VALIDATION OF THE AIRVIRO GAUSSIAN PLUME AND STREET CANYON MODEL FOR THE PREDICTION OF NO_x AND NO_2 CONCENTRATIONS ARISING FROM ROAD TRAFFIC

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INTRODUCTION

Under Section IV of the Environment Act 1995, local authorities within the UK are obliged to monitor and manage air quality within their areas. Local Air Quality Management (LAQM) is achieved via a framework of Review & Assessment (R&A) exercises. Several local authorities within the UK, ranging from rural regional authorities to large city councils, have adopted the Airviro Air Quality Management System in order to undertake R&A exercises.

Airviro is a modular system developed by the Swedish Meteorological and Hydrological Institute (SMHI). Individual modules are available within the system for the automatic collection of meteorology and pollutant concentrations, the creation of a dynamic emission database of grid, point, area and line (road) sources, and the modelling of pollutant dispersion via Gaussian Plume and Street Canyon models.

In order to validate the Gaussian and Street Canyon models within Airviro, annual-averaged ambient NO_2 concentrations predicted by these models, were compared to annual-averaged NO_2 concentrations arising from traffic emissions and monitored by diffusion tubes during 2004 and 2005. In this paper, validation study results are presented for three local authorities within the UK; Copeland Borough Council (CBC), Carlisle City Council (CCC) and Dudley Metropolitan Borough Council (DMBC). An assessment of the empirical method by which NO_2 concentrations were derived from NOx concentrations is also presented.

VALIDATION STUDY AREAS

Copeland Borough Council is a regional authority located in rural West Cumbria covering an area of 735 km^2 and with only 690,000 inhabitants distributed primarily between four towns. NOx emissions data within the borough are limited to 24 point sources and 59 road links, many of which make up just seven trunk roads. Carlisle City Council is a relatively small city occupying an area less than 60 km^2 and having 69,000 inhabitants. NOx emissions data within the city are limited to six point sources and 65 road links. In contrast to these local authorities, Dudley Metropolitan Borough Council is located on the western side of the West Midlands conurbation occupying 98 km^2 and having 302,000 inhabitants. NOx emissions data within the borough are available for 175 point sources and 720 road links. The three authorities provided a wide range of monitored annual average ambient NO_2 concentrations (4 – 55 $\mu g\ m^{-3}$) to which model predicted NO_2 concentrations could be compared.

For each of the three study areas, NOx emissions data were used to create dynamic emission databases (EDBs) within the Airviro Air Quality Management System. Given the limited NOx emission data available for CBC and CCC, 1 x 1 km grid emissions of NOx arising from each of the main UNECE sectors were obtained from the National Atmospheric Emissions Inventory (NAEI) (http://www.naei.org.uk/). Grid emissions data were edited to avoid the double counting of emissions from road and point sources that were specifically included in the EDBs. Edited grid emissions were then uploaded into the respective EDBs created for these two authorities.

GAUSSIAN AND STREET CANYON MODEL SIMULATIONS

For each of the three validation studies, initial Gaussian plume dispersion simulations were run for a model domain encompassing the entire area of the local authority on a coarse grid resolution (between 250 and 1000 m). Predicted NOx concentrations at several specific locations along the boundary of the model domain, where the impact of traffic and industry emissions would be minimal, allowed an estimation of background NOx concentrations originating from outside the area of each authority to be estimated. Gaussian plume simulations were also run at identical grid resolutions to those used during initial simulations for each study area, but covering a smaller model domain that encompassed the location of NO_2 diffusion tubes. Comparison of the ambient NOx concentrations predicted by the two simulations allowed regional background NOx concentrations to be derived for each study area. Finally, Gaussian simulations were run for each study area using a fine grid resolution (between 25 and 50 m) for traffic emissions only. The three successive dispersion simulation results allowed total ambient concentrations (national background + regional background + local traffic) to be derived at the location of NO_2 diffusion tubes for each study area. For those NO_2 diffusion tubes known to be located within a street canyon (three in the CCC study and five in the DMBC study), the Street Canyon Model within the Airviro system was used to derive ambient NOx concentrations from local traffic. In all cases, NO_2 concentrations were derived from predicted total NOx concentrations using the Derwent-Middleton formula (Derwent, R.G and D.R. Middleton, 1996).

RESULTS

The relationship between ambient NO_2 concentrations predicted using the Airviro Gaussian and Street Canyon models and those monitored using diffusion tubes are presented below in Figure 1.

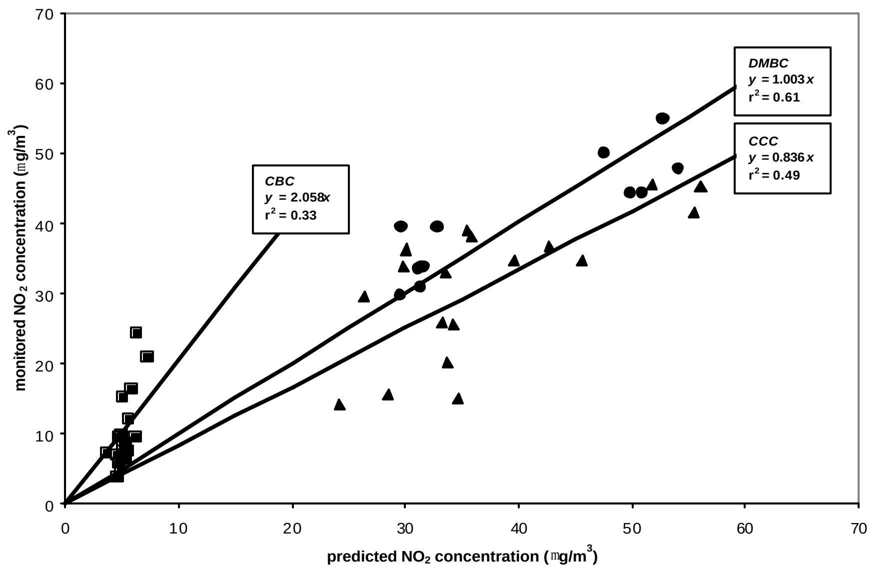

Fig. 1; Relationship between ambient concentrations of NO_2 predicted using the Gaussian and Street Canyon models in Airviro with those monitored by diffusion tubes for Copeland Borough Council (CBC) in 2004 (squares),Carlisle City Council (CCC) in 2004 (triangles) and Dudley Metropolitan Borough Council (DMBC) in 2005 (circles).

Fitting the data to a linear regression model revealed a strong and significant relationship between predicted and monitored NO_2 concentrations with >60% of variance accounted for during the DMBC study, where extensive data were available on point and road NOx emissions. Results obtained from the CBC study revealed that model predicted NO_2

concentrations were consistently and significantly lower than those monitored. Such observations are likely to be a reflection of the limited point and road emissions data available for this study and thus the heavy reliance on generic grid emissions. For the CCC study, there was a tendency for model predictions of NO_2 to be higher than those monitored. In order to account for the under- or over-prediction of ambient NO_2 concentrations, appropriate correction factors were derived for model predicted NO_2 concentrations from linear regression analysis.

A comparison of corrected NO_2 model predictions with those monitored by diffusion tubes for each of the three study areas are presented in Table 1 – 3. It is suggested in the UK LAQM Technical Guidance document TG3(00) (DETR, 2000), that an acceptable level of uncertainty for dispersion modelling results is ± 50%. It can be seen from the results that 80% of model predictions for CBC were within ± 50% of those monitored (Table 1), whilst for the CCC (Table 2) and DMBC (Table 3) studies, 94% and 100%, respectively, of model predictions were within ±50% of monitored concentrations.

Comparing measured and predicted concentrations of NO_2 allowed the determination of the Root Mean Square of the Difference (RMSD) for each study area, providing an indication of model accuracy. RMSD analysis demonstrated that the uncertainty limits for the dispersion model were ± 4, ± 7 and ± 5 $\mu g\ m^{-3}$ for CBC, CCC and DMBC, respectively.

Table 1. Comparison of ambient NO_2 concentrations predicted by the Airviro Gaussian model and those monitored using diffusion tubes by Copeland Borough Council during 2004.

Site	Predicted NO_2* concentration ($\mu g/m^3$)	Measured NO_2 concentration ($\mu g/m^3$)	% difference
1	15	21	-30.3
2	13	25	-48.4
3	12	10	+28.9
4	10	9	+16.2
5	11	8	+41.9
6	12	17	-29.1
7	10	8	+32.8
8	9	6	+60.6
9	11	12	-9.2
10	11	9	+22.1
11	10	10	-2.6
12	10	10	-1.1
13	9	7	+27.2
14	9	4	+123.8
15	10	9	+20.4
16	10	15	-34.3
17	10	7	+49.2
18	11	7	+63.6
19	7	7	-3.5
20	10	5	+83.3
RMSD between predicted and monitored NO_2 concentrations = 4 ($\mu g/m^3$)			

* = model predicted NO_2 concentrations multiplied by correction factor of 2.06

Table 2. Comparison of ambient NO_2 concentrations predicted by the Airviro Gaussian and Street Canyon models and those monitored using diffusions tubes by Carlisle City Council during 2004. Numbers in bold are NO_2 concentrations predicted using the Street Canyon Model.

Site	Predicted NO_2* concentration ($\mu g/m^3$)	Measured NO_2 concentration ($\mu g/m^3$)	% difference
1	20	14	+43.3
2	**47**	45	+3.4
3	38	35	+10.1
4	28	26	+7.5
5	29	26	+11.8
6	29	15	+92.1
7	24	16	+53.9
8	28	20	+40.2
9	33	35	-4.7
10	36	37	-2.8
11	25	36	-30.7
12	25	34	-26.3
13	**46**	42	+11.3
14	22	30	-25.4
15	28	33	-14.9
16	**43**	46	-5.0
17	30	38	-21.4
18	30	39	-23.9

RMSD between predicted and monitored NO_2 concentrations = 7 ($\mu g/m^3$)

* = model predicted NO_2 concentrations multiplied by correction factor of 0.84

Table 3. Comparison of ambient NO_2 concentrations predicted by the Airviro Gaussian and Street Canyon models and those monitored using diffusions tubes by Dudley Metropolitan Borough Council during 2005. Numbers in bold are NO_2 concentrations predicted using the Street Canyon Model.

Site	Predicted NO_2* concentration ($\mu g/m^3$)	Measured NO_2 concentration ($\mu g/m^3$)	% difference
1	**54**	48	-13.2
2	**53**	55	+3.8
3	**48**	50	+4.7
4	**50**	44	-12.7
5	**51**	44	-14.8
6	32	34	+7.1
7	30	40	+25.0
8	30	30	+0.3
9	31	34	+7.3
10	31	31	-1.6
11	32	34	+6.7
12	33	40	+16.8

RMSD between predicted and monitored NO_2 concentrations = 5 ($\mu g/m^3$)

* = model predicted NO_2 concentrations multiplied by correction factor of 1.00

In order to derive uncertainties in model predicted annual averaged NO_2 concentrations resulting from the empirical NOx to NO_2 conversion, ambient NO_2 concentrations derived using the Derwent-Middleton formula were compared to monitored concentrations for 76 chemiluminescent monitoring sites located throughout the UK in 2005. Figure 2 shows the relationship between empirically derived and measured NO_2 concentrations for the chemiluminescent sites.

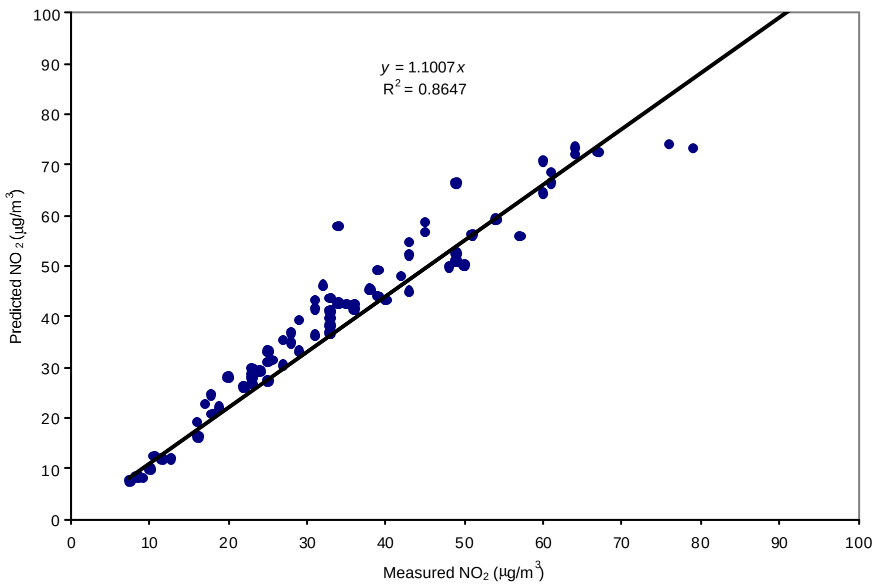

Fig. 2; Relationship between annual averaged ambient concentrations of NO_2 derived empirically using the Derwent-Middleton formula and those measured by chemiluminescent monitors located throughout the UK in 2005 .

It can be seen from Figure 2 that NO_2 concentrations derived empirically using the Derwent-Middleton formula are similar to those measured for a wide range of ambient concentrations (7 – 80 μg m^{-3}). Indeed, linear regression analysis on the relationship between the two concentrations revealed that 85% of variance was accounted for. Differences between empirically derived and monitored NO_2 concentrations ranged between 0.5 and 36% with an average difference of 11% calculated across all 76 chemiluminescent monitoring sites. Such observations suggest, therefore, that uncertainties associated with NO_2 concentrations derived empirically from predicted NOx concentrations are relatively small.

CONCLUSIONS

From the results presented in this paper, it can be concluded that the Gaussian plume and Street Canyon models in the Airviro Air Quality Management System provide reliable and meaningful predictions of ambient NO_2 concentrations arising from road traffic emissions. As such, the Airviro system provides a robust tool for the local management of air quality. Given the validity of model predicted NO_2 concentrations obtained from the DMBC study, where knowledge of point and road NOx emissions was extensive, this paper also clearly highlights the importance of a comprehensive emissions database when modelling ambient air concentrations.

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