6.19 THE ABL MODELS YORDAN AND YORCON – TOP-DOWN AND BOTTOM-UP APPROACHES

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INTRODUCTION

Two Atmospheric Boundary Layer (ABL) models are applied: YORDAN - for stable and neutral conditions (Yordanov, D. et al., 1983; 1998, 2004) and YORCON (a Convective Boundary Layer model) - for convective cases (Yordanov, D. et al., 1990). Both models are developed in accordance with the similarity theory and consist of a Surface Layer (SL) and an Ekman layer over it. The two models are used to obtain the vertical profiles of the temperature, wind velocity and the turbulent exchange coefficient in ABL. As input to these models the internal parameters are needed. The internal parameters are obtained from the experimental data applying two approaches: first one (the “top-down” approach) uses data for the geostrophic wind and the potential temperature (Yordanov D. et al., 1997). The second one (the “bottom-up” approach) uses data from the surface meteorological observations (Yordanov D. et al., 2003a; b).

THE TWO APPROACHES

In the classical “top-down” approach, applying the similarity theory and resistance lows, the internal parameters - the Monin-Obukhov length scale (L), the friction velocity (u_*) and the cross isobaric angle $|\alpha|$ are determined from the external parameters: the geostrophic wind $|V_g|$ and $\delta\theta$ - the difference between the potential temperature at ABL height and at the ground. These parameters can be determined from the numerical weather prediction or from radio sounding data as it was shown by Yordanov D., et al. (1997; 1998).

The “bottom-up” approach solves the inverse problem that consists of determination of the external ABL parameters and the vertical profiles of the temperature, wind velocity and the turbulent exchange coefficient from the surface meteorological measurements of the wind and atmospheric stability data. The description of this approach was given in details by Yordanov et al. (2003a; 2003b).

DETERMINATION OF L AND U_*

The Monin-Obukhov length scale L is defined as:

$$L = -u_*^3 \big/ \kappa\beta(\overline{w'\theta'})_0 \quad , \tag{1}$$

where u_* is the friction velocity, κ is the von Karman constant, $\beta = g/\overline{\theta}$ is buoyancy parameter, g is gravity acceleration, $\overline{\theta}$ is mean potential temperature averaged for the whole layer, $(\overline{w'\theta'})_0$ - the normalized by $c_p\rho$ vertical turbulent heat flux at the ground, c_p is the specific heat capacity at constant pressure, and ρ is the air density.
The values of L can be computed directly from the field measurements of u_* and the heat flux if data are available, but often L is estimated from routine meteorological measurements.

In the "bottom-up" approach L is determined using the Golder relations. Having the stability class experimentally determined every hour from the automatic measurements, the corresponding M.-O. length scale L can be calculated at given roughness as shown by Yordanov, D. et al. (2003a; 2003b).
The friction velocity u_* is determined from the measurements of the wind velocity at *10m* and the surface profile functions f_u and f_θ as shown in (Yordanov, D. et al. (2003 a; 2003b):

$$u_* = \frac{\kappa u_a}{f_u(\zeta_a, \zeta_0)}, \qquad (3)$$

here κ is fon Karman constant, u_a is the wind velocity at anemometer height, which is $z_a = 10m$, f_u is a function of the dimensionless height $\zeta_a = z_a/L$, and the dimensionless roughness $\zeta_0 = z_0/L$. All parameters in the right part of Eq. (3) are measured by the automatic stations.

For **stable and neutral stratification** the surface profile functions f_u and f_θ are taken as log-linear applying the PBL model YORDAN (Yordanov, D. et al., 1983). The model produces the vertical profiles of the wind and the vertical turbulent exchange coefficient and demonstrates good coincidence with a number of different experimental data sets (Yordanov, D. et al., 1998 and Djolov, G., D. Yordanov and D. Syrakov, 2004).

As it was shown in (Yordanov, D. et al., 2003a) replacing the expressions found for the profile function in equation (3) and taking into account that $u = u_a$ and $z = z_a$ the friction velocity can be determined.

For **unstable stratification** the universal profiles of Businger are used, applying the convective PBL model YORCON (Yordanov, D. et al., 1997) as shown by Yordanov, D. et al. (2003b).

EXTERNAL TO CPBL PARAMETERS ($\overrightarrow{V_g}$, α, AND $\delta\theta$)

PBL model YORDAN

The turbulent regime in a barotropic PBL under stable and neutral conditions is parameterized on the basis of the similarity theory using the following non-dimensional external parameters:

$$S = \frac{\beta(\theta_H - \theta_0)}{f\left|\overrightarrow{V_g}\right|} \quad \text{and} \quad Ro = \left|\overrightarrow{V_g}\right| / f z_0 \qquad (4a)$$

S - is the external to PBL non-dimensional stratification parameter; and Ro is - the Rossby number, $\delta\theta = \theta_H - \theta_0$ is the difference between the potential temperatures at the upper boundary of the PBL (θ_H) and at the ground (θ_0), V_g is the geostrophic wind vector, f is the Coriolis parameter. The non-dimensional internal PBL parameters that uniquely determine the turbulent regime of a barotropic PBL under stable and neutral stratification are:

$$c_g = \frac{u_*}{\left|\overrightarrow{V_g}\right|}, \quad |\alpha|, \quad \mu = \frac{H}{L} = \frac{\kappa u_*}{fL}, \qquad (5a)$$

where, c_g is the drag coefficient, α is surface wind deviation from the geostrophic wind or cross-isobaric angle (α *being negative in the Northern Hemisphere)*, and μ is the internal stratification parameter, $H = \kappa u_* / f$ is the PBL height scale.

To determine the external to PBL parameters as the geostrophic wind ($\overrightarrow{V_g}$), the cross-isobaric angle (α) and the difference between the potential temperature at the top and at the bottom of the PBL ($\delta\theta$), the resistance and heat exchange laws for the case of barotropic PBL are applied (Yordanov, D. et al., 1983; 1998):

$$\frac{\kappa \cos\alpha}{c_g} = \ln\frac{u_*}{f z_0} - A(\mu), \tag{6a}$$

$$\frac{\kappa \sin|\alpha|}{c_g} = B(\mu) , \tag{7a}$$

$$a_\theta(0)\frac{\kappa^3 S}{c_g \mu} = \ln\frac{u_*}{f z_0} - C(\mu). \tag{8a}$$

The absolute value of the geostrophic wind can be obtained from Eqs. (6a) and (7a):

$$\left|\overrightarrow{V_g}\right| = \frac{u_*}{\kappa}\left[\left(\ln\frac{u_*}{f z_0} - A(\mu)\right)^2 + B^2(\mu)\right]^{1/2} \tag{9a}$$

The absolute value of the cross isobaric angle α can be obtained from equation (8a):

$$|\alpha| = \arcsin\left[\frac{c_g}{\kappa} B(\mu)\right], \tag{10a}$$

$A(\mu)$, $B(\mu)$, $C(\mu)$ are universal functions of the internal stratification parameter μ.
The non-dimensional external stratification parameter S is determined from equation (8a) :

$$S = \frac{c_g \mu}{a_\theta(0)\kappa^3}\left[\ln\frac{u_*}{f z_0} - C(\mu)\right], \tag{11a}$$

$\delta\theta$ - the difference between the potential temperature at the top and at the bottom of the PBL is obtained from Eq. (4a) and Eq. (11a):

$$\delta\theta = \theta_{\mathrm{H}} - \theta_0 = \frac{u_* \mu f}{\alpha_\theta(0)\kappa^3 \beta}\left[\ln\frac{u_*}{f z_0} - C(\mu)\right]. \tag{12a}$$

To find the external PBL parameters S and $\delta\theta$ we use the expressions for the universal functions $A(\mu)$, $B(\mu)$, $C(\mu)$, as shown by Yordanov, D. et al. (2003a). From Eqs. (9a), (10a), and (11a) we obtain the final expressions for the geostrophic wind $\overrightarrow{V_g}$, the angle α and the stratification parameter *S*. Replacing the expressions for *Ro* and *S* from (4a) in the resistance laws (6-8a) and the defined by the PBL model universal functions $A(\mu)$, $B(\mu)$, $C(\mu)$, we obtain a system of non-linear algebraic equations for the internal parameters c_g , α and μ.
The numerical solution of this system of equations at different values of the external parameters *Ro* и *S* was solved and approximated with polynomials by Yordanov, D. et al. (1983). The values of the polynomial coefficients a_j, b_j and c_i for the barotropic and the baroclinic cases were calculated by Yordanov, D. et al. (1983) and Yordanov, D. et al. (1998), also (Djolov, G., D. Yordanov and D. Syrakov, 2004).

Convective PBL model YORCON
The turbulent regime in a barotropic PBL capped by inversion is parameterized using the following non-dimensional external parameters under convective conditions:

$$Ri_B = \frac{\beta\,\delta\theta\, z_i}{\vec{V}_g^2}, \quad Z_0 = \frac{z_0}{z_i}, \quad Ro_i = \frac{\left|\vec{V}_g\right|}{f z_i} \tag{4b}$$

Ri_B is the bulk Richardson number, Ro_i is the bulk inversion Rossby number, Z_0 is the non-dimensional roughness, $\delta\theta = (\theta_{z_i} - \theta_0)$ is the difference between the potential temperature at the inversion height z_i and at the ground (at z_o).

The turbulent regime in the CPBL is determined by the following internal parameters:

$$c_g = \frac{u_*}{\left|\vec{V}_g\right|}, \quad \alpha, \quad \mu_c = \frac{z_i}{L} \quad \text{or} \quad \mu = \frac{\kappa\, u_*}{f\, L} \tag{5b}$$

here, μ and μ_c are the internal stratification parameters in the CBL model. The relationship between the external and internal CPBL parameters is given by the resistance laws:

$$\frac{\kappa}{c_g} = \left\{\left[\left(\ell n Z_0 + A(\mu_c)\right]^2 + B^2(\mu_c, \mu)\right\}^{1/2} \tag{6b}$$

$$\sin|\alpha| = \frac{c_g}{\kappa} B(\mu_c, \mu) \tag{7b}$$

$$\alpha_\theta(0) Ri_B = -\frac{c_g^2}{\kappa^2}\left[\ell n Z_0 + C(\mu_c)\right] \tag{8b}$$

where $\alpha_\theta(0)=1.35$ and $\alpha_\theta(0)=K_\theta/K_m$ is the inverse Prandtl number.
For the absolute value of the geostrophic wind the following expression is obtained:

$$\left|\overrightarrow{V_g}\right| = \frac{u_*}{\kappa}\left[\left(\ell n Z_0 - A(\mu_c)\right)^2 + B^2(\mu_c, \mu)\right]^{1/2} \tag{9b}$$

and the absolute value of the cross isobaric angle α is obtained from Eq. (7b):

$$|\alpha| = \arcsin\left[\frac{c_g}{\kappa} B\left(\mu_c, \mu\right)\right], \tag{10b}$$

$\delta\theta$ - the difference between the potential temperature at the top and at the bottom of the PBL is obtained from Eq. (8b) as:

$$\delta\theta = \theta_{z_i} - \theta_0 = \frac{\theta_* \mu_c}{\alpha_\theta(0)}\left[-\ell n Z_0 - C(\mu_c)\right]. \tag{11b}$$

The universal functions A, B , C, in the resistance lows are derived by Yordanov, D. and M. Kolarova (1988) for the convective PBL model YORCON. In order to obtain the external CPBL parameters Ri_B , Ro_i , and Z_0 we use the universal similarity functions A, B, C, as was shown by Yordanov, D. et al. (2003b). Replacing the universal similarity functions in the resistance lows (6b-8b) we obtain a system of non-linear algebraic equations for the internal parameters c_g ,α , μ . The numerical solution of this system of equations at different values of the external parameters Ri_B , Z_o, Ro was obtained by Kolarova, M. et al. (1989).
Under convective conditions the evolution of the convective PBL height (mixing layer height) at conditions of horizontal homogeneity is calculated from the M.-O. length scale L and u_* as was shown by (Yordanov, D. et al., 1990 and 1997). A detailed description of this procedure was given by Yordanov, D. et al. (2003b). The model YORCON was discussed in details in (Yordanov, D. and M.Kolarova, 1988 and Yordanov, D. et al., 1990).
Applying the relationship between the external and internal parameters given by the resistance laws, and solving the obtained systems of equations in both cases applying the models YORDAN and YORCON the geostrophic wind $|V_g|$, the cross isobaric angle $|\alpha|$, and $\delta\theta$ can be finally determined. From these parameters we can easily obtain the velocity defects and from them the wind and temperature profiles for stable, neutral and convective conditions as shown in Yordanov, D. et al. (2003a; 2003b) and Djolov, G. et al. (2004).

The aim of the present work is to determine the vertical profiles of wind velocity and temperature in the Atmospheric Boundary Layer using experimental data from Sofia and applying the models YORDAN and YORCON. Comparisons with experimental data are given by Yordanov, D. et al. (2003a; 2003b) and Djolov, G. et al. (2004).

CONCLUSIONS

Applying the similarity theory and resistance lows we can generally determine the surface turbulent fluxes defined by L and u_* from the external to PBL parameters ($|V_g|$, $|\alpha|$ and $\delta\theta$), often determined from the numerical weather prediction. The "bottom-up" approach solves the inverse problem that consists of determination of the external to PBL parameters and the vertical profiles of the temperature, wind velocity and the turbulent exchange coefficient (given by the PBL models YORDAN and YORCON) from the ground station meteorological measurements of the wind and atmospheric stability.

The proposed parameterization was successfully applied in different practical tasks concerning air pollution modeling. The "top-down" version of the PBL model is built in various Bulgarian dispersion models as LRTP, LED EMAP etc., performing of-line and on-line meteorological processing. These models are successfully used for solving many practical tasks with different time and space scales like assessment of the long range sulphur and heavy metal pollution in the region of South-Eastern Europe and some regions in Bulgaria, exchange of sulphur pollution between Bulgaria and Greece, etc.

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