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Air quality monitoring and modelling techniques for street canyons: the Paris experience

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Abstract

A better understanding of the dispersion and transformation of atmospheric pollutants in urban micro-environments is required to address the increasing public concern about human exposure in such areas. A joint research program has been established between INERIS (France) and University of Greenwich (UK) with the aim of developing efficient air quality monitoring and modelling methodologies to cover the needs of public health and road traffic managers in Europe.

An intensive monitoring campaign was conducted at a representative canyon street in Paris in winter 1998. This experiment was designed to establish the spatial and temporal variation of pollution within the canyon, and test readily available dispersion models. Active and passive techniques were used to sample a wide range of traffic generated pollutants (VOC and inorganic gases) at different heights and distances from the kerb. Local meteorological and traffic information was also obtained. The observed CO and NO concentrations were compared with predicted values, calculated using AEOLIUS, the street canyon model developed by the UK Meteorological Office.

The results demonstrate strong spatial pollution gradients within the canyon, large differences between roadside and background pollution levels, and pronounced temporal variability.

1 Introduction

In recent years, the increasing public concern about the adverse health effects of atmospheric pollution has led to the revision of air quality legislation at national and European level. Consequently, more stringent regulations have been proposed by the European Commission for several toxic gases mainly induced by road traffic (CO, NO_2, benzene, ozone, etc.)

In most European countries, municipal authorities have an important role in ensuring that the air quality objectives are achieved. Particularly in the UK, the Local Air Quality Management legislation (Part IV of the Environment Act 1995) requires local authorities to conduct periodic reviews and assessments of air quality. In the cases where the objectives specified in the Air Quality Regulations 1997 are not likely to be met by the end of 2005, an Air Quality Management Area (AQMA) has to be declared. In such a case, the local authority has to carry out an assessment of present and future air quality in the area concerned, and prepare an action plan in order to reach the objectives [1].

The compliance with regulatory standards is one of the tasks related to air quality that local administration has to undertake. In addition to that, health risk assessments, traffic management and transport planning studies need to be carried out on a regular basis. To manage these tasks, competent authorities need efficient monitoring and modelling tools and methodologies to determine pollutant concentrations in ambient air. As far as actions need to be taken at local level, these tools should produce reliable results at a low acquisition and operational cost. Furthermore, they should be user-friendly and well documented.

Within this context, particular attention should be given to those environments where population exposure to atmospheric pollutants is likely to be significantly higher than the urban average (e.g. busy streets and intersections, highways, petrol stations or industrial plants). A series of air quality monitoring campaigns is being conducted in Paris by the *Institute National de l'Environnement Industriel et des Risques (INERIS - France)* with the collaboration of the *University of Greenwich (UK)*, aiming to develop a standard method for the characterisation of such environments.

The experimental approach adopted in this study comprises: (a) the use of mobile air quality and meteorological monitoring equipment for the spatial and temporal characterisation of urban micro-environments; (b) the application of simple dispersion models for assessing their potential as predictive tools.

2 Field experiment

2.1 Site description

A field campaign was carried out in December 1998 in Bd. Voltaire, a typical four lane avenue of Paris with wide pavements and car parkings on both sides of the street. The part of Bd. Voltaire which was selected for this experiment constitutes a nearly perfect canyon with uniform buildings lining up continuously on both sides, height-to-width ratio of 0.8, and no major intersections along a straight road segment of approximately 300 m. Traffic lights were operating at both ends of the canyon, and there was a pedestrian crossing at a distance of 34 m from the main sampling point. The street axis bearing from the north was 140° and therefore nearly perpendicular to the westerly winds prevailing in the region during the measurements.

2.2 Measurement techniques

Parallel techniques, both active and passive, were used during one week to sample a wide range of traffic related atmospheric pollutants (CO, NOx, O_3, VOC). For the same period of time, local meteorological and traffic data were also collected.

Continuous CO, NOx, and O_3 analysers based on radiation absorption principles were used for the description of the temporal variation of pollution levels in the street. These analytical instruments were sheltered in a trailer, which was parked on the east side of the road.

Diffusive VOC samplers were located at different heights on both sides of the canyon in order to reveal the spatial variability of the compounds. For the estimation of the urban background contribution to the concentrations measured in the street, passive samplers were also placed in an adjacent park locations.

Active sampling for VOC was carried out during one day of the campaign. Ambient air was pumped for one hour periods at a constant flow rate through a tube filled with the appropriate adsorbent. The hourly VOC concentrations obtained using pumped tubes were directly comparable with the observed CO levels, since both measurements were carried out through the same sampling line.

Carbotrap-B Supelco [2] was used as adsorbent for passive and active VOC sampling. After removal from the tubes with thermal desorption, the VOC samples were analysed in the laboratory using Gas Chromatography (column type: CP-SIL 5CB, 50 m x 0.32 mm, 1.2 μm). A quality assurance programme, including sampling duplicates, blanks and instrument calibration with standard gases was followed during the sampling and analytical work.

A 3-D ultrasonic anemometer and a weather mini-station were used for meteorological monitoring. These instruments were situated on the top of a mast (of 3.7 m height) next to the trailer, at a distance of 8.5 m from the wall of the nearest building. The location of the sampling and monitoring equipment is shown in Figure 1. Traffic data were continuously recorded by an automated counter located at the end of the canyon.

3 Results

3.1 Correlation between CO and benzene

Most of the atmospheric pollutants generated by traffic in urban environments (e.g. VOC, CO) can be considered as inert compounds due to the very short distances between sources and receptors. For this reason, the proportionality between them is expected to be nearly constant in a specific area and for a period of time with no significant changes in vehicle fleet composition and traffic pattern. If a simple mathematical relationship expressing such a proportionality between CO and benzene is established, then it will be possible to estimate CO concentrations using benzene measurements and vice-versa on the basis of this relationship [3].

In order to establish such a relationship, active VOC sampling was performed in Bd. Voltaire during one day of the campaign, simultaneously with CO monitoring and through the same sampling line. Figure 1 shows the hourly variation of the detected benzene, toluene, m,p-xylenes, and CO concentrations. Figure 2 illustrates the linearity between CO and benzene measurements (correlation coefficient = 0.93, slope = 3.97×10^{-3}, and intercept = 0.15×10^{-3}). The empirical formula obtained from this regression, benzene (ppb) = 4 × CO (ppm), can be consequently used for the calculation of CO levels at all locations where benzene measurements are available, or for the estimation of benzene variation with time. This simple methodology makes use of the practical advantages of passive-active VOC sampling (low cost and autonomy-portability of samplers) and continuous CO monitoring (accuracy and high time resolution) to provide a detailed temporal and spatial description of the pollution levels in an urban canyon.

3.2 Spatial and temporal variability

Using benzene as an indicator, strong pollution gradients were identified in the horizontal and vertical sense within the canyon. Differences of more than 2 ppb of benzene were observed at street level between the two opposite sides of the canyon, and of more than 1 ppb between roadside and urban background (Figure 3). A hot-spot of benzene (weekly average: 4.5 ppb) was detected on the leeward (up-wind) side of the street at 4.2 m height. In addition to the horizontal pollution gradients, a significant reduction in benzene concentrations along with the height was also observed. Very similar trends were identified for the rest of the VOC compounds sampled with passive tubes during the campaign.

While benzene measurements described the spatial variability of pollution in the street, CO continuous monitoring provided detailed information on the temporal variability of inert pollutants. Two peaks of CO were observed during the campaign. The first one (16th December) can be explained by the presence of low wind conditions (wind speed ≤ 2.5 m/s) in the region, and the second one

(17 December) by the presence of relative low winds (2.5 - 3.0 m/s) blowing from directions parallel to the street axis (Figure 4).

4 Model simulations

The observed CO and NO concentrations were compared with predicted values, calculated using AEOLIUS, the street canyon model developed by the UK Meteorological Office [4]. This model is designed to calculate a series of hourly concentrations of a pollutant at a single receptor location on either side of the street. It requires synoptic meteorological data, traffic information, emission factors, and description of the topography [5].

AEOLIUS is based on the OSP Model [6], which calculates the concentration of pollutants in the street as the sum of three components: the contribution from the direct flow of pollutants from the source to the receptor, the recirculation component due to the flow of pollutants around the horizontal wind vortex generated within the canyon, and the urban background contribution. The direct component is calculated by the model using a simple plume dispersion algorithm, while the recirculation component is calculated using a box model formulation. Finally, the background contribution is an additive term introduced by the user.

In this application, the diurnal variation of measured CO and NO concentrations was clearly reproduced by the model (Figures 5 and 6). Nevertheless, the model predictions were quantitatively satisfactory only after introducing a constant fitting parameter. Given the strong pollution gradients in the street, this adjustment may be justified by the fact that the model was not configured to calculate the concentration of pollutants at the exact location where the measurements were taken. In addition to that, it is expected that the predicted concentrations would be closer to the observed values if locally measured (above-roof) wind data had been used for running the model. Finally, AEOLIUS appears not to be able to reproduce the measured peaks of pollution on an hourly basis, which is expected as models are rarely able to capture extreme pollution events [7].

5 Conclusions

A combination of air quality monitoring and modelling techniques has been proposed for assessing air quality in urban canyons. During the presented campaign, the simultaneous use of passive and active sampling systems provided a detailed description of the temporal and spatial variation of atmospheric pollution in the street and its vicinity. The strong horizontal and vertical concentration gradients may raise questions about the representativeness of routinely obtained air quality data from fixed monitoring stations.

The empirical CO-benzene relationship established for the specific environment can be used for achieving a better time and space resolution of roadside concentrations for both compounds. AEOLIUS can give reliable CO and NO predictions when it is carefully calibrated by measurements.

Following these air quality monitoring-modelling techniques, an optimum use of resources can be achieved. The relatively low cost of monitoring devices (e.g. passive and active tubes), the public domain software (AEOLIUS), and the limited amount of computational time and user expertise involved, make this method a cost-effective tool for the determination of air quality levels in urban canyons.

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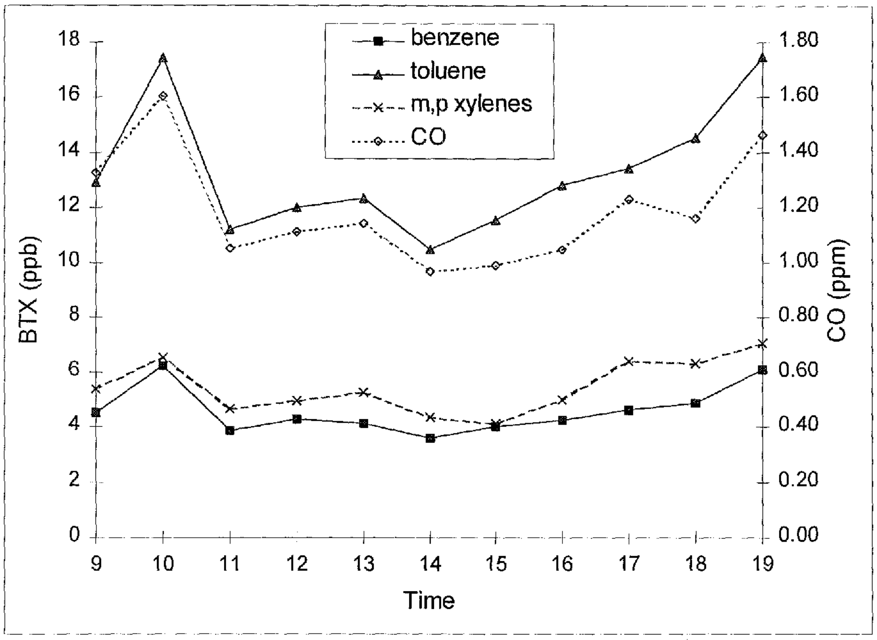

Figure 1: Daily variation of benzene, toluene, m,p-xylenes, and CO

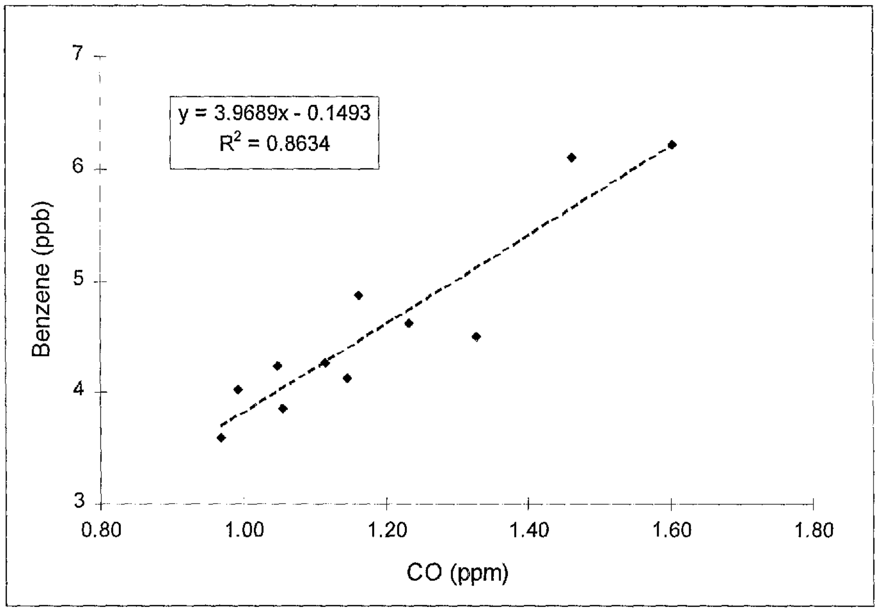

Figure 2: Benzene against CO

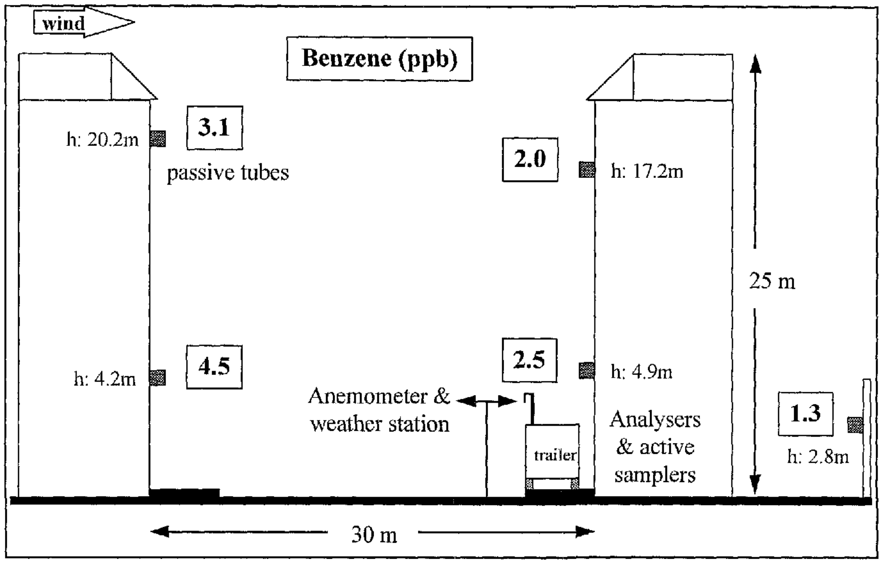

Figure 3: Spatial variability of benzene in Bd. Voltaire (Paris)

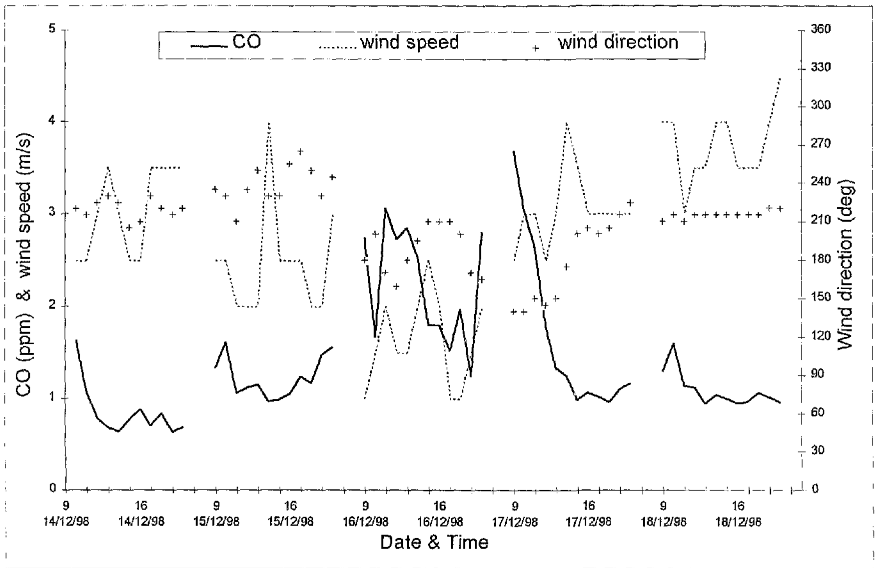

Figure 4: Time series of CO, with above-roof wind and direction

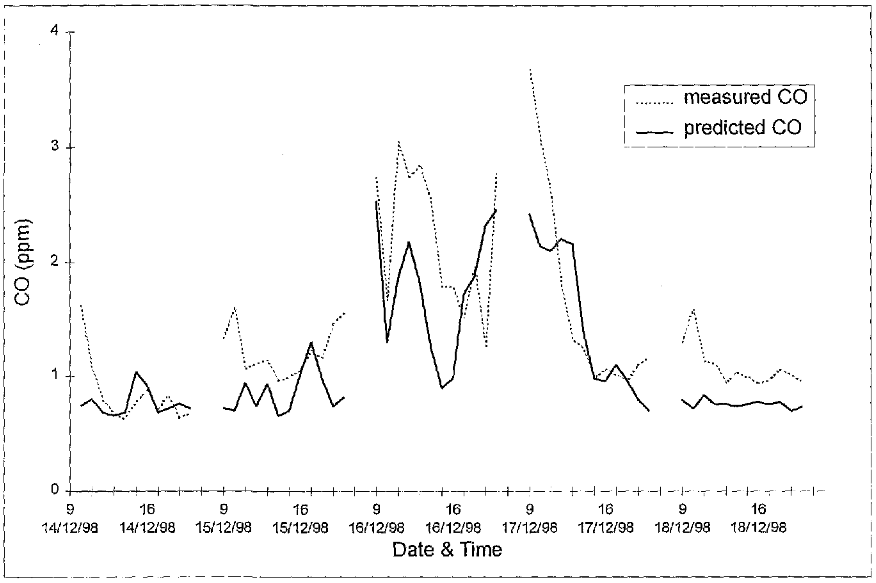

Figure 5: Time series of measured and predicted CO

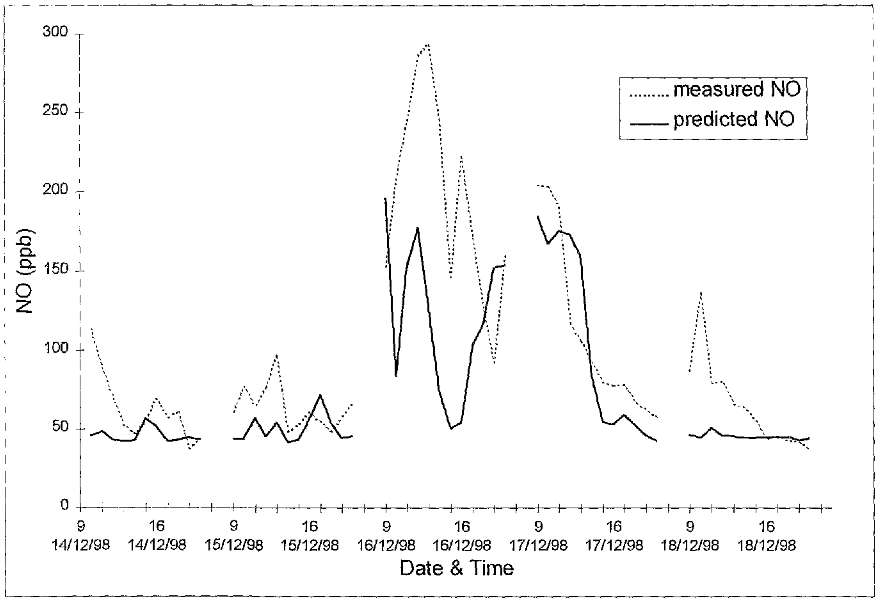

Figure 6: Time series of measured and predicted NO