Traffic pollution modelling in a complex urban street

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Abstract: This study explores for the first time, the applicability of the Danish Operational Street Pollution Model (OSPM) in the city of Buenos Aires where street canyons are very irregular. The model is applied in an irregular and asymmetric street canyon of a five-lane avenue near a street intersection. Urban background concentrations estimated by the DAUMOD model are considered. Meteorological information registered at the domestic airport located in the city is used in calculations. Three months of hourly NO_x, NO_2 and CO estimated concentrations are compared with measurements inside the street canyon. Statistical evaluation of model results shows that OSPM performance is quite good.

Keywords: street canyons; traffic pollution modelling; OSPM; operational street pollution model; model evaluation; Buenos Aires.

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1 Introduction

Traffic emission is one of the major sources of air pollutants in urban areas. With the economic development, more high-rise buildings appear in cities, forming so-called 'street canyons' and making air pollutants emitted by traffic in urban areas more difficult to dilute. Numerous studies have been conducted over the last decades to help understand the air-flow pattern and air pollution in urban street canyons. Also several traffic-related urban street models (Berkowicz et al., 2006; Buckland, 1998; Johnson et al., 1973; Mensink and Cosemans, 2008; Papathanassiou et al., 2008; Soulhac et al., 2009; Yamartino and Weigand, 1986) have been developed. One of the most popular and validated models is the Danish Operational Street Pollution Model (OSPM) (Berkowicz, 2000). OSPM is a simple parameterised model. It is a practical tool for estimating traffic-related pollution dispersion in urban street canyon-type geometries. OSPM has been successfully tested against data monitor stations in Denmark, in other European countries, some cities in Asia and in New York (Aquilina and Micallef, 2004; Berkowicz, 1998, 2000; Berkowicz et al., 2002, 2006, 2008; Fu et al., 2000; Gokhale et al., 2005; Jensen et al., 2009; Ketzel et al., 2000; Kukkonen et al., 2001, 2003; Mensink and Cosemans, 2008; Vardoulakis et al., 2007).

This study explores for the first time the applicability of the OSPM model in the city of Buenos Aires where most of the street canyons are very irregular. The Windows version of the OSPM (WinOPSM) model is applied to estimate hourly concentrations of Nitrogen Oxides (NO_x), Nitrogen Dioxide (NO_2) and Carbon Monoxide (CO) in an asymmetric and irregular street canyon. Three months of estimated values are compared with measurements at one of the monitoring stations of the Environmental Protection Agency of the Government of the city of Buenos Aires.

2 Models overview

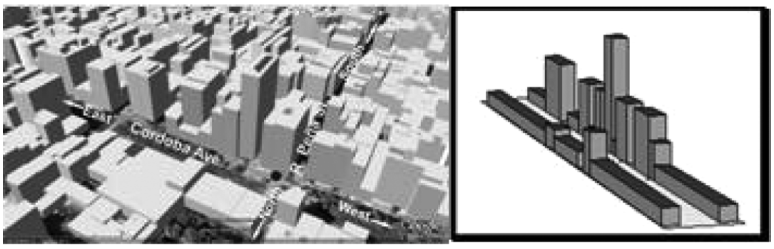
The OSPM is a parameterised semi-empirical model for flow and dispersion conditions in street canyons. The model calculates concentrations of exhaust gases using a combination of a plume model for the street direct contribution and a box model for the re-circulating part of pollutants in the street. An important feature of OSPM is modelling of the turbulence in the street. The turbulence in the street is assumed to be composed of two parts: a part dependent on wind speed (ambient turbulence) and a part due to traffic induced turbulence. 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 this model, see Berkowicz (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.

In this study, background concentrations of NO_x, NO_2 and CO have been estimated using the urban atmospheric dispersion model DAUMOD. This simple urban dispersion model makes use of a gridded emission data with a spatial resolution of 1×1 km^2. Concentrations at a given receptor are calculated adding the contributions from each of the individual area sources located upwind. A simple steady-state plume model is used for description of the contributions from individual area sources. DAUMOD has been validated using observations from Buenos Aires and different cities in Europe and the United Sates. For a more detailed description of the model and its applications the reader is referred to Mazzeo and Venegas (1991) and Venegas and Mazzeo (2002, 2006). In this study hourly NO_2 background concentration is calculated from NO_x concentration using a polynomial expression (CERC, 2003; Derwent and Middleton, 1996).

3 The site

In June 2009 an air quality monitoring station that belongs to the Environmental Protection Agency of the Government of the city of Buenos Aires started to operate in a commercial area. This station will form part of the air quality monitoring network that is planned for the city. At this station, hourly CO, NO_x and NO_2 concentrations and wind speed and direction are measured inside the street canyon. The station is located on the southern side of Córdoba Ave. (Figure 1) near the intersection with R. Peña St. Córdoba Ave. has five lanes and it is orientated E-W. Traffic flow in the avenue is approximately 38,000 veh/day and in R. Peña St. it is 13,000veh/day. The street canyon where the monitors are located is very irregular and asymmetric. The width of the avenue is W = 30 m. Building heights (*H*) at both sides of the avenue are very different. On the northern side, buildings are low and almost uniform (approximately 10 m high). Therefore, the 'northern-side' aspect ratio is H/W= 0.33. On the southern side, building heights show a wide variation from 10 m to 80 m. Their average height is approximately 40 m giving a 'southern-side' aspect ratio of H/W≈ 1.3. Measurement height inside the canyon is 2.5 m.

Figure 1 Left: 3D perspective of monitoring site location (●) (Picture: Google Earth 2009). Right: scheme of Córdoba Ave. street canyon considered in WinOSPM calculations



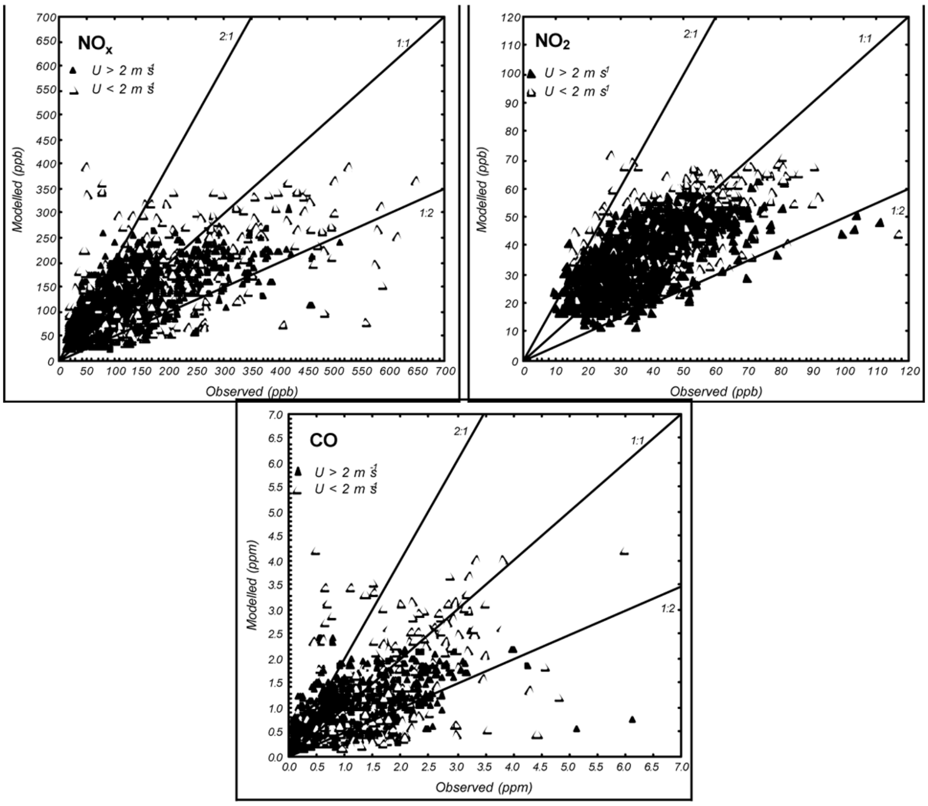
4 Results and discussion

Three months (June-August 2009) of hourly concentrations of NO_x, NO_2 and CO in the monitoring site were estimated using the WinOSPM model. The scheme of the street configuration considered in model runs is shown in the right side of Figure 1. In this scheme the street intersection was included as an opening between buildings. Information on traffic flow, average road traffic speed and composition of road traffic was obtained from several reports elaborated by local authorities (GCBA, 2006, GCBA-ACOM, 2006). Unfortunately there was no information on traffic flow for the period of study. Built-in emission factors for year 2000 were used because they were quite similar to the ones used in the development of the NO_x and CO emission inventories for the city (Mazzeo and Venegas, 2003; Pineda Rojas et al., 2007). These emission inventories were used as input data in DAUMOD model to obtain urban background concentrations. Estimated hourly concentrations were obtained applying WinOSPM to traffic flow in Córdoba Ave. considering the modelled urban background concentrations. Traffic flow in the canyon where the monitors are located is three times greater than the traffic flow in the crossing street and can be expected to be the main responsible for observed air pollutant concentrations. Hourly meteorological data registered at the meteorological station of the National Weather Service in the domestic airport located in the city were used in WinOSPM and DAUMOD calculations.

4.1 Comparison of hourly observed and modelled concentrations

Comparisons of observed and modelled hourly concentrations of NO_x, NO_2 and CO are presented in Figure 2. The data have been categorised into two ambient wind speed (U) classes, U > 2 ms^{-1} and U ≤ 2 ms^{-1}. Scatter plots show that there is an underestimation of high values. Observed values higher than estimations probably result from the input traffic data considered in calculations.

Figure 2 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



For all pollutants considered, the scatter of data is wider for light ambient wind speeds (U ≤ 2 ms^{-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 and Hanna, 2004). Statistics values for all data are similar to the obtained for other street canyons in the literature (Jensen et al., 2009; Kukkonen et al., 2003). These results show a good agreement between modelled values and observations. In general, model underestimates the observed values. However, it must be considered that measurements are affected by the traffic flow along the crossing street. Table 1 shows that in this application the model has a better performance for U >2 ms^{-1} than for low ambient winds.

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

	All data			U> 2 ms^{-1}			U ≤ 2 ms^{-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.	132.6	39.9	0.93	115.9	37.6	0.77	198.7	48.9	1.48
Mean mod.	122.1	38.6	0.86	111.8	36.5	0.73	162.7	47.1	1.31
Median obs.	107.2	38.0	0.64	96.0	36.5	0.50	167.3	48.2	1.42
Median mod.	109.6	39.1	0.64	104.6	37.5	0.58	147.6	49.0	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

4.2 Comparison of observed and modelled mean concentrations

Figure 3 shows the observed and modelled air pollution roses for NO_x, NO_2 and CO. The patterns of the air pollution roses for NO_x and CO are quite similar showing that local traffic is the main source of these pollutants at this site. On the other hand, NO_2 shows a different pattern because it is mainly a secondary pollutant. In general, model estimations are quite acceptable. Great differences between estimations and observations are obtained for S-W quadrant especially for NO_x and CO. The irregularities of building heights, the traffic flow in the crossing street and the location of the monitoring station near the intersection may explain the differences between modelled and observed air pollution rose patterns.

Studies of pollutant dispersion in urban street intersections (Dobre et al., 2005; Robins et al., 2002; Soulhac et al., 2009) show that the flow is very sensitive to the wind direction relative to the intersection so that even small asymmetries in the configuration can lead to very different dispersion patterns. When the wind blows parallel to the crossing street, sidewise corner eddies rotating around vertical axes at the ends of the street canyon are generated. These corner eddies may transport air pollutants emitted in the crossing street towards the monitoring site. For example, Mazzeo and Venegas (2010) analysed the wind measured inside the street canyon during this period and related it with the ambient wind registered at the local airport and found that for southern ambient wind, W wind has been observed at street level in 17.4% of the cases. Corner eddies combined with west compound of flow may lead to the greater observed concentrations in the directions S, SSW and SW of the air pollution roses. During the analysed period, only 2.4% of cases with N ambient wind registered W wind at the monitoring site. From air pollution roses in Figure 3, average observed concentrations for ambient wind directions N, NNW and NW do not show any extra contribution coming from the emissions in the crossing street. Ambient flow blows from the opposite side of the wide avenue and corner eddies seem to be less effective in carrying air pollutants from the crossing street towards the monitoring site than in S, SSW and SW ambient wind conditions.

The comparison of daily variation of hourly mean modelled and observed concentrations is presented in Figure 4 for NO_x, NO_2 and CO. In general, diurnal and weekly variation is well reproduced. The uncertainties in traffic flow input data along the avenue, the existence of traffic flow in the intersection near the monitoring site and the irregularity pattern of this street canyon may explain the departures between estimated and observed mean values.

Figure 3 Comparison between observed (line) and modelled (dash) air pollution roses for NO_x, NO_2 and CO. The avenue is indicated

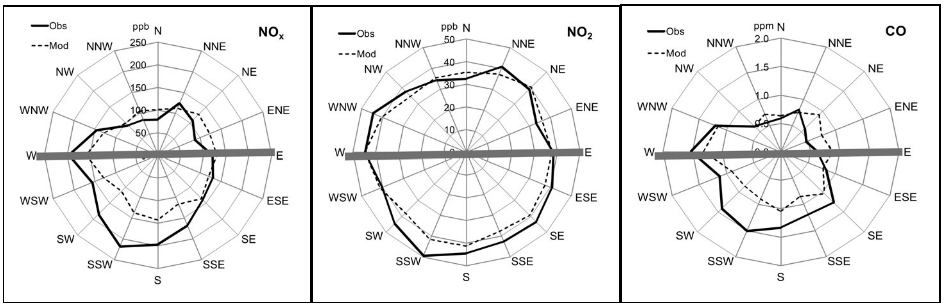
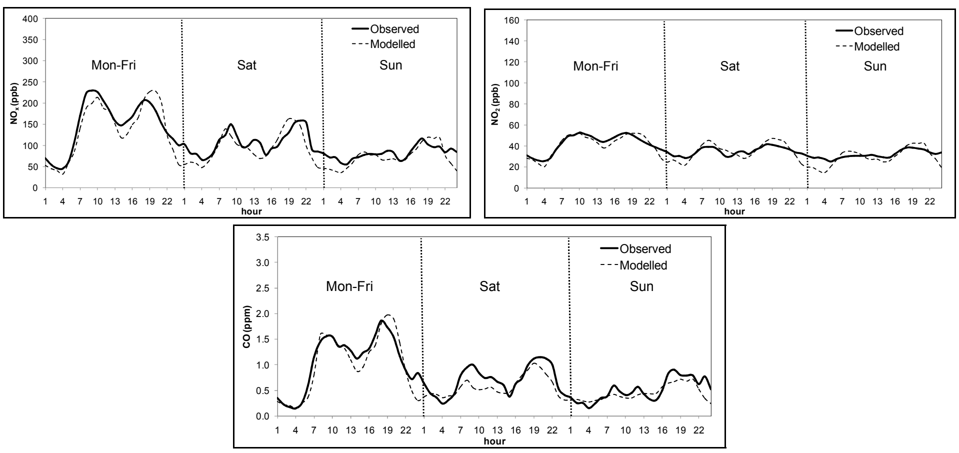


Figure 4 Average diurnal variation of observed and modelled NO_x, NO_2 and CO concentrations



5 Conclusions

This study presents the first attempt to explore the applicability of the Danish Operational Street Pollution Model (OSPM) in the city of Buenos Aires where most of the street canyons have non-uniform building structures. The task includes the application of the model using ordinary available data (official reports on traffic flow and composition, routine meteorological observations in the city). WinOSPM calculations combined with DAUMOD background contribution estimations, show acceptable results for an irregular and asymmetric street canyon of a five-lane avenue. Three months of hourly NO_x, NO_2 and CO concentrations are estimated and compared with observations at a site located near a traffic intersection. Statistical evaluation of model results gives that 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. There is a good agreement between the measured and the modelled concentrations. Model performance improves in the higher wind speed cases.

The results obtained in this study suggest that the applicability of the OSPM in the irregular street canyons of the city of Buenos Aires is acceptable. It is expected to compare model estimations with observations at other sites in the city, as soon as new monitoring data are available.

Results also support the fact that relatively simple methods for modelling traffic pollution can provide reasonable good results without excessive computing time.

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