

Evaluating the performance of the low-cost black carbon sensor bcMeter at an urban background site

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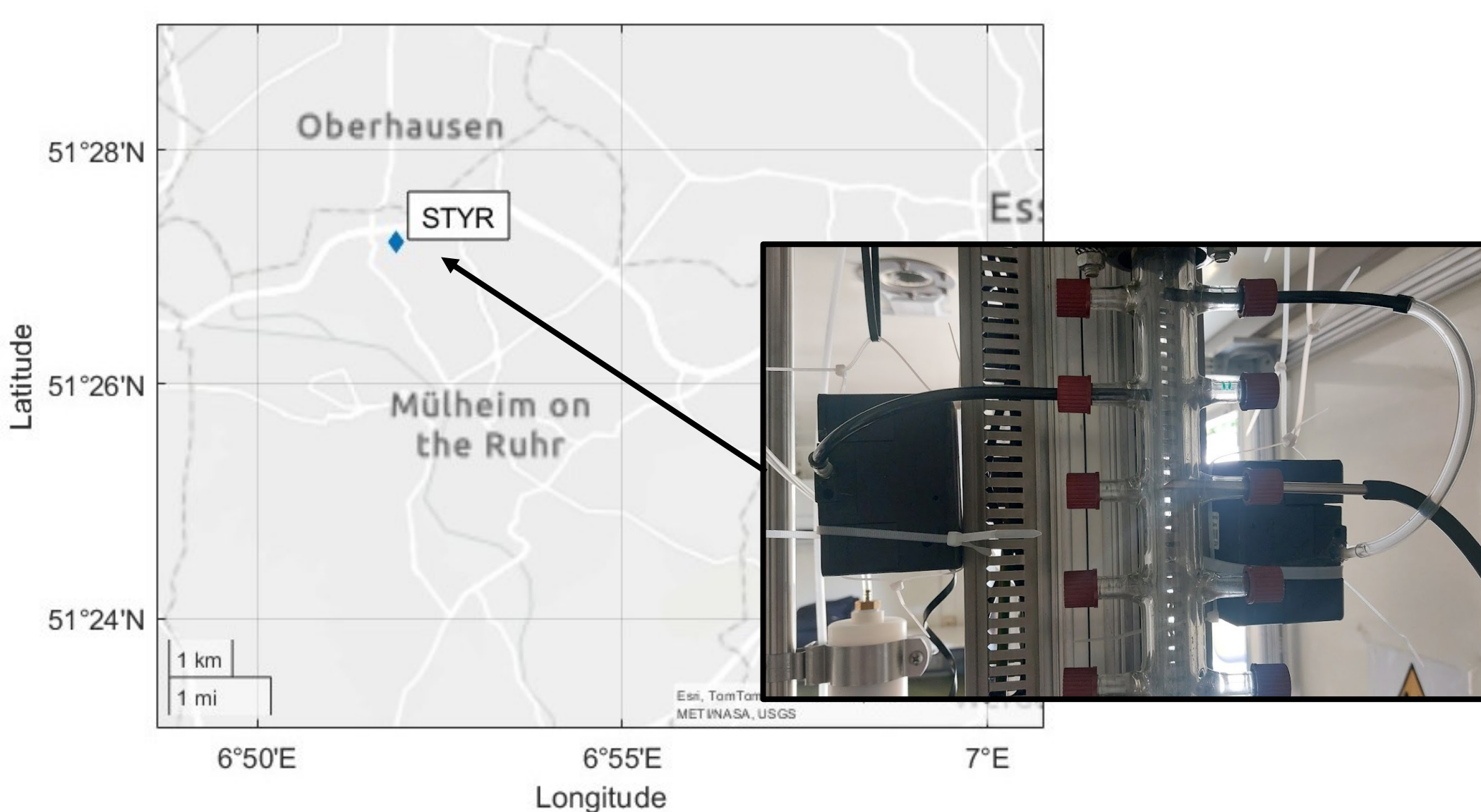
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Introduction

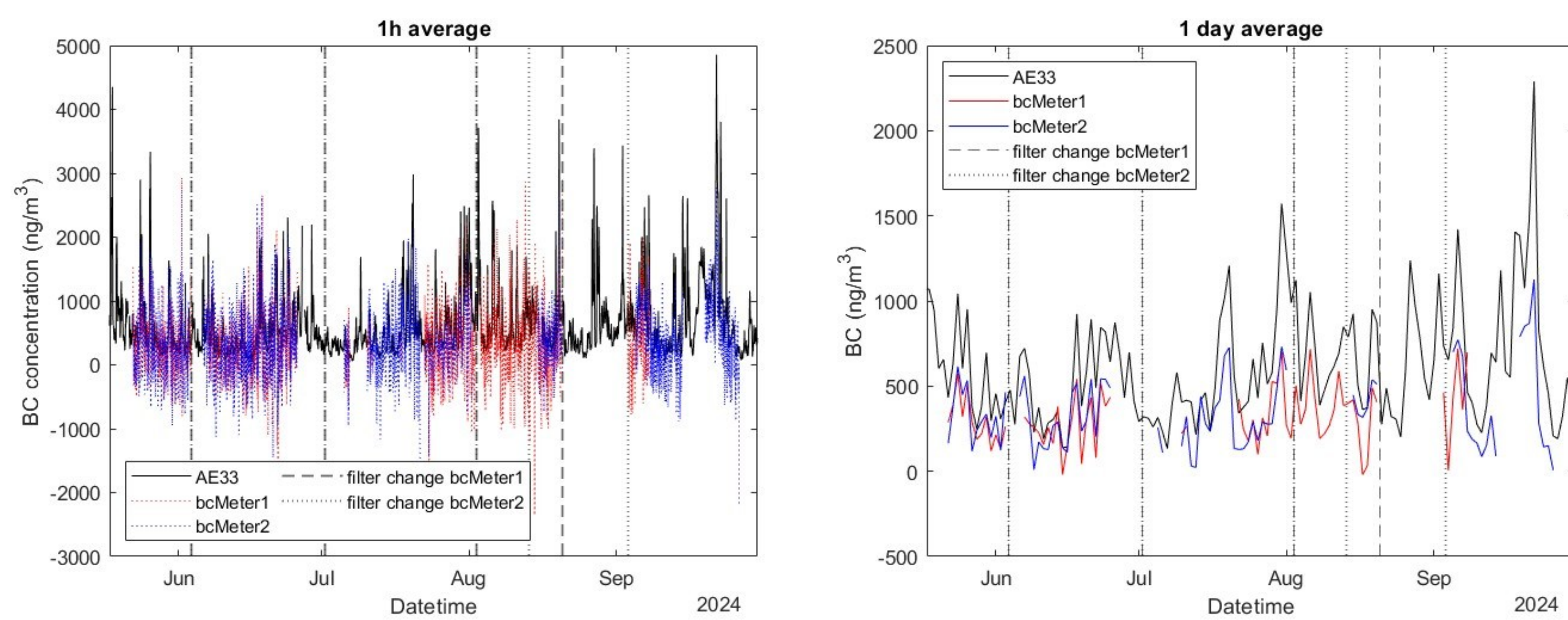
- The impacts of atmospheric Black Carbon (BC) on both health and climate are well known and documented in the scientific literature.
- BC is usually measured off-line by collection on a filter or by online sampling using a filter based optical technique at a specific infrared wavelength (880 nm). While these techniques provide accurate results, information about the spatial distribution of BC concentrations are often scarce due to high cost and deployment difficulties, often limiting the source of data to a small number of reference monitoring sites throughout the territory.
- The deployment of low-cost sensors alongside traditional monitoring could facilitate denser BC-measurement networks, greatly enhancing the spatial and temporal resolution of data.
- The bcMeter is a DIY low-cost sensor released open source for community use. The device operates through the same principle as a traditional aethalometer, measuring the attenuation of infrared light (IR, 880 nm) after absorption of BC on a filter.
- This sensor aims, through a lower bill of materials (< 300 €) compared to standard BC-measuring devices like aethalometers and ease of assembly and use, to facilitate the spatial coverage of BC measurements.
- The performance of two bcMeter sensors was evaluated over a five-month period at an urban background site against a research grade AE33 aethalometer.

Methodology



- Measurements were conducted at an urban background site in Mülheim-Styrum, Germany (51.453459° N, 6.86505° E). Two bcMeter were installed from 17/05/2024 to 30/09/2024 in a monitoring container operated by IUTA.
- Reference BC concentrations (hourly averages) were obtained from a co-located container operated by LANUK, deploying an AE33 aethalometer (Aerosol Magee Scientific).
- Both bcMeter were set to sample with an airflow of 0.25 l/min and a 5-minute time resolution, averaged to 1 h resolution after data collection to allow direct comparison with data obtained from the LANUK station.

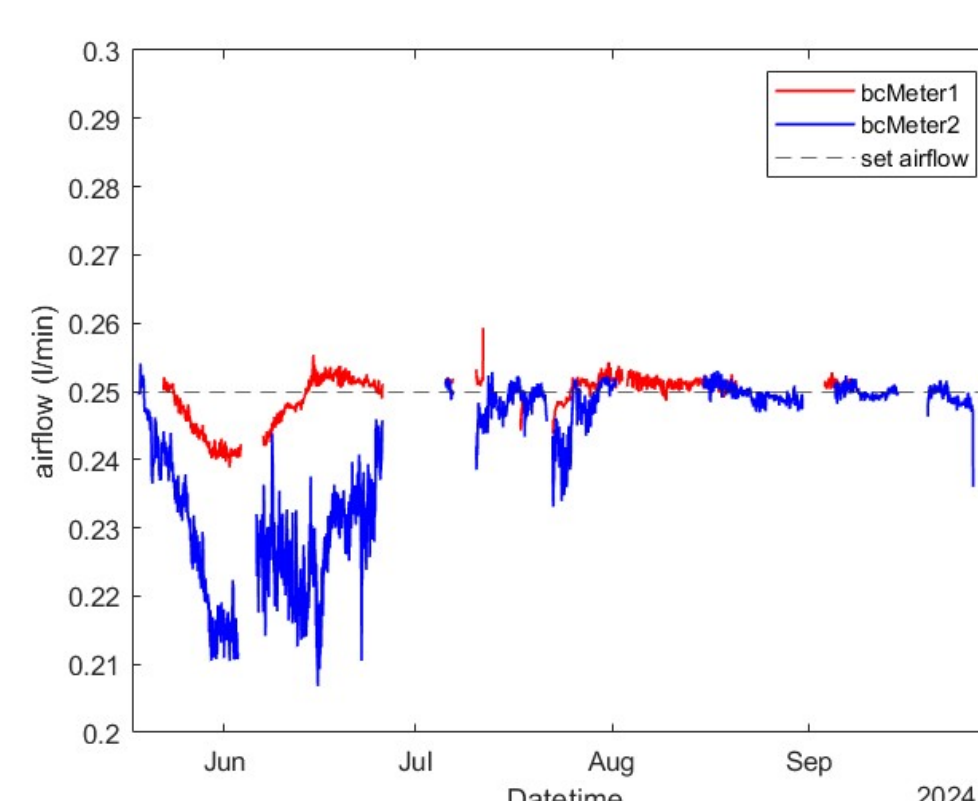
Results



Average period	bcMeter1 slope	bcMeter1 R ²	bcMeter2 slope	bcMeter2 R ²
1 h	0.53	0.22	0.51	0.28
12 h	0.47	0.49	0.53	0.69
24 h	0.40	0.49	0.53	0.79

- Hourly averages of BC concentrations obtained for both bcMeters are highly scattered and cannot directly be used to meaningfully evaluate the sensor performance.
- Linear correlation fits for both bcMeter against the reference AE33 aethalometer show almost no correlation between the devices (R² = 0.22–0.28). Daily (24 h) averages showed moderate correlation between the bcMeter and the reference AE33. While bcMeter1 data is still more scattered (R² = 0.49), bcMeter2 correlated acceptably well with the reference sensor (R² = 0.79).
- While both sensors followed the same BC trend as the reference aethalometer, both consistently underestimated BC concentrations.

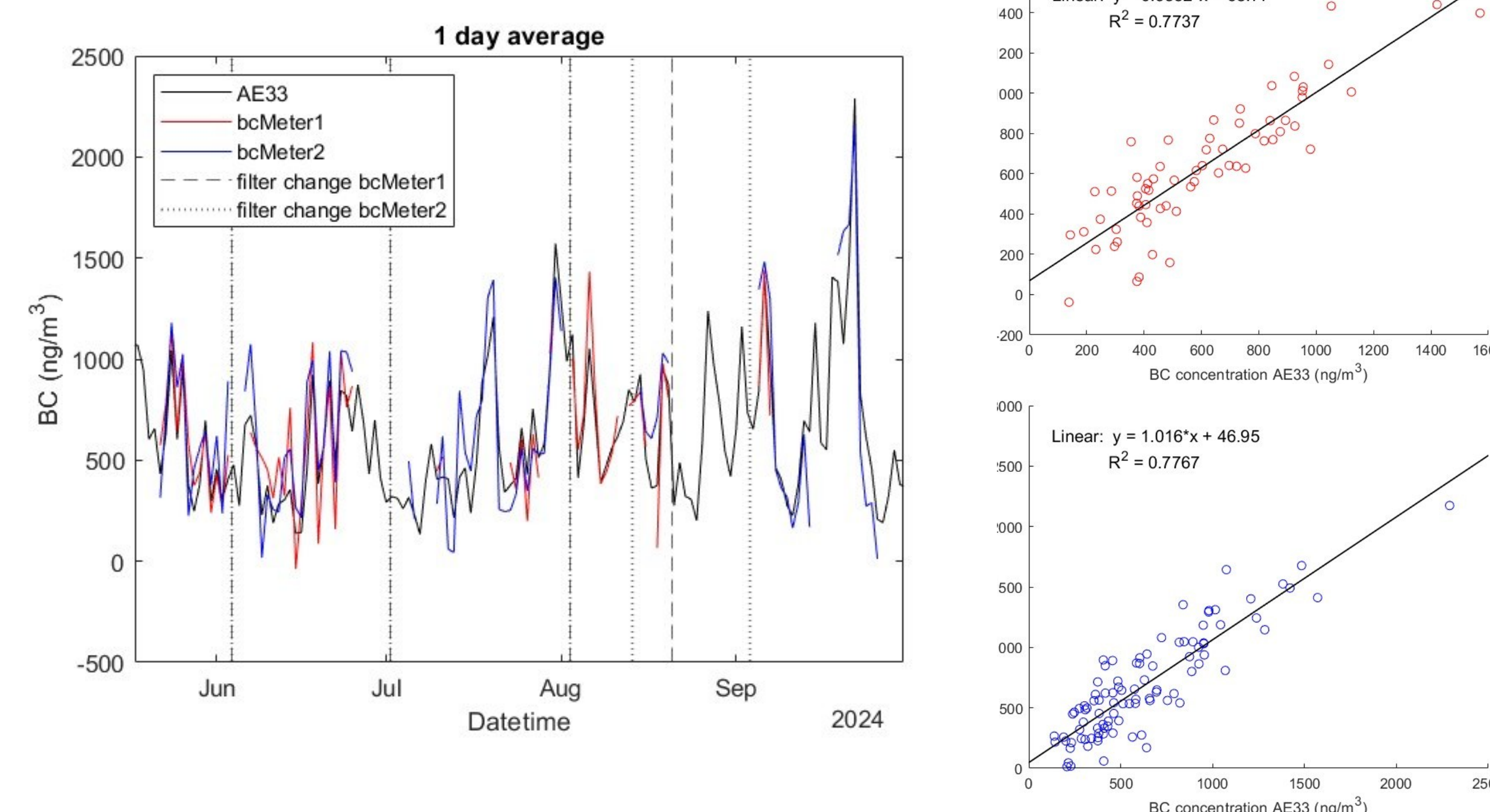
The primary factor contributing to the underestimation was an issue with the total airflow drawn by the instruments. While the airflow for both bcMeter was set to 0.25 l/min, and reported by the internal measurement to be on average 0.2498 ± 0.0034 l/min and 0.2413 ± 0.0262 l/min for bcMeter1 and bcMeter2, respectively, the actual flow measured at the inlet with an external flow meter was approximately half (0.12 l/min) for both sensors.



A correction factor was then calculated as the ratio of average reported airflow (over the entire duration of sampling) over externally measured flow (approximated to a fixed value of 0.125 l/min).

	bcMeter1	bcMeter2
Correction factor	1.998	1.930

Computing the obtained factors into the BC algorithm corrected the underestimation (slope = 1.02) for bcMeter2, and bcMeter1 (slope = 0.94).



Conclusions

- Both employed low-cost sensors followed the same trend over time in BC concentration as the reference AE33 aethalometer, operated by the LANUK station in daily averages.
- Hourly averages for BC concentrations obtained with the bcMeter were affected by instrumental noise and were highly scattered, with no meaningful interpretation.
- Daily averages (24 h) showed higher correlation with the reference data and revealed that bcMeter 2 performed much better (R² = 0.79) than bcMeter 1 (R² = 0.49). Outlier removal via robust regression allowed to reduce data dispersion for bcMeter1, leading to comparable correlation (R² = 0.77).
- Both sensors showed a constant underestimation of BC concentrations, that was traced back to a difference between the airflow at the inlet and the set value for both units. Both bcMeter showed good correlation with the reference aethalometer after application of an airflow-based correction factor.
- The employed low-cost sensor showed several technical limitations, on both hardware and software level, that impacted the entire campaign with frequent interruptions in the measurements.
- Given the significant data scattering at higher time resolutions, the bcMeter appears to be inadequate for high time resolution monitoring of BC; the sensor is a promising option for application in monitoring networks for orientation measurements, where daily data resolution is sufficient.