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Contrasting the direct use of data from traffic radars and video-cameras with traffic simulation in the estimation of road emissions and PM hotspot analysis

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ABSTRACT

This study investigates the effect of traffic volume and speed data on the simulation of vehicle emissions and hotspot analysis. Data from a microwave radar and video cameras were first used directly for emission modelling. They were then used as input to a traffic simulation model whereby vehicle drive cycles were extracted to estimate emissions. To reach this objective, hourly traffic data were collected from three periods including morning peak (6–9 am), midday (11–2 pm), and afternoon peak (3–6 pm) on a weekday (June 23, 2016) along a high-volume corridor in Toronto, Canada. Traffic volumes were detected by a single radar and two video cameras operated by the Southern Ontario Centre for Atmospheric Aerosol Research. Traffic volume and composition derived from the radar had lower accuracy than the video camera data and the radar performance varied by lane exhibiting poorer performance in the remote lanes. Radar speeds collected at a single point on the corridor had higher variability than simulated traffic speeds, and average speeds were closer after model calibration. Traffic emissions of nitrogen oxides (NOx) and particulate matter (PM_{10} and $PM_{2.5}$) were estimated using radar data as well as using simulated traffic based on various speed aggregation methods. Our results illustrate the range of emission estimates (NO_x: 4.0–27.0 g; PM_{10}: 0.3–4.8 g; $PM_{2.5}$: 0.2–1.3 g) for the corridor. The estimates based on radar speeds were at least three times lower than emissions derived from simulated vehicle trajectories. Finally, the PM_{10} and $PM_{2.5}$ near-road concentrations derived from emissions based on simulated speeds were two or three times higher than concentrations based on emissions derived using radar data. Our findings are relevant for project-level emission inventories and PM hot-spot analysis; caution must be exercised when using raw radar data for emission modeling purposes.

1. Introduction

While a number of traffic-related air pollutants are often detected in near-road environments, nitrogen oxides (NO_x) are considered as markers of traffic-related air pollution and have been associated with various chronic and health effects (Chaloulakou

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et al., 2008). Besides, particulate matter (PM) from vehicle emissions has been identified as a major public health risk, particularly in urban areas (Weinmayr et al., 2016). Two size ranges, $PM_{2.5}$ and PM_{10}, are widely monitored in the ambient air. Vehicles mainly emit fine particles ($PM_{2.5}$) from the tailpipe exhaust and coarse particles (PM_{10}) from tirewear and brakewear (Ferm and Sjoberg, 2015). The development of modeling tools able to simulate the contribution of road traffic on near-road air quality is crucial in order to assist project-level analysis and in investigating the impacts on air pollution of various strategies, such as changes in road capacity or development of bicycling infrastructure.

Vehicle emission models have been developed to predict traffic-induced emissions at macroscopic, mesoscopic, and microscopic levels (Abo-Qudais and Qdais, 2005). Macroscopic models provide network-wide emissions using average aggregated network variables, such as density, flow, and network speed (Jiang et al., 2015). Mesoscopic models provide emission estimates according to average link speeds. These models can take into account spatial and temporal variability across the network although they cannot represent explicitly the vehicle behaviour (Sider et al., 2014). Given that traffic impacts on local networks have drawn increased attention, microscopic emission models have become of great interest (Abou-Senna and Radwan, 2013). They are able to predict vehicular emissions at a second-by-second resolution by taking vehicle operating conditions as inputs including acceleration, deceleration, idling, and cruising (Song et al., 2012).

In recent years, various studies have sought to simulate traffic emissions through the integration of traffic and emission models. In the city of London, a combination of a microscopic traffic simulation model (VISSIM) and the Comprehensive Modal Emissions Model (CMEM) was applied to evaluate the effect of changes in available road capacity on vehicle emissions (Noland and Quddus, 2006). In Greenville, the traffic model PARAMICS and the Motor Vehicle Emission Simulator (MOVES) were linked to investigate the impact of alternative fuelled vehicles on traffic emissions (Xie et al., 2011). PARAMICS was also integrated with CMEM in a study evaluating the impact of intelligent speed adaptation on energy and emissions (Servin et al., 2006). Various studies have also integrated the USEPA emission model MOVES with the traffic simulator VISSIM (Ghafghazi and Hatzopoulou, 2015). For instance, various scenarios of land configuration at intersections have been studied by integrating these two models to analyze potential designs that can mitigate traffic congestion and reduce emissions (Bing et al., 2014).

Signalized road intersections have been identified as pollution hotspots in urban environments, since commuter exposures to traffic-related air pollution such as NO_x and PM tend to be higher than average as vehicle acceleration, deceleration, and idling occur more frequently in such microenvironments (Goel and Kumar, 2014). The USEPA has recommended several air quality models for estimating near-road air quality, such as AERMOD, CALINE 4, and CAL3QHC. A comprehensive analysis was conducted to compare these three models, noting that CALINE 4 and CAL3QHC performed moderately well for an intersection in Sacramento, California, while AERMOD under-predicted $PM_{2.5}$ concentrations. Besides, for a busy road in London, CAL3QHC was observed to perform better than other models (Chen et al., 2008). Another study in India employed three air quality models including the 'modified General Finite Line Source Model' (M-GFLSM), CALINE3, and CAL3QHC to evaluate the PM concentrations at one of the busiest traffic intersections in the city of Guwahati. The authors found that the CAL3QHC model performed better than CALINE3 in predicting $PM_{2.5}$ and PM_{10} (Gokhale and Raokhande, 2008).

While the resources and capability to develop traffic simulation models for the purpose of modeling emissions are available in academic environments, planning agencies are often limited to the data collected by municipal traffic operation departments. These data often include video-camera recordings and data from traffic radars scattered at various sites across an urban area. As such, in practice, detailed traffic variables across a network are non-existent or difficult to gather therefore assumptions must be made (Sider et al., 2016).

The primary objective of this study is to explore the effects of data derived from (1) video-cameras, (2) radars, and from a (3) traffic simulation model on the resulting traffic emissions and near-road air quality across a busy road segment in Toronto, Canada. While radars can provide speed data for every vehicle (or ensemble of vehicles) passing through a specific location, traffic simulation models are able to simulate the entire vehicle kinematics along a road segment. Are these two approaches comparable in terms of the final emission estimates? What is the effect of speed aggregation on the resulting emissions and hotspot analysis?

This study was motivated by the need to identify the most important inputs for project-level analysis of traffic emissions and near-road air quality. Traffic microsimulation is rarely available as a tool for government agencies. As cities invest in infrastructure for traffic counting, our study investigates the effect of using traffic counts to derive estimates of emissions along a road segment using a coarse estimate for vehicle speed. This approach is compared with an emission estimate generated using a full analysis of individual vehicle drive-cycles derived from a calibrated traffic simulation model. Our study is significant because it quantifies the variability in emissions and concentrations obtained using various sources of traffic data and provides recommendations for project-level analysis and PM hotspot analysis.

2. Materials and methods

2.1. Study area and data collection sites

Our study consists in estimating traffic emissions for a single road segment on College Street, a four-lane major arterial roadway, with a daily traffic volume ranging from 15,000 to 20,000 (Sabaliauskas et al., 2012). It crosses downtown Toronto from the west to the east ends and goes through various land-uses (residential on both ends and commercial/institutional as it crosses downtown Toronto). Around our study site, College Street is bordered by University of Toronto buildings on the north side and commercial/restaurant establishments on the south side. Our chosen segment on College Street spans two major intersections: College and St George on the west and College and McCaul on the east. Four-story buildings are present on both sides of the road.