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MODELLING ULTRAFINE PARTICLE CONCENTRATIONS AT STREET-LEVEL SCALE FOR THE ENTIRE CITY OF ANTWERP

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Abstract: In this study, an integrated model chain has been set up to assess the concentration of ultrafine particles at the local (street level) scale for an entire city, including both regional variability as well as local variation in sources of air pollution. The model chain starts from spatially and temporally distributed traffic emissions based on the HBeFa-methodology. These traffic emissions are subsequently used in IFDM, a bi-Gaussian plume model designed to simulate non-reactive pollutant dispersion at a local scale. The effects of street-canyons are added using the OSPM-module, which takes into account the specific dispersion characteristics in the street canyon. The model is subsequently successfully validated using a measurement campaign carried out in the city of Antwerp in 2013. This modelling exercise and the subsequent successful validation confirm the hypothesis that dynamical processes do not play a major role in the dispersion of ultrafine particles at the local and urban scale.

Key words: *Urban air quality, Ultrafine particles, Dispersion modelling*

INTRODUCTION

In recent years, the fraction of particulate matter with a diameter smaller than 0.1µg, more commonly known as ultrafine particles (UFPs), has gained a lot of attention. Given their small size, UFPs contribute little to the mass of particulate matter in ambient air, but they are the dominant contributors to the total particle number. Concern about the toxicity of UFPs arose since animal and in-vitro studies suggest that the ultrafine particles could be inhaled much further into the lungs, and that they may be translocated into the blood (HEI, 2013).

Currently there is no limit value to control the UFP-concentration, but if a policy for ultrafine particles is to be introduced in the future, performance evaluation of new and existing models against measured data in various conditions will be needed. In this study, an integrated model chain has been set up to assess the concentrations of ultrafine particles at the local (street level) scale for the entire city of Antwerp. The model is subsequently successfully validated using a measurement campaign carried out in the city of Antwerp in 2013. In the remainder of this extended abstract we first focus on the model chain and the measurement campaigns, and thereafter provide the detailed results of the validation.

MODEL CHAIN

The model chain consists of several models coupled to each other. The different components are discussed one by one in the next paragraphs.

The MIMOSA4.3 emission model (Mensink et al., 2000) is used to calculate local traffic emissions based on the HBeFa emission factors (Hausberger et al., 2009). However, the original emissions have been multiplied by ten in our methodology. The choice of multiplying the emissions with such a high factor is an important decision. There were, nevertheless, sufficient arguments to make this assumption reasonable. When the first simulations were performed, excluding this factor, it was clear that something was wrong. The resulting concentrations were too low, although the spatial correlation factor was very high. Furthermore, the UFP concentration maps were mainly dominated by the background coming from LOTOS-EUROS, although UFP in cities is mainly driven by local traffic. Moreover, other studies indicate much higher emission factors than those contained in the HBeFa-database, see for instance Nikolova et al. (2011). Finally, the underestimation in HBefa v3.1 is probably related to differences in emissions between test cycles and real driving conditions. Although HBefa uses the CADC-cycle, it is probable that real-world driving conditions are still different from this cycle.

The resulting spatially and temporally distributed emissions are used in the bi-Gaussian model IFDM (Lefebvre et al., 2011a; 2011b). IFDM (Immission Frequency Distribution Model) model is a bi-Gaussian plume model, designed to simulate non-reactive pollutant dispersion at a local scale. Apart from diffusion, all other dynamical specific UFP-processes, such as, i.e. nucleation, condensation, coagulation and deposition, are not represented.

To incorporate regional scale background concentrations, these results are coupled to output of the LOTOS-EUROS regional air quality model. A method to avoid double counting of the (local) emissions by the different models is applied (Lefebvre et al., 2011b). The street canyon contribution to the concentrations is calculated by using the IFDM output as boundary conditions to a street canyon module, OSPM, which takes into account the specific dispersion characteristics in the street canyon (Berkowicz, 1997). The results of the IFDM model and OSPM are subsequently combined using a post processing tool, so that the street canyon concentrations are confined to the street canyons, and the IFDM roof top concentrations are used outside of the canyons. The final output are (annual) average maps and time series at selected locations.

This model chain (also known as the IFDM-OSPM model) has previously been used at VITO to successfully model the concentrations of nitrogen dioxide, ozone, particulate matter, elemental and black carbon, and has now, within the scope of the INTERREG IVB Joaquin project, been adapted to model the concentrations of (total number of) ultrafine particles. The resulting annual mean concentration in Antwerp in 2013 is shown in Figure 1.

MEASUREMENTS

The methodology is validated over the city of Antwerp using two short-term measurement campaigns carried out during February and October 2013. The measurement data is described in detail in Frijns et al. (2013; 2014). Table 1 provides a list of the different stations and the naming convention applied in the following paragraphs, Figure 1 locates the measuring stations on a map of Antwerp.

During February, UFP-concentrations were measured at 7 diverse locations: three locations close to the busy Plantin-Moretuslei (at distances varying from 10m over 30m to 55m from the center of the road), at the suburban location at Linkeroever, at a station close to the busiest highway in Belgium (Ring of Antwerp), in the public park “Stadspark” and in a street canyon (Turnhoutsebaan). During October, measurements have been carried out at 4 locations: the station located at 30m of the Plantin-Moretuslei, at Linkeroever, in the public park and close to the Ring.

Table 1: Overview of the measurement locations and time frames. The number in the third column refers to the locations shown in Figure 1.

Official name	**Location**	**Location on map** (see Figure 1)	**Type**	**Period**
R801 Borgerhout	Telemetric monitoring station situated at approx. 30m from a busy road (Plantin-Moretus lei)	1	Urban background	February and October
Borgerhout 10m	Trailer at approx. 10m from a busy road (Plantin-Moretus lei)	1	Urban background	February
Borgerhout 55m	Trailer at approx. 10m from a busy road (Plantin-Moretus lei)	1	Urban background	February
Linkeroever	Linkeroever	5	Suburban	February and October
Ring	Near the busiest highway in Belgium	3	Roadside	February and October
Stadspark	In the city park	4	Public park	February and October
Turnhoutsebaan	Roadside of a busy road (Turnhoutsebaan)	2	Street canyon	February

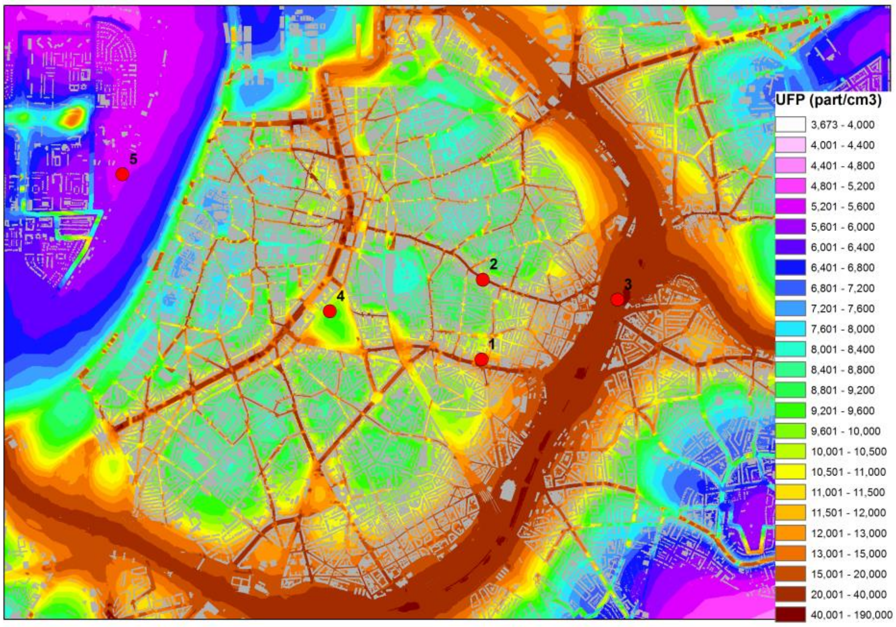

Figure 1: Annual mean UFP-concentration (in part/cm^3) in Antwerp in 2013. The map also shows the location of the measurement sites as indicated in Table 1.

VALIDATION

Within this extended abstract, we focus on two types of validations. Firstly, we assess the spatial pattern simulated by the model chain by comparing the mean values for the measurement periods with the modelled values. Secondly, we perform a spatio-temporal validation by focusing on 24h-averaged values. More details on the validation are reported in Hooyberghs et al. (2015).

Figure 2 shows the validation of the spatial pattern. We find a good agreement between the modelled data and the measurements. There is a slight underestimation of the concentrations (bias = -18%), some scatter (RMSE = 25%) and a high correlation (R^2=0.93). In the validation plot, the strong underestimation of the concentrations at the Turnhoutsebaan is clear. Without this location, the spatial validation parameters improve significantly (BIAS = -15%, RMSE = 17%, R^2 = 0.98). A comparison of the input traffic dataset with actual countings during the UFP-measurement campaign and with information on the website of the public transport company suggests that the number of heavy duty vehicles (and especially public busses) in the dataset is significantly underestimated at this location, which could explain the discrepancy. This situation illustrates the importance of getting good traffic data, since deficiencies in the traffic data (both in locations and in number of vehicles) can have a large influence on the final results.

Also the validation for 24h-averaged values is quite good, as can be seen in Figure 3. We find a slight underestimation of the concentrations (bias = -12%), some scatter (RMSE = 41%) and a reasonable high correlation (R^2 = 0.70). Studying the results in more detail, they point to a large underestimation at the Turnhoutsebaan, which is in line with the discrepancy observed for in the spatial validation. At most other locations, a small underestimation is found, except for the location near the Ring Road, where only a very slight negative bias is found.

In sum, both the spatial and the spatio-temporal validation are successful, indicating that, although assumptions have been made, the modelling chain provides accurate results for the UFP-concentration in the city of Antwerp. The success of the modelling chain moreover indicates that the dispersion of ultrafine particles at the local and urban scale is mainly governed by the dilution process, while other dynamical processes can be neglected.

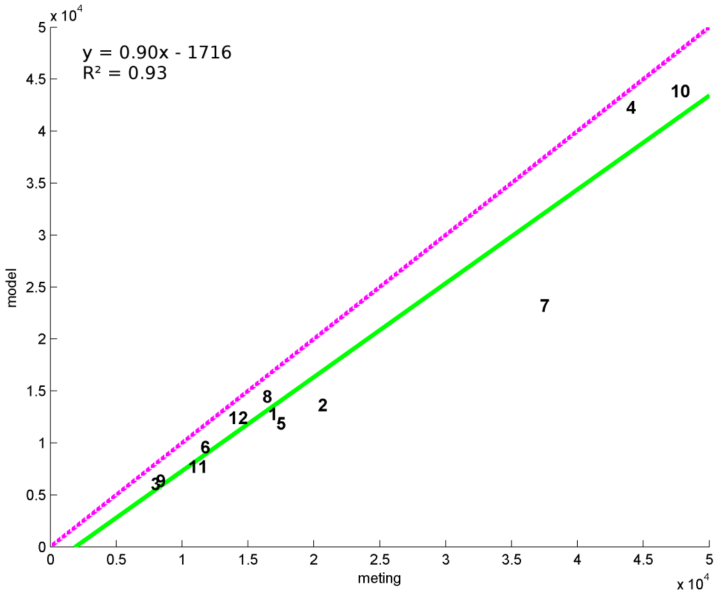

Figure 2: Spatial validation. The plot shows the average values for the different measurement campaigns for UFP (in particles/cm³). Every number denotes a measurement-model combination of averages at one location over the complete measurement campaign. Numbers 1 to 7 denote February values (VMM R801 (1), Borgerhout 10m (5) and Borgerhout 55m (2), at Linkeroever (3), close to the Ring Road (4), at the city park (6) and in the street canyon of the Turnhoutsebaan (7)). Numbers 8 to 11 are respectively measurements at R801 (8), at Linkeroever (9), close to the Ring Road (10) and at the city park (11) during October. Number 12 is the annual mean value at the R801 location. The (full) green line is the regression of the model on the measurements, while the (dotted) purple line is the 1:1-line.

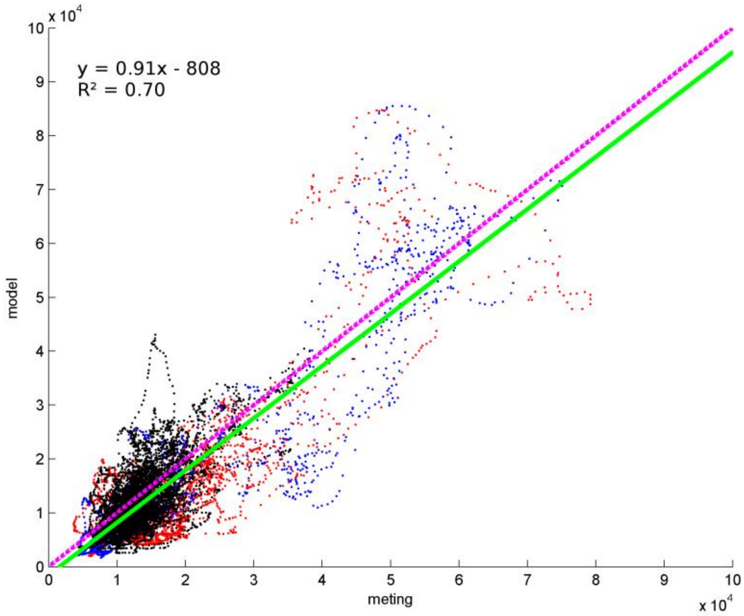

Figure 3 :Spatio-temporal validation. The UFP-validation plot (24h averages, in particles/cm³), for all measurement locations and periods (4 weeks) combined. Every dot is a corresponding measurement-model combination (blue = October, red = February, black = annual values at R801). The (full) green line is the regression of the model on the measurements, while the (dotted) purple line is the 1:1-line.

CONCLUSIONS

We have introduced an integrated model chain, the IFDM-OSPM model, to assess the concentration of ultrafine particles at the local (street level) scale for the entire city of Antwerp. The methodology is validated using measurement campaigns carried out in 2013. Although dynamical processes such as nucleation and coagulation are neglected in the local scale IFDM-OSPM model, in general, there is a very good agreement between the measurements and the model output. Especially the spatial validation is highly successful, and thus the model is certainly suitable to compose maps of annual mean ultrafine particle concentrations and to identify hotspots on a local and regional scale.

This modelling exercise and the subsequent successful validation confirms the hypothesis that dynamical processes do not play a major role in the dispersion of ultrafine particles at the local and urban scale. Here the dispersion pattern is mainly governed by the dilution process which is well simulated by the IFDM-OSPM model chain. Furthermore, the validation illustrates the importance of good traffic data, since deficiencies in the traffic data (both in locations and in number of vehicles) can have a large influence on the final results.

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