Development of a Two Dimensions Street Canyon Model

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1 Introduction

Some of the most severe air pollution caused by automobile emissions may appear along a road surrounded by high buildings. This type of road configuration is called a “street canyon”. The street canyon dispersion models of inert pollutants published in bibliography use analytical or arithmetical equations in order to estimate the dispersion pattern. Such a model comprises of two independent submodels. In the first submodel the momentum and the continuity equations are arithmetically solved in order to estimate the wind field. In the second submodel the dispersion pattern in calculated either by numerical integration of the conservation equation for species concentrations (Lee and Park, 1994) or by using a Monte Carlo dispersion scheme (Okamoto et al., 1996).

For a completely and easy application of such a model a computer program was constructed connecting both the dispersion calculations and the required data input procedure. The interface was constructed in order to make the above model easy to use and applicable in several cases. This program can also be used by anybody caring for further evaluation of the model performance.

In this work the Street Canyon Model developed in the Laboratory of Atmospheric Physics is presented. Section 2 of this paper begins with a brief theoretical description of the model structure and the input data needed for its application. In section 3 follow some examples data and figures generated from the model application and the results discussion

2 The Model Structure

The Street Canyon Model consists of three independent parts: 1) A database, 2) A custom GIS application and 3) The computer models for road emissions and dispersion.

2.1 The Database

The database (MS Access 2000) stores all the necessary information about the road network and the traffic activity. There are 3 different entities of data: road, traffic activity and emissions. In the Road Data section the characteristics of the roads are stored like length, width, number of lanes, traffic capacity etc. In the Traffic Activity section there are hourly data available about the average speed and the number of vehicles (for PC, taxi, urban buses, coaches, trucks and motorcycles). For each road the total hourly emissions are calculated and stored in the corresponding table.

2.2 The Geographical Information System Application

The custom Geographical Information System application (MapInfo OLE under Visual Basic 6 Environment) presents in a visual and user-friendly way all the data that are related with the street canyon and leads to a better understating of the situation (average speed, number of vehicles, street canyon width etc). In addition the GIS system allows the user to input the required data for the dispersion procedure by selecting a road from the city map.

2.3 The Street Canyon Dispersion Submodel

The street canyon dispersion submodel of inert pollutant comprises of two steps. In the first step the wind field in every transverse slice is calculated using two approximable equations based on the approach of Hotchkiss and Harlow (1973). The observations show (Lee and Park, 1994) that a single vortex can be maintained within a canyon with an aspect ratio (ratio of building height h to street width d) of about 1.5 when the ambient winds aloft are greater than 2 m/sec. Taking into account this remark we compute the wind velocity field within the street canyon according to the algebraic equations proposed from Hotchkiss and Harlow (1973):

$$U(x,z) = U_0 \cdot (1-\beta)^{-1} \cdot \left[\gamma(1+ky) - \beta \frac{1-ky}{\gamma} \right] \cdot \sin(kx) \qquad (1)$$

and

$$W(x,z) = -U_0 ky (1-\beta)^{-1} \cdot \left[\gamma - \frac{\beta}{\gamma} \right] \cos(kx) \qquad (2)$$

where $k=\pi/\beta$, $\beta=exp(-2kh)$, $\gamma=exp(ky)$, $y=z-h$ and U_0 is the wind speed above the canyon at the point $x=d/2$, $z=h$.
The above representation of the wind field is very simple. But in spite of this simplicity their result are in good agreement with the measurements (Yamartino and Wiegand, 1986). The wind speed in the bottom of the canyon does affected only from the roof level wind. Vehicles movement and solar radiation cause further variation. Vehicles produce turbulence which order of magnitude is 1 m/sec (Qin and Kot, 1993). In order to include this phenomenon we modify the wind field increasing the wind speed near the bottom adding 0.8 m/sec on its component (horizontal and vertical) when the vehicle speed effect is height and 0.4 m/sec when the vehicle speed effect is low. It is considered that the vehicle effect is linear and vanishes near the height of about 12 m. Thus the wind field is corrected taking into account the vehicle movement influence on the wind velocity on the street canyon bottom.
In the second step the species concentrations in every grid point are computed using numerical integration of the conservation equation (Hunter et al., 1992; Sini et al., 1996):

$$\frac{\partial C}{\partial t} + U_j \frac{\partial C}{\partial x_j} = -\frac{\partial \overline{u_j c}}{\partial x_j} + S_i \qquad (3)$$

Where C denotes the mean concentration of the chemical species, x_j the distance in the j direction, $\overline{u_j c}$ the turbulent concentration flux and S_i the emission rate in cell i:

$$-\overline{u_j c} = K_c \frac{\partial C}{\partial x_j} \qquad (4)$$

K_c is the turbulent diffusivity coefficient, $Sc_t=\nu_t/K_c$ the Schmidt number, $\nu_t = C_\mu \frac{k^2}{\varepsilon}$, C_μ=0,09 empirical constant (Delaunay, 1996), k the turbulent kinetic energy and ε its rate of dissipation.
The initial and boundary condition that are used are: $C=C_b$ (background concentration), $\frac{\partial C}{\partial z}=0$ in the boundary area, $k=4\cdot10^{-2}U_\delta$ into the canyon $k=8\cdot10^{-2}U_\delta$, outside the canyon, $\varepsilon = \frac{C_\mu^{3/4} k^{3/2}}{0,4\cdot z}$, and U_δ=5 m s^{-1} (Delaunay, 1996).

The computation of the wind filed from the equations (1) and (2) restricts the application of the above model in cases where the wind direction is perpendicular to the street canyon axis.
As an alternative method for the calculation of the species concentrations we use the algebraic equations used also from Stein and Toselli (1996) and Zoumakis et al. (1994):

$$C_L = C_b + K_L \cdot M_S \sum_i^n \left(\frac{(U+U_0)^{-W(T)}}{(X^2+Z^2)^{1/2} + L_0} Q(N,S,T) \right) \quad (5)$$

$$C_W = C_b + K_W \cdot M_S \sum_i^n \left(\frac{(U+U_0)^{-W(T)}}{\frac{d}{1-Z/h}} Q(N,S,T) \right) \quad (6)$$

C_L and C_W are the species concentrations at the leeward and windward side respectively, $Q(N,S,T)=N \cdot E(S,T)$ denotes the emission strength in the street (g/(m•s), N is the traffic density (vehicle/hour), $E(S,T)$ is the species emission factor (*gr*/*Km*), S is the average vehicle speed (*Km*/*h*), T is the mean hourly air temperature (^oC), C_b is the background concentration above the canyon, K_L, K_W are dimensionless constants obtained from least-squares fit to measurement concentrations (in this study we take K_L=K_W=K=7), X and Z are the horizontal distance and the height (*m*) of the receptor relative to the center of the i traffic lane, n the number of the traffic lane, W=0,95082 (Zoumakis et al., 1994) and M_S is a dimensionless stability parameter (we set M_S =1).
C_L and C_W are the species concentrations at the leeward and windward side. In order to compute the concentration C_{in} for receptors far away from the leeward and windward side we use the following extrapolating equation:

$$C_{in} = \left(\frac{X}{d}\right) C_W + \left(1 - \frac{X}{d}\right) C_L \quad (7)$$

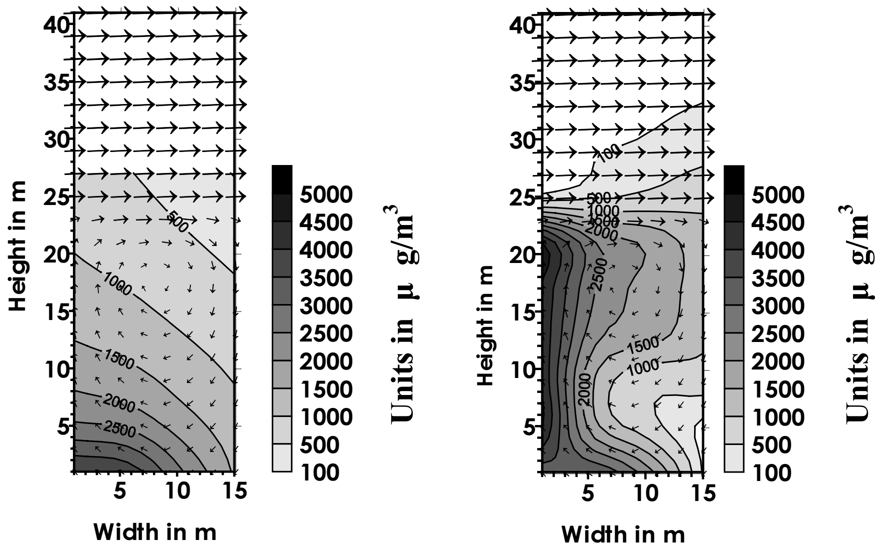
The emissions that are used as input to the model are calculated with the COPERT II methodology (Ahlvic et. al. 1997) taking into account the number of vehicles, the average velocity and the fleet composition. The results of the simulation are stored in the database connected with the GIS and the dispersions pattern is shown either in a textual or graphical mode, which is similar to the graphs presented in Figure 1.

3 Results and Discussion

In Table 1 the input data required for the model application are presented. These values correspond to a typical Street Canyon condition in Thessaloniki, Greece. Figure 1 shows *(a)* the calculated concentrations field with the alterative model (equations 5-7) and *(b)* the calculated concentrations field with the main model (equations 1-4) together with the computed wind field.
The results showing in Figure 1 are plotted directly from the computer program. This program has a visual interface that connect both the data input process and the output data proceeding.
The main model performs much better than the simple alterative approximation. The dispersion pattern is very similar to the real mode in a street canyon. This model allows also the investigation of the street canyon ventilation time. Simulations shown that the model performs quite satisfactorily for perpendicular wind flow as well as for small variations from the perpendicular flow.

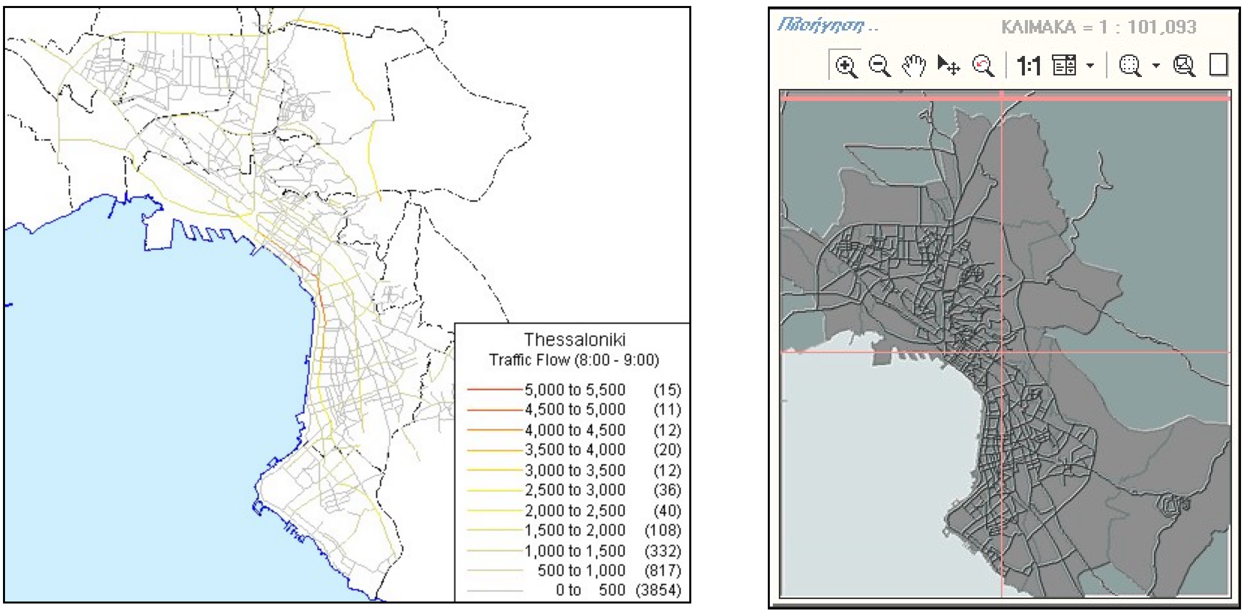
Table 1 Typical traffic condition for a Street Canyon in Thessaloniki Greece (V. Olgas avenue). These values are used as input data for the model application.

Wind direction (in degrees)	90	Vehicle speed in (m/sec)	30
Wind velocity (in m/s) on the roof level	5	Number of vehicle per hour	3077
Pavement width (in m)	2	Passenger cars	2079
Traffic lane number	4	Taxis	375
Height of the street canyon (in m)	26	Buses	86
Background concentration (in μg/m^3)	0	Trucks	332
Vehicle speed effect	High	Bikes	206



(a) (b)

Figure 1 Model output the typical traffic conditions presented in Table 1. This Figures present the calculated concentrations field with the alterative model (equations 5-7) *(a)* and the calculated concentrations field with the main model (equations 1-4) *(b)*, for CO concentrations. In the same figures the corresponding wind speed field is presented. It is calculated using equations (1) and (2).



(a) (b)

Figure 2 The custom GIS application of the Street Canyon Model. *(a)* Traffic flow data for the road network of Thessaloniki. *(b)* The map navigation window.

The model not treats any chemical transformation and so cannot be used for chemical reactive species. In spite of the simple wind representation of the model the computed concentration are in good agreement with the measurements. A parameter that can affect in a significant amount the model results is the background concentration. For better results we recommend to set the background concentration equal to their value 200 m above the building's top.
This model is connected to a wide database system of street canyons characteristics, which are presented through a GIS system (Figure 2), making their used very easy and efficient. The program can also be used by anybody caring for further evaluation of the model performance.

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