black carbon index (AQI).**

Aethalometer model AE36.

Aethalometer model AE36s.

Rigler et al., Demonstration of the new Aethalometer model AE36 performance

Aethalometer AE36



- The Aethalometer is a most widely used filter photometer capable of measuring <u>**the light-absorbing properties of aerosol**</u> particles.
- More than <u>**1000 scientific articles**</u> mentioning Aethalometer.

Real-time measurement of the absorption coefficient of aerosol particles

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University of California, Lawrence Berkeley Laboratory, Energy & Environment Division, Berkeley, California 94720.
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Sponsored by R. W. Terhune, Ford Motor Company
0003-6935/82/173060-03$01.00/0.
© 1982 Optical Society of America.

Recent studies have shown that large concentrations of graphitic carbon particles are found in the atmosphere in both urban and remote locations.[1] These particles are produced in combustion and have a large optical absorption cross section, of the order of 10 m^2/g. Their presence affects radiation transfer through the atmosphere, causing visibility degradation[2] and possible changes in the regional or global radiation balance.[3] The size of these effects depends critically on both the particle concentration and their single-scattering albedo,[4] which is determined by the relative magnitude of the scattering and absorption coefficients. The scattering coefficient is easily measured by nephelometry.[5,6] In this Communica-

The "dual-spot" Aethalometer: an improved measurement of aerosol black carbon with real-time loading compensation

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Abstract. Aerosol black carbon is a unique primary tracer for combustion emissions. It affects the optical properties of the atmosphere and is recognized as the second most important anthropogenic forcing agent for climate change. It is the primary tracer for adverse health effects caused by air pollution. For the accurate determination of mass equivalent black carbon concentrations in the air and for source apportionment of the concentrations, optical measurements by filter-based absorption photometers must take into account the "filter loading effect". We present a new real-time loading effect compensation algorithm based on a two parallel spot measurement of optical absorption. This algorithm has been incorporated into the new Aethalometer model AE33. Intercomparison studies show excellent reproducibility of the AE33 measurements and very good agreement with post-processed data obtained using earlier Aethalometer models and other filter-based absorption photometers. The real-time loading effect compensation algorithm provides the high-quality data necessary for real-time source apportionment and for determi-

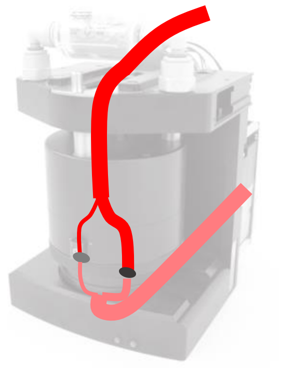
1 Introduction

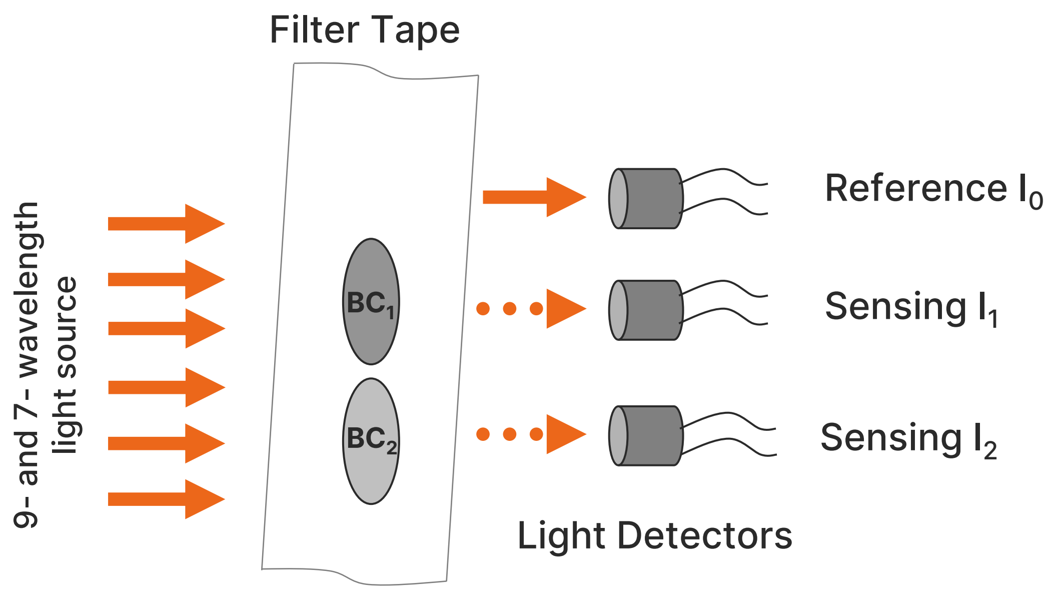
The combustion of carbonaceous fuels inevitably results in the emission of gas and particulate air pollutants. One of the fractions of the emitted particles are light-absorbing carbonaceous aerosol compounds, in particular black carbon (BC), an aerosol species exhibiting very large optical absorption across the visible part of the optical spectrum. Black carbon is a unique primary tracer for combustion emissions as it has no non-combustion sources. It is inert and can be transported over great distances (Hansen et al., 1989; Bodhaine, 1995; Sciare et al., 2009). Black carbon affects the optical properties of the atmosphere when suspended and is recognized as the second most important anthropogenic forcing agent for climate change after CO_2 (Ramanathan and Carmichael, 2008; Bond et al., 2013). Black carbon is also the leading indicator of the adverse health effects caused by particulate air pollution (Janssen et al., 2011, 2012; Grahame et al., 2014).

Source: <u>www.webofscience.com</u>, Hansen A.D.A. et al., 1982, Drinovec et al., 2015

Aethalometer AE36
Principle of operation

The Aethalometers AE36 uses similar optical chamber as AE33:





$ATN_1 = \ln(I_0 / I_1)$

$ATN_2 = \ln(I_0 / I_2)$

Dual Spot algorithm

$$b_{ATN} = \frac{S}{F}\frac{\Delta ATN}{\Delta t} f(ATN) = eBC \cdot \sigma$$

$$b_{ABS} = \frac{b_{ATN}}{C} = eBC \cdot MAC$$

C – multiple scattering parameter

Low **SSA** approximation

General Ängstrom exponent:

$$b_{ABS} \sim \lambda^{-\alpha}$$

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Aethalometer

Principle of operation

The Aethalometer is a widely used filter photometer capable of measuring the light-absorbing properties of aerosol particles.

$$b_{\text{ATN}} = \frac{S}{F} \frac{\Delta\text{ATN}}{\Delta t} f(\text{ATN}) = \text{eBC} \cdot \sigma$$

$$b_{\text{ABS}} = \frac{b_{\text{ATN}}}{C} = \text{eBC} \cdot \text{MAC}$$

C – multiple scattering parameter

low SSA approximation

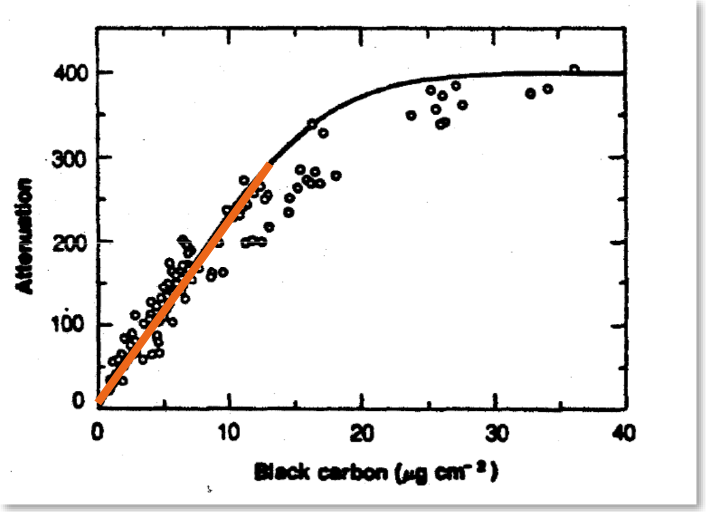
General Ängstrom exponent:

$$b_{\text{ABS}} \sim \lambda^{-\alpha}$$

THE RELATIONSHIP BETWEEN OPTICAL ATTENUATION AND BLACK CARBON CONCENTRATION FOR AMBIENT AND SOURCE PARTICLES*

L.A. GUNDEL, R.L. DOD, H. ROSEN and T. NOVAKOV
Applied Science Division, Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720, USA

Samples of aerosol particles were collected on quartz-fiber filters that had been prefired at 800°C for 12 hours. Both high (40 SCFM) and low (10-20 SCFM) volume samplers were used. One-third of the samples were size segregated, with a particle cutoff of < 2 µm. Ambient samples were collected in Berkeley (two sites) and Los Angeles, California; Warren, Michigan (ref.5); Vienna, Austria; and Ljubljana, Yugoslavia. Some of the sampling sites were source influenced:



Source: L. Gundel et al., The Sc. of the Tot. Env., 36, 1984

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Aethalometer AE36

AE36 default settings

MAC_{880} = **7.77 m²/g**
C = **1.39**

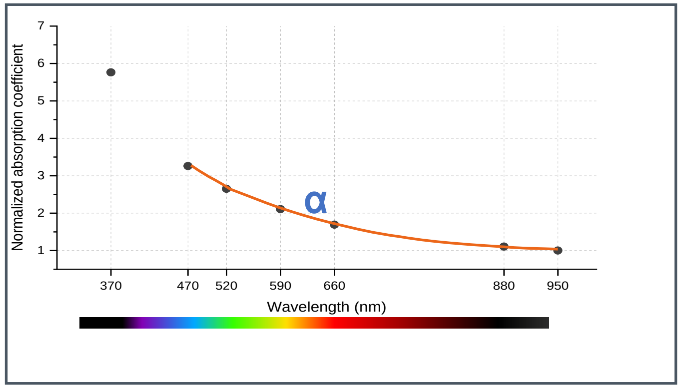
ACTRIS recommendation

MAC_{880} = **7.77 m²/g**
C_{ACTRIS} = **2.44** (H_{ACTRIS} = **1.76**)

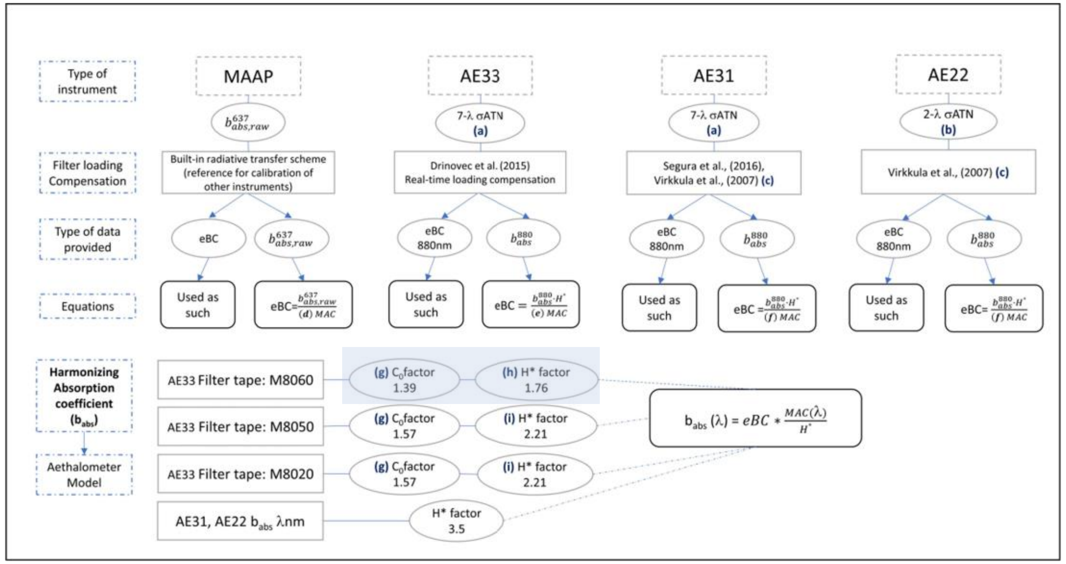
Aethalometer model recommendation

α_{ff} = **1.1** α_{bb} = **2.0**

- Limitations:
  - Only two sources of pollution (fossil fuel and biomass burning) where the characteristic α does not change.
  - Well mixed atmosphere.



Use of multiwavelength absorption data.



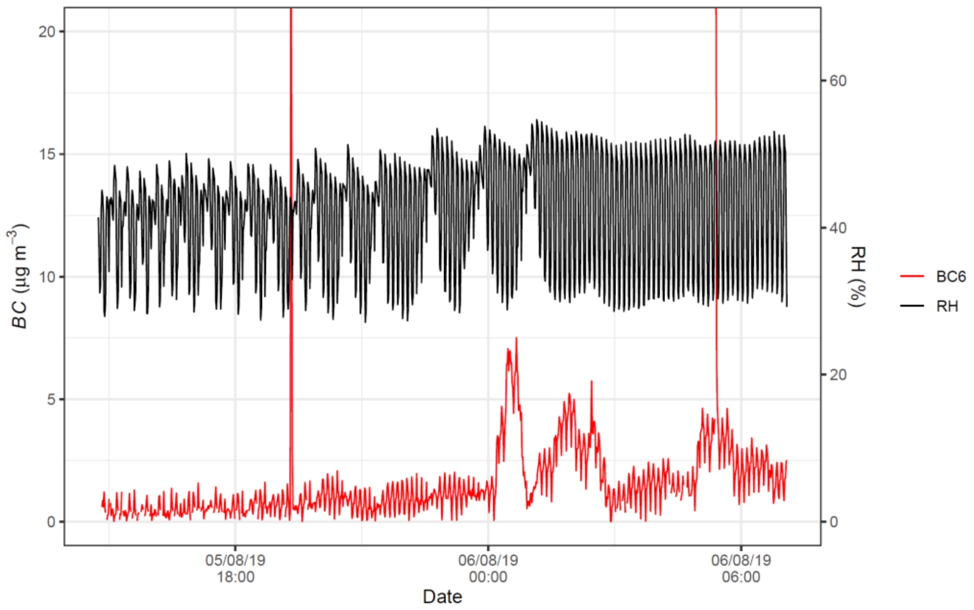
Source: Savadkoohi et al., Environment International, 2023; Savadkoohi et al., Environment International, 2024

Filter photometers and sensitivity to dRH/dt

Introduction

Aerosol samples and instrument surrounding air contain **water vapor**, which can be adsorbed to the fibres or to the binding material of the **filter tape** used in filter photometers.

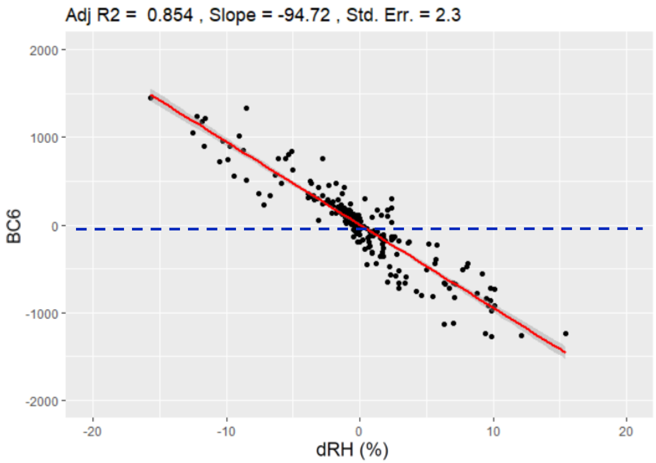
Water vapor can reach the filter through the **sample inlet** or enter through **openings in the filter tape (FT) compartment**, especially in environments where relative humidity changes rapidly (**air-conditioned (AC) containers, mobile stations**, etc.)

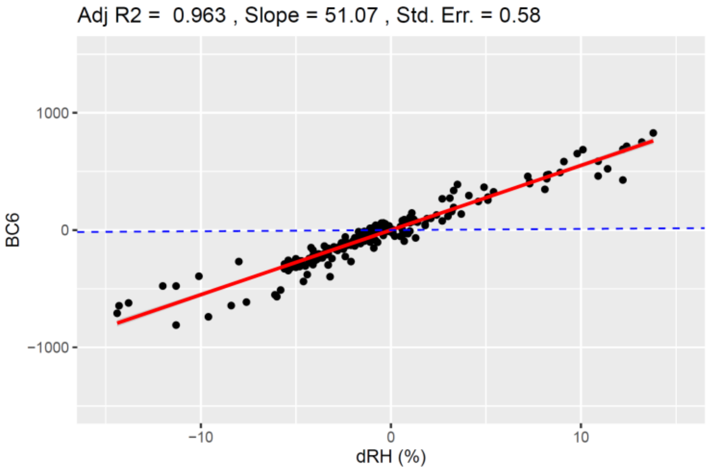


Example of the effect of AC on filter photometer data.

Source: Düsing S., et al., Atmos. Meas. Tech., 12, 5879–5895, 2019

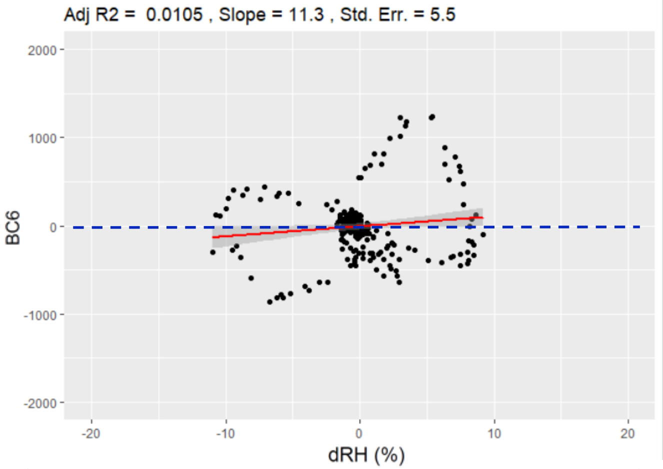
Filter photometers and sensitivity to dRH/dt





RH changes in FT compartment

RH changes in sample inlet



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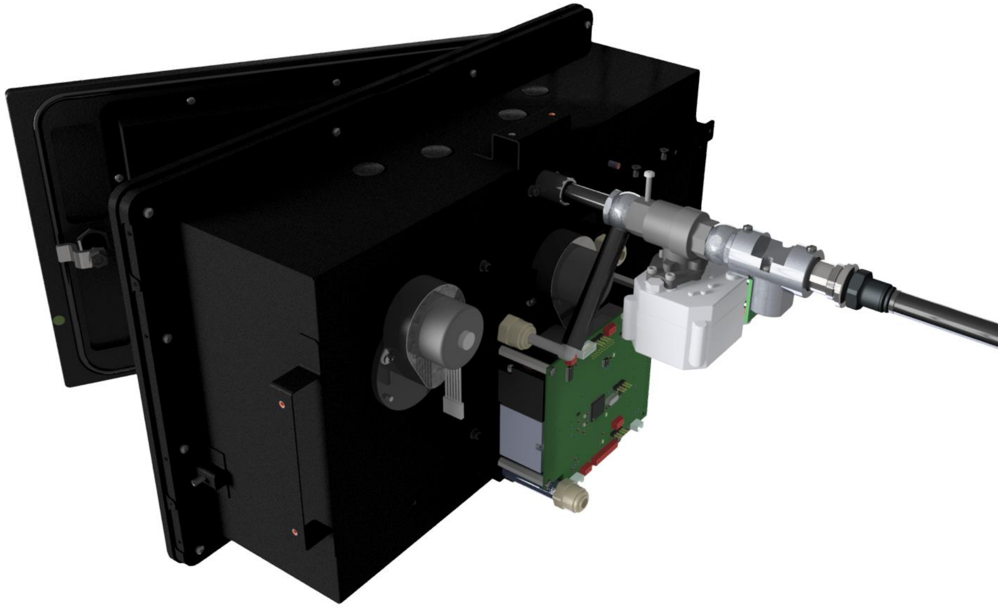
Filter photometers and sensitivity to dRH/dt

The problem of rapid RH changes in the vicinity of the filter tape is solved in the new Aethalometer by air sealing the filter compartment.



Air-sealed filter compartment of AE36.

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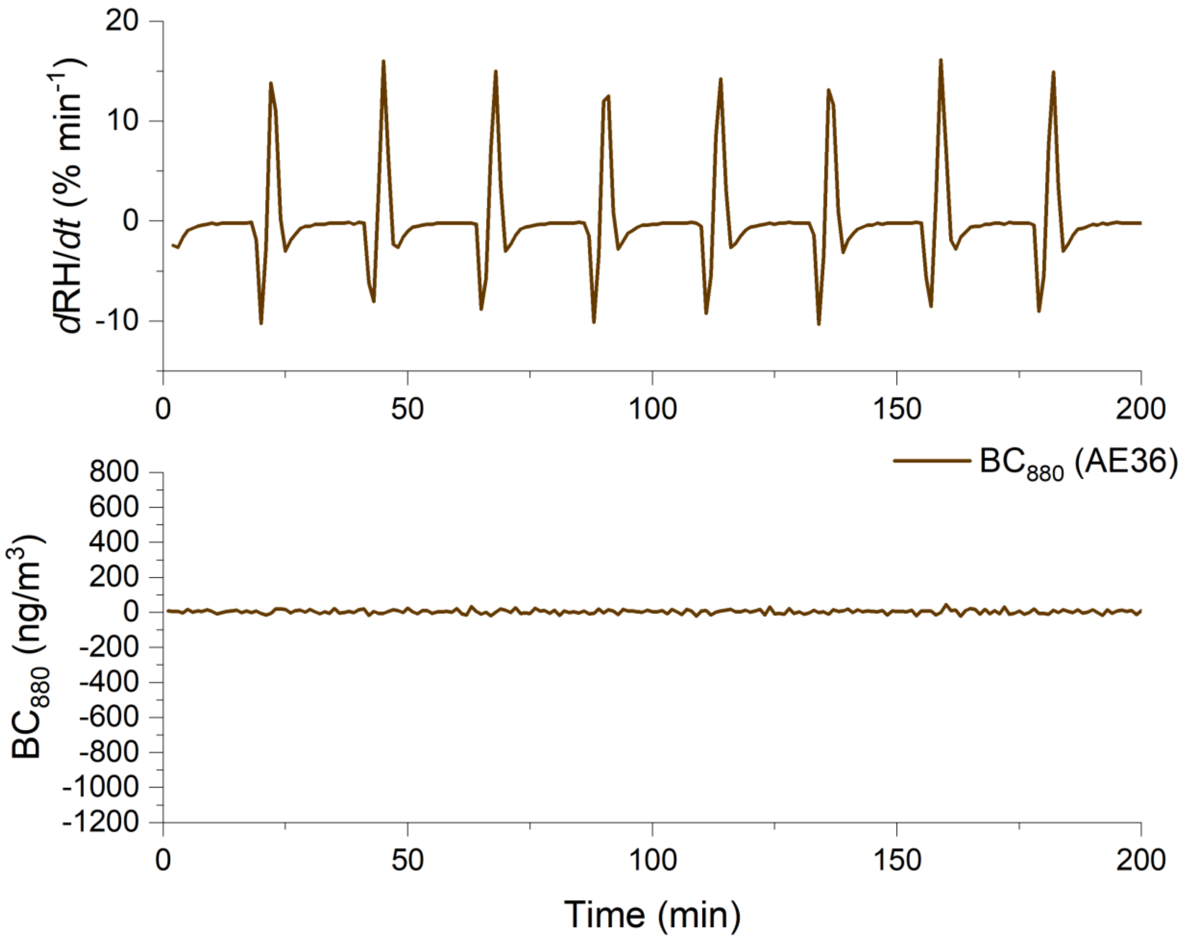
Filter photometers and sensitivity to dRH/dt

Controlled T and RH changes inside the simulation chamber.

Clean air with stable RH used as sample.

Simulation chamber with AE36. The humidity in the surroundings of the instrument changed rapidly, simulating the fluctuation of RH introduced by AC.



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Filter photometers and sensitivity to dRH/dt

Controlled T and RH changes inside the simulation chamber.

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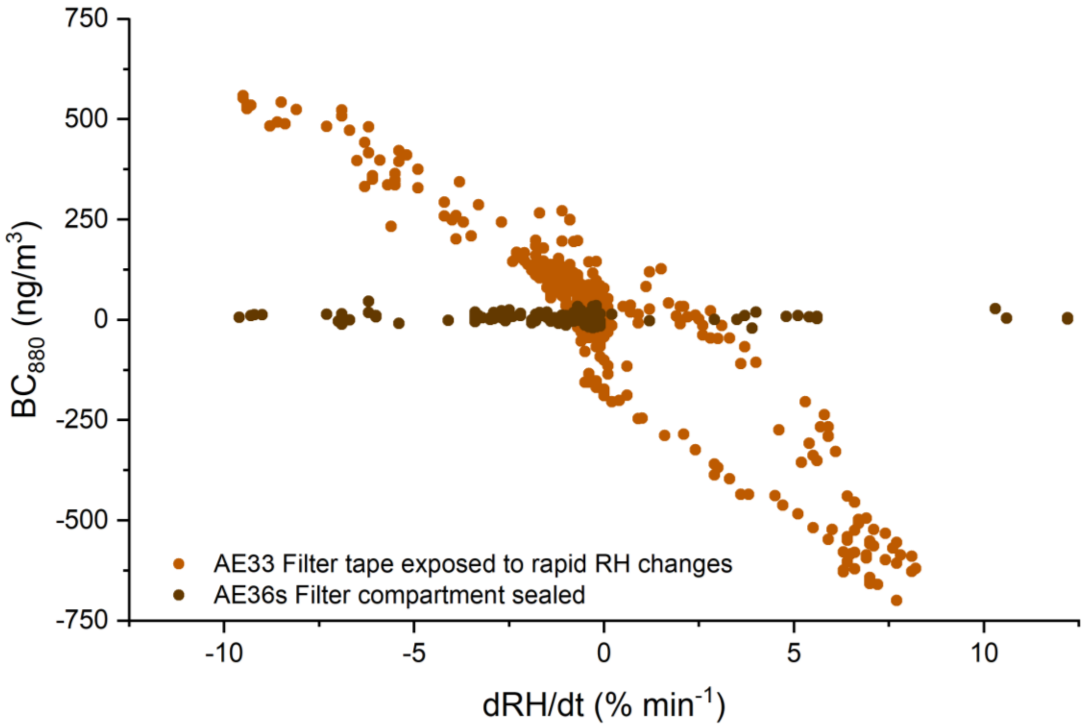
Simulation chamber with AE33. The humidity in the surroundings of the instrument changed rapidly, simulating the fluctuation of RH introduced by AC.



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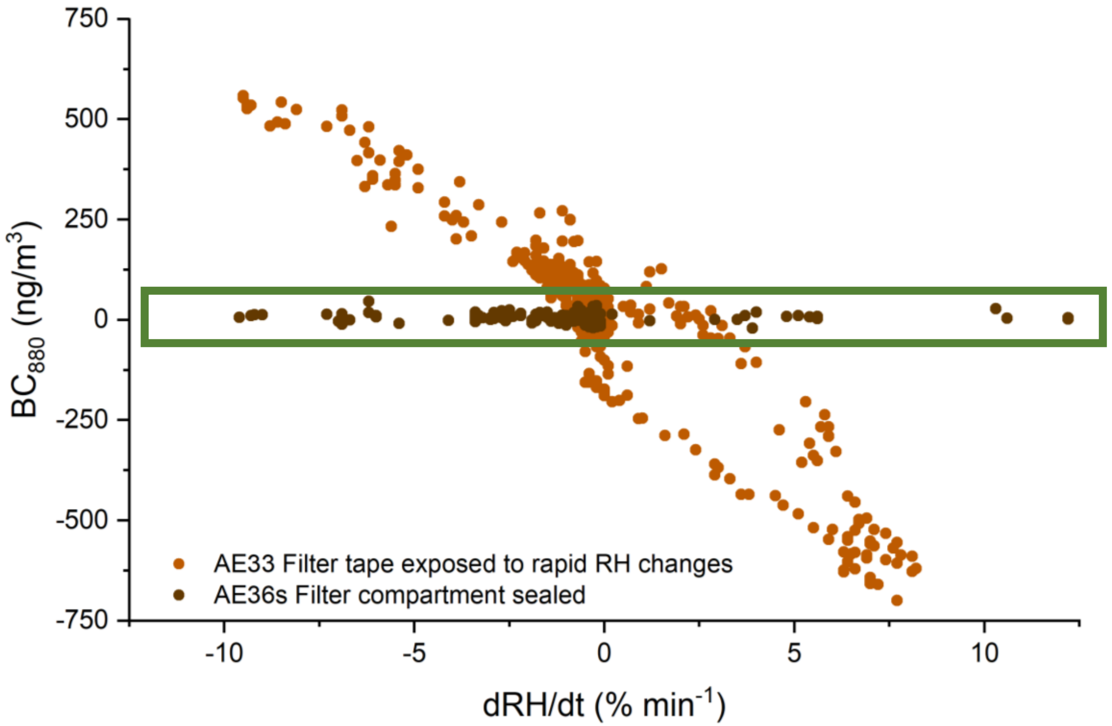

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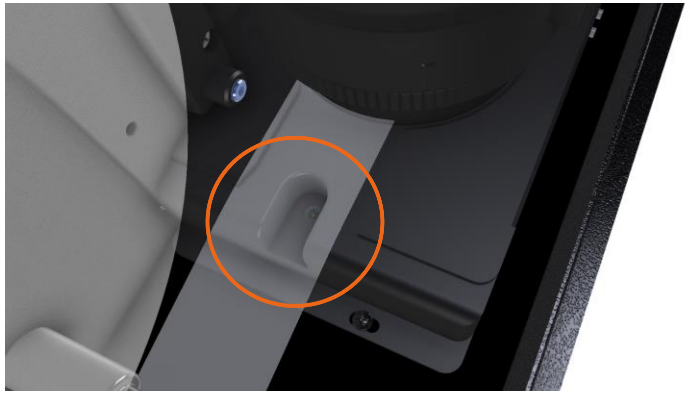
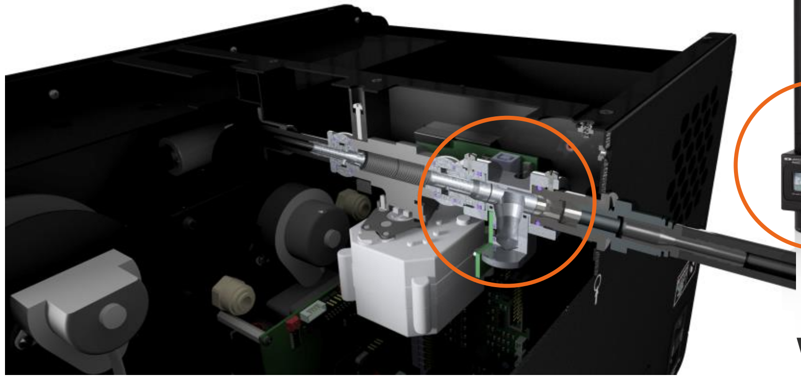
Filter photometers and sensitivity to dRH/dt

Additional RH sensors in AE36/AE36s





WMO/GAW Aerosol Measurement Procedures - Sampling

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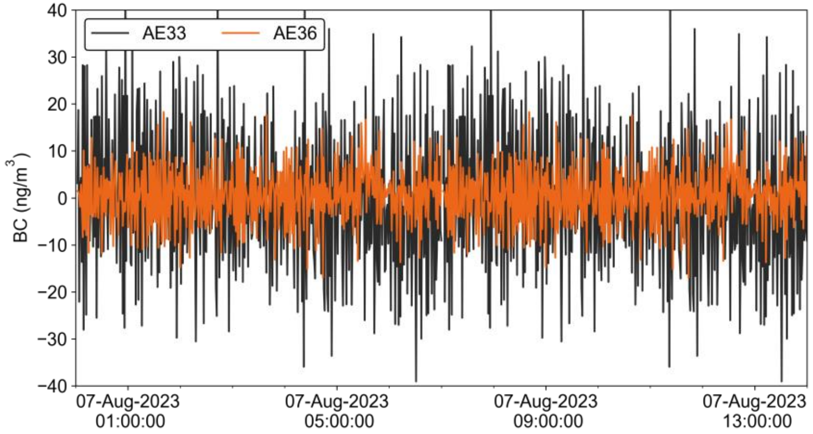
Improved performance of AE36/AE36s in respect to their predecessors

Limit of detection (mean ± 2σ, 3.8 LPM, 1 min):

- **AE33:** 40 ng BC
- **AE36:** **10 ng BC**



Robustness to RH ($s_{BC\text{-}dRH/dt}$ ± 2σ) :

- **AE33:** ~ 100 ng BC /%RH/min
- **AE36:** **>1 ng BC /%RH/min**

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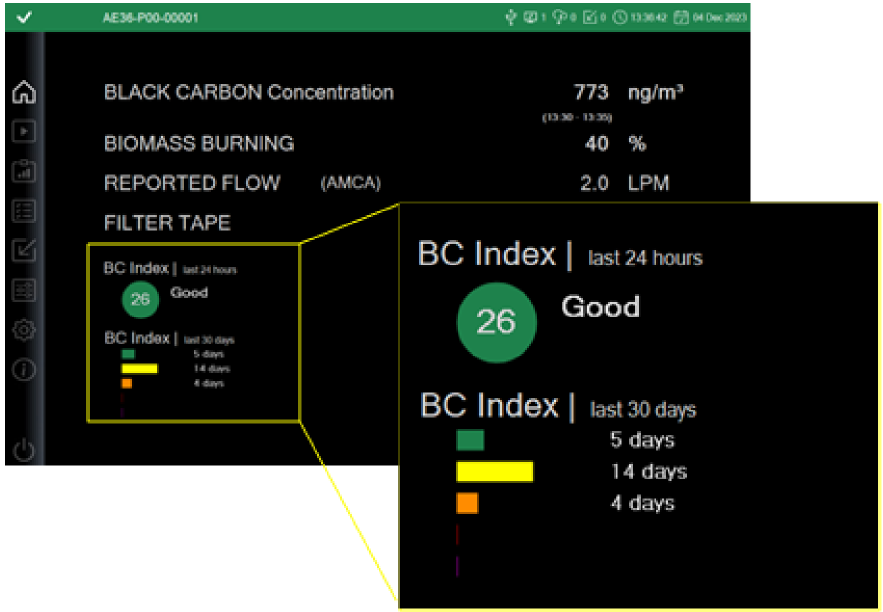
Black Carbon Index

- AE36 includes BC Index™ which is a proprietary measure of air quality based on Black Carbon concentrations. It helps organizations to monitor and communicate the level of air polluted with Black Carbon.

Index category	Category limits	BC limits (ng/m³)
Good	< 50	< 1000
Satisfactory	51 - 75	1000 - 3000
Fair	76 - 100	3000 - 7000
Poor	101 - 150	7000 - 12000
Very poor	151 - 500	60000



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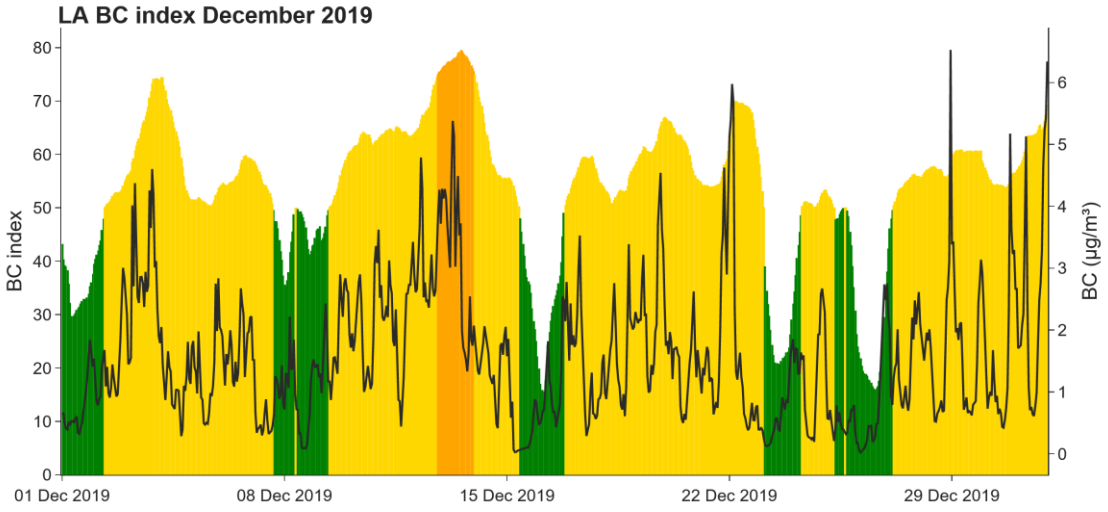
Black Carbon Index

$$\text{BC index} = \frac{I_{high} - I_{low}}{BC_{24\_high} - BC_{24\_low}} \left(BC_{24} - BC_{24\_low}\right) + I_{low},$$

BC_{24} is the 24-hour running mean of hourly averaged BC concentration.

BC_{24_low} and BC_{24_high} are the lower and upper limit of the index category.

I_{low} and I_{high} are the corresponding index values.




Science of the Total Environment
Two-year-long high-time-resolution apportionment of primary and secondary carbonaceous aerosols in the Los Angeles Basin using an advanced total carbon–black carbon (TC-BC(λ)) method

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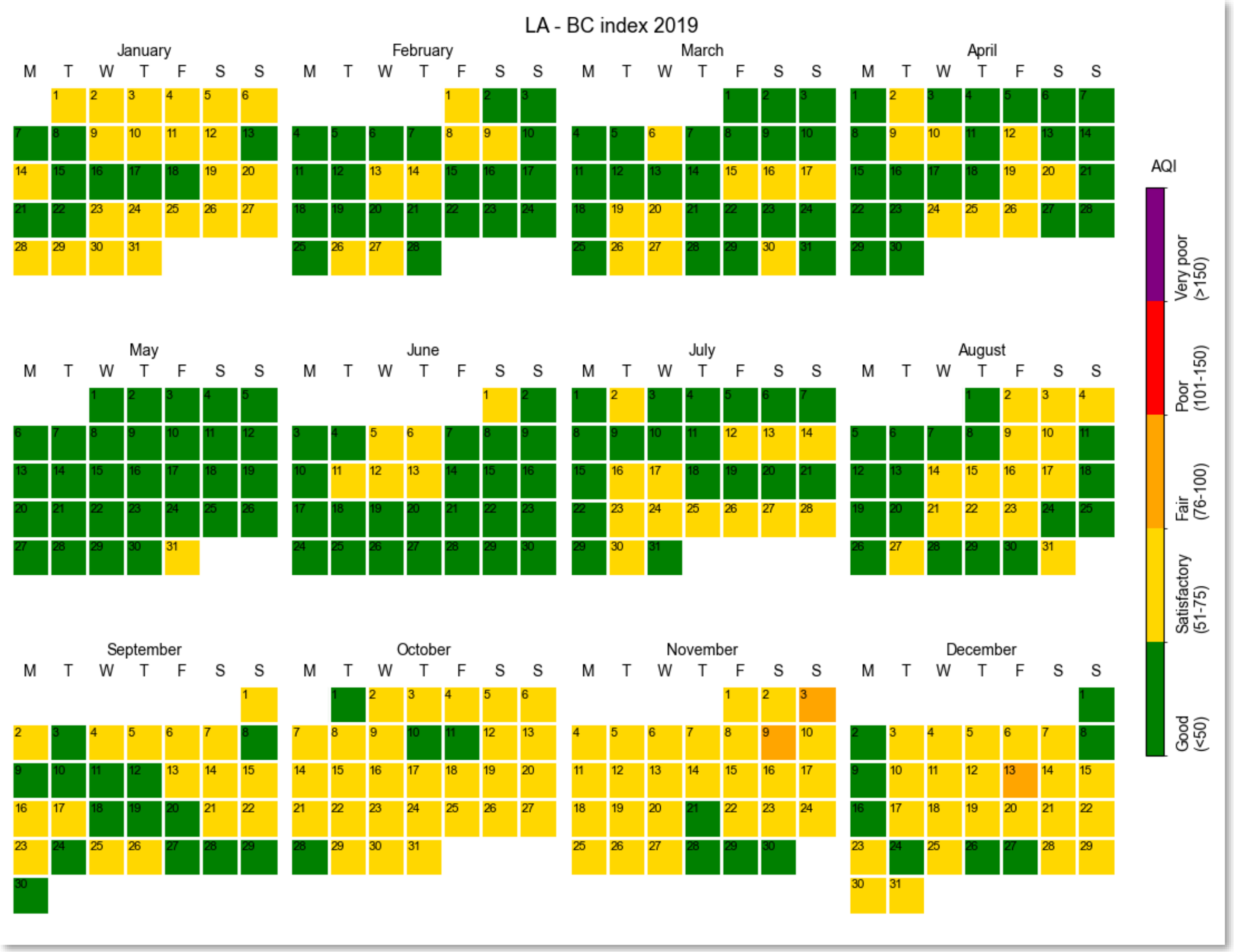
Black Carbon Index



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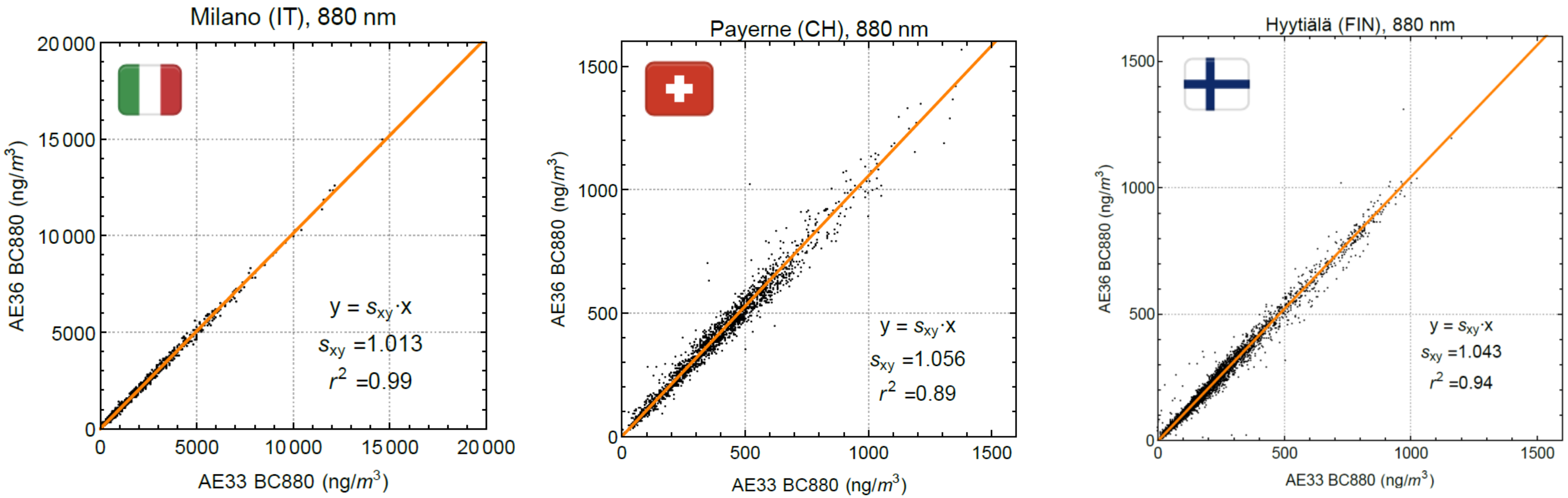
Equivalency campaigns

- Campaigns to demonstrate the equivalence of AE36 with its predecessor, AE33, are ongoing. In the US, we are currently working with the ASCENT network (Lawrenceville site, A. Presto). We are open to further collaborations.



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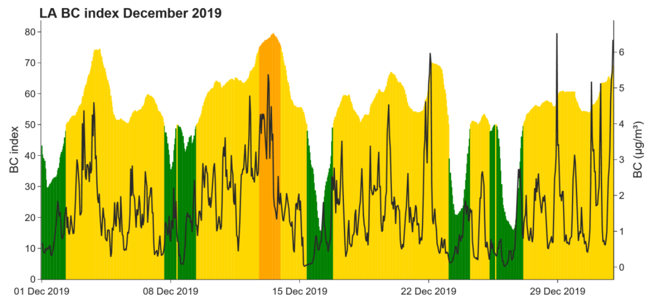
Conclusions

- Mitigation strategies must target specific sources, and source apportionment needs to be implemented in monitoring networks.
- Instrumentation: **new Aethalometer AE36**

  Robustness to relative humidity changes.
  Improved Limit of detection.
  20 m filter tape, self-cleaning procedure.
  Automatic data validation.
  Black carbon index (AQI).



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Thank you for your attention!

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