Hourly NO_X concentrations and wind direction in the vicinity of a street intersection

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Abstract: This study relates NO_x concentrations and wind (speed and direction) measured inside an asymmetric street canyon, with ambient wind. The monitoring site is located near a street intersection. The wind measured at the domestic airport located in the city, near the coast, has been considered as ambient wind. Wind direction at the monitoring site inside the canyon is mainly from the E, NE, W and NW for any ambient direction. In general, the behaviour of horizontal airflow at the monitoring site for different ambient wind directions seems to be quite similar to those observed at other street intersections reported in the literature.

Keywords: street intersections; street canyons; air quality monitoring; traffic pollution; Buenos Aires; NO_x concentration; wind direction.

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1 Introduction

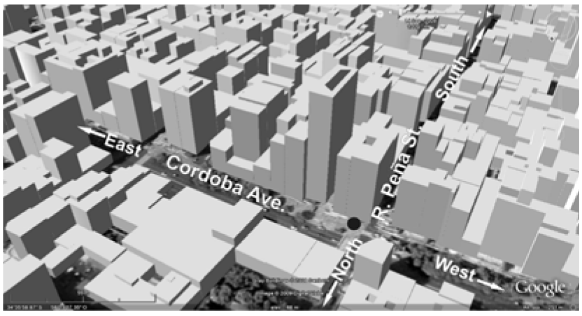
Pollutants emitted by vehicle traffic in urban areas have generally been accepted as being a cause of chronic health effects (Molina and Molina, 2004). Areas of high, localised pollution are usually found in cities. In street canyons, where narrow streets are flanked on both sides by buildings, poor 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 (Boddy et al., 2005; DePaul and Sheih, 1986; Eliasson et al., 2006; Longley et al., 2004) and in wind tunnel studies (Hoydysh and Dabbert, 1988; Soulhac et al., 2009). Street intersections play an important role in determining air pollution concentration levels in local scales in an urban area. First, 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. Second, street intersections are regions where there is significant exchange of pollutants between the connected streets. The correct analysis of pollutant concentrations measured close to, or within, street intersections requires a detailed understanding of the physical processes involved (Scaperdas and Colville, 1999; Soulhac et al., 2009; Tomlin et al., 2009). Dobre et al. (2005) demonstrated that flow within a complex street canyon is the vector sum of the 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 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 (Arnold et al., 2004; Boddy et al., 2005; Dobre et al., 2005; Robins et al., 2002; Soulhac et al., 2009; Tomlin et al. 2009).

This study relates the ambient wind with NO_x concentrations and wind (speed and direction) measured inside a street canyon of Buenos Aires. Concentrations of NO_x and wind speed and direction have been measured during three months inside an asymmetric and irregular street canyon of an avenue orientated east-west, at a few metres from a traffic intersection. Measurements of airflow and air pollution at a single site are not enough to draw conclusions on the three dimensional airflow patterns in a complex urban configuration (such as a street intersection). Observations obtained inside the street canyon at this site are analysed and related with the ambient wind, having in mind the results of more complex studies (experimental or numerical) carried out by other authors in similar urban configurations.

2 Site and data

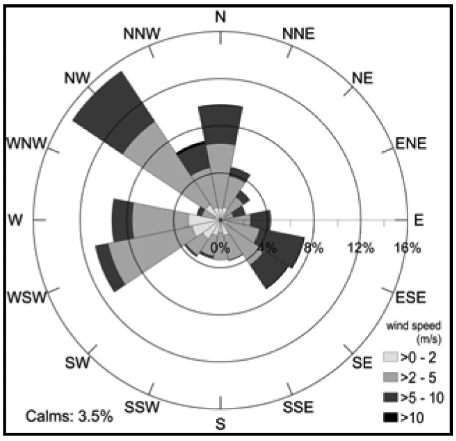
Figure 1 shows a 3D perspective picture of the study area, which includes the location of the air quality monitor sensors and meteorological instruments within the street canyon. Concentrations of NO_x and wind speed and direction were measured inside Córdoba Avenue between 01/06/09 and 28/08/09. This five-lane avenue runs east-west. It is 30 m wide, and has a traffic volume of approximately 38,000 vehicles/day. Buildings on the northern side of the avenue are low (~10 m) and quite regular. On the southern side, buildings are much taller and of different heights (10–80 m). The monitoring station is located on the southern side of Córdoba Ave., 9.5 m east from the intersection of this avenue with R. Peña Street. This street runs north-south. It is 17 m wide, and has a traffic volume of approximately 13,000 vehicles/day.

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



Due to lack of available information on ambient wind at the monitoring site, hourly measurements observed at the domestic airport had to be considered as ambient wind conditions. This airport is located in the city, 3.5 km from the monitoring site and near the coast. At the domestic airport, the mean temperature for the considered three months was 11.3°C, and the mean wind speed was 3.7 m/s. Ambient wind rose for the period of study is shown in Figure 2.

Figure 2 Ambient wind rose for the period of study

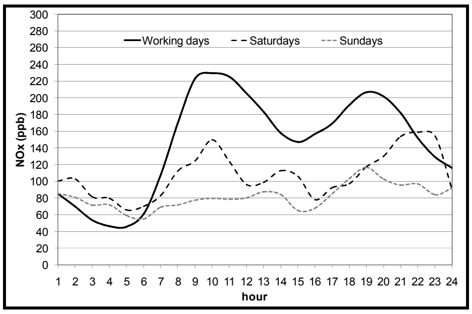


3 Results and discussion

3.1 Hourly mean NO_x concentrations

Figure 3 shows the daily variation of hourly average NO_x concentrations measured at the monitoring site during working days, Saturdays and Sundays (hours indicate local time). During working days averaged NO_x concentrations at the monitoring site show a typical diurnal variation. Two peaks appear at 09:00-10:00 and at 19:00–20:00, with lower values at 15:00. The minimum value occurs at 05:00. On Saturdays, hourly averaged concentrations show three peaks. Two similar high values appear at 10:00 and at 22:00–23:00 and a lower peak at 14:00. During Sundays, mean hourly NO_x concentrations are generally low, and increase in the evening.

Figure 3 Daily variation of hourly average NO_x concentrations



3.2 Air pollution rose for NO_x

The air pollution rose for NO_x related to ambient wind direction is shown in Figure 4. Mean concentration values registered in 'leeward' conditions (SSE→S→SSW) are greater than those observed in 'windward' conditions (NNW→N→NNE). Table 1 shows the mean concentration values for both sectors. 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. The presence of a wind vortex within the canyon might be responsible for this result.

Figure 4 Air pollution rose for NO_x

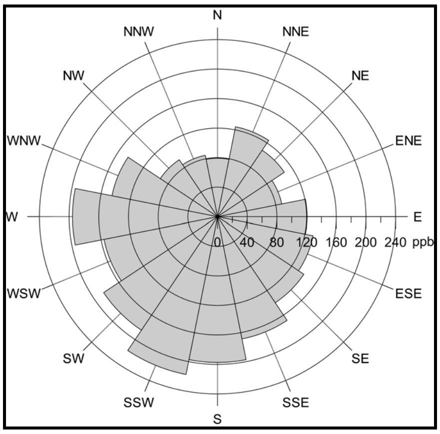


Table 1 Mean value of NO_x concentrations for different sectors of the air pollution rose

Pollutant	*Mean value SSE→S→SSW*	*Mean value NNW→N→NNE*	*Mean value ENE→E→ESE*	*Mean value WSW→W→WNW*
NO_x (ppb)	196.6	90.5	118.3	171.6

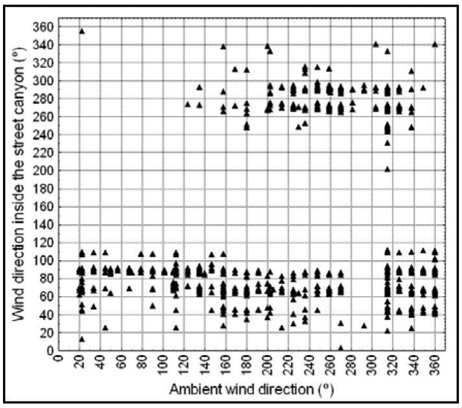
Analysing the directions along the canyon, the average concentration for the sector WSW→W→WNW is greater than that obtained for ENE→E→ESE (Table 1). The application of the t-Student test to these values indicates that the difference of the averages for both sectors is statistically significant at the 99% confidence level.

The greater mean concentration observed for WSW→W→WNW shows the influence of traffic flow in R. Peña Street, located west of the monitoring site (Figure 1).

3.3 Horizontal airflow and NO_x concentrations

Figure 5 shows the scatter plot of hourly values of local vs. ambient wind directions. Wind directions at the monitoring site are mainly from sectors 20º–110º and 250º–340º. The first group of wind directions can be observed with almost every ambient wind direction. Wind directions at the monitoring site from the second group are mainly associated with ambient wind directions from sector 140º–340º.

Figure 5 Scatter plot of inside the street canyon vs. ambient wind directions



For each ambient wind direction, the frequency (%) distribution of hourly wind directions measured inside the street canyon is shown in Table 2, on the basis of eight-sector wind roses. While analysing external winds perpendicular to Córdoba Avenue, for the southern ambient wind, it was found that 41.9% of the time, the wind at the monitoring site blew from the north-east, and 36.7% of the time, it ran east. On the other hand, the for northern external wind, in 75.2% of the cases the wind inside the street canyon blew from the east.

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) of wind directions registered simultaneously. Only averages obtained with more than 10 values are considered representative and included in the analysis.

Table 3 Mean NO_x concentrations (C) (ppb) and mean wind speed ($\bar{u}$) (ms^{-1}) registered at the monitoring site for 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*	
Ambient wind direction	C	ū	C	ū	C	ū	C	ū	C	ū	C	ū	C	ū	C	ū
N	*	*	94	0.9	89	1.4	0	0	0	0	0	0	*	*	*	*
NE	0	0	*	*	102	1.7	0	0	0	0	0	0	0	0	0	0
E	0	0	*	*	100	1.5	0	0	0	0	0	0	0	0	0	0
SE	0	0	*	*	149	1.0	0	0	0	0	0	0	*	*	*	*
S	*	*	159	0.7	211	0.6	0	0	0	0	0	0	139	0.8	*	*
SW	0	0	214	0.7	264	0.7	0	0	0	0	0	0	150	0.9	201	0.6
W	*	*	262	0.8	269	0.7	0	0	0	0	0	0	167	1.2	194	0.8
NW	*	*	81	0.9	64	1.0	0	0	*	*	*	*	110	1.2	*	*

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

Values in Table 3 should be analysed taking into account the fact that higher mean concentrations are expected to be associated with lower mean wind speeds ($\bar{u}$). The higher average NO_x concentrations were obtained with ambient winds from the south-west and the west. Combining results in Tables 2 and 3, high concentrations were mainly associated with the south-west ambient wind (41.6% with winds inside the canyon from the north-east and the east and 58.4% with winds inside the canyon from the west and the north-west). This ambient wind direction is associated with both contributions: the emissions from vehicles in R. Peña Street (for western and north-western winds inside the canyon) and the emissions from traffic in the avenue (for north-eastern and eastern winds inside the canyon).

Schemes showing average concentrations related to horizontal airflow directions at the monitoring site for different ambient wind directions are presented in Figure 6. These schemes have been elaborated considering the representative values in Table 3.

Figure 6(b) and (c) show that when the ambient wind is from the north and the north-east, the wind inside the street canyon is mostly from the north-east and the east. In these situations, the incoming ambient wind impacts against the windward face of the tall buildings located on the southern side of the avenue.

The eastern ambient wind (Figure 6d) is channelled along the avenue and at the monitoring site, the wind is also east.

The south-eastern ambient wind (Figure 6e) is associated with the eastern wind at the monitoring site 88.4% of the time (Table 2). It seems that inside the canyon, only the component of ambient wind parallel to the avenue remains. A similar pattern has been reported for other street intersections (Carpentieri et al., 2009; Soulhac et al., 2009; Xie and Castro, 2009).

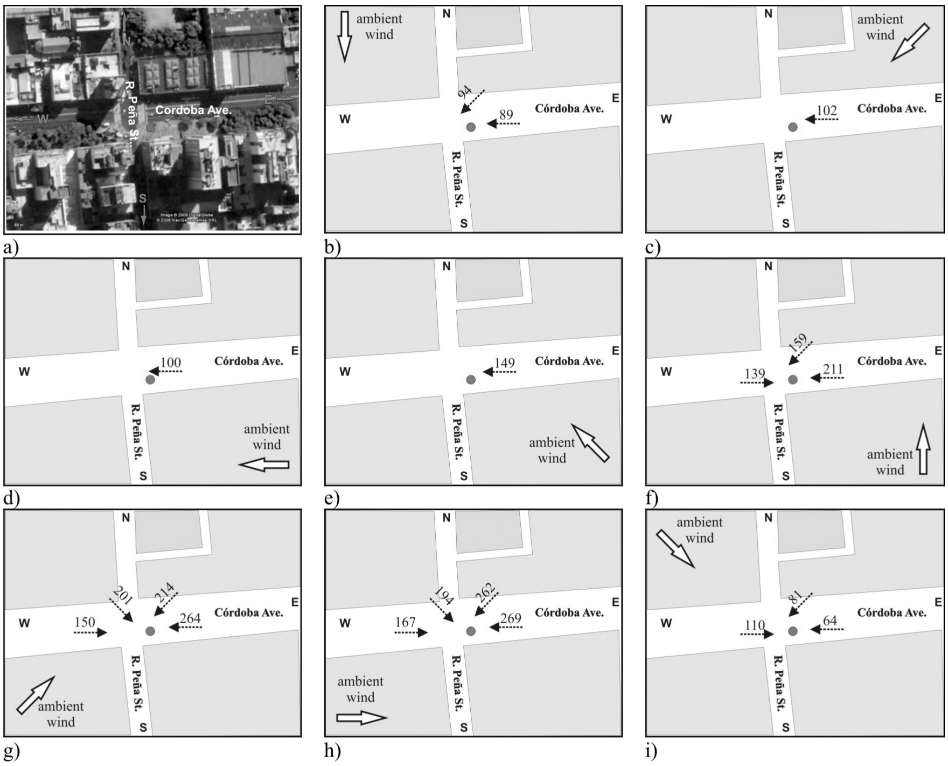
The southern ambient winds (Figure 6(f)) concur with winds from the north-east, the east and the west at the monitoring site most of the time. In these cases, the ambient wind might be affected by the tall buildings of irregular heights located on the southern side.

Figure 6(g) shows the situation for south-western ambient winds. In these cases, horizontal airflows registered at the monitoring site are from the west, the north-east, the east and the north-west. Western winds (47.5%) registered inside the canyon may come from the ambient wind component parallel to the avenue and from the street canyon channelling effect. Wind directions observed at the monitoring site agree with those reported by other authors in similar configurations (Carpentieri et al., 2009; Soulhac et al., 2009).

The western ambient wind (Figure 6(h)) generates a western wind inside the street canyon most of the time (76.2%). However, sometimes the vane at the monitoring site registers horizontal airflow from other directions. The irregular heights of the buildings at the four corners of the intersection and the structures built on the sidewalk, approximately 40 m east the monitoring site, disturb the airflow inside the canyon and affect the wind direction inside the canyon.

Figure 6(i) shows the situation for the north-western ambient wind. In these cases, the vane inside the canyon registered west (53.4%), east (26.0%) and north-east (13.4%) wind directions.

Figure 6 (a) Aerial view of the site (Picture: Google Hearth), (b)- i) schemes showing ambient wind direction with associated horizontal airflows (black arrows) and average NO_x concentrations (in ppb) at the monitoring site (●)



4 Conclusions

The analysis of ambient wind and hourly NO_x concentrations and wind speed measured at one site inside an asymmetric and irregular street canyon, close to a traffic intersection, in the city of Buenos Aires shows that:

- The shape of the air pollution rose related to the ambient wind might be explained by the presence of a wind vortex within the canyon, and the contribution of the traffic intersection located west of the air quality station.
- Higher average NO_x concentrations are observed when the ambient wind is from the south-west and the west.
- The wind direction at the monitoring site inside the canyon is mainly from the east, the north-east, the west and the north-west for any ambient wind direction.
- In general, the behaviour of the horizontal airflow at the monitoring site for different ambient wind directions, seems to be quite similar to those observed at other street intersections reported in the literature.

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