EGU26-17540, updated on 13 Jun 2026
https://doi.org/10.5194/egusphere-egu26-17540
EGU General Assembly 2026

Impact of multi-hop rendezvous calibration parameters on the accuracy of a network of low-cost PM sensors

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Low-cost particulate matter (PM) sensors can complement sparse regulatory stations and capture fine-scale urban variability, but their raw readings are affected by environmental sensitivity, drift, and inter-sensor variability. This work examines how reference instrument–sensor calibration and multi-hop rendezvous calibration jointly affect a network of 16 co-located optical PM sensors (eight Plantower PMS5003 and eight Sensirion SPS30) installed within 1 m of a Palas Fidas 200S reference analyser. Starting from experimental field co-location time series, we replay the measured sensor and reference data inside a controlled simulation framework to compare multiple calibration strategies and to identify encounter parameters that optimize the accuracy of a low-cost PM sensor network; the same 16 sensors are then virtually distributed over conceptual areas of 5, 10, and 15 km² to emulate different deployment densities. Sensor–sensor encounters and passages near the reference station are modelled as Poisson processes with a 2-minute time step; per-step interaction probabilities are derived from mean inter-event times and scaled by an effective density term so that larger areas (lower density) yield fewer interactions. Multi-hop rendezvous calibration is controlled by a multi-hop depth H (maximum number of successive updates) and a cumulative calibration influence Γ (the accumulated effect of multi-hop rendezvous calibration corrections applied to a sensor). Five calibration scenarios are compared: raw (no correction), linear regression, linear regression with robust Huber weighting, quadratic regression, and quadratic regression with Huber weighting. Reference instrument–sensor calibration uses a sliding buffer of recent sensor–reference instrument pairs with outlier filtering and time-weighted fitting, while multi-hop rendezvous calibration encounters provide additional limited corrections through a lightweight Kalman-filter update of calibration coefficients. This update provides a principled way to incorporate uncertain peer information while keeping corrections stable and limited through the filter's weighting of prediction versus noisy observations. Performance is evaluated against the reference instrument using calibrated root-mean-square error (RMSE) for particulate matter of different sizes: PM_1 (≤1 µm), $PM_{2.5}$ (≤2.5 µm), and PM_{10} (≤10 µm). Compared to uncalibrated measurements, the best-performing configurations reduce the RMSE from 2 to 1.1 $\mu g \cdot m^{-3}$ for PM_1 (−45%) and from 2.7 to 1.5 $\mu g \cdot m^{-3}$ for $PM_{2.5}$ (−45%) with robust quadratic calibration, while PM_{10} is best handled by a quadratic (second-order) model, improving from 5.4 to 3.3 $\mu g \cdot m^{-3}$ (−39%). Across all scenarios, robust quadratic calibration provides the strongest and most consistent gains for fine particles, whereas the non-robust quadratic model is the most effective choice for coarse particles; moderate multi-hop depth H and cumulative

calibration influence Γ further improve RMSE, while high H and Gamma can propagate local biases and increase variability.