Stable Boundary Layer Mixing in a Vertical Diffusion Scheme

Song-You Hong[1] and Si-Wan Kim[2]

[1]Department of Atmospheric Sciences, Yonsei University, Seoul 120-749, Korea

[2] NOAA/ESRL, Boulder, Colorado, USA

1. Introduction

The YSU PBL scheme is a revised vertical diffusion package with a nonlocal turbulent mixing coefficient in the planetary boundary layer (PBL). Based on the study of Noh et al (2004, BLM) and accumulated results of the behavior of the Hong and Pan algorithm, a revised vertical diffusion algorithm that is suitable for weather forecasting and climate prediction models is developed. The major ingredient of the revision is the inclusion of an explicit treatment of entrainment processes at the top of the PBL. The new diffusion package is named the YonSei University (YSU) PBL (Hong et al. 2006, MWR).

Meanwhile, Kim et al. (2006, WRF workshop) reported that the YSUPBL scheme tends to mix too little over the cold oceans, although YSU scheme overall outperforms the Mellor-Yamada type scheme. The YSU scheme also produces a little mixing over the continental valley in New Mexico (F. Zhang, personal communication). This behavior is regarded to be due to a deficiency in stable mixing in the current version of the YSUBPL as of October 2007, which requires a revision to the Hong et al. algorithm. This paper describes a revised stable boundary layer (SBL) in the YSU PBL for forecasting weather and climate. The new SBL scheme is tested on the platform of short-range and seasonal forecast as well as a one-D column testbed. The interaction with the SBL and precipitation physics is also investigated.

2. Implementation of a stable PBL scheme

The determination of the boundary layer height *h* in the YSUPBL is most critical to the representation of nonlocal mixing. The boundary layer height in the YSU PBL is given by

$$Rib = h\left(\frac{g}{\overline{\theta}}\right)\frac{\left[\theta(h)-\theta_s\right]}{U(h)^2} \qquad (1)$$

where Rib_{cr} is the critical Bulk Richardson number, *U(h)* is the horizontal wind speed at *h*, θ_{va} is the virtual potential temperature at the lowest model level, the θ_v (*h*) is the virtual potential temperature at *h*, and θ_s is the appropriate temperature near the surface.

The critical bulk Richardson number (Rib_cr) is set to be zero in the current version, which does not allow the mixing based on the prescribed profile function. Instead, the local mixing with the function of local Ri is responsible for the SBL.

Based on the accumulated verification results at NCAR, we attempt to allow enhanced mixing in SBL conditions by increasing the Rib_cr in (1). In the new SBL scheme, the vertical diffusion coefficients are computed by a prescribed parabolic shape function as in the case of the unstable conditions in the YSU PBL. The critical bulk Richardson number for the determination of the SBL top is set as a constant value of 0.25 over land, whereas it is a function of the surface Rossby number over the oceans, following the study of Vickers and Mahrt (2003, BLM), which is given by

$$Rib_{cr} = 0.16\left(10^{-7}R_o\right)^{-0.18} \qquad (2)$$

where R0 is the surface Rossby number. As seen in Fig. 1, this allows enhanced mixing when winds are weak.

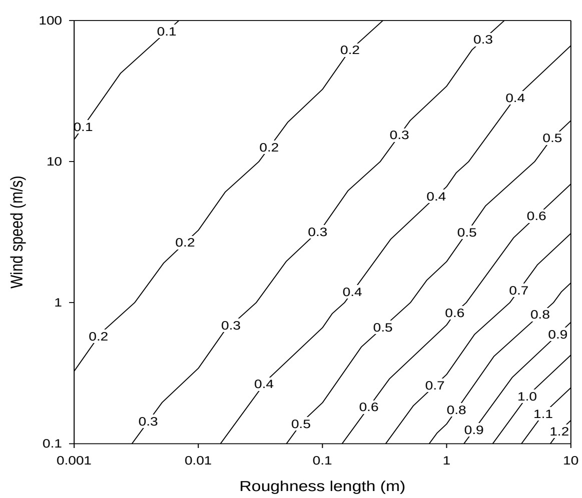

Fig. 1. The critical Richardson number (Rib_cr) in the

function of 10-m wind speed and surface roughness length in Eq. (2).

3. One-D test

The model setup for the one-D case is given in Hong et al. (2006).The results from the one-D column test framework show that the revised scheme reveals an enhanced mixing after the sunset (Fig. 2).

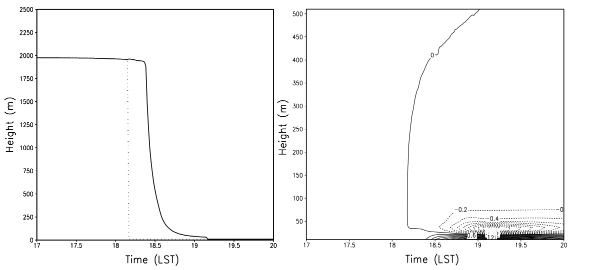

Fig. 2. Temporal evolution of the (a) PBL height from the new (solid) and old (dotted) SBL schemes and (b) the vertical profiles of the differences in potential temperature (new minus old).

4. Heavy rainfall and snowfall events

The description and model setup for the heavy rainfall and snowfall are given by Hong and Lim (2006, JKMS) and Jung et al. (2005, JKMS), respectively. It is seen that the new SBL schemes improves the heavy rainfall simulation by enhancing the precipitation near Seoul. The simulation of heavy snowfall is also improved by reducing a spurious peak in the North-South Korea border and increasing the amount in Chung-Cheong Province.

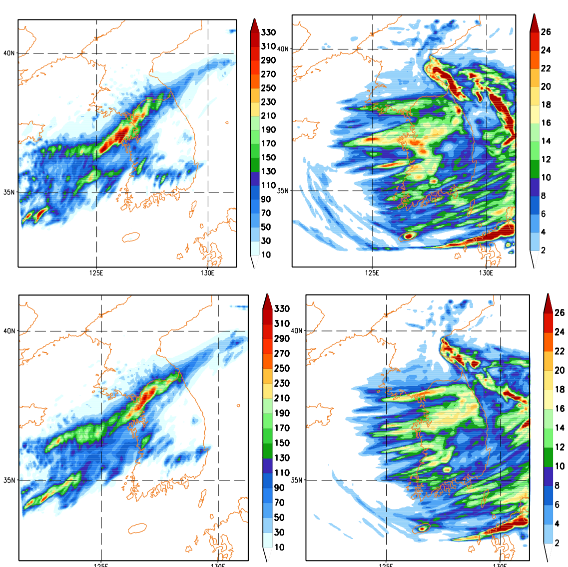

Fig. 3. Precipitation (mm) ending at 00Z 15 July 2001 (left) and ending at 12 Z 5 March 2004 (right) from the new (upper) and old (lower) SBL experiments.

5. Seasonal simulation

The model setup for the simulation is given in Byun and Hong (2007). It is clear that the new scheme improves the large-scale patterns (Fig. 4). The pattern correlation coefficients for the new and old SBL experiments are 0.68 and 0.72, respectively. Major improvements are seen in the southern hemispheric oceans and North America.

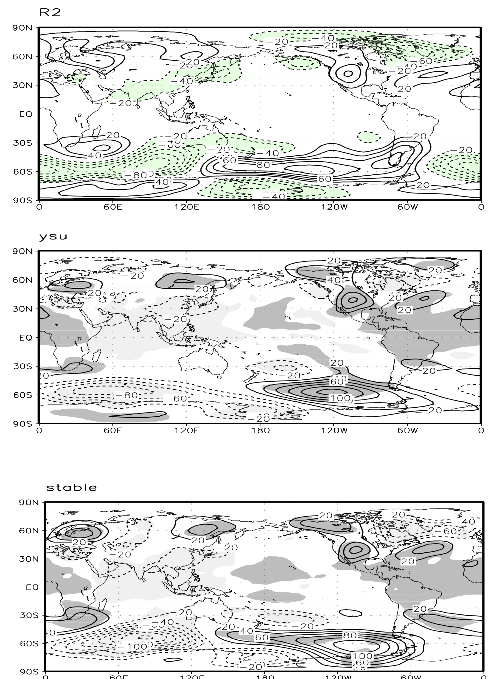

Fig. 4. 500 hPa standing eddies of the geopotential heights (m) for JJA 1996, obtained from the (a) observed (upper), and old (middle) and new (bottom) SBL experiments.

6. Concluding remarks

Together with the revised WSM6 scheme (Dudhia et al. 2007, JMSJ submitted), the new SBL scheme wasa announced to the public in April 2008, as a WRF 3.0 package.

7. Acknowledgments

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8. References: will be provided by the author at the request.