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ESTIMATION AND PARAMETERIZATION OF THE INFLUENCE OF SYNOPTIC CONDITIONS ON POLLUTION CHARACTERISTICS IN THE PBL

Evgeni Syrakov[1]*, Kostadin Ganev*[2]*, Milen Tsankov*[1]*, Emil Cholakov*[1]

[1]University of Sofia, Faculty of Physics, Sofia, Bulgaria
[2]National Insstitute of Geophysics, Geodesy and Geography, Bulgarian academy of Sciences, Sofia,Bulgaria

Abstract: An approach which includes joint use of resistance laws, PBL- and diffusion models, coordinated with the method of moments has been developed. The influence of a set of turbulent regimes, parameterizes by external parameters in similarity format, on diffusion processes in PBL has been studied on this basis.

Key words: *resistance laws, turbulent regimes, diffusion and statistical moments, inversion-slope-baroclynic effects.*

INTRODUCTION

The combination of external to the PBL aerologic-synoptic parameters, which are easy to obtain in prognostic/diagnostic aspect from synoptic maps, forms a wide range of turbulent regimes in PBL, which have a sound influence on the pollution characteristics. A qualitative categorization of this complex, mutually interacting processes have to be made, so that they could be studied in details and on this basis appropriate instruments for studying the processes have to be developed, which is the basic goal of the present work.

METHODOLOGY

The studies in the present work are based on methodological procedure, which includes several consecutive synchronized steps:

- The PBL resistance laws (RL-method) over flat terrain are applied:

$$\frac{\aleph\cos\alpha}{C_g} = \ln(R_0C_g) - A\,,\quad \frac{\aleph\sin\alpha}{C_g} = -B\,,\quad \alpha_0\frac{\aleph^2 S}{C_g\mu} = \ln(R_0C_g) - C \qquad (1)$$

and the respective more complex version of (1) over slope terrain (which due to the limited paper volume will not be shown here), where $C_g = U_*/G_0$ and $R_0 = G_0/fz_0$ are the gestrophic drag coefficient and the gestrophic Rossby number, $\aleph = 0{,}4$ is the von Karman constant, G_0 is the surface geostrophic wind, U_* is the friction velocity, α is the full cross isobaric angle, $\mu = (\aleph U_*/f)/L$ and $S = \beta\delta\theta/fG_0$ are inner and integral dimensionless PBL stratification parameters, L is the Monin-Obuchov length, A, B, C are universal functions. These functions are determined in sufficiently general form in (Syrakov, E., 1990, 2011) and on this basis a numerical solution of the system of transcendent equations (1) is obtained, giving the dependence of the basic transfer-interaction parameters C_g, α, μ on the dimensionless external parameters:

$$R_0\,;\ S\,;\ R_{0i}\,;\ S_x\,;\ S_y\,;\ (\text{or } M\,, \phi\,)\,;\psi\,;\ \mu_N\,, \qquad (2)$$

where $R_{0i} = G_0/fH_i$ is the inversion Rossby number, H_i is inversion height, $S_x = (\aleph^2/f)du_g/dz$ and $S_y = (\aleph^2/f)dv_g/dz$ are external dimensionless baroclinic parameters, which can be also expressed by the equivalent parameters $M = (S_x^2 + S_y^2)^{1/2}$ and ϕ - the angle between the surface geostrophic and thermal wind, ψ is the terrain slope angle, $\mu_N = N/f$ is the free-flow stability parameter, N is the free flow Brunt-Vaisala frequency, f is the Coriolis parameter.

- Coordinated with the so determined parameters C_g, α, μ, a PBL model (Syrakov, E. and Ganev, K., 2003, Syrakov et al, 2007)) is realized, taking into account the factors (2), and the velocity components u, v, the coefficients of vertical turbulent exchange k_z and $k_{z\vartheta}$ are determined.

- At these dynamic conditions a diffusion plume-MM model it is realized, based on the following construction (Syrakov, E. and Ganev, K., 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. The parameters Y and the dispersion σ_y are calculated by the definition formulae:

$$Y(x,z,t) = c_1/c_0\ ,\ \sigma_y^2 = c_2/c_0 - Y^2\ , \tag{4}$$

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. The respective puff-MM model for instantaneous point source is constructed in a similar way. These diffusion modelsare based on splitting the diffusion to horizontal and vertical parts, and are coordinated with the statistical moment's method, which allows determination of the trajectory–dispersion parameters in the process of solving the problem, i.e. without to give them a priori. The MM models are generalization of the conventional plume and puff models.

RESULTS AND DISCUSSION

A wide range of turbulent regimes, which have significant influence on the diffusion processes in PBL could be studied by varying parameters (2). A number of cases with $G_0 = 8m/s$ and $\mu_N = 0$, with parameters given in table 1 are chosen as examples.

Table 9. Basic PBL characteristics for the studied different turbulent regimes

PBL type	barothropic			baroclinic				inversions			terrain slope		
Case Input parameters	1	2	3	4	5	6	7	8	9	10	11	12	13
R_0	10^7	10^7	10^7	10^7	10^7	10^7	10^7	10^7	10^7	10^7	10^7	10^7	10^7
S	-500	0	500	-500	-500	-500	-500	-500	0	500	-500	0	500
R_{0i}	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1	400	400	400	~ 1	~ 1	~ 1
M	0	0	0	10	10	10	10	0	0	0	0	0	0
$\phi[^o]$	0	0	0	0	180	220	270	0	0	0	0	0	0
$\psi\,[rad]$	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0.1
H or H_i	1400	850	350	1600	1250	1300	1350	200	200	200	300	450	375

From the input parameters from Table 1, applying the above described methodology procedure, at first C_g, α, μ are obtained (some results for α are demonstrated in Figure 1) and consecutively then by the PBL the dynamic and by the plume-MM model (3), (4) the diffusion characteristics in PBL are obtained for cases 1-13, which will be considered in the present paper. The examples are for stationary point source with height $h_s = 150m$. The x axis is oriented along the wind at source height.

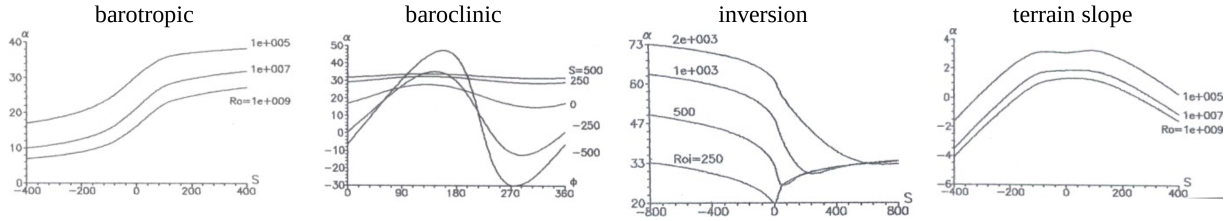
barotropic baroclinic inversion terrain slope

Figure 17. Dependence of full cross isobaric angle α .on the external dimensionless parameters (2) for different PBL types

A specific turbulent regime in the PBL corresponds to each set of external parameters (2). From the other hand parameters (2) for a given region can be determined from aerologo-synoptic parameters, taken from synoptic maps (in forecast/diagnostic mode) for each specific synoptic situation. This makes it possible the influence of different synoptic situations on the turbulent regime, hence on the basic pollution characteristics in the PBL to be studied by applying the methodology, described above.

These possibilities will be demonstrated by a chosen number of typical cases with input parameters (2) given in Table 1, which characterize basic PBL factors like baroclinicity, stratification, inversions and terrain slope effects. The pollution characteristics for cases 1 – 13 from Table 1will be analyzed at $\mu_N = 0$. The cases of free-flow stability effects $\mu_N > 0$ are considered in Syrakov et al (2011) – in the present proceedings. For all the considered cases the $0x$ axis is oriented along the wind at source height, which for all demonstrated experiments is $h_{source} = 150m$. The cases are divided and demonstrated in all the figures in two groups: unstable conditions ($S < 0$) - cases 1, 4-8, 11 and stable/neutral conditions ($S \geq 0$) - cases 2, 3, 9, 10, 12.

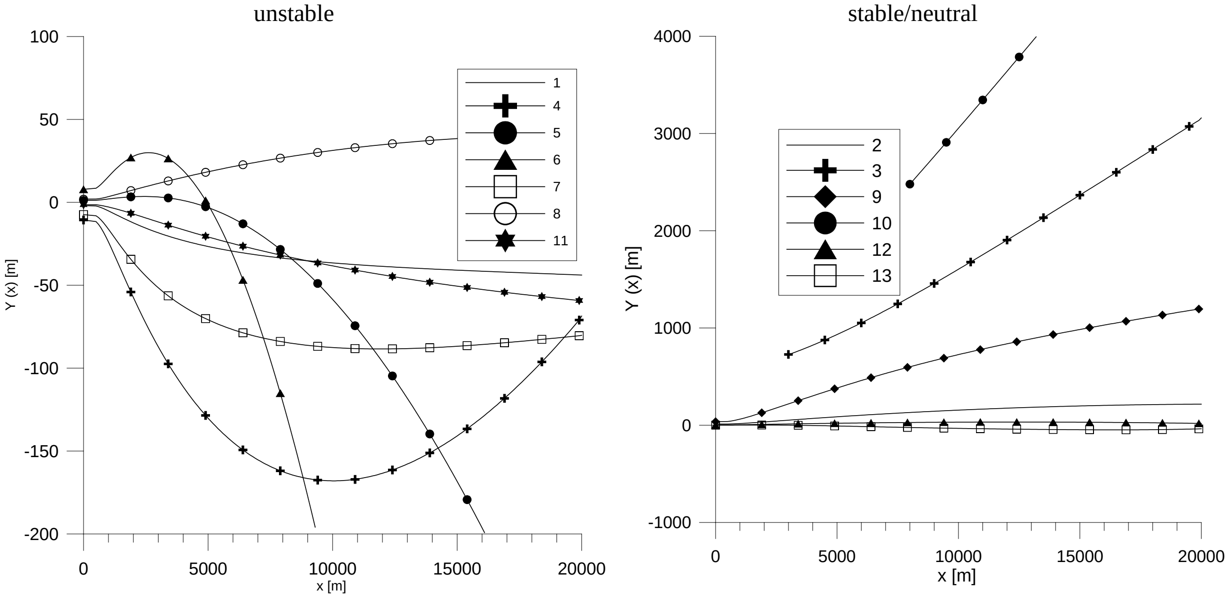

Figure 2. Surface horizontal displacement $Y(x)$ for turbulent regime cases 1 – 13: unstable cases 1,4,5,6,7,8,11 and stable/neutral cases 2,3,9,10,12,13, with input external parameters shown on Table 1

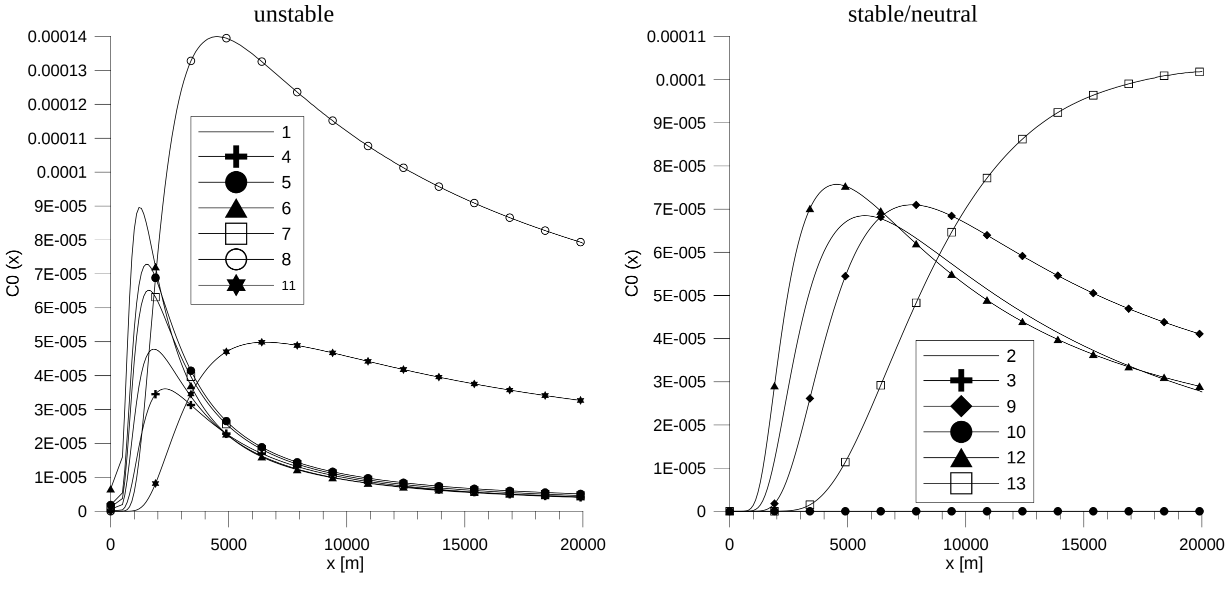

Figure 3. Surface concentrations along the plume axis for turbulent regime cases 1 – 13 with input external parameters shown on Table 1

The surface horizontal displacements $Y(x)$, which describe the plume axis rotation in respect to $0x$ axis are shown in Figure 2. The Rotation effect as a whole is better manifested for stable/neutral cases, which can be explained by bigger angle α and less intensive vertical exchange. It should be noted that in the terrain slope cases 11-13 for all stratifications the dynamic channelling slope effect dominates, which does not allow big displacements $Y(x)$. The $Y(x)$ behaviour for baroclinic cases 4-7 is also interesting. For the ϕ angles, chosen for these cases, the thermal wind opposes the geostrophyc, which leads to a decrease of the wind speed gradient. Combined with the significant turbulent exchange ($S = -500$) this leads to a relatively small right-hand rotation of the plume axis. For all the other cases, as can be seen from Figure 2, the displacement of the plume axis is to the left of $0x$ axis, qualitatively corresponding to the Eckmans spiral. Obviously the $Y(x)$ behaviour is formed by a complex balance of the joint effects of different factors. The same is valid for all the other pollution characteristics.

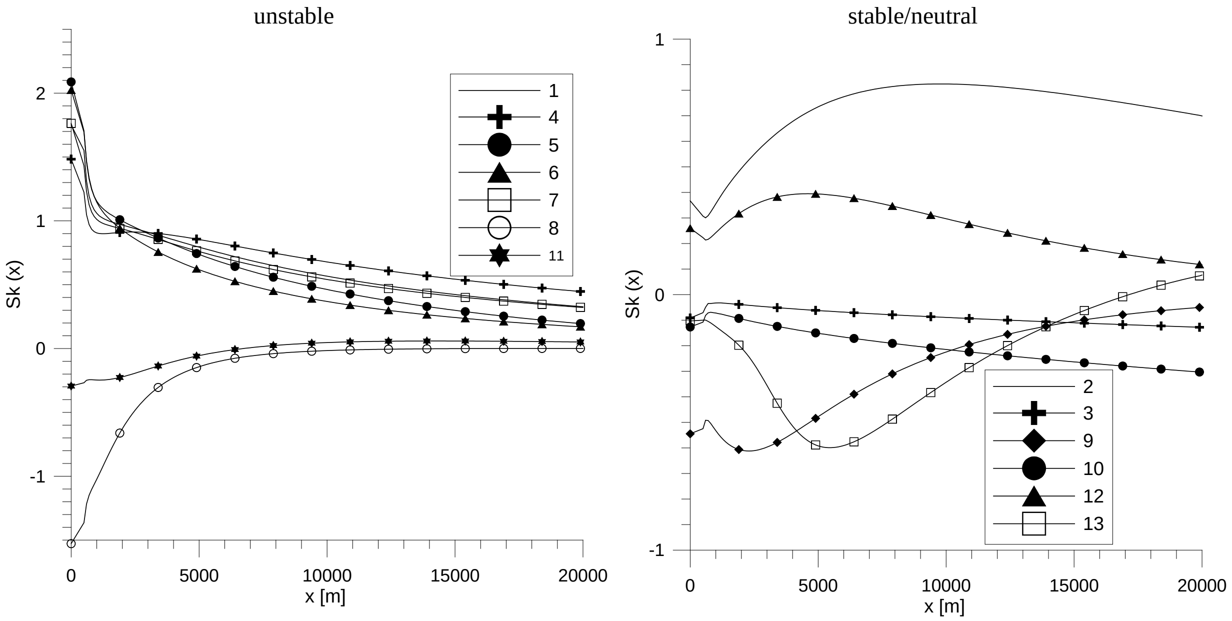

Figure 4. Skewness $Sk(x)$ for turbulent regime cases 1 – 13 with input external parameters shown on Table 1

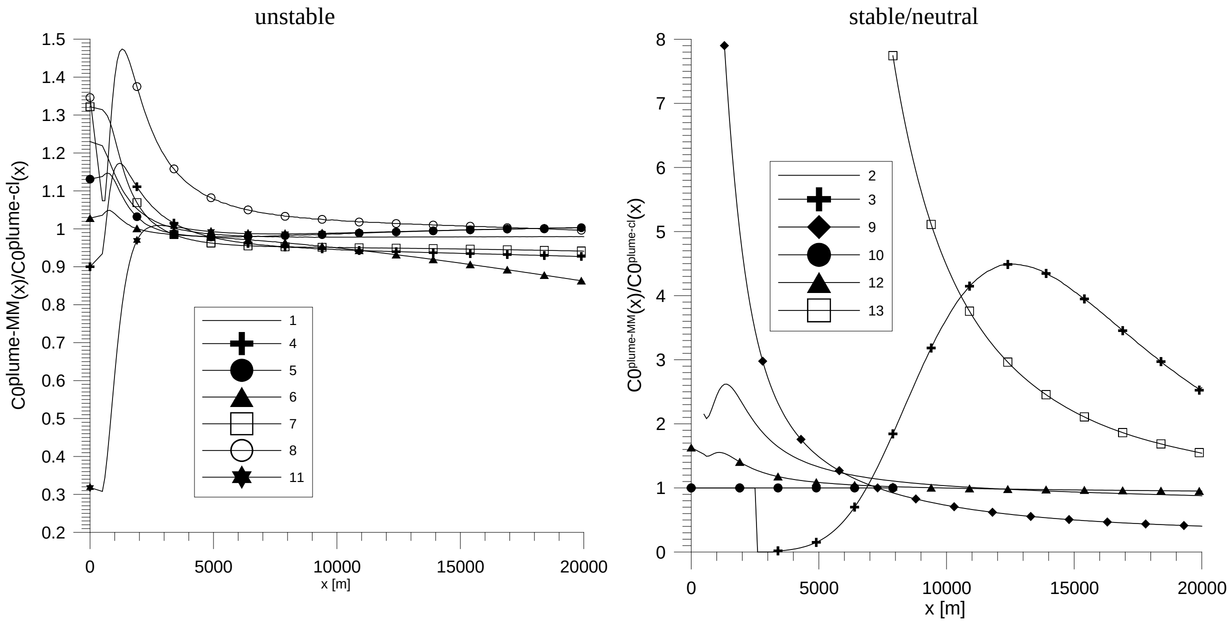

Figure 5. Ratios $c_0^{plume-MM}(x)/c_0^{plume-cl}(x)$ for turbulent regime cases 1 – 13 with input external parameters shown on Table 1

The normalised surface concentrations along the surface plume axis for cases 1 – 13 are shown in Figure 3. At unstable conditions the biggest concentration occurs for the inversion case 8 and for stable/neutral conditions – for the terrain slope stable case 13. The maximal surface concentrations for stable/neutral conditions are significantly further from the source than the unstable cases.

The vertical skewness $Sk(x)$ is shown in Figure 4. The difference from Gausian vertical concentration distribution ($Sk(x)\neq 0$) is best manifested at distances 4-5000 m from the source. Maximal deviations can be observed for cases 5, 8 and 2.

The ratios $c_0^{plume-MM}(x)/c_0^{plume-cl}(x)$, where the surface plume concentration along the axis $c_0^{plume-cl}(x)$ is again simulated by the plume-MM model, but with $Y(x)=0$ and constant with height wind speed, equal to the wind speed at source level are shown in Figure in order the relatively independent influence of the wind rotation to be demonstrated. As it can be seen, the effects are strongest for cases 9, 3, 13.

CONCLUSIONS

The obtained results demonstrate the significant influence of the turbulent regimes (and the respective synoptic situations) on the diffusion processes in the PBL. The suggested methodology makes it possible the detailed study of the influence of wind sheer and rotation, roughness, stratification, inversions, baroclinicity, terrain slope etc., in a similarity format, on the basic pollution characteristics – trajectories, dispersions, concentration and concentration field shape – skewness, kurtosis, etc. The approach can be used for applied tasks including estimation of extreme and critical pollution parameters, regulatory procedures and optimization, sub-grid parameterization procedures, etc.

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