Dispersion of Carbon Monoxide Traffic Emissions in Streets in Milan City

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In the frame of the CNR (Research National Council) research project entitled "Traffic planning and air pollution in urban areas" the PMIP of Milan is carrying out a study in order to describe the dispersion of a pollutant inside a street canyon. The final purpose of the outstanding project is to develop a support model for urban area planning which allows to value the impact on air quality of specific measures regarding signal phasing/timing and queue length near an intersection. The first phase of the project regards the intercomparison of different dispersion models in order to evaluate the most adequate to be applied during the field experiment as provided in the second phase of the study. This paper describes the principal results obtained in evaluating the performance of three modelling techniques, CALINE4, CPB-3, and Johnson's formula, in simulating CO concentrations in three streets of Milan. The input data include background concentrations, meteorological and traffic observations; these data are updated for every 1-hour simulation by developed databases processors. The hourly emissions have been calculated using the CORINAIR methodology taking into account vehicle fleet identification, hourly traffic flow and hourly ambient temperature measured by the monitoring network. Simulations have been computed for three streets of Milan with different facility types and location: the first one belongs to the dense traffic ring-road around the city, the second one is a low-traffic side street and the last one is a typical street canyon located in central business district. The models have been applied to compute 1-hour CO concentrations along a period of two months. The computed and observed CO concentrations time series have been compared using some models performance methods. The results are described in detail for each of the streets investigated. Moreover the application of a lagrangian model GEM to the same input datasets is nowadays in course: this paper illustrates some preliminary simulations obtained using GEM to one of the three steets.

1. INTRODUCTION

Milan is located in the North of Italy and is one of the most urbanized towns of the country. It has a population of approximately 1.5 millions inhabitants. Numerous industrial activities take place in the neighbouring towns while the most part of tertiary and commercial activities are concentrated in the city core. Milan and its surroundings are Air Quality standards nonattainment areas for carbon monoxide and nitrogen dioxide, also for ozone limitedly during summertime.

In order to investigate the transport and diffusion of carbon monoxide related to traffic emissions inside streets in Milan a research study is carried out within the framework of a project promoted by CNR (Research National Council). The final objective is to provide the opportunity of predicting the CO levels to be expected in association with specific traffic management scenarios in particular regarding signal phasing/timing and queue length near an intersection. For this purpose a field experiment will be carried out to obtain all observations needed to verify mathematic models forecasts. The first phase of the study consists in some preliminar tests for evaluating the performances of available modeling techniques that will be applied to the final measurement campaign CO datasets.

In this paper results of three urban microscale dispersion modeling methods are compared with CO observations measured during November and December '89 in some streets of Milan. A short descripstion of the case studied are given, selected simulations results are then presented in comparison with the corresponding measurements.

2. METHODS

The choice of the modelling technique to simulate the spatial distribution of pollutant concentration inside a street, depends on the particular topography considered since there is no model suitable for all situations. In this study four models have been considered: the CALINE4 (Benson [1984]), CPB-3 (Yamartino et al., [1989]) and GEM (Lanzani [1992]) models and the formula of Johnson et al., [1971]. The first one is a line source Gaussian model; the second one is a Plume-Box model and the third one is a Lagrangian particle model, the last one is an empirical box-model. A preliminary validation of available models was made by Lanzani and Tamponi [1994] using data of two experimental campaigns carried out in Germany and in France.

An appropriate processor MSP (Milan Street Processor), applies at user's request one or more models described above, extracting the hourly input data from traffic and metorological datasets sequentially for several days. It includes the calculation of emission factors and provides the mean 1-hour average concentrations computed by the models over a period of time selected by the user and for the selected receptors. The module used to calculate the composite emission factors is based on the CORINAIR-COPERT '90 (Co-Ordination Information AIR) method of the European Economic Community (Eggleston et al., [1991]). The module computes them as a function of vehicle fleet composition, hourly traffic flow, travelling speed and environmental temperature (Tamponi et al., [1992]). To obviate the circumstance in which, as in the present one, no information about the vehicle travelling speed is available, user can choose one of five empirical curves relating speed with traffic volumes for five different kinds of street (Bardeschi e al. [1990]). The dispersion models require, as meteorological input data, hourly values of wind speed and direction, ambient air temperature (used also by the emission module), mixing height, Pasquill stability class, wind direction standard deviation. Moreover stationary models cannot provide a time evolution of the situation, and the calculated concentration values do not include pollutant accumulation phenomena due to emissions in the previous hours. Such accumulation phenomena are especially important in the meteorological conditions that typically occur in winter in Milan (intense thermal inversions, calm winds, stable high pressure). The problem of adding, to the computed calculations, a background value is therefore crucial. A fixed background concentration is added to the model results concerning the same day. As a starting point for estimating the background the minimum among the 4:00, 5:00 and 6:00 a.m. measured concentration values for every day is used. If this data is not available, the background is evaluated from the average of daily minimum reached in the month.

3. THE MILAN DATA BASE

The dispersion models CALINE4, CPB-3 and Johnson' formula have been applied over a period of two months: October and November 1989.

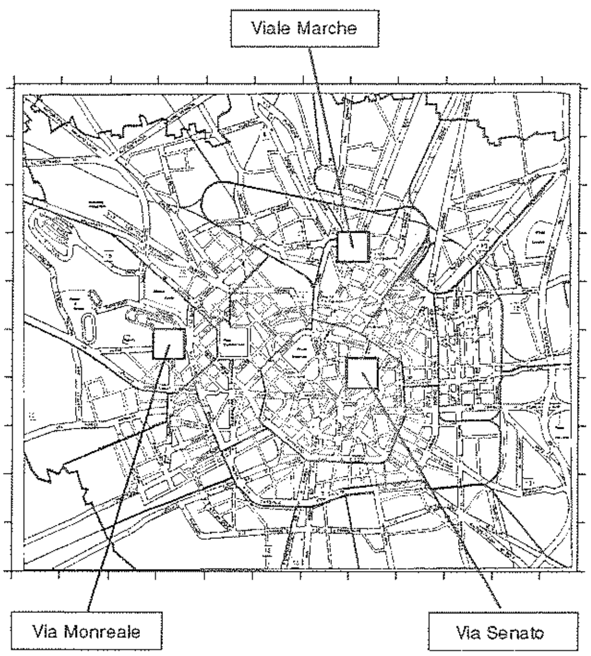

Figure 1: Map of Milan with the locations of the three sites

The available traffic data, hourly traffic volumes counted for each lane, concern the field experiment carried out in some streets of Milan by the Urban Police Force during the years 1989 and 1990. In the same sites the Air Quality Monitoring Network of the Province of Milan recorded meteorological parameters and CO concentrations used for the background concentrations.

The models have been applied to three streets with different facility types and locations: Viale Marche, Via Monreale and Via Senato (Figure 1).Viale Marche is a thorough-fare which is part of the Milan ring-road. It is a wide avenue (about 32 m) with a three-lined traffic island and quite low buildings (about 12 m) on both sides. Though a low-traffic side street, Via Monreale is a wide one (about 30 m) with a tree-lined traffic island and low buildings (about 10 m) on both sides. Via Senato is a street canyon, with high traffic intensity, situated in the centre of the city: it is a 14 m wide street with high buildings (about 15 m) on both sides.

As an example of various traffic conditions, Figures 2, 3 and 4 show the hourly traffic volumes recorded in the three streets of study during November '89. It is evident for all the three sites that different temporal trends characterize workday, Saturday and Sunday, even if traffic volumes depend on the street. It can be noticed that the vehicles number in Viale Marche is very elevated, also during nightime, and keeps on similar values on the different days of the week. Instead in Via Senato traffic volume tend to decrease during holidays (1 November and week-ends). Also in Via Monreale vehicles number decreases during holidays excepting Sundays in correspondence with the soccer-match played in the near stadium.

4. MODEL RESULTS

The three models were tested in three Milan streets (Viale Marche, Via Monreale, Via Senato) using the hourly data of November and December 1989. A statistical evaluation was performed for each model and for each street using the *NMSE*, *BIAS* and *Fractional BIAS* parameters defined by:

$$NMSE = \frac{\overline{(C_C - C_M)^2}}{\overline{C_M} \cdot \overline{C_C}}$$

$$BIAS = \frac{\overline{C_C} - \overline{C_M}}{\overline{C_M}}$$

$$FB = \frac{2 \cdot (\overline{C_C} - \overline{C_M})}{\overline{C_M} + \overline{C_C}}$$

where C_M is the mean observed concentration and C_C is the predicted concentration, respectively (Hanna, 1988).

Table 1 shows syntetically the results of the CALINE4, CPB-3 and Johnson' formula application to each of the three streets. The performance measures *NMSE*, *BIAS* and *FB* values are referred to the ensemble of concentrations data which were collected in the period of two months mentioned above.

As an example of temporal trends of predicted concentrations some of the results are reported. Figure 5 shows the observed CO concentrations time series of November '89 compared to the results of CALINE4 model applied to Viale Marche. In Figure 6 the observed CO concentrations time series of November '89 is compared with the results of CPB-3 model. Finally Figure 7 presents the CO concentrations time series of November '89 predicted by Johnson's formula and the corrisponding measured ones in Via Senato.

With regard to Johnson's formula, there is a little improvement in the model performance excluding the events in which wind is parallel to the street axis. In fact in that case *NMSE*, *BIAS* and *Fractional BIAS* values are 0.20, -0.21 and -0.23 respectively. Consequently, it is clear that, in the case of parallel wind, it is not correct to consider as a concentration value the average of the values obtained in leeward and windward cases (according to Johnson's hypothesis).

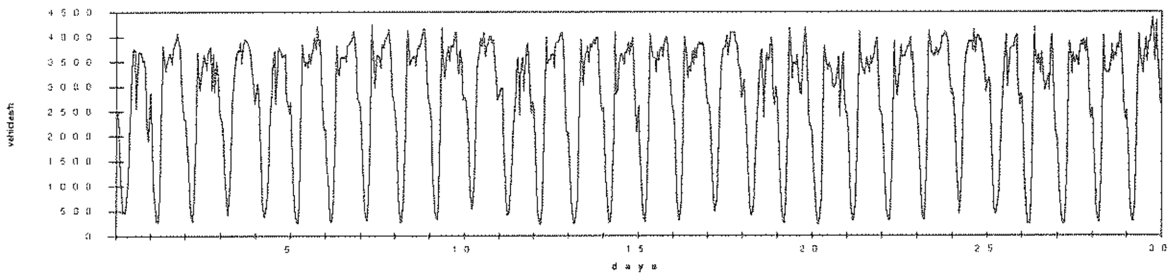

Figure 2: Traffic volumes of November '89 in Viale Marche

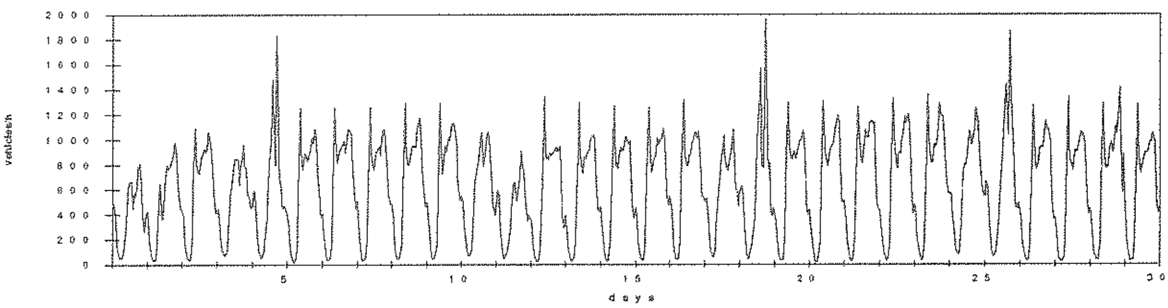

Figure 3: Traffic volumes of November '89 in Via Monreale

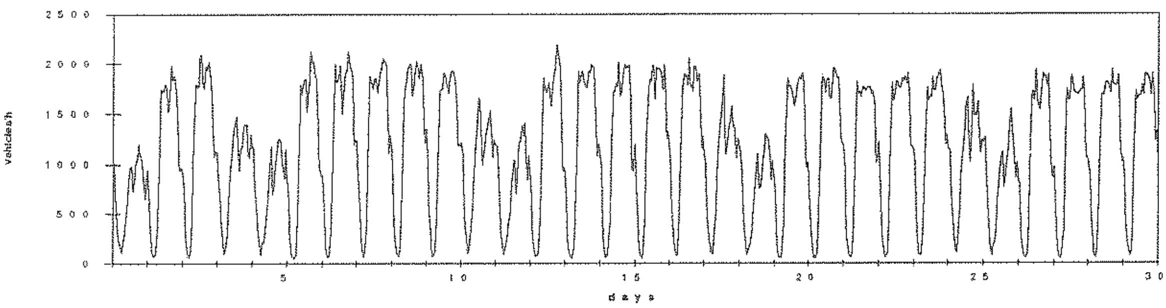

Figure 4: Traffic volumes of November '89 in Via Senato

The application of the lagrangian model GEM to the same input datasets is nowadays in course. Here are illustrated some preliminary simulations obtained using GEM to Via Senato. The typical canyon structure of this street speeds up the elaboration time of the model. Precisely, hourly data about 17 November '89 (between 6:00 a.m. and 11:00 p.m.) have been elaborated.

We made two tests about the first hour (6:00 to 7:00 a.m.): the first one (for a period of one hour) considers whole traffic volume divided into three lanes and the second one (for a period of 15 minutes) concentrates it in one middle lane. Comparing the results, it can deduced that, even if the maximum value of CO concentration obtained in the second test is much higher than in the first one, value on pavement road at man's height is similar in both cases.

Therefore, because of the shorter computation time, we carried on the remaining simulations considering all the traffic assembled in one lane. You can see in Figure 8 the evolution of concentration levels during the day related to variations of traffic volumes.

Computing statistical parameters on these few GEM outputs, we obtained the following values: $NMSE = 0.09$; $BIAS = 0.22$; *Fractional* $BIAS = 0.20$.

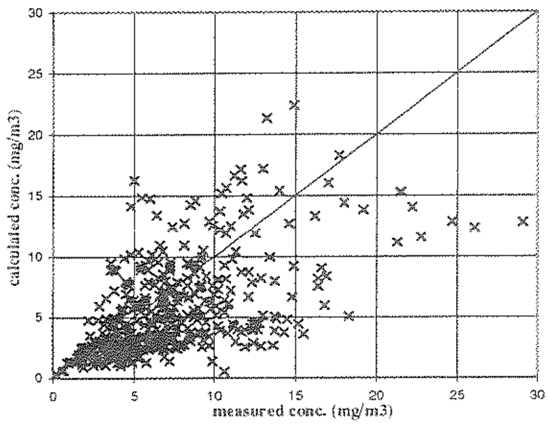

Figure 5 Observed and computed concentrations by CALINE 4 for Viale Marche

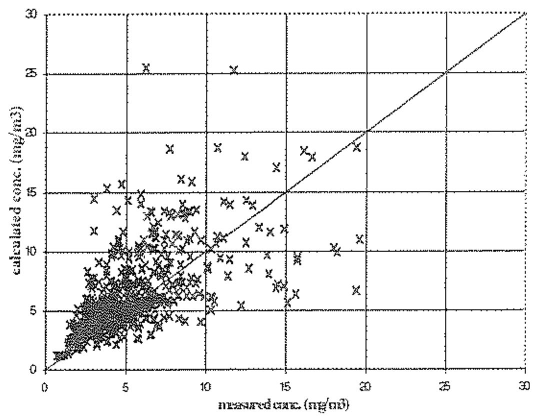

Figure 6 Observed and computed concentrations by CPB3 for Via Monreale

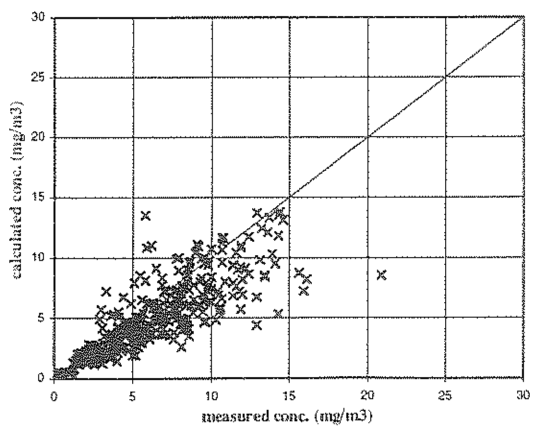

Figure 7. Observed and computed concentrations by Johnson' formula for Via Senato

Street	Dispersion Model	*NMSE*	*BIAS*	*FB*
V.le Marche	CALINE4	0.40	-0.22	-0.25
	CPB-3	0.53	0.02	0.02
	Johnson's formula	0.42	-0.04	-0.04
V. Monreale	CALINE4	0.46	-0.32	-0.38
	CPB-3	0.21	0.18	0.17
	Johnson's formula	0.30	-0.21	-0.24
V. Senato	CALINE4	1.19	-0.51	-0.68
	CPB-3	0.30	0.19	0.18
	Johnson's formula	0.22	-0.22	-0.25

Table 1: Performance measures for each model as a function of sites

5. CONCLUSIONS

These results point out that each of the three modelling techniques evaluated shows very different performances in simulating concentration of CO at the three streets considered.We can draw the following conclusions:

- CALINE4 model is the one which best describes the experimental data only in the case of Viale Marche, even if generally tends to underestimate the concentrations;
- CPB-3 model and Johnson's formula show the best outcomes for Via Monreale and Via Senato respectively, giving similar results even if the first model tends to lightly overestimate the concentrations while the second one tends to underestimate them. It can be noticed that these specific urban canyon modelling techniques simulate quite well CO in Via Monreale even if this is not a typical street canyon. The results of the few preliminary applications of GEM to Via Senato are very interesting and encourages to go with tests. Plans for the future could be to extend evaluation of the models to other kinds of streets and in particular at last to apply them to a specific mesurement campaign, with more detailled informations, as provided in the second phase of the project.

6. ACKNOWLEDGEMENTS

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6. REFERENCES

Benson, P.E., *CALINE4-A Dispersion Model for Predicting Air Pollutant Concentrations near Roadways*, California Department of Transportation, Sacramento, California, Report No. FHWA/CA/TL-84/15, 1984.

Eggleston, H.S., D. Gaudioso, N. Gorissen, R. Joumard, R.C. Rijkeboer, Z. Samaras and K.-H. Zierock, *CORINAIR Working Group on Emission Factors for Calculating 1990 Emissions from Road Traffic*, DRAFT Final Report, December, 1991.

Gualdi R., Bardeschi A., Gnagnetti M., Tamponi M., Tebaldi G., Angelino E., Colucci A., Meda *Studio Modellistico sull'inquinamento atmosferico da traffico autoveicolare nell'area urbana di Milano*, Provincia di Milano, 212 pp., Milan, 1990.

Hanna S.R., *Air quality model evaluation and uncertainty*, JAPCA 38:406, 1988

Johnson, W.B., W.F. Dabberdt, F.L. Ludwig and R.J. Allen, *Field Study for Initial Evaluation of an Urban Diffusion Model for Carbon Monoxide*, Comprehensive Report CRC and Environ. Protect. Agency (EPA) Contract CAPA-3-68 (1-69), 1971.

Lanzani, G., Analisi fisico-modellistica della dispersione nella bassa atmosfera del monossido di carbonio in area urbana, thesis in Physics, Università degli Studi, Milan, 1992.

Lanzani, G., and M. Tamponi, GEM: a lagrangian particle model for the dispersion of primary pollutants in urbanù canyons-Sensitivity analysis and first validation trials, in *Air Pollution Modelling and Its Application X*, edited by S.-V. Gryning and M.M. Millan, pp. 81-88, Plenum Press, New York, 1994.

Tamponi, M., E. Angelino, G. Tebaldi and E. Belloni, *Studio modellistico sull'inquinamento atmosferico da traffico e da riscaldamento nell'area metropolitana milanese*, Provincia di Milano, 145 pp., Milan, 1992.

Yamartino, R.J., D.G. Strimaitis and T.A. Messier, *Modification of Highway Air Pollution Models for Complex Site Geometries*, DRAFT, Report No. FHWA-RD-89-112, 1989.

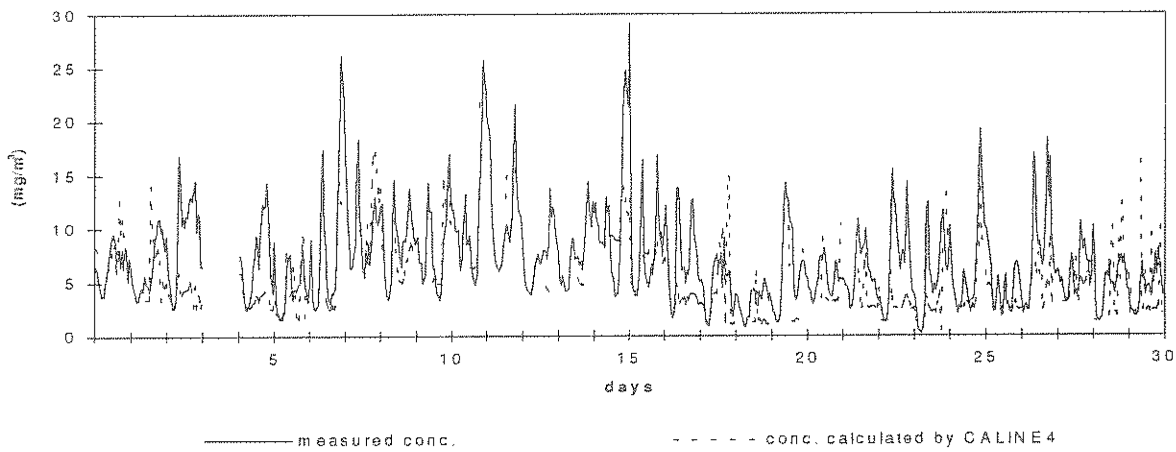

Figure 8: Comparison between observed and computed CO concentration time series of November '89 in Viale Marche

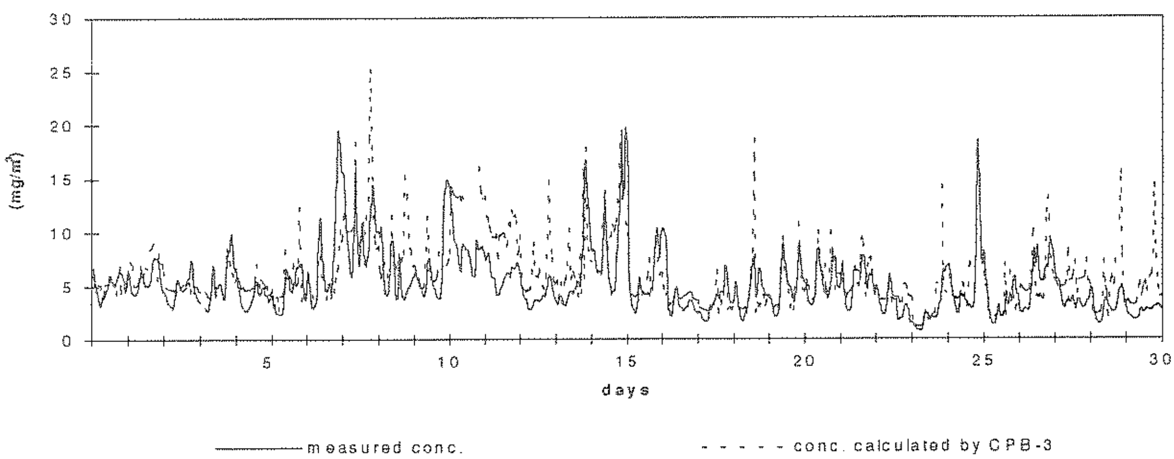

Figure 9: Comparison between observed and computed CO concentration time series of November '89 in Via Monreale

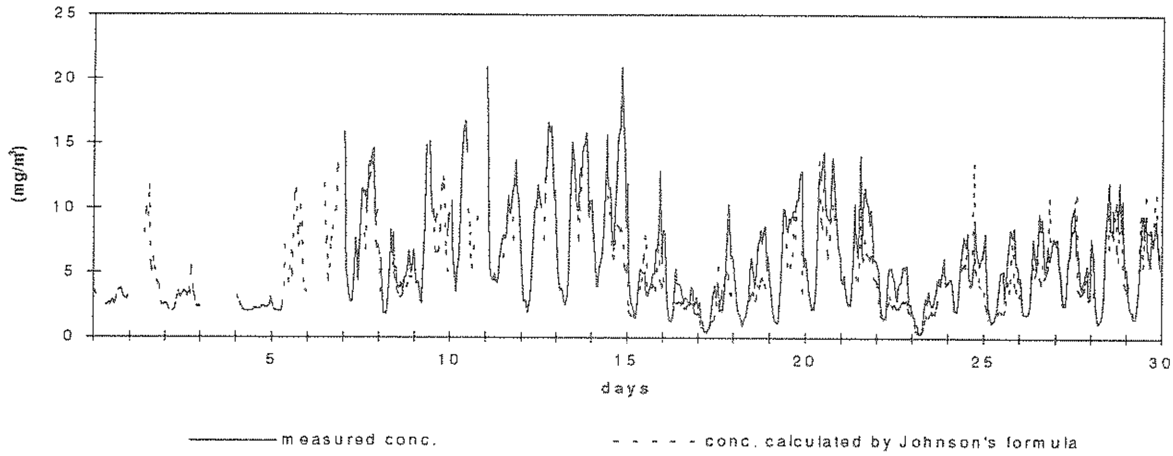

Figure 10: Comparison between observed and computed CO concentration time series of November '89 in Via Senato

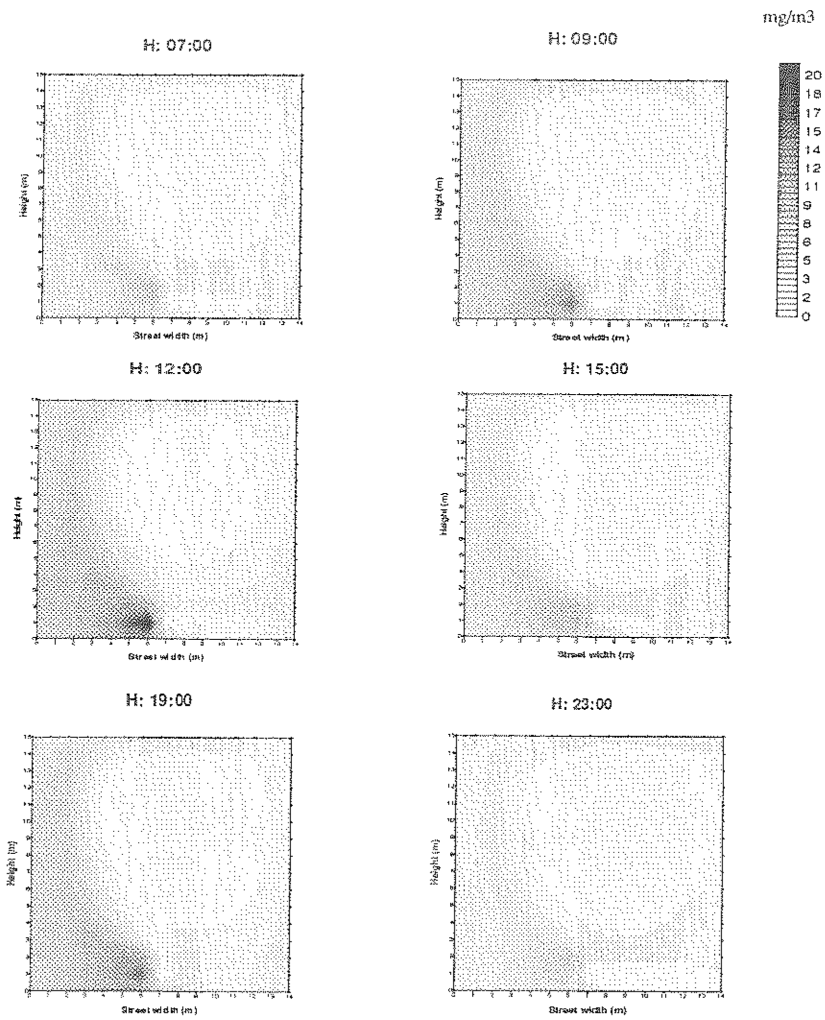

Figure 11: Evolution of CO concentrations computed by GEM model for the day 17 November '89 in Via Senato