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TRAFFIC POLLUTION MODELLING IN A COMPLEX URBAN STREET

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Abstract: This study presents the application of the Danish Operational Street Pollution Model (OSPM) in Buenos Aires city. Most of the street canyons in Buenos Aires are very irregular. The OSPM model is applied to estimate NO_x, NO_2 and CO concentrations in a street canyon of a five-lane avenue. The avenue axis is orientated E-W and the monitoring site is located on the southern side. Buildings on the northern side are quite regular and about 10 m high. On the southern side, building heights are irregular varying from 10m to 80m. There is a street intersection a few meters west of the monitoring site. The traffic in the avenue is about 38000veh/day and it is about 13000veh/day in the perpendicular street. Urban background concentrations are modelled with the DAUMOD model. Meteorological information registered at the domestic airport, located in the city, is used. Three months of hourly estimations have been compared with measurements. Though location of the monitoring station is not optimal for comparisons with the OSPM model estimations, model performance is good. As a whole, results slightly underestimate observed values. The fractional bias (FB) is 0.083 for NO_x estimations, 0.031 for NO_2 values and 0.077 for CO values. Furthermore, 80% of NO_x, 97% of NO_2 and 61% of CO estimated values are within a factor of 2 the observations. For wind directions from the sector where the intersection is located, the under-predicting (FBfn) and over-predicting (FBfp) components of FB are: FBfn(NO_x)=0.324, FBfp(NO_x)=0.056, FBfn(NO_2)=0.121, FBfp(NO_2)=0.079, FBfn(CO)=0.338 and FBfp(CO)=0.086. Underestimations can be mainly because traffic in the crossing street has not been included in model calculations.

Key words: *Street canyon; OSPM model; traffic pollution modelling; model evaluation; Buenos Aires*

INTRODUCTION
The increasing public concern on air quality in the city of Buenos Aires led local authorities to design and start the installation of an air quality monitoring network in the city. However, the network will be able to characterise the urban air pollution based on measurements at a few fixed points. This leads to a relatively high temporal resolution of the pollutant concentration evolution, while usually resulting in a rather poor spatial resolution. However, there are applications such as the estimation of the overall urban air quality or the exposure of the urban population to atmospheric pollution which require a much more detailed knowledge of the spatial variation of pollutant concentrations within individual streets. The purpose of this study is to apply the Danish Operational Street Pollution Model (OSPM) model 'operatively' using routine meteorological observations in the city and background contribution estimated using the DAUMOD model. The OSPM model has been successfully tested against monitor stations in Denmark, in other European countries, some cities in Asia and in New York (Berkowicz, R. 1998, 2000, Fu, L. *et al.*, 2000, Kukkonen, J. *et al.*, 2001, 2003, Aquilina, N. and A. Micallef, 2004, Gokhale, S.B. *et al.*, 2005, Vardoulakis, S. *et al.*, 2007, Berkowicz, R. *et al.*, 2006, 2008, Mensink, C. and G. Cosemans, 2008, Jensen, S.S. *et al.*, 2009).
This study is the first evaluation of the applicability of the OSPM model in the city of Buenos Aires, where most of the street canyons are irregular. Three months of estimated hourly concentrations of nitrogen oxides (NO_x), nitrogen dioxide (NO_2) and carbon monoxide (CO) are compared with measurements at one of the monitoring stations of the Environmental Protection Agency of the Government of the city of Buenos Aires.

THE MODELS
The OSPM is a parameterised semi-empirical model for flow and dispersion conditions in street canyons. The model calculates concentrations of exhaust gases using a combination of a plume model for the street direct contribution and a box model for the re-circulating part of pollutants in the street. The parameterisation of flow and dispersion conditions in street canyons was deduced from extensive analysis of experimental data and model tests. These results have been used to improve the model performance, especially with regard to different street configurations and a variety of meteorological conditions. For more detailed descriptions of the model, see Berkowicz, R. (1998, 2000). The application of OSPM model requires input data such as traffic in the street, street geometry, meteorological data and also background concentration contributions.
Background concentrations of NO_x, NO_2 and CO have been estimated using the urban atmospheric dispersion model DAUMODv.4 (Venegas, L.E. and N.A. Mazzeo, 2002, 2006). This version of the model estimates hourly-averaged NO_2 concentrations using a polynomial expression (Derwent, R.G. and D.R. Middleton, 1996, CERC, 2003).

SITE AND DATA
The monitoring station is located on the southern side of Córdoba Ave. (Figure 1) near the intersection with R. Peña St. This station will be part of the future air quality monitoring network of Buenos Aires city. It started to operate on June 2009. Córdoba Ave. is orientated E-W and it is approximately 30m wide. Measurement height is 2.5 m. Buildings on the northern side of this avenue are regular and low (approximately 10 m high). The height of the buildings on the southern side varies from 10 m to 80 m. The scheme of this street configuration considered in the OSPM runs is shown in Figure 2. The street intersection is included as an opening between buildings.

Figure 1. 3D perspective of monitoring site location (●) (Picture: Google Earth)

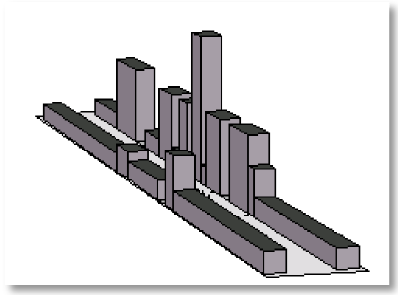

Figure 2. Scheme of Córdoba Ave. street canyon considered in OSPM calculations.

Traffic flow in Córdoba Ave. is approximately 38000 veh/day and in R. Peña St. it is 13000 veh/day. Information on traffic flow, average road traffic speed and composition of road traffic has been obtained from several reports elaborated by local authorities (GCBA, 2006, GCBA-ACOM, 2006). Unfortunately there is no information on traffic flow for the period of study (June-August 2009). Information on NO_x and CO emissions was obtained from the emission inventories elaborated for the city (Mazzeo N.A. and L.E. Venegas, 2003, Pineda Rojas, A. *et al*., 2007).
Hourly meteorological data registered at the domestic airport located in the city is used in OSPM and DAUMOD calculations.

RESULTS

Comparison of hourly observed and modelled concentrations

Hourly concentrations of NO_x, NO_2 and CO in the monitoring site were estimated using the OSPM model considering only the vehicles in Córdoba Ave. Comparison of observed and modelled hourly averaged concentrations of NO_x, NO_2 and CO are presented in Figure 3. The data have been categorised into two ambient wind speed classes, U> 2 m s^{-1} and U≤ 2 m s^{-1}. Scatter plots show that there is an underestimation of high peak values. These high values are probably due to the traffic data used as input to the model. For all pollutants considered, the scatter of data is wider for light ambient wind speeds (U≤ 2 m s^{-1}) than for higher ambient wind speeds. A summary of the observed and modelled data and their agreement is presented in Table 1. The statistics included in this Table are the number of values (N), mean, median, maximum and sigma values, bias, normalised mean square error (NMSE), correlation coefficient (Corr), fraction of modelled values between a factor 2 of observations (FA2), fractional bias (FB) and the under-predicting (FBfn) and over-predicting (FBfp) components of FB (Chang, J.C. and S. R. Hanna, 2004).

Table 1. Summary of the observed and modelled concentrations in Córdoba Ave.

	All data			U > 2 m s^{-1}			U ≤ 2 m s^{-1}		
	NO_x (ppb)	NO_2 (ppb)	CO (ppm)	NO_x (ppb)	NO_2 (ppb)	CO (ppm)	NO_x (ppb)	NO_2 (ppb)	CO (ppm)
N	1482	1482	1218	1183	1183	946	299	299	272
Mean obs.	132.61	39.85	0.93	115.91	37.55	0.77	198.67	48.94	1.48
Mean mod.	122.10	38.62	0.86	111.84	36.46	0.73	162.68	47.14	1.31
Median obs.	107.2	38.0	0.64	96.00	36.50	0.50	167.30	48.20	1.42
Median mod.	109.6	39.1	0.64	104.60	37.53	0.58	147.61	49.01	1.02
Max. obs.	648.8	118.0	6.14	512.0	110.0	6.14	648.8	118.0	6.01
Max. mod.	392.9	71.3	4.22	308.5	62.6	2.58	392.9	71.30	4.22
Sigma obs.	99.93	15.13	0.90	82.77	13.74	0.77	130.08	16.86	1.07
Sigma mod.	70.23	11.83	0.69	59.74	10.71	0.51	90.91	12.22	0.99
Bias	10.51	1.23	0.07	4.08	1.09	0.04	35.99	1.79	0.17
NMSE	0.34	0.09	0.56	0.27	0.08	0.55	0.40	0.09	0.47
Corr	0.684	0.656	0.682	0.696	0.647	0.696	0.576	0.529	0.589
FA2	0.802	0.967	0.605	0.819	0.974	0.595	0.732	0.940	0.640
FB	0.083	0.031	0.077	0.036	0.029	0.053	0.199	0.037	0.124
FBfn	0.246	0.126	0.282	0.215	0.124	0.276	0.321	0.129	0.294
FBfp	0.163	0.094	0.205	0.180	0.095	0.223	0.122	0.092	0.170

Statistics for all data are similar to that obtained for other street canyons in the literature (Kukkonen J. *et al.* 2003, Jensen, S.S. *et al.*, 2009). These results show a good agreement between modelled values and observations. In general, the model underestimates the observed values. However, it must be considered that measurements are affected by the traffic flow along the crossing street. Table 1 also shows that in this case the model has a better performance for U > 2 m s^{-1} than for low ambient winds.

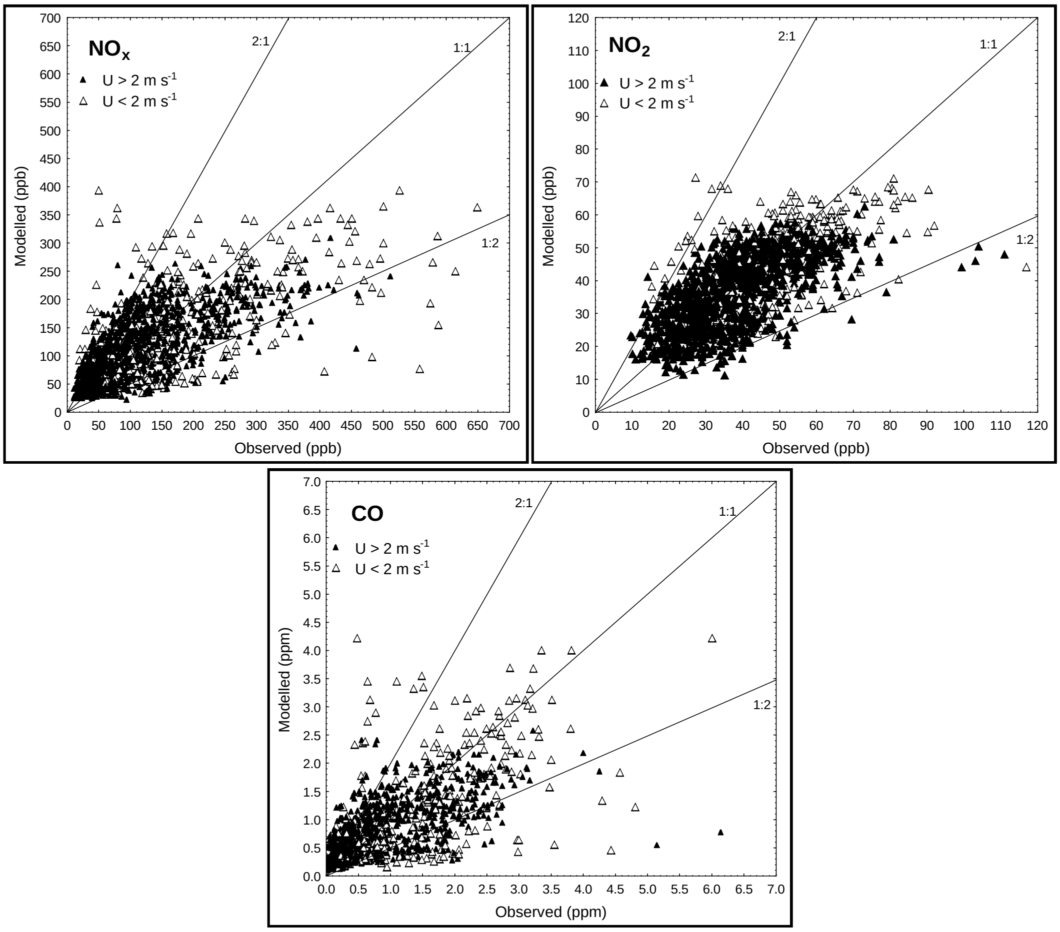

Figure 3. Comparison between observed and modelled hourly concentrations of NO_x (ppb), NO_2 (ppb) and CO (ppm), categorised into two wind speed (U) classes. Lines showing an agreement between estimations and data by a factor of two are also indicated.

Air pollution roses

The influence of traffic flow in the crossing street (R. Peña St.) can be seen in the air pollution roses included in Figure 4. Greater differences between observed and modelled mean values appear for the S-W quadrant. The differences observed for southern winds may be explained because these winds are usually low and 17.4% of these cases develop western winds at street level (Mazzeo, N.A. and L.E. Venegas, 2010).

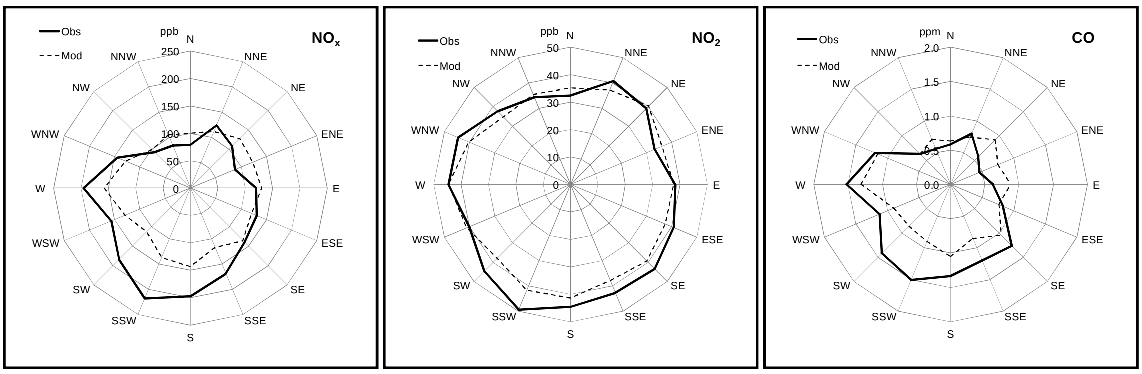

Figure 4. Comparison between observed and modelled air pollution roses for NO_x, NO_2 and CO.

Hourly concentration values were grouped into two classes according to wind direction: a) “traffic intersection effect” (SSW, SW, WSW, W and WNW) and b) “no traffic intersection effect” (other wind directions). The comparison of observed and modelled hourly values considering these two groups is summarised in Table 2. These results clearly show the influence of traffic in R. Peña St., especially for NO_x and CO (primarily emitted). The ratio (Mean mod./Mean obs.) is 0.76 for NO_x and 0.77 for CO, suggesting that the contribution of the traffic in R. Peña St. is about 24% of the observed values.

Table 2. Summary of the observed and modelled concentrations in Córdoba Ave. for two wind direction groups.

	"traffic intersection effect"			"no traffic intersection effect"		
	NO_x (ppb)	NO_2 (ppb)	CO (ppm)	NO_x (ppb)	NO_2 (ppb)	CO (ppm)
N	433	433	351	1000	1000	825
Mean obs.	179.00	43.57	1.33	109.88	37.98	0.73
Mean mod.	136.75	41.78	1.03	112.41	36.60	0.75
Median obs.	159.0	41.6	1.35	90.5	36.7	0.45
Median mod.	136.9	43.5	1.01	99.2	36.5	0.55
Max. obs.	614.0	118.0	4.57	585.9	99.4	6.14
Max. mod.	337.6	65.2	2.98	364.3	68.5	3.69
Sigma obs.	107.66	15.70	0.90	81.96	14.05	0.78
Sigma mod.	67.94	11.11	0.68	65.47	11.39	0.61
Bias	42.25	1.79	0.30	-2.53	1.38	-0.01
NMSE	0.29	0.09	0.34	0.30	0.08	0.63
Corr	0.749	0.612	0.733	0.676	0.683	0.673
FA2	0.838	0.972	0.687	0.803	0.978	0.587
FB	0.268	0.042	0.252	-0.023	0.037	-0.018
FBfn	0.324	0.121	0.338	0.192	0.128	0.243
FBfp	0.056	0.079	0.086	0.215	0.091	0.261

Hourly mean concentrations

The comparison of daily variation of hourly mean modelled and observed concentrations is presented in Figure 5 for NO_x, NO_2 and CO. In general, estimated variations are very close to the observed ones. Uncertainties in traffic flow input data may explain the departures between estimated and observed mean values. These differences are larger for weekend calculations.

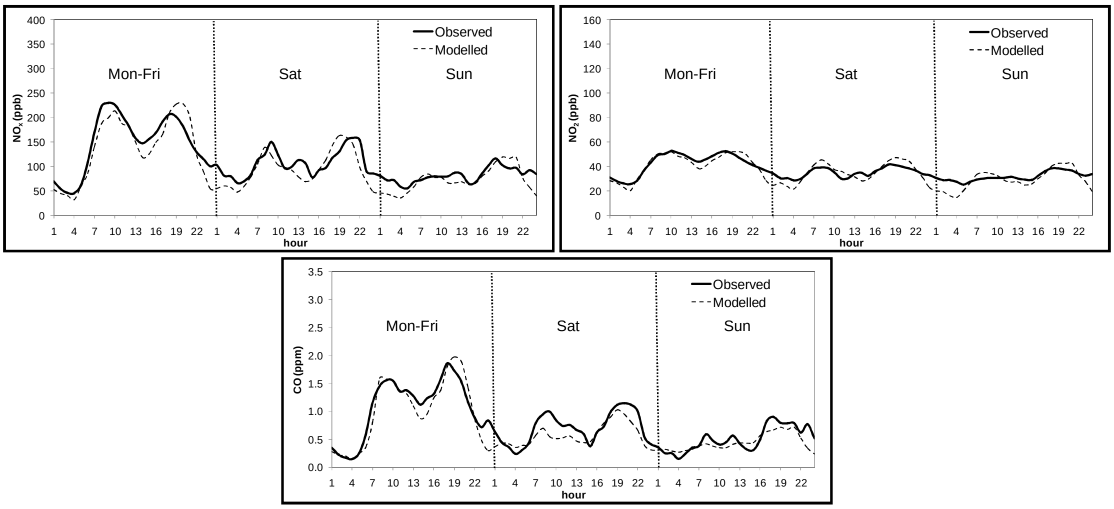

Figure 5. Average diurnal variation of observed and modelled NO_x, NO_2 and CO concentrations.

CONCLUSIONS

The results presented here support the fact that relatively simple methods for modelling traffic pollution can provide reasonable good results without excessive computing time. OSPM calculations combined with DAUMOD background contribution estimations, show acceptable results for a complex street canyon in the city of Buenos Aires. The fractional bias is 0.083 for NO_x estimations, 0.031 for NO_2 values and 0.077 for CO values. Furthermore, 80% of NO_x, 97% of NO_2 and 61% of CO estimated values are within a factor of 2 the observations.

The use of actual traffic data information and the inclusion of the traffic flow in the crossing street may improve the modelling results. The contribution of traffic emission in the crossing street seems to be approximately 24% of the measurements.

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