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IMPROVEMENT OF THE K-PROFILE MODEL FOR THE PLANETARY BOUNDARY LAYER BASED ON THE LARGE EDDY SIMULATION DATA

Woo-Geun Cheon *[a], Yign Noh [a], Song-you Hong [a], Siegfried Raasch [b]
[a] LAMOR, Dep. of Atmos. Sci., Yonsei University, Korea
[b] IMUK der Universität Hannover, Germany

1. INTRODUCTION

Troen and Mahrt (1986) developed the K-profile model in which the profile of eddy diffusivity is presumed a priori, considering non-local mixing property of the boundary layer. Although the TM model has been successfully applied to the larger scale models (Hong and Pan 1996, Holtslag and Boville 1993), its performance becomes poorer as the PBL approaches to the free convection (Ayotte et al. 1996). It also produces rather too strong shear within the convective boundary layer (Brown 1996). In particular, the entrainment is not directly related to the K-profile in the TM model, and the growth of the boundary layer is carried out by a separate process. Besides the velocity scale and the Prandtl number, which are determined at the surface layer are assumed to be constant throughout the boundary layer, still need to be verified.

Here we suggest a new K-profile model that resolves the above problems by analyzing the LES data

2. LES model and simulation

The LES model used in this study is PALM (Raasch and Schröeter 2001). The model domain is 4km, 2km, and 1.5km in the each direction (x, y and z), respectively, with the corresponding grid points 80 × 80 × 80. The initial temperature stratification was neutral up to 800m and stable (0.01 $\mathrm{Km^{-1}}$) aloft. Total 12 simulations with different values of Q_0 and U_g were carried out.

3. A new K-profile model

Based on the analysis of the LES data we suggested the modification of the TM model as following (Table 1). Various parameterizations introduced to the new model, i.e., the entrainment rate and non-local momentum mixing, are verified from the LES data.

* *Corresponding author address*: Woo-Geun Cheon, Yonsei Univ., Dept. of Atmos. Sci., Seoul 120-749, Korea; e-mail: cwg@atmos.yonsei.ac.kr

TABLE 1. Model Description

- velocity scale and Prandtl number

$$w_s = \left(u_*^3 + 7kw_*^3 z/h\right)^{1/3}$$

$$K_m \cong w_* h \left(\frac{z}{h}\right)^{4/3}\left(1-\frac{z}{h}\right)^2$$

$$\Pr = 1 + \left(\Pr_0 - 1\right)\times \exp\left[-\alpha\left(\frac{z-\varepsilon}{h}\right)^2\right]$$

- heat flux profile

i) $z < h$

$$-\overline{w'\theta'} = K_h\left(\frac{\partial\theta}{\partial z} - \gamma_h\right) - \overline{w'\theta'}_h\left(\frac{z}{h}\right)^3$$

ii) $z > h$

$$-\overline{w'\theta'} = K_h \frac{\partial\theta}{\partial z}$$

$$K_h = \frac{-\overline{w'\theta'}_h}{\left(\partial\theta/\ \partial z\right)_h}\exp\left[-\frac{(z-h)^2}{\delta^2}\right]$$

$$\left(\delta = 0.1{w_m}^2/\Delta b\right)$$

- momentum flux profile

$$-\overline{u'w'} = K_m\left(\frac{\partial u}{\partial z} - \gamma_m\right)$$

$$\gamma_m = S_m \frac{u_*^2}{w_s h}\left(\frac{w_*}{w_s}\right)$$

- heat and momentum flux at h

$$\overline{w'\theta'}_h = -A_R w_m^3 / h$$

$$\left(w_m^3 = w_*^3 + Bu_*^3, B = 5\right)$$

$$\frac{\overline{w'\theta'}_h}{\overline{u'w'}_h} = C_u \frac{\Delta\theta_h}{\Delta u_h}$$

- determination of h

$$\theta(h) = \theta(z^*) + \theta_p,$$

$$\theta_p = b_\theta \frac{\overline{w'\theta'}_h}{w_s}$$

The new model can be summarized by three major modifications; the incorporation of the entrainment rate into the K-profile, the inclusion of non-local momentum mixing, and the variation of the velocity scale and the Prandtl number with height.

4. Comparison of TM model and a new model with the LES data

The 1-D PBL models were applied to the profiles of the quasi-steady state from LES. The comparison was made only over the subsequent period

Fig. 1 shows the profiles of temperature and heat flux for the PBL dominated by shear production (A3) and for the free convection (B4). The TM model shows that the entrainment is too strong in the shear-dominated PBL, and too weak in the free convection. It is also observed that the temperature gradient is overestimated in the upper part of the PBL. Moreover, the profiles of the mean velocity shows too strong shear, as expected from the absence of non-local momentum mixing (not shown). The new model rectifies these discrepancies, and shows good agreement with the LES data.

The PBL height predicted from the TM model and the new model are compared with the LES data in various experiment, which also attests to the improvement of the new model (Fig. 2)

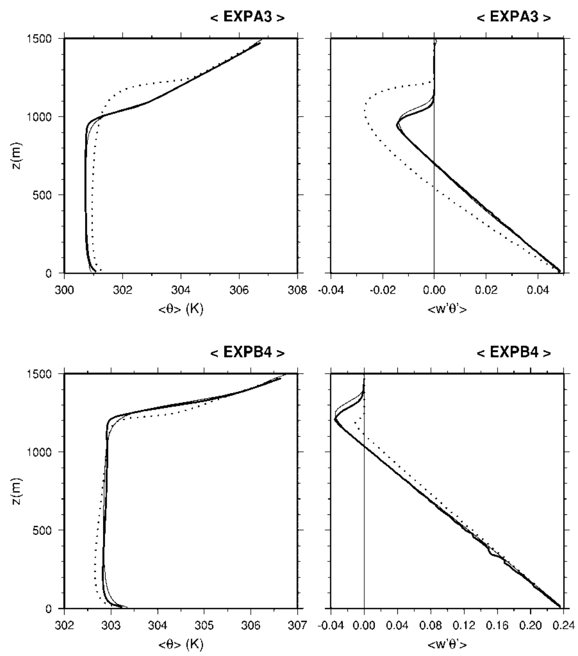

FIG. 1. Vertical profiles of potential temperature and heat flux for PBL dominated by shear production (A3 : Q_0=0.05Kms^{-1}, U_g=15ms^{-1}) and for the free convection (B4 : Q_0=0.24Kms^{-1}, U_g=0.0ms^{-1}) . LES (thin solid), our model (thick solid), TM (dotted).

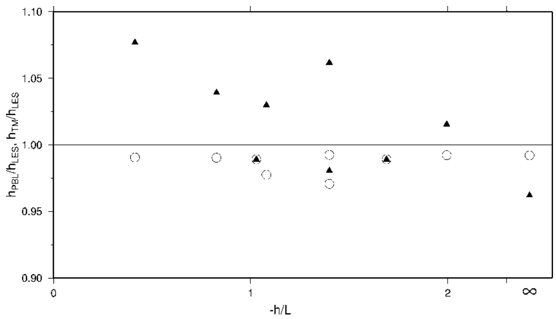

FIG. 2. Comparison of the PBL height predicted from the TM model and the new model with the LES data in various experiment. $h_{new}/\ h_{LES}$ (open circle), $h_{TM}/\ h_{LES}$ (closed triangle)

5. REFERENCE

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