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Errors associated with the use of roadside monitoring in the estimation of acute traffic pollutant-related health effects

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ABSTRACT

Near-road monitoring creates opportunities to provide direct measurement on traffic-related air pollutants and to better understand the changing near-road environment. However, how such observations represent traffic-related air pollution exposures for estimating adverse health effect in epidemiologic studies remains unknown. A better understanding of potential exposure measurement error when utilizing near-road measurement is needed for the design and interpretation of the many observational studies linking traffic pollution and adverse health.

The Dorm Room Inhalation to Vehicle Emission (DRIVE) study conducted near-road measurements of several single traffic indicators at six indoor and outdoor sites ranging from 0.01 to 2.3 km away from a heavily-trafficked (average annual daily traffic over 350,000) highway artery between September 2014 to January 2015. We examined spatiotemporal variability trends and assessed the potential for bias and errors when using a roadside monitor as a primary traffic pollution exposure surrogate, in lieu of more spatially-refined, proximal exposure indicators.

Pollutant levels measured during DRIVE showed a low impact of this highway hotspot source. Primary pollutant species, including NO, CO, and BC declined to near background levels by 20–30 m from the highway source. Patterns of correlation among the sites also varied by pollutant and time of day. NO_2, specifically, exhibited spatial trends that differed from other single-pollutant primary traffic indicators. This finding provides some indication of limitations in the use of NO_2 as a primary traffic exposure indicator in panel-based health effect studies. Interestingly, roadside monitoring of NO, CO, and BC tended to be more strongly correlated with sites, both near and far from the road, during morning rush hour periods, and more weakly correlated during other periods of the day. We found pronounced attenuation of observed changes in health effects when using measured pollutant from the near-road monitor as a surrogate for true exposure, and the magnitude varied substantially over the course of the day. Caution should be taken when using near-road monitoring network observations, alone, to investigate health effects of traffic pollutants.

1. Introduction

Epidemiologic evidence exists linking traffic-related air pollution (TRAP) with a range of acute and chronic health effects, with particular concern for those living in close proximity to heavily-trafficked roadways (Health Effects Institute, 2010; Künzli et al., 2000). The recent establishment of an EPA-supported near-road monitoring network, was aimed to improve assessment of exposure to primary traffic emissions for urban populations, especially for individuals living near highways (Batterman, 2013). The 75 near-road monitoring sites are mostly located within 30 m of highly-trafficked highways.

While near-road monitoring offers opportunities for conducting direct measurements of freshly-emitted traffic-related pollution, it is unclear how well these sites reflect near-road levels at varying proximities to the traffic source. Specifically, despite the recent progress in assessing the spatial representativeness of urban air quality monitoring stations (Santiago et al., 2013; Martín et al., 2015), questions remain regarding the comparability of spatiotemporal variability patterns of

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Fig. 1. Map of sampling locations for the DRIVE study on the campus of the Georgia Institute of Technology (GIT) in Atlanta, GA. The section of highways represents where Interstates 75 and 85 come together, with more than 350,000 vehicles passing by every day. Roadside site serve as a near-road-monitoring site and Jefferson St site was a center monitoring site that was 2.3 km away from this traffic hotspot. Two additional outdoor sites, along with two indoor sites, were located at the two student dormitories: 'Near Dorm', approximately 20 m west of the highway, and 'Far Dorm', approximately 1.4 km west of the highway.

primary pollutants from traffic at near-road sites to those at varying distances from highways (Batterman et al., 2014b; Beckerman et al., 2008; Zhu et al., 2002), and whether these near-road measurements offer accurate means of assigning exposures to traffic pollution. An additional concern relates to the use of outdoor monitors as surrogates of exposure for population that spend the majority (> 85%) of their time indoors (Lim et al., 2012). Precise and accurate exposure assignment is essential for quantifying and reducing measurement errors, which stem both from the lack of spatial representativeness in outdoor monitors as well as indoor-outdoor exposure discrepancies (Dionisio et al., 2014; Zeger et al., 2000).

Epidemiologic studies utilizing panel-based and small cohort study designs have been particularly useful for examining short-term health effects of air pollution exposures within near-road settings, given their ability to measure a range of exposure and health endpoints on an individual-level (Delfino et al., 2006, 2008; McCreanor et al., 2007; Sarnat et al., 2012). For these study designs, in particular, inter-individual variability in mobility and activity patterns can result in varying times spent near traffic pollution sources. The ability to monitor study participants at closer proximities may, consequently, be especially important for accurately modeling differing levels of exposure to TRAPs and reducing exposure misclassification. Adding to this challenge is the growing evidence that the near-road environment is changing rapidly (Blanchard et al., 2013a, 2013b; Henneman et al., 2015; Vijayaraghavan et al., 2014), due mainly to general reductions in primary automotive emissions. Today, primary traffic source contributions, fate and transport dynamics, and exposure factors for primary traffic pollutants likely differ from those reported historically. Zhai et al. (2017), for example, estimated that mobile source PM impacts decreased by about 30% between 2002 and 2013 in Georgia (Zhai et al., 2017), while national reductions in on road emissions decreased 49% (U.S. EPA). NO_x emissions decreased 51% in Georgia and 45% nationally during the same period. Substantial gaps exist in our understanding of how TRAPs vary in space and time in this changed near-road environment and whether near-road measurements can represent exposure to primary traffic emissions for broader population.

To address these research gaps and more closely examine emerging trends related to characterizing traffic pollution exposures, we conducted the Dorm Room Inhalation to Vehicle Emissions (DRIVE) study, an extensive near-road field-monitoring campaign. The focus of DRIVE centered around a prominent near-road environment in Atlanta, GA, with the goal of understanding the impact of a highway on its adjacent environment, and the potential implications for conducting and interpreting traffic pollution epidemiology for individuals living within this setting. The current analysis, specifically, assesses relationships between outdoor and indoor primary traffic exposure indicators within an approximate 5 km^2 spatial domain. To address the above research gaps, we report spatiotemporal variability patterns at sites within this domain and present findings from a simulated panel-based epidemiologic study of individuals living in close proximities to these sources.

2. Methods

The DRIVE study was conducted on and around the Georgia Institute of Technology (GIT) campus in Atlanta, GA, at outdoor and indoor monitoring sites adjacent to one of the most heavily trafficked highway arteries in the US (a section of highway, where Interstates 75 and 85 merge in a 16-lane corridor with average annual daily traffic over 350,000 vehicles). Intensive field sampling was conducted from September 2014 to January 2015. This location was, in many ways, ideal for an examination of traffic emission impacts within an urban near-road domain, given our ability to conduct simultaneous measurements at multiple monitors at varying linear distances from this major traffic source.

Sampling was conducted at six dedicated monitoring sites (four outdoor and two indoor) ranging from less than 0.01–2.3 km away from the highway (Fig. 1). The main near-road sampling site ('Roadside' or RDS) consisted of a highly instrumented trailer with an inlet at a distance of 10 m from the closest highway center lane. Urban background outdoor pollutant concentrations away from the road were collected at the Southeastern Aerosol Research and Characterization (SEARCH) network at the Jefferson Street center monitoring site (CMS) located 2.3 km west of the highway (Hansen et al., 2006). Measurements from the Jefferson Street CMS have been used previously to generate population exposure estimates in analyses examining short-term associations between air pollution and daily morbidity (Darrow et al., 2008, 2011; Metzger et al., 2003a, 2003b; Sarnat et al., 2008a, 2008b; SE Sarnat et al., 2008a, 2008b; Sarnat et al., 2010; Strickland et al., 2010; Tolbert et al., 2000) and is generally considered to be representative of Atlanta urban background pollutant concentrations and composition (Edgerton et al., 2005; Liu et al., 2005; Solomon et al., 2003). Two additional outdoor sites, along with two indoor sites, were located at the two