Convective boundary layer growth: Analytical and numerical approaches

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Abstract

The transition phase from neutral boundary layer to convective boundary layer (CBL) is the focus of this paper. The characteristics of the turbulent kinetic energy (TKE) during the growth phase of the CBL are analyzed with the help of two analytical spectral models. The TKE evolutions generated by the analytical models agree fairly well with the results of Large Eddy Simulation for different vertical levels.

Resumo

A fase de transição de uma camada limite neutra para uma camada limite convectiva (CLC) é tópico do presente artigo. As características da energia cinética turbulenta (ECT) durante a fase de crescimento da CLC são analisadas com o uso de dois modelos espectrais analíticos. A evolução gerada pelos modelos analíticos concorda bem com os resultados de simulação de grandes turbilhões para diferentes níveis verticais.

1. Introduction

The study is focused on the behavior of TKE during the morning period through analytical modeling. Here, the TKE during the morning phase starting from a neutral layer is modeled by two theoretical models (hereafter, M1 and M2) of neutral and convective spectra for use in the growth models of convective layer, as described in the next section. The precision and characteristics of TKE spectra generated by theoretical models are compared with data obtained by the Large-Eddy Simulation (LES) model for three different levels in the vertical.

2. A spectral model for the CBL growth

The CBL growth model is obtained by solving the dynamic equation for the TKE spectrum using the Heisenberg theory, which considers the interaction between large and small eddies (Stanišiæ, 1988). Following Campos Velho (2003), the energy transfer has the solution

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

where $E_0(k)$ is the 3-D spectrum of the neutral layer, and the second term on the right hand side $H(k)/(2k^2\nu_T)$ is the 3-D convective energy spectrum. The 3-D spectrum is obtained from 1-D spectra (Kristensen et al., 1989; Goulart et al., 2003):

$$E(k) = k^3\frac{d}{dk}\frac{1}{k}\frac{dF_L}{dk} + 2k^4\int_0^{k^{-2}} s^2 g'''(s)\,ds - \frac{14}{9}k^{4/3}\int_0^{k^{-2}} s^{2/3} g'''(s)\,ds \quad (2)$$

where F_L is the 1-D spectrum in the longitudinal direction for convective and neutral layers, $s=k^{-2}$, and $g(s)$ is a given function (Kristensen et al., 1989). Different analytical spectral models are obtained employing different parameterizations. The velocity variances formulations presented in Kristensen's et al. (1989) paper will be named M1-model, and M2-model is addressed by using the formulation described by Degrazia et al. (1997) and Mangia et al. (2000).

3. Results

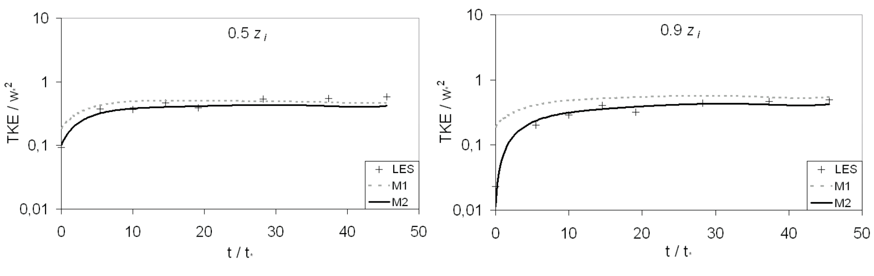
Analytical models are compared with outputs from a large eddy simulation (LES) computer code (Moeng, 1984), with subgrid parameterization from Sullivan et al. (1994). Table 1 presents some parameters used for LES execution.

The numerical experiment is performed as follows: (a) the boundary layer starts with a convective boundary layer, up to reach the quasi-stationary state (QSS); (b) established the QSS, a CBL is simulated by about 1 hour; (c) the decay of CBL is simulated, decreasing the surface heat flux up to zero (following the simulation presented by Goulart et al. (2003)); (d) after the decay of the heat flux, the neutral boundary layer is simulated for 2.5 hours; (e) the growth of the CBL is simulated increasing the surface heat flux from zero up to 0.24 Kms^{-1}, (f) finally, the simulation is carried out with constant heat flux of 0.24 Kms^{-1} for almost 2 hours of simulation.

Table 1. Parameters for LES execution.

Potential temperature	300 K (vertical domain)
Roughness length	0.16m
Geostrophic wind (u)	10 ms-1
Geostrophic wind (v)	0 ms-1
Domain: (x,y,z) directions	(5×103 m) × (5×103 m) × (2×103 m)
Number of grid points	96×96×96

Figure 1 shows the evolution for the TKE computed from analytical spectral model M1 (dotted line), analytical spectral model M2 (continuous line), and from LES results (crosses). There is a good agreement between results from the analytical models and LES at the middle of the CBL. However, for the top of CBL, the analytical model M1 shows unrealistic behavior: the initial TKE for model M1 has a greater value than model M2 and LES. This indicates that the impact of the different parameterizations on the dynamics.



(a) (b)

Figure 1. TKE for the CBL growth simulated by LES and considering two analytical spectral models: (a) results for the middle of the CLB, (b) results for the top of the CBL.

5. References

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