PRODUCING ANNUAL STATISTICS WITH MICROSCALE MODELS FOR POLICY SUPPORT : A NUMBER OF TEST CASES IN ANTWERP

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Abstract: It is well known that computational fluid dynamics (CFD) models require significant amounts of processing time. Producing annual statistics, which are often required for policy support and EU directive compliance testing, is therefore unfeasible with current typical computing infrastructures. In this contribution, we will describe the application of a meteo-averaging methodology as described in Parra et al, (2010) and similarly Sollazo et al, (2011) for two test cases in Antwerp, partly in the frame of the ATMOSYS (http://www.life-atmosys.be) project co-financed by the European LIFE+ program. Normalised NO_x concentrations for 18 wind directions were simulated as a passive tracer in the ENVI-met model (Bruse et al, 1998) for each of 5 different major line sources in the domain. In-situ measurements were used to parameterize the local NO_2/NO_x ratio. The simulation results were compared on an hourly basis to the NO_2 concentration difference of a curb-side station and a station which is located some 30 m further away from the road. In addition, we will illustrate the approach for an urban development project in the city of Antwerp near the busy ring road. Here, the effect of a row of shielding-houses on the annual averaged NO_2 concentrations in the area as calculated by the CFD meteostatistics approach, was estimated and superimposed onto an earlier street-level air quality assessment (Lefebvre et al, 2012).

***Key words:** Meteostatistics, computational fluid dynamics, air quality directive*

INTRODUCTION

The continued growth of cities poses significant challenges. Space for new urban development projects becomes more and more scarce. At the same time, civilians are becoming more and more engaged and it therefore new development plans need to be subject to several environmental impact assessments, testing how they will affect the quality of living. In case of air quality clearly EU directives have to be met. The scale at which most practical mitigating measures in a city can be taken is clearly that of a typical building block or typical neighbourhood. Indeed, a broad spectrum of structural measures (sound screens, erection/destruction of buildings, urban green implantation etc...) impact to a large extent only the pollutant concentrations at micro-scale. Clearly this requires obstacle resolving modelling techniques involving computational fluid dynamics (CFD). It is well known however that CFD models require significant amounts of computing time before a single steady state solution given a certain set of boundary conditions is found. Assessing the impact of mitigating measures e.g. on annual concentration averages, as required by the EU directives, therefore becomes unfeasible.

Recently Parra et al, (2010) proposed an approximation based on non-dimensional concentration fields calculated in a set of steady state RANS simulations using the k-epsilon turbulence model for different wind directions. Such non-dimensional concentrations C^* were obtained by assuming the concentrations to be proportional to the roof-level windspeed u and the emission strength E :

$$C^* = \frac{C.u}{E.L}$$

Where L is a characteristic length scale. By rescaling these non-dimensional concentrations with hourly wind velocities and emission strength, they were able to reconstruct a full time series. The obtained results were satisfactory, yet it was seen that the scaling assumption breaks down at lower windspeeds, where transport is more driven by turbulent diffusion rather than advection. Solazzo et al, (2011) described a similar methodology, using a total of 8 different wind sectors and 4 wind speed ranges explicitly calculated in CFD. Average concentrations were subsequently obtained through a weighted mean using the relative frequency of occurrence over the period of interest of each combination of wind direction, velocity and emission source strength.

In this contribution we will discuss some results obtained for a test case in the Belgian city of Antwerp,

CASE STUDY 1 – PLANTIN AND MORETUSLEI

A first case study is centered around the busy *Plantin en Moretuslei* entrance road as shown below. The domain contains two operational monitoring stations (42R802 and 42R801) of the Flemish environmental agency (VMM), one at curbside, another one some 30 meters away from the road. A 3D view of the modelled domain is shown as well.

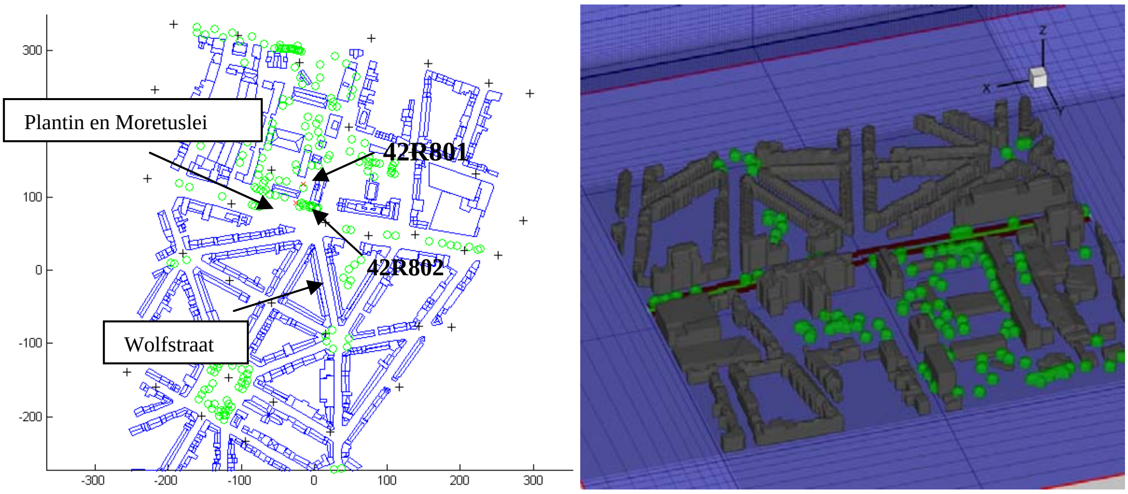

Figure 1 : (left) Schematic drawing of the selected test case domain near the Wolfstraat. (Right) : 3D view on the modelling domain depicted on the left.

Since the difference between both stations will be for a large part driven by micro scale effects, it is an interesting exercise to see to what extent this concentration difference can be reproduced by such a rescaling approach. A CFD run database was generated for 18 wind directions, in steps of 20°. The ENVI-met model (Bruse and Fleer, 1998) was used to this end. ENVI-met uses a Reynolds-Averaged Navier-Stokes method with k-epsilon turbulence model. The model was initialised with a (rather arbitrary) wind speed of 4 ms^{-1} at 10 m height using cyclic boundary conditions for TKE. The steady state solutions were obtained under neutral conditions and thermal effects in the model were switched off. The domain contained 211x211x46 grid cells having a base horizontal resolution of 2 m in the core model domain and 1 m in the vertical, but with telescoping grid cells in both horizontal and vertical directions. The top of the model domain (144 m) was located roughly at 4 times the height of the tallest structure (36 m) and the in and outflow boundaries were 130 m away from the building edges.

For the road traffic emissions, MIMOSA4 was used. MIMOSA4 is the most recent version of MIMOSA (Mensink et al., 2000; Vankerkom et al., 2009), which generates hourly output for different types of emissions, such as NO_2, PM_{10} and $PM_{2.5}$ for Flanders (see also Lefebvre et al., 2011b). The latest version of MIMOSA4 relies on the COPERT 4 methodology (COPERT 4, 2007) for the energy consumption and emission functions for the conventional fuels (diesel, petrol and LPG). It is important to mention the fact that modelled emissions were used as traffic counts were not readily available on every road segment in the city. Contributions from the 5 major roads were calculated separately in the approach, resulting in a total of 90 steady state simulations.

The most problematic pollutant in terms of EU directive compliance for the city of Antwerp is NO_2, more specific the 40 µg/m^3 limit. It is however unclear in this approach how to consistently treat the photochemical equilibrium when computing yearly averages. We therefore decided to perform the CFD steady state simulations with NO_x –total emissions, treating it as a passive tracer. In post-processing the NO_2 concentrations were derived from the NO_x total using local measurements of the NO_2/NO_x ratio. To this end the NO_2/NO_x ratio, as measured in the 42R802 station, present in the modelling domain, was fitted with a polynomial function, as indicated below in Figure 2.

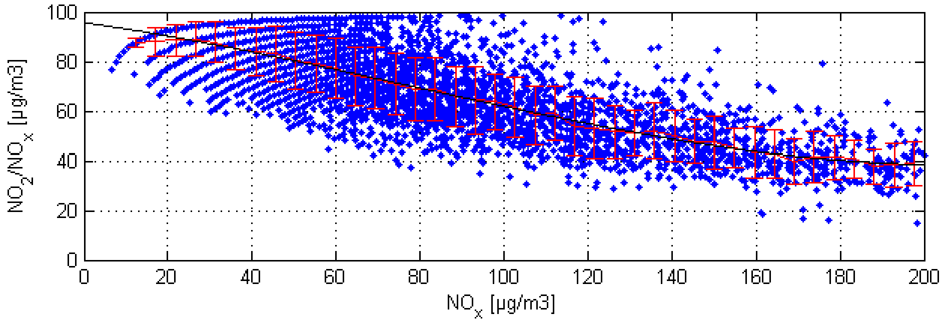

Figure 2 : Parametrisation of the NO_2/NO_x ratio (in %) based upon hourly measurements in Borgerhout (42R802) during. The blue dots are individual hourly measurements, the red symbols represent the average and standard deviation in

Next to the emission strength, the MIMOSA4 model provides emission time factors as well with which yearly average emissions can be modulated on a monthly/daily and hourly basis. Using the database of steady state CFD results, the mentioned time factors and a time series of wind speed and direction measurements at 30 m from a nearby (2 km) meteo mast, we computed the time series of NO_2 concentrations fields. For a correct rescaling, the actual inflow wind speed at 30 m in the CFD runs was evaluated from the ENVI-met 1D model which is used to force the main 3D CFD computation.

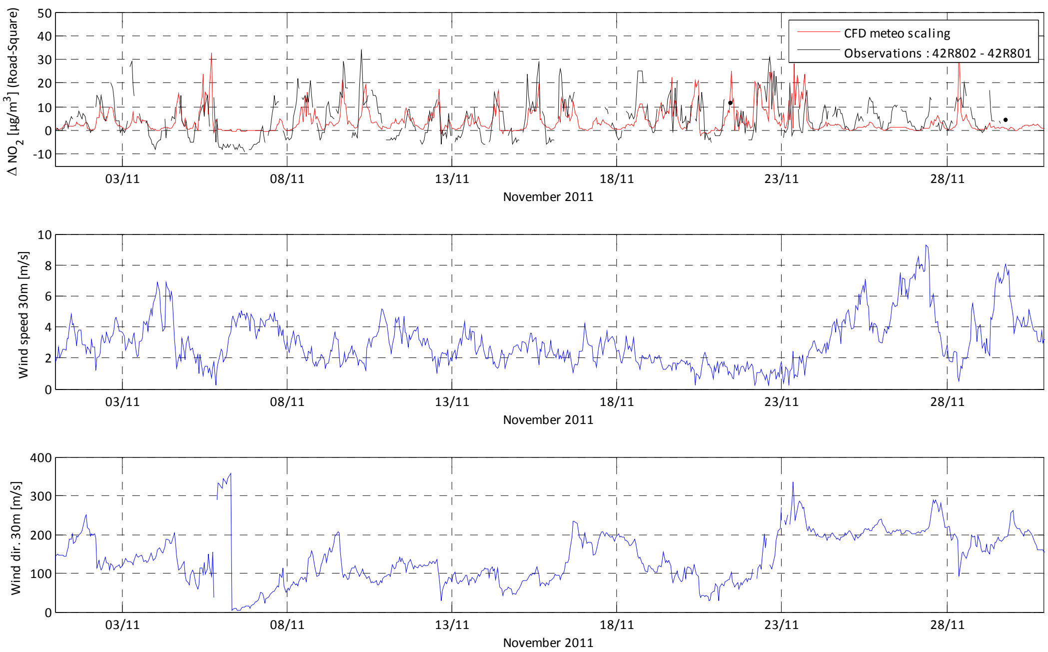

Figure 3 : Validation time series for the concentration difference in NO_2 between the roadside station (42R802) and the station some 30m away from the road (42R801) .

The measured and modelled concentration difference between both stations in Figure 1 is shown below in Figure 3 for the month November of 2011, together with the measured windspeed and wind direction. We believe it is fair to state that the modelled concentration difference for this period does show some predictive power given the very coarse assumptions concerning the emissions and the approximations in the methodology. Some interesting features could be noted, the most important of which being the lack of negative difference in the modelled concentration runs. This seems to be predominantly present under northerly wind directions as can be inferred from the figure around Nov. 6th. Interestingly, near the end of the month, some peaks seem to be missing in the model results as well. This seems to coincide with a period of higher wind speeds and south-easterly winds. More detailed analysis is required to explain and more importantly learn from these features.

CASE STUDY 2 – EFFECT OF BUILDING WALL

For a second test case, we used the approach of Solazzo et al (2011), where we computed the annual average concentrations as a weighted mean of the steady state results for a number of different meteorological conditions. The aim of the study was to assess what impact the construction of a building wall would have on the yearly average NO_2 concentrations for an envisaged urban development project close to the extremely busy Antwerp ring highway (R1).

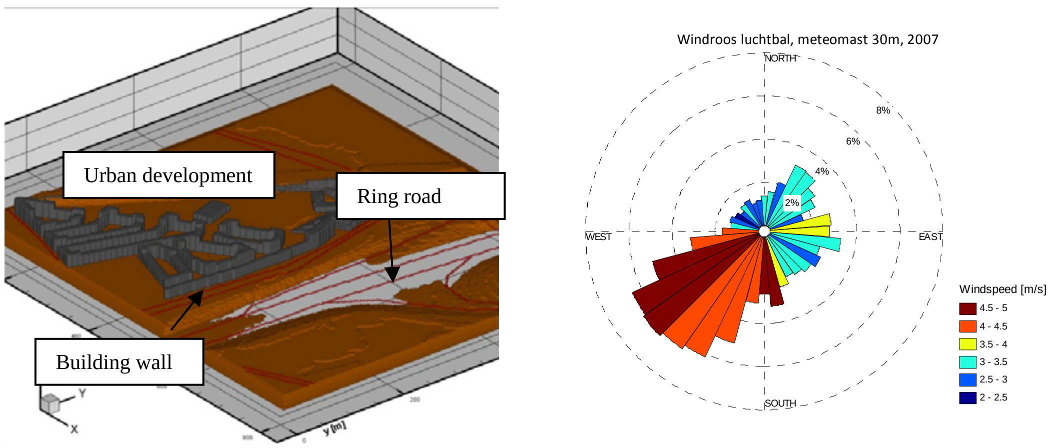

Figure 4 : Left : 3D domain sketch of the development site, situated in between the Zurenborg district in Antwerp and the busy R1. Right: wind rose for winds speed / direction at 30 m height, measured at the VMM Luchtbal meteo mast during 2007.

Yearly average emissions were used corresponding to a future mobility scenario (Lefebvre et al, 2012). In total 12 wind directions were chosen, in steps of 30°. Particular topographic features were present in this modelling domain : the busy ring road is 6 m lower than the development terrain and a 6 m high train verge is present at the North – Westerly side of the terrain.

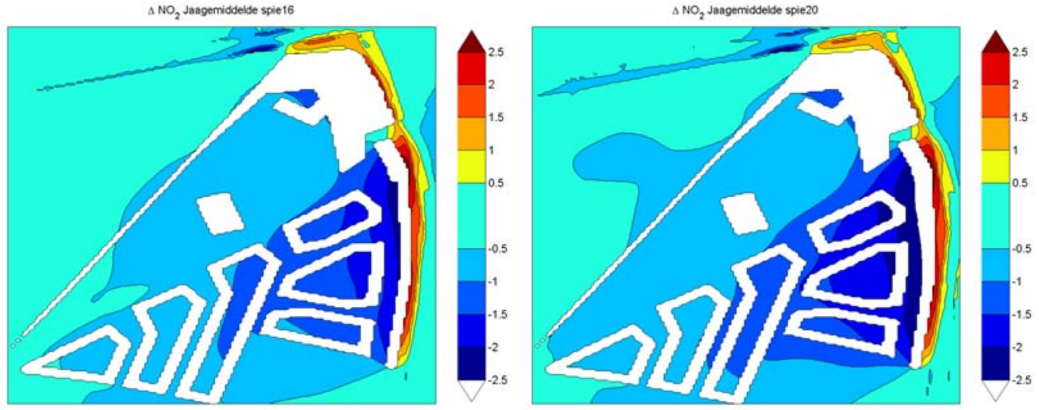

Figure 5 : Resulting effect of the building wall on the yearly average NO_2 concentrations for two different wall heights (left: 16 m high buildings, right: 20m high buildings). Scale is concentration difference in µg/m^3.

We compared the effect of a building wall of 16 and 20m high. Figure 5 above shows a rather small effect on the yearly average NO_2 concentrations of maximally 2.5 µg/m^3 reduction at ground level for screen houses of 20 m high. The reason for this is that even though the envisaged building wall does have a significant impact under Easterly wind directions, the prevailing wind direction is clearly South-West (Figure 4). Under this scenario obviously the building wall has no effect given the relative orientation of the wall and the dominant emission source. In a final step, the results were compared and ultimately superimposed onto an earlier NO_2 street-level air quality calculation using a Gaussian dispersion model with a street canyon parameterisation in order to assess whether the envisaged building wall could potentially aid in meeting the EU NO_2 targets for the re-developed area.

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