VALIDATING THE RIO-IFDM-STREET CANYON COUPLING OVER ANTWERP, BELGIUM

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Abstract: Further integration of different spatial scales in concentration modeling is important for assessing the European limit values for NO_2. The local NO_2-concentrations are influenced by the regional background, the local emissions and the street canyon effects. Therefore, it is important to combine all these contributions in the model chain that one wants to use for such an assessment. In this paper, we present the results of a coupled model chain, using an intelligent measurement interpolation tool, a bi-gaussian plume model and a street canyon model to simulate the concentrations over the city of Antwerp, Belgium. The results of this model campaign are validated against weekly averaged NO_2 measurements at 49 locations in the city of Antwerp, during both a winter and a summer week. It is shown that the model performed well, with an R^2 between 0.73 and 0.90, RMSE around 5 µg/m³ and small biases. Next to this validation, the performance of different model parts is shown, in order to provide information on the importance of the different components.

Key words: *validation, street canyons, NO_2 concentrations, passive samplers*

INTRODUCTION

The European annual NO_2 limit of 40 µg/m³ has to be reached at every location. However, Eulerian models have limited spatial resolution and will provide an average concentration over a larger zone, typically about 1 km². A concentration in this zone which is lower than the limit is not instructive in assessing whether the limit is reached at every location within this zone.

Measurements can solve this problem partially as they can measure at specific hotspots, although they are typically limited in space or time. As such, measurements do not provide concentrations averaged over a certain zone but result in point concentrations. While a well-distributed measurement network can thus give reliable information about exceedances of the European limits, it is in fact a series of point measurements. As a result, compliance to European Union limit values at all air quality monitoring stations does not necessary imply a compliance at every location in the area.

It is therefore essential to create a reliable modelling framework which is able to capture both the spatial diverseness of the concentrations on a street-level scale, while still providing complete coverage over the studied region. This paper evaluates such an integrated modeling framework against independent measurements in the city of Antwerp. A comparison with measured concentration over two seasons is presented and the performance of different model components is discussed. As such, we can be assured that major characteristics of the concentration distribution are captured by the model.

MEASUREMENTS

Measurements reported in this paper are part of a larger multidisciplinary study (HAEPS; Health Effects of Air Pollution in Antwerp Schools) dealing with health impact of traffic related air pollution on school children. To assess the exposure of the children at home, air quality measurements were performed at selected home locations.

NO_2 was measured over 7 days at different locations (chosen to represent different ranges in concentration fields such as street canyon locations, urban traffic locations and urban background locations) in an urban area using diffusive sampling tubes (IVL, Sweden; Ferm and Svanberg (1997)) resulting in weekly average concentrations. The locations are characterised by differences in traffic exposure. Diffusive samplers are placed in a dedicated rain shield attached to a rainwater pipe, a balcony or a streetlamp, near the front door.

At each location, NO_2 was monitored during late spring (May – June 2011) and late autumn (November – December 2011). In both seasons, measurements were performed at 8 locations simultaneously during 5 consecutive weeks resulting in 40 locations sampled. In addition, all 40 locations were sampled simultaneously for one week in each season, including also 12 extra locations, resulting in 52 locations. During the entire sampling campaign, NO_2 was measured at an urban location of the AQ monitoring network.

The concentrations measured over different times are identified by season and week number. Measurements in late Spring or late Autumn are denoted by respectively S and A. The sample week is indicated by w1-w5 for week 1 up to week 5 respectively and by wAll for sampling performed over all locations simultaneously. Combining these time-related indicators, this results in e.g. S_w2 for the second week in the Spring campaign and A_wAll for the week in autumn in which all locations were measured simultaneously.

Measurements for which the location was separated from the adjacent road by buildings (2 measurement locations), or the location was situated outside of the city of Antwerp (4 measurements locations) were not taken into account in this validation. As a result, we end up with 185 weekly average NO_2 concentrations.

MODEL SETUP

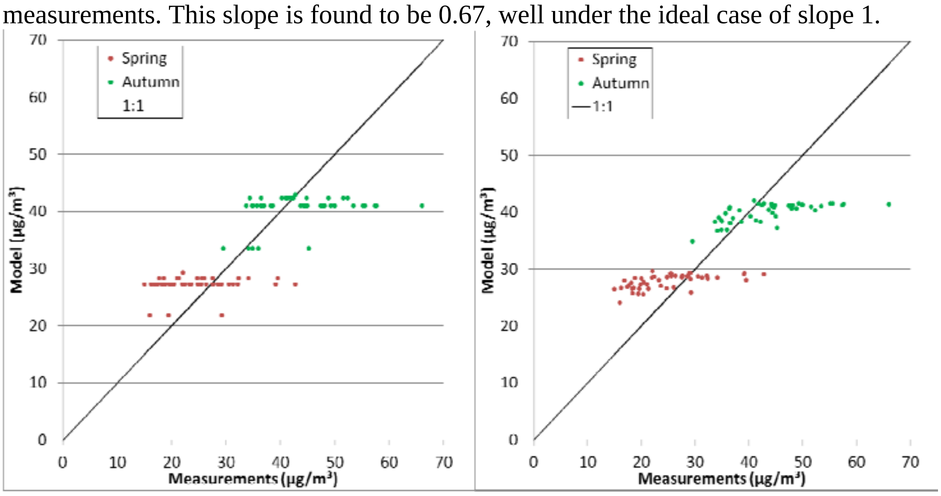
An integrated model chain has been set up to assess the air quality at the local (street level) scale, including both regional variability as well as local variation in sources of air pollution. The model chain is shown in Figure 2 and the different components are discussed in the next paragraphs. The MIMOSA4 emission model (Mensink et al., 2000; Vankerkom et al., 2009) is used to calculate local traffic emissions. The resulting spatially and temporally distributed emissions are used in the bi-Gaussian model IFDM (Lefebvre et al., 2011a; 2011b). These results are coupled to output of the land-use regression model RIO (Hooybergs et al., 2006; Janssen et al., 2008). A method to avoid double counting of the (local) emissions by the different models is applied (Lefebvre et al., 2011b). Finally the output of the IFDM model is coupled as boundary conditions to the IFDM street canyon module. In all these coupling steps, care is taken to consistently take into account the fast NO_x-O_3-chemistry. Finally, the results of the IFDM model and the IFDM street canyon module are 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 integrated model chain has been used to perform simulations for the city of Antwerp, using meteorological data of a local meteo station, situated in the northern part of the city.

VALIDATION

The Integrated Model Chain

First of all, we compare all weekly model values to all weekly measurement values (not shown). This yields a very good correlation (R^2=0.86), combined with a small RMSE (5.28 µg/m³) and a low bias (1.5 µg/m³). However, as we have combined measurements at different locations in both seasons for several separate weeks the resulting correlation might be artificially increased. This is due to the fact that the late autumn concentrations are systematically higher than the late spring concentrations. As this seasonal effect is covered by RIO (which takes into account the concentrations measured in the stations of the telemetric network around Antwerp), we automatically get a large R^2 by using all the measurement values together. Therefore, we will focus our analysis on the two weeks with the majority of the data, one in autumn, and one in spring (Figure 1, lower right). This leads to a similar R^2 (0.87), RMSE (5.31 µg/m³) and a somewhat higher bias (1.91 µg/m³). However, if we only look at concurrent measurements, i.e., measurements that have been made during the same week, we get an R^2 of respectively 0.80 and 0.62 in spring and autumn, an RMSE between 5 and 6 µg/m³ for both weeks and a bias ranging from almost 5 µg/m³ in spring to about -1 µg/m³ in autumn. The latter values do not mix spatial and temporal correlation and are thus a good indication of the spatial predictive power of the model. As can be seen in Figure 1, lower right, the model underestimates the higher concentrations and overestimates the lower concentrations. The spatial and temporal variability of the model is thus slightly too small. The underestimation of the spatial variability is also represented by the slope of the linear regression of the modeled values on the measurements. This slope is found to be 0.67, well under the ideal case of slope 1.



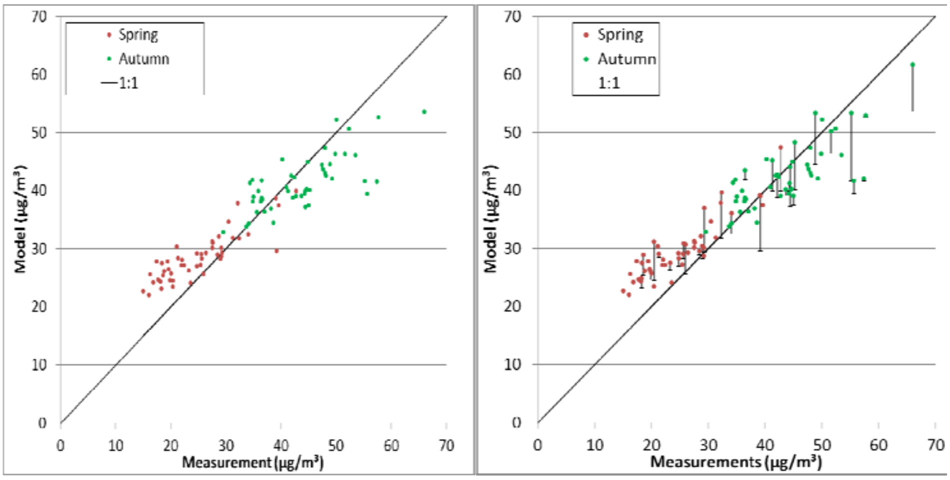


Figure 1: Validation plots for different steps in the methodology. Upper left: for RIO. Upper right: for the interpolated RIO. Lower left: for RIO+IFDM. Lower right: the complete model chain. Every point represents the weekly averaged concentration (in µg/m³) measured (X-axis) and modeled (Y-axis). The black lines on the graph represent the street canyon contribution.

Step by Step

In the previous section, the overall model performance was evaluated. In this section we want to investigate to what extent each of the different model steps improves the modeled concentrations. This is done by comparing the slopes of the regression curve, correlation coefficients, RMSEs and biases for the different model steps. For this analysis, we have repeated the validation exercise for the different steps in the model chain setup:

1. The RIO model (Figure 2, upper left panel; Figure 1, upper left panel);
2. The interpolated RIO model (Figure 2, upper right panel; Figure 1, upper right panel);
3. The interpolated RIO combined with IFDM (Figure 2, lower left panel; Figure 2, lower left panel);
4. The full integrated model chain, taking into account street canyon effects (Figure 2, lower right panel; Figure 2, lower right panel).

Figure 1 upper left panel shows that the RIO model cannot account for the spatial variability of the measurements within an urban scale. This is as expected, as the RIO model has a resolution of only 4x4 km². Indeed, all the measurement locations can be found in 4 RIO cells. However, the bias in the RIO model is already relatively small, as is the RMSE. Nevertheless, the R^2 is small when evaluating the autumn and the spring week separately, although it is quite high (0.65) for the combination of both seasons. This shows that RIO is representing correctly the difference between the autumn and the spring week. The difference in bias between the autumn and the spring week is about 16%, with underestimation of the concentrations in the autumn season and overestimation in the spring season. This shows that the RIO model is responsible for a large part of the (small) bias in the final results, although the bias in both RIO and the integrated model chain is quite limited.

The interpolation of the RIO results (4x4 km²) to the IFDM grid (Figure 1, upper right panel) does not lead to significant changes in the average modeled concentrations. However, the discrepancy between the seasonal biases increases, with a stronger negative bias in autumn and a stronger positive bias in spring. Indeed, the interpolation step increases concentrations in cells surrounded by cells with higher concentrations, while decreasing concentrations in cells surrounded by cells with lower concentrations. In spring, the RIO cells north of the study domain have higher concentrations whereas in autumn, the cells with the highest concentrations in the whole region are those of the study domain. This difference can probably be attributed to the heating emissions inside the city centre which are much more important in late autumn than in late spring. As a result the city centre displays higher concentrations that its harbor in the North during autumn but not during spring. Next to the change in bias, there is an increase of correlation due to the interpolation and a decrease in the RMSE, although the skill still remains low at this local scale.

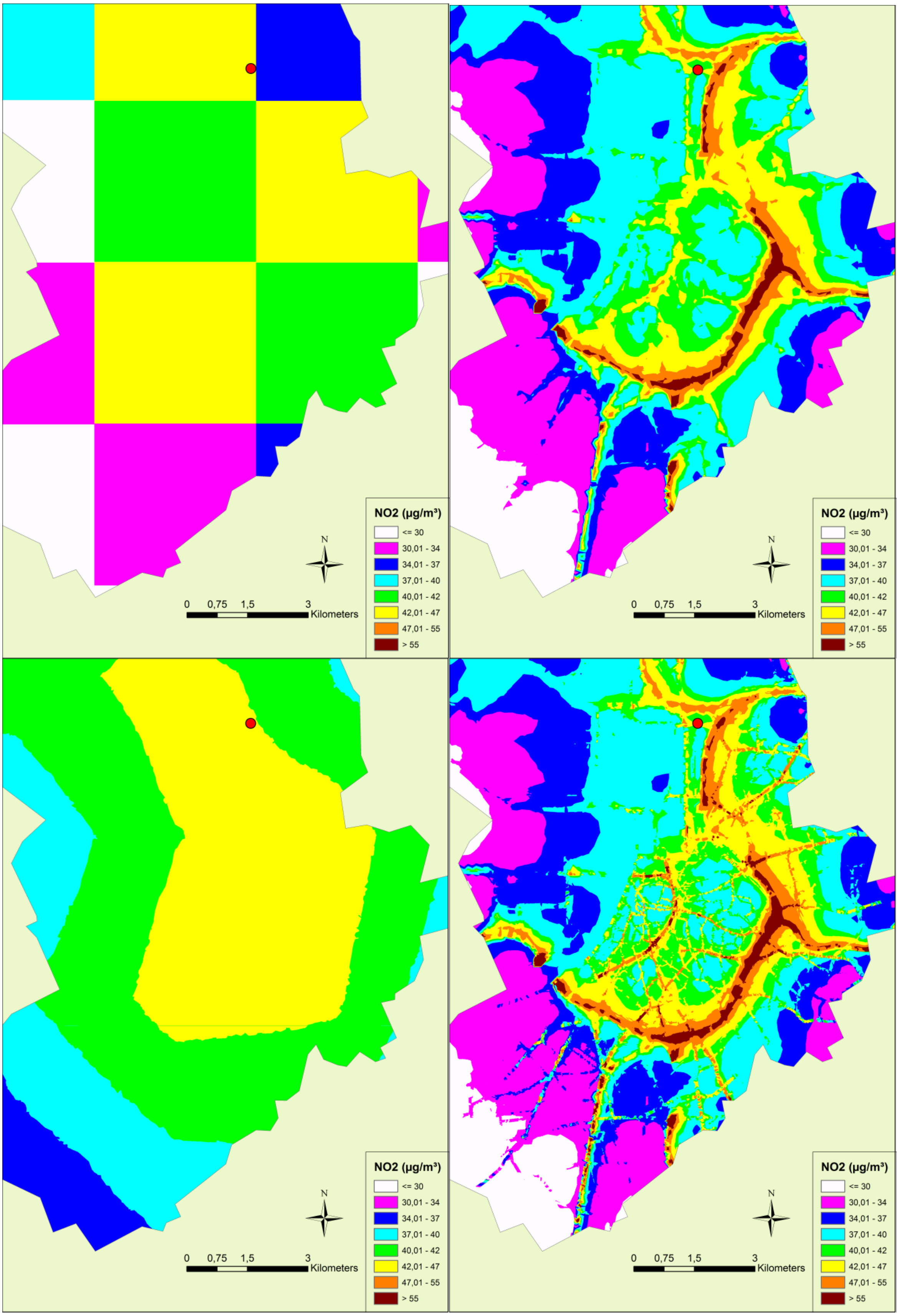


Figure 2: Concentration maps (NO_2, in µg/m³) in different steps of the methodology for the AwAll-week. Upper left: the RIO-map. Upper right: the interpolated RIO-map. Lower left: the concentration map including IFDM. Lower right: the complete map. The red dot is the location of the meteorology measurement. Only concentrations within the city of Antwerp are shown.

The addition of IFDM, taking into account local emissions and their characteristics, (Figure 1, lower left panel) leads to an important change in the validation parameters. First of all, the R^2 values rise from 0.75 to 0.86. However, for the separate seasons, the rise is even more pronounced with values increasing from 0.46 to 0.53 in autumn and soaring from 0.34 to 0.74 in spring . The average modeled concentration is higher when IFDM is included, leading to an elimination of the bias averaged over both seasons. However, the spread between the two seasons remains approximately at the same level as for the interpolated RIO results alone. Furthermore, the slope of the regression also increases strongly. Finally, the RMSE values decrease, confirming the increased skill of the model once IFDM is included.

The increase of the model skill with and without the street canyon model seems rather small (Figure 1, lower right panel). However, this is due to the fact that many of the locations on which measurements were performed are not found in a street canyon and are thus not affected by the inclusion the street canyon model (Figure 1, lower right panel). Overall, the inclusion of the street canyon model increases slightly the R^2, the bias and the RMSE. However, for individual locations, it increases the skill of the model. This can be seen in Figure 8 (right panel), where the black lines represent the street canyon contribution in order to show the effect of adding the street canyon model to the model chain. The resulting effect is also seen in the improvement of the slope of the regression curve.

CONCLUSIONS

This paper presents an integrated model framework for calculating concentrations at the urban to street level scale. The method is validated by an NO_2 monitoring campaign, using passive samplers in a late spring and late autumn period. The validation analysis show that the model is able to represent the spatial variability within an urban environment. As a result, the model can be used to improve the exposure assessment of people living in the urban area and to complement fixed monitoring stations that are often only limited in number in a city.

The validation analysis was performed for the different steps in the model chain revealing the strengths of the different components in creating these concentration maps. First of all, it was shown that RIO is well able to represent the differences between the seasons. However, due to the relatively low resolution, it is not capable of representing the spatial variability between the different locations. Interpolating these RIO-results to the measured locations does not add much skill to the model. The use of the plume model improves strongly the accuracy of the results. In particular, the RMSE decreases and the R^2 soars. This last parameter improves even more when taking into account street canyons.

More information can be found in Lefebvre et al. (2013).

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