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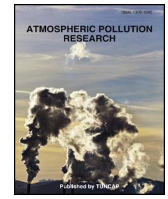

Low-cost methodology to estimate vehicle emission factors

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ABSTRACT

Road traffic emission factors (EFs) are important parameters in managing air quality. Estimation typically requires data from advanced (and expensive) monitoring systems which remain unavailable in some regions (e.g. in developing countries). In this context, the use of simpler (lower-cost) systems may be more appropriate, but it is essential to guarantee the robustness of EF estimations. This article describes a methodology designed to estimate vehicle EFs from street canyon measurements of traffic fluxes, wind speed and direction, and pollutant concentration levels by using low-cost devices, all samples at a one-minute interval. We use different moving window filters (time periods) to average the raw measurements. Applying standard multiple linear regressions (MRL) and principal component regressions (PCR), we show that there is an optimal smoothing level that best relates traffic episodes and pollutant concentration measurements. An application for PM_{10}'s EFs on four vehicle categories of Havana's fleet shows a preference for PCR over MLR techniques since it reduced the collinearity effects that appear when traffic fluxes are naturally correlated between vehicle categories. The best regression fits (R > 0.5 and standard deviation of estimates < 15%) were obtained by averaging data between 40′ and 60'; within the boundaries of 95% confidence interval motorcycles have an EF = 111.1 ± 2.7 mg km^{-1} veh^{-1}; modern, light vehicles have an EF = 90.6 ± 11.2 mg km^{-1} veh^{-1}; old, light vehicles have an EF = 125.4 ± 18.5 mg km^{-1} veh^{-1} and heavy vehicles have an EF = 415.1 ± 31.2 mg km^{-1} veh^{-1}. We showed that upgrading old light vehicles is a promising scenario for reducing PM_{10} air pollution in Havana by between 10 and 17%.

1. Introduction

Vehicle traffic is an important contributor to air pollution in many urban areas (Huang et al., 2016; Wang et al., 2017). Sound policy decisions on the control and management of traffic-related pollution depend on a reliable emission inventory and the emission characteristics of the vehicle fleet (Smit et al., 2017). Among others, one important parameter to be evaluated is the emission factor (EF) (Zarate et al., 2007); it characterizes the amount of pollutant emitted per mass of fuel consumed (fuel-based), per distance driven (task-based) or per energy used (task-based) (Brimblecombe et al., 2015). The EF can differ from one country to another depending on vehicle maintenance, driving patterns and fuel brands. More specifically, in developing countries, traffic flow is heterogeneous in nature (Jaikumar et al., 2017), and in most cases, exhaust emission standards fail to represent the real-world emissions from vehicles in these regions.

Different methods have been developed to estimate vehicle EFs. They typically require data from advanced monitoring systems (cf. Amato et al., 2016; Borrego et al., 2016; Ferm and Sjöberg, 2015; Keuken et al., 2016; Pang et al., 2014); chassis dynamometer tests (Jung et al., 2017; Li et al., 2013; Nakashima and Kajii, 2017; Pang et al., 2014) and on-road methods (Ait-Helal et al., 2015; Kam et al., 2012) are useful for providing accurate information about individual vehicle contributions. Both are often costly and time-consuming, and the number of testable vehicles (i.e., sample size) is limited. Approaches using measurements from road tunnels (Brimblecombe et al., 2015; Riccio et al., 2016; Zhang et al., 2015) and street canyons (Belalcazar et al., 2010; Klose et al., 2009; Vardoulakis et al., 2003) consider the contribution of the fleet in "real-world" driving conditions. Their basic principles are based on a statistical analysis of traffic and concentration episodes under specific pollutant dispersion rates.

In road tunnel studies, airflow conditions are well defined (i.e., by active mechanical ventilation systems or piston effects). Instead, problems might arise from the long pollutant residence time since receptor devices capture both the concentrations generated by passing vehicles and those retained, which could result in an overestimation of emission rates (Gertler et al., 1991). Additionally, if the instruments become saturated, they may not effectively capture the concentration peaks,

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and consequently, the EF results are underestimated (Brimblecombe et al., 2015). In street canyon studies, even if natural ventilation is reduced by the presence of buildings, the rate at which the street exchanges air with the atmosphere is greater, and the pollutant residence time is shorter compared to road tunnel studies, especially for the larger-sized particles that are greatly affected by gravity. In addition, wind flows are primarily controlled by micro-meteorological effects of urban geometry and dispersion phenomena, such as the mechanical turbulence induced by moving vehicles, and the atmospheric stability conditions are widely studied (e.g., Berkowicz and Danmark, 1997; Huang et al., 2016; Kakosimos et al., 2010; Kastner-Klein et al., 2003; Ketzel et al., 2000; Moradpour et al., 2017; Sokhi et al., 2008).

In this work, we use basic assumptions previously documented in other street canyon studies to estimate EFs. Testing different moving window filters (time periods) to average the raw measurements, we show the optimal smoothing levels that best relate traffic episodes and pollutant concentration measurements. To do that, we collected traffic counts and average concentration measurements for one-minute time steps. The pollutant dispersion is also quantified in one-minute steps by modelling changes (low-cost estimation) on meteorological and traffic constraints.

In section 2, we start with a brief description of the measurement campaign: data collection and processing. In section 3, we explain the methodology, detailing the most important assumptions for estimating EFs. The results of a case study are presented in section 4 (EFs of particulate matter -PM_{10}-for Havana's vehicle fleet); then, we assess the performances of the methodology used for different averaging times. Finally, in section 5, we discuss the effect of changing PM_{10} EF values under several abatement scenarios.

2. Sampling location and data

For this study, we examine data obtained over a 10-day measurement campaign in Havana in summer 2015. Data collection occurred in an urban canyon (see Fig. 1: Simon Bolivar Street with west-east direction). Data include traffic volume, wind speed and direction, and PM_{10} concentration levels.

Traffic was recorded on videotapes and then manually counted at a temporal resolution of 1′. The fleet of vehicles was classified into four clearly identifiable categories, i.e., motorcycles; modern light-duty cars (post-1980s); old light-duty cars (pre-1980s and of Russian or American origin); and heavy vehicles, including buses and trucks. No visual differentiation could be made in terms of technology or fuel system injection since many cars have been modernized with new parts (e.g., engines and disk brakes).

Wind speed and direction data were automatically registered from an IRDAM – WST7000C anemometer placed on the roof of the highest building (at a height of 13.6 m) within a 1-km radius; any other accurate meteorological station could be used. PM_{10} concentrations were recorded using a Thermo-Scientific ADR 1500 profiler (a low-cost device based on a highly sensitive light-scattering photometer technique) installed at a height of 1.5 metres on the southern side of the street canyon.

3. Methods

3.1. Basic assumptions

Due to the short distances between sources and receptors inside street canyons, only very fast chemical reactions significantly influence the measured concentrations (Berkowicz and Danmark, 1997). This enables us to ignore the chemical transformations of slowly reacting gases. Therefore, a linear relationship between released emissions and measured concentrations is valid (Palmgren et al., 1999), leading to the following equation:

$$C^t = D^t E^t + C_0^t \quad (1)$$

where C^t(g m^{-3}) and E^t(g m^{-1} s^{-1}) are the concentration and the traffic-related emissions at a time "t", respectively. The linearity between C^t and E^t is defined by two parameters: C_0^t(g m^{-3}), which corresponds to the concentration level at the receptor location when emissions are from sources other than street traffic ($E^t = 0$), and D^t(s m^{-2}), which is a dilution factor that quantifies the dispersion resulting from turbulence induced either by atmosphere flows or vehicle

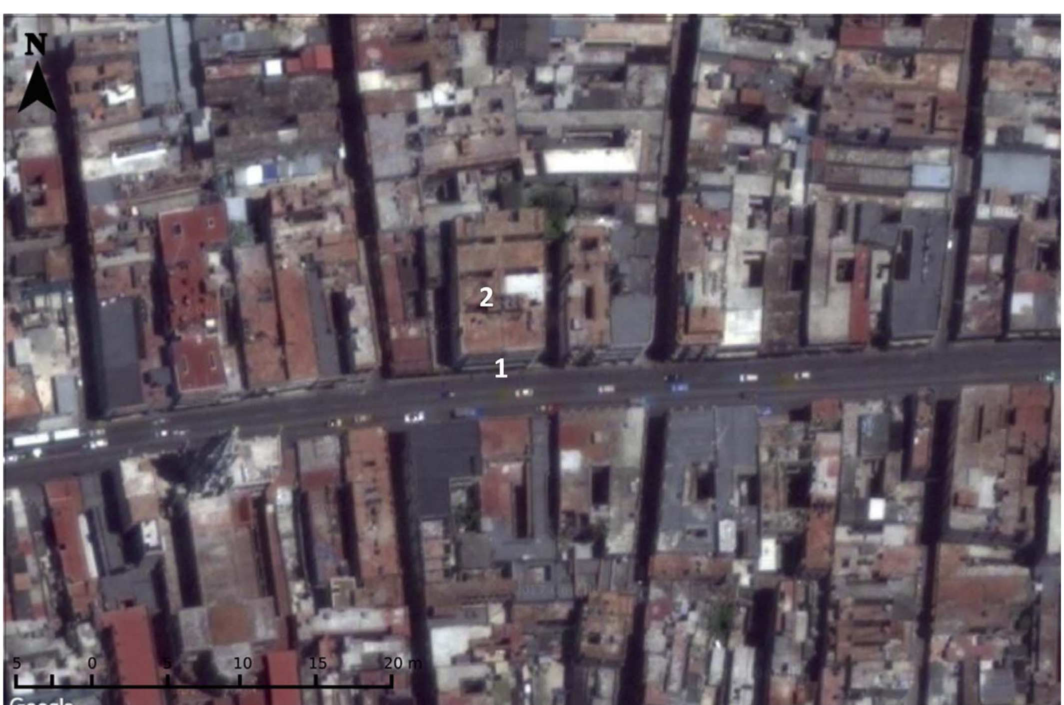

Fig. 1. Data collection site (Simon Bolivar Street). 1: Thermo-Scientific ADR 1500 profiler and traffic video recording. 2: AIRDAM anemometer. Adapted from Google Earth.