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SMALL-SCALE SPATIAL VARIABILITY OF AIR POLLUTION IN A COMPLEX ROADSIDE ENVIRONMENT: REPRESENTATIVENESS OF MONITORING DATA

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ABSTRACT

The strong spatial and temporal variability of air pollution detected at roadside locations in a number of European cities has raised the question of how representative the site and time period of air quality measurements actually can be. To address this question, a long-term sampling campaign was carried out on a major road axis leading to a very busy intersection in central Paris, covering the surroundings of a permanent air quality monitoring station. Diffusive BTX samplers as well as a mobile monitoring unit equipped with gas analysers and meteorological instruments were used to reveal the small-scale pollution gradients and temporal trends near the permanent monitoring station. The diffusive measurements were taken at different heights above the ground and distances from the kerb covering summer and winter periods. The analysis of this comprehensive data set may help to assess the representativeness of air quality monitoring information and generally revise the existing siting criteria for roadside receptors.

1. INTRODUCTION

Since the total number of permanent air quality monitoring stations in a city is limited due to practical constraints (cost and bulk of equipment, power supply, etc.), alternative measurement techniques are needed in order to assess urban air quality with respect to population exposure and compliance with regulations.

In general, receptors should be located near places of expected pollution hotspots but also must be reasonable as related to population exposure over the averaging times associated with ambient air quality regulations. It has been suggested in the past that receptors should be placed at the edge of pavement, at the corner of two intersecting streets. Although such locations may satisfy the criterion of maximum ambient concentrations, it can be argued that pedestrians do not usually spend a lot of time at street corners. Specific EU guidelines require that sampling points be located between 1.5 and 4 m above the ground, at least 25 m away from the edge of any major junctions, and at least 4 m from the centre of the nearest traffic lane. For CO, the sampling inlet should be no more than 5 m from the kerbside and for benzene it should be located near the building line, but at least 0.5 m away from the nearest wall (European Commission, 2000).

In order to study the small-scale spatial and seasonal variability of traffic-related pollutants in a complex urban site in central Paris, a combination of air quality monitoring techniques was used between June and December 2001. Both active and passive means were applied to sample a wide range of traffic-related pollutants at different roadside and background locations.

2. METHODOLOGY

The measurements were carried out in the asymmetric canyon of Avenue Leclerc and the major intersection of Place Basch. Avenue Leclerc is a busy road axis linking Bd. Périphérique (i.e. the major ring motorway of Paris) in the south with the city centre in the north. Roadside measurements were taken within the straight road segment between Rue Sarrette (south) and Pl. Basch (north), and around Pl. Basch where four avenues are intersecting. In addition, urban background measurements were carried out in Montsouris Park, at approximately 800 m distance in the SE of the roadside monitoring site (Fig. 1).

The height and shape of the urban canopy surrounding Av. Leclerc is not uniform, since there is a mixture of traditional (usually) six-storey buildings, modern tower blocks, and few detached houses. The large road segment between Rue Sarrette and Rue Daudet can be considered as an asymmetric street canyon, with the buildings on the east side being approximately 12 m taller than those on the west side. The traffic flow in Av. Leclerc is very high (approx. 66,000 veh/day) and quite congested during morning and afternoon rush hours.

Diffusive BTX samplers (Perkin Elmer) were exposed to ambient air during 28 consecutive seven day periods between June and December 2001 (Vardoulakis, 2002). The samplers were placed at 2.6 m height at the ten roadside locations indicated in Fig. 1, and at one urban background site in Montsouris Park. In addition, diffusive samplers were exposed at different heights (2nd, 5th and 10th floor) near the walls of the asymmetric canyon in Av. Leclerc during one week (16-23 July). During the same week, a mobile monitoring unit was parked on the east side of the canyon, inside the separate parking lane. That allowed to record real time CO, NO_x and O_3 values (24/24 h). Furthermore, active VOC sampling was conducted at the same location by drawing ambient air during several one hour intervals at a constant flow through Supelco tubes.

Continuous CO and NO_x measurements were obtained from a roadside air quality monitoring station (AIRPARIF) permanently operating in Pl. Basch. The exact location of this station is on a narrow traffic island in the middle of a pedestrian crossing in Av. Leclerc, very near Pl. Basch (Fig. 1). Synoptic meteorological data were obtained from the Montsouris and Orly weather stations throughout the campaign. During the intensive monitoring period (16-23 July), two anemometers and a weather mini-station were located at the kerb, near the mobile unit. Traffic volume and average vehicle speed were obtained from permanent automatic counters operated by the Local Authority of Paris (Mairie de Paris) within the selected road segment. Manual vehicle counts were taken during the campaign and compared for consistency with the data obtained from the automatic network. The vehicle fleet composition was estimated from on site spot measurements. Finally, a QA/QC programme including sampling duplicates, field and laboratory blanks, and instrument calibration with standard gases was followed.

3. RESULTS AND DISCUSSION

The diffusive sampling measurements revealed that location H (roundabout) was the most polluted sampling site during the campaign. This is the location were the highest weekly mean concentrations of benzene were detected for 16 out of 28 weeks of sampling, as well as the highest benzene value averaged over the seven months of the campaign. Locations D, A and F were the second, third and fourth most polluted sites respectively, according to the same criteria. It should be noted that these three locations are on the west site of Av. Leclerc, which was more often leeward than the opposite side of the canyon (Fig. 1). The lowest benzene concentrations were observed at locations C and J, on the mostly windward pavement of the asymmetric canyon of Av. Leclerc (i.e. east side). Apart from the prevailing wind direction, the relative large distance (12 m) of receptors C and J from the main traffic lanes of Av. Leclerc may explain these relatively low concentrations. In the asymmetric canyon, there was no significant reduction in ambient benzene concentrations along with height above the ground (16-23 July), probably due to the presence of big trees, which increased mechanical turbulence and hence vertical mixing within the street.

There was no marked seasonal variation in the observed benzene levels in Pl. Basch and Av. Leclerc, although in most roadside sampling locations slightly lower concentrations occurred during the summer months. At all locations, the highest benzene concentrations were observed in the month of October, due to the relatively low winds (average wind speed = 2.8 m/s) coming from the S and SW, thus parallel to Av. Leclerc. These meteorological conditions probably induced wind flow along Av. Leclerc, transporting polluted air masses from Bd. Périphérique and Porte d'Orléans junction towards Pl. Basch. The lowest benzene concentrations were at most roadside locations observed in August, mainly due to the reduced traffic density during this month.

During sampling, background benzene concentrations at Montsouris Park were significantly lower than those detected at all roadside locations. Monthly averages were within the range of 0.5 – 1.0 ppb at the background (BG), except for the month of October when the benzene average value in Montsouris Park was 1.5 ppb. On the roadside, monthly benzene averages ranged between 1.3 and 4.0 ppb (Fig. 1).

The influence of the synoptic wind direction on pollutant dispersion within the asymmetric canyon is illustrated on the pollution roses plotted for CO and NO_x (Fig. 2a). Hourly mean CO and NO_x concentrations observed in Av. Leclerc (canyon) and normalised with respect to the wind speed and traffic volume, were assigned to the corresponding synoptic wind directions, and then mean concentrations were calculated for each wind direction sector. Both CO and NO_x roses demonstrate a clear dependence of pollution levels on the synoptic wind direction. They show that, keeping the other factors constant, winds parallel or near-parallel to the street axis (i.e. from S and N directions) favour pollution built-up on the kerbside, while perpendicular winds (i.e. from W and NW directions) provide better dispersion conditions. Furthermore, it can be observed that normalised CO and NO_x concentrations were significantly higher for southerly winds than for winds

coming from the north. This might be explained by the contribution of Bd. Périphérique and Porte d'Orléans junction, which are both major air pollution sources in the south of Av. Leclerc.

Following the same methodology, normalised CO and NO_x concentrations from the AIRPARIF station were used to plot pollution roses, in order to identify the influence of wind direction on pollutant dispersion in Pl. Basch (Fig. 2b). According to this graph, there is no clear dependence of the observed pollution levels on the synoptic wind direction, although higher normalised CO and NO_x concentrations are more often associated with parallel and near-parallel winds.

The AIRPARIF monitoring station in Pl. Basch has recorded the highest CO and NO_x concentrations during recent years in the region of Paris (AIRPARIF, 1999). The CO and NO_x values recorded by AIRPARIF were much higher than the values observed within the asymmetric canyon sector of Av. Leclerc during the intensive monitoring campaign (16-23 July). That mainly reflected the influence of the high traffic density and the short distance between the AIRPARIF station and the car exhausts.

The average NO_2 value in the asymmetric canyon during the intensive monitoring period (16-23 July) was 24 ppb, thus exceeding the annual EU objective of 21 ppb. Although the averaging times were different, this value indicates that the air quality objective for NO_2 might not be met in the long run. The long-term (i.e. seven-month) benzene averages at all roadside locations were clearly above the annual EU limit of 1.6 ppb, while the average value in Montsouris Park was below this threshold during the same time period.

4. CONCLUSIONS

Diffusive BTX sampling was proved an efficient technique for revealing the spatial variability of air pollution in a complex roadside environment. The air circulation within Av. Leclerc gave rise to relatively high pollutant concentrations on the leeward side of the street. Nevertheless, winds parallel or near-parallel to the street axis induced the highest roadside concentrations, while perpendicular winds generally reduced pollution levels (especially on the windward side of the street). There was no marked seasonal variation in the observed values. Higher concentrations were mainly associated with relatively low southerly winds, which probably transported polluted air masses from Bd. Périphérique toward Pl. Basch. Concern was created over the observed benzene values, which seemed to exceed the EU objective at all roadside locations, although the urban background average remained below the same threshold. Given the pronounced small-scale spatial variability of urban air pollution, the siting of monitoring equipment becomes crucial.

The permanent AIRPARIF monitoring station in Pl. Basch does not fulfil the siting criteria specified in the EU directive, since the sampling inlet is placed in the middle of a very busy avenue and very close to a major intersection. At this position, the direct intake of undiluted exhaust gases cannot be excluded. Not surprisingly, the AIRPARIF station in Pl. Basch has recorded the highest CO and NO_x concentrations during recent years in the region of Paris. Furthermore, the CO and NO_x values recorded in this station were much higher than the concentrations observed within the asymmetric canyon segment of Av. Leclerc during an intensive one-week monitoring period. Even though people have access to the narrow traffic island where the AIRPARIF station is permanently located, they do not stay there for long. Therefore, it can be argued that this is not an appropriate monitoring site for estimating population exposure in Paris, although it may be still useful for observing traffic emission trends.

5. ACKNOWLEDGEMENTS

This study was funded by the French Ministry for the Environment. The authors would like to thank Jean-Claud Pinard for his technical assistance, Armelle Frezier for the chemical analysis of the samples and Nathalie François for the preparation of the devices at INERIS. The Local Authority of Paris is also acknowledged for providing traffic information.

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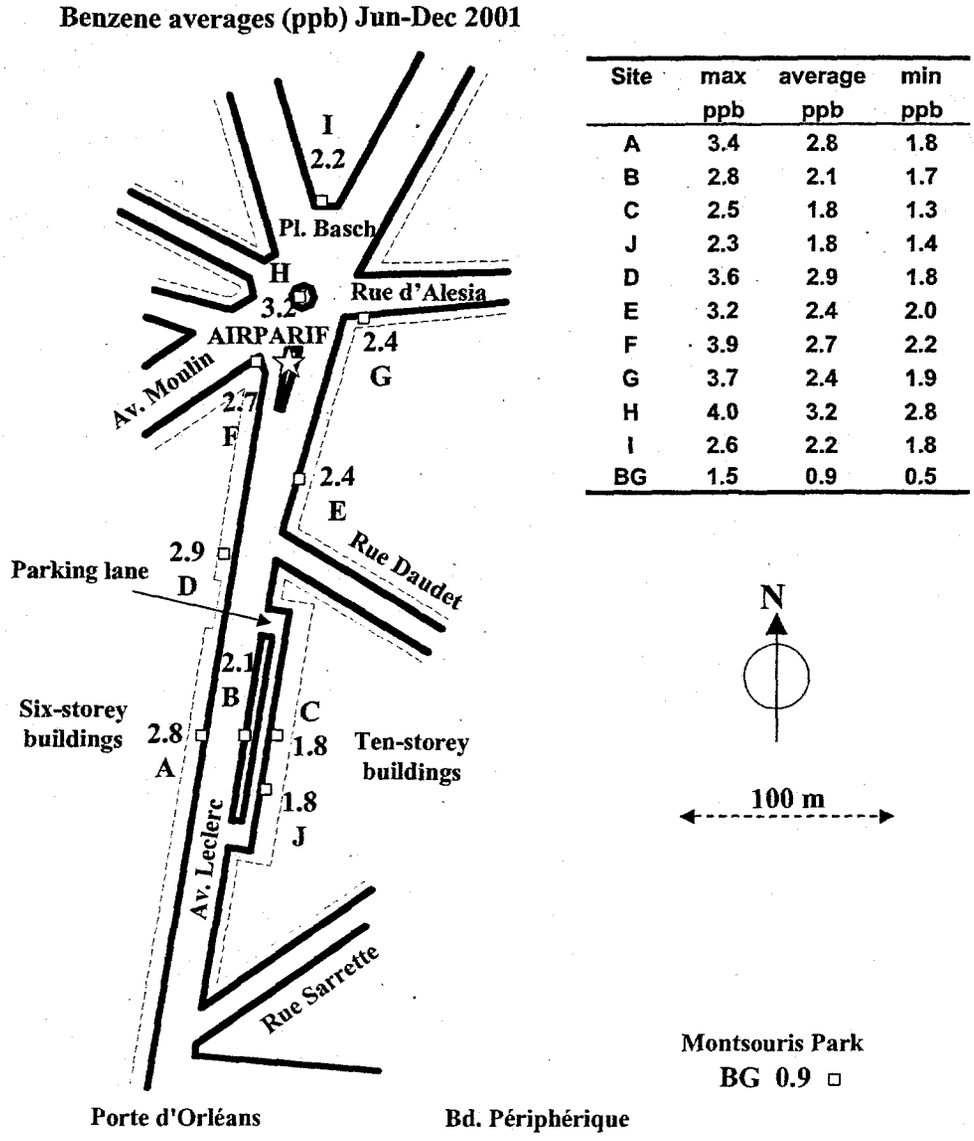

Site	max ppb	average ppb	min ppb
A	3.4	2.8	1.8
B	2.8	2.1	1.7
C	2.5	1.8	1.3
J	2.3	1.8	1.4
D	3.6	2.9	1.8
E	3.2	2.4	2.0
F	3.9	2.7	2.2
G	3.7	2.4	1.9
H	4.0	3.2	2.8
I	2.6	2.2	1.8
BG	1.5	0.9	0.5

Fig. 1: Average benzene concentrations (ppb) in Av. Leclerc – Pl. Basch during seven months (plan view).

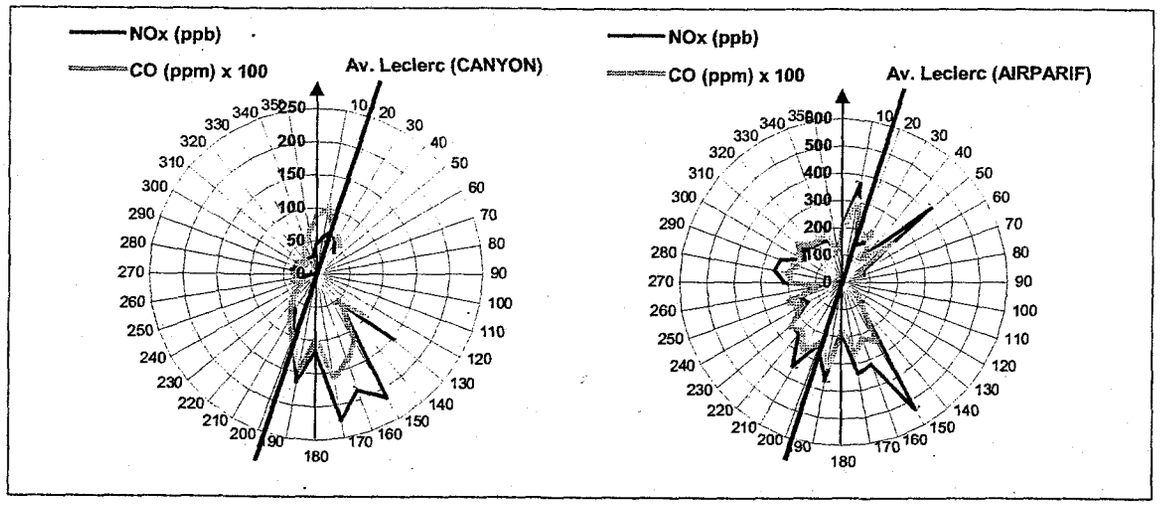

Fig. 2: Pollution roses in (a) Av. Leclerc (left) and (b) Pl. Basch (right). The heavy line indicates Av. Leclerc.