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Assessment of potential improvements on regional air quality modelling related with implementation of a detailed methodology for traffic emission estimation

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HIGHLIGHTS

- Improvement on air quality simulation using detailed methodology of traffic emissions
- Combination of top-down/bottom-up approaches applied to build an emission inventory
- Bottom-up approach: most suitable when PM_{10}/CO concentrations are a major concern.
- To apply the bottom-up approach, the quantity/quality of input data is relevant.
- Several improvements achieved in the air quality results, mainly for PM_{10}, CO and O_3

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ABSTRACT

The accuracy and precision of air quality models are usually associated with the emission inventories. Thus, in order to assess if there are any improvements on air quality regional simulations using detailed methodology of road traffic emission estimation, a regional air quality modelling system was applied. For this purpose, a combination of top-down and bottom-up approaches was used to build an emission inventory. To estimate the road traffic emissions, the bottom-up approach was applied using an instantaneous emission model (Vehicle Specific Power — VSP methodology), and an average emission model (CORINAIR methodology), while for the remaining activity sectors the top-down approach was used. Weather Research and Forecasting (WRF) and Comprehensive Air quality (CAMx) models were selected to assess two emission scenarios: (i) scenario 1, which includes the emissions from the top-down approach; and (ii) scenario 2, which includes the emissions resulting from integration of top-down and bottom-up approaches. The results show higher emission values for PM_{10}, NO_x and HC, for scenario 1, and an inverse behaviour to CO. The highest differences between these scenarios were observed for PM_{10} and HC, about 55% and 75% higher (respectively for each pollutant) than emissions provided by scenario 2. This scenario gives better results for PM_{10}, CO and O_3. For NO_2 concentrations better results were obtained with scenario 1. Thus, the results obtained suggest that with the combination of the top-down and bottom-up approaches to emission estimation several improvements in the air quality results can be achieved, mainly for PM_{10}, CO and O_3.

1. Introduction

Atmospheric dispersion is a complex process which depends on topography, land use, meteorology and emissions (Seinfeld and Pandis, 2006). In the last decades, these data have been systematized allowing a general use of air quality models and an increasingly complex estimation of air concentrations (Zhang et al., 2012a,b). However, despite the complexity behind the development of these models, the accuracy and precision of their results are often low and usually associated with the emission inventories used as input in those models (Taghavi et al., 2005).

Atmospheric emission inventories are usually quantified using one of two approaches: (i) top-down, based on the disaggregation process of total emissions from a certain area to smaller administrative units or a regular grid with higher resolution (Ossés de Eicker et al., 2008); and (ii) bottom-up, based on emission estimation using detailed data of each emission source.

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The top-down approach is very useful namely when local detailed information on main emission generating activities is poor (Palacios et al., 2001). Tuia et al. (2007) verified that for a medium-sized city, the application of a top-down approach presents good results when compared with a bottom-up approach. Nevertheless, Wang et al. (2009) verified that the top-down approach overestimated the activities of Heavy Duty Vehicles (HDV) and Light Duty Vehicles (LDV) and underestimated the vehicle kilometres travelled for passenger car, taxi, shuttle bus, and bus. In fact, the top-down approach has some limitations. This is particularly true for the transportation sector in urban areas where this sector is responsible for 70% of emissions of local pollutants and 40% of carbon dioxide (CO_2) emissions (EC, 2007). For emission estimation traffic data are usually based on local car registrations or on the average annual mileage (Ossés de Eicker et al., 2008). However, a vehicle can be registered in a certain city but emits the pollutants in a different region. Thus, simple methods for assessing accurately the spatial distribution based on bottom-up approaches are needed for urban environmental management (Ossés de Eicker et al., 2008).

Several studies with traffic emission modelling using bottom-up approaches based on average speed models have been performed (such as Borge et al., 2012; Cai and Xie, 2011; Ho and Clappier, 2011; Wang et al., 2009). Tchepel et al. (2012) analyzed the uncertainty in transport activity data and a contribution of cold-start emissions to the total daily values in an urban area. Vogel et al. (2000) showed that the difference between the top-down and bottom-up (with an average speed model) approaches was less than 15% in the case of carbon monoxide (CO) and approximately 35% for nitrogen oxides (NO_x). However, they verified that the CO emissions in the real-world were much higher than the calculated. Similar studies used emission average speed models based on average speed, therefore they did not take into account the speed variability due to specific driving behaviour, and different levels of congestion. The research of Vogel et al. (2000) demonstrated this gap, showing that the estimated CO emissions were much lower than the observed, while Gokhale (2011) showed that the peak concentration changes with different states of traffic congestion.

Some studies have included instantaneous emission models to analyze air quality dispersion (Ishaque and Noland, 2008; Lee et al., 2012; Martins et al., 2009; Mensink and Cosemans, 2008). These new emission models, obtained directly from laboratory testing, tend to be more realistic than average speed models (Bishop et al., 2010; Hausberger et al., 2009; Smit and Bluett, 2011). Ishaque and Noland (2008) used CMEM emission model linked with CAL3QHC dispersion model to verify that the proximity of pedestrians to the roads is a crucial factor for pollutant exposure. Lee et al. (2012) used the EPA MOVES model and estimated a decrease of PM health costs by 96% in 2012 with the replacement of drayage trucks. Mensink and Cosemans (2008) used PARAMICS traffic model, the street canyon model OSPM and the Gaussian Immission Frequency Distribution Model or IFDM model to demonstrate that $PM_{2.5}$ concentration exposure can be reduced between 10 and 70% with the stringent European emission standards for new vehicles. The authors observed that the modelled statistical limit values for the concentrations of nitrogen dioxide (NO_2) and particulate matter with an aerodynamic diameter <10 μm (PM_{10}), compared with their measured values in a street canyon in the city of Antwerp, show a very good performance, within 15% accuracy. To assess the results of the air quality models, different validation methods can be employed at different spatial scales, including tunnel measurements, remote sensing, mass-balance, on-board measurements, and ambient concentration method (Smit et al., 2010).

Taking into account the scope of this paper, Table 1 presents a brief summary of research carried out using the traffic emission estimation, using pollutant concentrations for validation of the modelling system. As shown in Table 1, the majority of the studies of air quality modelling use emission results based on top-down approaches (7 studies) or bottom-up approaches using average speed models (12 studies). Only 4 papers are based on bottom-up approaches applying instantaneous emission models. Some of the research presented in Table 1 compared the results of top-down and bottom-up approaches. Wang et al. (2009) and Borrego et al. (2000) compared the top-down and bottom-up (using average speed models) approaches and verified that the top-down approach underestimated the emissions. In areas with higher traffic flow there are significant differences between these two approaches. When the traffic flow is higher and the population density is used as a disaggregation factor the bottom-up approach improves the resolution of emission data. However, the authors could not find any study comparing top-down and bottom-up approaches using an instantaneous emission model. The need for the use of these models is a controversial topic. While there are some evidences that the additional effort that these models imply does not seem to result in a significant improvement in the estimation of air quality (Smit et al., 2010), there is also a considerable number of studies showing that these models can improve the accuracy of the overall emission estimates (Ahn and Rakha, 2008; Bandeira et al., 2011; Dowling et al., 2005; Frey et al., 2008; Yue, 2008).

This paper aims to present an air quality regional modelling study using a combination of different road traffic emission models based on a bottom-up and a top-down approaches, in order to assess if the outputs of an air quality model can be improved in a regional level. For this purpose, an instantaneous road emission model – Vehicle Specific Power (VSP) (Coelho et al., 2009; Frey et al., 2008) – and an average speed emission model based on the CORINAIR methodology (EEA, 2009) were used as a micro-simulation approach. Thus, the main questions addressed by this research are:

1. Is there an enhancement in the air quality modelling results for a regional area with the application of a micro-simulation approach for road traffic emissions?
2. What is the quantitative difference between bottom-up (micro-simulation) and top-down approach to road traffic emission estimation for a regional area?

2. Methodology

Fig. 1 shows the main steps of the methodology applied in this study to assess two different scenarios of emissions. In the first step the emissions and meteorological models are used to provide inputs required by the air quality model. The estimated emissions for scenario 1 (S1) consider only a top-down approach, and for scenario 2 (S2) combine the bottom-up and the top-down approaches. The meteorological model requires the topography, land use and land-water mask datasets to produce 3D meteorological fields (temperature, wind speed and direction, etc.). In the second step, the meteorological and the emission outputs, as well as the initial and boundary conditions, are used in the air quality model, which was applied to compare concentration fields according to the emission methodology used for each scenario.

In the following sections, the emission (see Section 2.1) and the air quality (see Section 2.2) models used to estimate the impact of traffic emissions are presented. In these sections the main parameters used to assess the model performance are also described.

2.1. Emission modelling

Emissions are estimated considering two different scenarios: (i) scenario 1 (S1) includes the emissions from top-down approach; and (ii) scenario 2 (S2) includes the emissions resulting from integration of top-down and bottom-up approaches. In the last scenario while the top-down approach was applied to all SNAP's (*Selected Nomenclature for Air Pollution*), the bottom-up approach was only applied for the SNAP 7 (on road transport). Next, the main details of these methodologies (see Section 2.1.1 and 2.1.2) as well as their integration will be presented (see Section 2.1.3).