EDDY MIXING AND THE INTERMITTENT TURBULENCE IN ATMOSPHERIC FLOWS UNDER STRONGER STRATIFICATION

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Abstract Interest in the studies of turbulence in stably stratified atmospheric flows is associated with their scientifically intriguing nature and practical significance (e. g. weather forecasting, climate modelling, and pollutant transport). This paper is focused on modelling and simulation of eddy mixing of momentum and heat and the intermittent turbulence in a stable atmospheric boundary layer (SBL).

RANS TURBULENCE SCHEME FOR STRATIFIED GEOPHYSICAL FLOWS

The expressions for turbulent fluxes of momentum and heat can be derived from closed transport equations for these fluxes using an approximation of weakly equilibrium turbulence, and with an aid of a symbolic algebra code which yields [1]:

$$\overline{uw},\overline{vw} = -K_m\left(\frac{\partial U}{\partial z},\frac{\partial V}{\partial z}\right),\ \overline{\theta w} = -K_h\ \partial\Theta/\partial z\ +\gamma_c,\ K_m = E_k\, S_m\tau\ ,\ K_h = E_k S_h\tau\ , \qquad (1)$$

where $S_m = 1/D\ f_m\ G_h, N, \tau, \overline{\theta^2}$, $S_h = 1/D\ f_h\ G_h, N$ are the structural functions, and $\gamma_c = \gamma_c\,(G_m, G_h, N, \tau, \overline{\theta^2}\,)$ is the temperature counter-gradient, which incorporates the contribution of large-scale eddies to the total flux. A detail description of the functions $S_m, S_h,\ \gamma_c$ and D can be found in [1]. The three parameters of full explicit anisotropic expressions for turbulent fluxes of momentum and heat (1), namely the TKE, the spectral consumption ε (or the dissipation of TKE) and the temperature variance $\overline{\theta'^2}$ are determined from the solution of closed transport equations (see [1]).

EDDY MIXING IN THE STABLY STRATIFIED BOUNDARY LAYER (SBL)

The three-parameter RANS turbulence scheme [1] takes into account the contribution of internal gravity waves to sustaining the flow momentum at the strong stable case, correctly reflects the eddy mixing momentum and heat with growing flow stability.

Fig. 1 shows that the computed eddy diffusivities of momentum K_m (solid line 1) and heat K_h (solid line 2) is in agreement with the measurements data [2] in the SBL (open squares - K_m , open circles - K_h). The transition to a stable state occurs at $Ri_g \geq 0{,}2$. It follows from Fig. 1 that in a stable regime at the $Ri_g \geq 1.0$, the coefficient K_m remains approximately constant increase of the gradient Richardson number $Ri_g = N^2/S^2$ or slightly increases, while the coefficient K_h only diminishes with growth of the flow stability. An explanation of such behavior of the eddy diffusivities is that the flow turbulence is inhibited by stable stratification and thus the momentum and heat transfer by turbulent eddies diminishes. At strong stratifications, the flow sustains propagating internal waves which can effectively transport momentum, but not heat. Inclusion of the effect of internal gravitational waves on transport momentum in the three-parametric RANS turbulence scheme provides correct reproduction of the decaying trend of an inverse turbulent Prandtl number too [1].

INTERMITTENCY OF TURBULENCE IN THE SBL

In the present study we have tested possibility of the second order closure RANS turbulence scheme in reproduction of the intermittent turbulence in the SBL both near to a surface, and in above and below the low-level jet (LLJ). The simulation is intended to study the reaction of the turbulence scheme to given surface and dynamic forcings. Since this RANS study focuses on the quasi-steady-state SBL, the simulation results presented beneath are restricted to the later period of the simulations when a quasi-steady state is achieved.

Fig. 2 shows computed by present RANS turbulence scheme the intermittent events near to a surface. This turbulence bursts are generated by a local shear increase, propagating upwards through the turbulence transfer term in the TKE transport equation. This transport term is modelled as: $-\partial/\partial z\left[\overline{wE}+\overline{pw}/\rho_0\right] = \partial/\partial z\left[\ K_m/\sigma_E\ \ \partial E/\partial z\right]$, where σ_E is the turbulent Prandtl number for E that has no fixed value and as a rule used $\sigma_E = 1$. The value $\sigma_E = 2.5$ is necessary for simulating intermittent turbulence.

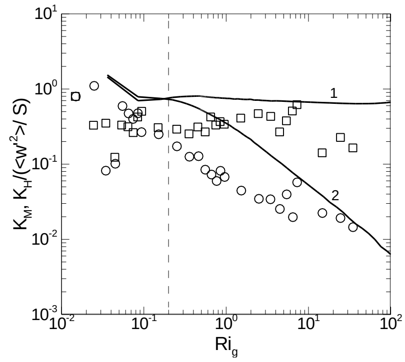

Figure. 1. The simulated eddy diffusivities K_m (line-1) and K_h (line-2) normalized by $\overline{w^2}/S$ with Ri_g in the SBL. The measurement data [2] are: K_m - □, K_h - O.

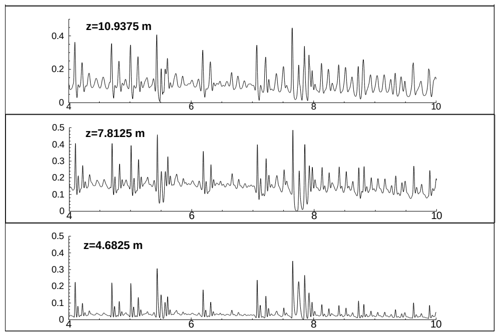

Figure. 2. Time series of $E = 1/2(\overline{u^2} + \overline{v^2} + \overline{w^2})$ at different heights from surface, computed with use the present RANS turbulence scheme for the strong stability case ($\overline{w\theta_s} = -0.05\,\mathrm{m\,s^{-1}}$).

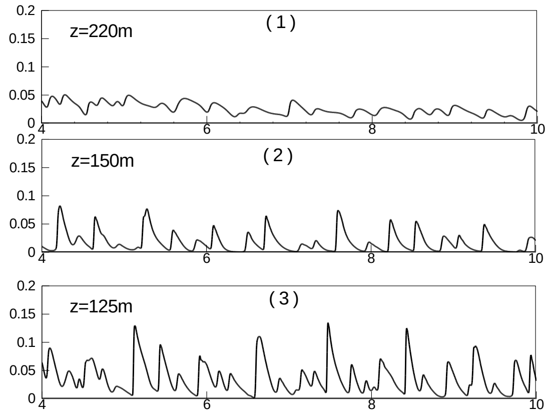

Figure. 3. Time series of $E = 1/2(\overline{u^2} + \overline{v^2} + \overline{w^2})$ at different elevations, computed with use the RANS turbulence scheme for the strong stability case ($\overline{w\theta_s} = -\,0.05\,\mathrm{m\,s^{-1}}$).

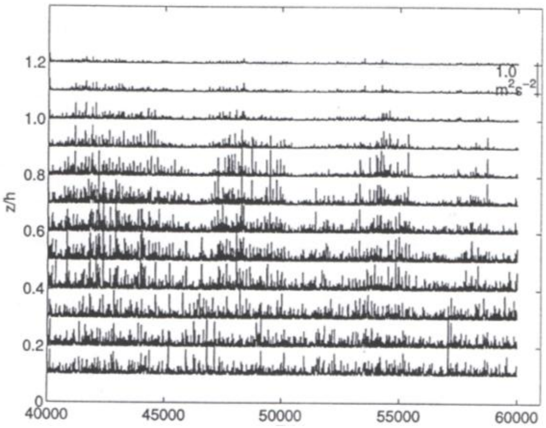

Figure. 4. Time series of $E = 1/2(\overline{u^2} + \overline{v^2} + \overline{w^2})$ at different elevations, computed by the LES scheme [3] for the strong stability case ($\overline{w\theta_s} = -0.05\,\mathrm{m\,s^{-1}}$).

Using the value, for instance, $\sigma_E = 1$ accelerates the turbulence diffusion, smoothing out the intermittent bursts. In strong stability case ($\overline{w\theta_s} = -0.05\,\mathrm{m\,s^{-1}}$) the turbulence can be generated aloft due to strong shear above and below the low-level jet (Fig. 4). Indeed, as numerical simulation by LES scheme [3], as well as by the $E_k - \varepsilon - \overline{\theta^2}$ RANS turbulence scheme show an intermittent presence of elevated TKE below the low - level jet. In the LES study [3] constant value of heat flux at a surface has been chosen for such test too. Are fixed extended periods where E is suppressed under strong stratification. This is more significant at higher elevations toward the LLJ nose at 160 m. In between the quiescent periods, large increases of E over the relatively short time scale are present. Therefore, the nature of the elevated TKE appears intermittent.

References

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