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High Resolution Probabilistic Quantitative Precipitation Forecasting in Korea

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ABSTRACT

Recently, several attempts have been made to provide reasonable information on unusual severe weather phenomena such as tolerant heavy rains and very wild typhoons. Quantitative precipitation forecasts and probabilistic quantitative precipitation forecasts (QPFs and PQPFs, respectively) might be one of the most promising methodologies for early warning on the flesh floods because those diagnostic precipitation models require less computational resources than fine-mesh full-dynamics non-hydrostatic mesoscale model.

The diagnostic rainfall model used in this study is the named QPM(Quantitative Precipitation Model), which calculates the rainfall by considering the effect of small-scale topography which is not treated in the mesoscale model. We examine the capability of probabilistic diagnostic rainfall model in terms of how well represented the observed several rainfall events and what is the most optimistic resolution of the mesoscale model in which diagnostic rainfall model is nested. Also, we examine the integration time to provide reasonable fine-mesh rainfall information. When we apply this QPM directly to 27 km mesh meso-scale model (called as M27-Q3), it takes about 15 min. while it takes about 87 min. to get the same resolution precipitation information with full dynamic downscaling method (called M27-9-3). The quality of precipitation forecast by M27-Q3 is quite comparable with the results of M27-9-3 with reasonable threshold value for precipitation. Based on a series of examination we may conclude that the proposed QPM has a capability to provide fine-mesh rainfall information in terms of time and accuracy compared to full dynamical fine-mesh meso-scale model.

1. Introduction

Recently, many people have suffered from the unusual severe weather phenomena such as heavy rains and very wild typhoons. However, it is not easy task to provide reasonable information on these severe weather events. Accordingly it has been eager to find a suitable methodology to provide an early warning against these severe weather events. Quantitative precipitation forecasts and probabilistic quantitative precipitation forecasts (QPFs and PQPFs, respectively) might be one of the most promising methodologies for reasonable warning on the flesh floods.

QPFs and PQPFs must be on time because severe weather phenomena have a tendency to be developed very quickly and locally. By these reasons, they may not allow to be announced in a reasonable advanced time. Accordingly it is desired to develop a methodology to provide detail information locally and quickly. A fine-mesh non-hydrostatic mesoscale model can be hired, however, it requires a significant computational resources as well as integration time so that it may not meet the time restriction to be forecasted in operational sense. An alternative way to provide necessary information on fine-mesh rainfall is utilizing a diagnostic rainfall model to avoid heavy computational requirement fine-mesh full-dynamics non-hydrostatic mesoscale model (Misumi et al, 2001).

The diagnostic rainfall model used in this study is the named QPM (Quantitative Precipitation Model), which calculates the rainfall by considering the effect of small-scale topography that is not treated in the mesoscale model.

2. Methodology

a. Experimental design

In this study, the basic concept of the diagnostic rainfall model is recalculating the rainfall field by introducing the effect of small-scale topography which is not allowed for in the large-scale model. For background rainfall fields for this model, we used the Mesoscale Model Version 3.4 (MM5) which has developed at the Pennsylvania State University (PSU) and National Center for Atmospheric Research (NCAR) (Anthes and Warner, 1978). And we use diagnostic rainfall model to predict the quantitative rainfall. Rainfall predicted by the mesoscale model on a 27 km (hereafter, M27) and 9 km (hereafter, M9) is disaggregated onto a 3 km grid (hereafter, M27_Q3 and M9_Q3) using a diagnostic rainfall model which adds the effects of small-scale topography. And we also perform the simulation of mesoscale model on the same grid (hereafter, M9_M3) as diagnostic rainfall model to compare with the result of diagnostic rainfall model. Fig. 1 and Fig. 2 show the main experimental design and model forecasting domain in this study. To verify these simulated results, Barnes (1964) objective analysis method is applied to construct the gauge rainfall onto a 3 km grid. The algorithm of Barnes is an interpolation technique based on iterative correction using distance weighting. It differs from the Cressman (1959) method in that the searching distance is fixed and the weighting coefficient is a negative exponential function of the gauge gridpoint distance.

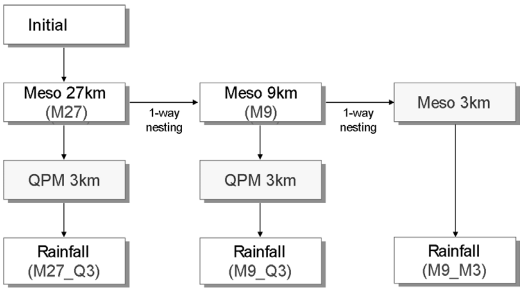

Fig. 1. Experimental design and procedure for model experiment.

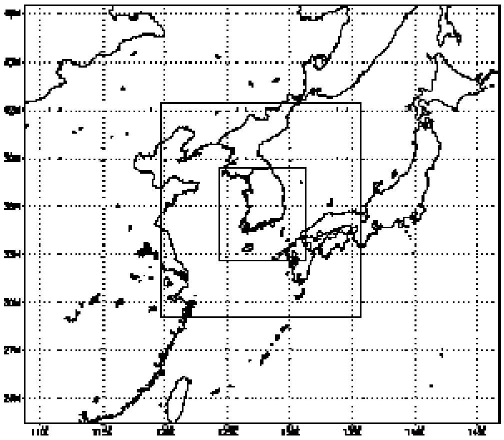

Fig. 2. The model forecasting domain (outermost panel, 106 x 106grid points, 27km mesh ; middle panel, 140 x 140grid points, 9km mesh ; innermost panel, 208 x 208 grid – points, 3km mesh).

b. Case description

The heavy rainfall case studied here covers a 48-h period from 0000 UTC 9 August to 0000 UTC 11 August 2002. The heavy rainfall over the Korean peninsula is caused by atmospheric depression which passed continuously over this region. Maximum precipitation of 240.5 mm was recorded at the southeastern Korean peninsula in this period.

3. Verification over the Korean Peninsula

a. 48-hr accumulated rainfall

The 48-hr accumulated rainfall from mesoscale model (M27, M9, and M9_M3) and diagnostic rainfall model (M27_Q3 and M9_Q3) are compared in Fig. 3. Both models simulate precipitation pattern very similarly, with a general agreement with pattern of observation. Significant amount of precipitation was produced lower over the eastern part of South Korea during this period (Fig. 3). The result of high- resolution mesoscale model is very similar to observation, especially. Also in the result of diagnostic rainfall model, it could catch rainfall like as mesoscale model and observation. We can think the tendency of rainfall from diagnostic rainfall model follows that of rainfall from mesoscale model.

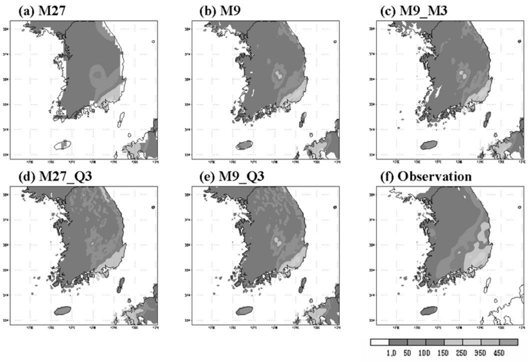

Fig. 3. Simulated 48-hr accumulated rainfall from (a) M27, (b) M9, (c) M9_M3, (d) M27_Q3, (e) M9_Q3, and (f) Obs. from 00UTC 9 to 00UTC 11 August 2002.

b. Peak rainfall amount

We should consider peak rainfall amount in case of short-term quantitative precipitation forecast. Fig. 4(a) shows that time series of peak rainfall amount in this case. Overall in the results of mesoscale model and diagnostic rainfall model, they produced rainfall amount somewhat similarly. The amount of simulated rainfall is more in the mesoscale model than in the diagnostic rainfall model. In general, the amounts of simulated rainfall according to the resolution of input data (M29_Q3 and M9_Q3) are very similar each other. In the difference between models and observations (Fig. 4(b)), we can see that the amount of simulated rainfall is more different in the mesoscale model that in the diagnostic rainfall model. In this case, the result of M27_Q3 shows a better aspect than M9_Q3 and M9_M3.

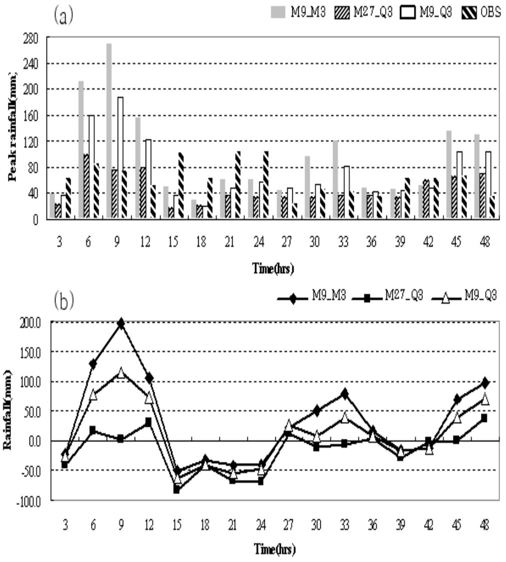

Fig. 4. Precipitation forecast of (a) peak rainfall amount (the upper panel), (b) the difference between models and observations (the lower panel) from 00UTC 9 to 00UTC 11 August 2002.

c. Dependency of rainfall area on the threshold rainfall amount

A comparison of the results for rainfall area suggests that there is little difference between the results of models and observation above the threshold of 0.5 mm / 3 hours (Fig. 5). Overall, the results of the diagnostic rainfall model have a tendency to simulate rainfall in more areas than those of mesoscale model. Although the results of each model show a little difference with observation between 27 hours and 36 hours, we can consider that

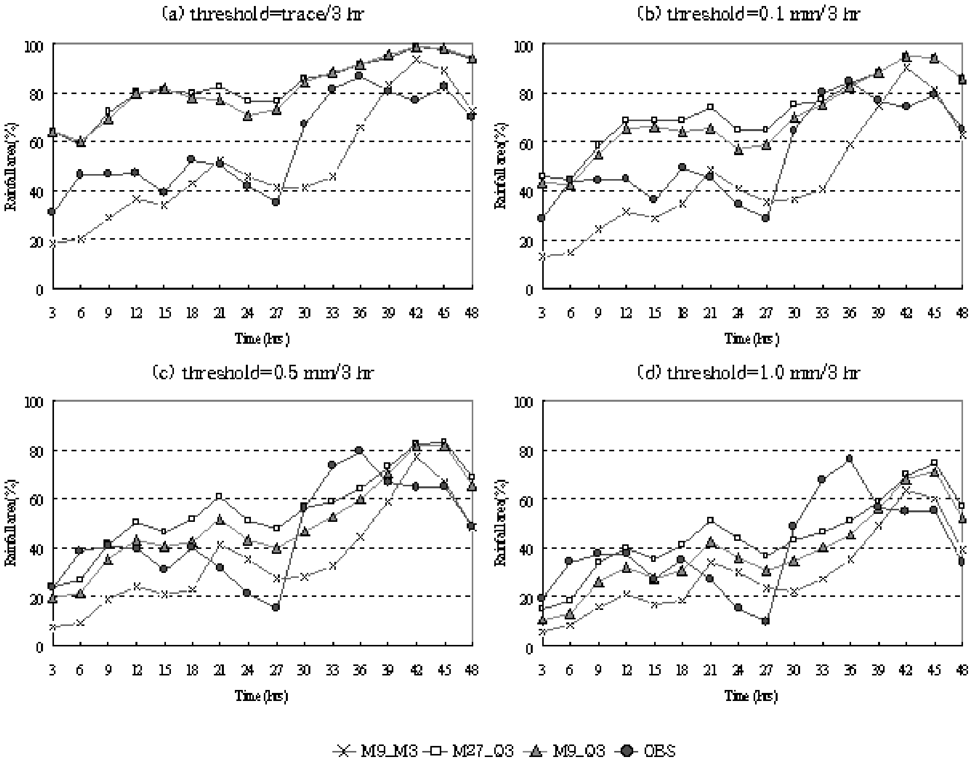

Fig. 5. Dependency of rainfall area on the threshold rainfall amount from 00UTC 9 to 00UTC 11 August 2002.

diagnostic rainfall model can produce rainfall area above a certain threshold.

d. Bias score analysis

We performed the statistical verification analysis in terms of how did the forecast frequency of “yes” events compared to the observed frequency of “yes” events. So a standard verification technique of bias score was used to evaluate model performance. Bias score measures the ratio of the frequency of forecasts events to the frequency of observed events. This indicates whether the forecast system has a tendency to underforecast (bias < 1) or overforecast (bias > 1) events (Wilks, 1995).

Bias score is defined as

$$\text{Bias score} = F / O = H + F / H + M \qquad (1)$$

where H is the number of grid points with correct “yes” forecasts, F is the number of grid points where the phenomenon was forecast but not observed, M is the number of grid points where the phenomenon was observed but not forecast.

The result of mesoscale model shows the tendency of underforecasting (bias <1), however, the result of diagnostic rainfall model shows that of overforecasting (bias > 1). The results of diagnostic rainfall models show a good bias score nearly 1.0 (Fig. 6). Also Fig. 6 show little difference in a magnitude respect according to the resolution of input data.

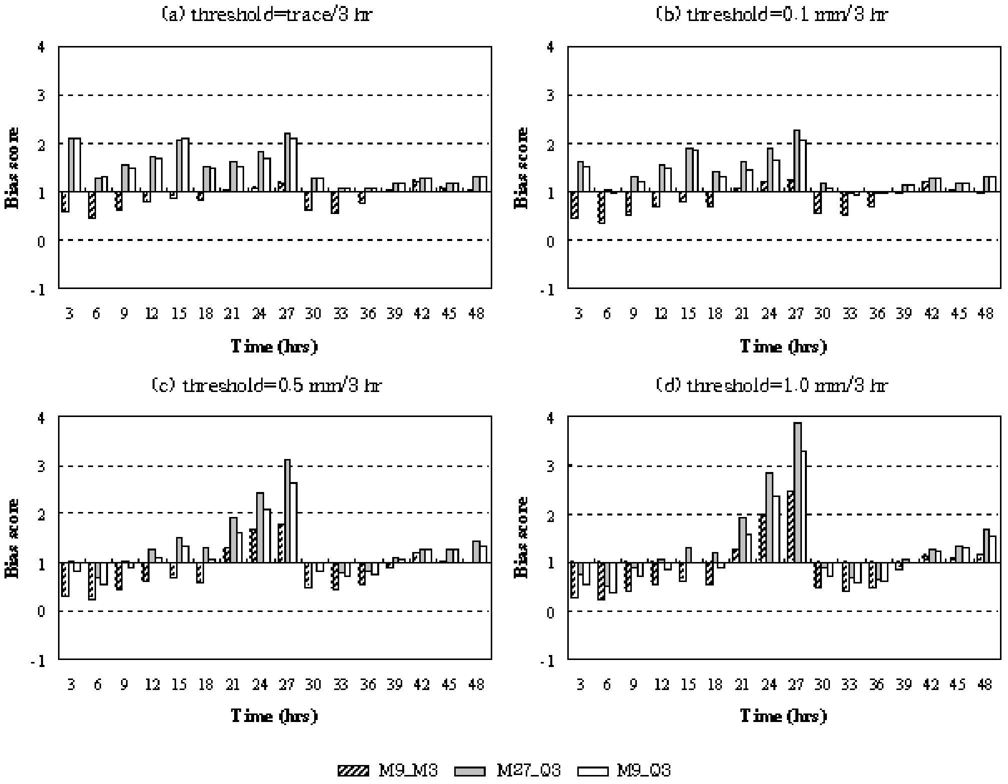

Fig. 6. Precipitation forecast biases on the threshold rainfall amount from 00UTC 9 to 00UTC 11 August 2002.

e. A comparison of integration time

In this study, we used the HPC (High Performance Computing) linux cluster which made of 8 nodes (16 CPUs) Myrinet and LAN in integrated climate system modeling lab of Pukyong National University. We also compared the integration time for each model. In case we simulate rainfall by using mesoscale model, it took 7 hours and 40 minutes. But when we use diagnostic rainfall model, it took 1 hour and 32 minutes (M9_Q3) and 15 minutes (M27_Q3). From these results, if we can calculate the rainfall by using diagnostic rainfall model (QPM), it will save us approximately a percentage of 97 for the total required time.

4. Summary

In this study, we perform the experiment about quantitative precipitation forecasts by using diagnostic rainfall model in heavy rainfall cases. When we use diagnostic rainfall model instead of fully dynamical mesoscale model, how is efficient in the performance of rainfall forecast. The diagnostic rainfall model, QPM, mainly reflects the small-scale topography when it produces rainfall.

We analyze the peak rainfall amounts. From this result, we can know that QPM has capability to simulate the rainfall amounts of observations. And we analyze the rainfall area for 3 km x 3 km grid number to know how well represented the rainfall area and features. The result shows that the rainfall area of diagnostic rainfall model is similar to those of mesoscale model and observation. We also compare the integration time for forecasting. The results show that the QPM has a capability to produce high resolution rainfall information in terms of time and accuracy compared to mesoscale model

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