5.13 SIMPLE MODEL OF THE FLOW AND DISPERSION OVER URBAN AREA

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INTRODUCTION

There have been numerous investigations into atmospheric boundary layer carried out, but relatively few of them were carried out in urban areas in contrast to the fact that the most direct impacts of air pollution are felt in cities. The continuous increase of vehicular traffic within densely populated cities adds further pressure on a deteriorating urban air quality in many towns. Therefore, in recent years, boundary-layer meteorologists' attention has been directed towards problems of Roughness and Internal Sublayers – e.g. Rotach et al.(2001). Velocity and temperature profiles over urban areas above this layer are of interest to designers of structures, buildings in towns, meteorologists. This topic is still considered very complex. Only a few engineering or micrometeorological rules are general enough to be exported from one city to another. Obviously the horizontally homogeneous atmospheric boundary layer belongs to the simplest cases. This layer is a theoretical case of the atmospheric boundary layer (ABL) with conditions, which in reality are never satisfied simultaneously. A simple "universal" mean velocity defect for the core of the urban atmospheric boundary layer (UABL) has been introduced in the framework of COST 715 for indifferent stratification by the parameterisation on Kazanskii-Monin (1961) theory– see Bezpalcova et al. (2002). Deardorfs' (1972) parameterisation method is used in the paper to generalise this results.

URBAN ATMOSPHERIC BOUNDARY LAYER

The structure and dynamics of the UABL are similar to the mixed layers of rural terrain according to Oke (1995). They are more turbulent, warm, dry and polluted during the daytime and neutral or slightly stable during the night. The simplest model of the UABL consists in considering that the flow over an urban area is similar to the flow over a rough surface, with a given, large, roughness length z_0 and a defined surface heat flux. In this way we shall model the UABL as the mixed layer over a rough surface.

The equations of motion for an inviscid fluid in tangent-plane coordinates reduce to

$$f\left(U - U_g\right) = \frac{d\left(\frac{\tau_y}{\rho}\right)}{dz} \tag{1}$$

$$-f\left(V - V_g\right) = \frac{d\frac{\tau_x}{\rho}}{dz} \tag{2}$$

where U and V are components of mean velocity in the direction and perpendicular of the surface stress, respectively, U_g and V_g are the components of the geostrophic wind, τ_x, τ_y are components of the horizontal Reynolds stress and f is the Coriolis parameter. The boundary conditions at the lower boundary are

$$z = z_0 : \qquad U = V = 0, \qquad \tau_x = \tau_{x0}, \quad \tau_y = \tau_{y0} \tag{3}$$

and at the upper boundary

$$z = z_i: \qquad U = U_g, \quad V = V_g \qquad \tau_x = \tau_{y'} = 0 \tag{4}$$

where z_i is a mixed layer thickness. The Boussinesque assumption on eddy viscosity:

$$\tau_x = \rho \nu_t \frac{dU}{dz} \qquad \tau_y = \rho \nu_t \frac{dV}{dz} \tag{5}$$

and the assumption of a constant thermal wind:

$$U_g = U_{g0} + \left(\frac{dU_g}{dz}\right)_c (z - z_0) \qquad V_g = V_{g0} + \left(\frac{dV_g}{dz}\right)_c (z - z_0) \tag{6}$$

are introduced to close the system of equations.

Recognizing the importance of the actual boundary layer height, Deardorf (1972) suggested the use of the following dimensionless parameters for the mixed layer parameterisation

$$Z = \frac{z}{z_i}, \quad \mu^* = \frac{z_i}{L}, \quad \mu = \frac{z_i}{L_E} \tag{7}$$

where L is Monin-Obukhov length and $L_E = \kappa u^*/f$ is the height of the Ekman layer. Let us non-dimensionalize the variables by using the friction velocity u^* and the parameters (7) in the following manner:

$$U=\kappa\mu(U-U_g)/u^* \qquad V=\kappa\mu(V-V_g)/u^* \qquad X=\tau_x/(\rho u^{*2}) \qquad Y=\tau_y/(\rho u^{*2}) \qquad K=f/(\kappa^2 \mu^2 u^{*2})\nu_t \tag{8}$$

Then the system of equations of motion (1), (2) under the very idealized assumptions made here can transformed into following form:

$$\frac{d^2 X}{d Z^2} + \frac{Y}{K_m} - \lambda_x = 0 \tag{9}$$

$$\frac{d^2 Y}{d Z^2} - \frac{X}{K_m} + \lambda_y = 0 \tag{10}$$

where λ_x and λ_y are components of thermal wind. The boundary conditions (3) and (4) transform into

$$Z = Z_0 \qquad X \to 1, \quad Y \to 0 \tag{11}$$

$$Z = 1 \qquad X \to K(1)\lambda_x, \quad Y \to K(1)\lambda_y \tag{12}$$

where Z_0 denotes dimensionless roughness length.

The set of equations (9) – (10) and boundary conditions (11) – (12) depends on four internal parameters - λ_x, λ_y, , μ and μ* and similarly to Bezpalcova at al. (2002) the Rossby number similarity and the Blending height can be introduced. According to it the profiles X(Z, λ_x, λ_y, μ, μ*), Y(Z, λ_x, λ_y, μ, μ*), K_m(Z, λ_x, λ_y, μ, μ*) and velocity defect components $\kappa(U-U_{g0})/u^*$, $\kappa(V-V_{g0})/u^*$ are universal in the interval (Z_b ;1) where Z_b denotes dimensionless Blending height (≈0.1 for indifferent case – see Bezpalcova et al. (2002)).

COMPARISON WITH EXPERIMENT

There have been relatively few available experiments performed in urban areas to test the above-introduced results. For example: Jones et al. (1970) used a captive balloon to carry measurement instruments for wind and other meteorological magnitudes above Liverpool urban area. The boundary layer depth and the dependence of power-law index on stratification had been assessed. Dobbins (1976) selected data from low-level soundings over Cambridge, U. S. A. and determined the data on the basis of an "Ekman-like" variation of the wind vector with altitude. There are radio sounding impulses launched from the top of the Physics School building, Barcelona two times a day (Soriano (2001). Radio sounding is launched by INSTITUTO de METEOROLOGIA (Portugal hydro meteorological institute) in Lisbon, Èvora and Neves Corvo. Sodar measurements for wind (and concentrations) above city centre of Prague are performed for COST 715 project by LIDAR s. r. o., CR. The urban type small-scale flow and dispersion in the neutrally stratified urban atmospheric boundary layer 9 according to guidelines ASCE (1995) was simulated at a scale of 1:200 in wind tunnel - see Schatzmann et al. (2003).

Much information concerning the experimental data sets from in situ measurements is missing e. g. detailed topography, urban surface, upwind characteristics. Therefore only a qualitative comparison has been performed. Indifferent stratification (determined from mean velocity profile) has been taken into account for this reason. Examples of the dimensionless velocity defect profiles from Barcelona measurements are on Fig. 1 and compared with numerical nonpenetrative simulation (Bezpalcova et al. (2002) and physical modelling (Schatzmann at al. (2003). Results of simulation correspond to the measurements. A wind velocity defect inside the internal layer can be explained by an influence of the topography.

Perturbations influences have been searched to support the idea of the horizontally homogeneous urban atmospheric boundary layer. Emissions from a line source simulating the vehicular traffic were modelled by a continuous line source and concentration spread has been assessed inside the canopy layer. It has been demonstrated that the strong turbulent mixing causes rapid homogenisation of the mean concentrations across the flow in contrast to the slow decay of the mean concentrations along the flow (except near the source). The comparison of the dimensionless concentration K spread

$$K = \frac{U_{ref} H_{ref} C}{\frac{Q}{L}} \qquad (13)$$

within the canopy layer just behind the linen source and between the next roughness elements row are sketched on Fig. 2. Here are: L - characteristic length of the linen source, the reference velocity $U_{ref} = U(H_{ref})$, the characteristics height of the roughness elements H_{ref} and Q-pollutant flow rate.

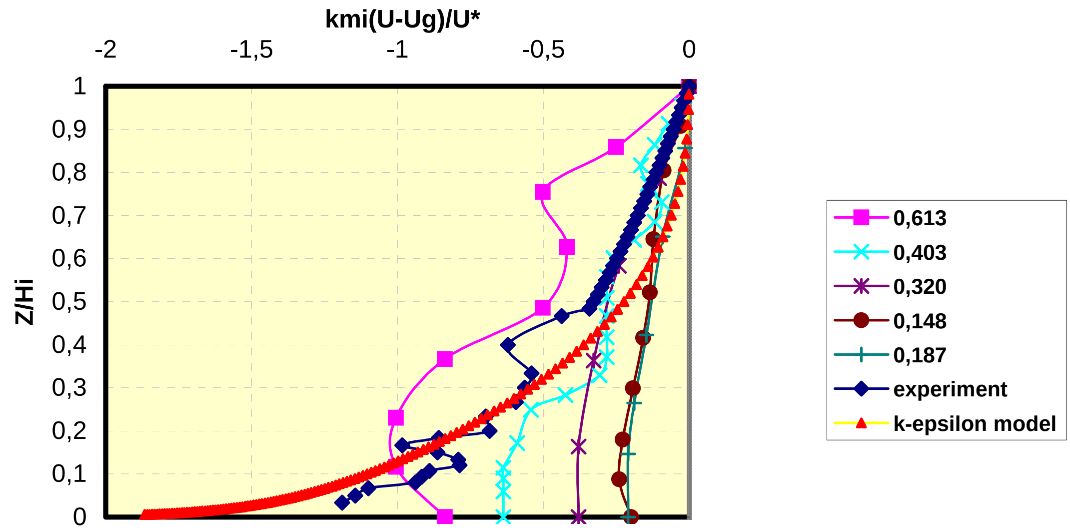
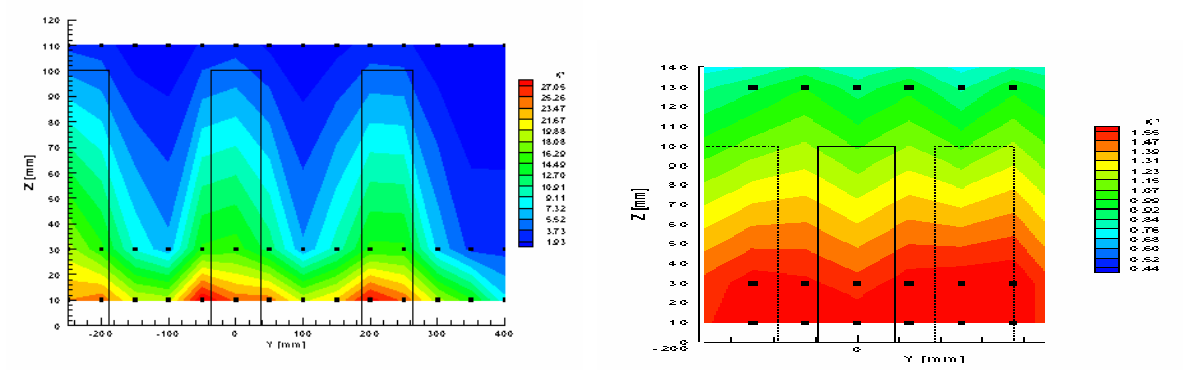


Figure 1. Comparison of velocity defect profiles inside the UABL simulations with radio sounding launched in Barcelona and wind tunnel experiment. (Number denotes the value of μ)



a) b)

Figure 2. Mean concentration spread within the canopy layer behind the linen source a) $x/S_x = 0{,}1$ b) $x/S_x = 1{,}1$ (Here S_x denotes roughness element spacing, x=0 for linen source and rectangles denote the roughness elements).

CONCLUSION

The horizontally homogeneous mixed layer over rough surface with a large, roughness length z_0 has been introduced to model the simplest cases of the UABL over flat plain. It is suggested that the height of the upper inversion layer z_i is more appropriate height scale for this case. Then the Rossby number similarity has been demonstrated for the core of the urban atmospheric boundary layer (UABL). It means that the profiles $X(Z, \lambda_x, \lambda_y, \mu, \mu^*)$, $Y(Z, \lambda_x, \lambda_y, \mu, \mu^*)$, $K_m(Z, \lambda_x, \lambda_y, \mu, \mu^*)$ and velocity defect components $\kappa(U-U_{g0})/u^*$, $\kappa(V-V_{g0})/u^*$ are universal and independent on surface characteristics for $Z > Z_B$. The Rossby number similarity cannot be used for non-dimensional components of the velocity. The qualitative comparison of the numerical simulation with in-situ experimental results and the physical simulation demonstrated reasonable agreement as for as above-mentioned universal profiles. Influence of roughness elements on homogenisation of the canopy layer was suggested to support the model assumptions.

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