EXAMINATION OF TRAFFIC POLLUTION DISTRIBUTION IN A STREET CANYON USING THE NANTES'99 EXPERIMENTAL DATA AND COMPARISON WITH MODEL RESULTS

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Abstract. During the Nantes'99 experiment, pollution concentrations, temperature, flow and turbulence conditions were measured at several locations in Rue de Strasbourg, Nantes, France. Traffic was measured by vehicle counters at different places within the street. Traffic speed was monitored as well. The measuring campaign was conducted in the period June–July 1999 but only data from a selected intensive observation period are used in this study. This period was selected to suit conditions required for study of the traffic produced turbulence and the thermal effects and is characterised by quite low wind speeds. The data are used here for examination of concentration distributions in the street. Measurements are compared to model results calculated by a simple parameterised model, the Operational Street Pollution Model (OSPM) and a 3-D CFD model MISKAM. Both models reproduce reasonably well the observed distribution of pollutants in the street. Due to predominantly low wind speed conditions, such effects as the traffic produced turbulence play a quite significant role. The model results provided by MISKAM are scaled using a velocity scale depending on the traffic produced turbulence. Application of a scaling velocity depending on wind speed only, provides unrealistic results.

Keywords: MISKAM, OSPM, traffic pollution, traffic produced turbulence, vertical distribution

1. Introduction

Traffic pollution in a street canyon is characterised by large temporal, horizontal and vertical variability, which is not only related to the diurnal variation in the traffic amount but is also influenced by the meteorological conditions. This has a great importance for e.g. evaluation of the urban population's exposure to the traffic pollution and therefore requires special attention. Very little is still known about the vertical distribution of the pollution in street canyons. Only a few experimental data exists and most of the data are from wind tunnel experiments (Pavageau *et al.*, 1997). Recently a new unique data set became available based on results from the Nantes'99 experiment. During this experiment, pollution concentrations, temperature, flow and turbulence conditions were measured at several locations in Rue de Strasbourg, Nantes, France. A detailed description of the experimental set-up

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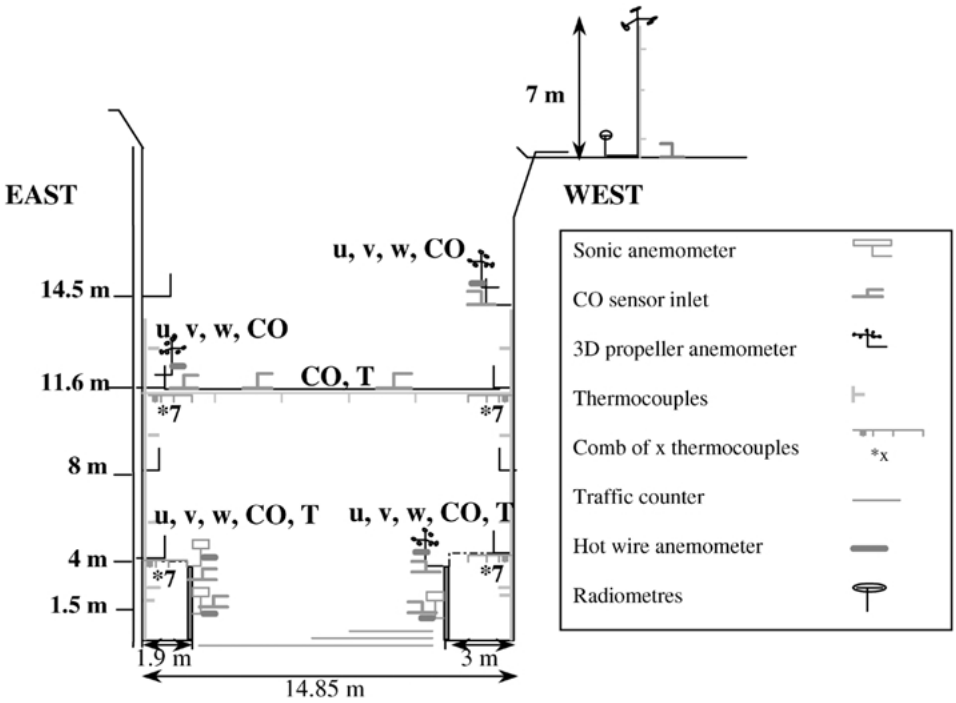

Figure 1. The experimental set-up of the measuring campaign in Rue de Strasbourg.

is given in Vachon *et al*. (1999). Analyses of the turbulence measurements in the street, with special emphasis on the dependence on traffic flow and thermal effects, are presented in Vachon *et al*. (2001) and Louka *et al*. (2001). In this article we focus on examination of the spatial distribution of traffic pollution and the effect the meteorology has on this variation.

The experimental data are compared with results from two models: the Operational Street Pollution Model (OSPM) (Berkowicz, 2000) and a 3-D CFD model MISKAM (Eichhorn, 1995). The models are not described in this article, and the readers are referred to the original publications. However, it should be emphasised that OSPM is a highly simplified, parameterised model, while the CFD model MISKAM is much more advanced and is believed to be suitable for detailed modelling of flow and dispersion conditions in urban streets. Some results of evaluation of several CFD models, incl. MISKAM, on wind-tunnel and field data are presented in Sahm *et al*. (2001) and Ketzel *et al*. (2001a).

2. The Site and the Experimental Set-up

Rue de Strasbourg is a 3-lane, one-way, highly trafficked street. The mean height of the buildings along the street is ca. 21 m and the width of the street is ca. 15 m,

resembling a street canyon of the W/H ratio of ca. 0.7. The street orientation is 28° to West with respect to North. The experimental set-up is shown in Figure 1.

The components of flow and turbulence were measured by 3-D sonic and propeller anemometers at three levels on each side of the street. Meteorological parameters were also measured on a 7 m high roof mast, on the westerly side of the street.

Concentrations of CO were measured on both sides of the street at 1.5, 4 and ca. 12 m on the East side, and 1.5, 4 and ca. 16 m on the West side. Measurements were also available from an upper level location in the middle of the street, but they are not used in this study. Background concentrations were monitored at the roof location, the same place as the meteorological mast.

Traffic was measured by vehicle counters at different places within the street. Traffic speed was monitored as well.

3. The Data

The measuring campaign was conducted in the period June–July 1999 but only data from a selected intensive observation period are used in this study. This period was selected to suit conditions required for study of the traffic produced turbulence and the thermal effects (Vachon *et al.*, 2001; Louka *et al.*, 2001) and is characterised by quite low wind speeds. The frequency distribution of wind speed measured on the roof mast and the frequency distribution of wind directions are shown in Figure 2.

The available traffic measurements were used to construct an average diurnal traffic profile for the street (Figure 3a). The CO emissions calculated using the traffic flow data and vehicle emission factors are shown in Figure 3b. It should be noted here, that significant uncertainty must be attributed to the emission data. CO emissions are known to depend very much on driving conditions, the vehicle types and such factors as e.g. cold-start percentage. Only very rough estimates of these parameters were available for this study.

The data mentioned in this section, together with background concentrations measured at the roof location (see Figure 1) are used for the presented model calculations.

4. The Modelling Procedure

Due to the low wind speed conditions prevailing during the measuring campaign, some special adaptation of MISKAM modelling results was required.

MISKAM is a very CPU time-demanding model and calculations are usually done for selected wind directions (in this case for 12 directions with 30° interval) and one reference wind speed only. Assuming that both the concentrations and the

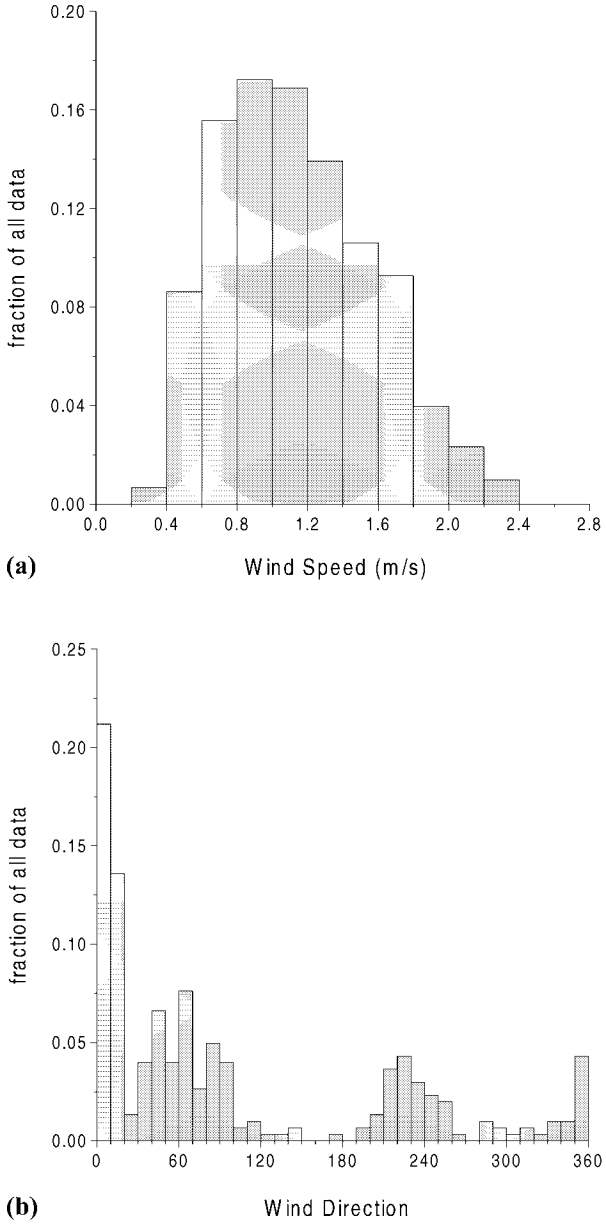

Figure 2. Frequency distribution of (a) wind speed and (b) wind direction as measured during the selected intensive observation period.

wind field data will scale with the reference wind speed, the model results can be given in terms of the non-dimensional concentration c^*,

$$c^* = c \cdot u_r \cdot S/Q \ , \tag{1}$$

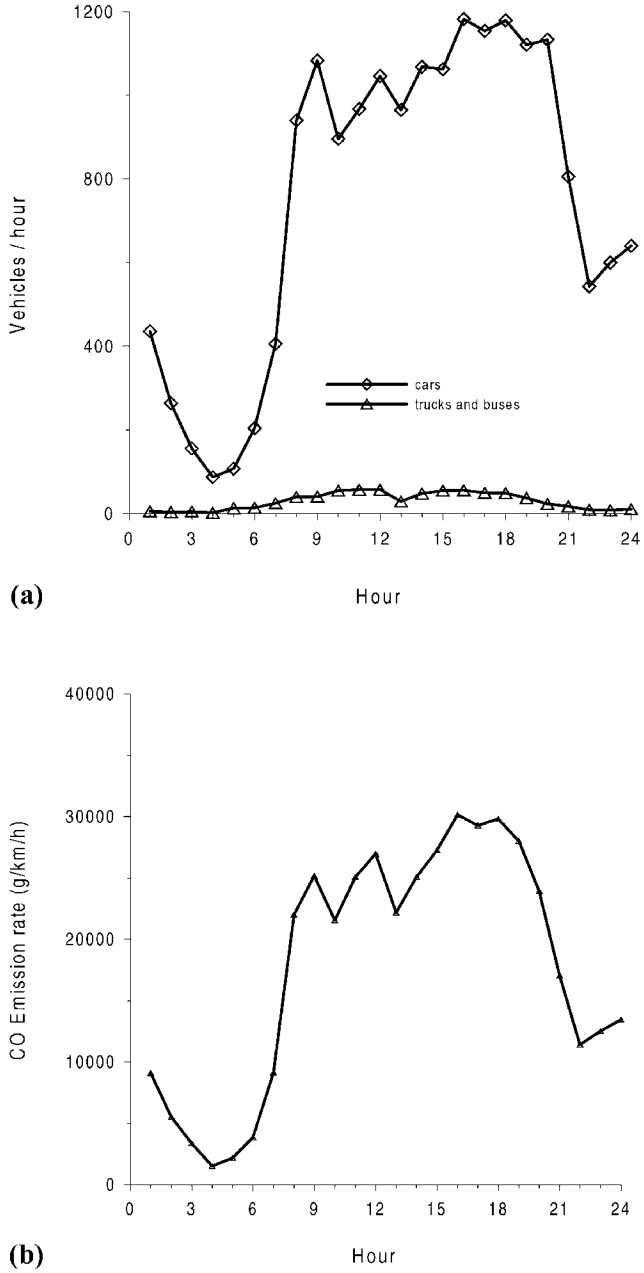

Figure 3. The average diurnal traffic profile (a) and the CO emission rate (b).

where u_r is a reference wind speed, Q is the emission rate and S is a length scale related to the street dimensions (here we use the height of the buildings).

Using Equation (1) for calculation of concentrations for any value of wind speed implies the assumption that the ambient wind is the only mechanism responsible for dispersion of pollution in the street. This is a reasonable approximation for higher wind speeds, but fails totally for lower wind speeds. It is believed that at low wind speed conditions, the main mechanism governing dilution of the car exhaust gases is the turbulence created by the traffic itself (Kastner-Klein *et al.*, 2001; Vachon *et al.*, 2001). However, the traffic produced turbulence is not directly included in the present version of MISKAM. Therefore, in order to account for this additional dilution mechanism, the concentrations within the street canyon, for a particular ambient wind speed u, are calculated here using the following formula:

$$c = c^* \cdot \frac{Q}{S \cdot \sqrt{u^2 + (\alpha \cdot \sigma_{\text{traf}})^2}} \,. \tag{2}$$

In Equation (2), σ_{traf} is the additional turbulence created by the traffic in the street and α is an empirical parameter, which depends only on the ambient wind direction. No provision was made here to account for the variation of the traffic produced turbulence with the height above the street. This means that the vertical concentration gradients predicted by MISKAM are not altered by this 'renormalisation' procedure. The traffic contribution to the turbulence in the street (the value of σ_{traf}) is calculated in the same way as in OSPM (Berkowicz, 2000). More details concerning the empirical parameter α, as well as some more test results of the procedure are presented in Ketzel *et al.* (2001b).

5. Results

Hourly averaged CO concentrations were calculated with OSPM for all the measuring points in the street. OSPM is a highly simplified model but previous model tests have proven its reasonably good performance. This study is however the first intensive test of the model using data from different heights in the street. Results of model comparison with measurements in the street are shown in Figure 4.

A similar comparison, but with results obtained with the 3-D numerical model MISKAM (version 4.1) using the procedure outlined in Section 4, is shown in Figure 5.

In each of the above figures, both the 1:1 line, as well as the best-fit line, are indicated too. The scattering around the 1:1 line is quite substantial, and especially for the lowest receptor heights. Some of the scatter can be attributed to the large uncertainties in determination of the hourly emissions of CO from the traffic in the street. However, the model deficiencies to reproduce the flow and dispersion conditions at the low wind speed conditions, should also be taken into account.

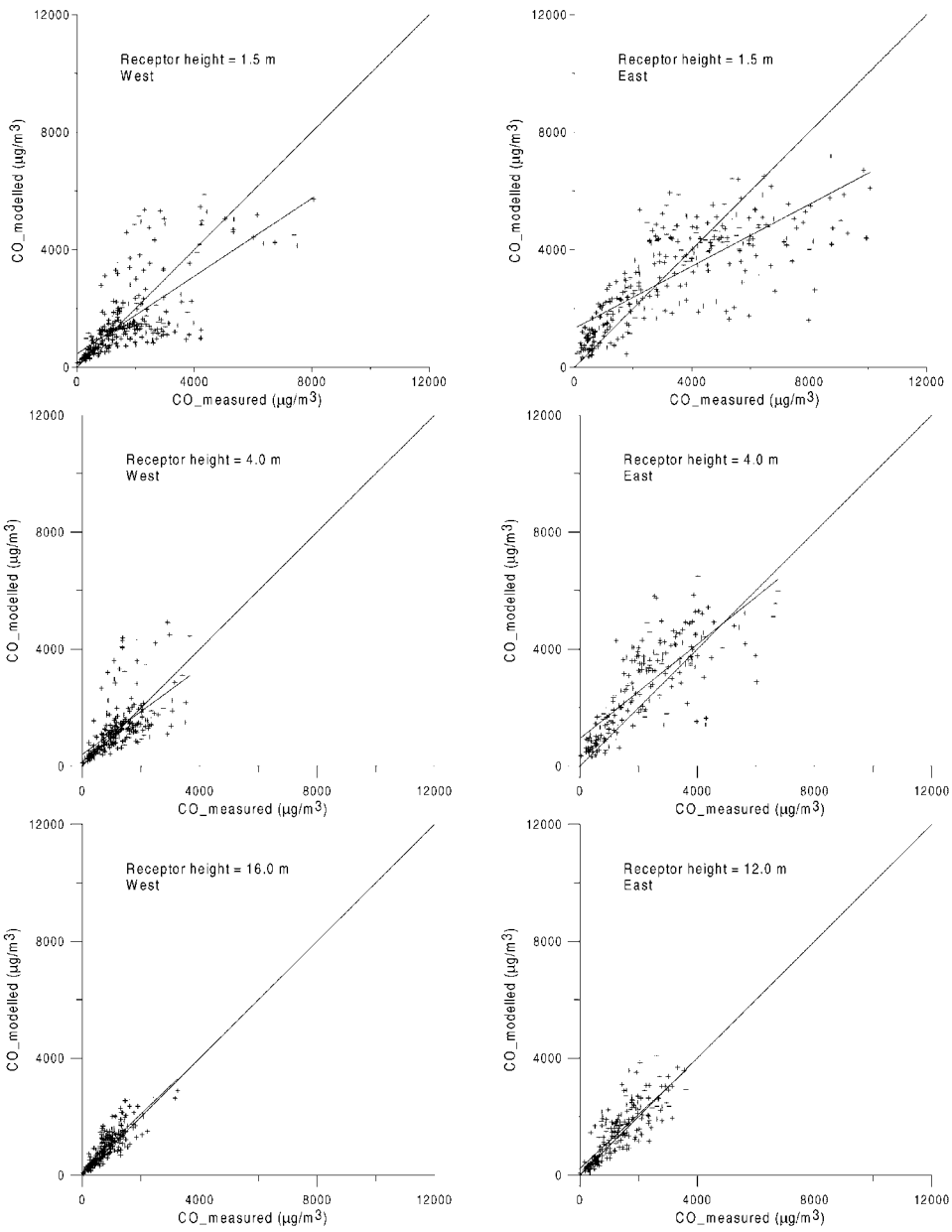

Figure 4. Comparison of OSPM results with CO measurements in the street. Location of the receptor points is indicated in the figures.

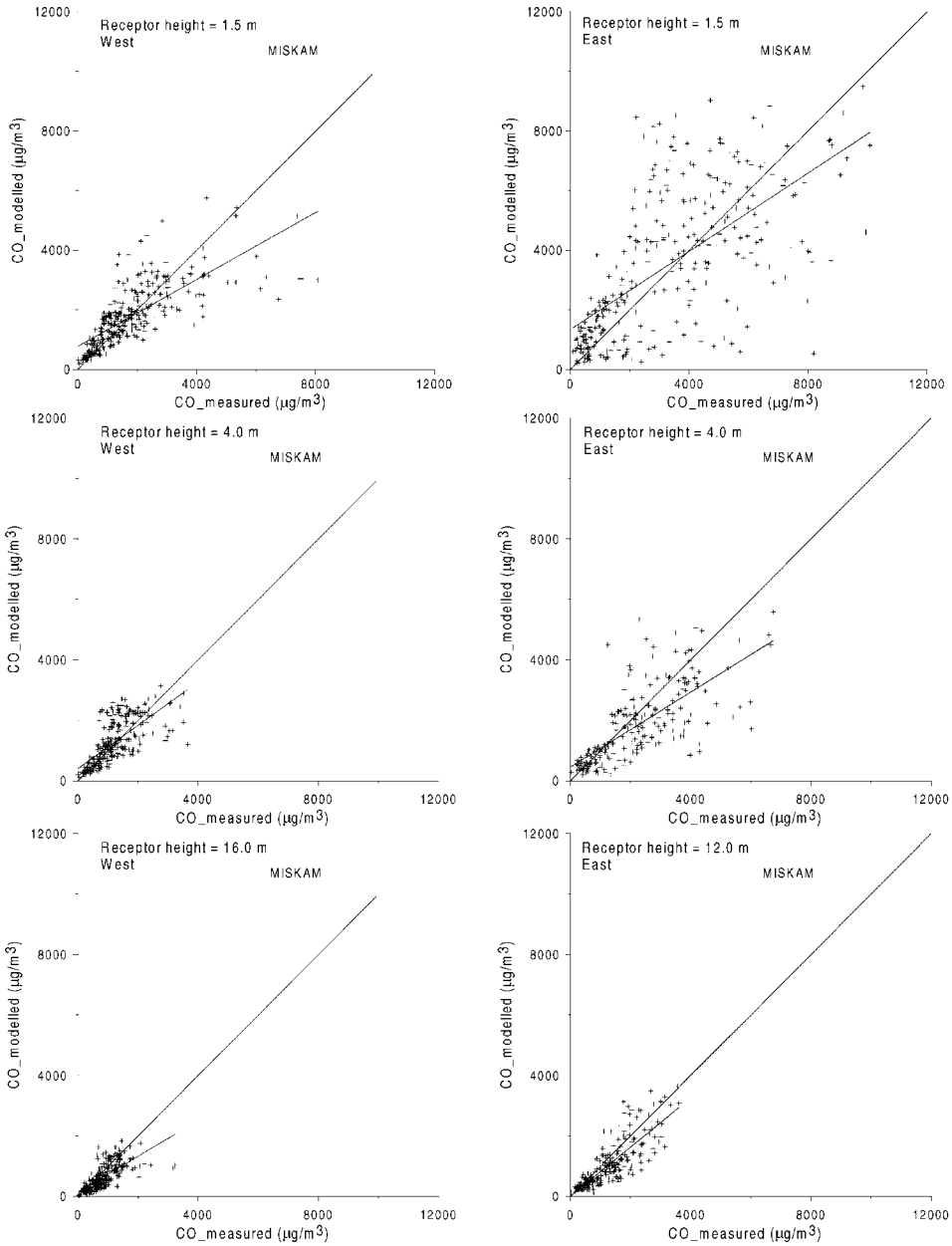

Figure 5. Comparison of MISKAM results with CO measurements in the street. Location of the receptor points is indicated in the figures.

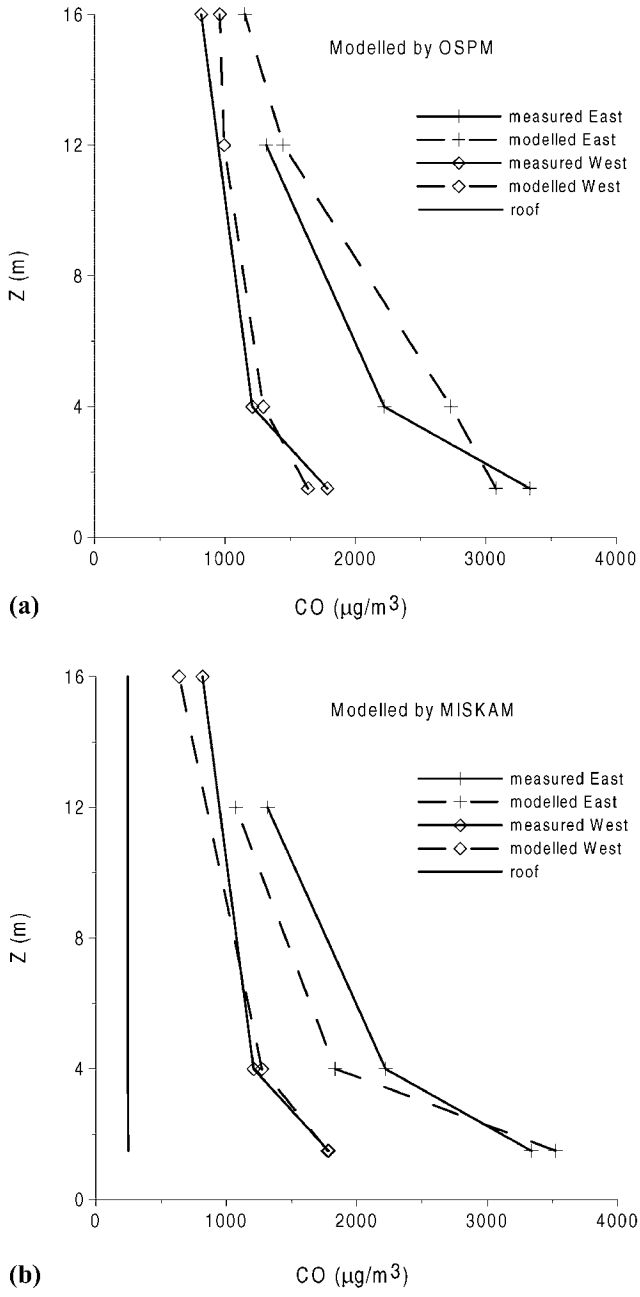

Figure 6. The vertical distribution of the measured and modelled concentrations. Results are shown both for (a) OSPM and for (b) MISKAM.

The vertical distribution of CO concentrations in the street is shown in Figure 6. The presented profiles represent average concentrations for each of the measuring locations. The averaging is made using all the available data. Background concentrations (roof monitor) are shown as well.

The average concentrations on the East side of the street are significantly higher than on the West side. This is the result of prevailing Easterly winds during the campaign (see Figure 2). For Easterly winds the East side of the street is leeward and receives higher concentrations than the windward West side. The variation with height is somewhat smaller on the West side (predominantly windward) than on the East side. This variation is quite well reproduced by MISKAM. OSPM underestimates the vertical gradient on the East side. The main reason for the underestimation of the vertical gradient by OSPM is the assumption on the initial vertical dispersion of vehicle exhausts. In OSPM this value is assumed to be 3 m. In MISKAM, the initial mixing is set to 2 m, which is the height of the first numerical grid. Smaller initial mixing height results in larger vertical gradients in the lowest level of the street.

The good agreement between the MISKAM results and the average vertical profiles shown in Figure 6 might however be somewhat fortuitous. The absolute values of the averaged concentrations are quite dependent on the above mentioned 'renormalisation' procedure. Taking into consideration that this procedure was parameterised using the same data as used for the present comparison, the good agreement for the average concentrations, in spite of the large scatter evident in Figure 5 for the single observations, is not surprising. However, the good performance of MISKAM concerning predictions of the magnitude of the vertical concentration gradients is still obvious.

The difference in the behaviour of pollutants on the leeward and the windward sides of the street is illustrated in Figure 7. Here, the dependence of concentrations (street contribution only) normalised by emissions is shown as function of wind speed. The wind directions are selected so, that the East side is always leeward and the night time hours with small emissions are excluded. The dependence on wind speed is less pronounced on the leeward side (the East side). This is again believed to be due to larger contribution of the traffic produced turbulence to the dispersion conditions on the leeward side. The scatter in the experimental data is, however, very large and the results must be taken with some caution.

6. Conclusions

The experimental data collected during the measuring campaign Nantes'99 in Rue de Strasbourg provide an excellent opportunity to study the traffic pollution distribution in a street canyon. The data represent conditions with predominantly low wind speeds and such effects, as traffic produced turbulence have a significant impact on the dispersion of pollutants in the street.

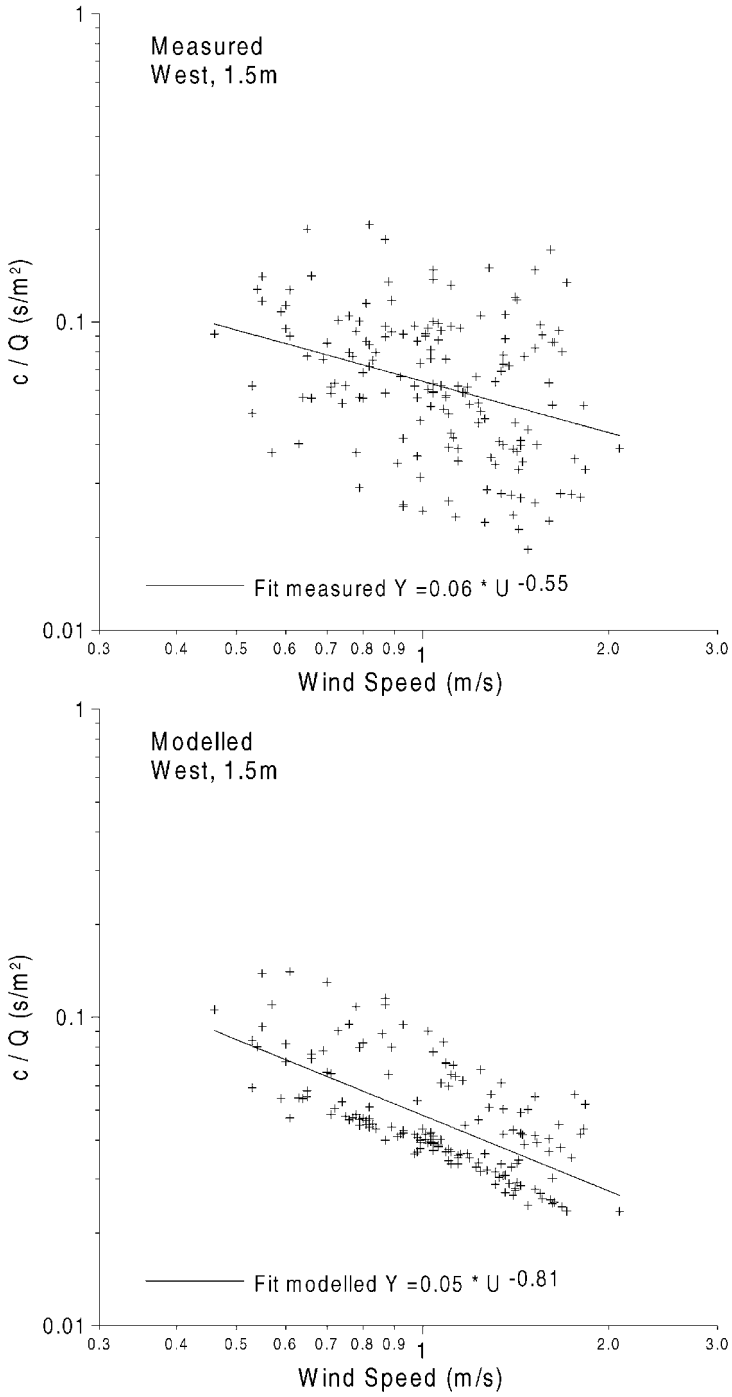

Figure 7a. The dependence of the windward (West) concentrations on wind speed. Both model results (OSPM) and measurements are shown.

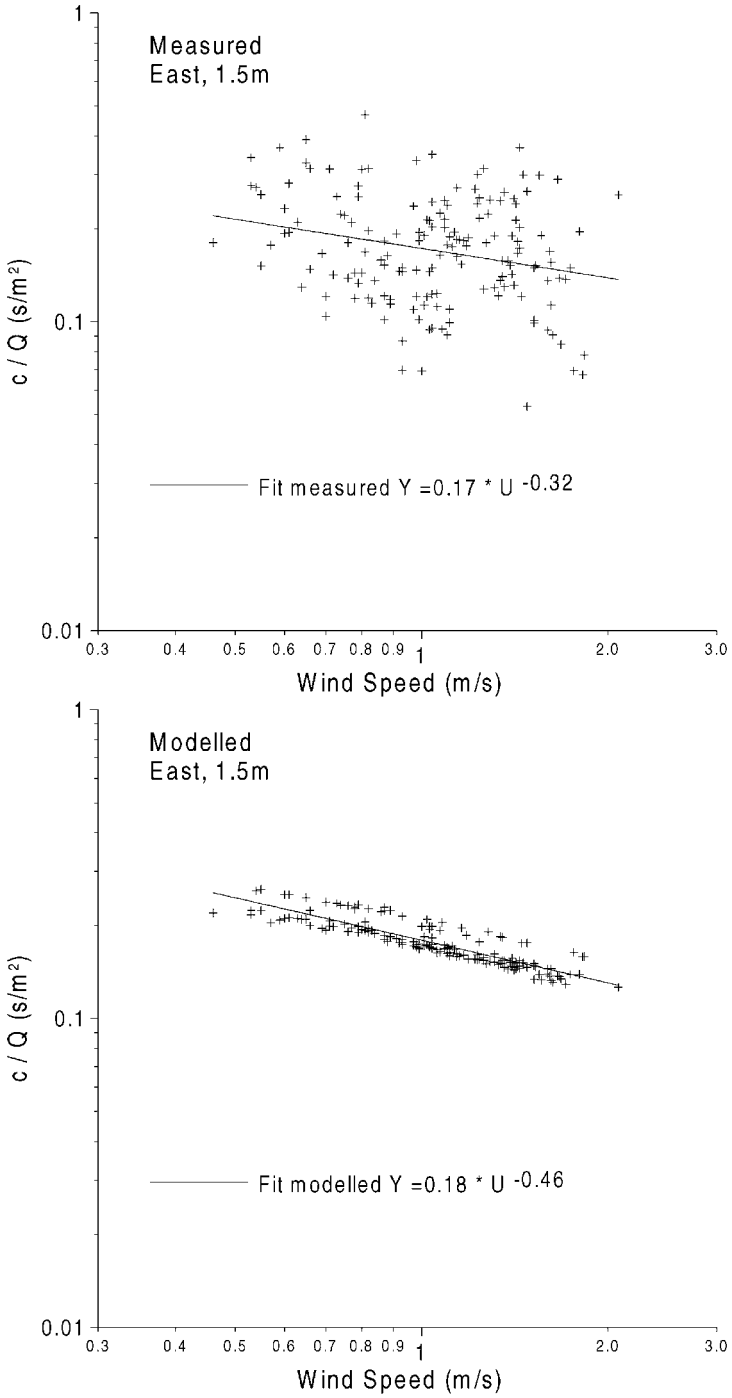

Figure 7b. The dependence of the leeward (East) concentrations on wind speed. Both model results (OSPM) and measurements are shown.

The concentration levels on the leeward side of the street are, as a rule, higher than on the windward side. Remarkable vertical gradients are observed and these gradients are more pronounced on the leeward side than on the windward side.

The experimental data are compared to model results using a simple parameterised model, OSPM, and a more advanced 3-D CFD model MISKAM. Both models reproduce reasonably well the observed distribution of pollutants in the street. The MISKAM model performs better in reproducing the vertical gradients. The OSPM results show less variation with height in the lowest 4 m than the observed data. This behaviour is believed to be due to the assumptions made about the initial dilution height of car exhaust gases.

A significant improvement of model results is achieved when a velocity scale based on the traffic produced turbulence is applied to calculate concentrations with the CFD model MISKAM. Scaling based on wind speed alone results in totally unrealistic concentration values.

It would be desirable to extend this study with data from the remaining period of the experimental campaign. Examination of pollution distribution under higher wind speed conditions will provide additional, valuable information for development and test of traffic pollution models.

Acknowledgements

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