INVESTIGATING NEAR-ROAD PARTICLE NUMBER CONCENTRATIONS ALONG A BUSY URBAN CORRIDOR WITH VARYING BUILT ENVIRONMENT CHARACTERISTICS

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1. Introduction

Ultrafine particles (UFP) make up the smallest size fraction among airborne particulate matter and are the dominant contributors to particle numbers (HEI Review Panel, 2013). Exposure to UFP has been associated with both acute and chronic health outcomes (Brunekreef et al., 2009; Chen et al., 2013). 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 (Hagler, Thoma, & Baldauf, 2010; Kozawa, Winer, & Fruin, 2012; Weichenthal, Van Ryswyk, Goldstein, Shekarrizfard, & Hatzopoulou, 2015). 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. It also demonstrates 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. In addition, this study was conducted in the winter and therefore provides insight into the UFP levels in cold environments. FIGURE 1 illustrates the four different segments (1 to 4), each segment extends from one intersection to another.

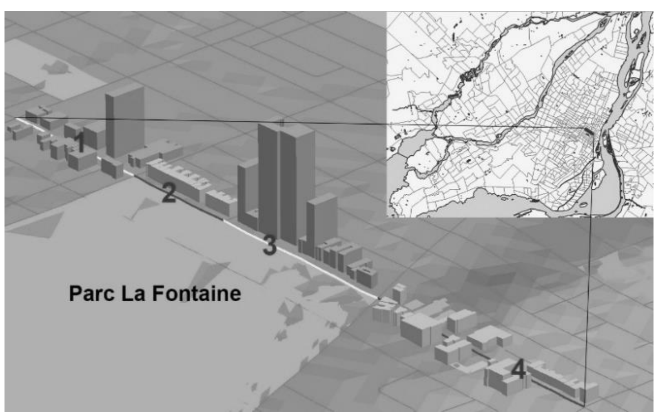

FIGURE 1: Study corridor and measurement locations

2. Material and Methods

2.1 Data Collection

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. Each visit lasted for 2 consecutive hours. In total, 32 hours of data were collected for each road segment. At the same time, meteorological data were logged by a portable weather station, which was placed in close proximity to one of the CPCs, always on the same side of the road. Simultaneously, a digital camcorder was affixed on the traffic light controller box located at the upstream intersection with respect to the sampling location, recording real-time traffic information, including vehicle types, vehicle counts for all directions and their corresponding route decisions. To investigate the effects of the site characteristics, land use data surrounding each specific site were collected and processed using a combination of ArcGIS, Google Maps, and orthophotographs.

2.2 Data processing

Traffic information was manually extracted from video camera recordings. Volumes of passenger cars, passenger trucks, school buses, transit buses, single unit short-haul trucks, and single unit long-haul trucks were noted. The presence of trucks in particular was of interest, so the total number of diesel vehicles along with the diesel ratio were computed. The diesel ratio is defined as the ratio of total diesel vehicles to the total number of vehicles.

Wind direction recorded by the portable weather station could follow one of eight directions. To supplement data collected by this local station, meteorological data were also extracted from a nearby fixed station operated by Environment Canada, located approximately 3 kilometers from our study corridor.

In order to calculate the angle between the road and the wind direction measured by the fixed station, the orientation of Papineau Avenue was measured with respect to the true north in the clockwise direction using Google Earth. An orthogonality index K was then calculated as the absolute sine of the above difference in order to obtain a value ranging from 0 to 1. A value of 1 would represent a wind direction orthogonal to the road while a value of 0 would represent a wind parallel to the road.

2.3 Statistical analysis

Since every location was visited 16 times, 128 observations were collected per road segment under varying meteorological and traffic conditions. This led to a total of 512 observations. Among them, 410 valid observations were used for analyses of the mean UFP concentrations, whereas only 261 valid observations were selected for investigating the differences between both sides of the road. This is due to issues such as lack of calibration, non-synchronized measurements, or accidental gaps in the data.

Prior to any analysis, values of mean UFP concentrations or the absolute UFP differences were log transformed to correct for their positively skewed distributions. Pearson correlations were also calculated; if the correlation coefficient between two variables was higher than 0.7, the predictor with the stronger effect in the regression was retained. Both linear and non-linear effects were tested for each variable as well.

Two linear mixed-effects models were selected in light of the repeated number of observations at each segment: One regression explaining the mean UFP across both sides of the road (by averaging the UFP values recorded on each side), and another regression explaining the difference between UFP levels recorded on the two different sides.

3. Results

In terms of the mean UFP concentrations at the four different segments, the concentrations at locations 2 and 3 were notably lower than those at locations 1 and 4 (data not shown). This is not surprising since segments 2 and 3 are bound on one side by the Parc La Fontaine which leads to better dispersion of pollutants. In general, UFP concentrations were higher in the morning than in the afternoon (data not shown), which could be explained by higher diesel ratios and lower temperatures. FIGURE 2 illustrates the effects of wind speed and wind direction (in terms of the orthogonality index) on mean UFP concentrations. Despite the fluctuations on the surface due to a lack of data points in certain regions, peaks in UFP concentrations are visible in the area where wind speed is lower than 1 m/s, and where the wind orthogonality index is almost 1, indicating orthogonal winds. FIGURE 3 illustrates the effect of wind speed and direction on the difference in UFP concentrations between both sides. There is a noticeably ascending trend of the 3D fitting surface: the maximum levels of absolute UFP differences could be detected in the area where wind speeds are reading as low as 0 m/s and the wind orthogonality index approaches 1.

TABLE 1 presents our final model explaining mean UFP concentrations including a random intercept and a random slope for the wind orthogonality index. It indicates that the influence of wind direction on the UFP concentrations at street level is different at the four different segments. In other words, the built environment and road configuration at each segment alters the effects of the wind direction on UFP. Increasing humidity was shown to significantly decrease the UFP concentrations. Temperature was also found to have a significant negative influence on UFP concentrations. Wind speed was introduced as a non-linear effect, illustrating the stronger influence of wind speeds less than 1m/s. The wind orthogonality index indicates that UFP concentrations are lower when the wind direction is parallel to the street. The largest positive impact comes from the total number of vehicles.

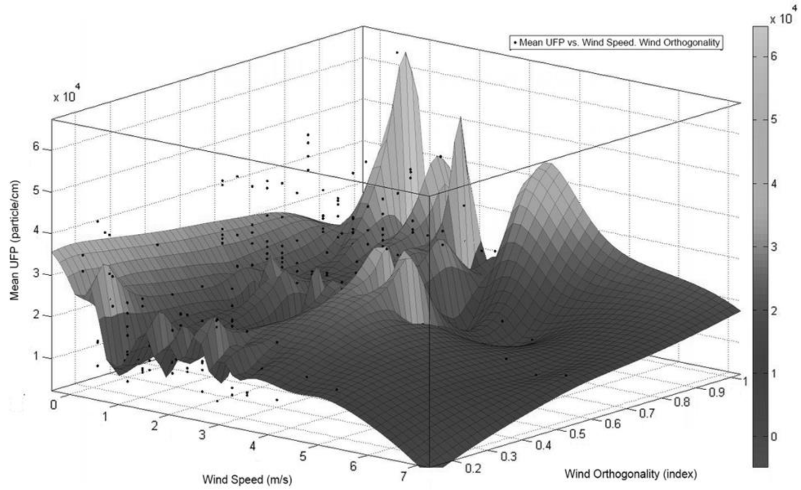

FIGURE 2: 3D surface illustrating the effects of wind orthogonality and wind speed on mean UFP concentrations

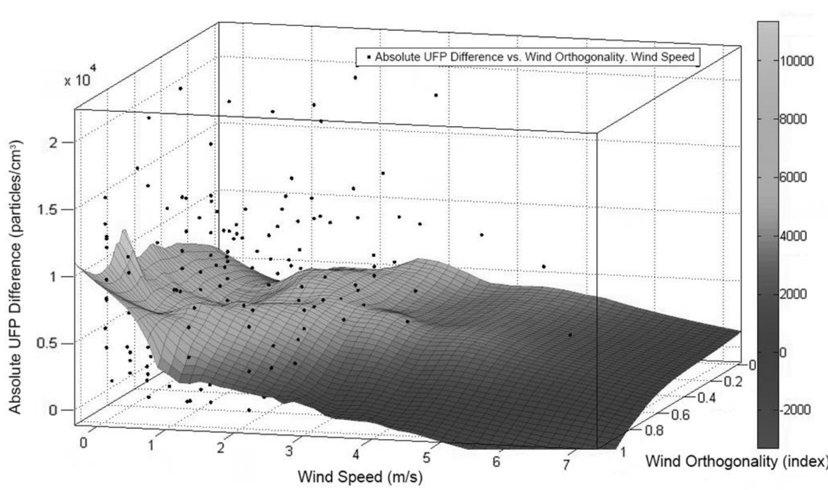

FIGURE 3: 3D surface illustrating the effects of wind orthogonality and wind speed on the difference in UFP concentrations on both sides of the street

TABLE 2 presents the final model explaining the difference in UFP concentrations on both sides of the street. Due to the fact that no variables are introduced in the random part of the model, it can be concluded that all variables in the fixed part of the model influence the absolute UFP difference in the same way. The strongest influences on the absolute difference in UFP concentrations come from the built environment. The dummy variable 'Buildings on Both Sides', when equal to 1, indicates that both sides of the street have buildings present, which is conducive to the formation of a vortex inside the street when the wind is orthogonal to the street direction. The vortex could reduce the dispersion of pollutants, and push the UFP toward the leeside of the street, resulting in a large concentration gradient. The presence of open areas also indicate the higher rate of advection from the upwind to the downwind side. In this particular scenario, UFP concentrations would disperse much more quickly on the side with open space compared to the side with buildings present. Relative humidity was negatively associated with both UFP concentrations as well as UFP concentration differences. Higher wind speeds were associated with lower differences on both sides due to the higher mixing. As expected, the impact of the wind orthogonality, increased the difference between the two sides. No significant impacts relating to traffic were observed. Unlike the abovementioned variables, traffic variables are more likely to explain the mean UFP concentrations rather than the differences.

TABLE 1: Linear mixed-effects model for mean UFP concentrations

Estimates of Fixed Effects *(AIC 436.985; Adjusted R^2 0.3281)*					
Parameter	Estimate	S.E.	Mean Percent Change with a change of 1% in the independent variable	95% CI	
Outdoor Temperature	-0.029	0.004	-0.005	-0.006	-0.003
Outdoor Humidity	-0.006	0.001	-0.036	-0.046	-0.025
Wind Orthogonality	0.269	0.094	0.016	0.002	0.029
Wind Speed < 1m/s	-0.192	0.073	-0.016	-0.028	-0.004
Wind Speed > 1m/s	-0.055	0.024	-0.004	-0.008	-0.001
Total Number of Vehicles	0.001	0.000	0.032	0.011	0.053
Intercept	9.919	0.151	-	-	-

TABLE 2: Linear mixed-effects model for ln (|∆UFP|)

Estimates of Fixed Effects *(AIC 846.872; Adjusted R^2 0.1498)*					
Parameter	Estimate	S.E.	Mean Percent Change with a change of 1% in the independent variable	95% CI	
Wind Orthogonality	0.500	0.253	0.034	0.000	0.068
Outdoor Humidity	-0.009	0.003	-0.055	-0.089	-0.021
Buildings on Both Sides	2.695	1.322	0.174	-0.051	0.399
Wind Speed	-0.124	-0.124	-0.021	-0.044	0.002
Open Area in 150 Meter Buffer	151.716	73.274	0.168	-0.050	0.386
Intercept	5.653	1.345	-	-	-

4. Conclusion

This study presents an innovative design for an air pollution data collection campaign on two sides of the road during the winter months, using a portable weather station in order to assess the effects of meteorology at street level. Despite the low predictive power of the statistical models (which are only meant to be used to understand the strengths of certain predictors), our results themselves provide insight into the complex nature of near-road air pollution.

We highlight the important role of meteorological factors such as temperature, humidity, wind speed, and wind direction. It is also worth noting that although land use variables were not included in the final model explaining mean UFP concentrations, their indirect impacts could be interpreted by the presence of wind direction as a random effect. In addition, traffic was also shown to be a notable contributor in explaining variations in UFP concentrations.

With regards to the absolute UFP difference on two sides of the road, the primary finding was that wind orthogonality and speed act as important predictors. Winds orthogonal to the road have a tendency to increase differences on two sides of the road. However, the most substantial impact on air pollution was the presence of buildings on both sides of the road, which is evidently common in major cities.

5. References

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