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HOURLY NO_X CONCENTRATIONS AND WIND DIRECTION IN THE VICINITY OF A STREET INTERSECTION

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Abstract: Street intersections play an important role in determining air pollution concentration levels in an urban area. Traffic emissions often increase in the vicinity of street intersections and the complex airflow patterns that take place within the intersections determine pollutant concentrations at adjoining streets. This study focuses on traffic-related air pollution within an area close to a busy street intersection in the city of Buenos Aires. Concentration of NO_x and wind speed and direction were measured inside an asymmetric street canyon of an avenue orientated east-west. The monitoring site is located on the southern side of the avenue a few metres to the E of the street intersection. Measurements obtained at the domestic airport located on the shore of the city, were considered as ambient wind conditions. Wind directions at the monitoring site were predominantly E, NE, W and NW. While the first ones were registered with any ambient wind direction, W and NW were observed with ambient wind from SW to NW directions. An analysis of average concentrations obtained for the most frequent horizontal airflows directions inside the street canyon originated by different ambient wind directions is presented. Results show that airflow and air pollutant dispersion at the monitoring site are affected by the asymmetric and irregular building heights, and the proximity of the monitoring site to the traffic intersection.

Key words: *Street intersection, street canyon, air quality monitoring, traffic pollution*

INTRODUCTION
Pollutants emitted by vehicle traffic in urban areas have generally been accepted to be a cause of chronic health effects (Molina M.J. and L.T. Molina, 2004). Areas of high, localised pollution are usually found in the cities. In street canyons, where narrow streets are flanked on both sides by buildings, poor dispersion conditions often arise, leading to occurrence of pollution hot-spots. Pedestrians, cyclists, drivers and residents are likely exposed to pollutant concentrations exceeding current air quality standards within street canyons. Cross canyon recirculation flows, including the formation of helical vortices, have been observed in canyon studies in the field (De Paul, F.T. and C.M. Seith, 1986; Longley, I.D. *et al.*, 2004; Boddy, J.W. *et al.*, 2005; Eliasson, I. *et al.*, 2006) and in wind tunnel studies (Hoydysh, W.G. and W.F. Dabbert, 1988; Soulhac, L. *et al.*, 2009).

Street intersections play an important role in determining air pollution concentration levels in an urban area. Firstly, traffic flows are disrupted and vehicles are obliged to accelerate and decelerate, thereby increasing emissions. In congested intersections or at intersections controlled by traffic lights, idling vehicles will increase emissions above the level for free-flowing traffic. Secondly, street intersections are regions where there is significant exchange of pollutants between the connected streets. Finally, when pollutant concentrations are measured close to, or within, street intersections, the correct analysis of these data requires a detailed understanding of the physical processes involved (Scaperdas, A. and R.N. Colville, 1999; Tomlin, A.S. *et al.*, 2009; Soulhac, L. *et al.*, 2009). Dobre, A. *et al.* (2005) demonstrated that flow within a complex street canyon is the vector sum of channelled flow and a recirculation vortex which depend linearly upon the along-street and cross-street components of the roof top reference wind respectively.

Several field studies are necessary in order to assess whether features such as cross canyon vortices and helical flows are relevant to a wide variety of real city environments, and whether additional features may result from the presence of side streets and intersections (Robins, A. *et al.*, 2002; Arnold, S. *et al.*, 2004; Boddy, J.W. *et al.*, 2005; Dobre, A. *et al.*, 2005; Soulhac, L. *et al.*, 2009; Tomlin, A.S. *et al.* 2009).

This study focuses on traffic-related air pollution within an area close to a busy street intersection in the city of Buenos Aires. Concentrations of NO_x and wind speed and direction have been measured inside an asymmetric and irregular street canyon of an avenue orientated east-west, at a few metres to the E of the traffic intersection.

SITE AND DATA
Figure 1 shows a 3D perspective picture of the study area, which includes the location of the air quality monitor sensors and meteorological instruments within the street canyon. Concentrations of NO_x and wind speed and direction were measured on the southern side of Córdoba Avenue. Measurements obtained at the domestic airport located on the shore of the city, were considered for ambient wind conditions.

Córdoba Ave. is approximately 30m wide. Buildings on the northern side of this avenue are low (~10m) and quite regular. On the southern side, buildings are much taller and of different heights (10m – 80m). Traffic volume in the five-lane avenue is approximately 38,000veh/day. The monitoring station is located at a few metres to the E of the intersection of Córdoba Avenue and R. Peña Street. This street runs north-south; it is 17m wide and has a traffic volume of approximately 13,000veh/day. Three months of NO_x concentration and wind speed and direction hourly data are analysed.

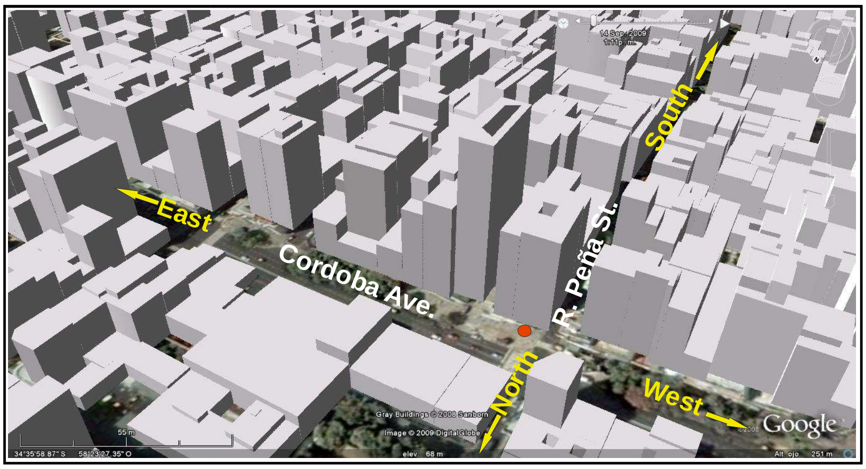

Figure 1. 3D perspective of monitoring site location (●) (Picture: Google Earth)

RESULTS AND DISCUSSION

Hourly mean NO_x concentrations

Figure 2 shows the daily variation of hourly average NO_x concentrations measured at the monitoring site during working days, Saturdays and Sundays. During working days averaged NO_x concentrations at the monitoring site show a typical diurnal variation. Two peaks appear at 09:00-10:00h and at 19:00-20:00h with lower values at 15:00h. The minimum value occurs at 05:00h. On Saturdays, hourly averaged concentrations show three peaks. Two similar high values appear at 10:00h and at 22:00h-23:00h and a lower peak at 14:00h. During Sundays, mean hourly NO_x concentrations are generally low and increase in the evening.

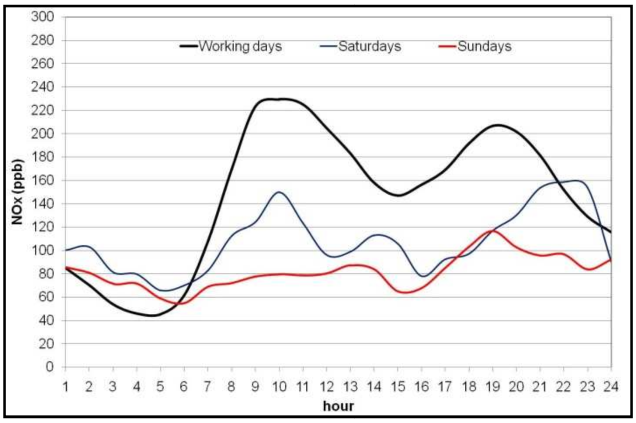

Figure 2. Daily variation of hourly average NO_x concentrations.

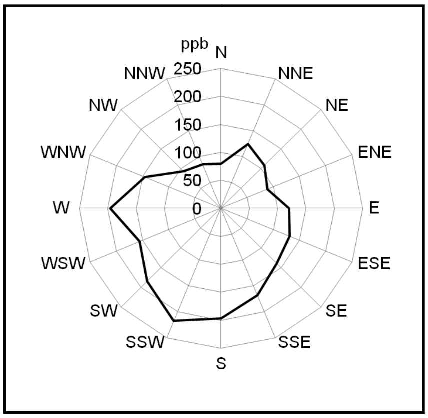

Figure 3. Air pollution rose for NO_x.

Air pollution rose for NO_x

The air pollution rose for NO_x (Figure 3) shows the evidence of: a) the recirculation airflow inside the street canyon and b) the influence of the traffic intersection located west of the monitoring site. These results are analysed considering the average concentrations of: a) sectors E→S→W and W→N→E and b) sectors N→E→S and S→W→N, respectively (Table 1).

Table 1. Mean value of NO_x concentrations for different sectors of the pollution rose.

Pollutant	Mean Value E→S→W	Mean value W→N→E	Mean value N→E→S	Mean value S→W→N
NO_x (ppb)	162.1	105.4	120.1	137.7

Mean concentration for the sector E→S→W is greater than for W→N→E sector. The application of the t-Student test reveals that the difference between the averages for both sides is statistically significant at the 99% confidence level. At this point, it can be inferred the existence of recirculation airflow inside the street canyon responsible for this result.

On the other hand, mean concentration values for sectors N→E→S and S→W→N show the influence of traffic flow in R. Peña Street located to the west of the monitoring site (Figure 1). The average concentration for the sector S→W→N is greater than the one for the opposite sector (Table 1). The application of the t-Student test to these values indicates that the difference of the averages for both sides is statistically significant at the 99% confidence level.

Horizontal airflow and NO_x concentrations

The frequency distribution of wind directions measured inside the street canyon for each ambient wind direction is included in Table 2. Winds inside the street canyon from NE and E directions can be observed with any ambient wind direction. Wind directions at the monitoring site from W and NW are mainly associated with ambient wind directions from the sector SW→NW. At the monitoring site, recirculation flow inside the street canyon seems to be quite irregular. Analysing external winds perpendicular to Córdoba Ave., it can be found that when ambient wind direction is S, 41.9% of the time the wind at the monitoring site is NE and 36.7% of the time is E. On the other hand, northern external wind generates E wind inside the street canyon in the 75.2% of the cases. This behaviour of the airflow may be a consequence of the pronounced asymmetry of the street canyon and the proximity of the monitoring site to traffic intersection.

Table 2. Frequency (%) distribution of wind directions inside the street canyon for each ambient wind direction.

		WIND DIRECTION INSIDE THE STREET CANYON								
		N	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**	**TOTAL**
AMBIENT WIND DIRECTION	**N**	1.1	21.0	75.2	0.0	0.0	0.0	2.4	0.3	100.0
	NE	0.0	8.2	91.8	0.0	0.0	0.0	0.0	0.0	100.0
	E	0.0	3.3	96.7	0.0	0.0	0.0	0.0	0.0	100.0
	SE	0.0	8.7	88.4	0.0	0.0	0.0	1.9	1.0	100.0
	S	2.0	41.9	36.7	0.0	0.0	0.0	17.4	2.0	100.0
	SW	0.0	25.8	15.8	0.0	0.0	0.0	47.5	10.9	100.0
	W	0.5	5.8	11.7	0.0	0.0	0.0	76.2	5.8	100.0
	NW	0.8	13.4	26.0	0.0	0.4	3.0	53.4	3.0	100.0

Table 3 shows the averages of hourly NO_x concentration (C) and wind speed ($\bar{u}$) at the monitoring site, for the pair ambient and inside the street canyon wind directions registered simultaneously. Only averages obtained with more than 10 values are considered representative and included in the analysis. Higher mean concentration values are obtained when wind direction inside the avenue is from NE and E sectors. Values in Table 3 should be analysed taking into account that higher mean concentrations are expected to be associated to lower mean wind speed ($\bar{u}$). Combining the results in Table 3 and in Table 2, it can be seen that with SW ambient wind, 41.6% of the time the wind inside the canyon can be NE or E showing high average NO_x concentrations. This ambient wind direction is associated to both contributions, the emissions from vehicles in R. Peña Street (for western and north-western winds inside the canyon) and from traffic in the avenue (for north-eastern and eastern winds inside the canyon).

Table 3. Mean NO_x concentrations (C) (ppb) and mean wind speed ($\bar{u}$) (ms^{-1}) registered at the monitoring site for the different conditions of simultaneous ambient and inside the street canyon wind directions.

		WIND DIRECTION INSIDE THE STREET CANYON															
		N		**NE**		**E**		**SE**		**S**		**SW**		**W**		**NW**	
		C	**ū**	**C**	**ū**	**C**	**ū**	**C**	**ū**	**C**	**ū**	**C**	**ū**	**C**	**ū**	**C**	**ū**
AMBIENT WIND DIRECTION	**N**	*	*	94	0.91	89	1.37	0	0	0	0	0	0	*	*	*	*
	NE	0	0	*	*	102	1.69	0	0	0	0	0	0	0	0	0	0
	E	0	0	*	*	100	1.47	0	0	0	0	0	0	0	0	0	0
	SE	0	0	*	*	149	0.99	0	0	0	0	0	0	*	*	*	*
	S	*	*	159	0.65	211	0.56	0	0	0	0	0	0	139	0.76	*	*
	SW	0	0	214	0.66	264	0.66	0	0	0	0	0	0	150	0.90	201	0.64
	W	*	*	262	0.82	269	0.73	0	0	0	0	0	0	167	1.21	194	0.79
	NW	*	*	81	0.93	64	1.01	0	0	*	*	*	*	110	1.15	*	*

* not enough cases to obtain a representative average (0 < number of cases < 10)

Schemes showing average concentrations related to horizontal airflow directions at the monitoring site for different ambient wind directions are presented in Figure 4. These schemes have been elaborated considering the representative averages in Table 3.

Figure 4. a) Aerial view of the site (Picture: Google Earth), b)- i) schemes showing ambient wind direction with associated horizontal airflows (black arrows) and average NO_x concentrations (values in ppb) at the monitoring site (●).

Figures 4b and 4c show that when ambient wind is from N and NE the wind inside the street canyon is mostly from NE and E. In these cases the oncoming wind impacts against the windward face of the tall buildings located on the southern side of the avenue. Some air passes over the top of the buildings and part streams down the windward face and may enhance the lee eddy of the upwind low building. The rest is deflected around the sides of the tall buildings and to the ground, resulting in NE and E airflow registered by the vane at the monitoring site.

The eastern ambient wind (Figure 4d) is channelled along the avenue and at the monitoring site wind is also E.

The south-eastern ambient wind (Figure 4e) generates eastern winds at the monitoring site 88.4% of the time (Table 2). It seems that only the component of ambient wind parallel to the avenue remains. A similar pattern has been reported for other street intersections (Soulhac, L. *et al.*, 2009; Xie, Z-T and I. Castro, 2009; Carpentieri, M. *et al.*, 2009). The component of ambient wind perpendicular to the avenue can be obstructed by the tall buildings south of the monitor which may act as a windbreak. These buildings may slow down horizontal airflow but generate a zone with increasing turbulence.

Southern ambient winds (Figure 4f) generate winds from NE, E and W at the monitoring site most of the time. In these cases, ambient wind is affected by the tall buildings of irregular heights located on the southern side. The wakes and air turbulence structures at the leeward side of these buildings may generate the horizontal components of the airflow registered at the monitoring site.

Figure 4g shows the situation for south-western ambient winds. In these cases, the most frequent horizontal airflows registered at the monitoring site are W, NE, E and NW. Western winds registered inside the canyon may come from the ambient wind component parallel to the avenue. North-eastern horizontal winds registered at the monitoring site can be a consequence of the street canyon effect. On the other hand, the eastern (15.8%) and north-western (10.9%) winds registered at the monitoring site can be generated by the corner eddies and the irregular heights of the buildings located on the southern side of the avenue.

Western ambient wind (Figure 4h) generates western wind inside the street canyon most of the time (76.2%). However, a few times the vane at the monitoring site registers horizontal airflow from E (11.7%), NE (5.8%) and NW (5.8%). These horizontal movements may come from the interaction of the ambient wind with the irregular buildings located near the monitoring site. The buildings adjacent to the intersection (Figure 1) are tall (30m - 40m) except on the NE corner where the building is approximately 9m high. Furthermore, there are some structures built on the sidewalk approximately 40m east of the monitoring site (a dense group of trees can be seen in Figure 4a to the E of the monitor, at the place where these structures are located). These structures may contribute to generate air turbulence responsible for the eastern wind registered at the monitoring site. Finally, Figure 4i shows the situation for north-western ambient wind. In these cases, the vane inside the canyon registered W (53.4%), E (26.0%) and NE (13.4%) wind directions. The impact of ambient wind against the buildings close to the monitoring site and the corner eddies may explain the horizontal airflow registered at the monitoring site.

CONCLUSIONS

The analysis of ambient wind and hourly NO_x concentrations and wind speed measured inside an asymmetric and irregular street canyon, close to a traffic intersection, in the city of Buenos Aires gives the following results:

- the air pollution rose shows evidence of a recirculation flow inside the street canyon and the influence of the traffic intersection on the west side of the monitoring station,
- the frequency distribution of wind directions inside the street canyon for different ambient wind directions shows that winds at the monitoring site are mainly from E, NE, W and NW,
- the recirculation structure at the monitoring site seems to be very irregular, as a consequence of the asymmetric and irregular street canyon, and the development of corner eddies,
- the complexity, irregularity and asymmetry of this street canyon and the proximity to the traffic intersection affect the airflow and air pollutant dispersion at the monitoring site.

Unfortunately, there is no information available to study the three dimensional airflow patterns inside this street canyon. However, the behaviour of horizontal winds at the monitoring site is quite similar to that observed at other street intersections reported in the literature.

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REFERENCES

Arnold, S., H. ApSimon, S. Belcher, M. Bell, D. Boddy, R. Britter, H. Cheng, R. Clark, R. Colville, S. Dimitroulopoulou, A. Dobre, B. Greally, S. Kaur, A. Knights, T. Lawton, A. Makepeace, D. Martin, M. Neophytou, S. Neville, M. Nieuwenhuijsen, G. Nickless, C. Price, A. Robins, D. Shallcros, P. Simmonds, R. Smalley, A. Omlin, H. Wang and P. Walsh, 2004: Dispersion of air pollution and penetration into the local environment, DAPPLE. *Science of the Total Environment*, **332**, 139-153.

Boddy, J.W. D., R.J. Smalley, N.S. Dixon, J.E. and A.S. Tomlin, 2005: The spatial variability in concentrations of a traffic-related pollutant in two street canyons in York, UK-Part I: The influence of background winds. *Atmospheric Environment*, **39**, 3147-3161.

Carpentieri, M., A.G. Robins and S. Baldi, 2009: Three-dimensional mapping of air flow at an urban canyon intersection. *Boundary-Layer Meteorol.*, **133,** 277-296.

De Paul, F.T. and C.M. Seith, 1986: Measurements of wind velocities in a street canyon. *Atmospheric Environment,* **20**, 455-459.

Dobre, A., S. J. Arnold, R. J. Smalley, J.W.D. Boddy, J.F. Barlow and A.S. Tomlin, 2005: Flow field measurements in the proximity of an urban intersection in London, UK. *Atmospheric Environment*, **39**, 4647-4657.

Eliasson, I., B. Offerle, C.S.B. Grimmond and S. Lindqvist, 2006: Wind fields and turbulence statistics in an urban street canyon. *Atmospheric Environment*, **40**, 1-16.

Hoydysh, W.G. and W.F. Dabbert, 1988: Kinematics and dispersion characteristics of flows in asymmetric street canyons. *Atmospheric Environment*, **22**, 2677-2689.

Longley, I.D., M.W. Gallager, J. R. Dorsey, M. Flynn and J. F. Barlow, 2004: Short-term measurements of airflow and turbulence in two street canyons in Manchester. *Atmospheric Environment*, **38**, 69-79.

Molina, M.J. and L.T. Molina, 2004: Megacities and Atmospheric Pollution. *Journal of Air & Waste Management Association*, **54**, 644-680.

Robins, A., E. Savory, A. Saperdas and D. Grigoriadis, 2002: Spatial variability and source-receptor relations at street intersection. *Water, Air and Soil Pollution, Focus*, **2**, 381-393.

Scaperdas, A. and R.N. Colvile, 1999: Assessing the representativeness of monitoring data form an urban intersection site in central London, UK. *Atmospheric Environment*, **33**, 661-674.

Soulhac, L., V. Garbero, P. Salizzoni, P. Mejean and R.J. Perkins, 2009: Flow and dispersion in street intersections. *Atmospheric Environment*, **43**, 2981-2996.

Tomlin, A.S., R.J. Smalley, J. E. Tate, J. F. Barlow, S. E. Belcher, S. J. Arnold, A. Dobre and A. Robins, 2009: A field study of factors influencing the concentrations of a traffic-related pollutant in the vicinity of a complex urban junction. *Atmospheric Environment,* **43**, 5027-5037.

Xie, Z-T and I. Castro, 2009: Large-eddy simulation for flow and dispersion in urban streets. *Atmospheric Environment,* **43**, 2174-2185.