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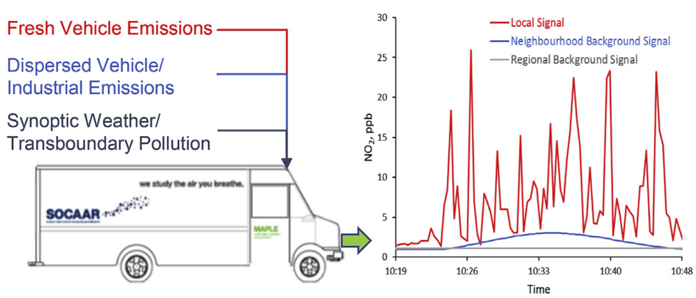
Characterizing the spatial variability of local and background concentration signals for air pollution at the neighbourhood scale

Kerolyn K. Shairsingh*, Cheol-Heon Jeong, Jonathan M. Wang, Greg J. Evans

Southern Ontario Centre for Atmospheric Aerosol Research, Dept. of Chemical Engineering and Applied Chemistry. University of Toronto, Toronto, Canada

GRAPHICAL ABSTRACT



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ABSTRACT

Vehicle emissions represent a major source of air pollution in urban districts, producing highly variable concentrations of some pollutants within cities. The main goal of this study was to identify a deconvolving method so as to characterize variability in local, neighbourhood and regional background concentration signals. This method was validated by examining how traffic-related and non-traffic-related sources influenced the different signals.

Sampling with a mobile monitoring platform was conducted across the Greater Toronto Area over a seven-day period during summer 2015. This mobile monitoring platform was equipped with instruments for measuring a wide range of pollutants at time resolutions of 1 s (ultrafine particles, black carbon) to 20 s (nitric oxide, nitrogen oxides). The monitored neighbourhoods were selected based on their land use categories (e.g. industrial, commercial, parks and residential areas). The high time-resolution data allowed pollutant concentrations to be separated into signals representing background and local concentrations. The background signals were determined using a spline of minimums; local signals were derived by subtracting the background concentration from the total concentration.

Our study showed that temporal scales of 500 s and 2400 s were associated with the neighbourhood and regional background signals respectively. The percent contribution of the pollutant concentration that was attributed to local signals was highest for nitric oxide (NO) (37–95%) and lowest for ultrafine particles (9–58%); the ultrafine particles were predominantly regional (32–87%) in origin on these days. Local concentrations showed stronger associations than total concentrations with traffic intensity in a 100 m buffer (ρ:0.21–0.44). The neighbourhood scale signal also showed stronger associations with industrial facilities than the total concentrations. Given that the signals show stronger associations with different land use suggests that resolving the ambient concentrations differentiates which emission sources drive the variability in each signal. The benefit of

* Corresponding author. Southern Ontario Centre for Atmospheric Aerosol Research, Dept. of Chemical Engineering and Applied Chemistry. University of Toronto, 200 College Street, Toronto, ON, M5S 3E5, Canada.

E-mail address: Kerolyn.shairsingh@utoronto.ca (K.K. Shairsingh).

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this deconvolution method is that it may reduce exposure misclassification when coupled with predictive models.

1. Introduction

The effects of air pollution can range from illnesses such as asthma to premature deaths (Ontario Medical Association, 2005). According to the World Health Organization, outdoor air pollution causes more than 3 million premature deaths worldwide every year (World Health Organization, 2016). The International Agency for Research on Cancer recently classified diesel engine exhaust as carcinogenic (International Agency for Research on Cancer, 2012). Furthermore, numerous studies have shown associations between traffic-related air pollution and adverse human health effects - asthma, adverse pregnancy outcomes, respiratory mortality, cancer and cardiovascular mortality (Brauer et al., 2008; Brook et al., 2010; Chen et al., 2013; Dell et al., 2014; Jerrett et al., 2008; Maynard et al., 2007; Villeneuve et al., 2013). While this compelling body of evidence exists, substantial gaps still remain; the Health Effects Institute (Health Effects Institute, 2010) has classified the epidemiological association between traffic-related air pollution (TRAP) and adverse health outcomes as "suggestive but not sufficient evidence to infer the presence of causal association". Part of the remaining uncertainty arises due to the challenges in exposure assessment, such as properly isolating exposures due to traffic as opposed to other sources.

Unravelling human exposure to air pollution requires a greater understanding of emission sources and the mechanisms that drive the resulting temporal and spatial differences in concentrations. One way in which these concentrations can be characterized is through separation into background and local signals. For example, a study conducted in Detroit used local levels of air pollutants to understand the impact of specific factors, such as truck traffic, weekday versus weekend and wind speed on observed concentrations (Baldwin et al., 2015). While an extensive body of research has explored the spatial variation within cities (Dons et al., 2013; Eeftens et al., 2015, 2012; Fruin et al., 2014; Hagler et al., 2010; Jerrett et al., 2005; Marshall et al., 2008; Rivera et al., 2012), there is limited literature on the extent of variability at the neighbourhood-scale (Baldwin et al., 2015; Hu et al., 2012; Pattinson et al., 2014; Patton et al., 2014). In U.S. Metropolitan Statistical Areas it was documented that within-city variability was greater than the between-city contrast for nitrogen dioxide (Miller et al., 2007) while in Boston, greater inter-neighbourhood variation was observed for black carbon (BC), nitric oxide (NO), nitrogen oxides (NO_x) and carbon monoxide (CO) (Patton et al., 2014). Furthermore, significant concentration gradients within 100 m from highways have been reported for TRAP pollutants (BC, NO and ultrafine particles (UFP)) as well as elevated levels in neighbourhoods near highways (Baldwin et al., 2015; Hu et al., 2012; Jeong et al., 2015). Differentiating intra-neighbourhood and inter-neighbourhood variation will not only enhance our understanding of the variability at a fine spatial scale but it can also identify pollution "hot spots" that may require more stringent

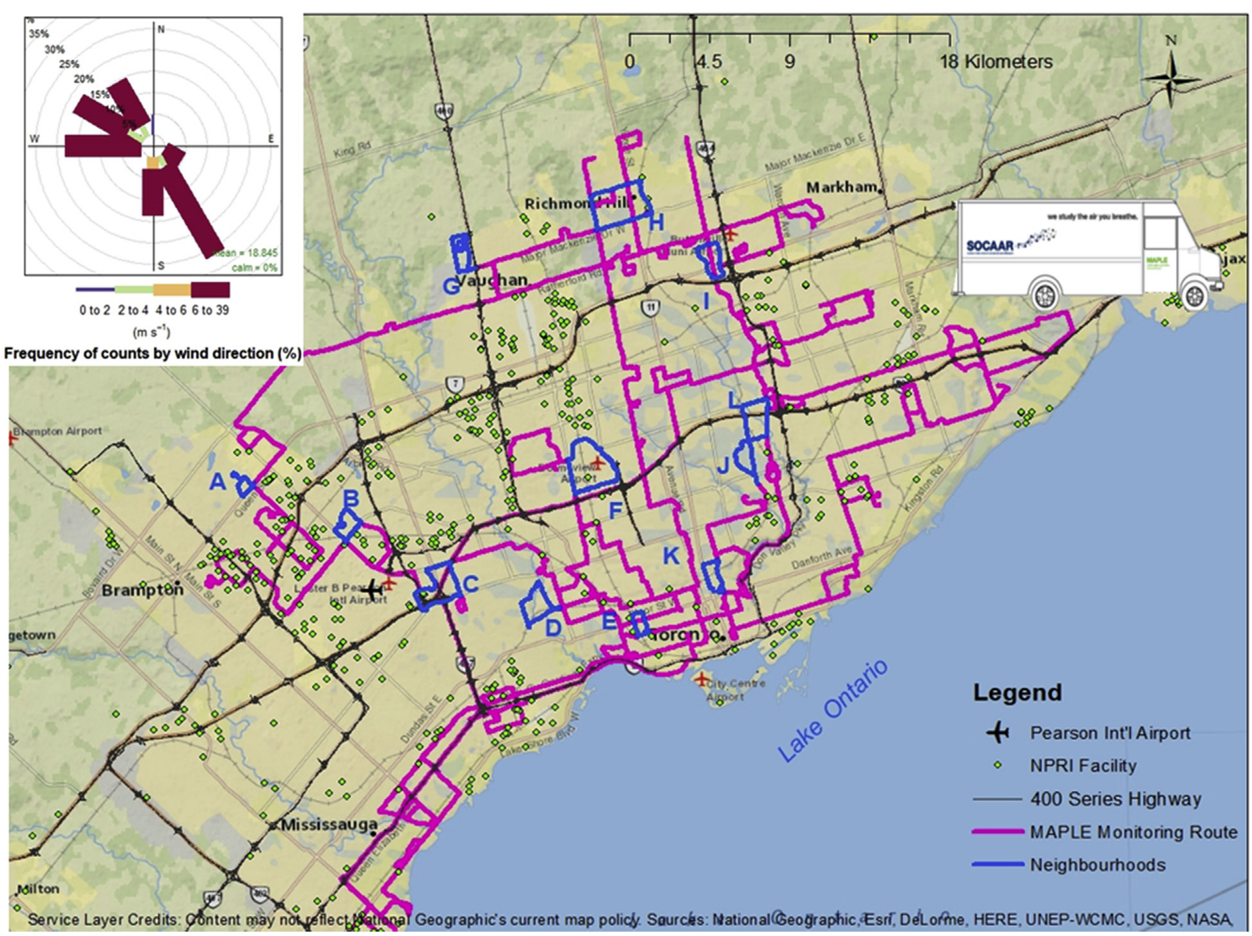

Fig. 1. Mobile monitoring routes for the entire campaign (pink lines) with neighbourhoods (A,B,C,D,E,F,G,H,I,J,K,L) highlighted in blue using the University of Toronto mobile van, Mobile Analysis of ParticuLate in the Environment (MAPLE).