

## Simulation of precipitation caused by a Baiu front: an evaluation study with radar data

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**Abstract** A numerical simulation of 24-h duration down to the 3-km horizontal resolution was performed with the PSU/NCAR mesoscale model Version 5 (MM5) to evaluate the ability of a mesoscale model to forecast heavy precipitation caused by a Baiu front. Evaluation of the simulated results using both the ECMWF analyses and the radar-based precipitation from the Radar-AMeDAS indicates that the simulation successfully reproduces most principal features of the event, including the synoptic atmospheric circulations, the frontal passage, and the distribution of precipitation. One of the shortcomings of the simulation is that the model tends to underestimate precipitation totals in some heavy rainfall areas. Comparison with winds retrieved from single-Doppler radar data indicates that the model cannot capture a terrain-induced convergence zone. Despite the several deficiencies, the simulated results are encouraging and data assimilation is needed for further improvements.

**Key words** Baiu front; heavy rainfall; mesoscale meteorological model, MM5; precipitation forecasting; radar

### INTRODUCTION

Heavy precipitation and flooding are undoubtedly some of the most significant weather events. Precipitation is an especially difficult weather element to forecast. Considerable studies based on simulations of mesoscale models have provided useful insights on the physical mechanisms and important factors for the formation of heavy precipitation. Recent remarkable improvements of a mesoscale model allow its potential application for short-term (or medium-range) precipitation forecasting to be wider range.

A Baiu front is one of the most significant circulation systems for the hydrological cycle in the East Asia monsoon region. During the Baiu season, the quasi-stationary Baiu front extends from southern China to Japan, and very intense and concentrated rainfall events are often associated with organized mesoscale convective systems, which are embedded within and propagated along the Baiu front (Chen *et al.*, 1988). The objective of this study is to investigate the capability of a mesoscale model to reproduce the spatial variability of precipitation and the associated fields along the Baiu front.

### MODEL DESCRIPTION

The numerical model chosen for this study is the nonhydrostatic version of the Pennsylvania State University—National Center for Atmospheric Research Mesoscale

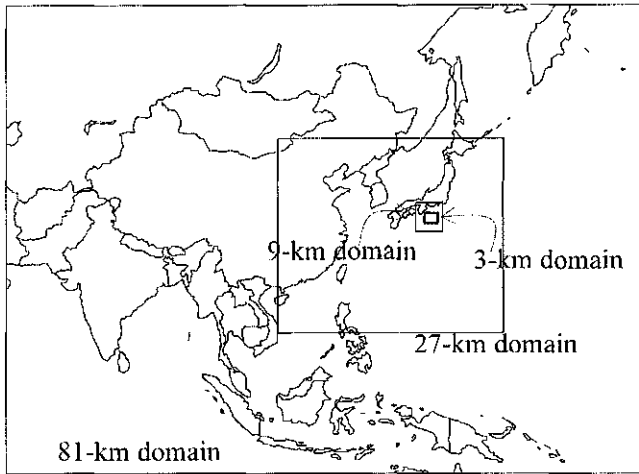


Fig. 1 Geographical location of domains for the MM5 simulation.

Model version 5.3.4 (hereafter referred to as MM5), described in detail by Dudhia (1993). The model configurations and parameterization schemes used in this study are as follows: the coarsest grid domain has a horizontal grid spacing of 81 km, and nested domains have 27, 9 and 3 km, respectively. The model contains terrain-following full-sigma levels in the vertical. The 31 sigma levels are set unevenly as 1.0, 0.99, 0.98, 0.96 ..., 0.13, 0.09, 0.05, and 0.0. The model top is located at the 50 hPa level. The geographic location for four grids can be seen in Fig. 1. The number of grid points in each of four domains is  $163 \times 121$ ,  $172 \times 151$ ,  $55 \times 61$ , and  $85 \times 64$ , respectively. The outermost domain is designed to simulate the synoptic-scale environment. The size of the outermost domain is chosen sufficiently large to minimize the influence of the lateral boundary conditions into the MM5 interior.

MM5 includes parameterizations of dynamical and microphysical processes that are important for mesoscale systems. The Dudhia explicit moisture scheme is used on all the four domains. This scheme accounts for the resolvable scale convection with explicit treatment of cloud water, rainwater, snow, and ice (Dudhia, 1993). The Grell cumulus parameterization is applied, except for the two innermost domains where convective processes could be resolved explicitly. The model uses the Blackadar's high-resolution planetary boundary layer parameterization (Zhang & Anthes, 1982) to calculate vertical fluxes of heat, moisture, and momentum at each vertical layer.

The model is initialized using archived analyses from the European Centre for Medium-Range Weather Forecasts (ECMWF) and Reynolds sea-surface temperature (SST) from the National Oceanic and Atmospheric Administration (NOAA), from which first-guess fields are generated on the coarsest model grid by interpolation at 6-h intervals (00:00, 06:00, 12:00 and 18:00 UTC). The ECMWF datasets are the spectral analyses with triangular truncation at wavenumber 106 (T106) with a horizontal resolution of approximately  $1.125^\circ$ . The time-dependent lateral boundary conditions for the 81-km domain are provided by repeating the above procedure at 6-h intervals and linear interpolation in time using a 16-point, two-dimensional parabolic function.

The two-way interactive nested grid system is adopted between the 27-km and 81-km domains. The 3-km and 9-km domains, however, receive information from the next coarser grid, but do not feed information back to the larger domain (that is called the one-way interface). The model simulation starts at 12:00 UTC on 27 June 2000 and runs for 24 h. A time step of 135 s is used in the coarsest grid domain.

## SYNOPTIC-SCALE CIRCULATION

The event studied here occurred in East Asia on 27–28 June 2000. Figure 2 shows the Geostationary Meteorological Satellite (GMS) Imagery at 00:00 UTC 28 June. The GMS imagery indicates that a cloud band ahead of the Baiu front stretches nearly continuously from the Yangtze River to Japan. The 500-hPa ECMWF analysis at 00:00 UTC, shown in Fig. 3(a), reveals that the contour line at 5840 m is highlighted to indicate the approximate southern boundary of the Baiu front. This boundary is related to the region of transition zone between the subtropical high and the westerly trough. The southerly low-level jet (LLJ) is also found around the Yangtze River basin. This flow is important for intensification of the mesoscale convective systems (e.g. Chen *et al.*, 1998). The 850-hPa relative humidity from the ECMWF analysis suggests that a west–east oriented high humidity belt coincides with the cloud band (not shown). The belt-like region is primarily determined by the northwest Pacific subtropical high, but the orientation of the belt seems to be difficult to forecast because of some oscillations during the Baiu season.

Here, we evaluate the ability of MM5 to forecast the synoptic atmospheric circulations using the forecasts for the 81-km domain and the ECMWF analyses. That is, the ECMWF analyses are used for initial and boundary conditions as well as the evaluation of the simulation. Since the simulation on inner grids is driven by larger-

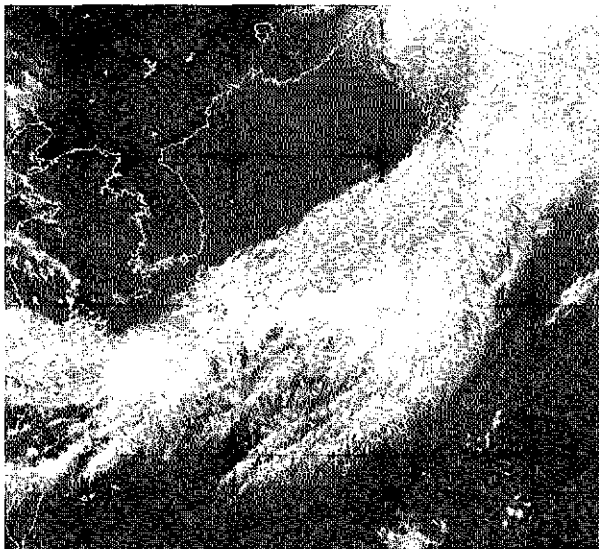
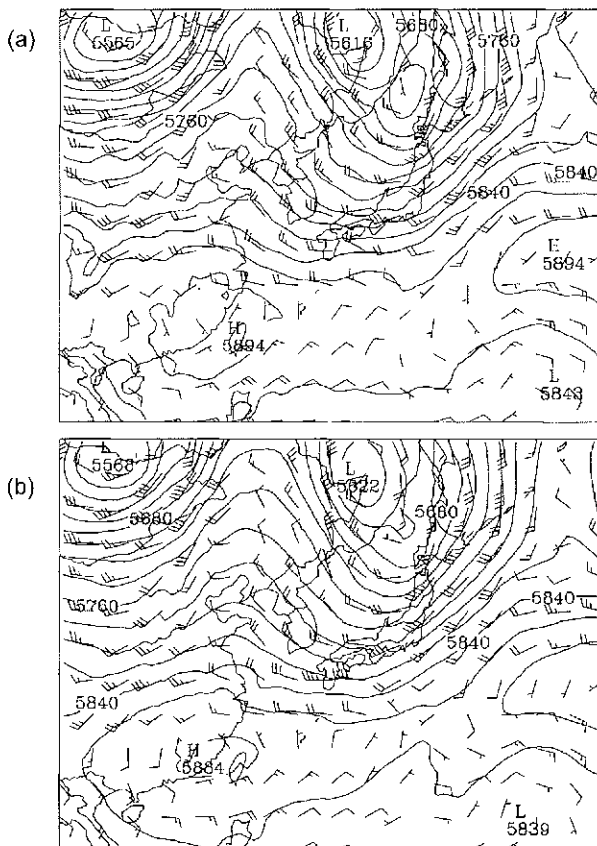


Fig. 2 GMS satellite image at 00:00 UTC on 28 June 2000.

scale atmospheric background, the model has to simulate reasonably well atmospheric circulations to reproduce regional features of the rainbelt and local rainfall maxima (Liu *et al.*, 1996). Figure 3(b) shows the 500-hPa geopotential heights and winds on the 81-km domain from the simulation at  $t = 12$  h. Comparisons of the simulated results with the analyses demonstrate that the model can capture the synoptic important features of the event. The simulated pattern of the atmospheric circulations at other levels agrees as well with the pattern of the analyses (not shown). Figure 3(b) indicates, however, that MM5 apparently simulates the earlier propagation of the Baiu front (contour line at 5840 m) better than the analysis. This is more evident in the simulation at  $t = 18$  h. Such a bias in the simulation would significantly affect distribution of precipitation.

### PRECIPITATION FORECASTS

The model ability to forecast precipitation is verified using radar-based rainfall data from the Radar-AMeDAS. The radar-based data are produced by calibration of data



**Fig. 3** The 500-hPa geopotential heights and winds for 00:00 UTC on 28 June 2000 from (a) the ECMWF analysis and (b) the MM5 simulation ( $t = 12$  h). Heights are contoured every 20 m. Full wind barb represents  $5 \text{ m s}^{-1}$ .

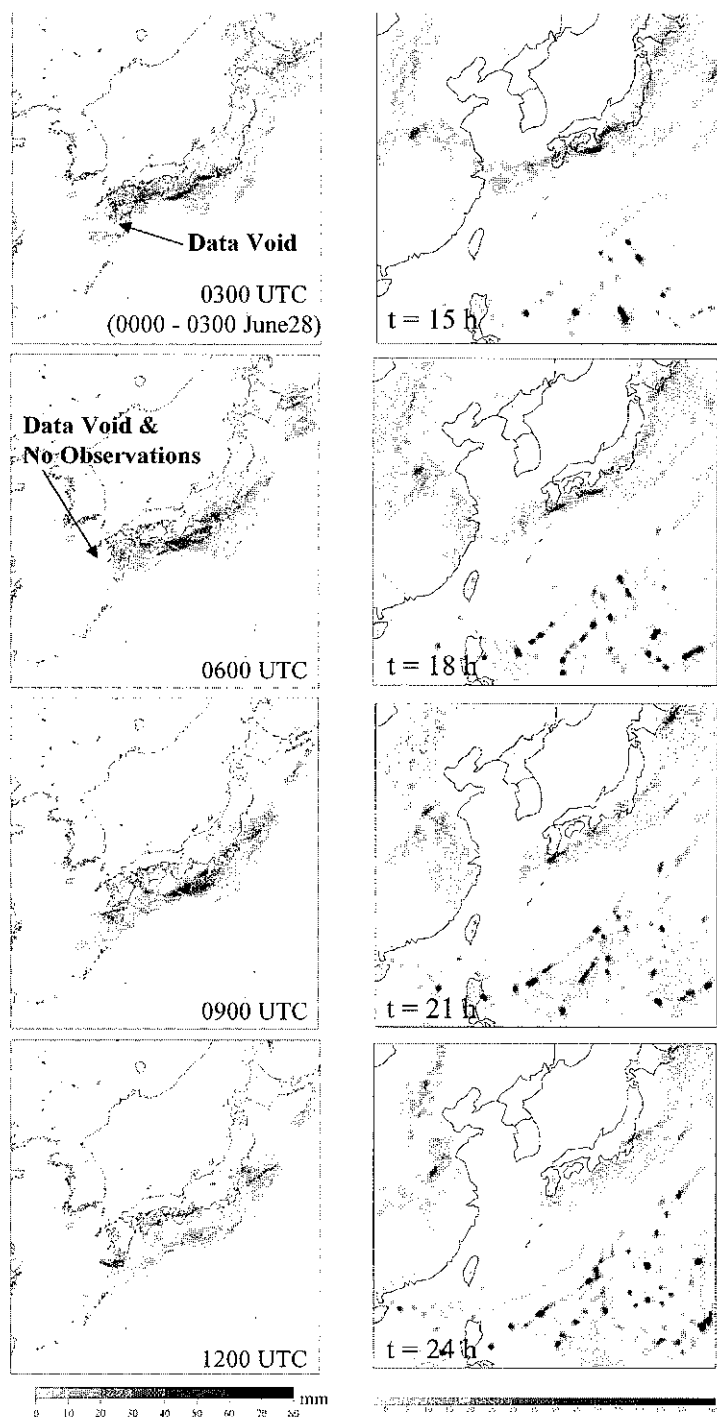


Fig. 4 The radar-based (left) and the simulated (right) sequential distributions of 3-h accumulated precipitation (mm) from 03:00 to 12:00 UTC on 28 June 2000 at intervals of 3 h.

from operational C-band radars around Japan using ground gauged rainfall data collected by the automated meteorological acquisition system (AMeDAS). Both the Radar-AMeDAS and the AMeDAS data are originally produced by the Japan Meteorological Agency. The resolution of radar-based data is about 5 km. Because of the difficulty to forecast, we focus on evaluating forecasts of the 3-h accumulated precipitation.

The left-hand column of Fig. 4 depicts sequential distributions of the 3-h accumulated precipitation yielded by the Radar-AMeDAS data from 03:00 to 12:00 UTC on 28 June at intervals of 3 h. The major aspects of the precipitation to be considered include:

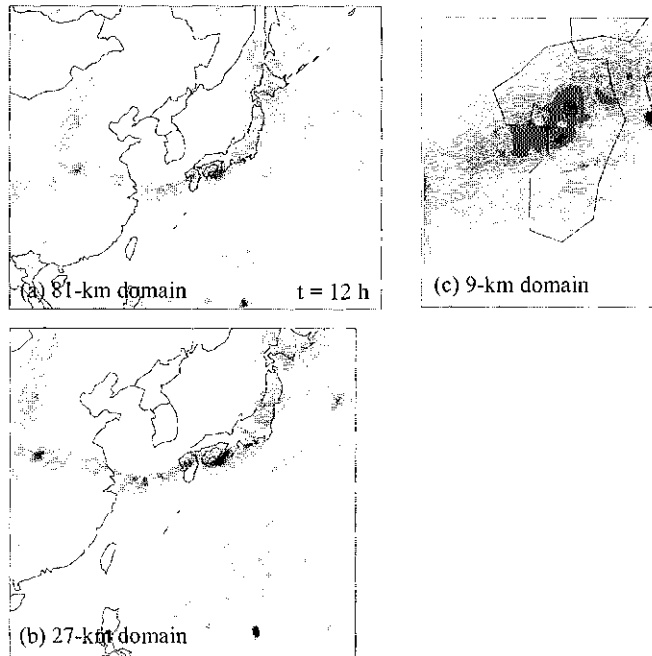
- (a) A west–east oriented rainbelt along the Baiu front is prominent, and several precipitation centres are found in the rainbelt.
- (b) The Baiu front propagates southward, while mesoscale convective systems embedded move eastward.

The distributions of the 3-h accumulated precipitation simulated on the 27-km domain during the same period (15, 18, 21, and 24 h) are shown in the right-hand column of Fig. 4. Despite the relatively coarse horizontal resolution, the MM5 simulation can provide a general description of the mesoscale features listed above. The approximate position and orientation of the precipitation maxima are realistically simulated. The major deficiencies of the model are its underestimation of the precipitation totals in some strong precipitation centres and to fail in reproducing some rainfall areas during the period of  $t = 18\text{--}24$  h, mainly due to the model forecast of the earlier frontal passage.

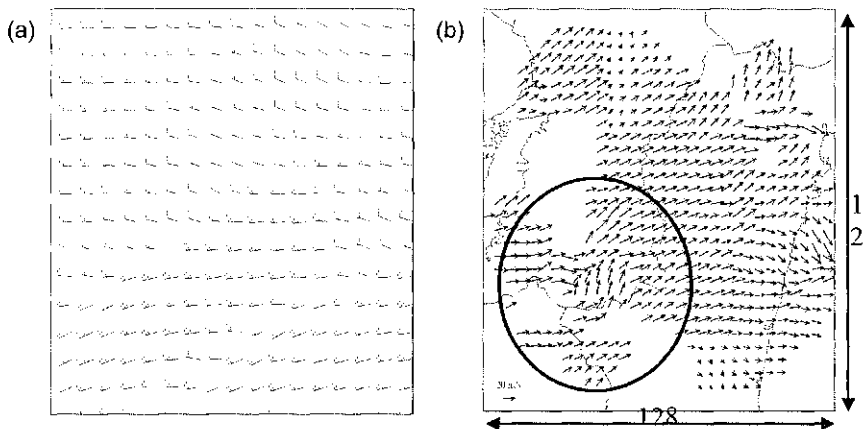
Figure 5 shows the distributions of the 3-h accumulated precipitation simulated on the 81-km, 27-km, and 9-km domains at 00:00 UTC on 28 June ( $t = 12$  h). The majority of the model simulated precipitation is generated by the convective scheme rather than by the grid-scale explicit scheme. Quantitative comparisons between the simulations and the observations indicate that several improvements are found in the result on the 27-km domain compared with the one on the 81-km domain, and that the simulation on the 9-km domain shows better performance than the simulation on the 27-km domain. However, there are not large discrepancies between the precipitation on the 9-km domain and the one on the 3-km domain (not shown). This suggests that simply decreasing the grid size of the model will not always yield a better representation of convective activities.

The simulated winds on the 3-km domain are shown in Fig. 6 together with the retrieved winds from Doppler radar data using the EVVP method (Sugimoto, 2002). The region displayed in Fig. 6 is very orographic, and the convergence zone (circled), which was persistent for several hours, was responsible for the formation of a terrain-induced and localized rainband in the meso- $\beta$  scale. Unfortunately, the simulated winds cannot resolve the convergence zone. The model terrain could be smoothed so that the interaction of the front and the terrain-induced flow cannot be represented.

The understanding of the statistical model behaviour for precipitation forecasting needs further studies on the effects of a microphysical parameterization, a scheme for smoothing the terrain, and others. In effect, precipitation and winds estimated from radar data are valuable information for an evaluation of the model. Moreover, it must be recognized that the resolution of the ECMWF analyses in this study is too coarse to



**Fig. 5** Model-accumulated precipitation for 21:00 UTC on 27 June to 00:00 UTC on 28 June 2000 ( $t = 12$  h) on: (a) the 81-km domain, (b) the 27-km domain, and (c) the 9-km domain.



**Fig. 6** Horizontal winds for the height of 3 km at 0200 UTC June 28 2000, derived by (a) the MM5 simulation and by (b) the EVVP method. Full wind barb represents  $10 \text{ m s}^{-1}$ . The displayed region for the simulation corresponds with the analysis area of the EVVP method.

resolve the variability of convections in the meso- $\beta$  scale. For circumventing the insufficient resolution of the initial and boundary conditions, mesoscale data assimilation should be required. Therefore, Doppler radar data is expected to provide a

potentially valuable source of upper-air data suitable for four-dimensional data assimilation.

## REFERENCES

- Chen, S.-J., Kuo, Y.-H., Wang, W., Tao, Z.-Y. & Cui, B. (1998) A modeling case study of heavy rainstorms along the Mei-Yu front. *Mon. Weath. Rev.* **126**, 2330–2351.
- Dudhia, J. (1993) A nonhydrostatic version of the Penn State—NCAR mesoscale model: validation tests and simulation of an Atlantic cyclone and cold front. *Mon. Weath. Rev.* **121**, 1493–1513.
- Liu, Y., Avissar, R. & Giorgi, F. (1996) Simulation with the regional climate model RegCM2 of extremely anomalous precipitation during the 1991 East Asian flood: an evaluation study. *J. Geophys. Res.* **101**, 26199–26215.
- Sugimoto, S. (2002) Kinematic properties in convective storms derived from Doppler radar observations in mountainous regions of Japan. In: *Mesoscale Convective Systems and Heavy Rainfall/Snowfall in East Asia* (Proc. Int. Conf.), 497–502. Japan Science and Technology Corporation & Chinese Academy of Meteorological Sciences, China.
- Zhang, D. & Anthes, R. A. (1982) A high-resolution model of the planetary boundary layer—Sensitivity tests and comparisons with SESAME-79 data. *J. Appl. Met.* **21**, 1594–1609.