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Investigating near-road particle number concentrations along a busy urban corridor with varying built environment characteristics

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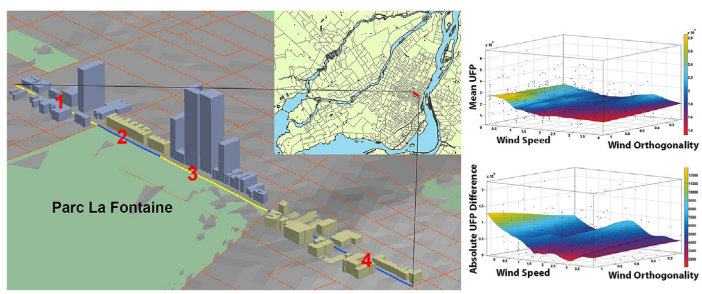
HIGHLIGHTS

- Near-road UFP concentrations are measured on both sides of the road.
- Traffic and meteorology are notable determinants of mean UFP concentrations.
- The presence of buildings increases the difference in UFP on the two sides.
- Winds orthogonal to the road increase mean UFP and differences in UFP on both sides.

GRAPHICAL ABSTRACT



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ABSTRACT

This study aimed at capturing the determinants of near-road concentrations of ultrafine particles (UFP) using linear mixed-effects models, investigating the effects of meteorology, built environment, and traffic. In addition, the differences in the levels of UFP between both sides of the road were investigated. To reach these objectives, field measurements were conducted on 16 weekdays in the months of March and April 2015, along Papineau Avenue, a high-volume street in Montreal, Canada. Four sites were identified varying in land use, building height, and road characteristics. Air quality measurements were conducted at each location (on both sides of the road) for two consecutive hours, at four different times during the day and repeated four times, leading to a total of 16 visits per location. Traffic volume and composition was also recorded. On-site meteorological variables including wind speed, wind direction, temperature and relative humidity were collected using a portable weather station. Linear mixed-effects models with random intercept were developed for both dependent variables: the natural logarithm of the mean UFP concentration and the difference in UFP concentrations between two sides of the road. Lower temperatures and wind speeds were associated with increased UFP concentrations. Winds orthogonal to the road tended to increase UFP concentrations as well as the differences between both sides of the road. Finally, built environment variables such as the presence of open areas and buildings on both sides of the road, had a positive influence on the difference between UFP on the two sides.

1. Introduction

Ultrafine particles (UFP) are defined as particles with a diameter of less than 100 nm. They make up the smallest size fraction among airborne particulate matter and are the dominant contributors to

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particle numbers (HEI Review Panel on Ultrafine Particles, 2013). Exposure to UFP has been associated with both acute and chronic health outcomes including myocardial infarction (Bard et al., 2014), atherosclerosis and systemic oxidative stress (Araujo, 2010), as well as inflammation of the cardiovascular and respiratory systems (Brunekreef et al., 2009; Chen et al., 2013; Dockery, 2001). Given the increased recognition of the health effects associated with UFP exposure, there has been growing interest in the measurement and modeling of UFP in near-road environments.

A number of studies have investigated the effects of meteorology, built environment and traffic on near-road air pollution. Among them, land use regression (LUR) models have been extensively used to characterize the spatial variability in air pollution (Briggs et al., 2000; Zwack et al., 2011). Variables explaining measured air pollutant levels typically include land-use characteristics within different buffers, proximity variables and traffic variables (Rivera et al., 2012). Some of those studies found that distance to the source plays a significant role in explaining the variation in UFP concentrations in urban areas (Weichenthal et al., 2016), while the distribution of UFP is influenced by site characteristics such as the presence of buildings or vegetation (Ragettli et al., 2014). The concentrations can also drastically increase as a result of an increase in traffic emissions, such as during rush hours (Moore et al., 2014). However, most LUR models generally sacrifice temporal resolution by conducting integrated air pollution measurements (Cyrys et al., 2008; Weichenthal et al., 2015; Zhou and Levy, 2007). Recent studies exploring the behavior of UFP in urban environments have shown that cooler temperatures associated with morning periods and low humidity were associated with higher concentrations of traffic-related pollutants (Ghafghazi, 2014; Janhall et al., 2006). Most existing studies incorporate meteorology data provided by regional weather stations, and the absence of weather conditions at street level has been repeatedly noted as a limitation (Collins, 2012; Quiros et al., 2013; Wu et al., 2012). Multivariable linear mixed-effects models attracted considerable attention from researchers investigating the effects of meteorology, built environment, and traffic on near-road concentrations of UFP (Fischer et al., 2014; Hennig et al., 2014; Ryan et al., 2015). This structure is able to account for potential correlations between repeated air pollution measurements collected at the same location (Weichenthal et al., 2014).

The city of Montreal has been the focus of an increasing number of air pollution related epidemiologic studies (Crouse et al., 2009; Ostiguy et al., 2010), as well as research concerning possible determinants of UFP in near-road environments (Farrell, 2014; Hatzopoulou et al., 2012). This study presents the design and results of a data collection campaign aimed at understanding the determinants of near-road UFP in Montreal across a wide range of meteorological conditions, built environments, land uses, and traffic flows. We also demonstrate a method to examine the urban canyon effect by taking field measurements simultaneously on both sides of the road, highlighting the impacts of meteorological factors in explaining much of the temporal variation. Our study was conducted in the winter and therefore provides insight into the UFP levels in cold environments.

In light of the aim of this study, which is to explore the factors influencing UFP concentrations in near-road environments, our focus is on the environment in the immediate vicinity of the road whereby we can capture the effects of traffic, meteorology, and built form immediately surrounding the road. This is a different emphasis then the one adopted in the development of LUR models where the focus is on spatial coverage and long-term average concentrations. We specifically limited our campaign to four road segments and multiple repeated measurements in order to capture the influence of variables that wouldn't normally be included in a LUR model. Our study also aims to capture the urban canyon effect which states that when the direction of the mean wind is parallel to the street, channelization effects will accelerate the dispersion of pollutants, while when the mean wind direction is perpendicular to the street direction, the vortex formed inside leads to higher mean concentrations.

2. Material and methods

2.1. Field data collection

Air quality data were collected at four different sites varying in built environment characteristics along Papineau Avenue in Montreal. Both ends of this avenue lead to bridges connecting the City of Montreal with the rest of the region, making it a high-volume road servicing local and "through" traffic. Each of the four data collection sites is located mid-block along a segment of Papineau Avenue. Fig. 1 illustrates the four different segments (1–4), each segment extends from one intersection to another. There are no emissions-generating businesses along the corridor, such as gas stations, service stations and restaurants, etc. Buildings on two sides of the road are primarily residential or office buildings and a few commercial establishments including a sport center.

Segment 1 is predominantly surrounded by low residential buildings (with an average height of 9.7 m and an aspect ratio of 1.1) on both sides. Segment 2 has low residential buildings one side of the road and a park (Parc La Fontaine) located on the opposite side, with an average height of 10.5 m and an aspect ratio of 0.6. Segment 3 is bound by high residential buildings on one side and park area on the other, with an average height of 21.1 m and an aspect ratio of 1.3. The last segment has a gradient of −4.29% in the southbound direction, with low commercial and residential buildings (with an average height of 7.8 m and an aspect ratio of 0.6) on both sides of the street. There are no significant slopes from Segment 1 to Segment 3. The four segments were selected in an effort to maximize variations in the set of potential built environment predictors of UFP, while maintaining reasonable consistency in terms of traffic volume and composition.

Field data measurements were conducted on 16 weekdays over a four-week period in the months of March and April of 2015. To avoid selection bias, visits to the measurement locations were randomly scheduled keeping the constraint that each segment is visited a total of 16 times during 4 different time periods: peak morning (08:00–10:00) and afternoon (16:00–18:00) periods, as well as off peak in the mid-day (10:30–12:30) and (13:30–15:30). Each visit lasted for 2 consecutive hours. In total, 32 h of data were collected for each road segment.

UFP concentrations were collected using condensation particle counters (CPC Model 3007, TSI Inc., Shoreview, MN, USA), placed at a height of approximately one meter on both sidewalks. On account of the CPC's operating temperature ranging from 10 to 35 °C, each CPC was surrounded with glass wool and rechargeable hand warmers and placed in an insulated bag maintaining the equipment's working temperature. A 30-cm-long sampling tube was connected to one end of the CPC while the other end was extended outside of the insulated bag letting in fresh air. The sampling tubes were tested and were not observed to affect the readings.

In order to test whether the insulation and the tube affected the results, we co-located the 2 CPCs side by side at the same location and first made sure that they read very similar values. Then, one CPC was equipped with a tube and installed in the insulating bag while the other was not. Comparison of the results showed that mean concentrations were not statistically different ($p < 0.05$). Fig. 2 presents comparative data collected over an hour.

In addition, another hole was drilled on the side of the foam