

## THE ASSESSMENT OF THE TSP PARTICULATE MATTER IN THE URBAN AMBIENT AIR

C. BĂLĂCEANU, S. ȘTEFAN<sup>1</sup>

<sup>1</sup>University of Bucharest, Faculty of Physics, P.O.Box MG-11, Bucharest, ROMANIA

e-mail: [sabinastefan@hotmail.com](mailto:sabinastefan@hotmail.com)

(Received July 22, 2004)

*Abstract.* Air quality modelling is an essential tool for most air pollution studies. The air quality models are the means whereby pollutant emissions can be related to atmospheric pollutant concentrations. The uncertainties in assessment of air quality are related to both the quality of measured values of pollutant concentrations in local network and the input data for the models. The better estimation of air quality requests to combine the results of measurements with the results obtained by modelling.

The aim of our paper is to assess the air quality in Craiova and therefore the results of measurements were compared with the results of two very used models in pollution studies: Climatologic (CDM) and OML (Operationelle Meteorologiske Luftkvalitets-modeller). The dispersion models are Gaussian-type models.

The OML improves the methods for the simulation of dispersion processes in terms of certain physical parameters, with importance to boundary layer turbulence.

Intercomparison study was applied for 3 sites in Craiova City, where the concentrations of pollutants were measured. The distribution in space and time of the TSP (Total Suspended Particles) concentrations were studied.

The results show differences between measured and modelled values of TSP concentrations and consequently, for the assessment of air quality it is necessary to improve the methods of measurements of this type of pollutant and to be carefully with the input of meteorological data for models.

*Key words:* urban pollutants, air quality, models

### 1. INTRODUCTION

Particles that remain suspended in the air do so due to their size, shape and density. Large heavy particles fall out quickly, while fine light particles remain suspended for longer. These fine particles can be inhaled into the human's respiratory tract. Particles less than 10  $\mu\text{m}$  have the greatest chance of reaching the deepest parts of the lung, leading to possible adverse health effects [1; 3]

Particles come from a wide variety of sources, both natural and man-made. Natural sources include forest fires, volcanic eruptions, sea spray, soil and rock erosion, pollen grains and fungal spores. Man made sources include combustion processes, the extraction and working of soil and rock, a wide variety of industrial processes, and the wearing of road surfaces by motor vehicles.

In the atmosphere the particulate matters (PMs) may be classed as either *primary* or *secondary*. *Primary particles* are those such as carbon particles from combustion, mineral particles derived from stone abrasion, and sea salt.

*Secondary particles* are those that are formed in the atmosphere by the chemical reaction of the gases, which combine to form less volatile compounds that then condense into particles. All particles, whatever their source or composition, are measured as PM<sub>10</sub> if they fall within the right size range.

Three size ranges, in the context of the mass balance and health aspects of particulate matter were defined. The entire domain of particulate matter is known as *Total Suspended Particulate*, TSP (IPCC, 2001). This includes all airborne solid and liquid particles, except pure water, ranging in size from approximately  $0.005 \mu m$  to  $100 \mu m$  in diameter.

The  $PM_{10}$  refers to particulate matter less than  $10 \mu m$  in aerodynamic diameter. It is commonly referred to as inhalable or thoracic particles as they can penetrate into the thoracic compartment (from the trachea down to and including the alveoli) of the human respiratory tract. Such particles are known to cause human health impacts [6].

The  $PM_{10}$  is generally subdivided into two modes: fine and coarse. Fine mode defines particles of  $2.5 \mu m$  or less diameter ( $PM_{2.5}$ ). Coarse mode refers to particles greater than  $2.5 \mu m$  (but less than  $10 \mu m$ ). The smaller the particle, the deeper it can penetrate into the lung and the greater the potential health impact. Industrial activity is an important source of  $PM_{10}$ .

The aim of this paper is the study of the air pollution in Craiova with particulate matter by the intercomparison of two very known dispersion models, OML and Climatologic.

The datasets were available for the year 2000 at four stations placed in centre of city and limit exterior of Craiova.

After a short description of geographical and climate conditions of the interesting region in Section 2, in Section 3 were presented the Climatologic and OML models. The using data sets were also shown in Section 3. The Section 4 consists in the results of the measurements and intercomparison of these models. The conclusions are presented in Section 5.

## 2. ABOUT CRAIOVA CITY

In cities such as Craiova the main components of TSP will be derived from vehicle and industrial emissions, whereas in rural areas it will be pollen grain fragments and fungal spores that may be of most concern. In areas of high traffic levels this contribution is usually in the range of 30-40%. On high pollution days it can be much more. It should be noted that the composition and contribution of sources of TSP can changed from day to day depending on weather conditions and the quantities emitted from stationary and mobile sources.

Craiova is situated in south - western part of the Romania. With a population of 770 000 it ranks as the fourth largest city in Romania. Craiova City is located into plain and hill region. The dominant atmospheric circulation over this region is from west to east (fig.1).

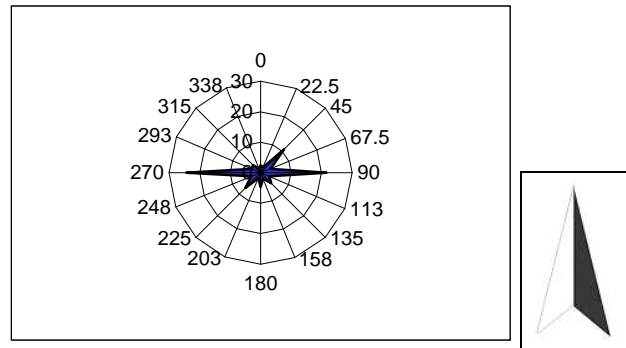


Fig. 1 – Distribution of the wind direction annual intensity

The climate of this city is temperate-continental. The precipitation amounts are much lower than other regions. Dominant wind is from northeastern, and east west. Annual mean temperature is about 10.0 – 11.5°C

Craiova is known for engine and cars production, chemical industry, power plants and oil industry.

As well as its industrial base the city has a university, world class sporting facilities, a growing cultural and entertainment centre, shopping malls and is a regional business and conference centre.

In Craiova it is the burning of coal for power plants or domestic heating that causes air quality problems but the most significant impact is the effects of emissions from road transport.

### 3. OML AND CLIMATOLOGICAL MODELS

The OML dispersion model is based on the Gaussian plume formulation. This is a gross simplification, as the Gaussian concept does not adequately describe the vertical structure of a plume, but it appears at present to be the only type of model capable of dealing satisfactorily with buoyant sources and with a wide range of stability conditions [2].

This model was shown capable of simulating dispersion in extremely convective conditions. The main innovation in the OML model is the way in which the dispersion parameters  $\sigma_y$  and  $\sigma_z$  are determined. The great majority of 'older' Gaussian models make use of the dispersion parameters and classification methods proposed by Pasquill (1961) and later slightly modified by Gifford (1961) and Turner (1964).

In the OML model, the dispersion parameters are directly related to the basic physical parameters describing the turbulent state of the atmospheric boundary layer. As the turbulent properties may in general change with the height above the ground, the same is true for the dispersion parameters. In the OML model this dependence is expressed explicitly, making the model applicable for sources of any height.

As a main rule, either of the  $\sigma_y$  and  $\sigma_z$  is composed of the

following three terms:

$$\sigma^2 = \sigma_{turb}^2 + \sigma_{int\ ern}^2 + \sigma_{building}^2 \quad (1)$$

where:

$\sigma_{turb}$  - represents dispersion due to the atmospheric turbulence;

$\sigma_{int\ ern}$  - is a contribution due to entrainment of the ambient air into a rising plume;

$\sigma_{building}$  - is a contribution due to enhancement of dispersion in the wake of buildings near the source.

The Climatologic model of Martin and Tikwart with Kao correction for complex relief was used. This model is used for the evaluation of the concentrations of pollutant on the long period of average for point sources or area sources.

The average concentration  $C(x, y, z)$  with  $Ox$  – represent wind direction and  $Oz$  – vertical orientation is:

$$C(x, y, z) = \frac{Q}{(2\pi)^{\frac{3}{2}} \sigma_y \sigma_z \sigma_x} \cdot \exp\left[-\frac{1}{2} \left(\frac{x-ut}{\sigma_x}\right)^2\right] \exp\left[-\frac{1}{2} \left(\frac{y}{\sigma_y}\right)^2\right] \cdot \left\{ \exp\left[-\frac{1}{2} \left(\frac{z+H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2} \left(\frac{z-H}{\sigma_z}\right)^2\right] \right\} \quad (2)$$

where:

$Q$  – emission (kg/h);

$u$ - wind velocity (m/s);

The Climatologic model is based on a diffusion equation that describes the three-dimensional concentration field. The dispersion parameters are generated by scheme Pasquill-Gifford, for urban or rural area.

### 3.1 Input data for models

#### *Input data for the OML model*

- Type of source (point or area), location in geographic co-ordinates (xylem), terrain height at source;
- Stack height (above surface), inner and outer diameter of stack top;
- Emission strengths (e.g. g/s), temperature (°o), volume flux (gas flow rate) (m<sup>3</sup>/s);
- Type of receptor net (circular net or square grid) and general or individual receptor height above ground.

#### *Input data for the Climatologic model*

- Meteorological data are given by the frequency function of the triplet: wind direction class, wind speed class and a stability class (after Pasquill-Gifford stability classes);
- Inner, geometrical height, speed and temperature, source coordinate, emission (kg/h).

#### *Meteorological data*

The meteorological part of the project has been synthesized into a software package the 'OML Meteorological Pre-processor' [3]. The standard version of the pre-processor has as input hourly meteorological measurements from a synoptic or analogous surface station, and twice-daily vertical profiles of temperature from a nearby radiosonde station. Output is in this case hourly values of turbulence parameters: most essentially sensible heat flux, Monin-Obukhov length, friction velocity and mixing height. More specialized versions of the pre-processor have been designed for non-standard input such as mast measurements instead of synoptic surface data.

For Climatologic model meteorological data are given by the frequency function of the triplet: wind direction class, wind speed class and a stability class (after Pasquill-Gifford stability classes).

As mentioned in the introduction of paper, the necessary input data were available for the year 2000. Area sources include both stationary sources as well as road traffic emissions.

## **4. RESULTS AND DISCUSSIONS**

In order to gain confidence in the modelling tools a comparison of measured and calculated TSP values have been performed.

### **4.1. Particulate matter measured concentrations values.**

The measurement stations of the particulate matter are: MPA (Medium Protection Agency), Electric Power Craiova (EPC), Water Station Isalnita (WSI). These measurement stations are representative as street station located close to major roads (MPA) and as point sources that include emissions from large factories or industrial plants (EPC, WSI). The stations locations are shown in fig. 2.

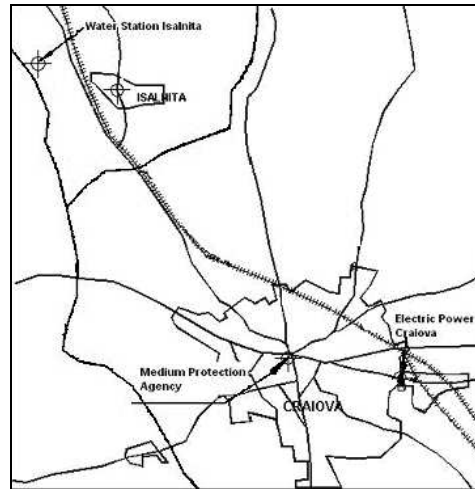


Fig.2. The locations where were made the measurements of TSP concentrations

The daily averaged concentrations for the four seasons of the 2000-year are shown in figures 3,4,5,6. We used the mean concentrations because of well-known fact that episodes with extremely high concentrations are the most difficult to model when performing hourly calculations.

The concentration values are in all the seasons larger at the MPA station than the EPC and WSI stations. These larger values are explained by the contribution of the traffic.

The first EU Daughter Directive (1996) includes a 24-hour limit value for  $PM_{10}$  of  $50 \mu\text{g}/\text{m}^3$  not to be exceeded more than 35 times per year, and an annual limit value of  $40 \mu\text{g}/\text{m}^3$ . The both are to be achieved by 1<sup>st</sup> January 2005. Included in the indicative stage 2 Daughter Directive limit values are to be achieved by 1<sup>st</sup> January 2010. This allows only 7 exceedences per year of the  $50\mu\text{g}/\text{m}^3$  limit value.

The EU Council Directive 1999/30/EC target levels for  $PM_{10}$  which are to be reached within 2010 are: daily average  $50 \mu\text{g}/\text{m}^3$  with allowed days above the target level, 7 days; target level for the yearly mean value  $20 \mu\text{g}/\text{m}^3$ .

One can observe that the 24-hour mean objective of  $50 \mu\text{g}/\text{m}^3$  is not to be exceeded more than 35 times a year. The annual mean is  $40 \mu\text{g}/\text{m}^3$ . Both are based on the limit values contained within the European Air Quality Daughter Directive.

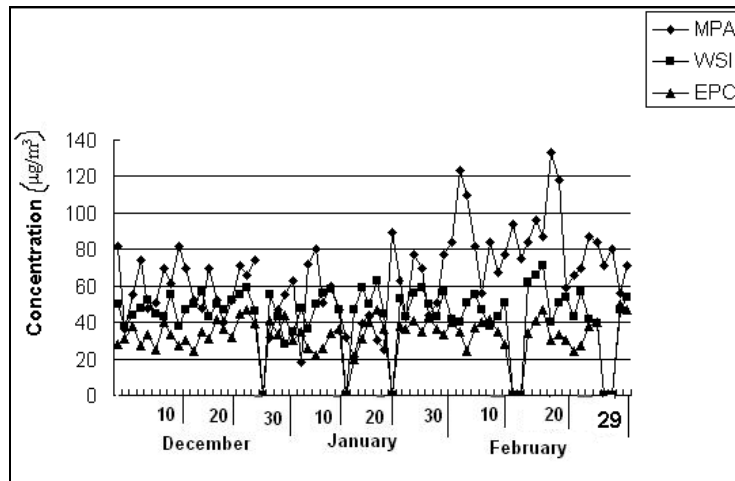


Fig. 3. The measured concentrations in winter.

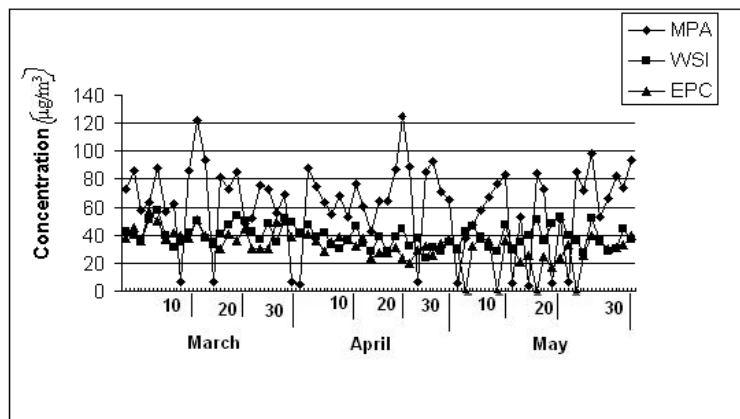
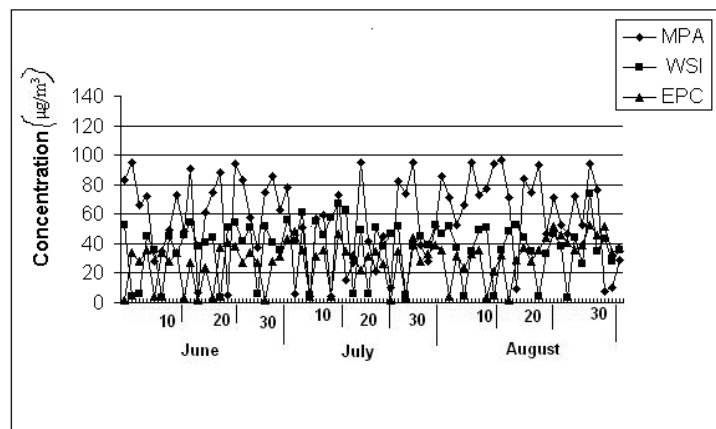


Fig. 4. The measured concentrations in spring.



The measured concentrations in summer.

Fig. 5.

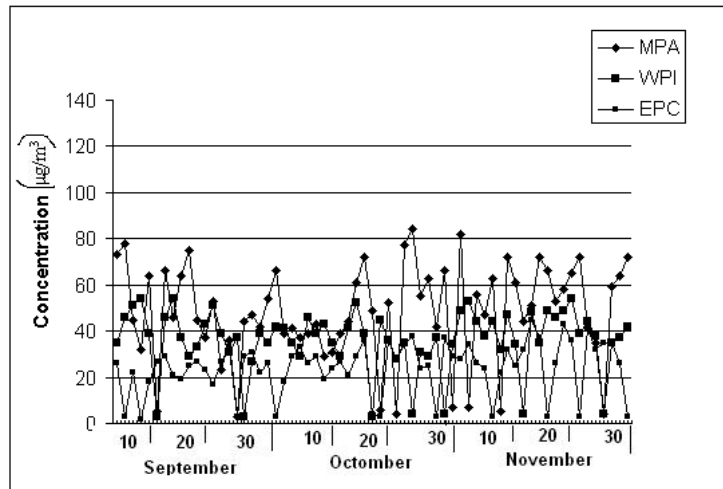


Fig. 6. The measured concentrations in autumn.

## 4.2 Intercomparison of the models

The intercomparison was performed using traditional statistical parameters recommended in the U.S. Environmental protection Agency (EPA) Guidelines [7]. The both, monthly averaged concentrations values obtained with the two models OML and Climatologic and the measured values of the three stations MPA (Medium Protection Agency), Electric Power Craiova (EPC), Water Station Isalnita (WSI) are presented in Table 1.

Table 1. Calculated and measured averaged monthly concentration values

Monthly	Concentrations ( $\mu\text{g}/\text{m}^3$ ) OML model			Concentrations ( $\mu\text{g}/\text{m}^3$ ) Climatologic model			Measured concentrations ( $\mu\text{g}/\text{m}^3$ )		
	MPA	WSI	EPC	MPA	WSI	EPC	MPA	WSI	EPC
January	47	11	20	49	15	18	49	49	35
February	46	33	28	48	33	29	48	50	36
March	30	41	21	34	43	27	62	43	40
April	5	29	7	7	32	9	67	35	31
May	12	62	12	12	59	14	58	39	25
June	16	58	14	15	59	14	62	36	24
July	10	36	9	17	42	12	46	42	29
August	14	24	8	18	27	8	64	36	33
September	5	24	7	7	22	10	48	37	21
October	27	38	20	22	45	25	45	33	25
November	46	49	28	46	52	32	52	39	27
December	65	30	41	68	35	45	60	48	33

One can observe monthly averaged concentration values from measurements are larger than the modeled values, for all the stations. The discrepancies are larger in summer than in winter (Table 1 and Fig.7a). If the winter is extended with the

months November and March the differences between measured and modeled values are the same (Figure 7b). The meteorological conditions, the state of the atmosphere, which affect the measurements, explain this result. Unfortunately, the discrepancies are most pronounced in situations when the very high concentrations levels are observed or calculated. The dispersion of concentration values is very high and any trend is observed (Figure 7a,b).

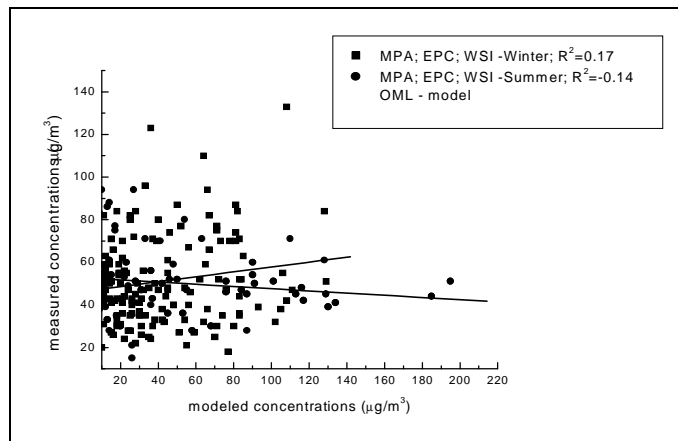


Fig. 7.a – Concentrations for summer and winter using model OML

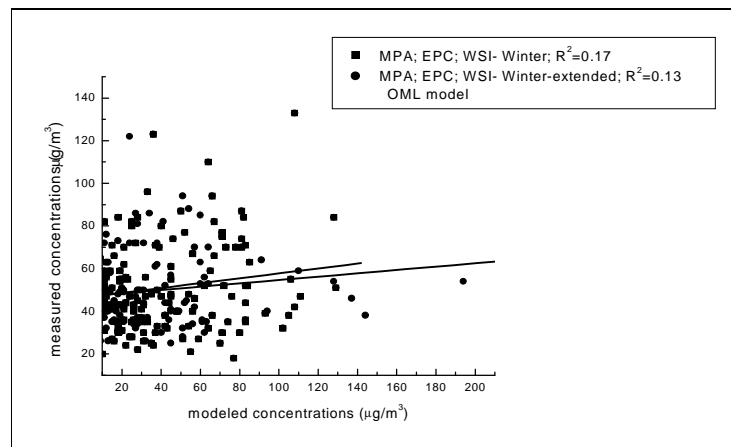


Fig. 7.b - Concentrations for winter extended and winter using model OML

The values also reveal that the agreement between observed and calculated values is general better for the WSI station (excepted January month) than for the MPA and EPC stations (Table 1). This is to be expected since at the WSI station the changes in emissions due to urban effect have not observed.

The results of the statistical analysis of the correlation between measured and modelled concentration values of TSP for urban area are shown in Table 2 and in the figures 8, 9 and 10.

Table 2. Calculated and measured annual mean concentration

Stations	Annual mean values TSP ( $\mu\text{g}/\text{m}^3$ )			Bias ( $\mu\text{g}/\text{m}^3$ )		Standard deviation	
	OML model	CDM model	Measured values	OML model	CDM model	OML model	CDM model
MPA	27	29	58	31	29	22	21
EPC	18	20	30	12	10	9	7
WSI	36	39	41	5	2	4	1.4

The annual mean values emphasize the observed results in monthly mean values: the good agreement between observed and modeled values for the WSI station (Table 2). Nevertheless, the correlation between measured and calculated values is negative (Figs.8, 9) for the both OML and Climatologic models.

The larger bias for MPA station and the poorly correlation between the measured and modeled values (Figs.8, 9) are explained by larger variability due to the traffic contribution.

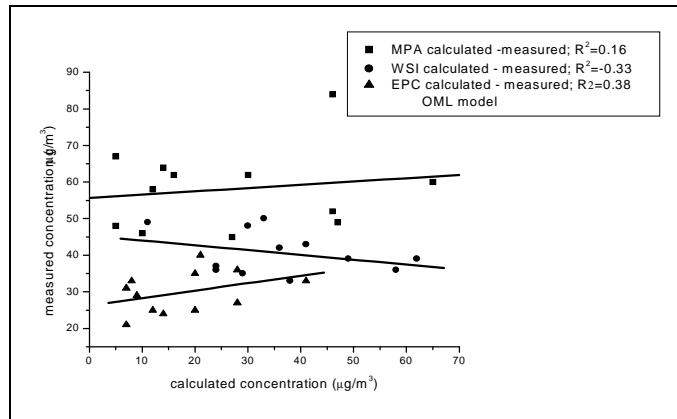


Fig.8. Correlation between observed and calculated (with OML model) monthly values

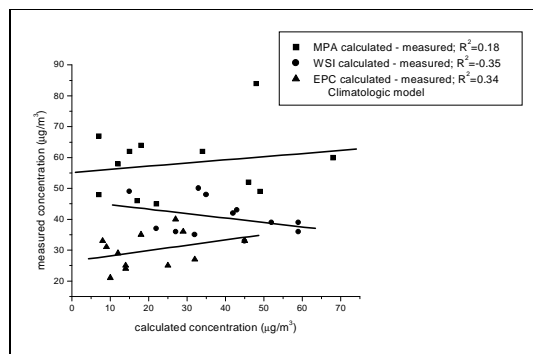


Fig. 9. Correlation between observed and calculated (with Climatologic model) monthly values

The European Daughter Directive (order 592 on June 25, 2002) specifies that the method for determining should be a gravimetric method. This method was used in measurements.

In figures 8 and 9 can be observed the discrepancies between values measured and calculated by using the two models. The figure 10 shows a very closed correlation between the computed concentration values with the OML and Climatologic models.

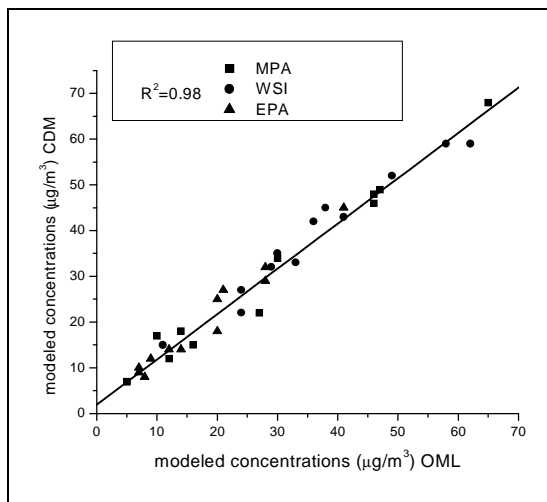


Fig. 10. Correlation between calculated monthly values by using the two models.

Therefore, we consider that the poor correlation between measured and modeled values is related to the deficiencies in measurements.

Consequently, the measurement results should be treated with care, especially when the higher levels of concentration are observed and also the initial conditions for the models to obtain the good conclusions related to air quality.

## 5. CONCLUSIONS

Air quality objectives were set for the particulate matter (TSP) in Craiova at different sites.

In Craiova, the monthly averaged concentration values from measurements are larger than the modeled values, for all the stations. The discrepancies are larger in summer than in winter but the 24-hour mean objective of 50 µg/m<sup>3</sup> is not to be exceeded more than 35 times a year.

The highest concentration levels of TSP in Craiova city typically occur in winter, early spring (March) and November. That means that is reasonable to assume that the six-month winter period would suffice for the calculation of the exceedances of the percentile levels of the EU Council Directive, with a correction for the yearly averages.

The correlation between the measured and calculated values for this

period of year emphasizes this finding.

The similar results obtained with the two different models allow concluding that it is very important using the models to estimate the TSP concentrations.

The models results can give valuable information on the qualitative effect of various types of abatement measures.

The model simulations can be helpful in detecting problem areas, as far as air quality is concerned, at an early stage and thereby provide local authorities with important information with respect to city planning.

### **Acknowledgements**

The authors gratefully acknowledge the Medium Protection Agency Craiova for access to the measured data series.

## **REFERENCES**

1. Zanetti, P., *Air Pollution Modelling*, Boston, 500pp., 1990
2. Berkowicz, R. and Prahm, L.P.: *Sensible heat flux estimated from routine meteorological data by the resistance method*, 1983
3. Hosker, R. P., *Practical applications of air pollutant deposition models – current status, data requirements and research needs*. Proc. Internat. Conf. on Air Pollutants and their Effects on the Terrestrial Ecosystem, S. V. Krupa and A. H. Legge, eds. John Wiley and Sons, New York, ATDL Contribution, 80/8, NOAA, Oak Ridge, TN, 71 pp; 1980
4. Vedal, S., *Health effects of wood smoke*, 34pg:  
<http://www.env.gov.bc.ca/ske/skeair/pm10/pm10gen.html>, 1993
5. IPCC 2001, *Intergovernmental Panel on Climate Change*, Third Assessment Report, Cambridge University Press, 2001
6. Wilson R. and Spengler J.D., *Particles in Our Air; Concentrations and Health Effects*. Harvard University Press, 1996
7. \*\*EPA (1984) Interim Procedures for Evaluating Air Quality Models (revised). Research Triangle Park, NC. OAQPS, EPA (EPA-450/4-84-023).