AIR QUALITY MONITORING NETWORK DESIGN TO CONTROL PM_{10} IN BUENOS AIRES CITY

L. E. VENEGAS and N.A. MAZZEO

National Scientific and Technological Research Council (CONICET)
Department of Atmospheric and Oceanic Sciences. Faculty of Sciences. University of Buenos Aires
Ciudad Universitaria. Pab. 2. 1428 Buenos Aires, Argentina
venegas@at.fcen.uba.ar – mazzeo@at.fcen.uba.ar

***Abstract*— An air-quality monitoring network properly designed is a key component of any air quality control programme. This paper presents an objective procedure to determine the minimum number of monitoring sites needed to detect the occurrence of background air pollutant concentrations greater than a reference concentration level (C_L) in an urban area. We propose an air quality monitoring network design based on the analysis of the results of atmospheric dispersion models, in order to identify the grid cells (in which the city is divided) where the air pollutant concentration exceeds C_L. At present, Buenos Aires city has not an air quality monitoring network. This paper also describes the application of the proposed methodology to design a monitoring network to control PM_{10} levels in Buenos Aires. Results show that four monitoring stations are required to detect the occurrence of PM_{10} 24h-concentrations greater than C_L=0.150 mg m^{-3}.**

***Keywords*— Urban Air Quality, Air Quality Management, PM_{10} Monitoring Network.**

I. INTRODUCTION

Cities are by nature concentrations of humans, materials and activities. They therefore exhibit both the highest levels of pollution and the largest targets of impact. Air pollution is, however enacted on all geographical and temporal scales, ranging from strictly “here and now” problems related to human health and material damage, over regional phenomena like acidification and forest die back with a time horizon of decades, to global phenomena, which over the next centuries can change the conditions for man and nature over entire globe. In this respect the cities act as sources.

Urban areas with high population densities are often exposed to poor air quality. While in the past the major source of poor air quality was industrial activity, because of the rapid increase in mobility the major current urban air pollutants are particulate matter, nitrogen oxides and ozone. The best example of this can be found in the poor air quality of Los Angeles area (USA), Mexico City, Santiago (Chile) and Sao Paulo (Brazil). Motorized traffic is responsible for a considerable part of nitrogen oxides emissions and emissions of ozone precursors.

The monitoring of pollution levels in the atmosphere is of fundamental importance because it enables us to measure the extent to which pollution is actually occurring, it provides us a guide as to how effective our controls are proving and it indicates where greater effort is needed. The design of an air pollution monitoring network depends on the purpose for which the information concerning pollution levels is to be used, the degree of accuracy required and the economics of establishing and operating a network. In previous studies, various statistical and optimisation models have been applied for designing representative air quality monitoring systems. Most of them have been developed for point sources (Noll *et al.*, 1977, Noll and Mitsutomi, 1983, Mazzeo and Venegas, 2000) and some of them for urban area sources (Elsom, 1978, 1979, Venegas and Mazzeo, 2003c). Among these procedures, spatial correlation (Elsom, 1979, Handscombe and Elsom, 1982), Monte-Carlo variance reduction approach (Nakamori *et al.*, 1979), population dosage product and statistical technique based on Fisher’s information measures (Husain and Khan, 1983), have commonly been applied in the past. Other procedures have been presented in Shindo *et al.* (1990) and Wu and Chan (1997). Different authors have presented methodologies for designing an air pollution-monitoring network using atmospheric dispersion models (Seinfeld, 1972, Noll *et al.*, 1977, Noll and Mitsutomi, 1983, Mazzeo and Venegas, 2000, Tseng and Chang, 2001, Venegas and Mazzeo, 2003c).

Buenos Aires City and surroundings is one of the three largest megalopolises in Latin America. The population of the city state is about three million inhabitants and the population of the entire area is about fourteen million. Buenos Aires City is located on a flat terrain close to the de la Plata River. This river is a shallow large-scale coastal plain estuary that covers an approximate area of 35000 km^2 and has a width of approximately 42 km in front of the city.

At present, Buenos Aires City has no air-quality monitoring network. However, several studies on air pollution in the city and air-quality monitoring campaigns have been carried out (Bogo *et al.*, 1999, 2001, 2003; Venegas and Mazzeo, 2000, 2003a; Mazzeo and Venegas, 2002, 2004, Mazzeo *et al.*, 2005). Another studies of the air quality conditions in Buenos Aires include the development of the first version of an emission inventory of CO and NO_X (Mazzeo and Venegas, 2003) for the city and the application of urban atmospheric dispersion models (Venegas and Mazzeo, 2003b;

2005) to estimate background concentration distributions of these pollutants in Buenos Aires.

This paper presents an objective procedure to determine the minimum number of monitoring sites (and their locations) needed to detect the occurrence of background air pollutant concentrations greater than a reference concentration value in an urban area. We propose an air pollution monitoring network design based on the analysis of the results of atmospheric dispersion models to identify the grid cells (in which the urban area is divided) where the background air pollutant concentration may exceed the reference value. Unlike previous studies, the developed system is compound by the DAUMOD+ISCST3 atmospheric dispersion models and an iterative method to select the minimum number of grid cells where to locate the monitoring stations. The proposed methodology is particularly useful to identify the locations of a minimum number of monitoring sites if the resources available are limited. Therefore, it can be a useful tool either to start with a new air quality network or to prioritise site relocation in an existing monitoring network. Furthermore, another contribution of this study is the application of the proposed methodology to design, for the first time, a monitoring network to control PM_{10} levels in Buenos Aires City.

II. AIR QUALITY MONITORING NETWORK

The first step in designing any monitoring system is to define its overall objectives. There are many rationales for air quality monitoring. These may include statutory requirement, policy and strategy development, local and national planning, measurement against standards, identification of risk and public awareness. Some air quality monitoring objectives may be:

- Identifying threats to natural ecosystems or population health
- Informing the public about air quality and raising awareness
- Determining compliance with state, national or international standards
- Providing objective inputs to air quality management, traffic and land-use planning
- Policy development and prioritisation of management actions
- Development/validation of management tools
- Assessing point or area source impacts
- Trend qualifications, to identify future problems or progress against management/control targets.

Although monitoring systems can have just a single, specific objective, it is more common for them to have several targeted programme functions. There are no hard and fast rules for network design, since any decisions made will be determined ultimately by the overall monitoring objectives and resource availability.

In practice, the number and location of air quality monitoring stations required in any extended network depend on the area to be covered, the spatial variability of the air pollutant being measured and the required data usage.

There are a number of approaches to network design and site selection. Source-orientated monitoring often targets worst-case "hot-spot" environments, while background or baseline studies are usually optimised for assessing general population or ecosystem exposure to pollutants of concern. Although the overall requirement is to maximize spatial coverage and representativeness, in practice this goal is only approached by grid-based monitoring strategies: these can be optimised to provide detailed information on spatial variability and exposure patterns for priority pollutants. However, this approach is highly resource-intensive. To reduce resource requirements, a grid approach can be utilized in conjunction with intermittent or mobile sampling. However, use of this technique is not consistent with the need to maximize temporal representativeness as well as spatial coverage. A more flexible approach to network design, appropriate over city-wide or national scale, involves placing monitoring stations or sampling points at carefully selected representative locations, chosen on the basis of required data usages and known emission/dispersion patterns of the pollutants under study. This approach to network design requires fewer sites than grid strategies and it is, in consequence, cheaper to implement. However, sites must be carefully selected. Microscale location considerations are also important in ensuring that meaningful and representative measurements are made. If background concentrations are to be assessed, then monitoring sites should be adequately separated from local pollutant sources or sinks.

III. DESCRIPTION OF THE PROPOSED SITE SELECTION PROCEDURE

Assuming a limitation on the number of sites, as determined by resource availability, the objective of the proposed network design procedure is to determine the minimum number of monitoring stations and their locations, needed to detect the occurrence of cases ($C > C_L$) with background air pollutant concentration (C) greater than a reference concentration (C_L) in the area.

In the first step we need to set the reference concentration level (C_L). Then, the second step is to compute the horizontal distribution of hourly background air pollutant concentrations in the urban area for at least one year. This can be done running urban atmospheric dispersion models.

The next step is to identify the cases and the grid cells with estimated concentrations greater than C_L. The locations of the monitors will be selected among the grid cells identified at this stage. The pre-selected grid cells are ranked according to the number of exceedances ($C>C_L$). The first monitoring site will be located at the grid cell with the highest score. All the cases with $C>C_L$ at the selected grid cell are discarded, so they are not included in the further analysis.

Considering the remaining cases, in the next step the grid cells are ranked again in order to select the next site location. Once the second monitoring site location is determined, all remaining cases with $C>C_L$ at this grid-cell are discarded. The procedure continues until the last case has been eliminated and the site locations needed to “detect” the occurrence of $C>C_L$ in the area, are determined.

Fig. 1 shows a scheme of the site selection procedure.

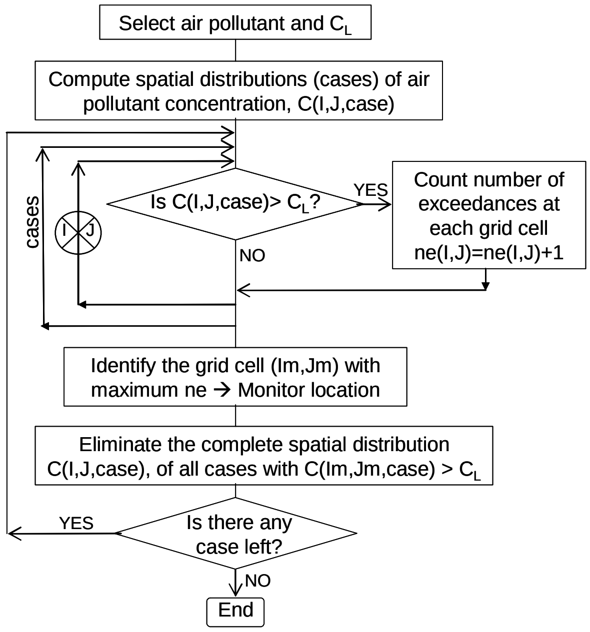

Figure 1. Scheme of the site selection procedure

The efficiency of this network design procedure depends on the accuracy of model predictions and it is also related to the quality of the registration of emissions.

Once the network is operating, the measurements can be applied to “calibrate” the network design. This “feedback” procedure is beyond the scope of this paper.

IV. MONITORING NETWORK DESIGN TO CONTROL PM_{10} IN BUENOS AIRES CITY

We include the application of the site selection methodology described above to determine the minimum number of sensors and their location to identify the occurrence of daily PM_{10} concentrations greater than a given value in Buenos Aires. We consider the reference concentration level ($C_{L24\text{-}h}$) for daily concentrations equal to the Air Quality Standard value for PM_{10} valid in Buenos Aires City: 0.150 mg m^{-3}.

For Buenos Aires City, emission data (Venegas and Martin, 2004) include the following activities as area sources of PM_{10}: residential, commercial, small industries, road traffic and aircraft operations at the Domestic Airport located in the city. This inventory is divided into a grid net with a resolution of 1km x 1km that covers the entire city and has a typical diurnal variation. There are also three power plants located at the side of the river. The stacks of these power plants are the only point sources to be considered because there is no other large industry in the city. We use the hourly meteorological data registered at a weather station of the Argentine Meteorological Service located at the Domestic Airport. We apply the urban atmospheric dispersion model DAUMOD (Mazzeo and Venegas, 1991) to area source emissions and the Industrial Source Complex ISCST3 (USEPA, 1995) dispersion model to point source emissions to estimate hourly concentrations. We run the atmospheric dispersion models considering one year of hourly information.

A. The Urban Atmospheric Dispersion Model (DAUMOD)

In the development of the DAUMOD model (Mazzeo and Venegas, 1991), a semi-infinite volume of air, bounded by the planes z=0 and x=0 is considered. According with Gifford (1970), for steady-state conditions, with the x-axis in the direction of the mean wind and the z-axis vertical, the concentration [$C(x,z)$] of pollutants emitted from an area source at the surface, satisfies the bidimensional diffusion equation:

$$u(z)\frac{\partial C(x,z)}{\partial x} = \frac{\partial}{\partial z}\left[K(z)\frac{\partial C(x,z)}{\partial z}\right] \quad (1)$$

because only the vertical diffusion contributes significantly to the process. In Eq.(1), $u(z)$ is the mean wind speed and $K(z)$ is the vertical eddy diffusivity for contaminants.If the effluents are emitted continuously from the surface, the lower boundary condition is:

$$K(z)\left.\frac{\partial C(x,z)}{\partial z}\right|_{z=0} = -Q \quad (2)$$

where Q is the source strength, in units of mass per unit area per unit time. Other basic assumption is that at a given distance, the vertical extension of the plume of contaminants is $h(x)$, where $C(x,h(x))$ = 0. Then, there is no transport of mass through the upper limit of the plume, and this can be expressed as:

$$K(z)\left.\frac{\partial C(x,z)}{\partial z}\right|_{z=h} = 0 \quad (3)$$

The boundary condition $C(x,h(x))$ = 0, can also be satisfied assuming that the solution of Eq.(1) is given by the following polynomial form:

$$C(x,z) = C(x,0)\sum_{i=0}^{6} A_i\left(\frac{z}{h}\right)^i \quad (4)$$

The coefficients A_i have been computed fitting Eq.(4) to the following expression (Pasquill and Smith, 1983):

$$C(x,z) = C(x,0)\exp\left[-4.605\left(\frac{z}{z_m}\right)^s\right] \quad (5)$$

where s is a shape factor which depends on atmospheric stability and surface roughness (Gryning *et al.*, 1987) and z_m is the height at which $C(z_m)$ = 0.01 $C(0)$.The height z_m is usually considered to be the upper limit of the plume, so we assumed $h = z_m$. Considering different atmospheric stability conditions, we obtained the coefficients (A_0, A_1,…A_6) of the polynomial of grade 6 for each fitting. We obtained excellent fittings to the polynomial form given by Eq.(4) to the Eq.(5) with coefficients of determination of ≈ 1.0 (the reader can find details of these results in Mazzeo and Venegas, 1991).

The following expressions are considered for the wind speed and the eddy diffusivity (Arya, 1988):

$$u(z) = (u_* / k)\ \left[\ln(z / z_0) + \psi(z / L)\right] \tag{6}$$

$$K(z) = k\, u_* \left(z + z_0\right) / \phi(z / L) \tag{7}$$

where u_* is the friction velocity, k is the von Karman´s constant (=0.41), z_0 is the surface roughness length, L is the Monin-Obukhov´s length, $\phi(z/L)$ is the dimensionless wind shear and $\psi(z/L)$ functions determine stability correction due to stratification (Gryning *et al.*, 1987, Arya, 1988):

$$\phi(z/L)\begin{cases} 1+6.9\,z/L & z/L\geq 0 \\ (1-22z/L)^{-1/4} & z/L< 0\end{cases}$$

$$\psi(z/L)\begin{cases} 6.9\,z/L & z/L\geq 0 \\ 1-\phi^{-1}(z/L) & z/L< 0\end{cases}$$

Substituting Eqs.(4) and (7) into Eq.(2), we obtain the following expression:

$$C(x{,}0) = Q\ h(x)\ /\ (|A_1|\ k\ u_*\, z_0) \tag{8}$$

$C(x,0)$ can be obtained from Eq.(8) knowing the form of $h(x)$. Therefore, considering the equation of pollutant mass continuity expressed by Gifford (1970), Pasquill and Smith (1983):

$$\int_0^x Q\, dx = \int_{Zo}^h u(z)\ C(x, z)\, dz \tag{9}$$

and Eqs.(4), (6) and (8) along with the boundary condition $C(h)=0$ the following expression can be obtained when Q= constant:

$$x / z_0\ = (h / z_0)^2 \big/ (\ |A_1| k^2\ )\ F\left(z_0/h\, ; h/L\right) \tag{10}$$

The form of $F(z_0 /h;\, h/L)$ is not simple (the complete expression is included in Mazzeo and Venegas, 1991), however the values of (h/z_0) computed from Eq.(10) can be fitted with great accuracy to potential functions (see Mazzeo and Venegas, 1991) given by:

$$h / z_0 = a\, (x / z_0)^b \tag{11}$$

a and b depend on atmospheric stability.

Substituting Eq.(11) in Eq. (8), we obtain:

$$C(x{,}0) = a\ \ Q\ \ (x/z_0)^b\ \ /\ \left(|A_1|\ k\ u_*\right) \tag{12}$$

which is the expression for a semi-infinite area source emitting continuously with a uniform strength (Q). The expression for a finite and continuous source located between x= 0 and x= x_1, with strength Q, can be derived from Eq.(12). Subtracting the concentration due to a continuous semi-infinite source with strength Q lying through $x > x_1$, from Eq.(12):

$$C(x{,}0) = \frac{a\, Q\left[\ x^b - (x - x_1)^b\ \right]}{\left(|A_1|\ k\ z_0^b\ u_*\right)} \tag{13}$$

In an urban area, we may assume horizontal distribution of area sources with strength varying according to a typical square grid pattern. Each grid square has a uniform strength Q_i (i = 0, 1, 2, …, N). The variation of the concentration with x, for $x > x_i$ (i = 0, 1, 2, …, N) is given by:

$$C(x{,}0) = \frac{a\left[Q_0\ x^b + \sum_{i=1}^{N} (Q_i - Q_{i-1})(x - x_i)^b\right]}{\left(|A_1|\ k\ z_0^b\ u_*\right)} \tag{14}$$

The expressions of $a(z_0/L)$, $b(z_0/L)$ and $|A_1|(z_0 /L)$ considered in calculations are (Venegas and Mazzeo, 2002, 2005):

- For $z_0 /L < -10^{-4}$,
a= 3.618833 + 0.2369076 * ln(| z_0 /L|)
b= 0.5356147 + 0.0234187 * ln [(| z_0 /L|) + 0.01]
$|A_1|$ = 9.254667 + 0.8043134 * ln(| z_0 /L|)
- For $-10^{-4} \leq z_0 /L \leq 10^{-4}$
a= -384.73 (z_0 /L) + 1.4
b= -130.0 (z_0 /L) + 0.415
$|A_1|$ = -3853.31 (z_0 /L) + 1.461

- For $10^{-4} < z_0 /L$
a= 0.6224632 + 7.37387x10^{-5} / ln [(z_0 /L) + 1]
b= 0.5065736 - 1.196137 / ln [2802.315 + 9 / (z_0 /L)]
$|A_1|$ = 0.05478233 + 0.0001021171 / ln[(z_0 /L)+1]

A constant wind direction is required for application of Eq.(14). It has been noted from the applications of Eq. (14) that estimated concentration at any receptor is mainly originated from the emission in the grid square in which the receptor is located. This is because area source distributions in a city are generally fairly smooth and, the contribution of upstream grid squares (from Eq.(14)) rapidly reduces with distance to the receptor. The simplification of assuming that the uniform area source strength Q_i only varies with x (in the wind direction), suppose to consider a "narrow plume" hypothesis. This assumption has also been included in other simple urban dispersion models (Gifford, 1970, Gifford and Hanna, 1973). The performance of DAUMOD model in estimating background concentrations has been evaluated comparing estimated and observed concentration data from several cities. Results for Bremen (Germany), Frankfurt (Germany) and Nashville (USA) have been reported in Mazzeo and Venegas (1991) and for Copenhagen (Denmark) can be found in Venegas and Mazzeo (2002). The validation of the application of DAUMOD to Buenos Aires has been reported in several papers. The comparison of estimations of CO and NO_x with observations can be found in Mazzeo and Venegas (2004) and Venegas and Mazzeo (2005). The results of DAUMOD in estimating particulate matter in Buenos Aires are reported in Venegas and Martin (2004). The results show that the performance of the model in estimating short-term concentrations (hourly and daily) is good and it improves when estimating long averaging time values (monthly and annual). The bias of DAUMOD predictions is: ±50% for hourly concentrations and ±20% for daily concentrations.

B. The Industrial Source Complex Dispersion Model (ISCST3)

The three Thermal Power Plants burn natural gas during most part of the year except for a few days (the coldest) during winter when they burn gas-oil. Their contribution to PM_{10} concentrations in the city is very small. However, we estimated their contribution by running the ISCST3 model to the emissions from the stacks, according to the Argentine regulations.

The ISCST3 model is a bi-Gaussian plume model developed by the United States Environmental Protection Agency (USEPA, 1995) widely used. This model uses the Gaussian equation to estimate the concentration at a particular location. A detailed description of the model and references on the evaluation of its performance can be found in USEPA (1995). The ISCST3 model accepts hourly meteorological data to define de conditions of plume rise, transport and dispersion. The model estimates the concentration value for each source and receptor combination for each hour of input meteorology. The hourly concentrations calculated for each source at each receptor are summed to obtain the total concentration produced at each receptor by the combined source emissions.

C. Results

We obtained daily PM_{10} concentrations on the basis of the hourly PM_{10} concentrations estimated by the DAUMOD + ISCST3 model system for each grid cell ($1km^2$ of resolution) for one year.

After the application of the network design methodology described in Section III, we obtain the minimum number of monitoring sites and their location to identify the occurrence of daily background PM_{10} concentrations greater than $C_{L24\text{-}h}$ =0.150 mg m^{-3} in the city. The objective selection procedure suggests that four monitors of PM_{10} are needed to detect 100% of the cases with $C > C_{L24\text{-}h}$ in the city. Monitoring site locations are shown in Fig.2. Table 1 summarises the percentage (%) of cases with estimated daily background concentrations greater than 0.150 mg m^{-3} that different monitoring network configurations would be able to detect.

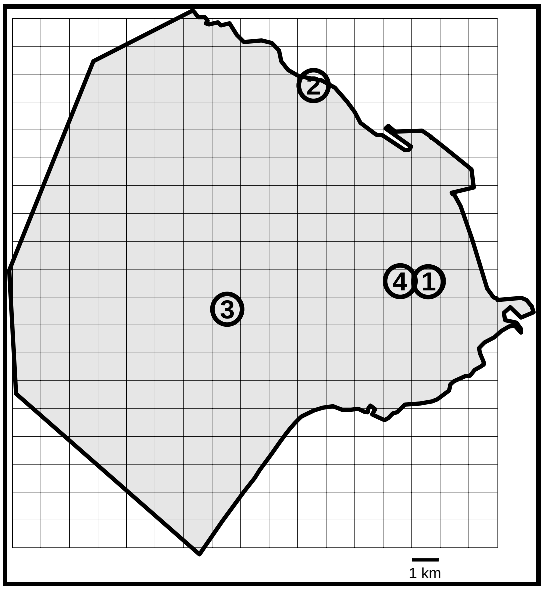

Figure 2. Site locations of PM_{10} monitoring stations. Shadowed area indicates the city of Buenos Aires. (The grid resolution is 1km x 1km).

Table 1. Percentage of annual cases with daily concentrations $C > C_{L24\text{-}h}$ that different network configurations would be able to detect. (see Fig. 2 for site locations)

Monitoring sites			
1, 2, 3, 4	1, 2, 3	1, 2	1
100%	97.9%	95.7%	80.9%

V. CONCLUSIONS

This paper presents an objective method for designing an urban air-quality monitoring network to identify the occurrence of background concentrations greater than a given value (reference concentration) in an urban area using atmospheric dispersion models. The developed system includes the DAUMOD+ISCST3 atmospheric dispersion models and an iterative method to select the minimum number of grid cells where to locate the monitoring stations. The proposed procedure can be summarised as follows:

- the selection of a reference concentration value (C_L),
- the use of an urban atmospheric dispersion model to calculate background concentration (C) distribution over the urban area,
- the identification of the cases (date and time) and the grid cells with $C > C_L$,
- the selection of monitoring sites to 'detect' the occurrence of $C > C_L$ in the urban area

This methodology was applied to design a PM_{10} background monitoring network for Buenos Aires city, for the first time. A typical diurnal variation of PM_{10} emissions for the city and one year of hourly meteorological data were considered. The network obtained comprised four stations with 100% of efficiency.

If the resources available are limited, this method can help in the selection of a minimum number of monitoring stations and their locations. It can be a useful tool either to start with a new air quality network or to prioritise site relocation in an existing monitoring network.

ACKNOWLEDGEMENTS

This work has been partially supported by Projects: UBACYT-X060, CONICET-PIP 6169. The authors wish to thank to the Argentine Meteorological Service for providing the meteorological data used in this study.

REFERENCES

Arya, S.P. *Introduction to Micrometeorology*. Academic Press Inc. San Diego, California, 303 pp (1988).

Bogo, H., R.M. Negri and E. San Román, "Continuous measurement of gaseous pollutants in Buenos Aires City," *Atmos. Environ.,* **33**, 2587-2598 (1999).

Bogo, H., D.R. Gómez, S.L. Reich, R.M. Negri and E. San Román, "Traffic pollution in a downtown site of Buenos Aires City," *Atmos. Environ.,* **35**, 1717-1727 (2001).

Bogo, H., M. Otero, P. Castro, M.J. Ozafrán, A. Kreimer, E.J. Calvo and R.M. Negri, "Study of atmospheric particulate matter in Buenos Aires city," *Atmos .Environ.,* **37**, 1135-1147 (2003).

Elsom, D.M. "Spatial correlation analysis of air pollution data in an urban area," *Atmos. Environ.,* **12**,1103-1107 (1978).

Elsom, D. M. "Spatial correlation analysis of air pollution data in an urban area-discussion," *Atmos. Environ.,* **13**, 421-423 (1979).

Gifford, F.A. *Atmospheric Diffusion in an Urban Area,* NOAA Research Lab*.,* **33**, 8pp. (1970).

Gifford, F.A. and S.R. Hanna, "Modelling urban air pollution. *Atmos. Environ.,* **7**, 131-136 (1973).

Gryning, S.E., A.A.M. Footslog, J.S. Irwin and B. Sivertsen, "Applied dispersion modelling based on meteorological scaling parameters," *Atmos. Environ.,* **21**, 79-89 (1987).

Handscombe, C.M. and D.M. Elsom, "Rationalisation of the national survey of air pollution monitoring network of the United Kingdom using spatial correlation analysis: a case-study of the greater London area," *Atmos. Environ.,* **16**, 1061-1070 (1982).

Husain, T. and S.M. Khan, "Air monitoring network design using Fisher's Information Measures - A case study," *Atmos. Environ.,* ***1***7, 2591-2598 (1983).

Mazzeo, N.A. and L.E. Venegas, "Air pollution model for an urban area," *Atmos. Res.,* **26**, 165-179 (1991).

Mazzeo, N.A. and L.E. Venegas, "Practical use of the ISCST3 model to select monitoring site locations for air pollution control," *Int. J. Environ. Poll.,* **14**, 246-259 (2000).

Mazzeo, N.A. and L.E. Venegas, "Estimation of cumulative frequency distribution for carbon monoxide concentration from wind-speed data in Buenos Aires (Argentina)," *Water, Air and Soil Poll.: Focus,* **2**, 419-432 (2002).

Mazzeo, N.A. and L.E. Venegas, "Carbon monoxide and nitrogen oxides emission inventory for Buenos Aires City (Argentina)", In: Sokhi RS, Brechler J, editors. *Fourth International Conference on Urban Air Quality – Measurement, Modelling and Management,* Prague, Czech Republic, 159-162 (2003).

Mazzeo, N.A. and L.E. Venegas, "Some aspects of air pollution in Buenos Aires City (Argentina)," *Intl. J. Environ. Poll.,* **22**, 4, 365-378 (2004).

Mazzeo, N.A., L.E. Venegas, and H. Choren, "Analysis of NO, NO_2, O_3 and NO_X concentrations measured at a green area of Buenos Aires city during wintertime," *Atmos. Environ.,***39**, 3055-3068 (2005).

Nakamori, Y., S. Ykeda and Y. Sawaragi, "Design of air pollutant monitoring system by spatial sample stratification," *Atmos. Environ.,* **13**, 97-103 (1979).

Noll, K.E., T.L. Miller, J.E. Norco and R.K. Raufer, "An objective air monitoring site selection methodology for large point sources," *Atmos. Environ.,* **11**, 1051-1059 (1977).

Noll, K.E. and S. Mitsutomi, "Design methodology for optimum dosage air monitoring site selection," *Atmos. Environ.,* **17**, 2583-2590 (1983).

Pasquill, F. and F.B. Smith, *Atmospheric Diffusion*. John Wiley & Sons, New York, (1983).

Shindo, J., K. Oi and Y. Matsumoto, "Considerations on air pollution monitoring network design in the light of spatio-temporal variations of data," *Atmos. Environ.,* **24B**, 335-342 (1990).

Seinfeld, J.H., "Optimal location of pollutant monitoring stations in an airshed," *Atmos. Environ.,* **6**, 847-858 (1972).

Tseng, C.C. and N-B. Chang, "Assessing relocation strategies of urban air quality monitoring stations by GA-based compromise programming," *Environ. Intl.,* **26**, 523-541 (2001).

USEPA, *User's Guide for Industrial Source Complex (ISC3) Dispersion Model, Vol.II: Description of Model Algorithms*, U.S. Environmental Protection Agency, EPA-454/B-95-003b (1995).

Venegas, L.E. and P.B. Martin, "Particulate Matter Concentrations in the City of Buenos Aires," *Proc.14th Congreso Argentino de Saneamiento y Medio Ambient,* AIDIS-Argentina. Buenos Aires, #20 (2004) (in Spanish).

Venegas, L.E. and N.A. Mazzeo, "Carbon monoxide concentrations in a street canyon at Buenos Aires City (Argentina)," *Environ. Mon. Assess.,* **65**, 417-424 (2000).

Venegas, L.E. and N.A. Mazzeo, "An evaluation of DAUMOD model in estimating urban background concentrations," *Water, Air & Soil Poll.: Focus* , **2**, 433-443 (2002).

Venegas, L.E. and N.A. Mazzeo, "Air quality in an area of Buenos Aires City (Argentina)," *Proc. III Congresso Interamericano de Qualidade do Ar,* Canoas, Brasil (2003a) (in Spanish).

Venegas, L.E. and N.A. Mazzeo, "Modelling of NO_X concentration in Buenos Aires City (Argentina)," *Proc. 13th Congreso Argentino de Saneamiento y Medio Ambiente.* AIDIS-Argentina. Buenos Aires, #18 (2003b) *(in Spanish).*

Venegas, L.E. and N.A. Mazzeo, "Design methodology for background air pollution monitoring site selection in an urban area," *Int. J. Environ. Poll.,* **20** (1-6) 185-195 (2003c).

Venegas, L.E. and N.A. Mazzeo, "Modelling of urban background pollution in Buenos Aires City (Argentina)," *Environ. Mod. & Soft.* (2005) (in press, available on line).

Wu, H.W.Y. and L.Y. Chan, "Comparative study of air quality surveillance networks in Hong Kong," *Atmos. Environ.,* **31**, 935-945 (1997).

Received: December 16, 2005.
Accepted for publication: July 19, 2006.
Recommended by Editor A. Bandoni.