Calibration of filter-based absorption photometers against two reference standards

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Soot particles in the atmosphere can be found in different forms: fresh soot with high elemental carbon content, aged soot and soot externally mixed with inorganic salt and/or dust particles. Depending on the composition, the single scattering albedo (SSA) of the aerosols can span the range from 0 to 1. Organic or inorganic admixtures to Black Carbon (BC) can cause interference with the BC measurements. Filter-based absorption photometers measure light transmission through a sample collected on filter. These make several assumptions to determine the aerosol light absorption coefficient (relevant for climate) and convert it to equivalent BC mass concentration (eBC) (relevant for air quality) with a fixed mass absorption cross-section (MAC) value. As a result, they suffer from high measurement uncertainties due to the lack of suitable calibration procedures. Kalbermatter et al. (2022) compared different filter-based and in-situ BC monitors with a photothermal interferometer (PTAAM-2λ, Haze Instruments, Slovenia; Drinovec et al., 2022) using well-characterised fresh and aged soot particles as test aerosols. This study builds upon the work by Kalbermatter et al., but extends the measurements to well-defined synthetic PM_1 ambient aerosols and internal or external mixtures of salt and soot. The aerosols were prepared to mimic fresh and aged soot particles under different environmental conditions. Fresh soot with an SSA of 0.01 to 0.03 was simulated by generating combustion particles with a miniCAST generator and aged soot (SSA: 0.2-0.53) by coating the miniCAST particles with secondary organic matter. Mixtures of soot and inorganic salt (ammonium sulphate) as well as pure ammonium sulphate particles were generated to reach aerosol SSAs of about 0.93 and 1.00, respectively. Furthermore, synthetic ambient-like aerosols consisting of mixtures with known amounts of fresh soot, coated soot, secondary inorganic salts and mineral dust particles, with an SSA of 0.30 were generated with the PALMA facility (Horender et al., 2021).

Aerosol properties other than absorption, such as mass/number concentration and chemical composition, were characterised with a number of additional instruments: mobility size distribution via a scanning mobility particle sizer (SMPS), total particle mass via tapered element oscillating microbalance (TEOM), particle number/mass via Grimm-11D aerosol spectrometer, total carbon concentration via the FATCAT analyzer (Keller et al., 2023), ratio of elemental and organic carbon (EC-OC) via an online analyzer (Sunset Lab) and offline, aerosol morphology via transmission electron microscopy (TEM) and the composition of the aerosol via single particle photometer (SP2) and ion chromatography (IC). Different photometers, such as Aethalometers (AE22, AE31, AE33, AE36s, MA200 and MA350), MAAP, PAX, PAS-4λ, BC-1054 and MSS2 were calibrated against the two reference methods for light absorption (Photothermal Interferometry, PTI / PTAAM-2λ and Extinction Minus Scattering, EMS, which combines 3 CAPS PM_{ex} and a nephelometer Aurora 4000).

Motivation

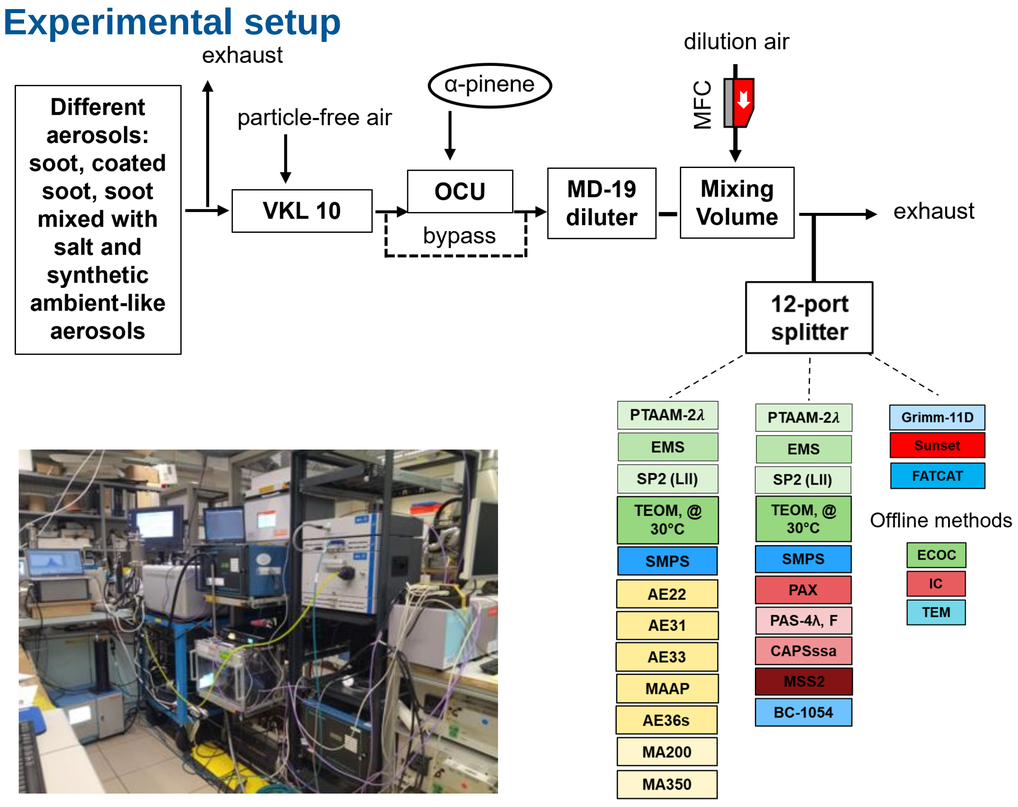
High measurement uncertainties for filter-based photometers:

- up to 60 % for the determination of the aerosol light absorption coefficient
- up to 400 % for eBC mass concentration
- these uncertainties depend on the aerosol properties at the measurement location

Goals of the StanBC project

- Calibrate filter-based light absorption photometers against in-situ reference methods
- Use aerosol site-specific parameters for conversion of the optical measurements into mass
- Establish new documentary standards for the determination of aerosol light absorption and Black Carbon mass concentration

Experimental setup



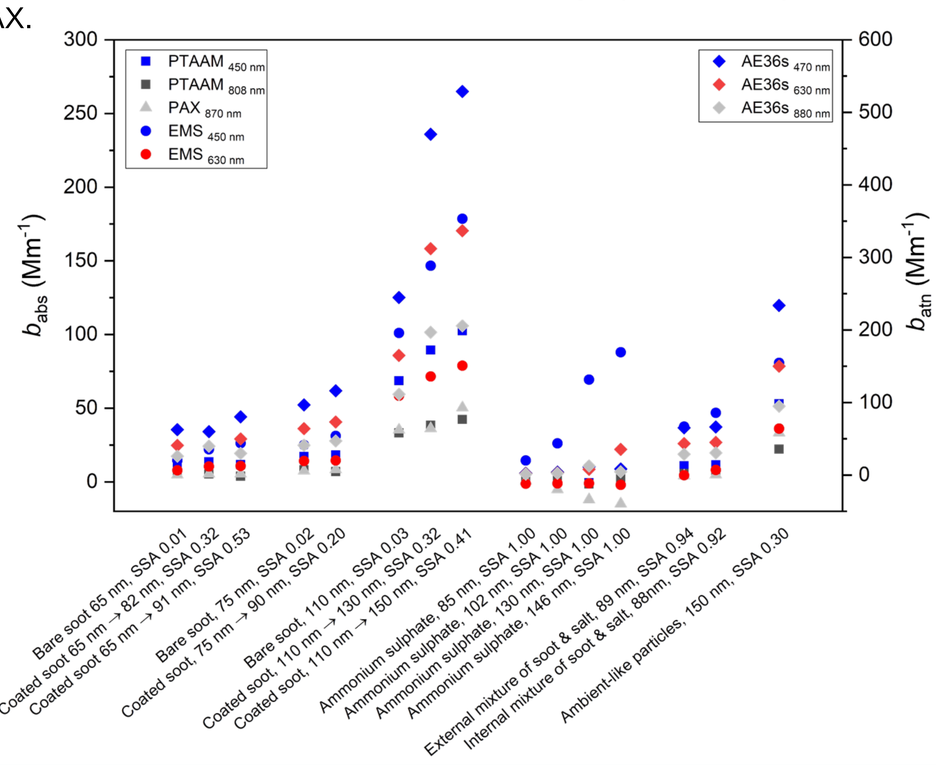
Aerosol generation: soot with a miniCAST 5201 BC, ammonium sulphate with an ATM 220 nebulizer and ambient-like aerosol using the PALMA facility (Horender et al., 2021). Dilution using a VKL 10 diluter and coating of the aerosol with products from the ozonolysis of α-pinene in the organic coating unit (OCU). Further dilution with the rotating disc diluter (MD-19, Matter). Splitting of the aerosol stream using a custom-made 12-port splitter with flowrate-specific inserts. Calibration of filter-based absorption photometers, such as AE22, AE31, AE33, AE36s, MA200 and MA350, MAAP and BC-1054 and in-situ photometers, such as CAPS PM_{ssa}, PAS-4λ, PAX and MSS2 against the two reference methods for aerosol light absorption (PTI with the PTAAM -2λ and the EMS method, which combines 3 CAPS PM_{ex} and a nephelometer Aurora 4000).
Characterization of the aerosol properties: mobility size distribution via a scanning mobility particle sizer (SMPS), total particle mass via tapered element oscillating microbalance (TEOM), particle number/mass via Grimm-11D aerosol spectrometer, total carbon concentration via the FATCAT analyzer (Keller et al., 2023), ratio of elemental and organic carbon (EC-OC) via an online analyzer (Sunset Lab) and offline, aerosol morphology via transmission electron microscopy (TEM) and the composition of the aerosol via single particle photometer (SP2) and ion chromatography (IC).

Preliminary experimental results

The absorption coefficients (b_{abs}) measured with the two reference methods PTI / PTAAM and EMS were compared to each other and to the b_{abs} measured with a photoacoustic instrument (PAX) and to the attenuation coefficient (b_{atn}) of a filter-based instrument (AE36s). $b_{atn} = b_{abs\ measured\ by\ AE36s} \times C$ (AE36s-internal multiple scattering coefficient of 1.39)

The wavelengths at which the b_{abs} and the b_{atn} were recorded are indicated in the figure below. b_{abs} and b_{atn} are shown on the left and right y-axis, respectively. The EMS data was corrected for truncation and AE36s data was corrected for filter loading effect.

- PTAAM, EMS and PAX show similar b_{abs} in the red/infrared wavelength range of 630 nm to 880 nm for bare soot with SSAs of 0.01-0.02, while the b_{atn} values from AE36s are by a factor of about 4 higher
- Greater deviations in the b_{abs} and the b_{atn} for aerosols with higher SSAs
- b_{abs} and b_{atn} in the blue wavelength range of 450 nm to 470 nm increase with increasing coating thickness
- Size effect for the b_{abs} measured for ammonium sulphate particles particularly visible for the 450 nm channel of the EMS; slightly decreasing values for the PAX.



Outlook

- Ongoing data treatment: data from all tested instruments will be included in the comparison
- Comparison of the attenuation coefficients (b_{atn}) measured with all filter-based photometers to the absorption coefficients (b_{abs}) measured by the reference instruments to get accurate multiple scattering coefficients (C)
- Aerosol / site-specific correction parameters for the conversion of the optical measurements into BC mass concentration

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