Dependency of horizontal and vertical resolutions, and turbulence schemes on snowfall forecasts: Part II Differences of vertical profiles

Teruyuki KATO

Japan Meteorological Agency/Meteorological Research Institute, Chiyoda-ku, Tokyo, Japan
(E-mail: tkato@mri-jma.go.jp)

1. Introduction

Kato (2011) reported that the dependency of horizontal resolutions (500 m - 5 km) and vertical ones, and turbulence schemes (Mellor-Yamada level 3 (Nakanishi and Niino 2006): MYNN, Deardroff (1980): DD) on snowfall forecast, by using the Japan Meteorological Agency (JMA) nonhydrostatic model (Saito et al. 2007), and showed in comparison with the 1km-model with DD that MYNN increased sensitive and latent heat fluxes through the enhancement of low-level wind speeds, while it deceased snowfall amounts. In this study, the reason is examined from the stratification of lower atmosphere and the vertical profiles of updrafts and cloud water amounts.

2. Experimental designs

At first, 12-hour forecasts for a domain shown in Fig. 1a are conducted every 6 hours during 16-20 December 2009 by the 5km-model whose initial and boundary conditions are produced from 6-hourly available JMA mesoscale analyses with a horizontal resolution of 5 km. Then, 9-hour forecasts with 2km-, 1km- and 500m-models for a domain shown in Fig. 1b are conducted by driving the 3-hour to 12-hour forecasts of the 5km-model. Verification datasets for 5 days are produced from hourly output of last 6-hour forecasts of each model. Statically analyses are made for an area shown in the red rectangle in Fig. 1b.

A bulk-type microphysics parameterization scheme in which two moments are treated only for ice hydrometeors (i.e., snow, graupel and cloud ice) is used for precipitation processes in all models, and the Kain-Fritsch convection parameterization scheme is additionally used in the 5km-model. In comparison with control simulations (50 vertical layers), the simulation with 70 vertical layers has about a half vertical resolution below a height of 3 km.

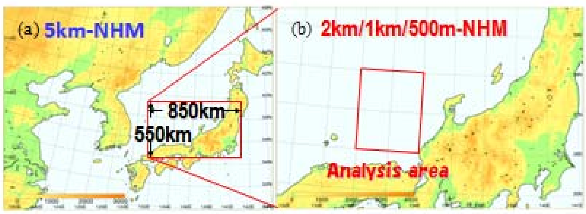

Fig. 1 Model domain and topography of (a) 5km-model and (b) 1km-model. The domains of 2km- and 500m-models are the same as (b).

3. Differences of 1km-NHM results between MYNN and Deardroff

Table 1 shows 5-day mean values in 1km-models with MYNN (dx01) and DD (dx01_dd) averaged within the red rectangle in Fig. 1b. The latent heat flux is about 20 % larger in dx01 than in dx01_dd, while the precipitation amount is about 8 % smaller. The larger values of latent and sensitive fluxes in dx01 are mainly caused by about 16 % larger values of the maximum and mean horizontal speeds for dx01_dd. The difference of specific humidity between the lowest model layer and the sea surface (Δq_v) is larger in dx01 than in dx01_dd, while that of potential temperature (ΔPT) is smaller. This causes that the ratio (dx01/dx01_dd) of sensitive heat flux (11%) becomes smaller than that of latent heat flux. These differences indicate that MYNN immediately transports water vapor upward to decrease its amounts remained near the surface.

Table 1 also shows that the difference of precipitation between dx01 and dx01_dd is almost brought from that of graupel. Since strong updrafts and lots of cloud water are necessary for the production of graupel, it can be supposed that cloud water amounts are less in MYNN than in DD and updrafts are weaker.

Table 1 Five-day mean values in 1km-models with MYNN (dx01) and DD (dx01_dd) averaged within the red rectangle in Fig. 1b. The ratio means dx01/dx01_dd, and SHflux indicates sensitive heat flux, LHflux latent heat flux, MaxWind the maximum horizontal wind speed, MeanWind mean horizontal wind speed. ΔPT and Δq_v indicate the differences of potential temperature and specific humidity between the lowest model layer and the sea surface, respectively.

	dx01	dx01_dd	ratio
SHflux (W/s)	**214.1**	*193.2*	**1.11**
LHflux (W/s)	**346.1**	*288.2*	**1.20**
MaxWind (m/s)	**20.93**	*18.83*	**1.11**
MeanWind (m/s)	**13.08**	*11.29*	**1.16**
MeanWind (m/s)	**13.08**	*11.29*	**1.16**
ΔPT (K)	*13.07*	**13.46**	*0.97*
Δq_v (g/kg)	**8.27**	*7.85*	**1.05**
Precipitation (mm)	*39.15*	**42.65**	*0.92*
Rain (mm)	*10.42*	**10.73**	*0.97*
Snow (mm)	**21.73**	*21.09*	**1.03**
Graupel (mm)	*7.00*	**10.83**	*0.65*

4. Vertical profiles in the lower atmosphere

Five-day mean vertical profiles of virtual potential temperature (Fig. 2) shows that the classification can be made by turbulent scheme, not horizontal resolutions. In DD an absolute unstable layer is found below a height of 200 m, while in MYNN a neutral layer is produced below a height of 500 m. Such an absolute unstable layer is often observed over the Sea of Japan in winter. This indicates that vertical mixing is too strong in MYNN. Moreover, both DD and MYNN produce almost the same vertical profile above a height of 1500 m, but near-surface temperature becomes 0.3 K higher in MYNN than in DD. This is mainly caused by the difference of sensitive heat flux (Table 1).

Figure 3 shows the appearance frequency of lapse rates of virtual potential temperature simulated by 1km-models with MYNN and DD. Absolute unstable layers are scarcely found in MYNN, and most of lapse rates are nearly 0 K km^{-1} below a height of 500 m. In DD, the peak height of the appearance frequency of absolute unstable layers (~ 100 m) is lower that mean values (blue line in Fig. 3b), and unstable layers due to the condensation extend to a height of 4.5 km. The latter produces buoyancy to cause the moist convection. Meanwhile, the strength of absolute instability is considerably smaller in MYNN than in DD. This means that MYNN releases most of the instability by itself. It should be noted that top heights of convective mixing layers in MYNN are almost the same as that in DD, which is independent of horizontal resolutions (not shown).

5. Vertical profiles of vertical velocity and cloud water

The vertical profile of strong updrafts (Fig. 4a) also shows that the classification can be made by turbulent schemes (MYNN and DD), except for simulations with 70 layers. The maximum of strong updrafts is found around a height of 1.1 km in DD, while the height shifts 500 m upward in MYNN. These correspond to the peak heights of the appearance frequency of absolute unstable layers (Fig. 3). In the simulations with 70 layers, updrafts weaken and the heights of strong updrafts extend vertically.

In the vertical profiles of cloud water amounts (Fig. 4b), a peak is found corresponding to the heights with the maximum updraft (Fig. 4a), and it is about 20 % larger in MYNN than in DD while such a difference is not found in strong updrafts. Larger production of cloud water in DD, which is made by larger condensation due to lower temperature (Fig. 2), could cause the effective formation of graupel to bring larger snowfall amounts, in addition to strong updrafts.

References

Kato, T., 2011: Dependency of horizontal and vertical resolutions, and turbulence schemes on snowfall forecasts. CAS/JSC WGNE Research Activities in Atmospheric and Oceanic Modelling, 41, 3.03-3.04.

Nakanishi, M. and H. Niino, 2006: An improved Mellor-Yamada level-3 model: Its numerical stability and application to a regional prediction of advection fog. *Bound.-Layer Meteor.*, **119**, 397-407.

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

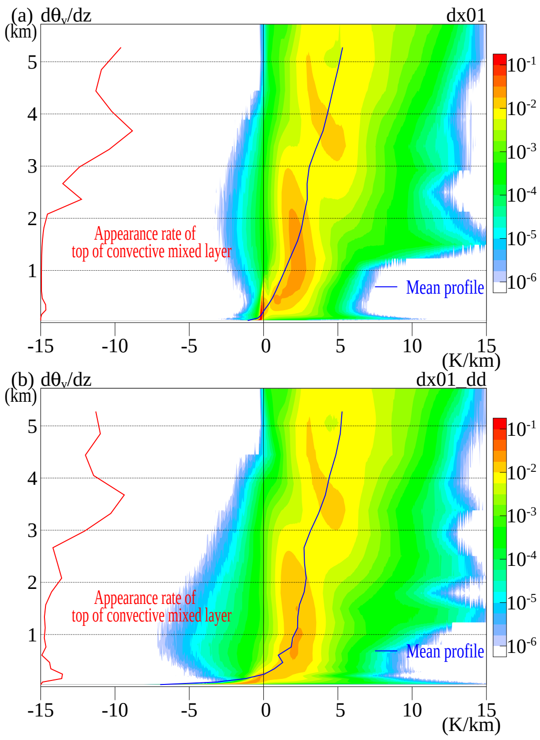

Fig.3 Same as Fig. 2, but the appearance frequency of lapse rates, simulated by 1km-models with (a) MYNN and (b) DD. Blue and red lines denote mean values and the appearance frequency of top heights of convective mixing layers, detected by $d^2\theta_v/dz^2 = 0$.

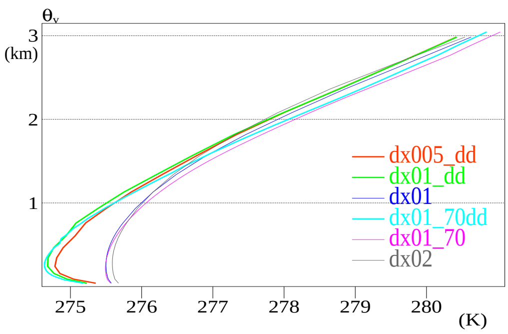

Fig. 2 Vertical profiles of 5day-mean virtual potential temperature θ_v averaged within the red rectangle in Fig. 1b. The results of 2km-, 1km- and 500m-models are indicated by dx02, dx01 and dx005, respectively. Additional symbol of '_dd' indicates the results with DD, and the others those with MYNN. The symbol of '70' also indicates the results with 70 vertical layers.

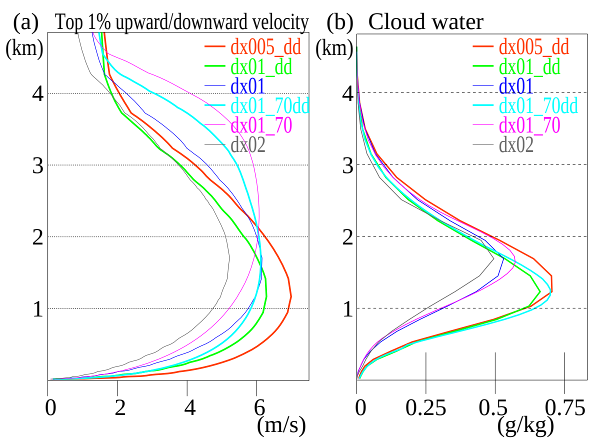

Fig. 4 Same as Fig.2, but (a) the vertical velocity of top 1% updraft and (b) the mixing ratio of cloud water.