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Field comparison of portable and stationary instruments for outdoor urban air exposure assessments

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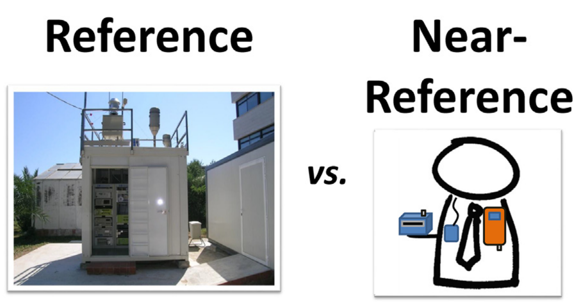
HIGHLIGHTS

- Epidemiological studies highlight the need for exposure assessment studies.
- Portable and stationary monitors were compared for exposure assessment.
- Good agreements were found: R^2 mostly >0.80; relative differences <20%.
- Relative differences were <10% between different units of the same instrument.
- Parameters assessed were BC, N, LDSA and mean particle diameter, in outdoor air.

GRAPHICAL ABSTRACT



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ABSTRACT

The performance of three portable monitors (micro-aethalometer AE51, DiscMini, Dusttrak DRX) was assessed for outdoor air exposure assessment in a representative Southern European urban environment. The parameters evaluated were black carbon, particle number concentration, alveolar lung-deposited surface area, mean particle diameter, PM_{10}, $PM_{2.5}$ and PM_1. The performance was tested by comparison with widely used stationary instruments (MAAP, CPC, SMPS, NSAM, GRIMM aerosol spectrometer). Results evidenced a good agreement between most portable and stationary instruments, with R^2 values mostly >0.80. Relative differences between portable and stationary instruments were mostly <20%, and <10% between different units of the same instrument. The only exception was found for the Dusttrak DRX measurements, for which occasional concentration jumps in the time series were detected. Our results validate the performance of the black carbon, particle number concentration, particle surface area and mean particle diameter monitors as indicative instruments (tier 2) for outdoor air exposure assessment studies.

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1. Introduction

Numerous studies have proven the link between air pollution and health (Lim et al., 2012), with outdoor air pollution being classified as carcinogenic to humans by the International Agency for Research on Cancer (IARC, 2013). According to recent studies, adverse effects derived from exposure to air pollution are being observed at ever-lower concentrations of pollutants (Brunekreef et al., 2015; WHO, 2013a, 2013b). In Europe, fine particles ($PM_{2.5}$) in the air are the most important environmental health concern among the major drivers of ill health and premature mortality in the population (Lim et al., 2012).

Degraded air quality is an environmental and health issue affecting citizens around the globe, most of them in urban areas, where approximately 75% of the European population lives (EEA, 2014). To protect the population, Directive 2008/50/CE set the guidelines for monitoring atmospheric pollutants across the EU Member States, as well as the reference methods by which this should be achieved. However, a substantial percentage of the European urban population is still exposed to air pollutant levels exceeding the WHO Air Quality guidelines and the EU Air Quality standards (EEA, 2014). Recent research recommends that current air quality monitoring networks should have a stronger link to health (AirMonTech, 2013; Gao et al., 2015; Snyder et al., 2013; Steinle et al., 2013), which could be achieved by monitoring population exposure. The need for exposure monitoring has been evidenced by numerous works (Buonanno et al., 2011; De Nazelle et al., 2013; Gehring et al., 2013; Gu et al., 2015; Karanasiou et al., 2014; Kaur et al., 2007; Morawska et al., 2013). In addition, current trends in the US suggest that present-day sophisticated ambient air pollution monitoring technology is not economically sustainable as the sole approach and cannot keep up with current needs (Snyder et al., 2013; US-EPA, 2013). Portable monitors and sensors are currently being developed to enable a move towards exposure monitoring (as opposed to background concentration monitoring). One added value of these monitors, because of their smaller size and weight when compared to reference monitors, is that they may also be used in indoor air, e.g. for occupational exposure assessments.

US-EPA advocates a tiered system for different types of air monitors based on cost, application, and end user (US-EPA, 2013): near-reference, monitors/sensors intended for indicative use, and mainly qualitative sensors intended for educational use. The performance of each of these three types of portable monitors must however be tested against reference instrumentation, or against the most widely used instruments in the case of unregulated parameters (e.g., ultrafine particle number concentration, particle surface area) for which no reference is available. The present work focuses on near-reference instruments in indoor and outdoor air applications, with the aim to test their performance against widely used stationary instruments. The use of this kind of instruments is recommended in tier 2 exposure assessment studies within NEAT (nanotechnology emission assessment technique; Methner et al., 2010). As described by Asbach et al. (2012) for workplace air assessments, instruments for tier 2 need to be easy to use, battery operated, portable, and able to deliver a limited but meaningful data set to estimate exposure levels. This is also the case for indoor and outdoor air exposure assessments, which are the focus of this work. The performance of portable monitors for indicative use is assessed for particle number concentration (N), mean particle diameter, lung-deposited particle surface area (LDSA), black carbon (BC) concentration, and particle mass concentration (PM_{10}, $PM_{2.5}$, PM_1). The final goal is to evaluate whether the portable instruments under study are comparable to their reference (or widely accepted) stationary counterparts, for outdoor and indoor air quality studies.

Previous studies have presented comparisons for certain instruments and parameters (Asbach et al., 2012; Fierz et al., 2011; Mills, 2013; Stabile et al., 2014; Tasić et al., 2012). However, most of them tested the instruments under laboratory conditions and challenging the instruments with purposely-generated aerosol types (e.g., NaCl, soot, etc.). In the present work, stationary and portable instruments are compared under real-world operating conditions, measuring ambient urban aerosol and under changing meteorological scenarios, with the aim to assess the performance of portable monitors under the most representative conditions for urban outdoor air monitoring. If their performance is validated, these lower-cost near-reference monitors could be proposed as viable addition to existing air quality monitoring networks, to achieve a broader spatial coverage and a more representative characterisation of population exposure.

2. Materials and methods

All instruments described below were simultaneously co-located inside the air quality monitoring station at Palau Reial at IDAEA-CSIC located in an urban background area in Barcelona (Spain), connected to an inlet or with the sampling tubes through a window to sample outdoor air. Sampling tubes were kept to a minimum to minimise diffusion losses. The portable instruments were placed on a table, with sufficient distance to each other to avoid interferences, and sampled at approximately the same height. The clocks of all instruments were synchronized prior to the first measurement in each intercomparison. The inlets of the stationary instruments for comparison were located within a 1.5 m radius of those of the portable instruments, and at the same height above ground.

The following air quality parameters were evaluated:

- Black carbon (BC) concentration was measured with six Microaeth AE51 (Aethlabs) instruments, and compared with a Thermo Multi-Angle Absorption Photometer (Carusso MAAP). Five of the AE51 instruments were identical, and unit BC5 was a prior version (Magee). The AE51 instruments were operated at a flow of 100 ml m^{-1}, and filter tickets were exchanged every 24 h. No cyclone was used at the inlet. The MAAP instrument was connected directly to outdoor air, with a heated inlet (Müller et al., 2011).
- Particle number concentration (N) was measured with five identical DiscMini (Testo; Fierz et al., 2011) instruments in the range 10–700 nm, and compared with a water condensation particle counter TSI CPC3785 (5–1000 nm). The DiscMini instruments were connected each to an impactor with a cutoff at 700 nm to prevent interference with coarse particles. Anti-static tubing was used during all intercomparison exercises (see details below). The CPC was only available for 2 out of the 4 intercomparison exercises.
- Mean particle diameter was measured with five identical DiscMini (Testo) instruments in the range 10–700 nm, and compared with a scanning mobility particle sizer SMPS system (TSI 3936). The SMPS was comprised of an Electrostatic Classifier (TSI 3080) and a Differential Mobility Analyser (DMA, TSI 3081), connected to a condensation particle counter (CPC TSI 3772). The SMPS provided particle number size distributions between 10.9 and 478.3 nm (N10.9–478.3) in 64 channels/decade, and completed two scans every 5 min. Measurements were corrected for multiple charge and diffusion losses within the system.