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Variability of airborne particle metrics in an urban area☆

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ABSTRACT

In the present study a mobile monitoring approach (i.e. bike with onboard instruments) was proposed and applied to investigate the spatial variability of all the key airborne particle metrics in an Italian urban area from a statistical point of view. Particle number, alveolar-deposited surface area, and PM_{10} concentrations were measured through hand-held monitors and compared to simultaneous background concentrations by means of non-parametric tests and further post-hoc tests (Kruskal-Wallis test). Streets characterized by exposure levels statistically higher than the background levels for all the particle metrics were identified for different seasons in a pilot urban area (Cassino, Italy). A higher number of hot spots was detected for metrics affected by ultrafine particles (i.e. number and alveolar-deposited surface area concentrations) with respect to PM_{10}. The effect of metrological requirements of the instrumentation on the proposed method was also discussed.

1. Introduction

In recent years many studies have focused on airborne particle monitoring in order to estimate the human exposure in urban environments. This increase in technical and scientific attention is motivated by the findings in the medical field relating the exposure to high particle concentration levels to adverse health effects (Buonanno et al., 2013b; Gómez-Moreno et al., 2011; Loomis et al., 2013).

Previous epidemiological studies have linked the exposure to $PM_{2.5}$ and PM_{10}, namely mass concentration of particles smaller than 2.5 or 10 μm in diameter (Buonanno et al., 2010a), to cardiovascular diseases, such as increases of blood pressure and reduction of heart rate variability, and to inflammation and thrombosis (Basagaña et al., 2015; Delfino et al., 2010; Graff et al., 2009; Samoli et al., 2013; Weichenthal et al., 2011). Recently, surface area and particle number concentrations, whose prevalent contribution is due to ultrafine particles (UFPs, particles with a diameter less than 100 nm) are becoming the main airborne particle metrics for studies focused on health effect evaluation (Atkinson et al., 2010; Bos et al., 2011; Buonanno et al., 2009b; Gomes et al., 2012; Jacobs et al., 2010; Kumar et al., 2011). Even though the assessment of the health effect due to the exposure to UFPs is still scarce and far from being definitive, recent studies reported epidemiological evidence on the association between short-term exposures to UFPs and cardiorespiratory health, as well as the health of the central nervous system (World Health Organization, 2013). Furthermore, UFPs are capable of carrying large amounts of condensed toxic pollutants to the deepest regions of the respiratory system causing negative pulmonary effects and increasing the lung cancer risk (Buonanno et al., 2015; Delfino et al., 2005; Hoek et al., 2010; Knol et al., 2009; Phalen et al., 2006).

1.1. Exposure to airborne particles in urban areas

Urban area represents an environment characterized by many emission sources which significantly contribute to the daily total particle exposure for humans. In particular, the predominant contribution to the overall emission in urban areas is due to anthropogenic activities, including industrial and residential sectors as well as vehicular traffic, i.e. sources mostly involving combustion phenomena emitting high levels of sub-micrometric and ultrafine particles (Morawska et al., 2008). Since people spend a not negligible amount of their time in urban environments, they can be significantly exposed to such emissions (Dos Santos-Juusela et al., 2013). Thus, it is crucial to characterize the sources' emission and, more importantly, the actual exposure of population at urban

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microscale. Nonetheless, the exposure to airborne particles is also affected by the particle dispersion phenomena (Buonanno et al., 2011; Kaur et al., 2005). The urban street canyons, i.e. a typical urban configuration made up of a street flanked by buildings on both sides, represent an example of urban microenvironment in which high levels of pollutants are easily reached therefore they are also recognized as "hot spots" in terms of people exposure (Marini et al., 2014; Stabile et al., 2015). This is due to the combination of street geometry, wind direction and traffic density which have a negative effect on the pollutant dispersion (Kanakidou et al., 2011; Morawska et al., 2008; Scungio et al., 2015).

The limit values of airborne particles in outdoor environments (and thus in urban areas) are, to date, defined in terms of PM_{10}, and for $PM_{2.5}$ only guideline values are provided (European Parliament and Council of the European Union, 2008; U.S. Environmental Protection Agency, 2006). In order to map the outdoor air quality in terms of PM_{10} and $PM_{2.5}$, the current European legislation (European Parliament and Council of the European Union, 2008) suggests a limited number of fixed sampling points (FSPs) as representative of the exposure of the entire urban population living within this area; however, this does not take into account for the personal exposure factors, factors related to the transport mode, traffic and meteorological factors, as well as variations of particle concentrations due to meteorological conditions and source emission properties which can strongly affect the real exposure of the population. This is an oversimplified approach considering the spatial variability of PM in cities (Buonanno et al., 2011; Kaur et al., 2005; Peters et al., 2013); moreover, the method is even less valid for UFPs which are recognized for having a greater spatial variability than PM_{10} (Buonanno et al., 2009b, 2011; Kaur et al., 2005; Pérez et al., 2010; Puustinen et al., 2007). Since several studies have demonstrated that airborne particle monitoring through fixed stations provide inadequate evaluations and not related to the exposure of the entire population (Peters et al., 2013), a personal monitoring is needed to evaluate the actual exposure to airborne particles of people living/working in or crossing several urban microenvironments (Cattaneo et al., 2009; Gulliver and Briggs, 2004; Kaur et al., 2007; Westerdahl et al., 2005). Such personal monitoring should also include the UFPs, which are currently not considered in the normative guidelines (Hasenfratz et al., 2015). In view of a proper evaluation of the personal exposure, recent studies have developed mobile monitoring platforms (bikes, buses, etc.) using real-time instruments able to assess high resolution mapping of the spatial variability of air quality in urban microenvironments (Castellini et al., 2014; Fung et al., 2013; Hagler et al., 2010; Kaur et al., 2007; Westerdahl et al., 2005). Most of these on road studies have been conducted using vehicle-based mobile monitoring to obtain concentration maps of particles and gaseous pollutants. In order to facilitate simultaneous or pseudo-simultaneous measurements of near real time airborne particle concentrations, zero-emissions and low cost mobile platforms were usually used (e.g. bicycle). This method doesn't affect the traffic and also provides the real exposure of pedestrians. Studies performed on the basis of such methodology allowed to evaluate the spatial and temporal variation in concentration of several pollutants: as an example, studies performed in Los Angeles area revealed that UFP concentrations along Los Angeles freeways were often ten times higher than those on residential streets (Westerdahl et al., 2005), nevertheless even in residential neighborhoods (e.g. Boyle Heights (Hu et al., 2012),) different UFP concentrations were found due to different social, roadway network and built environments.

1.2. Aims of the work

The aim of the present work was to investigate the spatial variability of all the key particle metrics (number, alveolar-deposited surface area and mass concentrations) in an urban area with the use of a mobile monitoring approach. Pseudo-simultaneous measurements, taking into account various parameters which may influence human exposure, were performed in order to assess the different urban hot spots, i.e. streets where the particle exposure levels are statistically higher compared to the background ones.

The proposed low-cost and time-saving approach could be useful in properly designing a city-specific measurement network made up of a limited number of FSPs able to characterize the local exposure to particles within the urban areas.

2. Methods

2.1. The sampling sites

The study was conducted in Cassino (41°30′0″N-13°50′0″E), Central Italy (resident population: 33,000 inhabitants; daily commuter students and workers: 20,000 people; surface area: 83 km^2), between December 2014 and July 2015.

Five streets, that differ in terms of geometry, traffic density and velocity (Fig. 1) were considered in the study:

- Street A: two-ways single-lane street with heavy free flow traffic conditions characterized by a daily average traffic density of 16 ± 2 vehicles min^{-1} (details on its measurement are reported in the methodology section), and a maximum allowed vehicles' speed of 50 km/h. This street is a wide canyon characterized by large openings on the walls (e.g. the east side street is flanking by a green park);
- Street B: one-way two-lane street characterized by a daily average traffic density of 9 ± 3 vehicles min^{-1}. The street can be considered a street canyon as the aspect ratio H/W (H: building height, W: street width) is about 1.2;
- Street C: two-way single-lane urban street with slow traffic conditions characterized by a traffic density of 7 ± 2 vehicles min^{-1}, which can be considered a street canyon with an aspect ratio of about 1.3;
- Street D: one-way single lane street characterized by a traffic density of 8 ± 2 vehicles min^{-1} and an aspect ratio of 0.85.
- Street E: one-way single lane street characterized by a traffic density of 11 ± 2 vehicles min^{-1} and an aspect ratio of about 1.1.

The above-listed streets B, C, and D were further divided in several road links (B1, B2, C1, C2, D1, D2) related to the presence of intersections, roundabouts or large openings. In Fig. 1 the road links of the streets are shown as well as the sides of the analyzed streets are defined (e.g. east and west sides of the street A were indicated as A_1 and A_2, respectively).

A further fixed sampling site (background site) was considered. The background site was placed in an urban park (see Fig. 1) not directly influenced by emission sources as defined by the national regulation (Decreto Legislativo 155/2010, 2010). Indeed, the sampling site is at distance of about 120 m from the nearest road (street A), such distance can be considered sufficient to obtain a significant decrease in UFP concentration as reported in Buonanno et al. (2011).

2.2. Experimental apparatus

Several instruments were used during the experimental campaign to measure total particle concentrations in terms of number, alveolar-deposited surface area and mass fractions:

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