Dependency of horizontal and vertical resolutions, and turbulence schemes on snowfall forecasts

Teruyuki KATO

Japan Meteorological Agency/Meteorological Research Institute, Chiyoda-ku, Tokyo, Japan

1. Introduction

Kato and Hayashi (2007) showed that the Japan Meteorological Agency (JMA) nonhydrostatic model (Saito et al. 2007) with a horizontal resolution of 5 km overestimated snowfall over mountainous regions on the Japan-Sea side of the Japan Islands during winter monsoon season and underestimated it over plane regions, whereas such forecast tendencies are improved when a horizontal resolution of 1 km was used. In this study, the dependency of horizontal resolution (5km, 2km, 1km, 500m), the lowest height of vertical layers (LH: 20m, 10m), number of vertical layers (NV: 50, 70) and turbulence scheme (Mellor-Yamada level 3 (Nakanishi and Niino 2006): M-Y3, Deardroff (1980): DD) on snowfall forecasts is examined. The evaporation effect of hydrometeors is also investigated.

2. Experimental designs

At first, 12-hour forecasts 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 analysis data with a horizontal resolution of 5 km. The model domain covers the area of 2500 x 2000 km^2 including the Sea of Japan (not shown). The other models (2km-, 1km- and 500m-models) are nested within forecasts of the 5km-model. These models have the same model domain (850 x 550 km^2) shown in Fig. 1, and their initial conditions are produced from 3-hour forecasts of the 5km-model. Figure 1 also shows the topography of the 1km-model. Model top is set about a height of 21 km in all models. Verification datasets for 5 days are produced from hourly output of the last 6-hour forecasts. 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 the simulation with NV=70, so many vertical layers are set in the lower level that the 41^{st} vertical layer from the surface can have a depth of 100 m.

3. Results

The control simulation (LH: 20m, NV: 50, M-Y3) of the 1km-model well reproduces the horizontal distribution of five-day accumulated precipitation amounts observed raingauges (Fig. 2), although the amounts are slightly underestimated in the Hokuriku District. The precipitation amounts averaged over plain regions with a terrain height lower than 100m are about 90 mm both in the observation and the 1km-model control simulation (Fig. 3b), indicating that the 1km-model has also quantitatively high forecast accuracy.

Figure 3 shows the precipitation amounts of rain, snow, graupel and their total amounts, averaged over the sea and over plain regions with a terrain height lower than 100m in the domain left of black bold line in Fig. 1. The ratio of graupel precipitation amounts to total amounts of snow and graupel (i.e., snowfall) increases as the horizontal resolution becomes higher, and it exceeds 50 % around coastal regions in the 1km-model control simulation (Fig. 4). This high appearance frequency of graupel precipitation around coastal regions well agrees with observations. It should be noted that the 5km-model rarely simulates graupel precipitation, because it cannot represent strong updrafts that are necessary for the production of graupel due to a coarse resolution.

The difference between total precipitation amounts simulated by 1km-model (dx01) and 500m-model (dx005) with DD is small, whereas the 5km-model (dx05) considerably underestimates total amounts in both regions. In the simulations of DD = 10m (thin lines in Fig. 3), precipitation amounts for M-Y3 increase compared with that for DD independent of the horizontal resolution. This is because M-Y3 more largely transports upper-level strong winds to the near surface due to implicitly vertical mixing in comparison with DD, and consequently latent heat flux from the sea becomes larger (not shown).

The dependency of horizontal resolution, LH, NV and turbulence scheme on total precipitation amounts over the sea, plain regions (< 100 m), mountainous regions (> 500 m) and middle height regions (100 m ~ 500 m) are compared with the 1km-model control simulation (Fig. 5). The simulation with DD = 10m increases the amounts for all regions, while the other simulations increase the amounts over the sea and decrease them on land. The decrease of precipitation amounts on land is considerably small for NV=70 (L70) and the simulation in which evaporation rates of snow and graupel are set half (fac0.5). The results of fac0.5 could be brought from the suppression of organization of mesoscale convective systems (MCSs) due to the decrease of evaporation cooling over the sea, which decreases water vapor flux into the land. The precipitation amounts over the sea are considerably larger for DD than for M-Y3. This is because M-Y3 more forcibly produces convective mixing layer over the sea to reduce the atmospheric instability, and consequently MCSs more easily form and develop for DD than for M-Y3 to cause the increase of precipitation amounts.

References

Deardorff, J. W., 1980: Stratocumulus-capped mixed layers derived from a three-dimensional model. *Bound.-Layer Meteor*., **18**, 495–527.

Kato, T. and S. Hayashi, 2007: Relation of Dec. 2005 heavy snowfall and cloud-top heights around the Japan-Sea side of the Japan Islands, estimated from objective analyses and forecasts of cloud-resolving model. *CAS/JSC Research Activities in Atmospheric and Oceanic Modeling*, **37**, 5.13-5.14.

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.

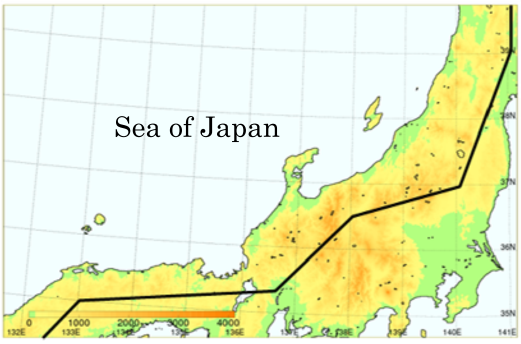

Fig. 1 Model domain and topography of the 1km-model.

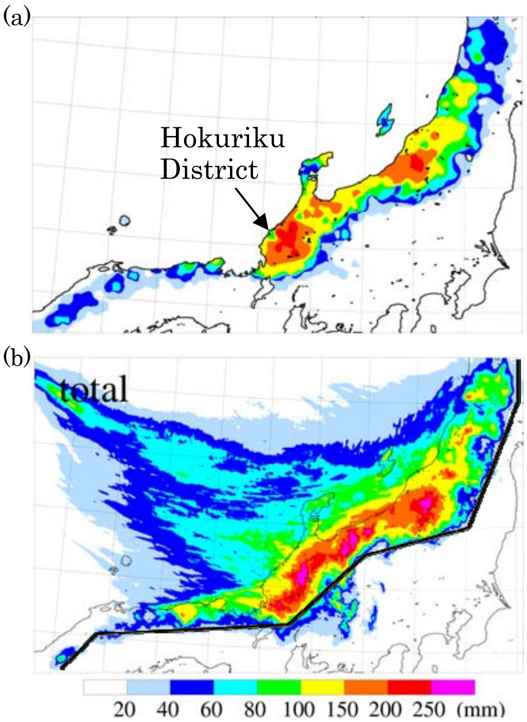

Fig. 2 Five-day accumulated precipitation amounts (a) observed by raingauges and (b) simulated by the 1km-model.

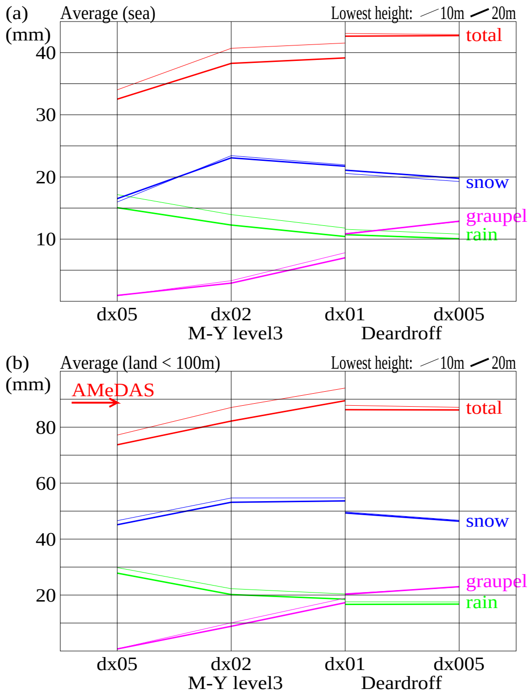

Fig. 3 Precipitation amounts averaged over (a) the sea and (b) the plain region with height lower than 100 m in the domain left of black bold line in Fig. 1. AMeDAS denotes the raingauge observation.

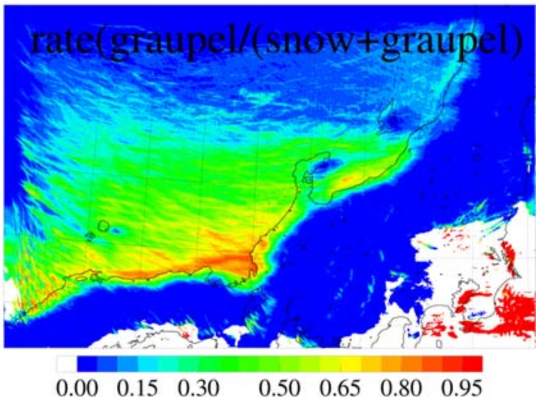

Fig. 4 Same as Fig. 2b, but for the ratio of graupel precipitation amounts to total amounts of snow and graupel.

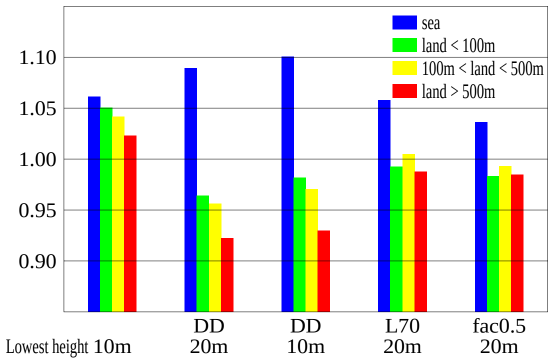

Fig. 5 Comparison with the control simulation of the 1km-model (LH: 20m, NV: 50, M-Y3). Axis of ordinate shows the ratios of averaged total precipitation amounts.