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Identifying drivers for the intra-urban spatial variability of airborne particulate matter components and their interrelationships

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HIGHLIGHTS

- Peripatetic measurements of UFP, BC and $PM_{2.5}$ were taken in an urban environment.
- Spatial variability in UFP and BC were much larger than in $PM_{2.5}$.
- UFP and BC were significantly correlated with traffic counts, while $PM_{2.5}$ was not.
- $PM_{2.5}$ variability was largely determined by synoptic meteorological influences.

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ABSTRACT

The aim of this work was to compare the variability in an urban area of fine particles ($PM_{2.5}$), ultrafine particles (UFP) and black carbon (BC) and to evaluate the relationship between each particle metric and potential factors (local traffic, street topography and synoptic meteorology) contributing to the variability. Concentrations of the three particle metrics were quantified using portable monitors through a combination of mobile and static measurements in the city of Edinburgh, UK. The spatial variability of UFP and BC was large, of similar magnitude and about 3 times higher than the spatial variability of $PM_{0.5-2.5}$ (the PM size fraction actually quantified in this work). Highest inter-daily variability was observed for $PM_{0.5-2.5}$, which was approximately 2 times higher than inter-daily variability of BC and UFP. Elevated concentrations of UFP and BC were observed along streets with high traffic volumes whereas $PM_{0.5-2.5}$ showed less variation between streets and a footpath without road traffic. Both BC and UFP were significantly correlated with traffic counts, while no significant correlation between $PM_{0.5-2.5}$ and traffic counts was observed. BC was significantly correlated with UFP, with significantly different regression slopes between working days and non-working days implying that the increased number of diesel powered heavy goods vehicles during working days contributed more to BC than to UFP. It is concluded that variations in BC and UFP concentrations were mainly determined by the nearby traffic count and varying background concentrations between days, while variation in $PM_{0.5-2.5}$ concentration was mainly associated with regional sources. These findings imply the need for different policies for managing human exposure to these different particle components: control of much BC and UFP appears to be manageable at local scale by restricting traffic emissions; however, abatement of $PM_{2.5}$ requires a more strategic approach, in cooperation with other regions and countries on emissions control to curb long-range transport of $PM_{2.5}$ precursors.

1. Introduction

Evidence continues to accumulate of the adverse health impacts of $PM_{2.5}$, the mass concentration of airborne particulate matter (PM) with an aerodynamic diameter of less than 2.5 μm (WHO, 2013). However, metrics of other characteristics of ambient PM

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including numbers of ultrafine particles (UFP, particles of diameter <100 nm) and black carbon (BC) concentrations are emerging as important in terms of their association with health effects (Heal et al., 2012). A relevant issue is the extent to which UFP and BC concentrations vary within populated areas, since a shortcoming in many epidemiological studies is assumption of homogenous exposure within the study area. This might be plausible for pollutants with less spatial variability but could result in significant bias in exposure-response relationships for highly spatially variable pollutants (Hoek et al., 2002). In this context, variables related to the contribution of emissions from major roads (e.g. traffic intensity, or distance to the road) are commonly identified as significant predictors for a range of traffic-related air pollutants in many studies applying land-use regression models (Hoek et al., 2008), the validity of which might be influenced by the underlying causes of the variability of different pollutants. Thus one of the aims of this work was to evaluate the extent to which potential factors affect the spatiotemporal variability of ambient BC, UFP and $PM_{2.5}$ in an urban area. These factors include local traffic, street topography and synoptic meteorology which, although recognised in the literature, have rarely been compared in terms of their influences on different metrics.

The three airborne particle metrics are closely related to traffic in urban environments (HEI, 2010; Kassomenos et al., 2014; Sandradewi et al., 2008) but, for $PM_{2.5}$ in particular, synoptic-scale meteorology also affects the dispersion and long-range transport of secondary particles (Pinto et al., 2004). UFP variability is also subject to high intensity secondary formation associated with strong solar radiation (Reche et al., 2011). Street canyons, which are ubiquitous in many urban environments, introduce complex dispersion characteristics that further increase the spatial variability of BC and UFP (Peters et al., 2014; Rakowska et al., 2014). One limitation of inter- and intra-urban studies of airborne particle concentrations is that the fixed-site measurements on which they are based are rarely sufficient in number, and thus in spatial coverage, to explore the variability of exposure to particles at street level. One way to monitor particle concentration at high spatiotemporal resolution is by use of mobile monitoring instruments, which has good prospects for wider application in the assessment of human exposure to air pollution in the future (Steinle et al., 2013).

Both UFP and BC have received increasing interest in recent studies (Patton et al., 2014; Ruths et al., 2014), as they can be considered markers of a range of traffic-related particulate pollutants. Therefore the relationships of UFP and BC with traffic volume and composition need to be understood in order to correctly assign exposure to traffic pollution in health studies. In the UK and many other countries, $PM_{2.5}$ and PM_{10} are the only two regulated PM metrics (AQEG, 2012). Given the increasing evidence for the harmfulness of UFP (WHO, 2013) with its ability to penetrate deep into the airways (Knibbs et al., 2011), investigation on the relationship between UFP and $PM_{2.5}$ can provide insight on the extent to which current policy can effectively protect human health. Thus another aim of this work was to investigate the inter-relationships between the different metrics of PM and their relationships with traffic.

In this work, pairs of portable instruments were used to measure $PM_{0.5-2.5}$ (used here as a measure of $PM_{2.5}$), UFP number and BC concentrations within the city of Edinburgh (Scotland) in two series of measurement campaigns in winter and in spring. Analyses of data from a combination of mobile and stationary measurements were used to evaluate possible causes of the variations in the concentrations of the different PM metrics.

2. Methods

2.1. Study design

BC, UFP and $PM_{0.5-2.5}$ concentrations were measured across the south of the city of Edinburgh, UK (55.9° N, 3.2° W, population ~480,000) in two separate campaigns using 2 units of the following instruments: microAeth AE51 (AE51), TSI 3007 Condensation Particle Counter (CPC) and Dylos Corp. DC1700 (Dylos).

In the winter campaign, between December 2013 and January 2014, the measurements were conducted three times on Mondays and once on Sunday primarily near roadside by walking between and pausing at designated sites (Fig. 1a). The sites were selected to cover potential hotspots, urban background sites (at least 130 m from the nearest major road) and different street topographies

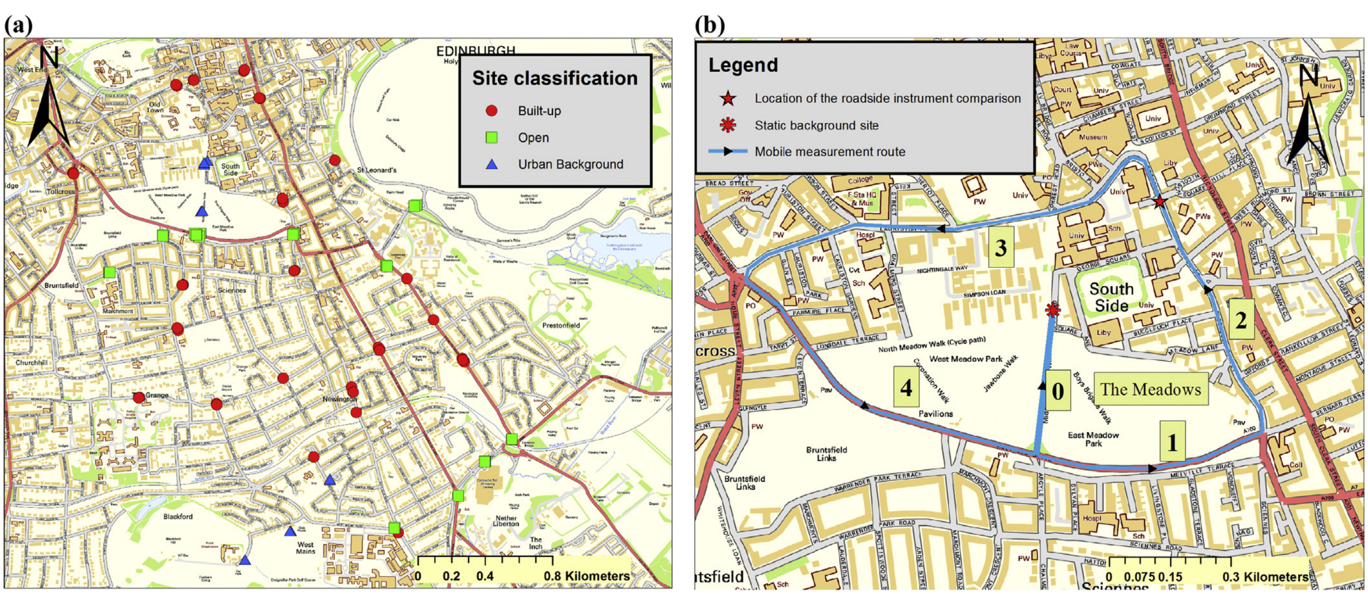

Fig. 1. (a) Location and classification of the static measurement sites. Streets with buildings on both sides are classified as built-up. Streets with buildings on only one side or no buildings on either side are classified as open. Background sites are at least 130 m away from the nearest major road. (b) Mobile measurement route and location of the contemporaneous background measurements. Segments of the mobile route are labelled from 0 to 4. Base map from Edina Digimap®.