Research on the cloud radiation scheme of the JMA Non-Hydrostatic Model

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The Japan Meteorological Agency Non-hydrostatic Model (NHM) has been developed for research and operational purposes. The 10-km resolution NHM has been the current operational mesoscale model since 1 September 2004, and its resolution will be increased to 5-km in March 2006. For this finer resolution model, physical processes are developed to improve overall performance of the model. Among these, developments of cloud radiation schemes are briefly described in this paper.

A sophisticated radiation scheme developed for the global spectral model of JMA (Kitagawa 2000) is implemented in the NHM since this scheme treats the cloud optical properties more properly than the current scheme developed by Sugi *et al.* (1990) does. This new scheme uses cloud properties such as cloud fraction and cloud water and ice content, which affect greatly the radiation calculation. These parameters from three methods are tested. First, the cloud fraction from predicted cloud water and ice content are directly used as in Xu and Randall (1996). Second, the cloud water content is diagnosed by a statistical relation between temperature and cloud water content (Heymsfield 1977). Third, the cloud water content is estimated from the precipitable water amount as in Hack (1998). When the methods of Heymsfield (1977) and Hack (1998) are employed, cloud fraction is diagnosed from relative humidity by a function of Ohno and Isa (1984). The following four combinations are examined. Ex4 uses the current scheme serving as a control experiment. The outline of the experiments is summarized in Table 1, and the experimental domain is shown in Fig. 1.

Ex1: Kitagawa (2000) + Xu and Randall (1996) (Xu)
Ex2: Kitagawa (2000) + Ohno and Isa (1984) + Heymsfield (1977) (Hey)
Ex3: Kitagawa (2000) + Ohno and Isa (1984) + Hack (1998) (Hack)
Ex4: Sugi *et al.* (1990) + Ohno and Isa (1984) (CTL)

Figure 2 shows Mean Error (ME) and Root Mean Square Error (RMSE), as a function of valid time, of predicted surface air temperatures verified against data from the surface observation meso-network of JMA. It shows negative (positive) bias in daytime (nighttime) in the forecasted temperatures in CTL as well as large RMSEs corresponding to this temperature bias. In Ex1, Xu-scheme reduced the greatly positive bias at nighttime, but it produces a large daytime positive bias and the associated large RMSEs. These deficiencies may be caused by the overestimation of downward shortwave radiation flux at surface because predicted cloud distribution may be less dense compared with the actual cloud distributions. With the Hey-scheme (Ex2), unlike the above-mentioned Xu-scheme, a negative bias with large magnitude as well as the corresponding large RMSEs are brought about. This may be due to the underestimation of the shortwave radiation flux at surface. The Hack-scheme (Ex3) gives almost similar results as in Ex4 (CTL) but negative bias in daytime is removed.

Figure 3 shows vertical profiles of ME and RMSE in the predicted temperature verified against sonde observations. In CTL, negative bias at around 200 hPa and positive bias at around 500 hPa are remarkable. The former may be caused by the black body cloud assumption of clouds. In the Xu-scheme, RMSE and ME are improved at most levels, but positive bias is remarkable at around 200 hPa and magnitude of RMSE at around 200 hPa is larger than CTL. This seems to be result from overestimation of predicted cloud ice content. In the Hey-scheme, negative bias at around 200 hPa is removed, but positive bias at around 500 hPa is not removed. With the Hack-scheme, negative bias at around 200 hPa and positive bias at around 500 hPa are improved to some extent; in terms of RMSE, improvement above 700 hPa is remarkable.

According to the experiments Ex1-4, it was found that the Hack-scheme gives reasonable results in the prediction of temperatures at the surface and aloft. Thus this scheme will be adopted for the radiation scheme in the 5-km resolution operational mesoscale model. This scheme is, however, somewhat rude in diagnosing the cloud fraction, an important parameter in the cloud radiation calculation. Since the results of the experiments indicate that the cloud radiation calculation greatly depends on the cloud distribution and the cloud water content, refinement of cloud diagnosing method and effective use of model-predicted cloud variables remain for future work.

References

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Table. 1 Outline of the experiments

Experimental period	From 7 to 8 Jun 2004 From 12 to 13 Jul 2004 From 16 to 17 Jul 2004 From 27 to 29 Sep 2004
Initial times	00, 06, 12, 18 UTC
Integration time	15 hours
Horizontal resolution	5km
Vertical layers	50
Initial condition	Operational meso analysis
Lateral boundary condition	Forecasts of Regional Spectral Model

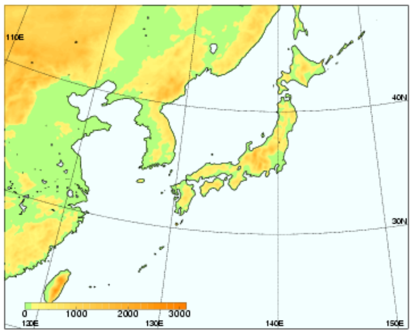

Fig. 1 Forecast domain for the experiments

a) ME b) RMSE

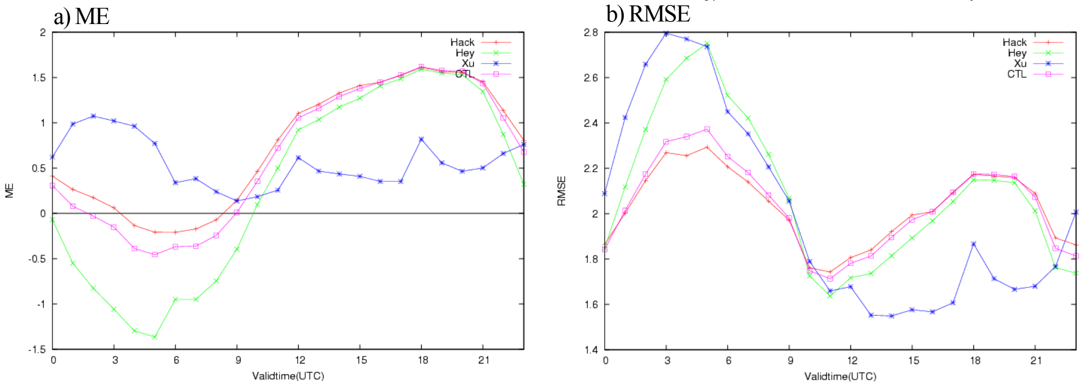

Fig. 2 a) ME and b) RMSE , as a function of valid time, of the surface air temperatures predicted by various input clouds verified against date from the surface observations network of JMA.

a) ME b) RMSE

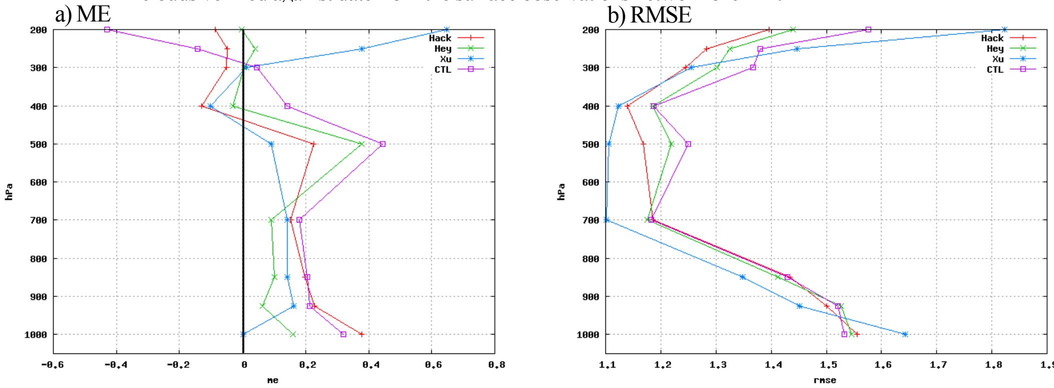

Fig. 3 Vertical profiles of a) ME and b) RMSE in the temperature predicted by various clouds verified against sonde observations. The data at 54 observational points included in the computational domain are used.