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An instantaneous spatiotemporal model to predict a bicyclist's Black Carbon exposure based on mobile noise measurements

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HIGHLIGHTS

- We performed combined Black Carbon and traffic noise measurements by bicycle.
- After correcting for the Black Carbon background concentrations a successful model is build.
- Personal noise measurements can be used as a proxy for Black Carbon exposure for bicyclists.

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ABSTRACT

Several studies have shown that a significant amount of daily air pollution exposure, in particular Black Carbon (BC), is inhaled during trips. Assessing this contribution to exposure remains difficult because on the one hand local air pollution maps lack spatio-temporal resolution, at the other hand direct measurement of particulate matter concentration remains expensive. This paper proposes to use in-traffic noise measurements in combination with geographical and meteorological information for predicting BC exposure during commuting trips. Mobile noise measurements are cheaper and easier to perform than mobile air pollution measurements and can easily be used in participatory sensing campaigns.

The uniqueness of the proposed model lies in the choice of noise indicators that goes beyond the traditional overall A-weighted noise level used in previous work. Noise and BC exposures are both related to the traffic intensity but also to traffic speed and traffic dynamics. Inspired by theoretical knowledge on the emission of noise and BC, the low frequency engine related noise and the difference between high frequency and low frequency noise that indicates the traffic speed, are introduced in the model. In addition, it is shown that splitting BC in a local and a background component significantly improves the model. The coefficients of the proposed model are extracted from 200 commuter bicycle trips. The predicted average exposure over a single trip correlates with measurements with a Pearson coefficient of 0.78 using only four parameters: the low frequency noise level, wind speed, the difference between high and low frequency noise and a street canyon index expressing local air pollution dispersion properties.

1. Introduction

Exposure to particulate matter is currently regulated in PM standards, that only distinguish between the size of the particles (PM10, PM2.5, ...). The soot fraction, Black Carbon (BC) is the part of the PM directly related to combustion processes. Recent evidence, summarized by the world health organization, documents the relevance of BC for evaluating traffic related health effects (WHO Europe, 2012). The first epidemiological results suggest health effects that are up to 10 times higher than a similar evaluation based on PM10 (Janssen et al., 2011). Further research into health effects is hampered by the difficulty to measure or model BC concentrations. An important reason for this is the strong spatial variability of BC compared to PM10 (Karner et al., 2010). Building a monitoring network for BC would be a daunting task because of the large spatio-temporal gradients. In addition, efforts are now made to standardize BC measurements as a first step to including BC in the set of official air pollution standards. For these reasons, this paper

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takes a closer look at an innovative way to predict a bicyclist's Black Carbon exposure.

Large personal exposure measurement campaigns prove the relevance of the in-traffic exposure contribution (Dons et al., 2011, 2012). Technology for mobile air pollution measurements is however scarce and expensive. On the one hand, cheap implementations do not meet quality requirements, on the other hand high quality equipment is often highly demanding on the operator (e.g. changing filters or liquids, limited portability). In contrast, mobile noise measurements can be done with low intrusive measurement equipment like dosimeters and new mobile technologies. Mobile noise measurements are a popular theme in noise exposure modeling (Eisenman et al., 2009; Kanjo, 2010; Maisonneuve et al., 2009). Noise levels are strongly correlated with traffic related air pollution levels and might be a good proxy to model personal air pollution exposure (Dekoninck et al., 2012; Can et al., 2010, 2011; Eisenman et al., 2009). Since in-traffic personal air pollution exposure is a major component of the total personal diurnal exposure and diurnal activity patterns are very diverse within the population, epidemiology would benefit from including exposure differences due to different activity patterns when investigating the health effects of air pollution (von Klot et al., 2011; Dons et al., 2012). The use of a proxy which is easy to monitor could result in improved personal exposure estimates on larger population samples at a reasonable cost.

Numerous efforts have been made to quantify the exposure and health effects of cycling in dense traffic since the current trends in sustainable mobility focus on establishing modal shifts towards biking and walking (de Nazelle et al., 2011; Int Panis et al., 2010; Berghmans et al., 2009; de Hartog et al., 2010). Exposure of cyclists is directly influenced by the distance to the local traffic, strongly related to local traffic conditions (congestion, traffic lights etc.) and highly influenced by meteorological conditions. Since cyclists often travel along low-traffic-density roads, there is in general no traffic data available from either counting loops or traffic models. The most important exposure parameter is therefore unknown in most studies. Local traffic on low density roads is also highly variable in both space and time. A suitable traffic description should reflect these short-term effects with an adequate spatial and temporal resolution. Mobile noise exposure therefore has the potential to become this key indicator to predict the local component of traffic related air pollution exposure.

Based on theoretical aspects of traffic dynamics, the relationship between noise and particulate matter emission and the potential to extract one from the other have been discussed earlier (Dekoninck et al., 2012). The focus there was on the selection of noise descriptors correlating best with vehicular particulate matter emissions for typical traffic dynamics. However, noise exposure close to the source is not strongly influenced by the meteorological conditions while air pollution is strongly affected by the meteorological conditions. This is one of the reasons why the average of repeated noise exposure measurements will converge faster compared to repeated air pollution exposure measurements. So, if mobile noise measurements are proven to be a valid proxy for air pollution exposure, fewer measurements will be needed to predict the personal exposure at a higher spatial and temporal resolution.

To establish an instantaneous relationship between noise exposure and air pollution exposure meteorological conditions have to be taken into account. A major concern is the influence of long term meteorology and long distance air pollution transport on the background concentrations influencing the actual personal exposure. In this paper two major research questions are addressed: (1) is a prediction model for BC exposure improved by separating out long term variations in the background concentration; (2) can the instantaneous local Black Carbon exposure be predicted based on instantaneous local noise exposure and meteorological conditions. For the latter, the question how to derive the local traffic dynamics that influence the instantaneous Black Carbon exposure from noise measurements is addressed. Section 2 will address the methodology including the definition of the models and the noise exposure parameters. Section 3 gives the results of the models and the model validations. Results are discussed in Section 4.

2. Methodology

2.1. Measurement equipment and setup

The experimental setup contains a basic GPS (in an HTC Desire smart phone), a Type 1 Noise Level Meter (Svantek 959) and a micro-aethalometer (Model AE51 MageeScientific, 2009) to measure Black Carbon. The measurements were performed while commuting by bicycle from the villages to the west of Ghent (Belgium) into the city center, thus covering the sparsely build areas in the villages, the city center, open recreational areas and natural reserves in between. A total of 209 biking trips were performed, covering a distance of 2300 km, a total measurement time of 128 h at an average speed of 18 km per hour. More than 75 km of distinct roads were sampled at least 3 times. Almost all measurements were made between 7:30 h–9:30 h and 16:30 h–18:30 h. Some of the longer trips, for example when sampling in the vicinity of the highway, were partially made outside these time windows.

The details of the measurement setup, temporal resolution, preprocessing, meteorological data and the spatial mapping on aggregation points p_{x} along the network with a spatial resolution of 50 m are available in the Supplementary data. In the instantaneous model only one spatial attribute, the street canyon index StCan_{p_x} at aggregation point p_{x} is included, identifying 'street canyon likeliness' of the built-up area along the trip trajectories. More detail on the calculation of StCan_{p_x} is available in the Supplementary data.

2.2. Black Carbon, background and local contribution

The BC exposure during a cycling trip consists of a contribution of local sources and a background contribution. The latter varies only little over a large area and can thus easily be obtained from a well-located fixed measurement station. The background contribution strongly depends on long-term meteorological conditions. The proposed model assumes that the dominant source of BC in the vicinity of the cyclist is the local traffic on the traveled road. An additive approach is used; the BC exposure is viewed as the sum of the background level $BC_{j,\mathrm{bg}}$ during trip j and the "local" contribution $\mathrm{BC}_{\mathrm{loc}}$. Similar procedures are used in exposure estimations where regional and local scale models are added to estimate personal exposure (Isakov et al., 2009). The available background measurements are averaged concentrations over half an hour (see Supplementary data). Subtracting a fixed measurement with a temporal resolution of a half hour from mobile BC measurements sampled at 1 s time interval is not trivial. When sampling air pollution at a shorter time interval, concentrations below the "background" concentrations can be measured at some of the low traffic locations. Adjusting for the background concentration could then result in negative local concentrations. The proposed models will use a logarithm of BC as an outcome variable because noise is also measured on a logarithmic scale and hence negative values cannot be allowed. For this reason the background concentration is not removed completely but replaced by a typical but constant low background concentration. The choice of this constant is not very critical since it will be added again to the model outcome and constants do not affect the model. This approach enables the dataset to retain spatial variation also for low density roads.