

Mixed-Physics Ensemble Forecasting during the Mei-Yu season

Ming-Jen Yang^{1*}, Ben Jong-Dao Jou², Pay-Liam Lin¹, Fang-Ching Chien³,
Jen-Hsin Teng⁵, Jing-Shan Hong⁵, Hui-Chuan Lin⁶, and Shih-Chieh Wang⁴

¹National Central University

²National Taiwan University

³National Taiwan Normal University

⁴Chinese Culture University

⁵Central Weather Bureau

⁶Civil Aeronautics Administration

1. INTRODUCTION

The concept of ensemble forecasting was first introduced by Lorenz (1963), where he examined the initial state uncertainties in the atmosphere and discussed the well-known “butterfly” or chaos effect. Much progress has been made in ensemble forecasts using numerical weather prediction (NWP) models, especially for global NWP application (Krishnamurti et al. 2000a, b). With the increase of computational power, now is the time to attempt the ensemble forecasting on the mesoscale (Grimm and Mass 2002).

Wang and Seaman (1997) performed a comparison study of four cumulus parameterization schemes (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.

Du et al. (1997) examined the uncertainties of initial condition and cumulus parameterization on quantitative precipitation forecasts (QPFs) for a cyclogenesis case in the United States using the Penn State/NCAR MM4 model. Ensemble QPF had large sensitivity to initial condition uncertainties. Ensemble averaging reduced the root-mean-square error for QPF and nearly 90% of QPF improvement was obtained

using ensemble sizes as small as 8-10. Further sensitivity experiments showed that the QPF improvement by ensemble forecasting exceeded the improvement by doubling horizontal resolution.

Mullen et al. (1999) investigated the impact of differences in analysis-forecast systems on dispersion of an ensemble forecast for a cyclogenesis case. Error growth by initial condition uncertainties significantly depended on the analysis-forecast system. QPFs and probabilistic QPFs were extremely sensitive to the choice of precipitation parameterization in the model, similar to the findings of Yang et al. (2000) for a Mei-Yu frontal precipitation event. Therefore, the combined effect of uncertainties in precipitation physics and the initial conditions provides a means to increase the dispersion of QPF ensemble forecast system.

2. ENSEMBLE FORECAST IN THE 2000 MEI-YU SEASON

Based on the concept of ensemble forecasting discussed in the introduction, scientists at several universities and operational centers in Taiwan have joined together to conduct the Ensemble Forecast Experiment during the Mei-Yu season (May and June) since 2000. The participating sites in Taiwan included National Taiwan University (NTU), National Central University (NCU), National Taiwan Normal University (NTNU), Chinese Culture University (CCU), Central Weather Bureau (CWB), and Civil Aeronautics Administration (CAA). Each site used the Penn State/NCAR MM5 (Grell et al. 1994) Version 3.3 as a common model with different precipitation (cumulus and microphysics) parameterizations at different institute. Table 1 lists the physics schemes used in the 2000 MM5 ensemble experiment. In Year 2001, Dr. Jim Bresch at NCAR also joined the Ensemble Forecast Experiment and conducted additional four MM5 runs in order to increase the ensemble spread and test new physics schemes.

The model configuration for the MM5 ensemble forecast experiment includes a coarse mesh of 45-km grid size and a fine mesh of 15-km grid size.

*Corresponding author address: Dr. Min-Jen Yang,
Institute of Hydrological Sciences, National Central
University, Chung-Li, Taiwan, 320, ROC. Email:
mingjen@cc.ncu.edu.tw

Domain size is 81×71 for coarse mesh and 79×79 for fine mesh, with 23 σ levels in the vertical. Each MM5 run is 36 hours. The initial condition for MM5 ensemble is provided by the analysis field of the Central Weather Bureau Global Forecast System (CWBGFS; Liou et al. 1997) as the first-guess field and the boundary condition is provided by the CWBGFS forecast field through the “regrid” package. Surface observations and sounding data are included by objective analysis to improve the first-guess field through the “little-r” package.

During the Mei-Yu season (May and June), Miss Hui-Chuan Lin at CAA put the initial-condition and boundary-condition files for the MM5 ensemble runs at a common ftp site (provided by CWB) twice a day (00 UTC and 12 UTC). Each participating site came to this ftp site to obtain files for the MM5 ensemble run. Because of the narrow bandwidth of Taiwan’s educational network, each participating site only ftped the digital 6-hourly rainfall forecast of 15-km MM5 run back to CWB. Dr. Jen-Hsin Teng at CWB then produced ensemble rainfall forecasts to be used by forecasters to assist CWB’s issuing of heavy rainfall warnings in the Mei-Yu season.

3. PRELIMINARY RESULTS

In order to verify the precipitation forecast, we first utilized the objective analysis technique of Cressman (1959) to interpolate the observed rainfall data recorded by islandwide 343 rain gauge stations in Taiwan to the 138 grid points on the 15-km MM5 grid (Fig. 1). The influence radius of 8.46 km around a grid point was taken to perform interpolation, based on the small-scale nature of precipitation phenomenon and the grid size (15 km) of the MM5 fine mesh. This radius of influence was selected such that a circle with that radius had the same area coverage of a 15 km × 15 km grid square. Then the threat score, equitable threat score, and bias score were calculated (Hamill 1999; McBride and Ebert 2000) on the 15-km MM5 grid points in Taiwan by comparing the forecasted rainfall of each MM5 ensemble member with the “observed” rainfall after objective analysis.

Figure 2 shows the 12-h accumulated rainfall averaged for the 343 rain gauge stations in Taiwan during the 2000 Ensemble Forecast Experiment period (23 May to 20 June 2000). It is clear that the most severe rainfall occurred on 12-13 June with the average 12-h rainfall about 40 mm; the 12-h accumulated rainfall amounts for most precipitation events were about 10-15 mm. When comparing with the 1998 Mei-Yu season [see Fig. 3 in Chien et al. (2002)], this 2000 Mei-Yu season is relatively drier with fewer precipitation events and less accumulated rainfall.

Because during the first 12 hours, the MM5 was still in the spin-up period and had poor rainfall predictive skill, the verification results were not shown. Figure 3a shows the threat scores (TSs) for

the 12-24 h forecast for all 6 members of MM5 ensemble runs during the 2000 Mei-Yu season. It included the MM5 runs with both the 00 UTC initializations and 12 UTC initializations. In the figure, the “ensemble-mean forecast” (“Average” forecast) was done by simply averaging the rainfall forecasts of 6 MM5 ensemble members. The TSs decreased with the increase of precipitation threshold, consistent with Olson et al. (1995), Chien et al. (2002) and many others. It is evident from Fig. 3a that the ensemble-mean forecast usually had higher TSs than other forecasts, especially at the lowest threshold (0.3 mm). Figure 3b is the equitable threat score (ETS) for the 12-24 h forecast for all MM5 ensemble members. The ETSs in Fig. 3b are between 0.05 and 0.2, with higher ETSs at thresholds of 10-25 mm. This may be related to the fact that most precipitation episodes produced average 12-h rainfall of 10-25 mm, so all ensemble members had higher predictive skill for this range of precipitation thresholds. Figure 3c is the bias score (BS) of the 12-24 h forecast for all MM5 ensemble members, showing that the all 15-km MM5 members tended to over-forecast the occurrence of rainfall events (BSs > 1), especially for light-rainfall cases (thresholds less than 15 mm). The verification results for the 24-36 h prediction basically indicated similar forecast characteristics and therefore not shown. More information will be given at the conference.

Finally, the forecasts of NWP models have inherent limitation due to the uncertainties of initial condition and physical parameterization. Taiwan’s steep mountain and rich weather phenomena (Mei-Yu front, typhoon, winter-time cold front, summer-time afternoon thunderstorm and local circulation) make the NWP limitation more severe. In order to reduce the impact of uncertainties of initial condition and physical parameterization on NWP performance, ensemble forecasting is one way to enhance the NWP value and extend its predictability.

ACKNOWLEDGEMENTS

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Table 1: Physics schemes of the 2000 MM5 Ensemble members on the 45-km/15-km nested grid.

Site	Cumulus scheme	Microphysics scheme	PBL scheme
NTU	Grell	Resiner 1	MRF
NCU	Betts-Miller	Resiner 1	MRF
NTNU	Kain-Fritsch	Simple Ice	MRF
CCU	Kain-Fritsch	Goddard	MRF
CWB	Anthes-Kuo	Simple Ice	MRF
CAA	Kain-Fritsch	Resiner 1	MRF

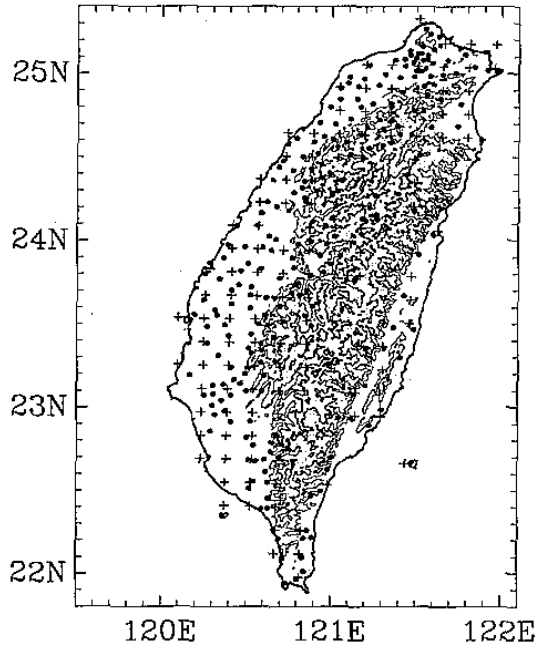


Figure 1: Rain gauge stations (dots) and the 15-km MM5 grid points (crosses) over the Taiwan area. Topographic contours are at 500, 1500, 2500, and 3500 m.

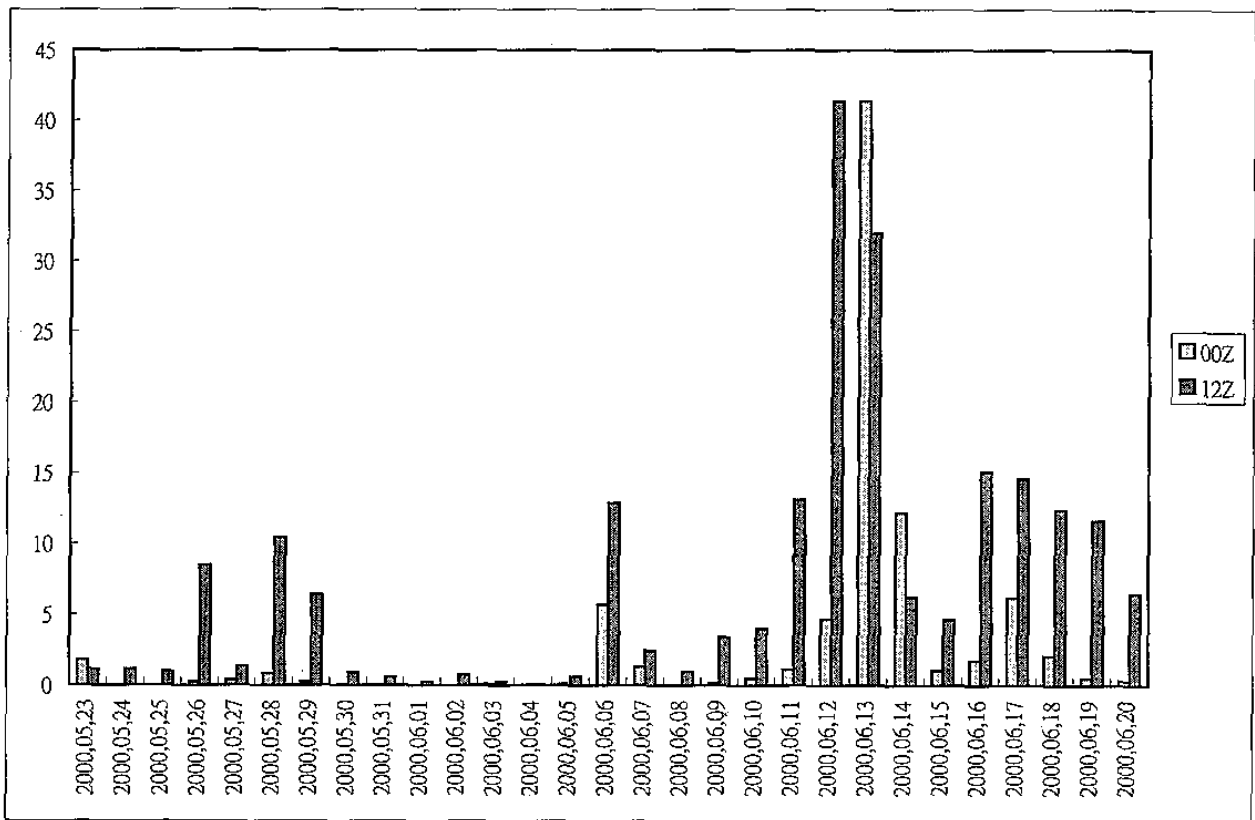
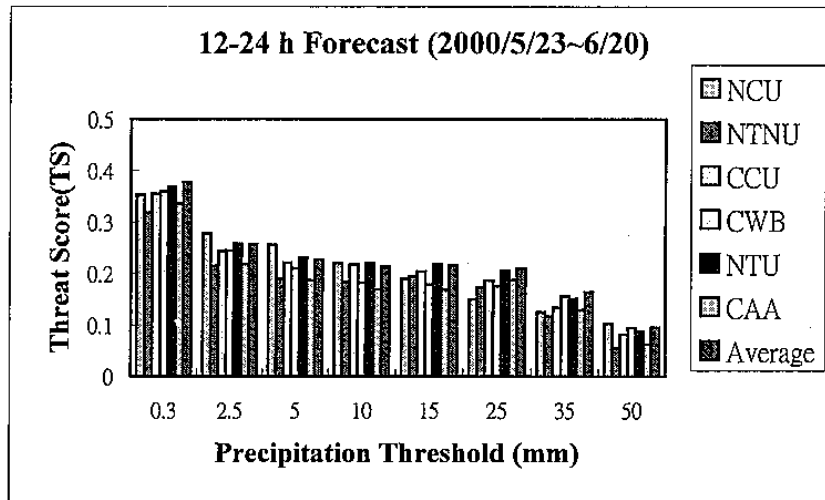
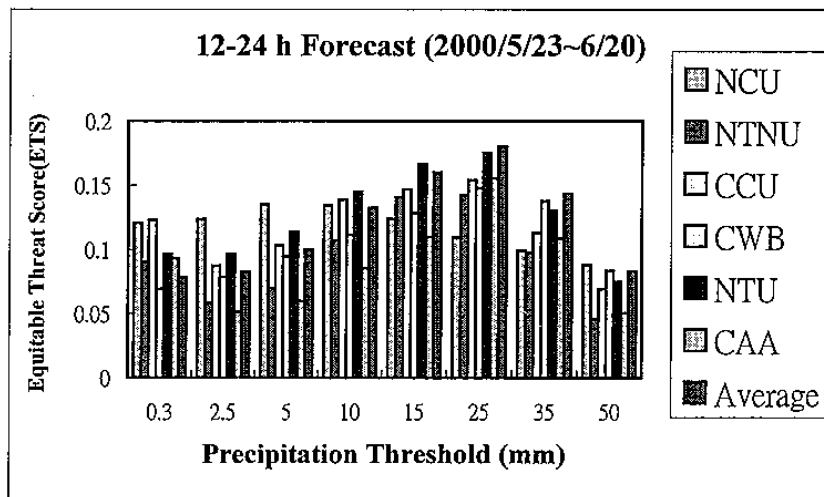


Figure 2: Twelve-hour accumulated rainfall (in mm) averaged for the 343 rain gauge stations in Taiwan during the 2000 Ensemble Forecast Experiment period (0000 UTC 23 May 2000 to 1200 UTC 20 June 2000) at a 12-h interval. The bars in light gray (00 Z) represents daytime accumulated rainfall (0000-1200 UTC, or 0800-2000 LST), and the bars in heavy gray (12 Z) represents nighttime accumulated rainfall (1200-0000 UTC, or 2000-0800 LST).

(a)



(b)



(c)

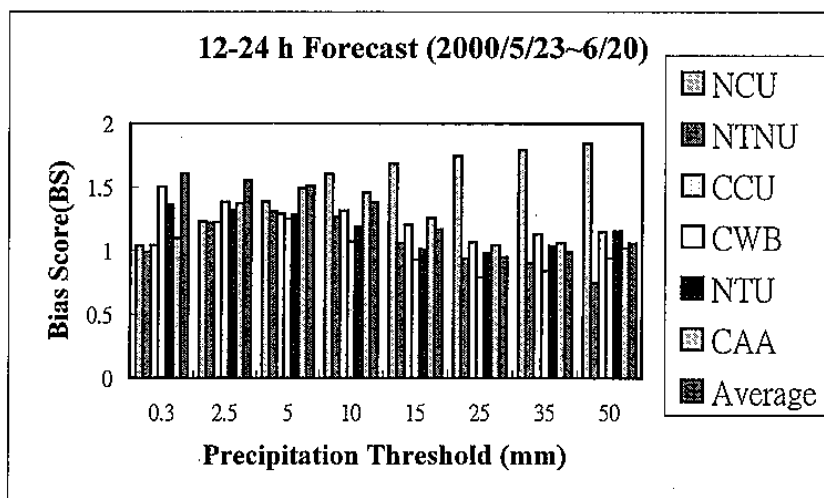


Figure 3: (a) The threat scores, (b) equitable threat scores, and (c) bias scores of the 12-24 h Ensemble Forecasts during the 2000 Mei-Yu Season.

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¹*National Central University*

²*National Taiwan University*

³*National Taiwan Normal University*

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Abstract

The concept of ensemble forecasting was first initiated by Lorenz (1963), where he examined the uncertainty in the atmospheric initial state and discussed the butterfly or chaos effect. Krishnamurti et al. (1999) further tested ensemble forecasting in global weather and climate predictions and found that the multimodel superensemble generally provided the best forecasts.

Based on the above concepts, scientists at several universities and operational centers in Taiwan have conducted the Ensemble Forecasting Experiment during the Mei-Yu seasons since 2000. Each ensemble member used the Penn State Univ./NCAR MM5 (Version 3.3) as a common model framework but different precipitation (cumulus and microphysics) parameterizations at different site. During the experiment periods, each member (six members totally) obtained the same initial-condition and boundary-condition files from the Central Weather Bureau (CWB) Global Model, and then conducted 36-h MM5 forecast at a 45-km/15-km nested grid twice a day (00 UTC and 12 UTC). After model executions, the 6-hourly rainfall forecasts of six 15-km members were sent back to the CWB in order to generate real-time ensemble rainfall forecasts, which were the arithmetic average of rainfall forecasts of six members.

The ensemble forecasts generally outperformed individual forecasts. With a simple arithmetic average, the improvement of ensemble forecasting could be as high as 30 %, as determined by the equitable threat score, and this improvement persisted for all rainfall thresholds. When different weightings are applied to different members in creating the ensemble mean, forecast skill was further enhanced. Therefore, there may be some potential to improve rainfall prediction in the Taiwan area by using an ensemble forecast with a mixture of precipitation parameterizations.