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Microscale traffic simulation and emission estimation in a heavily trafficked roundabout in Madrid (Spain)

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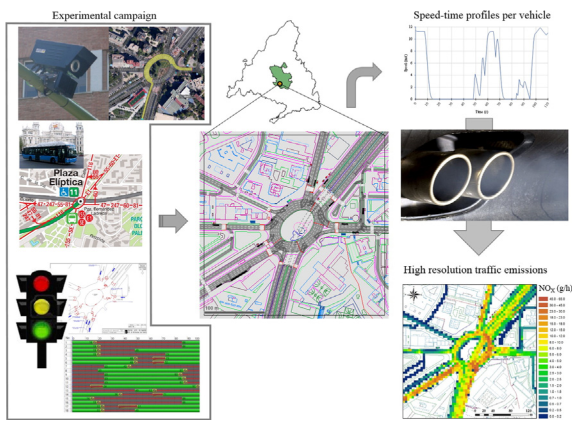
HIGHLIGHTS

- Microscale traffic and related NO_X and PM10 emissions were simulated in a hot-spot.
- 12 representative traffic situations throughout the week were analysed.
- Peak-hour emission factors up to 43% higher than those for free-flow conditions.
- Non-proportional dependency of total emissions with intensity in saturated conditions
- Emission results from ENVIVER fit well with the widely validated model COPERT 4.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper presents the evaluation of emissions from vehicle operations in a domain of 300 m × 300 m covering a complex urban roundabout with high traffic density in Madrid. Micro-level simulation was successfully applied to estimate the emissions on a scale of meters. Two programs were used: i) VISSIM to simulate the traffic on the square and to compute velocity-time profiles; and ii) VERSIT+$_{micro}$ through ENVIVER that uses VISSIM outputs to compute the related emissions at vehicle level. Data collection was achieved by a measurement campaign obtaining empirical data of vehicle flows and traffic intensities. Twelve simulations of different traffic situations (scenarios) were conducted, representing different hours from several days in a week and the corresponding NO_X and PM_{10} emissions were estimated. The results show a general reduction on average speeds for higher intensities due to braking-acceleration patterns that contribute to increase the average emission factor and, therefore, the total emissions in the domain, especially on weekdays. The emissions are clearly related to traffic volume, although maximum emission scenario does not correspond to the highest traffic intensity due to congestion and variations in fleet composition throughout the day. These results evidence the potential that local measures aimed at alleviating congestion may have in urban areas to reduce emissions. In general, scenario-averaged emission factors estimated with the VISSIM-VERSIT+$_{micro}$ modelling system fitted well those from the average-speed model COPERT, used as a preliminary validation of the results. The largest deviations between these two models occur in those scenarios with more congestion. The design and resolution of the microscale modelling system

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allow to reflect the impact of actual traffic conditions on driving patterns and related emissions, making it useful for the design of mitigation measures for specific traffic hot-spots.

1. Introduction

Road transport is often the main source of air pollution in urban areas, significantly affecting air quality in cities such as Madrid (Spain) (Borge et al., 2014). Due to the adverse effects of atmospheric pollution, the European Union has established legislation to improve air quality and reduce air pollution. In order to assess the fulfillment of air quality legal limits (Directive 2008/50/EC), air quality monitoring measurements are used. Although Madrid is expected to satisfy air quality limit values at a mesoscale level, these measurements are influenced by very local phenomena, and exceedances or non-compliance situations at some specific points are assumed for much larger areas. In this sense, mesoscale air quality models and traffic emission estimations have been used to define the air quality levels at national level (Borge et al., 2012; Burón et al., 2005) with a focus in Madrid city (Ariztegui et al., 2004; Lumbreras et al., 2008) and with efforts to focus on smaller urban areas (Borge et al., 2014). For that, traffic-situation models such as HBEFA were applied to Madrid. This model includes specific emission factors for every traffic situation and is representative of a variety of driving patterns making simplifications for the parameters that affect the processes at micro-level. Also, the average speed model COPERT was implemented. This model is considered as the reference tool to compute emissions at national or regional scale, but it has been even used at urban scale (Stamos et al., 2015). COPERT model was validated for Madrid (Pujadas et al., 2004) and has been executed and evaluated in the metropolitan area with a resolution of 1 km^2 and 1 h (Borge et al., 2012). These are the most detailed data available for the city of Madrid by now but they do not adequately reflect the driving effects, simplifying acceleration-deceleration processes that significantly influence emissions at a finer scale, and do not allow their calculation in short periods of time. Nevertheless, with these models higher concentrations along traffic networks have been observed, but not with the level of detail necessary to detect the hot-spots in a precise way (Timmermans et al., 2013).

Since pollution levels exceed the legal limits in specific traffic-related hot-spots locations and because an increasingly stringent legislation regarding air quality must be fulfilled, it is essential to develop emission reduction measures on hot-spots and highly polluted micro-environments. On these specific points, finer-scale tools are needed due to the complexity of the processes that determine emissions from mobile sources (Borge et al., 2014) and also to estimate the contribution of traffic to atmospheric emissions at local level (Smit et al., 2010) to be able to feed highly detailed microscale air quality models based on Computational Fluid Dynamics (CFD) (Santiago et al., 2015).

For those cases, a suitable combination of traffic and emissions micro-simulation models is needed to accurately define the emissions in a specific area. These models do not only describe the behaviour of the single entities which define the traffic such as individual vehicles and their interactions, but they also take into account traffic signs and lane changes for each vehicle. They use very short time steps, drivers' reaction times, route selection logic and lane change logic, obtaining detailed trajectories. This results in stop and go cycles that produce braking-acceleration patterns with a huge influence on emissions (Abou-Senna et al., 2013; Joumard et al., 1995). But also, speed management influences in a complex way vehicle emissions (Int Panis et al., 2006) so that differentiating between congested and non-congested scenarios is useful to suggest control strategies (Papson et al., 2012). Because of that, micro-simulation models are used to generate emission estimations with higher spatial and temporal resolution (Abou-Senna et al., 2013; Den Braven et al., 2012) and have already been used in other cities (Al Alami, 2012).

The aim of this work is to obtain detailed traffic emissions from a relevant and complex hot-spot in the city of Madrid. In order to obtain detailed traffic results, a microscale traffic flow simulation model was fed with real measured data collected by measurement campaigns. Twelve microscale traffic simulations representative of different daily and weekly traffic conditions were carried out. Traffic results were used as input for a microscale emission simulation model to obtain a detailed estimation of NO_X and PM_{10} emissions related to different vehicle types with five meters resolution. As a preliminary evaluation test, NO_X results for passenger cars were compared with those obtained from the well-known mesoscale emission model COPERT 4.

2. Methodology

2.1. Modelling domain

Fernández Ladreda (FL) square, is located in the district of Carabanchel-Usera in southern Madrid (Fig. 1 and supplementary geospatial data). It is a heavily trafficked roundabout that presents a

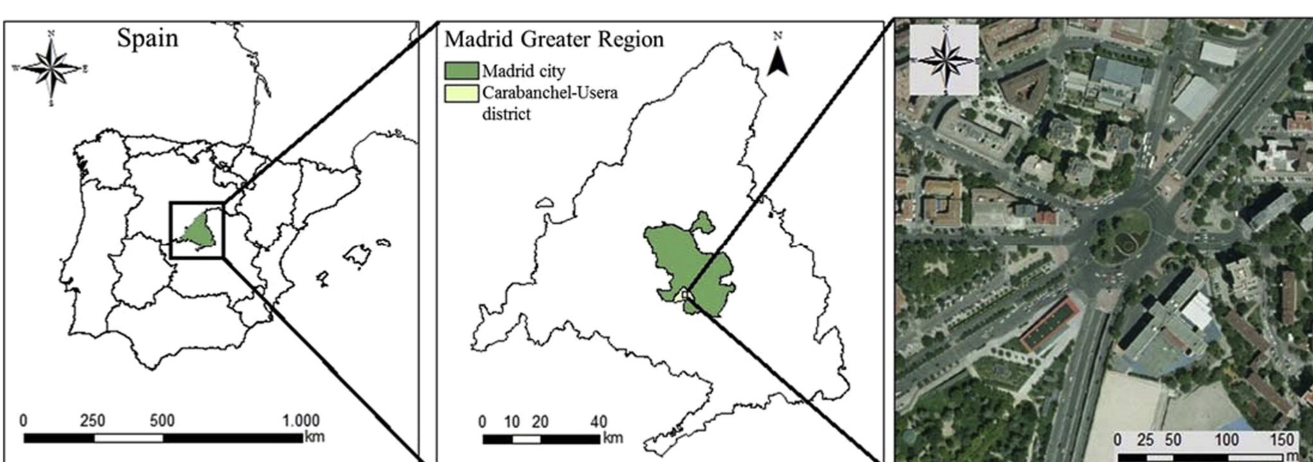

Fig. 1. Location of Fernández Ladreda square, Madrid (Spain).