Spatial scale of energy-containing eddies during the morning transition by theoretical modeling

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Resumo

O presente trabalho simula o crescimento da escala espacial dos vórtices que contém energia durante o período da manhã. Tal análise é feita por meio de um modelo analítico de espectro do crescimento da convecção.

1. Growing convection model

The morning transition is the evolving process between the nocturnal and the convective boundary layer (CBL). Its main feature is the convection growth due the gradual increasing of the thermal effect (surface sensible heat flux), causing an increasing of the turbulent kinetic energy (TKE). This paper is focused on the study of the spatial scales of the large eddies during this process, since they are the principal contributors to dispersion of scalars. Such task is investigated by means of analytical modeling of the growing convection based on three-dimensional (3-D) spectrum model (Campos Velho, 2003):

$$E(k,t) = E_0(k)\exp\left[-k^2(\nu_T+\nu)t\right] + \frac{H(k)}{2k^2(\nu_T+\nu)}\left\{1-\exp\left[-k^2(\nu_T+\nu)t\right]\right\} \qquad (1)$$

where the kinematic viscosity is given by

$$\nu_T = 0.038(\psi/z_i)^{1/3}(U/n_I)^{4/3}w_* \qquad (2)$$

with z_i the boundary layer height, U is the longitudinal wind, w_* is the convective velocity scale, $n_I \approx 10\,U/z_i$ is the frequency that representing the inertial subrange, and ν is the viscous dissipation. The dissipation rate is given by $\psi = \varepsilon\, z_i / w_*^3$, where $\varepsilon = 0.7\langle e\rangle^{3/2}/\Delta s$ is the nondimensional dissipation ratio. The subgrid TKE $< e >$ and the mean grid spacing Δs are obtained by large-eddy simulation (LES). As $t = 0$ we have $E(k) = E_0(k)$, the 3-D spectrum of the nocturnal (neutral) layer. For $t \rightarrow \infty$ we have the convective 3-D spectrum $E(k) = H(k)/2k(\nu_T + \nu)$, used to determine the thermal source $H(k)$. The 3-D spectrum is obtained following Kristensen and co-authors' formulation (see Nunes et al., 2007), and the convective velocity variance from the Taylor's theory (Nunes et al., 2007):

$$\sigma_{ci}^2 = 0.98\, c_i \left(z/z_i\right)^{2/3} \left(\psi / \left(f_m^*\right)_i^c\right)^{2/3} w_*^2 \qquad (3)$$

being z the height above the ground, and $\left(f_m^*\right)_i^c$ the spectral peak frequency.

2. Results and discussions

The convective spectrum is dependent on the surface heat flux H_s. Here, H_s increases the following way:

t (hs)	*0*	*1*	*2*	*3*	*4*	*5*
Hs (Kms-1)	*0.0*	*0.08*	*0.16*	*0.24*	*0.24*	*0.24*

Following equation (1), Figure 1 presents the evolution of the TKE for the CBL at three vertical levels: $0.1z_i$, $0.5z_i$, and $0.9z_i$.

From figure 1, one can realize that the spectral magnitude increases with time, due to the addition of energy into the PBL, presenting greater values in the lowest half of the CBL. The first hour of evolution shows a greater value at $0.1\, z_i$, indicating that in the rest part of the convective layer is not fully developed. However, from the second hour the spectral magnitude at $0.5\, z_i$ is close of that at $0.1\, z_i$. The spectral peaks move toward lower wavenumber values (in all vertical levels) during the PBL evolution process. Such behavior indicates an increasing of the energy-containing eddies wavelenght (λ_p). This process is the opposite from that found in the literature for the convection decay case. Figure 2 shows the time evolution of the ratio λ_p / z_i profiles, where the size of the large eddies grows with relation to the level z=1000 m (supposing to be the final PBL height), starting from the first hour of evolution.

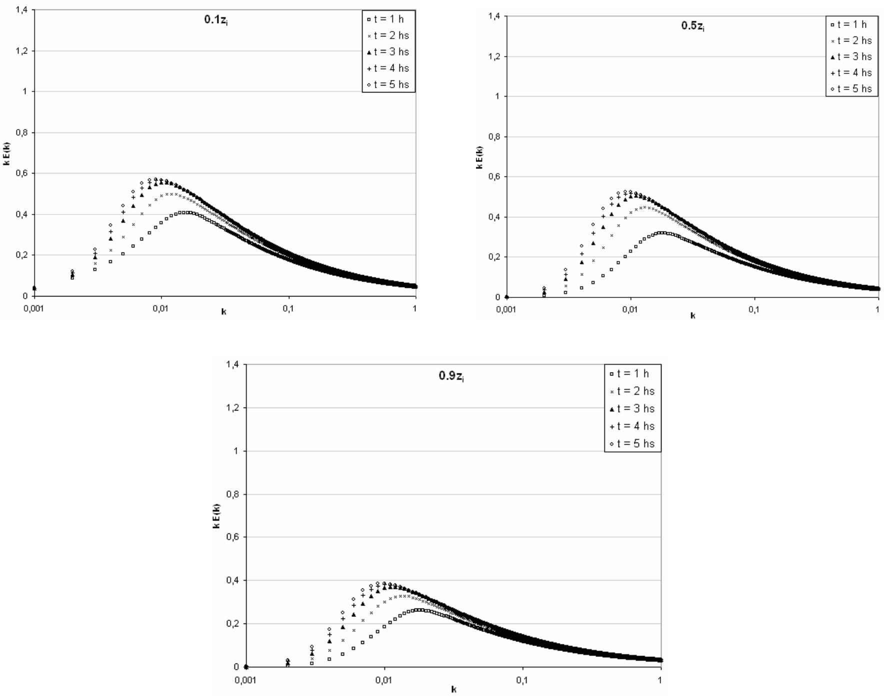

Figure 1. Spectra of morning transition for three vertical levels

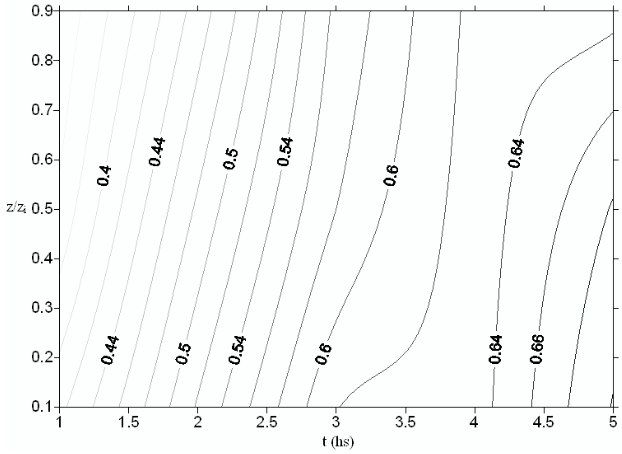

Figure 2. Time evolution for space scale of energy-containing eddies.

Close to the CBL fully developed state (H_s constant and maximum, after the third hour of evolution), the growing is maintained, but much slower. Geometrical constrains indicates that the maximum value of λ_p is the CBL depth. Figure 2 shows $\lambda_p \approx 0.66z_i$ for fully developed CBL.

3. Acknowledgment

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4. References

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