Environmental Research 147 (2016) 435–444

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

An examination of population exposure to traffic related air pollution: Comparing spatially and temporally resolved estimates against long-term average exposures at the home location

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ARTICLE INFO

Article history:
Received 21 September 2015
Received in revised form
18 January 2016
Accepted 29 February 2016

Keywords:
Traffic emissions
Air pollution
Exposure
Dynamic
Mobility
Nitrogen dioxide (NO_2)

ABSTRACT

Air pollution in metropolitan areas is mainly caused by traffic emissions. This study presents the development of a model chain consisting of a transportation model, an emissions model, and atmospheric dispersion model, applied to dynamically evaluate individuals' exposure to air pollution by intersecting daily trajectories of individuals and hourly spatial variations of air pollution across the study domain. This dynamic approach is implemented in Montreal, Canada to highlight the advantages of the method for exposure analysis. The results for nitrogen dioxide (NO_2), a marker of traffic related air pollution, reveal significant differences when relying on spatially and temporally resolved concentrations combined with individuals' daily trajectories compared to a long-term average NO_2 concentration at the home location. We observe that NO_2 exposures based on trips and activity locations visited throughout the day were often more elevated than daily NO_2 concentrations at the home location. The percentage of all individuals with a lower 24-hour daily average at home compared to their 24-hour mobility exposure is 89.6%, of which 31% of individuals increase their exposure by more than 10% by leaving the home. On average, individuals increased their exposure by 23-44% while commuting and conducting activities out of home (compared to the daily concentration at home), regardless of air quality at their home location. We conclude that our proposed dynamic modelling approach significantly improves the results of traditional methods that rely on a long-term average concentration at the home location and we shed light on the importance of using individual daily trajectories to understand exposure.

1. Introduction

Exposure to traffic-related air pollution has been associated with various acute and chronic health effects (Parent et al., 2013; Crouse et al., 2012; Gan et al., 2012). In particular, a number of studies have established positive associations between various health outcomes (e.g. cancers, hearth attacks, asthma) and exposure to nitrogen dioxide (NO_2), an accepted marker of traffic-related air pollution (Shekarrizfard et al., 2015a; Hamra et al., 2015; Lee et al., 2014; Snowden et al., 2014; Parent et al., 2013; Crouse et al., 2010). In view of the computational burden and uncertainty associated with the development of high-resolution urban air quality models, most of the assessments of the health effects of nitrogen dioxide (NO_2) have relied on measurements rather than modelling. Certainly, measurements alone cannot be sufficient for exposure analysis in an urban environment (Costabile and Allegrini, 2008). Many studies have used interpolation techniques to allocate exposures to subjects living in selected study areas (Götschi et al., 2008). One of the limitations of these studies is the misclassification of spatial variations in NO_2 within urban areas (Lee et al., 2014). Recently, several studies characterized nitrogen oxides (NO_x) and NO_2 concentrations using land use regression models (Crouse et al., 2010; Lee et al., 2014; Parent et al., 2013). A limited number of studies have employed atmospheric dispersion to estimate NO_2 concentrations (Shekarrizfard, Hatzopoulou (2015b); Int Panis et al., 2011; Hatzopoulou and Miller, 2010; Beckx et al., 2009a; Arain et al., 2007). Despite advances in the characterization of NO_x and NO_2 concentrations, a major limitation of current exposure analysis techniques are that they rely on estimates of average concentrations and disregard daily mobility patterns, only relying on average concentrations at the home location (Chen et al., 2008).

Recently, a number of interdisciplinary research initiatives have developed modelling frameworks that account for vehicle emissions whereby activity-based models were used to calculate person- and trip-level emissions for varieties of pollutants such as

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http://dx.doi.org/10.1016/j.envres.2016.02.039
0013-9351/

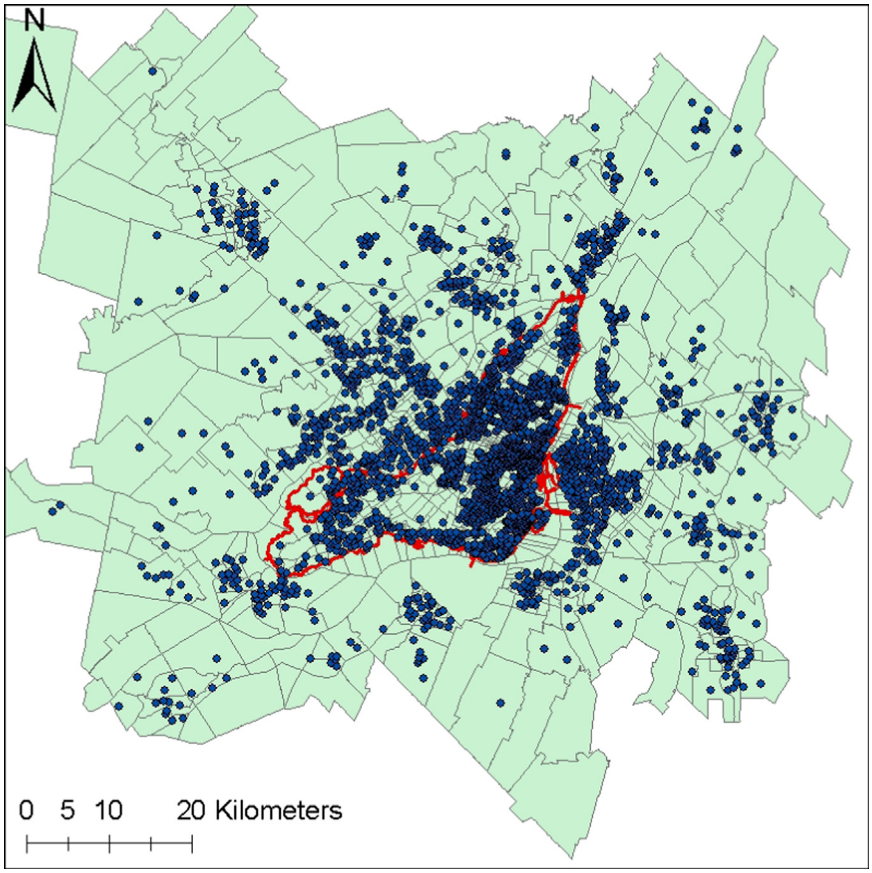

Fig. 1. Montreal region featuring the island of Montreal (red boundary) and home locations of individuals in the 2008 origin-destination survey.

PM_{10} (McCreddin et al., 2015) and PM, NO_x and CO_2 (Int Panis et al., 2011). However, limited studies have integrated the dispersion of transport-related emissions. In addition, most analyses of exposure took into account variations of the emission source, but assumed fixed receptor conditions (Bae et al., 2007). Based on this approach, individuals are considered to remain at home and, therefore, only exposed to pollutants at their home address. The attempts at dynamic exposure assessments are rare and often focus on long time scales (De Ridder et al., 2008). An activity-based approach takes into account individual mobility during the day and therefore inherently recognizes the fact that individuals are exposed to pollutants at different locations and different times of day (Beckx et al., 2009b). By combining detailed hourly NO_2 concentration maps with activity locations at the individual level, a dynamic exposure procedure can be established. Dhondt et al. (2012) found that the health impact of NO_2 using an exposure that integrates time-activity information was on average 1.2% higher than when assuming that people are always at their home address. In another study, Beckx et al. (2009a) developed a dynamic activity-based population model to estimate exposure to $PM_{2.5}$ in a Dutch urban area. The authors reported a difference of more than 20% (between the static and dynamic approaches) in the hours spent exposed to $PM_{2.5}$ concentrations above 20 $\mu g/m^3$. This is especially important considering that previous findings (e.g., Nyhan et al., 2014a, b) indicated exercise whilst commuting has an influence on inhaled PM and PM lung deposited dose, and these were significantly associated with acute effects on heart rate variability, especially in pedestrians and cyclists.

In this study, we developed a population exposure modelling approach taking into account population mobility. For this purpose, we used simulated road traffic volume and composition in order to derive spatially and temporally resolved emissions which were then used as input to an atmospheric dispersion model. This is an integrated modelling system for the analysis of vehicle movements, emission and dispersion of air pollutants, and population exposure. Using this model we were able to compare the daily exposure calculated based on mobility information using spatially and temporally resolved NO_2 maps (dynamic) against daily exposure obtained using the daily average NO_2 concentrations at the home location (static). We also estimated exposures during travel to identify the contribution of travelling/commuting to daily exposure. The aim of this study is to understand how individuals' mode choices, trajectories, and activity locations affect their exposure to traffic related air pollution. In addition, our individual-level analysis allowed us to identify individuals who reduce and those who increase their exposure during their daily trajectories and activities compared to the air quality at their home location. This study bridges the gap between individual and population level exposure studies. The fact that individual exposure studies attempt to track individual trajectories for exposure analysis makes the results more relevant to epidemiologic studies of air pollution compared to population exposure analysis. This is because of the improvement in the estimation of exposure itself which is subsequently used for the investigation of associations with specific health effects.

2. Materials and methods

Our methodology consists of four main steps: 1) set up an integrated transportation and emissions model linked with a dispersion model and generate daily average and hourly NO_2 exposure surfaces 2) assign daily trajectories to drivers, passengers,