ON THE PARAMETERIZATION OF DIFFERENT STABLE TURBULENT REGIMES IN PBL DIFFUSION PROCESSES

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Abstract: On the basis of practical orientated complex parameterization method it is determined basic characteristics in several types of stable turbulent regimes: nocturnal, long-lived and at over critical Richardson numbers. In particular the result can be used for differential studying of the diffusion processes in PBL depending on the type of SL-PBL stable conditions.

Key words: *parameterization, drag coefficient,nocturnal, long-lived, overcritical stable regimes*

1. INTRODUCTION

Recently it became clear that it can be distinguished several types of stable boundary layers (SBL), depending on the structure and the particularities of the turbulent regimes:
(a) Conventional nocturnal (short-lived) SBL in the middle latitudes, which is described by the Monin-Obuchov similarity theory.
(b) Long-lived SBL (in the high latitudes) and neutral BL too, influenced by the free-flow stability.
(c) very stable and weak intermittent turbulence regime at over critical numbers of Richardson (no critical Richardson concept).
The parameterization of these PBL regimes is the subject of the present work.

Parameterization method

According to the Monin-Obuchov similarity theory the following relations can be written:

$$\frac{du}{dz} = \frac{u_*}{\aleph z}\varphi_u(\xi), \; \frac{d\theta}{dz} = \frac{\theta_*}{\aleph_T z}\varphi_\theta(\xi), \qquad (1)$$

where u_* is dynamical velocity, $\theta_* = -q/u_*$ is scale for potential temperature, q is kinematics surface heat flow, $\aleph_\theta \approx \aleph = 0.4$ is constant of von Karman, $\xi = z/L$, $L = -u_*^3/\aleph\beta q$ is Monin-Obuchov length. Other important turbulent characteristics are the turbulent Prandtl's number P_{rt} and bulk Richardson number R_b

$$P_{rt} = \frac{\varphi_\theta}{\varphi_u}, \; R_b = \frac{\beta\Delta\theta}{u_1^2} z_1, \qquad (2)$$

where β is buoyancy parameter, $\Delta\theta = \theta_1 - \theta_0$, $u_1 = u(z = z_1)$, $\theta_1 = \theta(z = z_1)$, θ_0 is the aerodynamic surface potential temperature, z_1 is given level above the surface. In the conventional case (a), the universal functions are:

$$\varphi_u(\xi) = 1 + B_u\xi, \; \varphi_\theta(\xi) = 1 + B_\theta\xi, \qquad (3)$$

where B_u, B_θ are empirical constants. According to (1), (3) the numbers P_{rt} and R_b monotonously increase with increasing ξ and at $\xi \to \infty$ take their maximal limit values:

$$P_{rtm} = \frac{B_\theta}{B_u}, \; R_{bm} = R_{bcr} = B_\theta / B_u^2, \qquad (4)$$

where R_{bcr} is critical bulk Richardson number. We will note that according to (4) in case (a) the turbulence cuts off at $R_b > R_{bcr}$ and the values of R_b are in the range $0 \le R_b \le R_{bcr}$.

In case (b) after taking into account the effect of the static stability in the free atmosphere on the surface layer, $\varphi_u(\xi)$ and $\varphi_\theta(\xi)$ modify into the following expressions (Zilitinkevich and Essau, 2005):

$$\varphi_u(\xi) = 1 + \widetilde{B}_u\xi, \; \widetilde{B}_u = B_u(1 + C_{IM}^2 F_i^2)^{1/2}; \; \varphi_\theta(\xi) = 1 + \widetilde{B}_\theta\xi, \; \widetilde{B}_\theta = B_\theta(1 + C_{IH}^2 F_i^2), \qquad (5)$$

where $F_i = \aleph L I / u_* = sF_{i0}$ is dimensionless parameter, taking values in the range $0 \le F_i < 1$, $s = \aleph L / z_1$, $F_{i0} = I z_1 / u_*$, N is typical gradient of the potential temperature in the free atmosphere, C_{IM}, C_{IH} are new empirical constants. In this case the critical Richardson number (4) is substituted with the following expression (Syrakov, 2005):

$$R_{bcr}^{*}=R_{bcr}\phi\ ,\ \phi=\frac{\left(1+C_{IH}^{2}\ F_{i0}^{2}A^{-2}\right)^{1/2}}{1+C_{IM}^{2}\ F_{i0}^{2}A^{-2}}\ ,\ A=\frac{1}{B_u}\left(1-C_{IH}^{2}\ B_u^{2}F_{i0}^{2}\right)^{1/2}\ . \tag{6}$$

Since $\phi>1$ then $R_{bcr}^{*}>R_{bcr}$, which leads to larger range of values of R_b and increase of the critical Richardson number (Fig. 1).

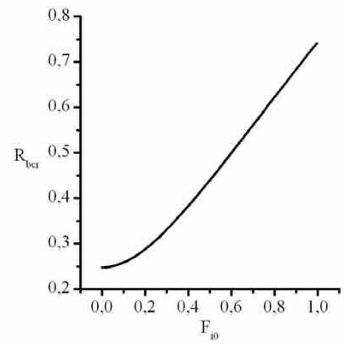

Figure 1. Dependence of the critical bulk Richardson number R_{bcr} on the free flow stability parameter F_{i0}

Experimental and LES data show, that at stable stratification turbulence can exists and at big over critical numbers R_b of order ~ 10 (case (c)). At such conditions it appears to be that the parameters (2) are increasing function of ξ. This means that the asymptotic ξ–dependence of φ_θ should be stronger than linear, e.g. quadratic (Zilitinkevich and Essau, 2007). Here we will use the following expression for φ_θ :

$$\varphi_\theta=1+B_{\theta 1}\xi+B_{\theta 2}\xi^2\ , \tag{7}$$

$B_{\theta 1}=B'_\theta\left(1+C_{IH}^{2}\ F_i^{2}\right)^{1/2}$, $B_{\theta 2}=B''_\theta\left(1+C_{IH}^{2}\ F_i^{2}\right)$, B'_θ and B''_θ are empirical constants.

After taking into account the corresponding universal functions φ_u,φ_θ and the specific particularities of the turbulent regimes (a), (b) and (c), for their parameterization it is used, developed in Syrakov, (1990, 2005) and Syrakov and Cholakov, (2005), practically orientated method including several mutual connected parameterization schemes: bulk Richardson (R_b –method), PBL resistance laws (RL–method) and combined (R_b –RL method), which is based on their joint and coordinated use.

2. RESULT AND DISCUSSION

Let's now go to the determination of basic turbulent characteristics of the listed above stable regimes. The following values of the constants are used at the realization of the parameterization methods: $B_u=5$, $B_\theta=6{,}25$ (at these values according to (4) $R_{bcr}=0.25$; $B'_\theta=5.5$, $B''_\theta=1.25$ (at these values there is a good coincidence of P_{rt} and R_i with the experimental data), $C_{IM}=0.06$, $C_{IH}=0.6$ (according to Zilitinkevich and Essau, 2005). For the reference height is chosen $z_1=10\,m$. First we will consider the drag coefficient $C_d^{1/2}=u_*/u_1$ and the heat transfer coefficient $C_t=\theta_*/\Delta\theta$. We will note that the number of Dalton C_H can be expressed by these two coefficient in the view $C_H=C_d^{1/2}C_t$. All of these coefficients taking into account (5), (6) depend on the dimensionless parameters:

$$\lambda_u\ ,\ \lambda_\theta\ ,\ R_b\ ,\ F_{i0}\ , \tag{8}$$

where $\lambda_u=\ln z/z_0$, $\lambda_\theta=\ln z/z_{0T}$, z_0 and z_{0T} are the respective aerodynamic and temperature roughness. The determined by the R_b –method, dependence of $C_d^{1/2}$ and C_t on R_b is shown on Figure 2. The results from Figure 2 at ($R_b=0$, $F_{i0}=0$) correspond to truly neutral regime, at ($R_b<0$, $F_{i0}=0$) to stable nocturnal, at ($R_b=0$, $F_{i0}>0$) to conventional neutral and at ($R_b>0$, $F_{i0}>0$) to long-lived stable.

The R_b –RL method allows determining a series of basic relations between SL–PBL parameters, for example:

$$f_u=\frac{u_{g0}}{u_1}\ ,\ f_v=\frac{v_{g0}}{u_1}\ ,\ f_g=\frac{G_0}{u_1}\ ,\ f_\theta=\frac{\delta\theta}{\Delta\theta}\ ,\ \alpha\ ,\ G_0(S)\ ,\ S(R_b)\ \text{and etc.,}$$

where $G_0 = (u_{g0}^2 + v_{g0}^2)^{1/2}$ is module of the geostrophic wind, $\delta\theta = \theta_H - \theta_0$ is the difference of the potential temperature in PBL, $S = \beta\delta\theta / fG_0$ is external integral parameter of the stratification in PBL, α is the angle of full turning of the wind in PBL. For example on Figure 3 it is shown the parameters f_g and α. It can be seen that the accounting of the non-local effects $F_{i0} \neq 0$ leads to increasing of the critical Richardson number. In this case the different regimes can be classified analogically as on Figure 2. At the parameterization of stable regime (c) have to be taken into account (7) which leads to respective corrections in the parameterization schemes. The respective to Figures 2 and 3 results for stable regime (c) at $F_{i0} = 0$ are shown on Figures 4 and 5.

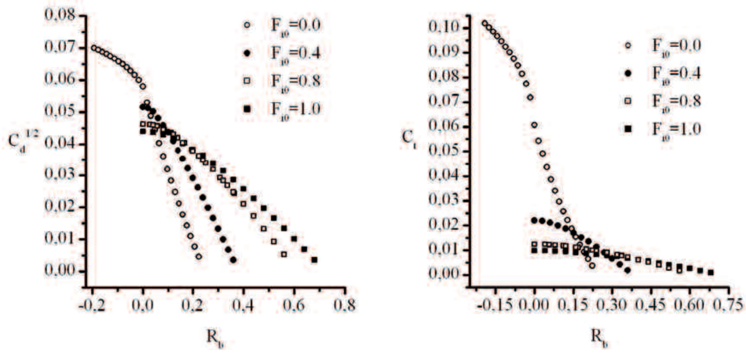

Figure 2. Dependence of the drag coefficient $C_d^{1/2}$ and heat transfer C_t on R_b at different values of F_{i0} and at $\lambda_u = \lambda_\theta = 7$.

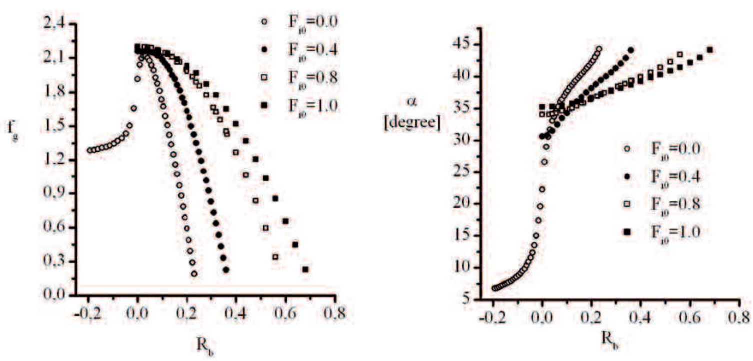

Figure 3. Dependence of $f_g = G_0/u_1$ and angle α on R_b at different values of F_{i0} and $\lambda_u = \lambda_\theta = 7$, $u_1/fz_0 = 3.10^6$.

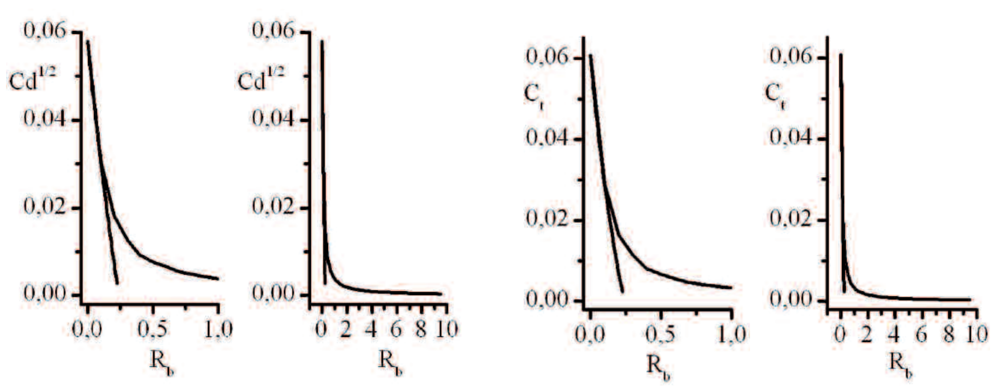

Figure 4. Comparison of the results for $C_d^{1/2}$ and C_t for conventional stable regime (a) (the curve at $R_b < R_{bcr} = 0.25$ and stable regime at overcritical Richardson numbers (c) (the curve at overcritical . $R_b > R_{bcr} = 0.25$.

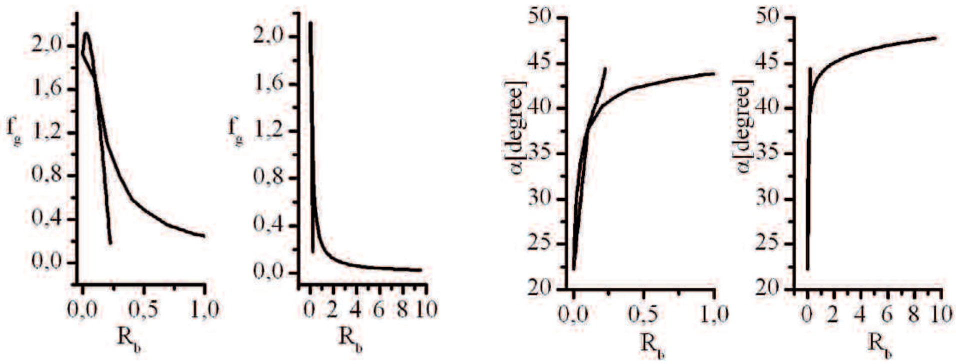

Figure 5. Comparison of the results for $f_g = G_0/u_1$ and angle α for conventional stable regime (a) (the curve at $R_b < R_{bcr} = 0.25$ and stable regime at overcritical Richardson numbers (c) (the curve at overcritical . $R_b > R_{bcr} = 0.25$.

The respective results are shown in two ranges of variations of R_b at $R_b \le 1$ and R_b from 0 to 10. On the figures it is shown comparison between traditional turbulent regime (a) at which $R_b < R_{bcr}$ and the intermittent, with overcritical Richardson numbers, turbulent regime (c), which is valid only for big values of R_b (for example $R_b > 1 \div 2$). In the intermediate range of R_b a transitional regime between the above two is realized. On Figure 4 we can see the behavior of the coefficients $C_d^{1/2}$ and C_t at overcritical numbers R_b. They are decreasing functions of R_b, which is due to the sporadic and gradually decreasing (with increasing of R_b) turbulence in this case. Besides we have to add and the fact that the wind is very weak (practically still). Obviously the description of the diffusion processes meats significant difficulties (see Luchar, A. 2007).

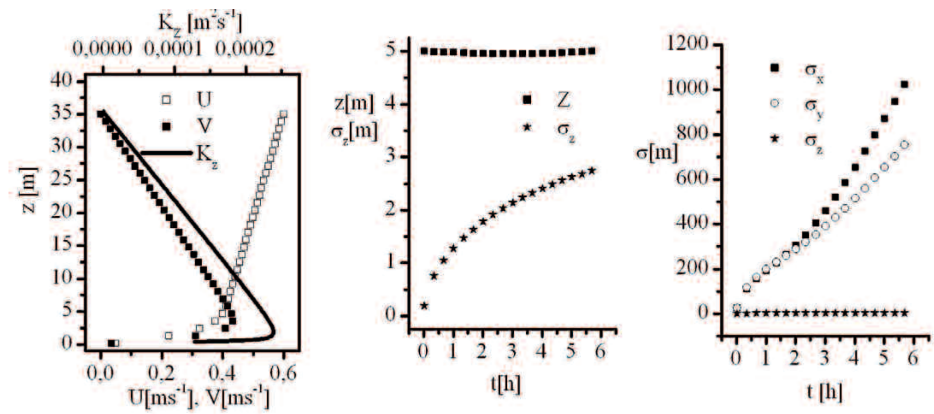

Figure 6. Turbulent PBL characteristics u , v , K_z , dispersions σ_x , σ_y , σ_z and vertical Lagrangian coordinate Z for height source $h_s = 5\,m$ for stable PBL regime at overcritical Richardson numbers (c) at $R_b = 5$, $u_{10} = 0.5\ ms^{-1}$, $z_0 = 0.01\,m$.

On Figure 6 it is presented some PBL and respective instantaneous cloud characteristics in the case of stable regime (c) obtained at the following input parameters: $R_b = 5$, $u_{10} = 0.5\ ms^{-1}$, $z_0 = 0.01\,m$, height source $h_s = 5\,m$. It can be seen that at such conditions, the cloud centre remains during the whole period at height $z = h_s = 5\,m$, the vertical dispersion is strongly limited, while at the same time $\sigma_x >> \sigma_z$ and $\sigma_y >> \sigma_z$ (the cloud has quasi two dimensional form), which corresponds to very strong anisotropy for that regime. The vertical coefficient of turbulent exchange k_z is very small and the vertical exchange processes are minimal, which creates conditions for big localized pollution.

3. CONCLUSION

The obtained results show that the turbulent characteristics vary in wide ranges depending on the type of SL-PBL stable regimes. This imposes a differential approach when it is studied dynamical and diffusion processes at these conditions. The developed in the work approach allows this to be done in the range of practically orientated similarity format.

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