2.4 A COMPARISON STUDY OF CUMULUS PARAMETERIZATION SCHEMES FOR PRECIPITATING SYSTEMS IN THE TAIWAN AREA

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1. INTRODUCTION

Precipitation is one of the most difficult parameters to forecast in numerical weather prediction (NWP). Despite substantial reductions in forecast errors for wind, temperature, sea level pressure, and geopotential heights as model improves, progress in precipitation forecast has been slow (Olson et al. 1995). One of the problems involves the representation of subgrid-scale convection and precipitation process, or the cumulus parameterization, in a NWP model. Many cumulus parameterization schemes (CPSs) have been developed and implemented into NWP models. However, most of CPSs are developed in specific convective environments and are evaluated in a limited number of cases (Yang et al. 2000). None of CPSs are specifically designed for the precipitating systems in the East Asia, or the Taiwan area in particular. Therefore, this paper presents a comparison study of a few CPSs for the heavy rainfall events in Taiwan.

Wang and Seaman (1997) performed a comparison study of four CPSs, the Anthes-Kuo, Betts-Miller, Grell, and Kain-Fritsch schemes, using the Penn State/NCAR MM5 model. Performance of these CPSs was examined using six precipitation events over the continental United States for both cold and warm seasons. They found that no one CPS always outperformed the others. The general 6-h precipitation forecast skill for these schemes was fairly good in predicting four out of six cases examined in the study, even for higher threshold. The forecast skill was generally higher for cold-season events than for warm-season events. There was an increase in the forecast skill with the increase of horizontal resolution, and the gain was most obvious in predicting heavier rainfall amounts. The model's precipitation skill is better in rainfall volume than in either the area coverage or the peak amount.

This study follows Wang and Seaman (1997) to evaluate the performance of four CPSs in the MM5 model, using six rainfall events in four seasons over the Taiwan area. Precipitation forecast is then evaluated statistically over the model grid points using the threat score and bias score for different threshold values based on island-wide raingauge observations.

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2. METHODOLOGY

The PSU-NCAR mesoscle model MM5 Version 2.11 is used as a common framework to investigate four CPSs. The MM5 model is run for six cases at grid sizes of 45 and 15 km.

The four CPSs chosen for evaluation are the Anthes-Kuo scheme (AK; Anthes 1977), the Betts-Miller scheme (BM; Betts and Miller 1993), the Grell scheme (GR; Grell 1993), and the Kain-Fritsch scheme (KF; Kain and Fritsch 1993). All four CPSs examined are the default versions that are implemented in the standard MM5. An ensemble forecast (AG) is also made by arithmetically averaging the rainfall forecasts by four CPSs.

The observations used to assess MM5 predictions are the hourly reports collected by the automatic raingauge stations at the Central Weather Bureau in Taiwan. This dataset consists of 343 stations around the Taiwan island with an average distance less than 5 km (Fig. 1). The raingauge rainfall data are then interpolated to the 15-km model grid points (155 points totally), using the Cressman (1969) objective analysis method with a radius of influence of 10 km.

Evaluation of the precipitation predictions focuses on the rainfall area and rainfall amount. For precipitation area forecast, rainfall forecast of the 15-km MM5 by each CPS experiment is compared to the "observed" rainfall (after objective analysis) and are evaluated quantitatively using statistical skill scores like the threat and bias scores (Anthes 1983) for several threshold values (at 0.25, 2.5, 10, 15, 20, and 25 mm). For precipitation amount forecast, the following statistical parameters are examined: mean error, mean absolute error, mean error percentage, mean absolute error percentage, precipitation summary percentage, and precipitation maximum percentage.

3. CASES AND MODEL

We select a number of cases that represent a variety of synoptic and mesoscale weather conditions producing heavy rainfalls over the

Taiwan area. Table 1 lists the case number, the period of simulation, the type of synoptic environment, the duration of precipitation, and the maximum 6-h rainfall for each case.

The numerical model used in this study is the Penn State/NCAR non-hydrostatic model MM5 (Grell et al. 1994) Version 2.11. The MM5 is a three-dimensional, limited-area, primitive-equation, nested-grid model with a terrain following σ (non-dimensional pressure) vertical coordinate. The MM5 physical parameterizations used in this study include the Blackadar (1979) planetary boundary layer scheme, the radiation scheme with the interaction between clear sky and clouds (Dudhia 1989), the grid-scale Simple Ice (Dudhia 1989) microphysics scheme, and the subgrid-scale cumulus parameterization. The model configuration includes a coarse mesh of 45-km grid size and a fine mesh of 15-km grid size. Domain size for each mesh is 81╳71 for coarse mesh and 91╳91 for fine mesh. There are 27 σ levels in the vertical (surface pressure level to 50 mb). Each MM5 run is 36 hours. The initial condition is provided by the analysis field of the Central Weather Bureau Global Forecast System (CWBGFS; Liou et al. 1997), and the boundary condition is provided by the CWBGFS forecast field. Surface observations and sounding data are included through the MM5 objective analysis package (RAWINS) to improve the initial condition field.

4. RESULTS

Principal finding for rainfall area prediction are summarized here:

- Besides the warm-season events (spring rainfall and summer-time thunderstorm), the 6-h precipitation forecast for four CPSs in the 15-km MM5 is fairly good (TS > 0.4) in predicting rainfall systems in Taiwan (Fig. 2).
- The forecast skill is generally higher for cold-season events (autumn cold front and winter cold-air outbreak) than for warm-season events (spring rainfall and summer-time thunderstorm).
- The 15-km MM5 has the highest forecast skill for heavy rainfall events (Mei-Yu front and Typhoon Otto) compared to other four precipitation cases.
- The predictive skill for each CPS has a large case-to-case variation in all six events, and none of the CPS consistently outperforms the others in all evaluation parameters.
- Besides the warm-season events (spring rainfall and summer-time thunderstorm), the ensemble forecast has the best skill in predicting the occurrence of rainfall (i.e., using a threshold of 0.25 mm).

Similarly, principal finding for rainfall amount prediction are summarized here:

- Besides the spring rainfall case, all CPSs underpredict the rainfall amount, especially for heavy rainfall events (Mei-Yu front and Typhoon Otto).
- The Grell scheme has the best rainfall prediction skill for spring rainfall, winter cold-air outbreak, Mei-Yu front and Typhoon Otto. The Anthes-Kuo scheme has the best skill for summer-time thunderstorm, and the Betts-Miller scheme has the best skill for autumn cold front.
- Among all six cases, the Anthes-Kuo scheme has the most false-rainfall points and the Betts-Miller scheme has the least false-rainfall points.
- For total precipitation volume prediction, the Grell scheme has the best forecast skill in predicting four out of six rainfall events.
- For precipitation maximum prediction, the Betts-Miller scheme has the best forecast score in predicting three out of six rainfall events.

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Table 1: Summary of precipitation events.

Case	Period	Case	Precipitation period	Max. 6-h rainfall (mm)
1	0000 UTC 18 Feb.— 1200 UTC 19 Feb. 1999	Spring rainfall	0600 UTC 18 Feb.— 1200 UTC 19 Feb.1999	40.5
2	1200 UTC 27 Aug.— 0000 UTC 29 Aug. 1998	Summer-time thunderstorm	Entire period	136
3	0000 UTC 6 Oct.— 1200 UTC 7 Oct. 1998	Autumn cold front	Entire period	151
4	0000 UTC 11 Jan.— 1200 UTC 12 Jan. 1999	Winter cold-air outbreak	Entire period	35
5	0000 UTC 27 May— 1200 UTC 28 May 1999	Mei-Yu front	Entire period	121
6	0000 UTC 4 Aug.— 1200 UTC 5 Aug. 1998	Typhoon Otto	Entire period	308

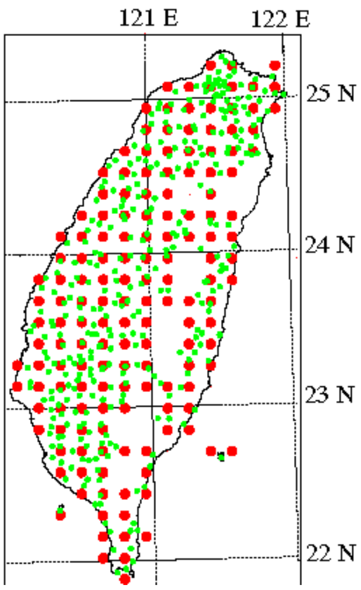

Figure 1: Raingauge stations (small dots) and the 15-km MM5 grid points (big dots) over the Taiwan area.

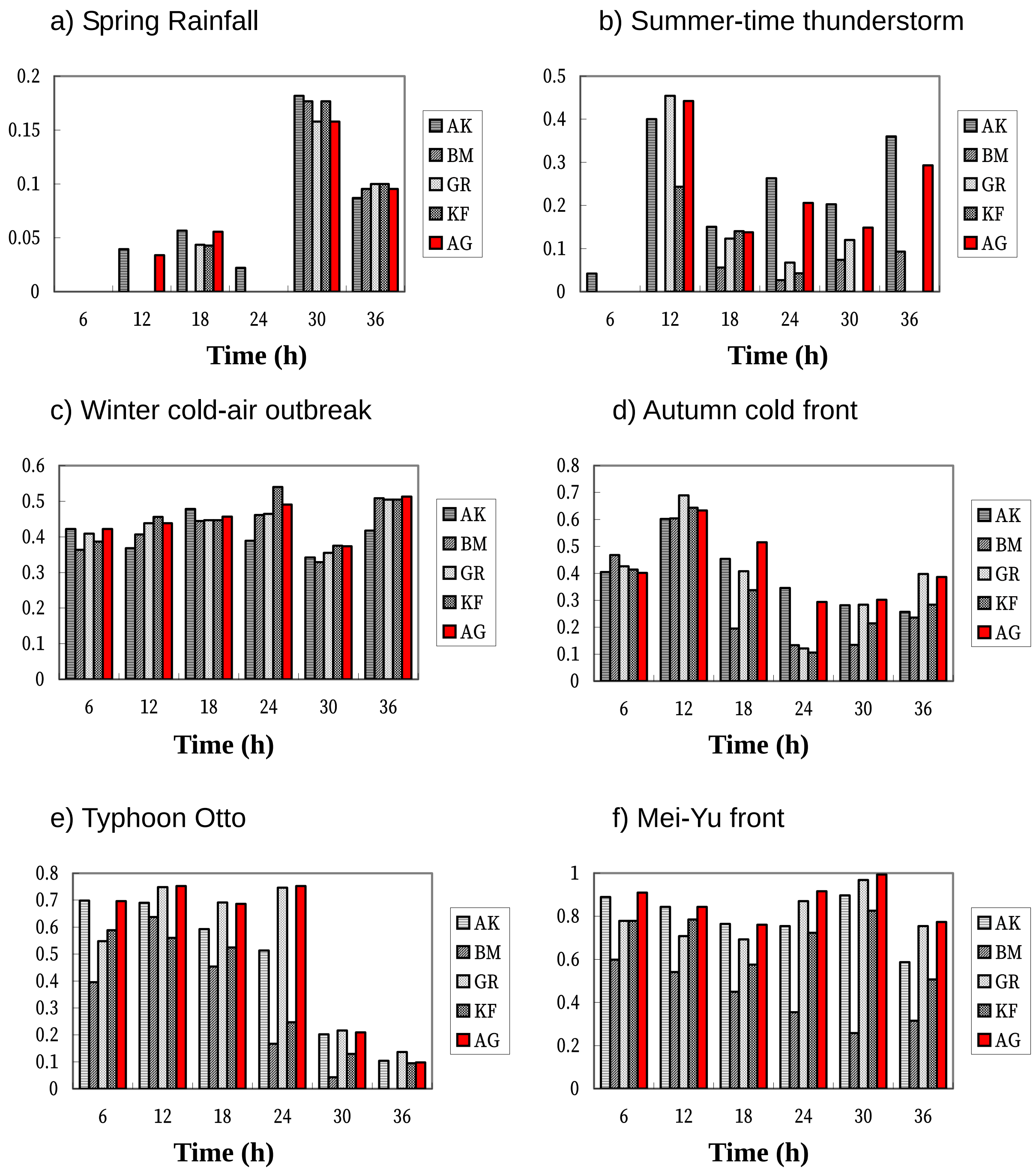

Figure 2: Threat scores (TSs) at the 0.25 mm threshold for 6-h rainfall predictions from 15-km MM5 runs for the a) spring rainfall, b) summer-time thunderstorm, c) winter cold-air outbreak, d) autumn cold front, e) Typhoon Otto, and e) Mei-Yu front case. The times on the abscissa are relative to the model initial time.