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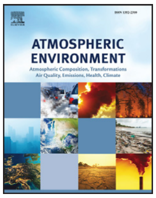

Improving the modeling of road dust levels for Barcelona at urban scale and street level

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HIGHLIGHTS

- The TNO URBIS (URBan Information System) model was applied in the city of Barcelona.
- New road dust emission factors and algorithm describe the time variability.
- Annual, daily and hourly road dust contributions were simulated and validated.
- Road dust contributed 9–15% and 23–44% to background and kerbside PM10.

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ABSTRACT

Road dust emission is an emerging issue in air quality due to the lack of remediation measures in contrast to vehicle exhaust emissions. The evidence of receptor modeling studies allows for quantifying impact on a few receptors, but the high cost of PM chemical speciation data and the questionable representativeness of single monitoring sites, limit considerably the development of population exposure estimates and epidemiologic studies based on georeferenced data. This study attempts to initiate and promote urban-scale dispersion modeling for road dust emissions, which will allow for a more robust estimate of population exposure and health outcomes. The TNO URBIS (URBan Information System) model was applied in the city of Barcelona, implementing a Gaussian line source and a street canyon dispersion model, together with new experimental estimates of road dust emission factors and algorithm to describe the time variability. Annual, daily and hourly road dust contributions were simulated and validated against observation of PM10, mineral dust and hourly PM2.5-10 concentrations. Results show that road dust contributed 9–15% to PM10 levels at background sites, and 23–44% at traffic sites. Highest contributions were modeled in the commercial/residential district where most of population live and work (Eixample) structured by 120 m wide square blocks, separated by roads with >10,000 vehicles per day. Street level contributions rise up to 20 $\mu g/m^3$ (96% of roads) and an additional 3% of roads within 20–40 $\mu g/m^3$. Hourly simulations of road dust contributions revealed to benefit from the implementation of the new emission module (Amato et al., 2012), able to describe the exponential recovery of road dust emission potential after rain events, when compared to common approach such as the use of constant emission factor or an ON/OFF approach. Correlation coefficients with observed data varied from 0.61, 0.58 and 0.43 for annual, daily and hourly means, respectively, revealing a clear improvement in terms of both spatial and temporal variability. However, more efforts need to be done in validating the model in different climatic scenarios and evaluating the seasonal variation of road dust emissions, due to droughts or Saharan dust events.

1. Introduction

Mineral dust contributes significantly to ambient concentrations of particulate matter (PM) (Querol et al., 2004; Putaud et al., 2004). In Europe mineral dust contributions to PM10 vary between 5 and 30% (Querol et al., 2004). Although the component of PM that

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causes its associated adverse health effects is not known, mineral dust is one of the suspects (Perez et al., 2008; Meister et al., 2012; Ostro et al., 2011). Mineral dust in cities is mostly emitted from vehicle non-exhaust emissions, which include brake-road-tyre wear (wear emissions directly to air) and mostly road dust resuspension (re-entrainment of particles deposited on road surface). Several studies have recently demonstrated the important impact of road dust emissions on urban PM levels in large cities across Europe (Harrison et al., 2012; Aldrin et al., 2008; Amato et al., 2009a and 2014a; Kahuaniemi et al., 2011; Berger and Denby, 2011). To assess source contributions to PM10 and PM2.5 exceedances of limit values and on the potential health impacts from this PM-fraction epidemiological studies need to be provided with reliable spatially resolved source contributions and population exposure estimates.

So far, road dust concentrations have mostly been quantified based on measurements of atmospheric PM mass concentrations and subsequent chemical characterization. Through factor analysis and/or chemical mass balance models these studies provided useful estimates of source contributions (Amato et al., 2009a). Due to the associated cost the experimental basis is usually limited to one or few measurement sites in a city. This information can be used to generate a first order assessment of the Long-term cumulative exposure. However, exposure estimates uncritically based on monitoring data may be biased if the stations are not representative. For example Duyzer et al. (2015) estimated that 3% of the population in the city of Barcelona is exposed to NO_2 levels higher than the maximum measured in the monitoring network and concluded that the network does not well represent modeled concentrations nor population exposure to NO_2. Therefore, it is highly recommended to use models to support the interpretation and spatial extrapolation of the results of measurement networks (Beelen et al., 2010). Dispersion models couple activity data (traffic data), emission factors and atmospheric dispersion to estimate the source impact on a given geographical domain (continent, country, region, city, street). However, dispersion models have been used only rarely for road dust emissions and only at a regional scale (Pay et al., 2011; Schaap et al., 2009) or at a specific road (Kahuaniemi et al., 2011; Denby et al., 2013a) without capturing the intra-city variability which is important to investigate the population exposure and the related health effects by means of epidemiologic studies.

An important lack of knowledge in current dispersion models is the adequate description of the spatial and temporal variability of road dust emission strength (Vautard et al., 2005; Schaap et al., 2009; Basart et al., 2012). The spatial variability of emissions strength depends on several factors such as vehicle fleet and speed type of pavement, distance to traffic lights and road dust loadings. For instance heavy vehicles emit on average 9 times more than a passenger car; lower emission factors were found generally lower at roadways with higher speed than at city center; quartzite and coarser pavement aggregate size generate less emissions than basaltic and finer size rock materials; finally road dust emission potential vary largely depending on road dust loading, thus reflecting the influence of local sources such as nearby unpaved areas and construction works (Schaap et al., 2009; Gehrig et al., 2010; Amato et al., 2011, 2013). The temporal variability of emission strength is governed by meteorology. In fact, differently from exhaust emissions, road dust emissions are dependent on meteorological conditions as they are inhibited by rainfall and high road moisture (Amato et al., 2012; Denby et al., 2013b). In Nordic countries, attempts have been made to describe the temporal variation of road dust emissions (Omstedt et al., 2005; Kauhaniemi et al., 2011; Denby et al., 2013b). These modules showed good behavior for Scandinavian climates where road dust emissions are heavily controlled by road sanding and the use of studded tires. However, their suitability for the rest of Europe, where these activities are not significant and the dominant roles are played by precipitation, and dust input from pavement and vehicle wear, remains unclear. Previous dispersion modeling studies (Schaap et al., 2009; Pay et al., 2011) applied an ON/OFF approach to road dust emissions, attributing zero emissions during rain events, and maxima emissions starting from a couple of days after the last rainy day. However, changes are not so drastic: several authors postulated a progressive increase of road dust emission potential due to the non-equilibrium between deposition and suspension fluxes (Pitt, 1979; Grottker, 1987; Omstedt et al., 2005). Venkatram (2000) noted that if road dust emissions depend on the amount of mobilized dust deposited on the road surface, this dust loading must evolve with time until it is replenished at the same rate as it is removed. Amato et al. (2012) found the experimental evidence of such process in Barcelona confirming the existence of an horizontal asymptote, allowing to derive the parameterization to describe the hourly variability of road dust emissions. We aim to assess if this parameterization for the temporal variability improves urban scale dispersion modeling for road dust in Barcelona.

In this study road dust contributions have been modeled for the city of Barcelona (Spain) using the TNO URBIS (URBan Information System) model (Wesseling and Visser, 2003; Beelen et al., 2008). Specific attention has been paid to the temporal variability of road dust contributions.

2. Methods

2.1. Dispersion modeling using URBIS

Following the approach from Lenschow et al. (2001) the PM10 concentration at street level (C_{slc}) can be calculated as:

$$C_{slc} = C_B + \Delta C_{UI} + \Delta C_{SC} \quad (1)$$

Where C_B is the regional background, ΔC_{UI} the urban increment due to traffic emissions, ΔC_{SC} is the street contribution. In this study the road traffic contributions are modeled by means of URBIS for annual mean conditions and URBIS-Real Time for hourly variability (see below). The regional background concentration was taken from the background monitoring station of Mataró (41°33′06.7″N 2°26′14.2″E, 30 m a.s.l.; 30 km NE away from Barcelona). The use of observation data is motivated by the fact that we are interested in the urban contributions to PM and do not want to introduce large uncertainties through the use of modeled regional background concentrations as regional scale models typically underestimate observed PM levels and only show a limited performance for capturing temporal variability at southern European stations (Schaap et al., 2009). Modeling only the primary urban sources is warranted, as secondary components do not show urban increments and they are assumed to be included in the suburban background concentrations observed at Mataró (Bressi et al., 2013).

The urban (ΔC_{UI}) and street level (ΔC_{SC}) contributions vary in space within 0–1000 m from the roads and they were modeled on annual mean by means of the URBIS. URBIS is an air pollution model designed for cities and regions with a variety of emission sources. The model is an implementation of the formal Dutch standard methods to calculate annually averaged concentrations. Input data can be emission data from traffic as line sources, large industrial point sources, shipping as point sources, and other diffuse sources such as households as area sources (emission per square kilometer). For the aim of this study only traffic line sources were used. Two sub-models are implemented in URBIS to calculate the urban increment and the street canyon contribution at each location: