Collaboration with: bcMeter Empa

Performance Evaluation and Calibration of the Open-Source, Low-Cost Black Carbon Monitor bcMeter

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1 Introduction

- **Black Carbon (BC):** climate forcer + health risks
- Monitoring gaps remain; **low-resource regions** particularly affected
- **Costly** instrumentation: reference grade aethalometers (e.g. Magee AE33) ≳ **20,000 CHF**; Mid-range portable BC sensors (e.g. AethLabs MA200 / MA350) **~5,000–7,000 USD**

bcMeter:

- **Open-source** (self-buildable); **low-cost** (material costs **< 300 CHF**)
- Insufficient independent validation + no calibration studies
- Doldi et al. (2025): R^2 = 0.22–0.28 at 1-h vs. AE33, rising to 0.77–0.79 only at 24-h averages (comp. R^2 ~0.7–0.95 for AE51 family)

2 Methods

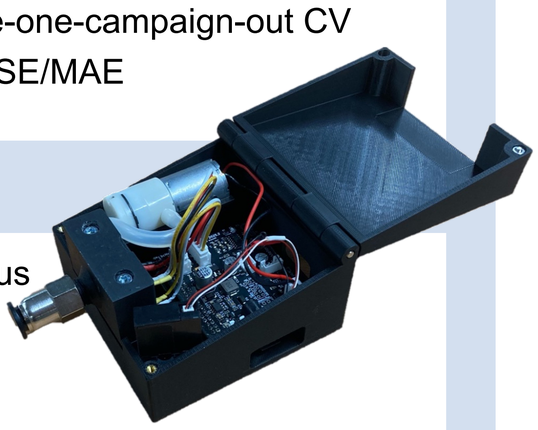
Co-location: 3 bcMeter units (BCM A/B/C) vs. AE33; 6 tests at Dübendorf and Zürich; **10-min temporal resolution**; n ≈ 3,940 paired observations.

Pretreatment: AE33 dropout interpolation, time alignment, 10-min resampling, IQR-based outlier removal (~0.38 %).

3 post-processing approaches compared:

- Untreated (pretreated only)
- CMA: centered moving average, window w = 5
- MLR (per-BCM OLS), evaluated with leave-one-campaign-out CV

Metrics: slope, intercept, R^2, MBE, MAE, RMSE/MAE



3 Results and Discussion

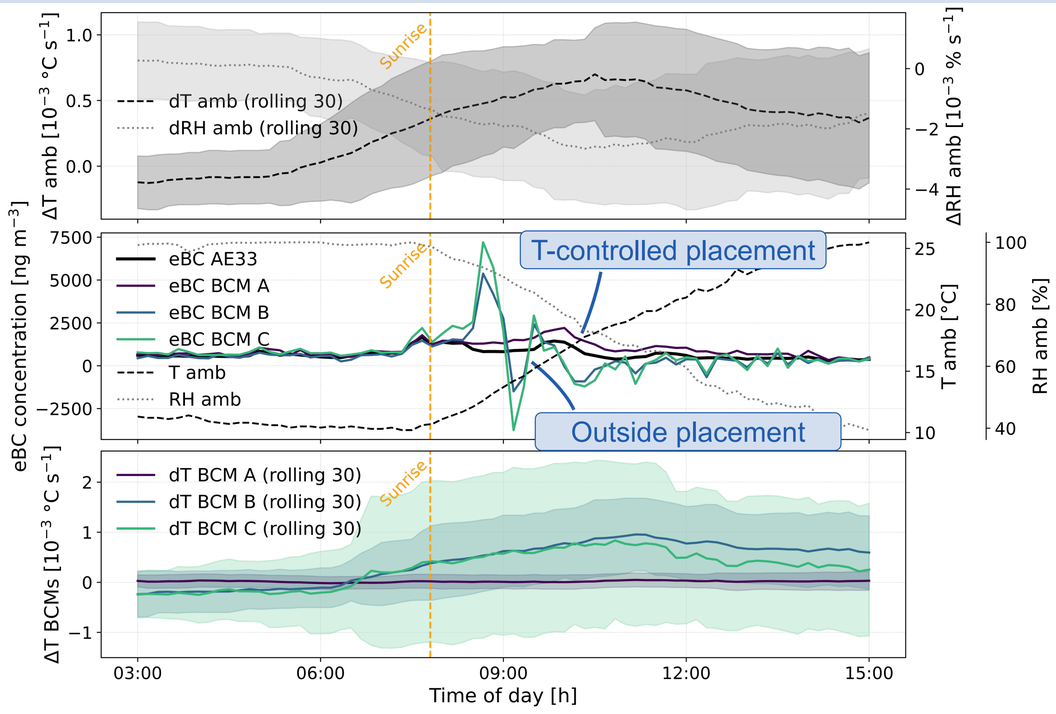


Fig 1: Timeseries plot (date: 2025-09-18) showing sunrise-driven eBC spike and the instrument-temperature transients behind it.

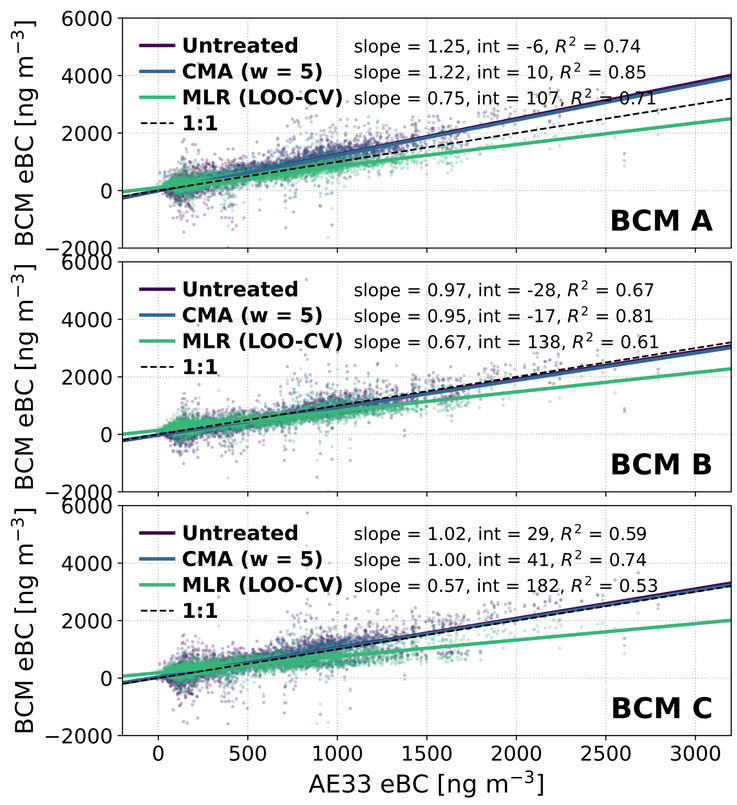


Fig 2: bcMeter vs. AE33 regression per BCM under the three corrections.

Dataset limitations – **heterogeneous study design:**

sensor conditions differ among instruments and campaigns (indoor / outdoor placement, different tubing materials), two AE33 under different RH conditions used

- Even without post-processing and with a heterogeneous dataset, the bcMeter reaches **R^2 = 0.59–0.74 against AE33 at 10-min resolution** – the raw scatter in Fig 2 already follows the 1:1 line for all three units.
- Around sunrise (Fig 1) the largest eBC anomalies in the raw signal coincide with rapid instrument-temperature change rates (ΔT_BCM band, bottom panel) – instrument-T transients are the dominant raw-signal failure mode and motivate the corrections below.
- **CMA** (w = 5) improves **R^2** (0.59–0.74 → **0.74–0.85**) and **MAE** (160–209 → **122–163 ng m⁻³**) while keeping the **slope near 1**; in Fig 3 the morning concentration spike is dampened without distorting typical variation.
- **MLR** (LOO-CV) reduces **MBE** (–42 to +116 → **–14 to –23 ng m⁻³**) and gives the lowest **RMSE/MAE** ratio (1.62–1.74 → **1.43–1.46**); in Fig 3 the systematic offset is corrected for BCM A. But the fitted **slope drops to 0.57–0.75** – visible in Fig 3 as the green regression lines diverging below the 1:1 – and **R^2 is slightly worse** than untreated.

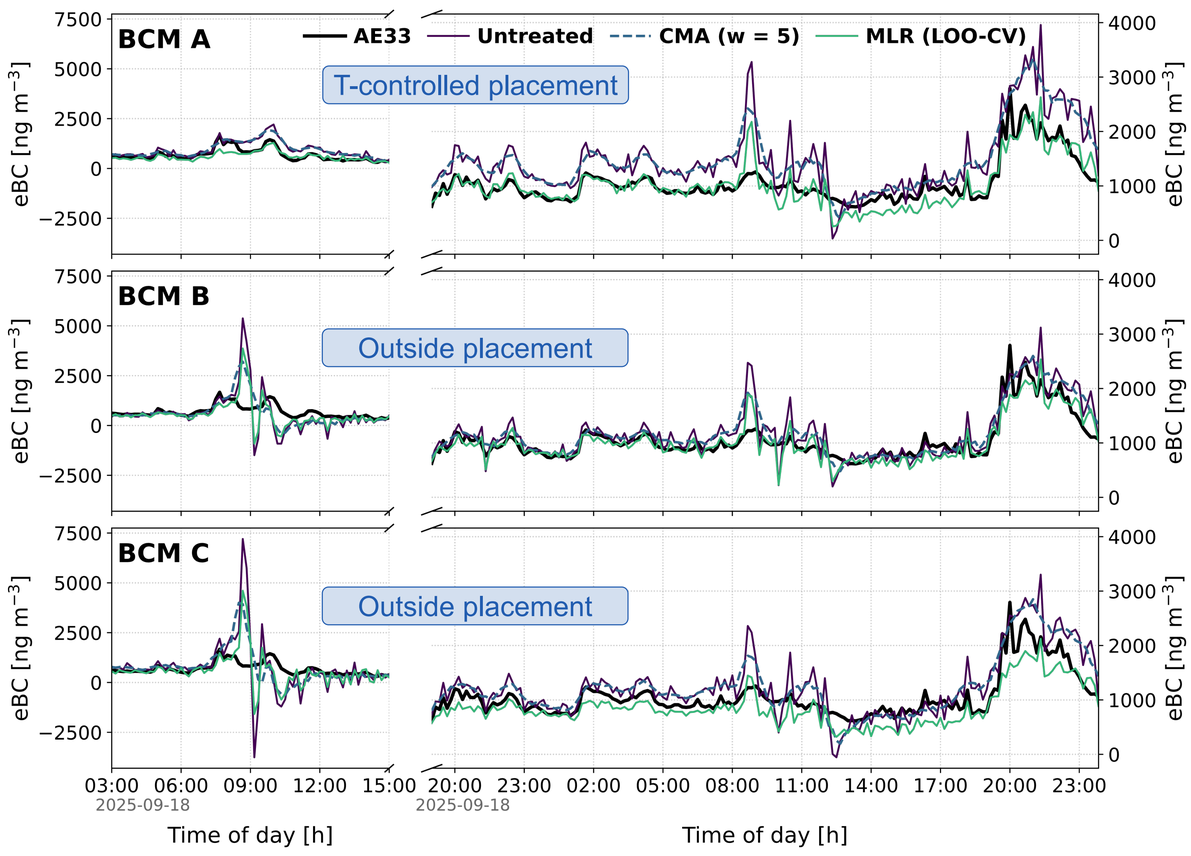


Fig 3: Multi-day bcMeter vs. AE33 timeseries: morning spike (left) and calmer tail (right).

4 Conclusion

Goal: assess bcMeter performance and compare post-processing approaches to bring it within field-deployable accuracy.

Key Findings:

- Clear potential at 10-min resolution – almost reaches Doldi et al. (2025)'s daily-mean working range.
- Untreated R^2 0.59–0.74 → CMA R^2 0.74–0.85, MAE 122–163 ng m⁻³.
- CMA: best noise + dynamic range. MLR: best bias removal – trade-off.

5 Ongoing Work

- New data collection campaign in progress

Goal:

- More data
- Homogeneous design
- Re-evaluate (more) post-processing approaches

References

- Doldi, A., et al. (2025). Evaluating the performance of the low-cost black carbon sensor bcMeter at an urban background site. Gefahrstoffe – Reinhaltung der Luft, 85(01-02), 5.
- Bond, T. C., et al. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. Journal of Geophysical Research: Atmospheres, 118(11), 5380–5552.

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