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Applicability of a noise-based model to estimate in-traffic exposure to black carbon and particle number concentrations in different cultures

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ABSTRACT

Several studies show that a significant portion of daily air pollution exposure, in particular black carbon (BC), occurs during transport. In a previous work, a model for the in-traffic exposure of bicyclists to BC was proposed based on spectral evaluation of mobile noise measurements and validated with BC measurements in Ghent, Belgium. In this paper, applicability of this model in a different cultural context with a totally different traffic and mobility situation is presented. In addition, a similar modeling approach is tested for particle number (PN) concentration.

Indirectly assessing BC and PN exposure through a model based on noise measurements is advantageous because of the availability of very affordable noise monitoring devices. Our previous work showed that a model including specific spectral components of the noise that relate to engine and rolling emission and basic meteorological data, could be quite accurate. Moreover, including a background concentration adjustment improved the model considerably. To explore whether this model could also be used in a different context, with or without tuning of the model parameters, a study was conducted in Bangalore, India. Noise measurement equipment, data storage, data processing, continent, country, measurement operators, vehicle fleet, driving behavior, biking facilities, background concentration, and meteorology are all very different from the first measurement campaign in Belgium. More than 24 h of combined in-traffic noise, BC, and PN measurements were collected. It was shown that the noise-based BC exposure model gives good predictions in Bangalore and that the same approach is also successful for PN. Cross validation of the model parameters was used to compare factors that impact exposure across study sites. A pooled model (combining the measurements of the two locations) results in a correlation of 0.84 when fitting the total trip exposure in Bangalore. Estimating particulate matter exposure with traffic noise measurements was thus shown to be a valid approach across countries and cultures.

1. Introduction

Particulate matter (PM) is currently regulated in Europe, the US, India and other countries based on specific particle size fractions (e.g., PM_{10}, $PM_{2.5}$). Black carbon (BC) and particle number (pN) concentrations are associated with transportation emissions but are typically unregulated. The World Health Organization suggests including BC when evaluating traffic-related health effects (WHO Europe, 2012). Recent epidemiological results for BC suggest that health effects per mass may be up to 10 times higher than PM_{10} (Janssen et al., 2011). Research into the health effects of traffic-related particulates is constrained by the stronger spatial variability for BC and PN concentrations relative to PM_{10} and $PM_{2.5}$. Detailed measurements for near-road settings have shown large spatial gradients for certain aspects of particulate air pollution. For example, ultrafine particles and BC show decreases of over 50% within the first 150 m from the edge of the road (Karner et al., 2010) and significant street-to-street differences in PN and BC have been reported by several authors (Boogaard et al., 2011; Dons et al., 2012, 2013). Building a fixed-site monitoring network for PN and BC to provide robust estimates of exposure patterns, would therefore be a daunting task.

In a previous work a novel way to predict a bicyclist's in-traffic BC exposure was presented based on mobile measurements of traffic-related noise and BC in Ghent (Belgium) (Dekoninck et al., 2013). The noise-based model yields spatially and temporally precise estimates of

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BC based on traffic noise measurements. The additive model successfully split the BC exposure of a bicyclist into a background component and a local, traffic-related component. The local component included the wind speed, a street canyon index and a noise-based characterization of instantaneous traffic volume and dynamics; specifically, an engine throttle noise component and a rolling noise component.

Here we extend our prior work by exploring the same category of modeling (correlating real-time measurement of noise with real-time pollution measurements) in Bangalore, India. Relevant environmental differences between Bangalore and Ghent include vehicle fleet and fuel use, driving patterns, speeds, densities, and behavior; levels of ambient and traffic-related noise and pollution, meteorological conditions, and limited biking facilities. Three important differences between the current investigation (Bangalore) and the prior investigation (Ghent) are: (1) a different location, with very different traffic conditions relative to the prior study, (2) measurement procedures were automated to allow use by bicyclists unfamiliar with the equipment, and (3) we study two pollutants (PN and BC) rather than only BC.

2. Methodology

2.1. Measurement equipment and setup

The original experimental setup for the measurement campaign in Ghent (Dekoninck et al., 2013) was based on a manually operated smartphone GPS, a Type 1 Noise Level Meter (Svantek 959) and a micro-aethalometer. The data was processed and merged manually. These labor intensive procedures needed to be automated to enable large scale, low support measurement campaigns. A low-cost noise measurement setup designed by the acoustics group at the Ghent University was modified to enable automated mobile measurements at a much lower hardware cost (Can et al., 2011a,b; Dauwe et al., 2012; Van Renterghem et al., 2011). The noise measurement module is extended with a GPS (Haicom HI-204 III USB), a micro-aethalometer (AE51, Aethlabs, San Francisco, CA) and a battery for off-grid operation (Fig. 1). Software was developed to automatically capture the 1-second data stream from the micro-aethalometer. The mobile node is designed to be mounted on the handlebar of a bicycle. In addition, a condensation particle counter (CPC 3007, TSI Inc., Shoreview, MN) was carried in a backpack by the bicyclist to measure PN. After each sampling run the mobile node was connected to the internet and the data was uploaded to a database on the server at the University of Ghent. An automated process synchronizes and merges the noise, GPS and BC data based on the timestamp of the mobile node. The CPC data was joined with the other data in a separate post-processing sequence.

2.2. Measurement location, strategy and processing

Measurements were carried out north of the city center of Bangalore, India, (elevation: 920 m; metropolitan population: ~10

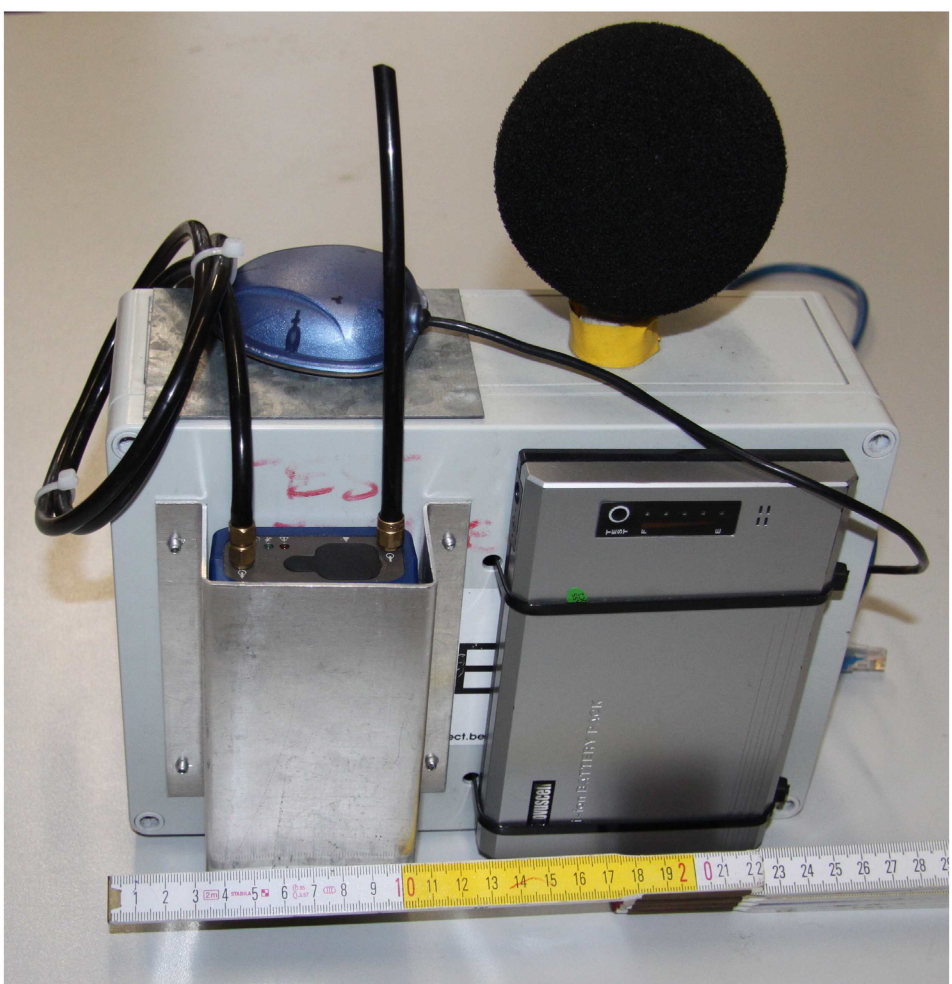

Fig. 1. Inexpensive mobile noise measurement equipment including the micro-aethalometer and GPS. The box containing all instruments is 23 cm by 9 cm wide and 17 cm high.