ON THE PROBLEM OF ESTIMATION OF THE CRITICAL POLLUTION CHARACTERISTICS FROM LOW AND HIGH SOURCES IN PBL

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Abstract: It is suggested an approach for complex estimation of dynamical and pollutant characteristics around sources in planetary boundary layer (PBL). The cases of pollution are systematically classified in groups and it is separately analyzed the conditions causing maximal / critical pollution.

Key words: *turbulent regimes, modelling system, maximal and critical pollutant characteristics.*

1. INTRODUCTION

The turbulent diffusion is multi scaled process. When it is modeled a transport of pollutants at larger scales it is made a ruder numerical discretization and averaging of the pollutant characteristics. At smaller scales, for example near the source, at which it is located the maximal and critical (max of max) concentration, it is necessary to account in details the local factors. The present work is devoted to studying that problem

2. MODELLING SYSTEM

It is used a multiple component modeling system (MCMS) with structure presented on Table 1, which allows to explore the influence of wide range of turbulent regimes (taking into account the effects of roughness, stratification, baroclinicity, inversion, terrain slope, entrainment, long-lived and overcritical regimes in stable case) on dynamical and pollution PBL characteristics. MCMS is realized (depending on the available data and the research purposes) with groups of input nondimensional parameters in similarity format (Syrakov and Cholakov, 2006, Syrakov et al, 2007[a]): external PBL aerologic-synoptic, surface (on two levels) or mixed (in this case the relation between the previous two groups of parameters is given by the R_b-R_L method) parameters, and also the Pasquil-Turner stability classes. On this basis the method uses as meteo processors the parameterization schemes: R_b - surface Richardson bulk method (Syrakov 2005, Syrakov and Cholakov, 2005), R_L- resistance law method (Syrakov, 1990, 2005), R_b-R_L - combined method based on the joint and coordinated use of R_b and R_L (Syrakov, 1990, 2005, Syrakov and Cholakov, 2005). They ensure the realization of diagnostic or evolution PBL model (including and option for determination of the full diffusion K_{ij} tensor) Syrakov and Ganev (2003), Syrakov et al. (2007[a], 2007[b]) and four layer PBL model used in the case of anomal distribution of the meteo elements with height. On this basis it is realized: puff–MM model, which takes into account the well-known statistically-based construction, which divides the vertical c_{00} and horizontal c_{hor} diffusion (Syrakov and Ganev, 2004):

$$c(x,y,z,t)=c_{00}(z,t)c_{hor}\,,\quad c_{hor}=\frac{1}{2\pi\sigma_x\sigma_y}\exp\left(-\frac{(x-X)^2}{2\sigma_x^2}-\frac{(y-Y)^2}{2\sigma_y^2}\right), \qquad (1)$$

where Lagrangian cloud characteristics $X=c_{10}/c_{00}$, $Y=c_{01}/c_{00}$, $\sigma_x=\sqrt{c_{20}/c_{00}-X^2}$, $\sigma_y=\sqrt{c_{02}/c_{00}-Y^2}$ in (1) are calculated as numerical solution of the system of equations describing the moments c_{01}, c_{10}, c_{02}, c_{20} and the vertical diffusion component c_{00} (zero moment) is determined according to numerical decision of equation:

$$\frac{\partial c_{00}}{\partial t}+(w-w_0)\frac{\partial c_{00}}{\partial z}+\alpha c_{00}=\frac{\partial}{\partial z}k_z\frac{\partial c_{00}}{\partial z} \qquad (2)$$

or the plume–MM model is based on the following construction (Syrakov and Ganev, 2003):

$$c(x,y,z,t)=\frac{c_0(x,z,t)}{\sqrt{2\pi\sigma_y}}\exp\left(-\frac{(y-Y)^2}{2\sigma_y^2}\right), \qquad (3)$$

where the wind rotation effect is accounted by the mean displacement Y (along y). The parameters Y and the dispersion σ_y are calculated by the definition formulae:

$$Y(x,z,t)=c_1/c_0\,,\quad \sigma_y^2=c_2/c_0-Y^2\,, \qquad (4)$$

where the first and second moments $c_1(x,z,t)$ and $c_2(x,z,t)$ are calculated numerically on the basis of moment's method (MM), and zero moment c_0 is determined from the equation for linear source. It can be seen that the above diffusion models are based on splitting the diffusion to horizontal and vertical parts, and are coordinated with the statistical moment's method (MM), which allows determination of the trajectory–dispersion parameters in the process of decision of the problem, i.e. without to give them a priori. We will note that the presented models have medium position between the simple short distance Gaussian regulator model (plume–RM in Table 1, see Syrakov and Tsankov Critical, 2005, 2007) and the more complex 3D Eulerian models. The models can be used for modeling of the pollution at taking into account of wide range of turbulent regimes at local-meso scales. They correct a series of inaccuracies and limits of the Gaussian regulatory models.

3. RESULTS AND DISCUSSION

When it is explored the concrete diffusion processes, the practical realization of MCMS is presented with the scheme of Table 2 in accordance to which the pollutant characteristics depend mainly on the distance from the source and the three basic group of parameters M, PG and T. By using a variation principle (analytically for the simple and numerically for the more complex cases) it can be determined the maximal concentration C_m and the distance x_m at which it occurs and the respective critical parameters (max of max) C_{cr} and x_{cr}, which are of main interest. The made numerical experiments and estimations (because of the concise volume it is presented only several of them) show that in methodical aspect it have to delimit several type of tasks:

Approximate regulatory estimations

On Figure 1 it is presented the dependence of the quantity $\widetilde{U}_{10cr} = U_{10cr}/F$ (where U_{10cr} is the critical velocity at 10 m height, F is the technological parameter from the Brigg's formula for the equivalent height of the source) on the geometrical height of the source h_s for stability classes A-D. This is determined on the basis of the analytical solution of plume–RM model of Syrakov and Tsankov (2005, 2007).

Precise estimations at accounting the PBL turbulent regimes effects

In this case there is deviation from the regulatory estimations 1). As a concrete example it will be realized an diagnostic option of MCMS at which as input parameters it is used the external parameters in similarity format (the axis Ox is chosen along the surface geostrophic wind):

$$Ro, S, Ro_i, S_x, S_y, (or\, M, \Phi); \varphi, \psi \quad , \qquad (5)$$

where $Ro = G_0 / fz_0$, $Ro_i = G_0 / fH_i$, $S = \beta\delta\vartheta / G_0 f$ are the geostrophic and inversion Rosby number and the external stratification parameter, $\delta\vartheta$ - the temperature defect in PBL, H_i - inversion height.

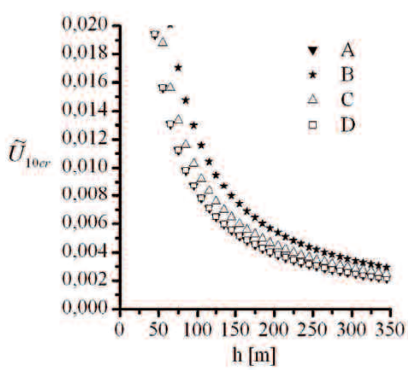

Figure 1. The dependence of the critical speed $\widetilde{U}_{10cr}$ on the source height h at different stability classes for rural region.

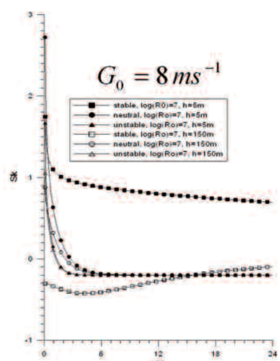

Figure 2. Plot of the vertical skewness Sk for stable (*S=500)*, neutral (*S=0*) and unstable (*S=-500*) stratification from surface source with height *h=5 m*.

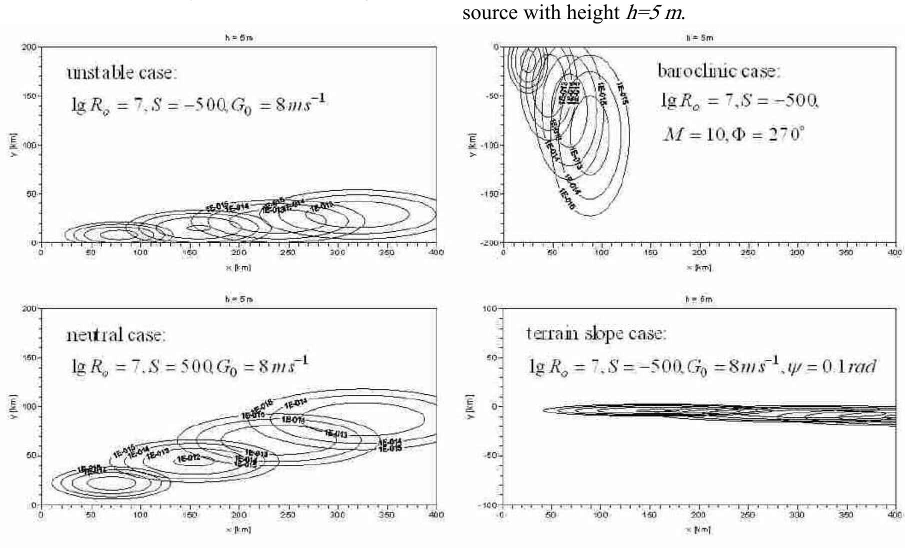

Figure 3. Isolines of surface cloud concentration *c(x,y,0,t)* in moments *t=3,6,9,12 h*, for different PBL turbulent regimes and *h=5 m* The isolines of the terrain slope case are the same as for the rest cases on the figure.

Table 1. Structure of MCMS

models	Structure			results
Input meteo (M) parameters	external	surface	mixed	Turbulent regimes characteristics
Parameterization methods	RL	Rb	Rb–RL	C_d, C_t, α, L etc.
PBL model options	PBL / diagnostic model			U, V, K_z, H_i etc
	PBL / evolution model			
	PBL / anomal situation model			
	K_{ij} – full tensor model			K_{ij} – full tensor component
Method of moments	With accounting of K_{ij}(i j) – full tensor With accounting of K_{ij}(i=j) – diagonal components			X, Y, Z σ_x, σ_y, σ_z Sk, Ku, etc.

Dispersion models	Puff–MM	Plume–MM	Plume–RM	Pollutant characteristics

Additional input parameters	Physical–Geographic (PG) parameters: roughness, slope and other terrain characteristics Technological (T) parameters: overheat, vertical ejection speed, power and etc.

Table 2. Schematic procedure for the realization of MCMS.

Input	M–parameters PG–parameters T–parameters	Dynamic models Diffusion models	Pollutant characteristics

$S_x = (\kappa^2 / f) du_g / dz$, $S_y = (\kappa^2 / f) dv_g / dz$ - external baroclinic parameters, which can be also introduced by the equivalent parameters $M = (S_x^2 + S_y^2)^{1/2}$, Φ - the angle between the surface geostrophic and the thermal wind, φ, ψ - the slope angles in x and y directions. On Figure 2 it is displayed the dependence of the cloud vertical skewness $Sk_z(t)$ at high ($h=150$ m) and low ($h=5$ m) sources at different stratifications in PBL. The biggest deviation from the Gaussian value 3 is at small times of diffusion and stable stratification. The sensitivity of the surface cloud concentration on the turbulent PBL regimes is demonstrated on Figure 3. It can be seen that the influence of turning of the wind in PBL (comparison of the barotropic cases to these of unstable and neutral stratification) is significant. The slope of the terrain causes a significant "channel" effect along the axis Ox of the slope. The influence of the baroclinic factor at the counted values of the parameters is particularly significant. Because of the limited space it will be given only one another example on Figure 4 where it is demonstrated the influence of the wind rotation effect on the plume surface concentration (at $z=0$, $y=0$) along the axis Ox. This effect is characterized with the parameter R, which is the ratio of the surface concentration along axe Ox of the plume-MM model (3) with accounting of rotation $Y \neq 0$ and without $Y=0$. The results show that the deviations from the regulatory estimations are significant.

Anomal conditions

These are comparable exceptional cases of anomal vertical distribution of the meteo elements. It is used PBL / anomal situation model from Table 1 with given profiles of the velocity and the temperature at four layers in PBL. The made numerical experiments in these cases show for example, that the biggest surface pollution from high

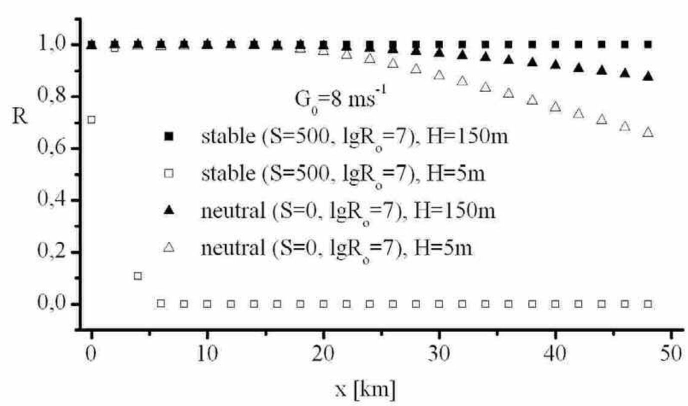

Figure 4. Dependence of wind rotation effect on the distance from the source x for plume surface concentration characterized by the dimensionless number $R(x)$, $R=1$ without rotation, $R \neq 1$ with rotation.

sources is at unstable stratification, weak surface wind (practically still conditions) and significant velocities 5÷9 ms^{-1} at the level of the source and of course in case of inversion at this level. At low sources the critical concentration is respectively at still conditions at the surface and surface inversion.

Evolution processes

The numerical experiment made with realization of the PBL evolution model show, that at nocturnal and late afternoon periods, the processes are quasi stationary and in the rest periods they are significantly nonstationary. The critical pollution parameters from high sources are observed in the morning (fumigation effect) and from low sources at nocturnal conditions in the second half of the period.

Special case of over critical Richardson number

As a special case it have to be separated the case of weak wind, strong stability and overcritical numbers of Richardson, when it is occured the biggest deviations of the model result from the experimental data for the pollution (see Luchar, 2007). Some estimation for that case are given in the work of Syrakov (2008) (see in the present Proceedings).

4. CONCLUSION

From general point of view the estimation of maximal / critical pollution parameters from sources in PBL is made by variation analyze about the input M, PG and T – parameters (Tab. 2). In first approximation, at idealized meteo conditions it can be used regulatory estimations from type a). The detailed exploration at variation of wide range turbulent regimes and conditions (for example cases b), c), d) and e)) gives principally significant deviations from the regulatory estimations. The considered method can be used for numerical monitoring of high and low sources in micro and meso scale as well as for sub grid parameterization (nesting procedure), when it is studied complex diffusion processes.

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