COMPARISON OF THE IFDM BUILDING DOWNWASH MODEL PREDICTIONS WITH FIELD DATA

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Abstract: Building downwash greatly affects the dispersion of pollutants in the vicinity of buildings. The building downwash parameterization for plume models proposed in Cosemans et al. (2012) is integrated in a plume model (IFDM, Immission Frequency Distribution Model) and the predictions of this model are compared with real-life field data. The field data are time series for four monitoring sites of daily arsenic (As) concentrations measured over a two year period (2010, 2011) near a plant that emits some As, as shown by in-stack emission measurements. These As emissions vary considerable over time. First, the modelling is done without and with building downwash using constant averaged emission for the two-year period. From this, we find that the measured concentrations fall apart in two partitions. During four (out of 24) 'outlier'-months, measured concentrations are about four times higher than during the other twenty months. Leaving out the 'outlier-months' partition from the model evaluation, we find that without the building downwash model, 5 of the 8 calculated yearly concentrations have a bias larger than 50% and none has a bias lower than 30%, whereas with the building downwash model, none have a bias larger than 50% and 7 out of 8 have a bias lower than 30%. In other words: measured yearly averages (without 'outliers') range from 6 till 34 ng/m³; modelling without building downwash gives 4 till 14 ng/m³; modelling with building downwash gives 7 till 36 ng/m³. Secondly, we modelled using a time-varying emission scenario. Measured yearly averages using all data range from 9.6 till 44 ng/m³; modelling without building downwash gives 4.6 till 13 ng/m³; modelling with building downwash gives 10 till 40 ng/m³. Finally, not only the yearly averages, but also the time series of measured and computed concentrations are evaluated, with R²-values up to 0.83.

Key words: *building downwash, Gaussian modelling, evaluation*

INTRODUCTION

Olesen et al. (2009) have shown that the state of the art of gaussian plume modelling at short distances from the building is disappointing, due to an inaccurate description of building downwash effects. They compared two major existing building downwash plume models and one computational fluid dynamics (CFD) model with the measurements of the Thompson wind tunnel dataset (Thompson, 1991; 1993). The CFD model shows reasonable correspondence to the measurements. However, the two plume models fail to reproduce some of the major characteristics such as the order of magnitude of the ground-level concentrations close to the building.

Therefore, in Cosemans et al. (2012), further denoted as CLM12, a new parameterization for building downwash in plume models has been developed on the basis of the Thompson (1991; 1993) dataset. The CLM12 parameterization reproduces the following major effects of building downwash by functions to quantify the following phenomena:

- Plume material, following the streamlines, is lowered towards the ground by ΔH over a distance x_{FPH}, where x_{FPH} is approximately the distance downwind the building where the maximum ground-level concentration is found;
- The increased turbulence caused by the building causes an upwind displacement (Δx_{DISP}) of the plume origin;
- Clean air gets mixed into the plume more rapidly than in absence of a building, which is reproduced by an increase of the virtual source origin value till a distance roughly equal to $2*x_{FPH}$;
- Finally, building downwash has an important effect on the plume rise.

It has been shown in CLM12 that this parameterization reproduces the Thompson dataset well. However, CLM12 did not show that the model is capable of reproducing real-life concentrations influenced by building downwash.

MODEL

The Immission Frequency Distribution Model (IFDM) is a bi-Gaussian plume model, used in Belgium since 1972 for impact assessment of complex configurations of industrial, residential, traffic and agricultural pollutant sources on a local scale. The Gaussian dispersion parameters depend on the Bulk Richardson number measured along a 120 m high meteorological tower located at the nuclear energy research site at Mol (Bultynck and Malet, 1972). More information on the IFDM model can be found in the European Model Database (http://airclimate.eionet.europa.eu/databases/MDS/index_html), which includes an extensive set of references regarding the validation of this model.

The parameterization proposed by CLM12 is based on single stack-single building configurations (almost 400 in total, all having the wind direction frontal to a building face) and the buildings having four different height/width/length ratios. The features additional to the CLM12 parametrization needed for arbitrary building-stack configurations as found in the real world are:

- Building height: the complete model is scaled to return to a building height as in the Thompson dataset.
- Building types: an interpolation is added between the different building types.
- Building dimensions for non-frontal winds: these are calculated based on a scheme of the OML-model (Olesen and Genikhovich, 2000).
- Most influential building: a scheme is devised to define which of the buildings is the most influential.
- Wind speed dependency: the vertical movement of the plume axis due to building downwash is made wind speed dependent
- Adaptations influencing the plume width: an adaptation of the original algorithm is made in order to eliminate spurious widening of the plumes.

MEASUREMENTS

Ground-level concentrations of As, measured near an industry plant located in flat terrain that emits small amounts of Arsenic (As) is used to evaluate the model. Four measurement locations (Figure 2) are operated by the Flemish Environmental Agency (VMM) and provide daily concentrations of As in PM_{10} for the period 2010-2011. The locations are indicated by the codes HB23, HB17, HB18 and HB01. The measurements (daily resolution) were delivered in integers in ng/m^3. Measured and modeled concentrations of 0 ng/m^3 are converted to 0.5 ng/m^3 in order to take into account the detection limit.

Two regions with presence of As-sources have been located within the company terrain (further called emission zones). In emission zone I, which is located within 150 m south-southwest of HB23, the pollutant is known to originate from several point sources on top of a large building (about 55 x 180 m^2, with a height of about 15 m). The sources have heights ranging from 18 to 60 m above ground level. Some of these sources emit at high temperatures, some have a reasonable mechanical momentum, while others are cold and lack mechanical momentum. The sources are regularly measured, and are shown to have a strongly variable emission. Another measurement instrument (Prbx, Pourbaix-measurement) is located in the recirculation loop over the roof of a building with some of the As-sources. At this location, As in TSP (total suspended particles) is measured, instead of As in PM_{10}, which is measured at the other locations. The weather dependency of these As-TSP concentrations is small. Indeed, in only 21% of the time (including downtime of the emission sources), the daily As-TSP concentration is less than 10 ng/m^3. If the Prbx-measurements were not in the recirculation loop, this percentage would be much higher as these high concentrations would have been observed only when the wind blows from the sources to the measurement.

In emission zone II, one of the sources has been recently identified. Region II is located about 650m west-southwest from HB23 and about 500 m southwest of HB17. The known source in this region is emitting at a height of 16 m which lacks significant plume rise. Furthermore, the source is surrounded by 14 buildings with heights ranging from 6 to 34 meter and one building ranging up to 60 meter. It is known that some more sources of As are present in this region, but these sources have not yet been identified and thus their emissions are currently unknown.

EVALUATION OF THE MODEL

Without Outlier-months

Two simulations have been made that use hourly meteorological data and two-year-averaged source characteristics. The first computation has no building downwash (const_nobd), the second computation takes into account building downwash (const_bd). The emission of the source was set to zero when the installation was not working.

The time series (Figure 1 for monitoring site HB23 (lower left) shows that two periods, namely (1) from January 2010 till the end of March 2010 and (2) the month February 2011, have very high measured concentrations. These high concentrations could be considered as ‘outliers’ in the two year time series (see e.g. Cosemans et. al, (2008), for a definition of outliers using the lognormal frequency distribution). Similar outliers are found in the time series for the other monitoring sites. They are due to periods with much higher emissions than during the rest of the 2-year period used in this study.

Statistics given in this section refer to the data without these ‘outliers’.

We see in Table 1 that model performance with building downwash (Const_bd) is greatly improved compared to model results without building downwash (Const-nobd). The parameters investigated are bias, the difference between the average of measured and computed concentrations, the RMSE (root mean square error), and the square of the regression coefficient R^2, a measure for the amount of variation in the measured time series that is explained by the modeled ones. The model performance statistics are given not only for the 1-day averages, but also for the central moving 14-day averages. The bias for the 14-day averages is equal to that of the 1-day averages, but the RMSE and R^2 are much better, probably because the impact of short term variations of the highly variable emissions have been ‘smoothed’.

Monitoring site	**Model Constant emissions**	**Daily averages**			**Central moving 14 day averages**		
		BIAS ng/m^3	**RMSE ng/m^3**	**R^2**	**BIAS ng/m^3**	**RMSE ng/m^3**	**R^2**
HB01	Const_nobd	-4.76	17.37	0.19	-4.86	7.62	0.41
	Const_bd	0.55	17.63	0.27	0.55	8.34	0.47
HB17	Const_nobd	-7.19	27.43	0.14	-7.43	12.73	0.37
	Const_bd	0.80	29.32	0.20	0.80	14.19	0.45
HB18	Const_nobd	-2.30	8.30	0.36	-2.33	3.66	0.59
	Const_bd	2.03	10.36	0.42	2.03	5.74	0.64
HB23	Const_nobd	-20.09	47.43	0.31	-20.14	23.98	0.55
	Const_bd	2.05	42.02	0.36	2.05	17.60	0.64

Table 1: For every measurement location (column 1) and every scenario (column 2), the BIAS (in ng/m^3), RMSE (in ng/m^3) and R^2 value for the daily averaged measurement/modelling (columns 3-5) and for the 14-days averaged measurement/modelling (columns 6-8), for the data excluding outliers.

With Outlier-months

In this section, we use time-dependent data of the emission source, taking into account the variability of the emissions using the Pourbaix-measurements on the roof of the building. Again, two simulations have been performed. The first one has no building downwash (var_nobd), while the second one takes into account building downwash (var_bd). Both simulations have variable emissions, created by scaling the emissions of sources in emission zone I with the results of the Prbx-measurement, so that the average emission is kept constant. Of course, this does not account for the possible intersource variability, nor is it a perfect measure of the source variability. Nevertheless, it can help to determine the exposure experienced by the population.

Statistics given in this section refer to the data including the ‘outliers’.

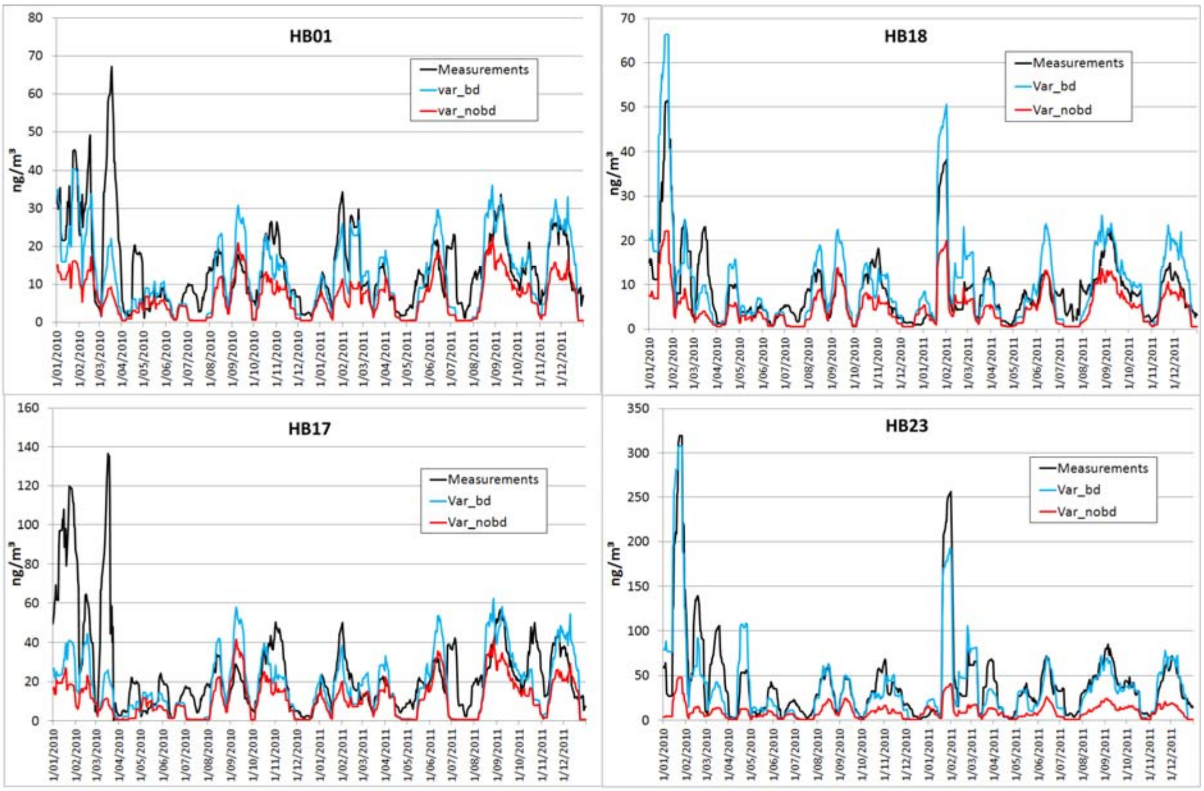

Figure 1: 14 day average measurements and modelling (in ng/m³) at the four measurement locations for the two scenarios with variable emissions. Building downwash: blue lines. No building downwash: red lines; Measurements: black lines.

With 'outliers' Variable emissions	**Year**	**Number of measurements**	**Period Average concentration (ng/m³)**		
Monitoring site			**Measured**	**Var_nobd**	**Var_bd**
HB01	2010	358	16	6.6	11.9
	2011	364	14	7.5	13.4
HB17	2010	349	29	10.1	16.3
	2011	357	23	13.0	20.7
HB18	2010	364	9.6	4.6	10.2
	2011	348	8.8	5.4	10.8
HB23	2010	364	44	8.7	40.3
	2011	357	41	11.0	37.0

Table 2: Yearly averaged measurement and model values (in ng/m³) for the different measurement locations and model scenarios, taking into account the outliers. In red: |bias| > 50% of the measurements. In green: |bias| < 30% of the measurements.

Looking at the annual mean characteristics, we see again a marked improvement between the model without and with building downwash (Table 2). Furthermore, the results show the ability to reproduce some of the outliers in the measurements (Figure 1, Table 3), especially for the high peaks at the beginning of February 2011. This difference is mainly observed for the measurement locations which are most influenced by the sources of emission zone I (respectively HB23, HB18 and to a lesser degree HB01, Table 3). The improvement in the model is most prominent in the dataset with the outliers, which are now in large part explained by the model (especially at HB18 and HB23). In HB18, the modelled Var-bd average is higher than is measured, in the other sites the modelled value is lower than measured, leaving 'room' for the impact of still unquantified emissions.

Monitoring site	**Model (Estimated time varying emissions)**	**Daily averages**			**Central moving 14 day averages**		
		BIAS ng/m^3	**RMSE ng/m^3**	**R^2**	**BIAS ng/m^3**	**RMSE ng/m^3**	**R^2**
HB01	Var_nobd	-7.56	23.52	0.24	-7.49	11.60	0.32
	Var_bd	-1.97	23.72	0.30	-1.97	8.34	0.48
HB17	Var_nobd	-13.80	49.35	0.08	-13.83	25.22	0.16
	Var_bd	-6.82	48.37	0.12	-6.82	21.83	0.24
HB18	Var_nobd	-4.04	13.74	0.51	-3.89	6.34	0.70
	Var_bd	1.45	19.56	0.52	1.45	5.50	0.80
HB23	Var_nobd	-32.68	99.14	0.62	-31.96	52.64	0.75
	Var_bd	-3.91	70.71	0.65	-3.91	20.72	0.83

Table 3: For every measurement location (column 1) and every scenario (column 2), the BIAS (in ng/m^3), RMSE (in ng/m^3) and R^2 value for the daily averaged measurement/modelling (columns 3-5) and for the 14-days averaged measurement/modelling (columns 6-8), for all data including outliers.

CONCLUSIONS

In this paper, several points concerning building downwash have been shown. First of all, the strong influence of building downwash on measurement sites close to the sources has been demonstrated. Secondly, the inclusion of a building downwash parameterization into a plume model has been established, explaining the choices that have been made. These choices can serve as a guide to other modelling groups wishing to include the same parameterization in their plume models. Thirdly, it has been shown that the building downwash parameterization improves the accuracy of the model in simulating cases affected by building downwash. Furthermore, it has been demonstrated that the model is capable of predicting at a sufficient accuracy the annual mean concentrations, so that estimations can be made if the European norms will be met. Finally, inclusion of more detailed emission data has revealed that the model is also capable of explaining the outliers which have been measured in the recent past. Therefore, the model can also be used in order to assess in detail the exposure of the population to the emitted pollutants. More information and a more thorough validation can be found in Lefebvre et al. (2013).

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