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ON THE INFLUENCE OF THE VERTICAL MOTIONS, INDUCED BY THE OROGRAPHIC AND THERMAL NONHOMOGENEITIES, ON SOME PROCESSES IN SYNOPTIC AND CLIMATIC ASPECT

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Евгени Сираков, Милен Цанков, Емил Чолаков. ВЪРХУ ВЛИЯНИЕ НА ИНДУЦИРАНИТЕ ОТ ОРОГРАФСКО-ТЕРМИЧНИ НЕЕДНОРОДНОСТИ ВЕРТИКАЛНИ ДВИЖЕНИЯ ВЪРХУ НЯКОИ ПРОЦЕСИ В СИНОПТИЧЕН И КЛИМАТИЧЕН АСПЕКТ

Разглеждат се някои аспекти на параметризация на планетарния граничен слой (ПГС) чрез използване на вертикалната скорост на горната граница на ПГС, отчитаща съвместното влияние на орографско-термичните фактори и триенето. Установени са корелационни връзки (съответствия) между термичния лапласиан и интензивността на цикло и антициклогенеза в климатичен аспект, обобщени са някои условия за съхранение на потенциалния вихър и е анализирано влиянието на вертикалните движения върху височината на ПГС в зависимост от конфигурацията на орографско-термичните хоризонтални нееднородности. Резултатите могат да бъдат използвани за параметризация на числени модели на времето и за изучаване на климата.

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It is considered some aspects of parameterization of the Planetary Boundary Layer (PBL) using the vertical velocity at the upper boundary of PBL, which accounts the joint influence of the orographic and thermal factors and the friction. It was found correlation connections (correspondences) between the thermal laplacians and the intensity of cyclo and anticyclogenesis in climatic aspect, it is generalized some conditions for conservation of the potential vortex and it is analyzed the influence of the vertical motions on the height of PBL in dependence of the configuration of the orographic and thermal horizontal nonhomogeneities.

The results can be used for parameterization of numerical forecast models and for studying the climate.

Keywords: orographic and thermal nonhomogeneity, vertical motion, equivalent topography, height of PBL, laplacian effects.
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1. INTRODUCTION

In distinction of the case of horizontal and homogeneous PBL, when there are orographic and thermal horizontal nonhomogeneities, the vertical velocity, induced at the upper boundary of PBL, describes a series of additional effects, caused by the interaction of the orographic and thermal factors and the friction [1-4].

The counted factors have a significant influence on a series of processes in synoptic and climatical aspect. Some of them will be considered below.

2. PBL-SIMILARITY FORMULATION OVER NONHOMOGENEOUS TERRAIN

The turbulent regime of orographic and thermal heterogeneous, baroclinic PBL depends on the external parameters:

$$-\frac{1}{\rho}\frac{\partial p}{\partial x},\ -\frac{1}{\rho}\frac{\partial p}{\partial y};\ Z_0(x,y),\ \delta\theta(x,y);\ f,\beta,$$

where ρ is the density, p–the pressure, f–the Coriolis parameter, β–the buoyancy parameter, $Z_0(x,y)$–the topography, $\delta\theta = \theta_{TOP} - \theta_0(x,y)$–the potential temperature increment in PBL in point (x,y).

Developing $Z_0(x,y)$ and $\delta\theta(x,y)$ in the arbitrary point with coordinates $(x = 0,\ y = 0)$ in a series to the second term, we find in a definite vicinity $\delta(x < \delta,\ y < \delta)$ of this point: [1,3,4]:

$$\begin{aligned} Z_0(x,y) &= Z_0(0,0) + \frac{\partial Z_0}{\partial x}x + \frac{\partial Z_0}{\partial y}y + \frac{1}{2}\frac{\partial^2 Z_0}{\partial x^2}x^2 + \frac{1}{2}\frac{\partial^2 Z_0}{\partial y^2}y^2 + \frac{1}{2}\frac{\partial^2 Z_0}{\partial x\partial y}xy, \\ \partial\theta(x,y) &= \partial\theta(0,0) + \frac{\partial\theta}{\partial x}x + \frac{\partial\theta}{\partial y}y + \frac{1}{2}\frac{\partial^2\theta}{\partial x^2}x^2 + \frac{1}{2}\frac{\partial^2\theta}{\partial y^2}y^2 + \frac{1}{2}\frac{\partial^2\theta}{\partial x\partial y}xy. \end{aligned} \quad (1)$$

Obviously the influence of $Z_0(x,y)$ and $\delta\theta(x,y)$ will be formed by both the $Z_0(0,0)$ and $\delta\theta(0,0)$, and also by the horizontal changes of Z_0 and $\delta\theta$ in a vicinity δ (first and second derivatives of Z_0 and $\delta\theta$). At $x = y$ the forth and the fifth terms of the right sides of (1) are expressed by the laplacians of Z_0 and $\delta\theta$:

$$\nabla^2 Z_0 = \frac{\partial^2 Z_0}{\partial x^2} + \frac{\partial^2 Z_0}{\partial y^2}, \nabla^2 \delta\theta = \frac{\partial^2 \delta\theta}{\partial x^2} + \frac{\partial^2 \delta\theta}{\partial y^2}. \quad (2)$$

At the top H of PBL, the upper boundary conditions of u and v are: $u = U$, $v = V$, where U and V are connected with pressure p:

$$-\frac{1}{\rho}\frac{\partial p}{\partial x} = fV + N_{XT}, \quad -\frac{1}{\rho}\frac{\partial p}{\partial y} = -fU + N_{YT},$$

$$N_{XT} = \frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} + V\frac{\partial U}{\partial y}, \quad N_{YT} = \frac{\partial V}{\partial t} + U\frac{\partial V}{\partial x} + V\frac{\partial V}{\partial y}.$$

For a zero approximation ($N_{XT} = N_{YT} = 0$); $-\frac{1}{\rho}\frac{\partial p}{\partial x}$ and $-\frac{1}{\rho}\frac{\partial p}{\partial y}$ are parameterized traditionally by the modul of the geostrophic wind G_0 and the baroclinic parameters Λ_X, Λ_Y:

$$G_0, \Lambda_X, \Lambda_Y, \quad (3)$$

where $G_0 = \left(U_{g0}^2 + V_{g0}^2\right)^{1/2}$, U_{g0}, V_{go} are the quantity of the geostrophic wind components $U_g(z), V_g(z)$ at surface level $z = 0$, $\Lambda_X = \mathrm{d}U_g/\mathrm{d}z$, $\Lambda_Y = \mathrm{d}V_g/\mathrm{d}z$.

In a non-linear approximation, when $N_{XT} \neq 0$, $N_{YT} \neq 0$ are expressed iteratively with zero approximation, to (3) are added several additional parameters, expressed by the derivatives of $U_{go}, V_{go}, \Lambda_X, \Lambda_Y$ over x, y and t.

Series of main PBL interaction characteristics like heat C_H and mass transfer C_d coefficients, angle of full turning in PBL-α, vertical velocity w_H, and etc. depend on the introduced above parameters. Here we will focus our attention mainly to the parameter w_H.

3. VERTICAL VELOCITY ON THE TOP OF THE PBL

On the basis of the equations of movements and continuity, after the respective iteration procedure in the linear and nonlinear approximation (see [2]) the expressions for the vertical velocity w_H are determined [2–4]:

$$w_H = w_I + c\Omega_g + \Delta w, \quad \Delta w = \Delta w_{or} + \Delta w_{\delta\theta} + \Delta w_{BC}, \quad (4)$$

where $w_I = u_{go}\frac{\partial Z_0}{\partial x} + v_{go}\frac{\partial Z_0}{\partial y} = \left(\vec{\nabla} Z_0 \bullet \vec{c}_{go}\right)$ is the standard kinematical velocity, $c\Omega_g$ is a friction in a horizontal homogeneous PBL, and Δw_{or}, $\Delta w_{\delta\theta}$, w_{BC} are corrections accounting the nonhomogeneity and baroclinicity–warm or cold thermal advection:

$$\Delta w_{or} = a\left(\vec{\nabla} Z_0 \cdot \vec{c}_{g_0}\right) + b\left(\vec{\nabla} Z_0 \times \vec{c}_{g_0}\right)_z - dG_0^2 \nabla^2 Z_0 - e\left(u_{g_0}^2 - v_{g_0}^2\right)\partial^2 Z_0 \frac{\partial^2 Z_0}{\partial x \partial y}, \tag{5}$$

$$w_{\delta\theta} = a_1\left(\vec{\nabla}\delta\theta \cdot \vec{c}_{g_0}\right) + b_1\left(\vec{\nabla}\delta\theta \times \vec{c}_{g_0}\right)_z - d_1 G_0^2 \nabla^2 \delta\theta - e_1 \frac{\partial^2 \delta\theta}{\partial x \partial y}\left(u_{g_0}^2 - v_{g_0}^2\right), \tag{6}$$

$$w_{BC} = -f_1\left(u_{g_0}\frac{\partial \bar{T}}{\partial x} + v_{g_0}\frac{\partial \bar{T}}{\partial y}\right) \equiv -f_1\left(\vec{\nabla}\bar{T} \cdot \vec{c}_{g_0}\right). \tag{7}$$

Here $c = \sqrt{2k/f}$, $k = (1/H)\int_0^H K_z(x,y)\,\mathrm{d}z$, is the vertical averaged turbulent exchange coefficient; $f_1 > 0$, $a > 0$, and $a_1 < 0$, $b_1 < 0$, $d_1 < 0$, $e_1 < 0$ are weight coefficients, which can be expressed by c. The explicit forms of c and k are determined on the basis of integral TKE method [3].

Formula (4) in the linear approximation ($d = f = e = o, d_1 = f_1 = e_1 = 0$) can be presented in the following equivalent but more convenient for analysis form (see [5]).

$$w_k = G_0 \nabla Z_0 (1+a)\left\{\cos\varphi\left[1 + \frac{\tilde{a}_1}{1+a}E\left(\cos\psi - \frac{b_1}{a_1}\sin\psi\right)\right] + \right.$$
$$\left.\frac{b}{1+a}\sin\varphi\left[1 + \frac{\tilde{b}_1}{b}E\left(\frac{b_1}{a_1}\sin\psi + \cos\psi\right)\right]\right\} - AcG_0\tilde{\Lambda}\sin\Phi + c\Omega_g, \tag{8}$$

where $A = \pi f^2/g\aleph^2$, $\aleph = 0{,}4$, $\tilde{\Lambda} = \left|\tilde{\Lambda}\right| = \left(\tilde{\Lambda}_x^2 + \tilde{\Lambda}_y^2\right)^{1/2}$, $\tilde{\Lambda}_x = \aleph^2 \Lambda_x / f$, $\tilde{\Lambda}_y = \aleph^2 \Lambda_y / f$ are the external baroclinic dimensionless parameters, $\tilde{a}_1 = a_1 f^2/\beta$, $\tilde{b}_1 = b_1 f^2/\beta$ and E is a dimensionless parameter:

$$E = \frac{\beta \nabla \delta\theta}{f^2 \nabla Z_0} \equiv \frac{\beta}{f^2}\frac{\left[\left(\frac{\partial \delta\theta}{\partial x}\right)^2 + \left(\frac{\partial \delta\theta}{\partial y}\right)^2\right]^{1/2}}{\left[\left(\frac{\partial Z_0}{\partial x}\right)^2 + \left(\frac{\partial Z_0}{\partial y}\right)^2\right]^{1/2}}, \tag{9}$$

which characterizes the relative contribution of thermal and orography heterogeneities in stratified rotating turbulent atmosphere to the formation of vertical velocity. At $E \to 0$, (8) describes pure topographic effects, at $E \to \infty$– pure $\delta\theta$–thermal effects, and at intermediate values of E (e.g. typical $E = 2.10^4$)– the joint thermal and topography effects. As it can be seen from (8), when weight coefficients are given, w_H depends on the dimensionless parameter E and three angles, which are characterizing respectively: φ–the flow orientated relative orography; ψ–the mutual orientation of orography and thermal heterogeneity; Φ–the warm or cold thermal advection. For example the dependence of $\tilde{w}_h = w_h / G_0 \nabla Z_0 (1+a)$ according to (8) (at $\tilde{\Lambda}$ = 0, $E = 2.10^4$) on φ at different typical values of ψ is given in Fig. 1.

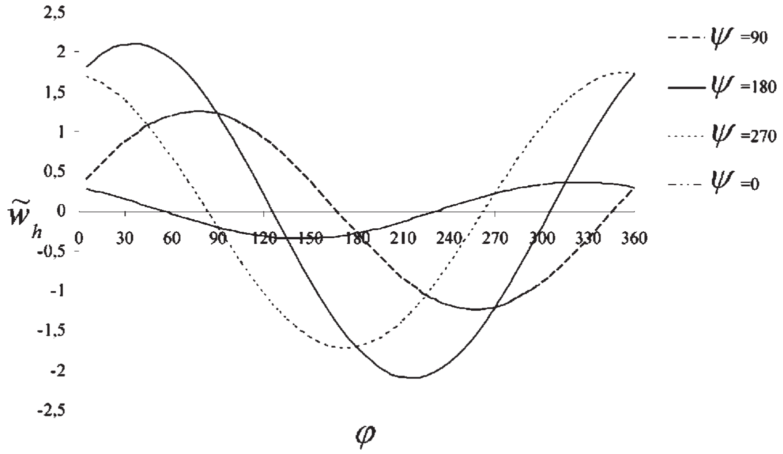

Fig. 1. The dependence of $\tilde{w}_h$ according to (8) at $E = 2.10^4$ and barotropic conditions ($\tilde{\Lambda}$ = 0) at different values of ψ

4. CLIMATIC EFFECTS

Here we will briefly consider some non-linear effects in (4–6) caused by the laplasians (2). Horizontal cards of the laplacians $\nabla^2 \delta\theta$ for July (summer half-season) and $\nabla^2 Z_0$ calculated from real data (with grid resolution two degrees) are shown on Fig 2. The respective terms in (5) and (6), related to these laplacians are:

$$\Delta w_{LZ_0} = -dG_0^2 \nabla^2 Z_0$$
$$\Delta w_{L\delta\theta} = -d_1 G_0^2 \nabla^2 \delta\theta \qquad (10)$$

They are invariant about the coordinate system and do not depend on the wind direction. That’s why we can consider that beside synoptic, terms (10) also have an accumulating significant climatic effect.

According to this it can be expected that between effects connected with (10) and a series of main climatical parameters exists a very significant correlation. The detail analysis confirms this suggestion as for the term containing ($\nabla^2 Z_0$), so and ($\nabla^2 \delta\theta$) laplacians. Here we will confine only with Fig. 3, which demonstrates very good correspondence between the value and the sign of $\nabla^2 \delta\theta$ and the zones of cyclo and anticyclogenesis according to [6] for July.

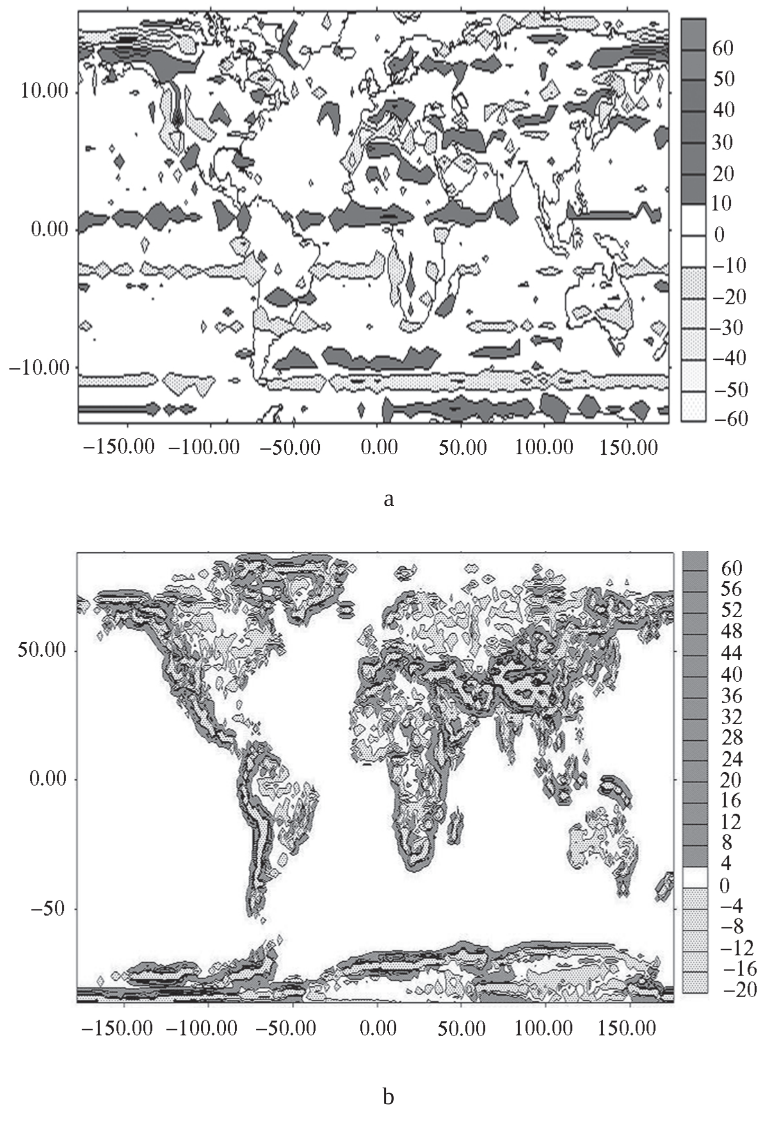

Fig.2. Distribution of the thermal laplacian $\nabla^2 \delta\theta$ in conditional normalization during July: a) at average scale 550 km and the orographic laplacian $\nabla^2 Z_0$**;** b) at average scale 250 km

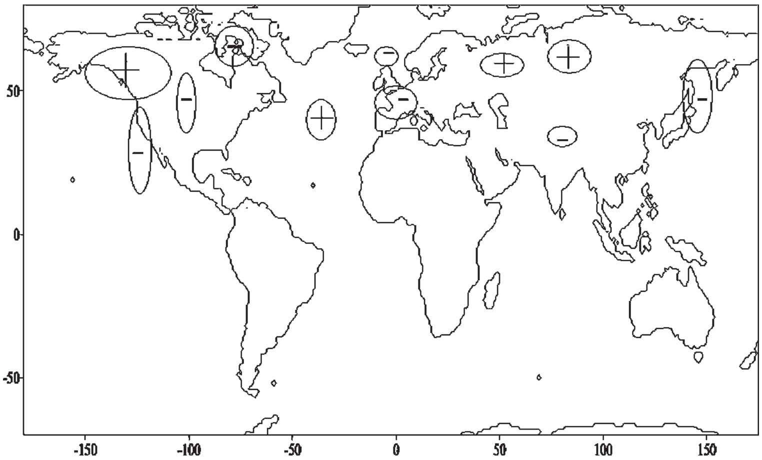

Fig.3. Distribution of the areas of maximal cyclo and anticyclogenesis (see [6]) during July (enclosed with thick curve) and the extreme values of the lapalcians with their signs ($\nabla^2\delta\theta < 0$ cyclogenesis, and $\nabla^2\delta\theta > 0$ anticyclogenesis)

5. CONCEPTION OF “EQUIVALEINT” TOPOGRAPHY

On the basis of the kinematical velocity:

$$w_I = u_{go}\frac{\partial Z_0}{\partial x} + v_{go}\frac{\partial Z_0}{\partial y}, \tag{11}$$

when we use the introduced in [7] “envelope” topography correction $\Delta Z_{0En}$and replace Z_0 with ΔZ_{0En}, we have “kinematic-envelope corrected” velocity w_{IEn}:

$$w_{IEn} = u_{go}\frac{\partial Z_{0En}}{\partial x} + v_{go}\frac{\partial Z_{0En}}{\partial y} \equiv w_I + U_{g0}\frac{\partial \Delta Z_{0En}}{\partial x} + V_{g0}\frac{\partial \Delta Z_{0En}}{\partial y}, \tag{12}$$

where

$$Z_{0En} = Z_0 + \Delta Z_{0En}, \quad \Delta Z_{0En} = r\mu_h, \tag{13}$$

where ΔZ_{0En} is “geometric” correction of Z_0. Here μ_k is a sub-grid geometric orographic scale height variance, r is the parameter depending on the scale averaging.

In the general case, when we take into account $Z_0 - \delta\theta$, studied above effects, analogically to (11)–(13) we introduce the “equivalent” topography Z_{0Eq} through the equation (see [8]):

$$Z_{0Eq} = Z_0 + \Delta Z_{0Eq}, \tag{14}$$

where Z_{0Eq} is "dynamically generated correction" of Z_0. The "equivalent" topography is determined from the condition:

$$w_H = u_{go}\frac{\partial Z_{0E}}{\partial x} + v_{go}\frac{\partial Z_{0E}}{\partial y}, \qquad (15)$$

where w_H is given by the formula (4). On the basis of (14) and (15), we receive the following equation for determination of ΔZ_{0Eq}:

$$u_{go}\frac{\partial \Delta Z_{0E}}{\partial x} + v_{go}\frac{\partial \Delta Z_{0E}}{\partial y} = w_H - w_I = c\Omega_g + \Delta w, \qquad (16)$$

whereΔw is taken from (4). When instead of (11), it is used the more general boundary condition (16), then for example the Rosby equation of conservation of the potential vorticity $\Omega_a = \Omega_z + f$ is:

$$\frac{\mathrm{d}_2}{\mathrm{d}t}\left(\frac{\Omega_z + f}{H_T - Z_{0E}(x,y)}\right) = 0, \text{ i.e.,} \qquad (17)$$

$$\left(\frac{\Omega_z + f}{H_T - Z_{0E}(x,y)}\right) = \left(\frac{\Omega_z + f}{H_T - Z_0 - \Delta Z_{0E}}\right) = \text{const}, \qquad (18)$$

where $f = f_0 + By$, $B = \mathrm{d}f/\mathrm{d}y$,H_T is the upper boundary height of troposphere. On this basis after determining ΔZ_{0E} from the equation (16), in which the right side is known according to (4), it can be estimated the influence of the containing into (4) effects over the deviation of the main atmospheric flow in dependence of the orographic and thermal factors in global scale.

We will briefly consider and the problem about the effect of the synoptic–scale vertical velocity at the upper stable boundary layer height H through the equation:

$$\frac{\partial H}{\partial t} + u_{g_0}\frac{\partial H}{\partial x} + v_{g_0}\frac{\partial H}{\partial y} - w_H \equiv C_E\,|f|\,(h - h_E). \qquad (19)$$

Keeping only the vertical advection term on the left side of the upper equation for the quasiequilibrium SBL height h_{QE} we have [9]:

$$h_{QE} = h_E + \frac{w_H}{C_E|f|}, \qquad (20)$$

where w_H is given by (4). For example in the private pure topographic case ($\delta\theta = 0$) and barotropic condition ($\Lambda = 0$) from (8) follows that:

$$w_h = G_0 \nabla Z_0 (1 + a) F_{or}(\varphi),$$
$$F_{or}(\varphi) = \cos\varphi + \frac{b}{1+a}\sin\varphi, \qquad (21)$$

where the first term in $F_{or}(\varphi)$ describes the across and the second – the parallel to the topography flow effect. At $\varphi = 90°$ and $\varphi = 270°$ a pure parallel flow effect is realized (see Fig.1). While in the first case, to the right side of the movement direction are the increasing topography values and $w_k > 0$, i.e. h_{QE} increases, and in the second case is the opposite, i.e.$w_k < 0$ and h_{QE} decreases. At the same way it can be studied and the influence of joint $Z_0 - \delta\theta$ effects over h_{QE} and to consider significantly more complex situations.

CONCLUSION

This research shows that the induced at the upper boundary of orographic and thermal nonhomogeneous PBL, vertical velocity is an important factor, which can influence on the atmospheric processes in synoptic and climatic aspect.

As an important future task it can be pointed out the accounting of the influence of the considered in this work factors on the baroclinic unstability over orographic and thermal nonhomogeneous terrain. This problem will be studied in other publication.

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