Dependence on resolution of the development of shallow cumulus over land

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1. Introduction

Recent computational resources enable meso-scale simulation with fine resolution by directly representing deep cumulus convection. However, these models are still insufficient in resolution to represent shallow cumulus. Then, as a practical matter, it is interesting to see how shallow cumulus is represented in these models and how the result is affected by an insufficiency of resolution. In this report the dependence on the grid spacing of the development of fine day's shallow cumulus over land are studied with Japan Meteorological Agency (JMA) nonhydrostatic model (hereafter referred to as NHM), based on an idealized setting for LES simulation intercomparison experiment of GCSS ARM case (Brown, 2002), which is built on observations made in the Southern Great Plains on 21 June 1997.

2. Experimental settings

Horizontally uniform surface sensible- and latent-heat fluxes with diurnal variation are prescribed (Fig.1). A large-scale horizontal pressure gradient is applied, which is equivalent to a geostrophic wind of 10m/s in the x direction at latitude 36N. Large-scale potential-temperature and moisture tendencies are imposed, which are small and do not essentially affect the results. The boundary conditions are periodic in the x and y directions. To initiate atmospheric motions, very small perturbations are applied in the initial filed.

Experiments are executed for grid spacing 67m (standard experiment in Brown et al., 2002), 250m, 500m, 1km with Deardorff's turbulence scheme and 2km with Mellor Yamada scheme modified by Nakanishi and Niino (MYNN scheme), represented as M67, M250, M500, M1k and M2kMY, respectively. All the models have horizontal grids of 100x100. The vertical resolution is 40m from the surface to about 5000m for M67 and stretched from 40m near the surface to about 900m at the top for other models. The models are run for 14 hours.

2. Results

It is not shown, but M67 shows results similar to those of LES models described in Brown et al. (2002). Figure 2 shows that grid-scale motions to transport heat from the surface to upwards start at around t=3, 4, and 6 hr for M250, M500 and M1k, respectively. These times are nearly equal to the time when the mixed layer has developed roughly to a depth of the model horizontal grid spacing. Before these times, the sub-grid scale turbulence transports heat in the mixed layer. The development of cloud layer above the mixed layer is also delayed for models with coarser resolution. M67's result is similar to that of M250, though grid-scale motions starts a little (about 30 minute) earlier in M67 than M250.

It is seen from Fig.3 that domain averaged vertical distributions of water vapor mixing ratio are not different so much between the models. It is true for potential temperature. (not shown). However, M2kMY has too-low cloud top and problematic distribution in the cloud layer (700m-2200m). Fig. 4 shows that M1k gives a little larger cloud amount than other models at levels near cloud top. M2kMY have no grid-scale cloud water, but sub-grid scale cloud amount is diagonized. The development to improve the problem caused by the current MYNN scheme, as seen in M2kMY, is now undertaken at JMA.

The horizontal cross sections of moisture field at an altitude of 2000m are presented in Fig.5 for M67, M250 and M1k. Note that the absolute scales are different; the domain sizes are 6.7kmx6.7km and 25kmx25km and 100kmx100km for M67. M250 and M1k, respectively. The diameters of active transporting clouds are about 0.2-0.6km in M67 , 0.5-1.2km in M250 and 2-4km in M1k. The cloud sizes are very different between the models, though the domain-averaged quantities are similar (Figures 3 and 4). It seems that grid-scale motions of the models are regulated in average by the requirement to transport heat from the surface to the free atmosphere, which may lead to a similar cloud amount and domain-average vertical profiles, if the model has a grid spacing finer than about 1km, which is nearly equal to the maximum vertical extent of the mixed layer.

3. Summary and concluding remarks

The switching of a roll to transport heat vertically from sub-grid to grid scale occurs at different times depending on the model resolution. It occurs earlier for higher resolution models: roughly speaking, it occurs when the vertical scale of mixing reaches model's horizontal grid spacing. The clouds represented are very different between the models, but, when once grid-scale motions develop, the domain-averaged quantities such as cloud amount and vertical profiles do not differ so much between the models, at least for resolution finer than ～1km. It should be kept in mind that these results are based on one special case and various case studies are needed.

4. References

Brown, A. R., et al., 2002: Large-eddy simulation of the diurnal cycle of shallow cumulus convection over land. *Q. J. R. Meteorol. Soc.*, **128**, 1075-1093.

Saito, K., J. Ishida, K. Aranami, T. Hara, T. Segawa, M. Narita, and Y. Honda, 2007: Nonhydrostatic atmospheric models and operational development at JMA. *J. Meteor. Soc. Japan*, **85**, 271-304.

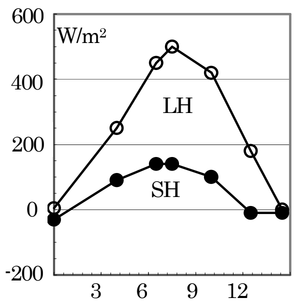

Figure 1. Time evolution of sensible (SH) and latent heat (LH) fluxes from the surface specified in the experiments.

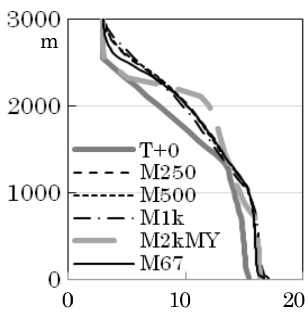

Figure 3. Vertical profile of water vapor mixing ratio (g/kg) averaged over the domain at t=10hr.

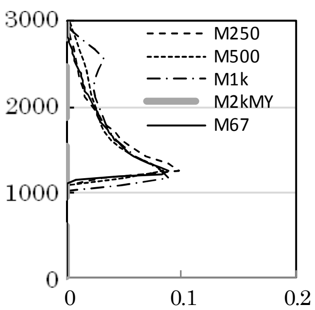

Figure 4. Vertical distribution of cloud amount at t=10hr.

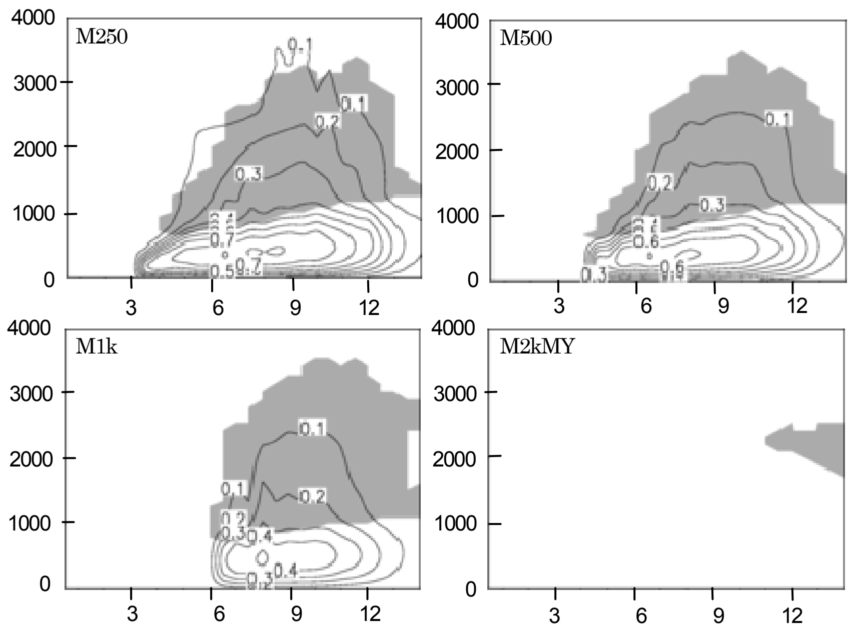

Figure 2. Time-height section of the domain-averaged square root of vertical velocity, w (contour). Shaded region represents cloud region.

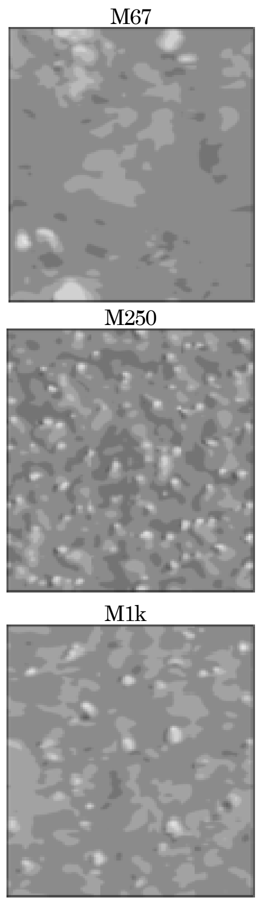

Figure 5. Horizontal distribution of water vapor mixing ratio at 2000m at t=10hr.