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MODELING OF CARBON MONOXIDE DISPERSION IN URBAN STREET CANYONS

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Summary. A dynamic grid-based numerical model and a simple microscale dispersion model (based on the physical principle of mass conservation) were used to predict the local effect of heavily travelled roads on CO-concentrations measured at nearby monitoring stations in the Athens and Thessaloniki basin.

Key Words: Dispersion model, micro-scale, street canyon.

Introduction

The main source of CO-emissions in the vicinity of Athens and Thessaloniki air pollution monitoring stations is the automobile. Since aerodynamic effects are important, the carbon monoxide concentrations at street level near the leeward sides of buildings are normally considerably higher than those near the windward sides[1],implying a helical cross-street circulation component near the surface in the opposite direction from the roof-level wind[2]. The direct result of the street canyon effect[3] is that the grid-models underestimate the CO-concentrations[4].

Application of the Urban Air Pollution Model

The mathematical basis for the urban air pollution model is the conservation of mass equation,

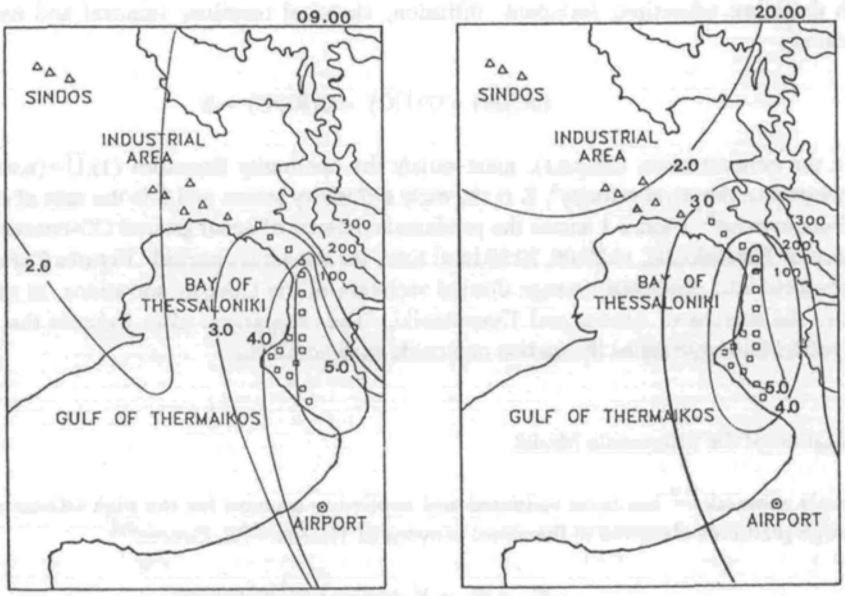

Figure 1 Predicted contours of equal ground-level CO concentrations (in ppm) at 09:00 and 20:00 local time for winter period, in the area of Thessaloniki. Residential and industrial areas are indicated by the symbols (□) and (Δ),respectively. Elevation in m.

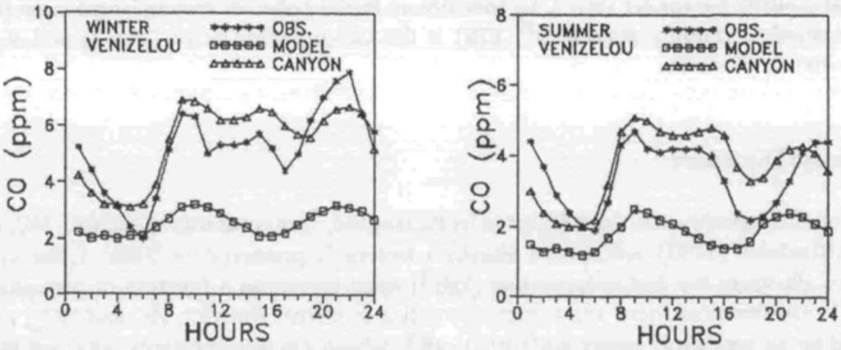

Figure 2 The observed and predicted average diurnal variation of the ground-level CO concentrations (in ppm), at Venizelou (Thessaloniki) monitoring station for winter and summer period.

which describes advection, turbulent diffusion, chemical reaction, removal and emissions of pollutants[5]:

$$(\partial C/\partial t) + \nabla(\overline{U}C) = \nabla(K\nabla C) + S \quad (1)$$

where the concentration $C(x,y,z,t)$, must satisfy the continuity Equation (1),$\overline{U}=(u,v,w)$ are the components of the wind velocity[4], K is the eddy diffusivity tensor and S is the rate of emission of CO from sources[6,7].Figure 1 shows the predicted contours of equal ground CO-concentrations in the area of Thessaloniki, at 09:00, 20:00,local time, for the winter period. Figures 2 and 3 present the observed and predicted average diurnal variation of the CO-concentrations, at several locations in the regions of Athens and Thessaloniki. The comparison plots indicate that the urban scale model underestimates the carbon monoxide concentrations.

Application of the Microscale Model

A simple submodel[1,8] has been validated and applied to account for the high CO-concentrations and large gradients observed in the street canyons of Thessaloniki, Greece[4,9]:

$$C_L = C_b + K_L M_S (u+u_0)^{-1} R^{-1} Q(N,S) \quad (2)$$

$$C_W = C_b + K_W M_S (u+u_0)^{-1} P^{-1} Q(N,S) \quad (3)$$

where $R=(x^2+z^2)^{0.5}+L_0$, $P=W[(h-z)/h]^{-1}$, $Q(N,S)=NE(S)$ is the emission strength ($gm^{-1}s^{-1}$) of the lane of traffic at distance x (horizontally) and z (vertically) from the receptor , C_L is the leeward side and C_W is the windward side concentration, C_b is the above-canyon background concentration, W is the width of the street , h is the buildings height, N is the traffic density (vehicles/hour), S is the average vehicle speed (Kmh^{-1}), u is the wind speed at rooftop and u_0 is a minimal dilution parameter (ms^{-1}), L_0 specifies an initial pollutant mixing length scale (m), M_S is a dimensionless stability parameter[9], E(S) is the CO-emission factor (gkm^{-1}) and K_L,K_W are dimensionless constants.

Results and Discussion

Based on the experimental work reported by Pattas et al.[10], an inventory of the CO, HC, NO_x, SO_x and particulates (TPM) automotive emission factors is presented in Table 1.The symbols in Figure 4 illustrate the fuel consumption (kgh^{-1}) when plotted as a function of the vehicle speed (kmh^{-1}) . On the other hand, the automotive emission factors (for CO, HC and NO_x) may be expressed by an empirical power law[4]: $E(S)=aS^{-b}$, where a,b, are constants obtained from least-squares fit to the test results. Figure 5(a) illustrates the observed[7] diurnal variation of CO as a function of height. Vertical CO-profiles are also given in Figure 5(b). The height variation of CO is seen to be well approximated by a simple exponential profile of the form: $C = C_0 \exp[-m(z/h)]$, where C_0 (ppm) and m (dimensionless parameter) are regression coefficients and z is the height. The corresponding value of m ranges from a minimum of 0.3 to a maximum of 1.9. Eventhough, both C_0 and m vary with wind direction the exponential regression provides a consistently good fit

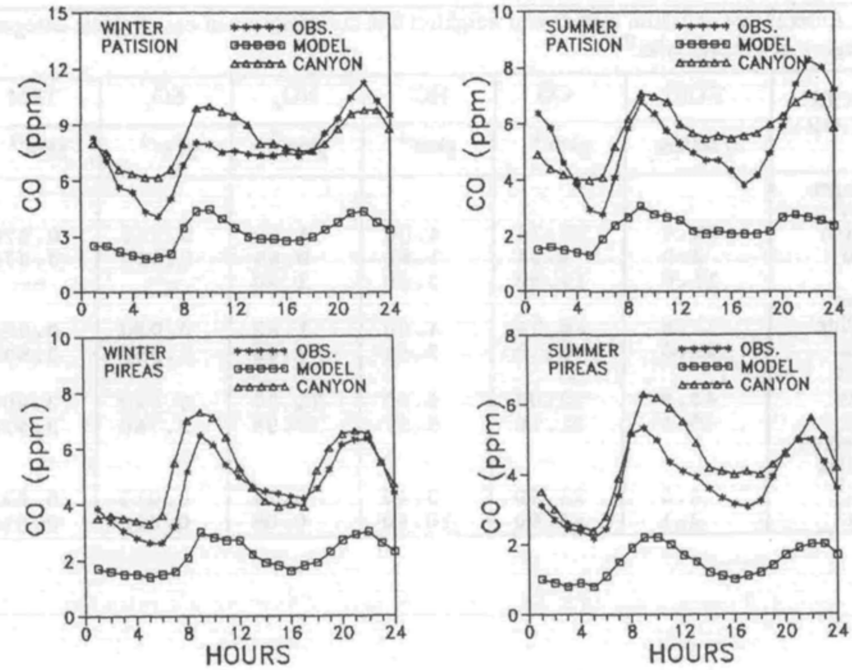

Figure 3 The observed and predicted average diurnal variation of the ground-level CO concentrations (in ppm), at Patision and Pireas (Athens) monitoring stations for winter and summer period.

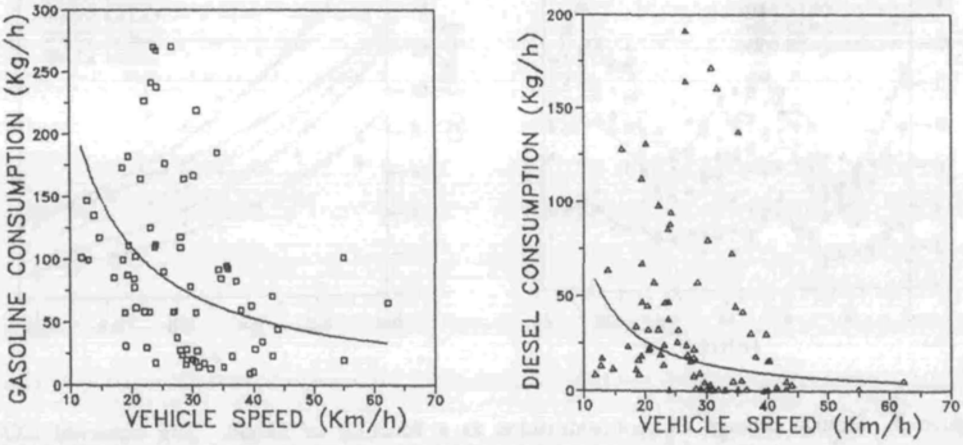

Figure 4 The fuel (gasoline and diesel) consumption (kgh^{-1}) as a function of the vehicle speed (kmh^{-1}). Data source Pattas et al.^{10}.

Table 1. Automotive emission factors and weighted fuel consumption of each vehicle category in the region of Thessaloniki[10].

VEHICLE CATEGORY	FUEL	CO	HC	NO_x	SO_x	TPM
	l/100km	gkm^{-1}	gkm^{-1}	gkm^{-1}	gkm^{-1}	gkm^{-1}
Passenger Cars						
Gasoline	11.4	45.76	4.00	1.62	0.030	0.070
Diesel	8.0	1.34	1.81	0.69	0.500	0.370
LPG	11.6	11.80	3.60	1.90	--	--
Vans						
Gasoline	11.4	45.76	4.00	1.62	0.030	0.070
Diesel	25.0	6.19	2.68	7.42	1.550	3.500
Buses						
Urban	48.9	23.00	6.05	11.30	3.020	3.200
Other	45.0	21.16	5.57	10.39	2.780	2.930
Two Weeled Vehicles						
$>50cm^3$	4.6	21.40	3.40	0.11	0.012	0.029
$<50cm^3$	2.1	14.00	10.40	0.05	0.005	0.014

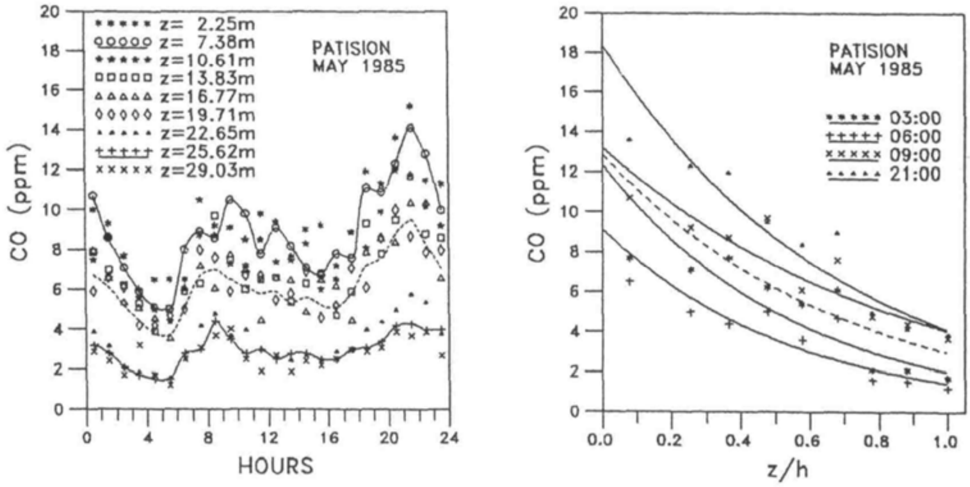

Figure 5 Hourly average CO-concentrations as a function of height. The observed CO-concentrations[7] are indicated by the small symbols and the regression curves by the solid lines (the dashed lines represent the street-canyon-average concentrations).

to the data[8].

Since carbon monoxide is emitted by automobiles, CO and traffic density (N) tend to have a similar pattern variation during the day (Figures 2 and 3). However, as mixing depth tends to increase during the late morning hours to midday period, the midday CO-peaks, often, are less (and less sharp) than CO-peaks during the morning and evening rush hours[9]. The plots indicate that the theoretical estimates for CO from the microscale model compares well with the data. The increased CO which were found in street canyons located in the Athens and Thessaloniki basin, mainly due to the poor maintenance quality of the vehicles (resulting in a significantly high CO-emission and in a high city fuel consumption) and to the complex influence of the urban landscapes morphology. In conclusion, the sub-grid scale model may be of considerable value in establishing a basis for formulating street-canyon air quality standards, when used in concert with the grid-based numerical model.

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