Comparisons on the boundary layer schemes using a single column model

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1 Introduction: Type of boundary layer schemes

The boundary layer parameterization represents effects of turbulent transport driven by the surface and the top of clouds. The boundary layer schemes can be roughly divided into two types of schemes: ”KP schemes” and ”TKE schemes”. The KP schemes are based on the first order closure scheme (down gradient formulation) but with fairly complicated parameterizations for the diffusion coefficients and non-gradient terms using non-local physical quantities like the height of mixed layer, cloud base, cloud depth, velocity scales, and entrainment rate (which is also a function of non local physical quantities). Each parameterization in the KP scheme is well corresponding to actual phenomena. The KP scheme is operationally adopted by the UK Met Office (UKMO) (Lock et al., 2000) and ECMWF.

On the other hand, the TKE schemes are based on transport equations for turbulent moments such as TKE and covariances. Production, dissipation, and transportation terms in the equations are parameterized, then the prognostic equations are integrated. Turbulent fluxes to determine tendency are derived using the integrated TKE. The TKE production terms are generated by shear and buoyancy. Especially in parameterizing TKE production due to buoyancy, partial condensation is considered because accurate evaluation of the production terms is one of the key points in the TKE schemes. The non-hydrostatic meso scale model developed in JMA (JMANHM), which is operationally employed, uses the improved Mellor-Yamada (MYNN) level 3 model (Nakanishi and Niino, 2009), one of the TKE schemes.

2 Comparison with a single column model

In order to see differences between the two type of schemes, the MYNN level 2.5 (MYNN2.5) and level 3 (MYNN3) as well as the first order TKE closure scheme have been implemented into the Unified Model (UM) in the UKMO, and their performances were investigated using the UM single column models for idealized typical boundary layers such as cloud free(GABLS2), capped by stratocumulus (EUROCS/EUCREM), and capped by shallow cumulus (GCSS-ARM). The two types of the schemes look very different in terms of structure of schemes as the KP schemes are based on diagnostics but the TKE schemes are on the prognostic equations. However, roughly speaking, the original boundary layer scheme in UM (UMBL) and MYNN2.5 and

3 give similar results, while the first order scheme is unsuitable in models where vertical turbulence transports cannot be represented explicitly. Of course, there are also differences coming from the differences of their basic frames.

The SCM experiments reveals lots of things. Especially, for the shallow cumulus capped case, it has been confirmed through the SCM experiments that lack of effects by skewness leads to shortage of turbulence mixing, and triggered to introduce the non-gradient buoyancy flux for shallow cumulus suggested by Lock and Mailhot (2006).

3 Stabilization of the Mellor-Yamada level 3 model

During this research, a computational instability problem of the MYNN3 was emerged, which was found in the SCM experiments as well. Terms linear to the prognostics variables are often implicitly discretized to avoid computational instability. The dissipation terms are just the case, and they have been treated implicitly in MYNN3. However, it is not sufficient to secure the stable integration. In fact, the correction terms corresponding to the counter gradient terms induced in the level 3 model also include linear terms to prognostic variables. What is more difficult than the dissipation terms is that one prognostic equation includes linear terms of other prognostic variables. It means that each equation is no longer simple tri-diagonal equations but large sparse equations. Furthermore, linear analysis for computational stability shows necessity of adjustment of production terms. With the implicit discretization for the correction terms and adjustment of production terms, noises are removed and the model is able to run with longer timestep. By trying various types of solvers for the simultaneous equations, the best solver in terms of efficiency and accuracy has also found.

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References

Lock, A. and J. Mailhot, 2006: Combining non-local scalings with a TKE closure for mixing in boundary-layer clouds. *Bound.-Layer Meteor.*, **121**, 313–338.

Lock, A. P., A. R. Brown, M. R. Bush, G. M. Martin, and R. N. B. Smith, 2000: A New Boundary Layer Mixing Scheme. Part I: Scheme Description and Single-Column Model Tests. *Mon. Wea. Rev.*, **128**, 3187–3199.

Nakanishi, M. and H. Niino, 2009: Development of an Improved Turbulence Closure Model for the Atmospheric Boundary Layer. *J. Meteor. Soc. Japan*, **87**, 895–912.