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RELATIONSHIPS AND CO-ORDINATION BETWEEN BASIC BL AND PBL TURBULENT AND STABILITY PARAMETERS USED IN POLLUTION TASKS

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Abstract: Hybrid (RL-RL)-method is used based on joint and coordinated combination of surface bulk-Richardson method and PBL resistance law. In this paper we determine and analyze a series of relationships between BL, PBL and free-flow stability parameters and stability classes.

Key words: bulk Richardson number, resistance law, stability classes, BL-PBL relationships.

INTRODUCTION

In studying the processes of pollution in PBL the surface (gradient based) or external PBL (based on aerolo-g-synoptic) meteo data is most often used. In the first case bulk Richardson number (\( \mathcal{R}_b \)) is used as a parameterization scheme and in the second – PBL resistance laws (RL – method). A new third important task has arisen with great practical significance – finding a simple relation between basic BL-PBL-free flow and other parameters at different meteorological conditions and their applications to some diffusion tasks. This is the aim of the present work.

METHOD

A wide range of PBL-turbulent regimes is considered, characterized by the following different groups of dimensionless parameters.

- external PBL aerologic–synoptic:
  \[ \mathcal{R}_b, \mathcal{S}, \mathcal{R}_u, \mathcal{A}_1, \mathcal{A}_2; \psi, X_\gamma, Y_\gamma, H_\gamma; \mu_u, \phi_u, \]

- surface (standard + non-local) \( \mathcal{R}_s \) - bulk parameters:
  \[ \mathcal{R}_s, \lambda_s = \ln \frac{z_s}{z_{u_0}}, \quad \lambda_s = \ln \frac{z_s}{z_{\eta_0}}; F_\phi, \]

and also the relatively subjective but often used Pasquill–Turner stability parameters:
\[ A, B, C, D, E, F, \]

where \( \mathcal{R}_b = G_u/f_{z_0} \) and \( \mathcal{R}_u = G_u/f_h \) are geostrophic and inversion Rosby number, \( h \) – diagnostic or prognostic (actual or inversion) height of PBL, \( \mathcal{S} = \beta \Delta \theta_{z_0}/f G_u \) – integral parameter of the stratification in PBL, \( \mathcal{A}_1, \mathcal{A}_2 \) are external baroclinic parameters, \( \psi \) is the terrain slope angle, \( X_\gamma, Y_\gamma, H_\gamma \) are entrainment convective PBL parameters (connected with momentum and heat flux on the top of PBL), \( \mu_u \) is a non-local stable long-lived PBL parameter, connected with free atmosphere stability (Zilitinkevich, S. and P. Calanca, 2000), \( \mathcal{R}_b \) is a bulk Richardson number in layer \((0–z_\gamma)\) in BL, \( F_\phi = N z_s/U_1 \) is non-local parameter, accounting the effect of the free–flow Brunt–Väisälä frequency \( N \) in long-lived PBL condition, the rest symbols are traditional. The PBL model used has different options for realization according to what are used as input parameters in each group (1)-(2) or mixed their variant. To determine simple relationships between these groups of parameters have to be constructed hybrid (\( \mathcal{R}_b \)-RL) method, based on joint and coordinated use of bulk \( \mathcal{R}_b \) method and PBL resistance laws. This is done after taking into account the obtained by \( \mathcal{R}_b \) method (see Syrakov et al., 2010 in present Proceedings) surface layer drag and heat transfer coefficients and parameter \( s = z_s/R L (L = -u'_v/R \beta \theta) \) is the Monin-Obukhov length:
\[ C^{uv}_s = f_s(\lambda_s, \lambda_a, R_s F_{\phi}), \quad s = f_s(\lambda_s, \lambda_a, R_s F_{\phi}) \]

Taking into account (4) after a series of transformations we present the resistance laws in the following form:
\[ \frac{u_{z_0}}{u_z} = f_{u_z}, \quad \frac{\nu_{z_0}}{u_z} = f_{\nu_z}, \quad \frac{G_u}{u_z} = f_{G_u}, \quad \alpha = \arctg \left[ R \left[ \ln (R_z C^{uv}_s) - A \right] \right], \quad \beta = \frac{B C^{uv}_s}{R}, \quad \phi_s = (C / R) \left[ \ln (R_z C^{uv}_s) - C \right], \]

where \( f_s = \left( f_s + f_s \right)^{-1}, \Delta \theta = \theta - \theta_s \) and \( \Delta \theta = \theta - \theta_s \) are temperature increment in PBL and in the layer \((0–z_\gamma)\), \( u_{z_0}, \nu_{z_0}, v_{z_0} \): \( G_u \) are components and module of the geostrophic wind, \( u_z = u(z = z_s) \), \( R = 0.4 \) is the von Karman constant \( \alpha \) is the angle of full turning of the wind in PBL, \( R_{s} = u_z/f_{z_0} \) is a local Rossby number in the layer \((0–z_\gamma)\): \( A, B, C \) are the resistance law universal functions, depending on the internal parameters (for simplicity the entrainment parameters are omitted):
\[ \mu, \mu_\eta, \lambda_\tau, \lambda_\lambda, \]

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whose explicit form is determined in Syrakov (1990), Syrakov (2005). Here $\eta = \mu \psi / R^2$ is the dimensionless terrain slope parameter, $H_i = h_i / (R U_*/f)$, $h_i$ is the inversion height, $\lambda_c$ and $\lambda_s$ are the dimensionless internal baroclinic parameters. Taking into account the relations $\mu \equiv S R C_{gA} \exp(-\lambda u_*$), $\mu_0 = R C_{gA} \exp(-\lambda u_*)$, $H_i = 1/R C_{gA} R_{i0}$ and (4), (6), it is easy to consider that the right parts of (5), i.e. and the quantities $f_*, f_\alpha$, $f_\beta$, $f_\theta$, $\alpha$ are simply determined by the series of parameters (see Syrakov, E. and E. Cholakov, 2005):

$$\lambda_c, \lambda_s, R_s, F_s, \lambda_c, \lambda_s, \psi$$

(7)

where $R_{i0} = u_*/f h_i$ is a mutual (SL-PBL) Rossby inversion number.

RESULTS AND DISCUSSION

For each group of input parameters (7) for the $(R_s-RL)$ method, the basic relations are determined (5), as well as other relations between BL-PBL parameters. For simplicity it will be considered barotropic, without inversion and plain terrain case, when input parameters are the first five parameters in (7). On Figure 1 it is shown the dependence of $G_{gA}$, geostrophic drag coefficient $C_{gA} = U_*/G_{gA}$, $\mu$ and $\alpha$ on $R_s$ for unstable and for different values of the nonlocal parameter $F_{i0}$ at stable stratification, at given input parameters (7) $R_{i0} = 3.10^4$, $\lambda_c = \lambda_s = 7$ (i.e. $u_{10} = 10 ms^{-1}$, $z_1 = 10 m$, $z_0 = z_{0\theta} = 0.01 m$).

Figure 1 Dependence of $G_{gA}$, $C_{gA}$, $\mu$, $\alpha$ on bulk Richardson number $R_s > 0$ for stable-neutral stratification at different values of the nonlocal parameter $F_{i0}$ and at $R_s < 0$ for unstable stratification.

At $R_s \geq 0$ the curves have four branches respective to different values of the nonlocal parameter $F_{i0}$. At $R_s = 0$ these branches correspond to (CN) regimes. The branch with parameter $F_{i0} = 0$ corresponds to (TN) regime. The rest of the cases at $R_s \geq 0$ correspond to long-lived PBL.

The results from Figure 1 show that at $F_{i0} = 0$ using only surface data $u_{10}$, $\Delta \theta$, $z_{10}$, $z_0$ at given parameters $\lambda_c$, $\lambda_s$, $R_s$, $R_{i0}$ from (7), by using the $(R_s-RL)$ method basic PBL characteristics $C_{gA}$, $\alpha$, $\mu$, $G_{gA}$, $s$ can be determined. As a concrete example this is done for two cases of stable ($z_1 = 10 m$, $u_{10} = 10 ms^{-1}$, $\Delta \theta = 2.7$ degr, $z_0 = z_{0\theta} = 0.01 m$) and unstable ($z_1 = 10 m$, $u_{10} = 10 ms^{-1}$, $\Delta \theta = -5.4$ degr, $z_0 = z_{0\theta} = 0.01 m$) stratification. On the basis of these input parameters
surface data, it is determined the respective $R_s = 0.1$, $R_s = 3.10^6$ for stable case and $R_s = -0.2$, $R_s = 3.10^6$ for unstable case. These parameters are input for ($R_s$ -RL) method. Using them for the ($R_s$ -RL) graphics on Figure 1 (and analogical for $S(R_s)$ but not shown here), the respective parameters $C$, $\alpha$, $\mu$, $G_s$ and $S$ are determined as given in Table 1.

### Table 1 Calculated by ($R_s$ -RL) method basic PBL parameters

<table>
<thead>
<tr>
<th>case</th>
<th>unstable</th>
<th>stable</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C$</td>
<td>0.055</td>
<td>0.016</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>8.5</td>
<td>35</td>
</tr>
<tr>
<td>$\mu$</td>
<td>-80</td>
<td>40</td>
</tr>
<tr>
<td>$G_s [ms^{-1}]$</td>
<td>4</td>
<td>5.25</td>
</tr>
<tr>
<td>$S$</td>
<td>-600</td>
<td>550</td>
</tr>
</tbody>
</table>

Using PBL model coordinated the parameters from Table 1, it can be determined the velocity components $u$, $v$ and coefficient of vertical turbulent exchange $K_z$ and $K_{z\sigma}$. We will consider some diffusion processes in PBL at these conditions. Puff-MM model is used (Syrakov, E., and K. Ganev, 2004, Syrakov et al., 2007), based on statistical construction which divides the diffusion to horizontal and vertical and coordination with the moments method, which allows determination of the trajectory-dispersion parameters in the process of decision of the problem, i.e. not to give them a priori. On Figure 2 some results are shown for instantaneous cloud for the considered cases. It can be seen that in the unstable case the vertical lagrangian coordinate $Z(t)$ significantly decreases and the cloud does not rotate with the height. In contrast in the stable case $Z(t)$ changes slightly but although that the effect of rotation of the wind is significant. The presented simple cases can be interpreted as a scenario of emergency when only surface meteo data is available.

![Figure 2](image-url)  
Figure 2 Horizontal section of the concentration of instantaneous cloud diffusing in PBL using parameters from Table 1 for stable and unstable cases and dependence of lagrangian vertical coordinate $z$ on time. Axis x is along the geostrophic wind.

In a similar way it can be solved and a series of other tasks. For example in Table 2 the correspondence between the Pasquill stability classes and basic BL and PBL parameters: $R_s$, $L$, $C$, $\alpha$, $S$, $G_s$ is given. These result are obtained by the ($R_s$ -RL) method using typical for the classes values of $u_m$ and $z_0 = 0.01m$ and using the estimations of Tagliazucca, M. and T. Nanni, 1983 for the correspondence of the parameter $\mu$ and the stability classes.
<table>
<thead>
<tr>
<th>classes</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_{10}$</td>
<td>1.5</td>
<td>2.5</td>
<td>4</td>
<td>6</td>
<td>3.5</td>
<td>2.5</td>
</tr>
<tr>
<td>$\mu$</td>
<td>-120</td>
<td>-85</td>
<td>-35</td>
<td>0</td>
<td>26</td>
<td>45</td>
</tr>
<tr>
<td>$R_b$</td>
<td>-0.38</td>
<td>-0.18</td>
<td>-0.04</td>
<td>0</td>
<td>0.05</td>
<td>0.12</td>
</tr>
<tr>
<td>$L$</td>
<td>-3.5</td>
<td>-8.4</td>
<td>-30</td>
<td>-</td>
<td>24</td>
<td>6.5</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>7</td>
<td>9</td>
<td>13.5</td>
<td>23.5</td>
<td>32</td>
<td>37.5</td>
</tr>
<tr>
<td>$C_d$</td>
<td>0.065</td>
<td>0.055</td>
<td>0.04</td>
<td>0.03</td>
<td>0.019</td>
<td>0.016</td>
</tr>
<tr>
<td>$S$</td>
<td>-880</td>
<td>-570</td>
<td>-250</td>
<td>0</td>
<td>330</td>
<td>600</td>
</tr>
<tr>
<td>$G_0 [ms^{-1}]$</td>
<td>2</td>
<td>3.5</td>
<td>6</td>
<td>11</td>
<td>7.5</td>
<td>3.6</td>
</tr>
</tbody>
</table>

We note that the $(R_b - RL)$ method allows at substitution of the given parameters $u_\infty$ and $z_0$ to be received respective new, different from the shown in Table 1 relationships between Pasquill classes and BL-PBL parameters.

**CONCLUSION**

The suggested approach allows determination of simple relationships between a series of basic BL, PBL and other parameters at different turbulent regimes including and affected by the free-flow stability. The results can be used for parameterization of a wide range of tasks connected with the structure of BL and PBL, determination of coordination of stability and other parameters taking an important role in the diffusion processes.

**REFERENCES**


