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Intercomparison of three modeling approaches for traffic-related road dust resuspension using two experimental data

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ABSTRACT

Two observational campaigns were conducted, one in the Grenoble area (South Eastern France), for the MOCoPo project, near an urban freeway in 2011 and the other one in a Paris suburb, for the TrafiPollu project, on a major surface street in 2014. PM_{10} concentrations were measured by Air Rhône-Alpes during the last 10 days of September 2011 for MOCoPo and by Airparif during 3 months from April to June 2014 for TrafiPollu. It has been shown that abrasion and resuspension processes represent a significant part of the total primary PM_{10} emissions of road traffic. Hereby, resuspended emissions originating from the road are estimated with several approaches and compared to PM_{10} measurements. We consider two different models available in the literature: HERMES (Pay et al., 2010) and NORTRIP (Denby et al., 2013), which differ in terms of formulation. We also apply an empirical method developed by Thorpe et al. (2007), based on near-road and background pollutant observations. The results vary depending on the traffic conditions and the modeling approach. In all cases, the resuspension emissions simulated are high enough to be considered in air quality modeling (ranging from 9 to 150% of the exhaust emissions). Those resuspension models were combined with atmospheric dispersion models to estimate near-road concentrations. We used a Gaussian line-source model for the Grenoble urban freeway and a street-canyon model (MUNICH) for the Paris suburban boulevard. The contribution of resuspension to traffic-related concentrations is hidden by a strong background contribution, which prevents us from concluding in terms of model performance. Nevertheless, a comparison with another dataset obtained near an urban freeway in Paris suggests that vehicle speed should be taken into account when estimating PM_{10} resuspension emissions.

1. Introduction

Resuspension caused by on-road traffic is defined as the suspension by air flow of particles after their deposition on the road surface. Mollinger et al. (2007) reviewed experiments of the resuspension caused by road traffic. The air flow is modified by various factors such as the movement, the shape and the type of vehicles. Other factors such as the type of road surface and the presence of moisture can also affect the amount of resuspension. As a consequence there is no predefined type of pollutants or particle size range

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since all pollutants available on the surface area can be potentially resuspended. Besides road dust resuspension, traffic is a source of gaseous and particulate air pollutants, and, therefore, resuspension contributes to particulate matter (PM) traffic-related emissions. We investigate here road dust resuspension in two distinct areas: an urban freeway in the Grenoble area in South Eastern France and a major suburban surface street near Paris. Measurements of major traffic air pollutants were conducted at near-road monitoring sites for extended periods (two weeks in Grenoble and three months in the Paris suburb). We apply here three different methods to estimate road dust resuspension rates: two deterministic models and one empirical method. In these three models, PM_{10} resuspension is estimated because the emission factors for wear process and resuspension are known only for this particle size. Near-road PM_{10} concentrations are then simulated using atmospheric dispersion models and the effect of taking in consideration road dust resuspension by traffic is assessed by comparison with the near-road measurements.

The Grenoble area is near the border between France and Italy and is subject to local as well as international traffic. As part of the MOCoPo project (Measuring and Modeling Traffic Congestion and Pollution), several studies have been conducted to assess the traffic contribution to air pollution. For example, Fallah Shorshani et al., 2015 simulated the air pollutant concentrations at the near-road monitoring site using a Gaussian plume dispersion model augmented with a parameterization for light wind conditions (Venkatram et al., 2013). The same atmospheric dispersion model will be used here to calculate near-road concentrations from direct vehicle emissions (including exhaust and wear abrasions processes) and road dust resuspension for this case study.

The Alsace-Lorraine Boulevard located in an Eastern Paris suburb has typical characteristics of a residential/business area impacted by local traffic as well as urban background. Despite reductions in pollutant emissions from vehicle exhausts, the PM_{10} concentrations measured near roadways in the Paris region have not decreased as much as expected and resuspension has been suggested as a possibly significant indirect source affecting near-road air quality. One of the objectives of the TrafiPollu project (multi-scale modeling of the pollution emitted from traffic) was to measure and simulate air pollutant concentrations on that suburban boulevard.

The current Nomenclature For Reporting (NFR) air pollutant emissions ignores the resuspension process (Amato et al., 2014) and further improvements in emission inventories and modeling will necessarily need to include resuspension. Consequently, there has been a recent interest in the literature to quantify and model resuspension. The HERMES emission model has been improved with the addition of resuspension (Pay et al., 2011). This model was used to compute resuspension emissions for a domain covering Spain for a whole year of simulation (2004). An evaluation of this model led to a good agreement (r = 0.41–0.5), in particular to predict PM_{10} ambient concentrations in dense areas of population. Compared to HERMES, the NORTRIP model (Denby et al., 2013a,b) is more detailed and takes into account traffic speed in addition to traffic flow. Furthermore, it is designed to determine all major processes involved in PM resuspension, such as vehicle wear rates, emissions due to traffic, road dust loading, retention of wear particles, and resuspended PM emissions based on road surface conditions (dry versus wet). Empirical approaches have also been applied to estimate resuspension. For example, Thorpe et al. (2007) calculated the resuspension contribution to PM_{10} concentrations from daily mean PM_{10}, $PM_{2.5}$, and NO_x concentrations. Positive Matrix Factorization (PMF), a principal component method, has been used to estimate the non-exhaust source at the Grenoble urban freeway, based on MOCoPo data measurements (Polo Rehn, 2013). Over the measurement period, the ratio of the non-exhaust source over the vehicle exhaust was estimated to be about 0.76 for PM_{10}. This PMF result was used by Fallah Shorshani et al. (2015) to estimate an average resuspension rate for air dispersion modeling. Amato et al. (2016) conducted an experimental program at the ring road in Paris and used PMF to quantify the contribution of PM_{10} resuspension to traffic-related emissions (22%) and near-road PM_{10} concentrations (13%). The U.S. Environmental Protection Agency developed a predictive emission factor for resuspension based on a regression analysis of 83 tests for PM_{10} including public paved roads, as well as controlled and uncontrolled industrial paved roads (U.S. EPA, 2006). This "AP-42" approach was recently applied to the Po Valley for January 2010 (Pepe et al., 2016). Monthly PM_{10} resuspension were shown to represent more than 60% of traffic emissions in a large domain (85 km × 85 km) covering Milan.

We apply here the two deterministic methods mentioned above, HERMES and NORTRIP, and the empirical method of Thorpe et al. to estimate road-dust resuspension for both the Grenoble urban freeway and the Paris suburban boulevard (locations are illustrated in Fig. 1). We first describe the resuspension models and the atmospheric dispersion models used in this study. Next, we present the results for the two sites and compare modeling results to measured PM_{10} concentrations. Finally, we discuss the results and provide conclusions and perspectives for further work.

2. Resuspension model descriptions

2.1. HERMES

The CALIOPE project aimed at establishing an air quality forecasting system for Spain (Pay et al., 2011). HERMES is the model used in CALIOPE to compute emissions. To estimate resuspension of PM_{10} the original formula adapted for the whole road network of Spain has been simplified here for a single road section (the Echirolles section of an urban freeway near Grenoble) or for a combination of street-segments (Boulevard Alsace-Lorraine in an Eastern Paris suburb):

$$E_{resuspension} = L_{road} \sum_{v=1}^{2} N_v FE_v \tag{1}$$

$E_{resuspension}$ (expressed in $g{\cdot}h^{-1}$) represents the resuspended PM_{10} emission rate, which depends on the length of the road (L_{road} in km), the traffic flow N_v (in $veh{\cdot}h^{-1}$) and the empirical emission factor FE_v ($g{\cdot}veh^{-1}{\cdot}km^{-1}$) specified for each type of vehicle for PM_{10} as