Atmospheric Environment 94 (2014) 782–792

Contents lists available at ScienceDirect

Atmospheric Environment

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

Using mobile monitoring to visualise diurnal variation of traffic pollutants across two near-highway neighbourhoods

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HIGHLIGHTS

- 47 h of high-resolution mobile sampling was conducted.
- Gradients of UFPs and CO were observed downwind of the highways.
- Concentrations of UFPs and CO were often higher at arterial roads than at highways.
- Some spatial homogeneity was apparent for PM_{10} and CO.
- 3D concentration plots can illustrate diurnal changes in spatial variation.

ARTICLE INFO

Article history:
Received 9 February 2014
Received in revised form
30 May 2014
Accepted 3 June 2014
Available online 4 June 2014

Keywords:
Mobile monitoring
Spatial variation
Near roadway
Highway community

ABSTRACT

It is widely accepted that concentrations of primary traffic pollutants can vary substantially across relatively small urban areas. Fixed-site monitors have been shown to be largely inadequate for representing concentrations at nearby locations, resulting in the increasing use of spatial modelling or mobile sampling methods to achieve spatial saturation. In this study, we employ the use of a simple bicycle to sample concentrations of ultrafine particles (UFPs), carbon monoxide (CO) and particulate matter (PM_{10}) at two small areas (<2.5 km^2) in South Auckland, New Zealand. Portable instruments were mounted inside a custom-built casing at the front of the bicycle and every street within each study area was sampled in a grid-like fashion, at four times of day (07:00, 12:00, 17:00 and 22:00). Each area has a six-lane highway running through its centre and the core aim was to visualise and describe spatial variability of pollutant levels about the highway, main arterials and quieter streets, at periods of contrasting meteorological and traffic conditions. A total of 20 sampling runs in each area (five at each of the four timings) were conducted. Meteorological data were logged continuously at background sites within each study area. Results show that the influence of highway traffic (UFPs, CO) was strongest during the mornings and late evenings when wind speeds were low, while for the midday and afternoon timings, concentrations were highest at the arterial and shopping zones. Concentrations of PM_{10} appeared to be strongest in the residential areas during mornings and late evenings, suggesting an influence of wood burning for home heating. For all timings combined, for all three pollutants, it appears the arterial roads featuring shops and numerous intersections with traffic lights, had a stronger influence on concentrations than the busier but more free-flowing highways. This study provides not only an insight into microspatial hotspot variation across suburbs, but also how this variation shifts diurnally.

1. Introduction

Traditionally, results from single or a few fixed monitoring stations have been used to inform research and policy on urban emissions management across wide areas. Concerns regarding representativeness have led to a range of monitoring strategies and spatial modelling techniques being developed to advance understandings of spatial variability. While concentrations of coarse particulate matter (PM) can be spatially uniform across several kilometres, pollutants with a short atmospheric residency often decay substantially across the space of just a few metres. For example, a study in metropolitan Los Angeles reported strong uniformity between sites over 5 km apart, due to similar source

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http://dx.doi.org/10.1016/j.atmosenv.2014.06.007
1352-2310/

type and intensity (Pakbin et al., 2010). Other studies have reported strong spatial correlations yet diverging absolute concentrations, highlighting the influence of common meteorology but differing emissions sources and source strengths (Chow et al., 2002; Qadir et al., 2014; Wilson et al., 2006). Conversely, UFPs and gases such as CO tend to have relatively low background concentrations, are highly dependent on an immediate source and have a spatial extent limited to 100–400 m (Zhou and Levy, 2007). Sampling campaigns assessing pedestrian and cyclist exposure have reported substantial reductions (22–30%) in concentrations of UFPs and CO when moving several metres away from emissions sources (Berghmans et al., 2009; Kaur et al., 2005; Pattinson, 2009).

To provide the greatest contrast in concentrations, traffic emission monitoring studies generally target heavily-trafficked roadways, with some stretching across multiple road types and land uses. Much of the work on highway areas has focused primarily on the decay in concentrations away from the main road, involving a series of fixed stations or shifting mobile stations situated at various distances from the traffic source (Baldauf et al., 2008; Clements et al., 2009; Hagler et al., 2009; Kimbrough et al., 2013). For major highways (Annual Average Daily Traffic, AADT > 100,000), long-term average concentrations of UFPs, nitrogen oxides (NO_x) and black carbon (BC) tend to be at least 50% higher within the first 50–100 m than sites further from the highway (Kimbrough et al., 2013; Padró-Martínez et al., 2012). This results in significantly elevated long-term exposures for residents living within this zone of influence. In addition, these residents are exposed to particle sizes and compositions that others generally only encounter for very short periods. Due to processes involving condensation, evaporation and gas-phase nucleation, the bulk of freshly emitted particles are extremely small (<10 nm) within the first 30 m then grow (30–90 m) and shrink (>100 m) further on (Zhang et al., 2004). Ultrafine particles are of increasing importance in epidemiological studies due to their ability to penetrate deep into the lungs and affect the cardiovascular system by means of systemic inflammation and oxidative stress (Araujo, 2011; Langrish et al., 2012).

The long-term, combined impact of exposure to the mixture of toxic fumes emitted from vehicle exhausts poses significant health risks to local populations, especially to those who are most vulnerable. While the implications for healthy adults are more limited, studies have reported an association between poor urban air and diabetes prevalence, exacerbation of asthma in young children and more rapid cognitive decline in the elderly (Evans et al., 2014; Pearson et al., 2010; Weuve et al., 2012). Subsequently, the composition of populations residing close to roadways is of key consideration in epidemiological research and is an important aspect of urban planning. Where possible, the placement of sensitive groups of individuals in the form of early childhood centres, schools, retirement homes and social housing projects next to high-emission zones should be avoided. Some researchers are now advocating for a complete separation of at least 100 m between all residential buildings and major roads (Barros et al., 2013). Considering this is impractical in most existing developed areas, there is a need to at least have representative regulatory monitoring in place and ideally, to attempt to understand the full spatial extent of impact under local conditions. A nationwide study of the USA found that 18 million people, or 32% of those living near high-volume roads, had no representative regulatory monitoring in their immediate area (Rowangould, 2013). As roadside communities often consist of low-income and minority populations, there could be a similar lack of monitoring in countries like Australia and New Zealand where cities tend to be built around dominating road networks, promoting unnecessary urban sprawl and potential issues of environmental injustice. Concern regarding the impact of busy roadways on communities has resulted in recent publications stressing the need for monitoring to be expanded right across communities to achieve full spatial saturation (Bassok et al., 2010; Buonocore et al., 2009; Padró-Martínez et al., 2012). With the exception of low-cost passive samplers with low temporal resolution, deploying a dense network of fixed samplers is complex and expensive. Instead, mobile monitoring methods are becoming increasingly popular due to the relative low-cost and ability to capture data at high spatial resolutions.

Mobile monitoring techniques have predominantly been employed in studies comparing differing levels of exposure depending on the mode of transport used and/or the transport routes chosen. These studies began with CO, ozone (O_3), nitrogen dioxide (NO_2) and volatile organic compound (VOC) sampling on bicycles and in cars in the early 1990s, followed by $PM_{2.5\text{-}10}$ in the late 1990s and then UFPs, $PM_{1.0}$, BC and polycyclic aromatic hydrocarbons (PAHs) in the early 2000s, as the development of portable instrumentation permitted. Since then, numerous works have assessed intra-urban variation in concentrations across small areas utilising a customised vehicle or bicycle, and pedestrian sampling has been used at the microspatial scale. Several pedestrian-based studies have focused their efforts around residential zones with schools, publishing concentration maps of the area (Adams et al., 2009; Buonocore et al., 2009; Levy et al., 2001). Although the timings (restricted to morning sampling) and spatial extent (<1.5 km^2) has been somewhat limited for these studies, two stand out for recruiting local school pupils to sample comprehensive routes over a one-month period, resulting in concentration plots covering the majority of streets in the study area (Buonocore et al., 2009; Levy et al., 2001). Despite having a relatively low sampling resolution of 1-min averages, both of these studies reported significant spatial and temporal variation and moderate-strong gradients away from roads with high traffic volume or a high proportion of heavy vehicles.

Due to the physical ease of sampling and the ability to carry more scientifically robust instrumentation, the bulk of mobile monitoring campaigns have used mobile labs inside vehicles. To eliminate the influence of self-pollution, a few have chosen to use electric vehicles (Hagler et al., 2010; Hu et al., 2012; Kozawa et al., 2009, 2012). As with fixed-site highway monitoring, mobile campaigns also typically focus on the highway or adjacent areas at peak, morning periods, when concentrations are highest. Some only map one road or monitor over a haphazard route, missing the variation across large parts of the study area. Only one has been identified where complete spatial saturation of the neighbourhood street network has been achieved. Bassok et al. (2010) measured BC over an approximate 800 m^2 highway corridor area of the International District of Seattle, WA, during 10 afternoon runs at a resolution of 5 s. Low-income, minority populations account for 80% of the residents and the area has disproportionately high rates (compared to the rest of Seattle) of respiratory issues. The study highlighted the importance of microscale monitoring in identifying impacts from arterial routes, potential mitigation through heavy traffic management and prohibiting new residential developments within 100 m of major roads.

Our study builds on the methodology employed by Bassok et al. (2010) by expanding it across two contrasting study areas, sampled at four times of day. Hu et al. (2009) have noted major diurnal variation in the spatial impact of freeway emissions and this is a very important air quality characteristic ignored by most mobile sampling regimes. Environmental setting is the key determinant of daily personal pollution exposure and for the near-highway resident, it is worth knowing the daily pattern of influence at the home location and throughout the local area.