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POLLUTANT DISPERSION MODELLING WITH OSPM IN A STREET CANYON FROM BUCHAREST

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Abstract. In urban areas, where the population is very numerous and the traffic is relatively high, the exposure of people to the traffic related concentrations is significant.

The aim of this study is to evaluate the predictions derived from the Danish Operational Street Pollution Model (OSPM) when the input data are obtained by simple measure methods. Pollution concentrations, temperature, flow and turbulence conditions were measured in Bucharest, Bd. Dacia, for different periods of year. The background concentrations ware obtained using the OML model. Measurements are compared to model results which reproduce reasonably well the observed distribution of pollutants in the street. The results indicate that the OSPM data might be useful in assessing long-term exposure to air pollutants in epidemiological studies.

Key words: pollutant concentrations, traffic, urban, meteorological conditions.

1. INTRODUCTION

In urban areas, where the population is very numerous and the traffic is relatively high, the exposure of people to the traffic related concentrations is significant [2, 10, 23]. In the last year, the vehicle traffic increased especially in urban areas [26]. As a consequence, the urban air quality was not improved significantly although they were implemented new techniques for controlling the emissions [17, 20]. In cities with densely buildings, placed on both sides of the street, the pollution levels often do not comply with air quality standards [1, 8].

For reducing the pollutants emissions in the atmosphere it is necessary to permanently monitor the air quality, which means high costs [8]. Using the pollutants dispersion numerical models for establishing the air quality is not so expensive. The models can be used only when measured data exist [7] (meteorological conditions and topography data) and when it is known the emission factors [9].

Significant increase in computer power makes it now possible to use advanced numerical models for air pollution studies. However, for many practical applications, the numerical models based on solution of the basic flow and dispersion equations are still too complex. The quality of input data is very important and sometimes there is no enough date to use this kind of models. Alternative are models that are basically parameterized semi-empirical models having few assumptions about flow and dispersion conditions [21]. These models need to be tested and their performance and limitations carefully documented [11]. The Danish Operational Street Pollution Model (OSPM), belongs to this category of parameterized models. Parameterization of flow and dispersion conditions in street canyons was deduced from extensive analysis of experimental data and model tests. The basic features of the model are described in this paper in section 2 and an example of the model evaluation is presented. The problem of uncertainties in model results is also addressed.

The levels of pollutants recorded depend on traffic, meteorological, background and topography conditions that contribute to pollutants dispersion or accumulation, in the studied area.

This research was made to use the OSPM to provide pollution data, to make a model validation and to study the causes and factors which influence the pollution in urban area. The cconcentrations levels of NO_x, NO_2 NO, CO and O_3 in a site from urban area were evaluated. The characteristics of the sites and the data used were presented in Section 3. The analysis of the measured concentrations was related to traffic and meteorological conditions. The direct contribution from traffic relative to the contribution from urban background was studied and the results shown in Section 4. In final of the paper some conclusions were presented.

2. THE ANALYSIS OF THE PROBLEM

2.1. OSPM DESCRIPTION

The Danish Operational Street Pollution Model (OSPM) belongs to the category of parameterized semi-empirical models, making use of a priori assumptions about the flow and dispersion conditions. This model must be intensively tested and their performance and limitations carefully documented. OSPM makes use of a very simplified parameterization of flow and dispersion condition in a street canyon. This parameterization was deduced from extensive analysis of experimental data and model tests [2, 3].

The main assumptions incorporated in the model are:

1. Traffic emissions are assumed to be homogeneously distributed across the street;
2. A vortex is formed in the street when the wind blows perpendicular to the street axis;

3. The upwind receptor (leeward side) receives the direct contribution from traffic and the recirculation part of the pollutants in the street;
4. The downwind receptor (windward side) mainly receives the contribution from the recirculated component;
5. If the wind speed is zero or the or the wind blows parallel to the street, the concentrations on both sides of the street become equal;
6. The direct contribution is calculated with a plume model assuming linear dispersion of pollutants with the distance;
7. The recirculation part is described by a box model;
8. OSPM modeled the turbulence in the street assuming that it is composed of two parts: the ambient turbulence (depended on wind speed) and traffic induced turbulence (which is important when the wind speed is low).

The most important pollutants emitted from traffic can be considered CO, NO, many hydrocarbons and a small portion of NO_2. Transport emissions and dispersion processes are not the only factors determining the concentrations of pollutants in the street. The chemistry is very important, too. NO reacts with ozone within the street, resulting NO_2 [25]. The time scale characterizing these reactions is of the order of tens of seconds, thus comparable with residence time of pollutants in the street canyon. Regarding the health effects, NO is considered to be harmless, at least at concentrations expected in urban air. On the contrary, NO_2 can have severe adverse health effects on humans.

The emission factors are dependent on vehicle classes and average driving speed. The hourly emissions of CO and NO_x were computed from traffic in the street, using measured hourly traffic volumes and the appropriate emission factors. The fraction of NO_x emitted as NO_2 was assumed to be 5% [7, 16].

The meteorological parameters required as input by OSPM are wind speed and direction, ambient air temperature and global solar radiation. The wind speed and direction should correspond to the flow conditions above the street canyon, while the temperature and global radiation should correspond to the average conditions inside the street canyon.

2.2. THE CHARACTERISTICS OF THE SITE

The field study was conducted for a year in a street canyon, which can be considered hot spot, Dacia Avenue, in the city of Bucharest, Romania, located to 135 degrees from North (Fig. 1). The measurements were made in 2002 year in all the seasons.

Traffic measurements have been done: the traffic flow (number of vehicle/hour) and concentration measurements for pollutants like NO_2 NO, NO_x, CO and O_3, using the devices from a mobile laboratory which belong to Romanian Auto Register (RAR). This complex device consists of an automatic machine Horiba, which

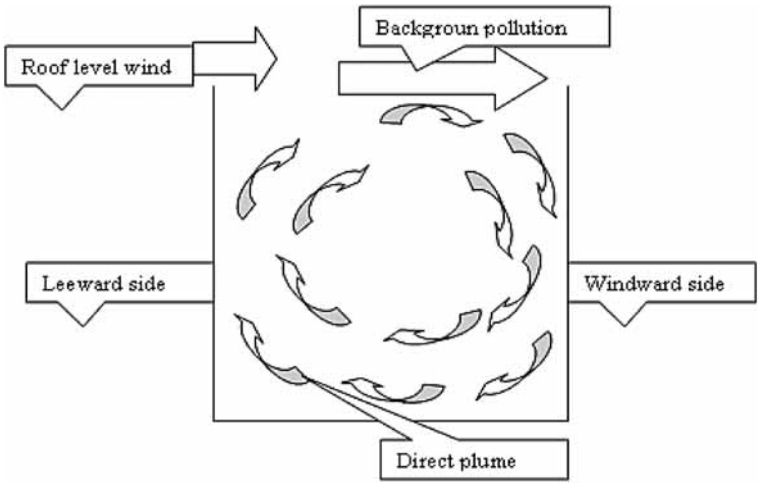

Fig. 1 – Schematic illustration of the basic model principles in OSPM; concentrations are calculated as a Sum of the direct plume contribution and the recirculation pollution.

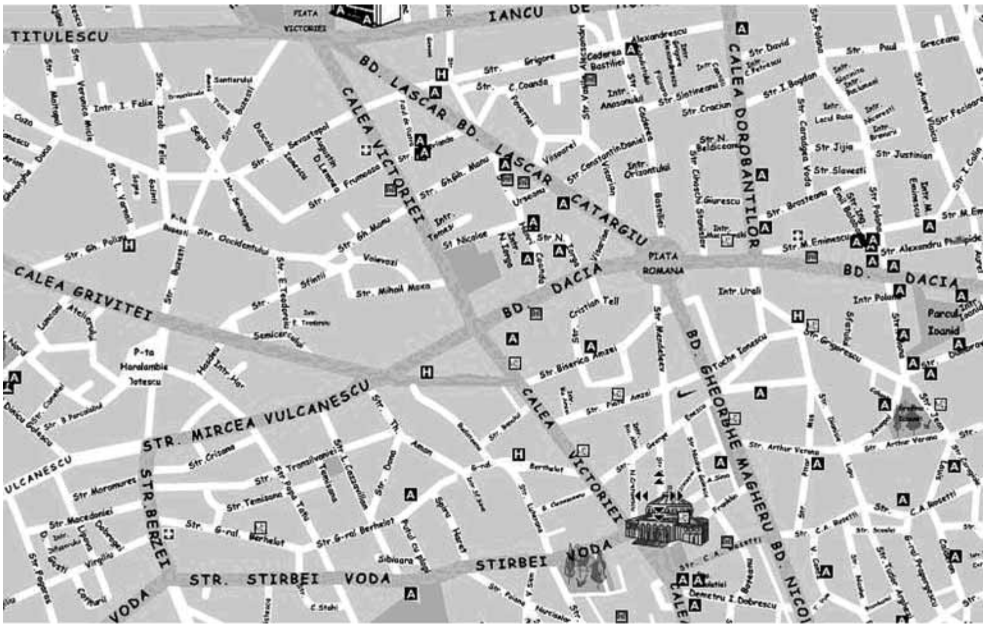

Fig. 2 – Dacia Avenue, Bucharest, Romania.

records the pollutants concentrations near the breathing level. The concentration of nitrogen oxides was analysed by chemiluminescence monitors, the concentration of ozone was analysed by an UV-absorbtion method and the concentration of carbon monoxide was measured by a monitor based on an IR method. Another machine

Vaisala records the meteorological parameters (temperature, humidity, solar radiation, wind speed, wind direction). The traffic counts were located at the same cross-section from street where were located the devices for monitoring pollution and meteorological data. The background concentrations ware obtained using the OML model [16].

Wind flow and pollutant dispersion within continuous street canyons essentially depend on the aspect ratio ($H/W = 1.16$, in this case where H is the mean height of the buildings along the street and W is the street width), the street length and building roof geometry [17].

The graph shows a higher traffic in the working days, decreasing to half in the weekend period when people leave the urban area. Fig. 3 shows every working day, the morning peak, around nine o'clock (when people go to work) and the afternoon peak (when people come back home).

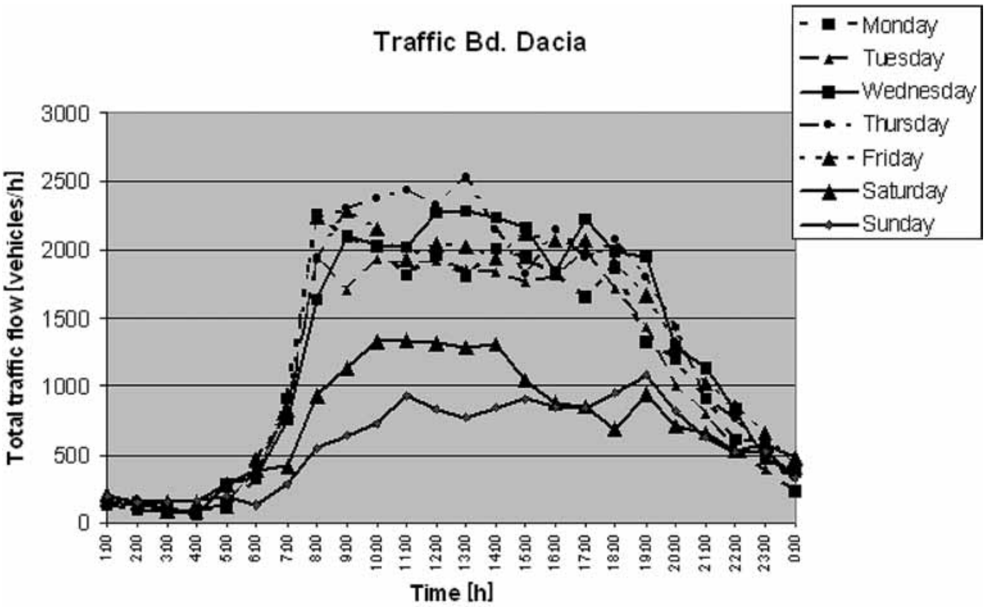

Fig. 3 – Total traffic frequency for each day of the week.

2.3. POLLUTANT CONCENTRATION DATA

Hourly concentration data (CO, NO_x, NO_2, O_3), measured for two days are plotted (Figs. 4–7). Figs. 4–7 show the influence of wind speed and traffic flow on CO, NO_x, NO_2 and O_3 concentrations. On Monday, 19th January 2002 there are big concentrations when the wind speed is small. On 20th January, the wind speed becomes bigger and the concentrations decreasing despite the fact that traffic are about the same values.

Fig. 7 doesn't show the same kind of correlation. Sometimes O_3 is too big despite the fact that the traffic is low. It is possible to be other O_3 source. This is a problem which it must be studied in the future.

The graphs show the temporal variability of pollutants levels. Studying the concentrations for all year, we will notice that the highest values are recorded for CO, while O_3 does not exceed 130 μg/m³.

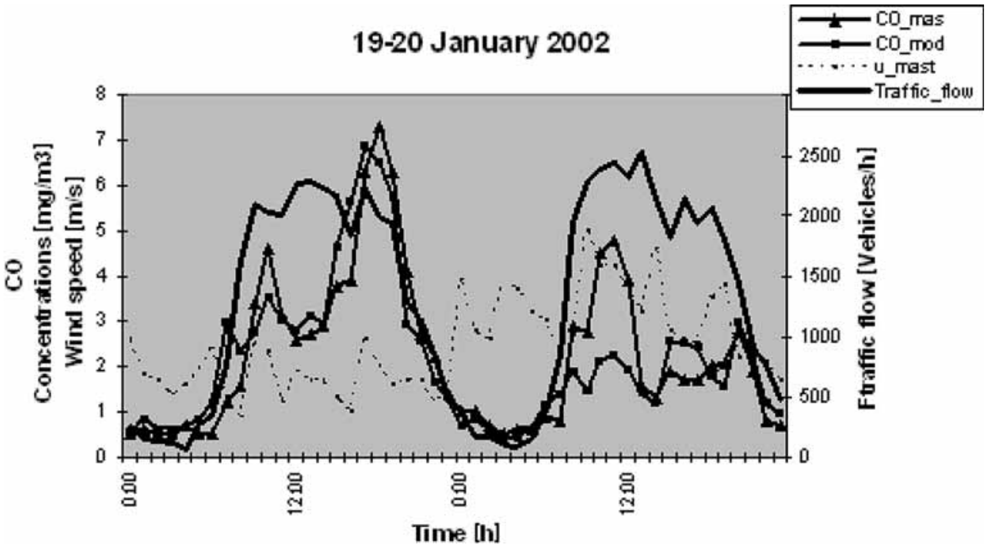

Fig. 4 – The influence of traffic flow and wind speed on CO concentrations.

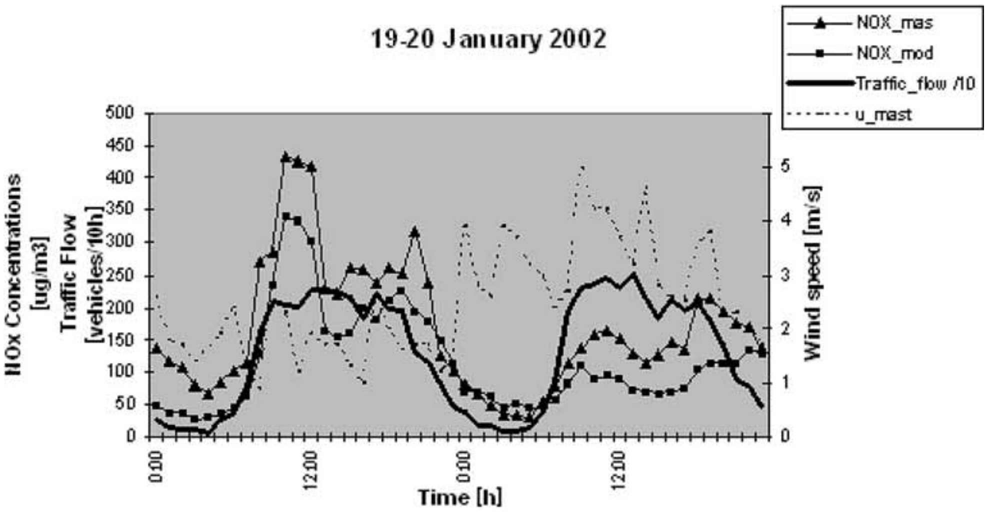

Fig. 5 – The influence of traffic flow and wind speed on NO_x concentrations.

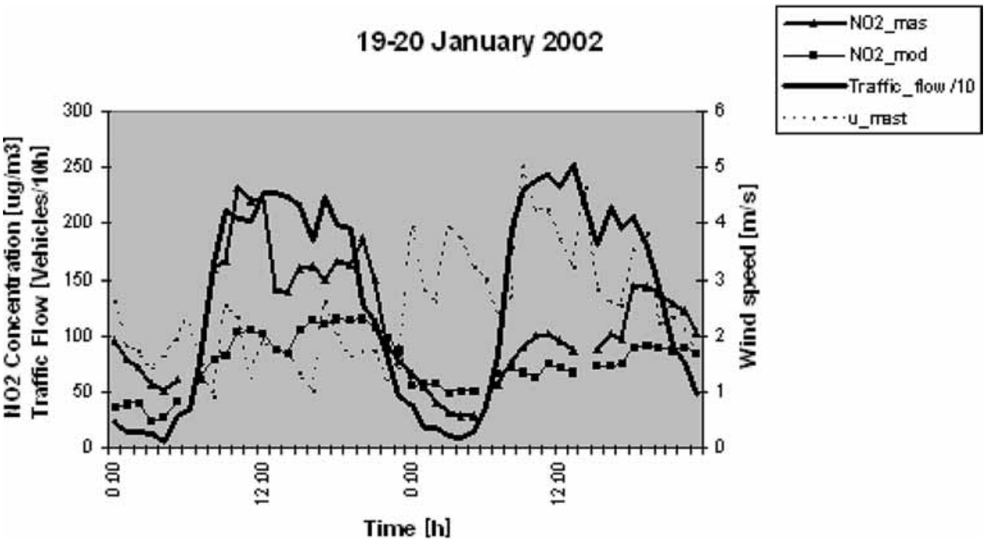

Fig. 6 – The influence of traffic flow and wind speed on NO_2 concentrations.

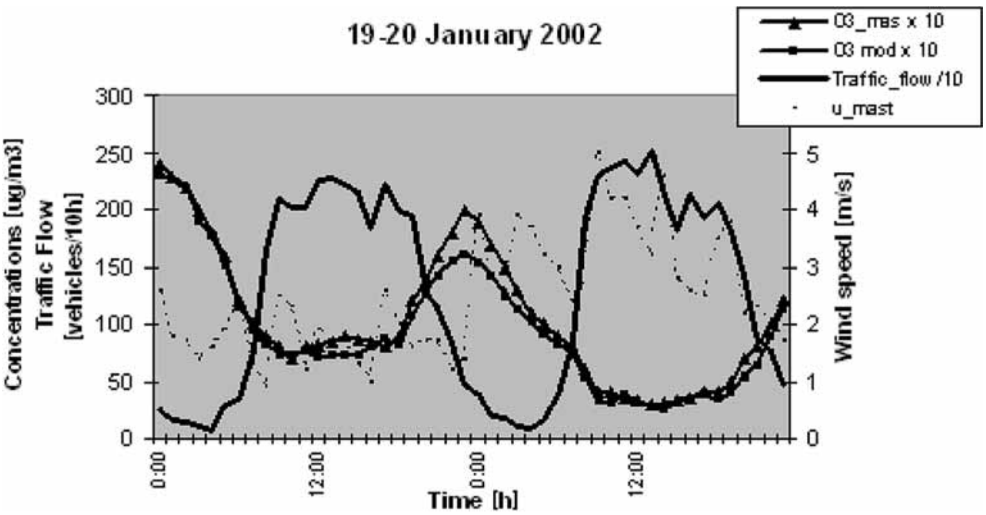

Fig. 7 – The influence of traffic flow and wind speed on O_3 concentrations.

Such distribution of concentrations proves that traffic is the most important source of CO and NO_x, these pollutants being emitted by the vehicle engines during its running.

The correlation between different pollutants is plotted in Figs. 8–10.

In Fig. 8 we can see a good direct correlation between CO and NO_x concentrations despite the fact that NO_x participate in photochemical reactions. In connection with O_3, the inverse correlations between NO_x and O_3 (Fig. 9) respectively

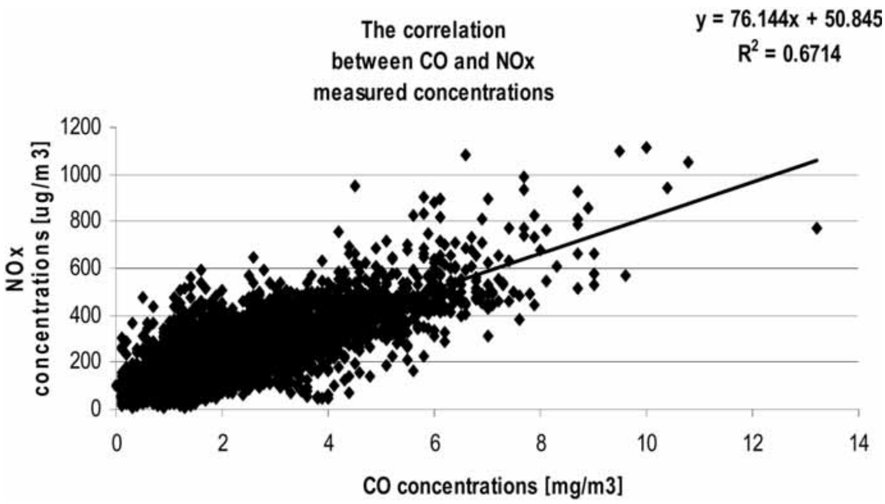

Fig. 8 – The correlation between CO and NO_x concentrations.

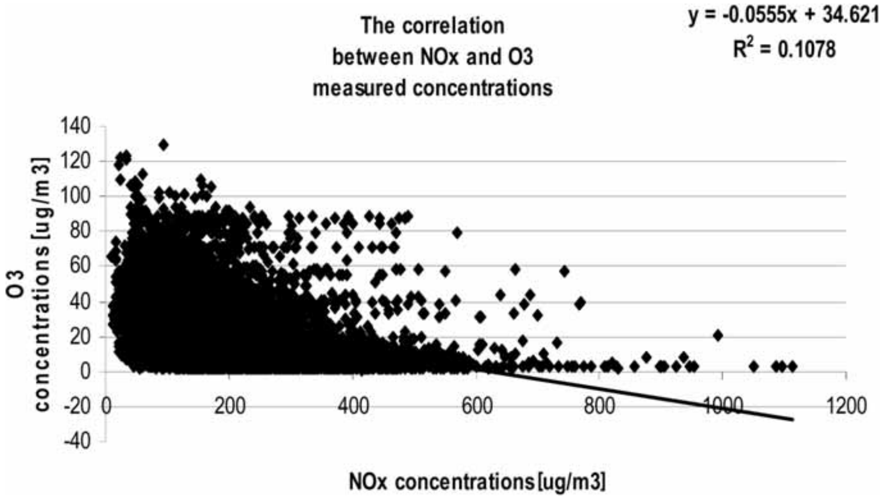

Fig. 9 – The correlation between NO_x and O_3 concentrations.

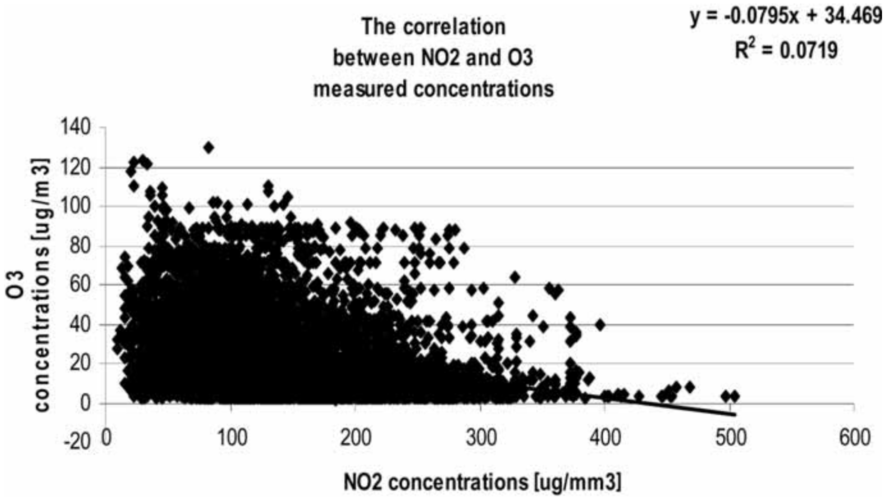

Fig. 10 – The correlation between NO_2 and O_3 concentrations.

NO_2 and O_3 (Fig. 10), is due to the fact that the emission of NO determine a consumption of ozone. This inverse correlation is however very poor, so it is possible to be another ozone source around.

2.4. THE COMPUTATION METHOD

The OSPM utilizes hourly time series of street level emissions, urban background concentrations data and meteorological data as input values, and predicts the concentrations of pollutants at the street level measurement location. I utilized the original model without any modifications; no adjustments or calibration of the model were introduced based on the data measured in this study.

For the calculation of NO_2 formation in the street, the urban background concentrations of nitrogen oxides and ozone must be given as an input. Temperature and total solar radiation are also needed as input values for the model in order to compute the chemical reaction coefficients. The urban background concentrations must also be given for other pollutants (CO) calculated by OSPM [11]. Often, these are available from measurements, but an urban background model can also be used to provide these input parameters. In this case, it was used OML – Multi.

The correlation between measured and modelled concentrations is shown in Figs. 11–14.

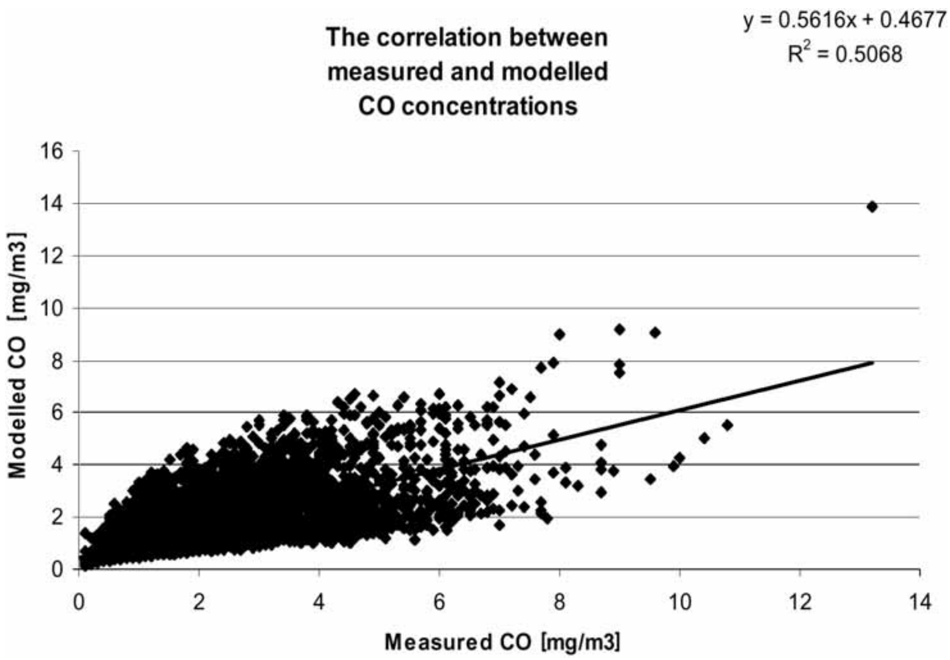

Fig. 11 – The correlation between measured and modeled CO concentrations.

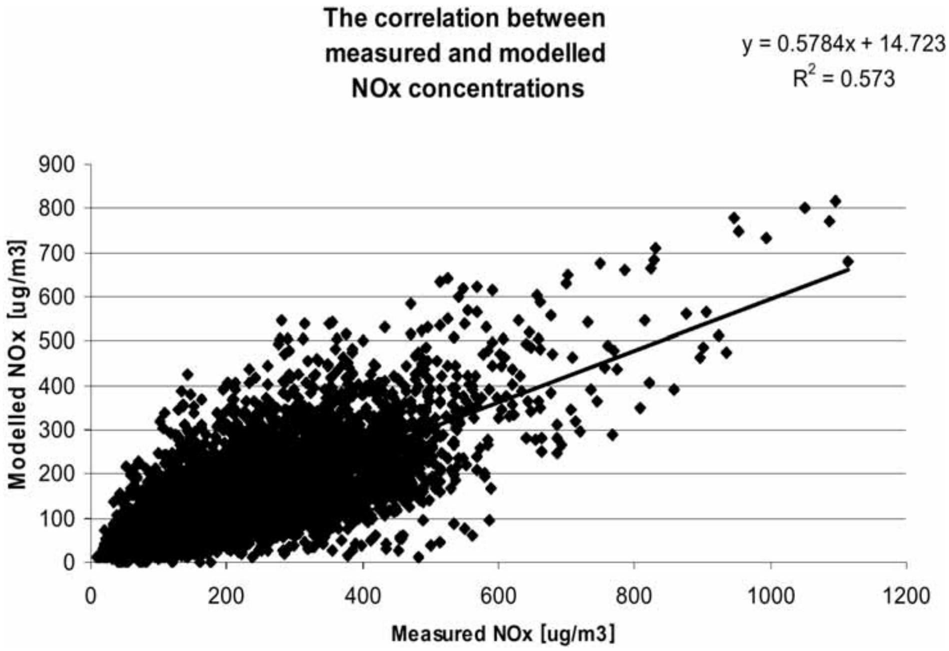

Fig. 12 – The correlation between measured and modeled NO_x concentrations.

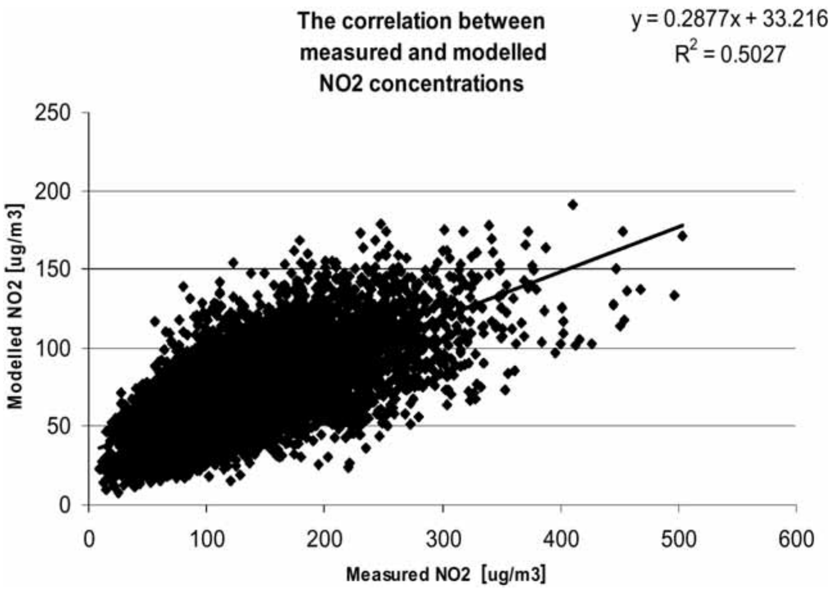

Fig. 13 – The correlation between measured and modeled NO_2 concentrations.

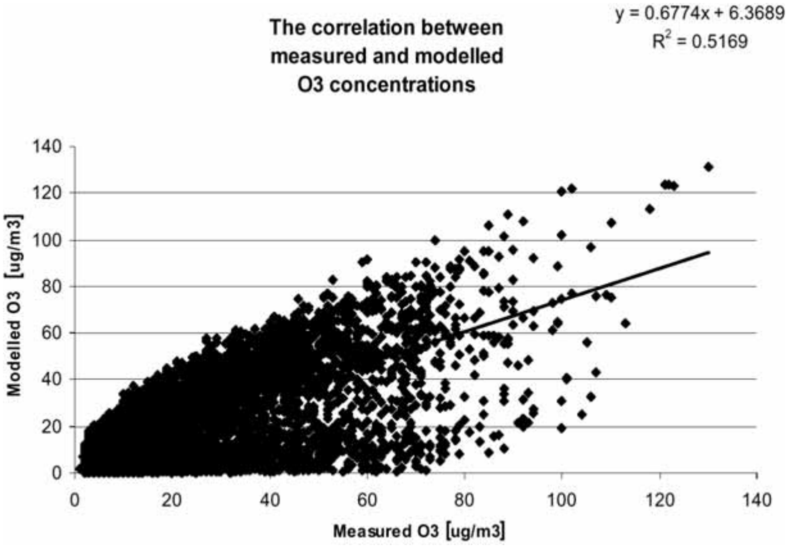

Fig. 14 – The correlation between measured and modeled O_3 concentrations.

3. RESULTS AND DISCUSSIONS

A diagnostic evaluation of the model performance requires an analysis of the behavior of model results in comparison with experimental data, with respect to the meteorological conditions. Such an analysis is presented in Figs. 3–5 in which the measured and modeled CO, NO_x, respectively NO_2 concentrations are plotted against the wind speed and direction. The measured and modeled concentrations show a very similar dependence on wind speed. The differences between measured and modeled data are caused by inaccuracies in the traffic emission estimates or in the measured concentrations and meteorological data. Part of the differences is also due to the background modeled data and, of course, the dispersion model. The highest concentration values are fairy well reproduced by the model. The graphs show the influence of wind speed to pollutants dispersion in the street canyon. When the wind speed is higher, the dispersion is more active and the pollutants dilution is better, resulting lower levels of pollution [12]. Counter, when the wind speed is lower, result elevated levels of pollutants.

As well as we expected, the highest levels of pollution were recorded when the traffic is very high. Here it can be seen a very good correlation between traffic and pollution. It means that the most important pollution proceed from traffic flow. The measurements are only available from one side of the street, so the experimental data didn't provide evidence for the formation in the street of a vortex in conditions of higher wind speed [14]. Results of more evaluation studies of the model are reported in Kukkonen [13].

A summary of the statistic indicators used for model validation is presented in Table 1 and Table 2 (where appears indicators for measured (m) and simulated (s) values).

Table 1

The averages, medians and standard deviations for measured and modeled pollutants values

	CO_m	CO_s	NO_x _m	NO_x _s	NO_2_m	NO_2_s	O_3_m	O_3_s
Average	1.821	1.490	189.001	124.035	131.764	71.127	24.095	22.690
Median	1.5	1.190	158	100.239	118	67.982	17	17.577
Stddev	1.334	1.052	123.439	94.311	70.526	28.610	20.899	19.691

Table 2

Bias, normalized residue (FB), normalized standard deviation (FS), normalized square error (NMSE) calculated for CO, NO_x, NO_2 and O_3

	CO	NO_x	NO_2	O_3
BIAS	–0.330	–4.966	–1.533	–1.404
FB	0.199	0.415	0.597	0.060
FS	0.236	0.267	0.845	0.595
NMSE	0.367	0.457	0.706	0.429
R^2	0.506	0.573	0.502	0.516

The averages are close by the medians; so, there are only few extreme different values. The scatters of data shown in Figs. 9–12 are large, indicating that the modeling of traffic induced turbulence still needs to be improved or other important dispersion mechanisms at low wind speed should be studied. The correlation coefficient is quite good, so, OSPM can be used to predict the pollutants concentrations in the street canyon.

Wind rose shows that the wind blows, over 16%, on the direction of 110 degrees, 16% on 35 degrees, 16% on 285 degrees toward the north. It means that the wind doesn’t blow perpendicular or parallel with the streets, and in this situation, in the street a helical vortex rises, which advances along the street, carrying on the pollutants. When the wind intensity increases, the turbulence increase and pollutants are dispersed (Fig. 12). The highest wind speed was recorded from 240 degrees (11.7 m/s).

In the winter and the summer concentration values of all the pollutants are higher than in spring and autumn. This behavior is explained in respect to air circulation types, different for different seasons. In the winter, the high field of pressure (anticyclone) dominates and in spring and autumn the transitory synoptic systems are more much present over the southern part of Romania, so over Bucharest.

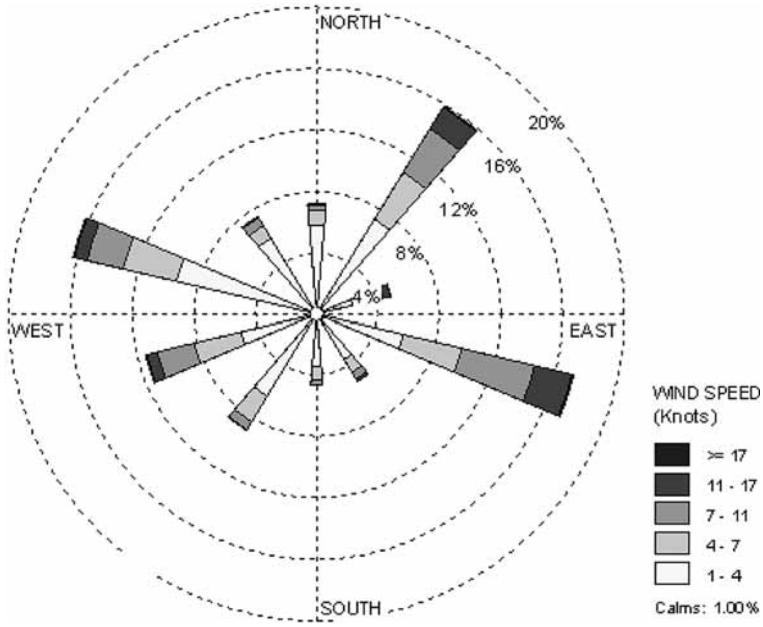

Fig. 15 – Wind rose for 2002 year.

4. SUMMARY AND CONCLUSIONS

An experimental survey campaign was conducted by Romanian Auto Register (RAR) in Bucharest, in 2002, to see if OSPM can be used in the street canyon in order to provide atmospheric pollution data, in the period to come, in the absence of measured data.

This paper examined the temporal variations in air pollution within realistic urban street canyon environment. What is novel about this study is that all aspects are considered: the links between traffic flow characteristics, background concentrations, meteorological conditions, pollutants concentrations in the street and predicted pollutants concentrations with OSPM.

OSPM has been extensively tested on field data [4, 5, 8–10]. Results of these tests were used to further improve the model performance, especially with regard to different street configurations and a variety of meteorological conditions.

In this model, the concentrations of exhaust gases are calculated using a combination of a plume model for the direct contribution and a box model for the recirculation part of the pollutants in the street. The turbulence within the canyon is calculated taking into account the traffic generated turbulence. The NO_2 concentrations are calculated taking into account NO-NO_2-O_3 chemistry, and the residence time of pollutants in the street (only the fastest chemical reactions can have any significance). The model is designed to work with inputs and outputs in the form of one-hour average.

In this paper I established a database containing all measured and predicted data, including traffic flow, emissions, background concentrations and meteorological parameters, together with the documentation.

The presentation of measured and predicted data as a function of wind speed and direction shows that the model qualitatively reproduces the observed data behavior well.

The graphs show relatively high levels for nitrogen oxides and traffic flow, around two times on day: in the morning between 7.00 and 10.00, when people go to work, and in the afternoon, between 16.00 and 19.00, when people come back home.

I presented the comparison between measured and modeled concentrations as scatter plots, and I calculated the statistic indicators used for model validation. The square correlation coefficients > 0.5 and BIAS < 0; this means that the model can be used to predict the pollutants concentrations in this street, but it under predicts. The under prediction of the concentrations could have been caused by the influence of the uncertainties in measured data or because the details of configuration of the street, mean and turbulent transport of pollutants being strongly influenced by buildings.

The comparisons between calculated and measured concentrations show that OSPM can successfully be applied for prediction of the street pollution from traffic. But, the simplifications made in OSPM lead to some deficiencies in the ability to resolve the fine structure in the pollutants concentrations and to solve new phenomena and situations. This model can be use in a street canyon when the measurements are not available.

Any dispersion model needs to be validated in various urban environments and for the whole range of meteorological conditions occurring in the real atmosphere.

This database is useful for testing and validation others street canyon models for the same location and to compare the results obtained.

A limitation of these measurements campaign is that no flow or turbulence measurements within the street canyon are available and the concentration measurements do not contain particulate matter.

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