Multi-method source apportionment of black carbon in Berlin: seasonal patterns, traffic influence, and biomass burning contributions

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Black carbon (BC) is a short-lived climate pollutant and major component of fine particulate matter ($PM_{2.5}$), with substantial impacts on air quality, radiative forcing, and human health. Accurate source attribution is therefore critical for designing effective mitigation strategies in urban environments. This study applies multiple source apportionment techniques to more than five years of high-time-resolution BC measurements in Berlin obtained with an Aethalometer AE33, complemented by co-located observations of $PM_{2.5}$, PM_{10}, NOx, and CO over a comparable period. In addition, one year of detailed carbonaceous and tracer measurements-levoglucosan, soluble potassium (K^+), and EC & OC from thermo-optical analysis using both reflection and transmittance protocols will be used to evaluate and refine the long-term source apportionment.

BC from fossil fuel (BC_{ff}) and biomass burning (BC_{bb}) is separated using the Aethalometer model (Sandradewi et al., 2008), which fits multi-wavelength absorption to a power law to derive Ångström absorption exponents (AAE). Site-specific AAE values and mass absorption cross-sections are calibrated using periods dominated by traffic or biomass burning, with biomass-burning periods identified using EC -BC & OC - BC comparisons together with characteristic seasonal and diurnal patterns. The selected AAE ranges and wavelength combinations for fossil fuel and biomass burning follow recent evaluations of source apportionment and multi-wavelength optimisation for BC (Savadkoohi, M. et al., 2025).

Pearson correlation analysis of the multi-year dataset already shows that BC is very strongly correlated ($r > 0.75$) with NOx, CO and PM at the roadside traffic site and somewhat correlated ($0.4 < r < 0.75$) at urban and regional background sites, consistent with local traffic being the dominant BC source near roads and with reduced BC-NOx coupling with distance. Preliminary Aethalometer-based source apportionment suggests seasonally elevated BC_{bb} in winter and the shoulder seasons and lower BC_{bb} contributions in summer, with significant differences between traffic, urban and background sites. Tracer-based analysis using levoglucosan and K^+ as biomass-burning markers, and NOx and CO as traffic-related fossil-fuel indicators, will be used to refine and evaluate the Aethalometer-derived BC_{ff} and BC_{bb}. $PM_{2.5}/PM_{10}$ ratios and UFP measurements will help distinguish fine-mode combustion aerosols from coarse non-combustion particles.

Positive Matrix Factorization (PMF) is planned on the combined dataset (BC, levoglucosan, K^+, NOx, CO, $PM_{2.5}$, PM_{10} and, where available, cations & anions, and carbon fractions) in order to derive empirical source profiles and time series for traffic, biomass burning and other relevant factors. The combined use of the Aethalometer model, correlation and tracer analysis, EC & OC diagnostics and PMF is expected to provide a detailed picture of BC_{ff} and BC_{bb} contributions at traffic, urban and regional-background sites, including potential winter and shoulder-season enhancements from biomass burning and associated spatial and seasonal patterns. The inter-comparison of these complementary source-apportionment techniques on a multi-year dataset is designed to deliver policy-relevant evidence on the relative importance of transport and residential combustion sources within the Net4Cities framework.

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