WRF Simulations of a Heavy Rainfall Event in Taiwan

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1. Introduction

Ensemble forecast has been extensively used in operations, since early 1990s, at many forecast centers over the world. In recent years, there have been many studies discussing the performance of an ensemble rainfall forecast (e.g., Du et al. 1997; Ebert 2001; Chien et al. 2004; Chien et al. 2006). Most of them have shown that the ensemble mean forecasts can provide more accurate results than the forecasts from a single ensemble member.

In 2004, a real-time mesoscale ensemble forecasting system that included a WRF model and two MM5 members was set up for regional forecasting in Taiwan and Southeast Asia (Chien et al. 2005). The modeling system was upgraded in 2005 by using WRF as the only forecast model. There were 3 WRF members which used the same physics combination but different initial conditions. The physics include Kain-Fritsch (new Eta) cumulus parameterization scheme, the WSM 5-class microphysics scheme, and the YSU PBL scheme. The 3 different ICs are the analysis and forecast fields from the NCEP GFS, the CWB (Central Weather Bureau of Taiwan) GFS, and the NCEP GFS with WRF Var. The members are named by W1, W2, and W3, respectively.

In June 2005, a heavy rainfall event occurred in southern Taiwan from the 12th to the 16th, with daily rainfall exceeding 300 mm at many stations. Observations show that before 12 June a weak Mei-yu front was moving southeastward from China toward Taiwan, while at the same time tropical cloud clusters were developing over the South China Sea (hereafter SCS). By 0000 UTC 12 June, the cloud clusters had moved northward with the increase of the southwesterly flow as a result of a westward extension of the Subtropical High over the Pacific. Consequently, many mesoscale convective systems (MCSs) were triggered and organized one after others when the cloud clusters encountered the Mei-yu front over southern Taiwan and the nearby ocean. This resulted in the enhancement of the stationary frontal system that extended southwestward from the south of Japan to Taiwan and Hong-Kong. The evolving MCSs along the front resulted in heavy rainfall and severe flooding in southern Taiwan until 16 June when the front weakened. In this study, we use simulated data from the real-time WRF ensemble system to diagnose the rainfall event. In addition, high-resolution (5 km) WRF simulations are used in order to examine the detail structure and evolution of the MCSs.

2. Comparisons of real-time simulations

The model configuration of the real-time ensemble system includes two domains with 45 and 15 km horizontal grid spacing and 31 vertical levels. The 15-km grids of the W1 and W3 members initialized at 1200 UTC 11 June 2005 simulated well the frontal position and the associated rainfall pattern at 1200 UTC 12 June 2005 (Fig. 1). However, the amount of rainfall was smaller than observations over southern Taiwan. This was probably related to the fact that the model terrain in the 15-km grid was not fine enough to simulate the strong terrain lifting effect when southwesterly flow impinged upon the southern Central Mountain Ranges.

At 36 h, the simulated front of the W1 and W3 members still showed a consistent position with the observation exhibited in satellite pictures. The 12-h accumulated rainfall increased slightly from the previous time period (not shown). But, again, the simulated rainfall did not reflect the development of the MCSs. It is therefore clear that the real-time forecast of the 15-km simulation can only provide synoptic pattern of the front. When the embedded MCSs are concerned, one has to increase the horizontal resolution to get good simulations. For this reason, our ensemble system has been upgraded to include a 5-km grid since the 2006 Mei-yu season. In the next section, we show the results of high-resolution runs (5-km) by re-running the heavy rainfall event.

3. High-resolution simulation

Figure 2 shows that the 24-h accumulated rainfall from the 5-km grid agreed well with gauge observations in Taiwan. At 12-36 h, the simulation (Fig. 2b) showed a maximum rainfall of 372 mm over southern Taiwan, where the observation had a maximum of 480 mm (Fig. 2a). At 36-60 h, the simulated rainfall was about 378 mm at the same region, while it was 250 mm in the observation (Figs. 2c, d).

From the simulated 925-hPa geopotential height, winds, and maximum radar reflectivity at h 19 (Fig. 3b), it is clear that the stationary (Mei-yu) front was located east-west-oriented across the central Taiwan. The front was associated with a convection line, relatively low pressure, and strong windshifts over the central Taiwan Strait (hereafter, TS). The frontal position was very close to a convection line that was observed at 1100 UTC 12 June 2005 (Fig. 3a). It is evident that the simulated rainband had a lead time of 4 h compared with the observation. To the south of Taiwan, rainbands developed in the warm and moist southwesterly flow.

A cross section made from the north to the south of the TS indicates that the air in the southwesterly flow was potentially unstable below 500 hPa (not shown). The instability was especially large below 850 hPa. The convection first developed at h 12 when the strong low-level southwesterly flow converged with the westerly flow over the northern SCS. The resulting upward motion provided lifting on the unstable air, which triggered strong convection with maximum updraft of 2.5 m s^{-1}. Large rainfall of ~40 mm h^{-1} occurred along the convection and moved northeastward toward southern Taiwan (see Fig. 3b), resulting in large accumulated rainfall shown in Fig. 2b. The convection line near the central TS developed at h 11 in a frontal environment where the warm and moist southwesterly flow was lifted by the relatively cold and dry air from the north. It reached the maximum intensity with an updraft of ~1.3 m s^{-1} at h 19-20.

After the southwesterly flow pushed further northward, the front moved to the north of Taiwan and the entire Taiwan surrounding region was occupied by the warm and moist southwesterly flow. However, there was still horizontal wind (speed) shear existing in the unidirectional flow over the ocean to the southwest of Taiwan. This resulted in upward motion that lifted the potentially unstable air and triggered convection after h 30. The convective cells developed, organized, and became several mesoscale convective systems (MCSs) along a northeast-southwest line at h 36 (Fig. 3d). This agreed well with radar observation at 2300 UTC 12 June 2005 (Fig. 3c). When moving overland, the MCSs were further enhanced by the terrain, resulting in large rainfall.

Using 1-hrly simulation data, we plot time series for maximum radar reflectivity, maximum CAPE, water vapor mixing ratio (average below 850 hPa), and along-section wind (average below 850 hPa) on a northeast-southwest cross section along line A in Fig. 3b. It is clear that the convection developed early at around h 12 near the northeast end of the cross section, and it reached the maximum intensity by h 18 (Fig. 4a). The air in this region was very unstable with large CAPE (Fig. 4b), and was moist (Fig. 4c). The southwesterly flow (Fig. 4d) contributed to the northeastward transport of large water vapor and CAPE, judging from the slope of maximum value in the time-distance plot.

The along-section winds increased significantly near the southwest end after h 30, and the momentum appeared to propagate toward the northeast. This resulted in large shear vorticity and triggered strong convection as aforementioned (Fig. 3d). The maximum radar reflectivity in Fig. 4a shows clearly that the convection first developed in the southwest and moved northeastward with time. After the convection, both water vapor and maximum CAPE decreased.

The above is just some of our preliminary results of the event. More will be presented in the workshop.

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Ebert, E. E., 2001: Ability of a poor man's ensemble to predict the probability and distribution of precipitation. *Mon. Wea. Rev.*, **129,** 2461-2480.

(a) **(b)** **(c)**

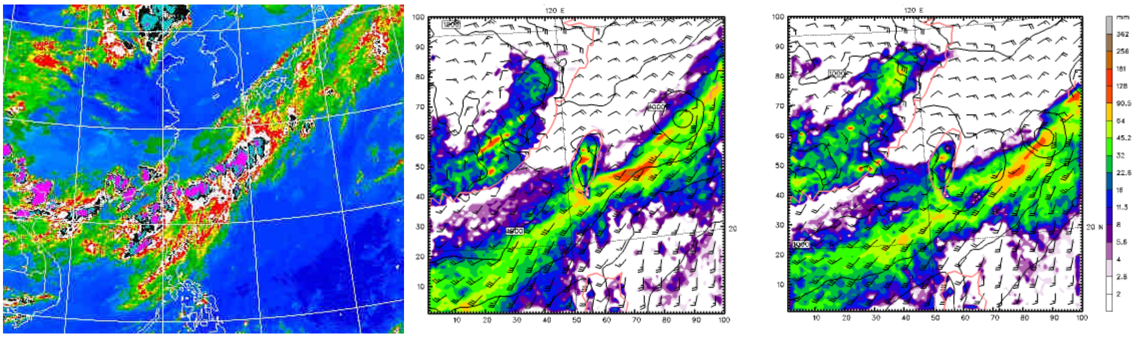

Fig. 1: (a) Satellite imagery at 1200 UTC 12 June 2005. (b, c) The 12-h accumulated rainfall, SLP, and surface winds at 24 h forecast of the 15-km grid of the W1 and W3 members, respectively.

(a)2005061200-1300 **(b)12-36h** **(c)2005061300-1400** **(d) 36-60h**

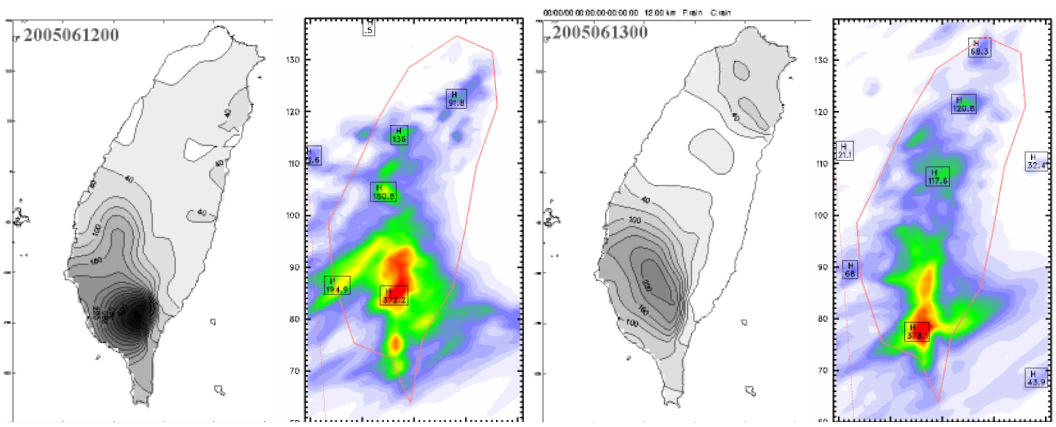

Fig. 2: (a) The 24-h accumulated rainfall observed from 0000 UTC 12 June to 0000 UTC 13 June 2005. (b) The 24-h simulated rainfall from 12 to 36 hours into the simulation. (c) Same as (a), but from 0000 UTC 13 June to 0000 UTC 14 June 2005. (d) Same as (b), but from 36 to 60 hours.

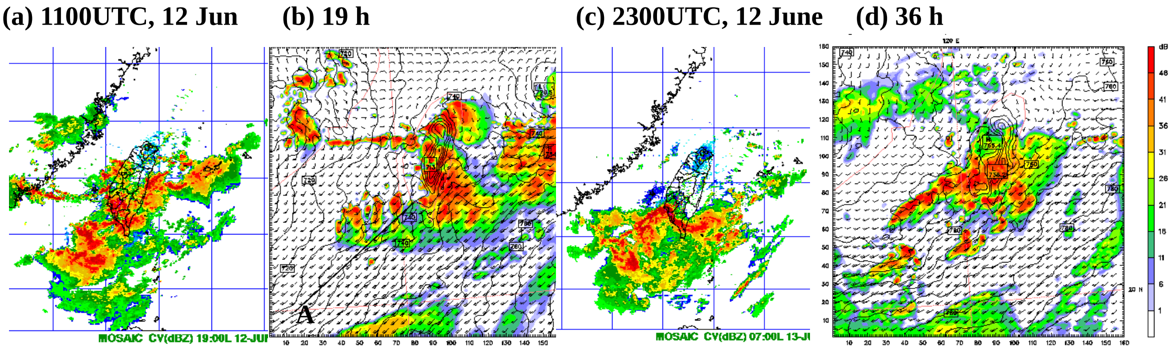

Fig. 3: (a) Radar reflectivity at 1100 UTC 12 June 2005. (b) Simulated maximum radar reflectivity and 925-hPa winds at 19 h. (c) Same as in a, but at 2300 UTC 12 June 2005. (d) Same as in b, but at 36 h.

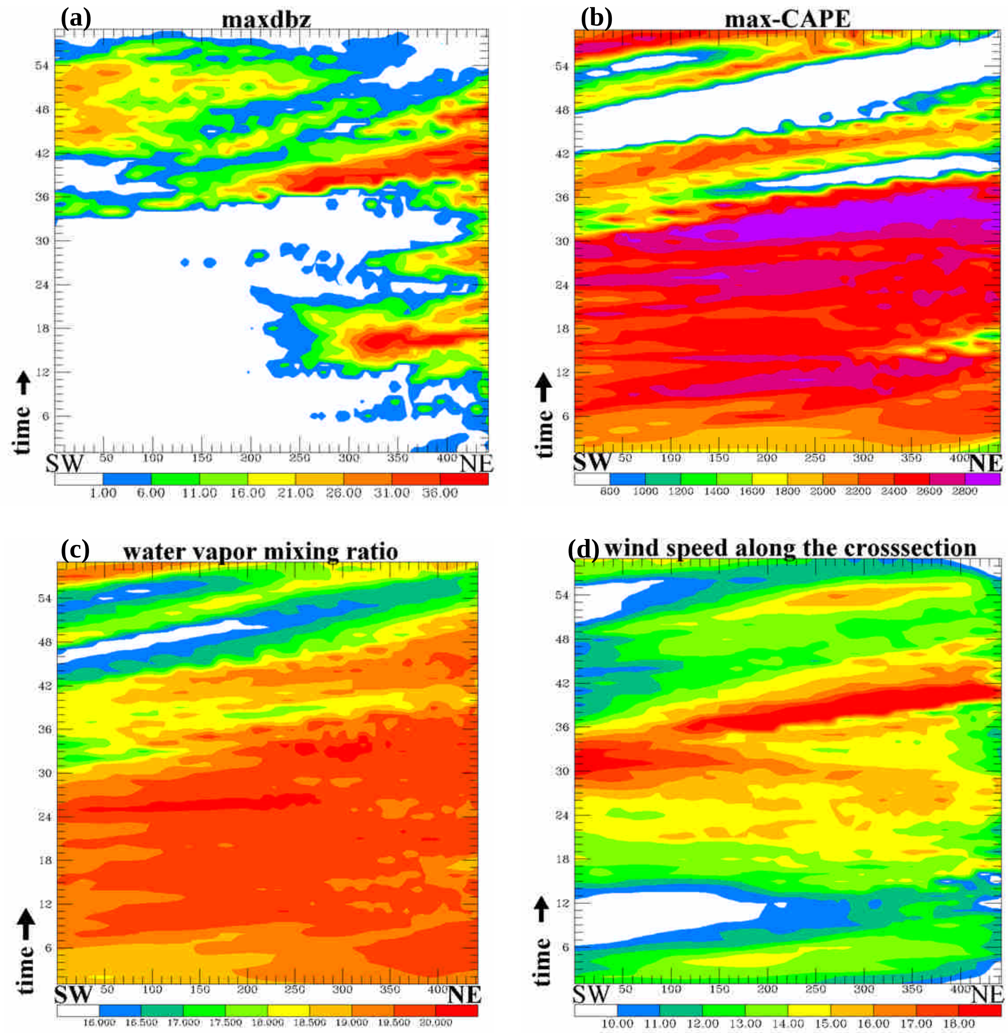

Fig. 4: Time series of (a) maximum radar reflectivity, (b) maximum CAPE, (c) water vapor mixing ratio (average below 850 hPa), and (d) along-section wind (average below 850 hPa, positive toward the northeast) along a southwest-northeast cross section shown in Fig. 3b.