Numerical Simulations of Typhoon Rusa and Associated Heavy Rainfall

Dong-Kyou Lee* and Suk-Jin Choi

Atmospheric Sciences Program, School of Earth and Environmental Sciences, Seoul Nation University, Seoul, Korea

1. INTRODUCTION

Typhoon Rusa, 2002 was one of the most disastrous tropical cyclones in Korea. Rusa caused a record-breaking heavy rainfall event at the Gangneung surface station with an hourly rainfall amount of 100.5 mm and daily rainfall of 870.5 mm. The record-breaking precipitation was resulted from not only the intense typhoon itself, but also multi-scale interactions between typhoon, synoptic environment and topography in Korea (Frank et al., 1999; Harr et al., 1996). The objective of this study is to investigate the capability of the WRF model to simulate the large precipitation amount and distribution, and the development mechanisms of two peaks in the hourly rainfall caused by Rusa (Figure 1).

2. RAINFALL

Figure 1 shows the observed rainfall caused by the typhoon Rusa from 12UTC 30 August to 00UTC 01 September 2002. After the Rusa landfall at Goheung, the daily rainfall at Goheung and Chupungryeong was 406.5 mm and 286.8 mm, respectively, actually in less than 24 hours. The time series of hourly rainfall at Gangneung, the maximum rainfall station, had two rainfall peaks which were different from those of two stations. The first rainfall peak at Gangneung occurred 4 hour earlier than that of Goheung due to the development of a mesoscale front induced by warm southerly flows of the northeastward-moving typhoon and cold air over the northern region of the East Sea (the Sea of Japan). The second rainfall peak at Gangneung occurred similarly in Goheung and Chupungryeong during the pass of the typhoon through the peninsula. In this study we focus on the two different rainfall occurrences at Gangneung resulting from typhoon, synoptic scale conditions and the effect of topography near Gangneung (Romin and Wilhelmson 2006, Wu et al. 2002, and Peng and Chang 2002).

Before the typhoon landfall, warm and moist air was conveyed

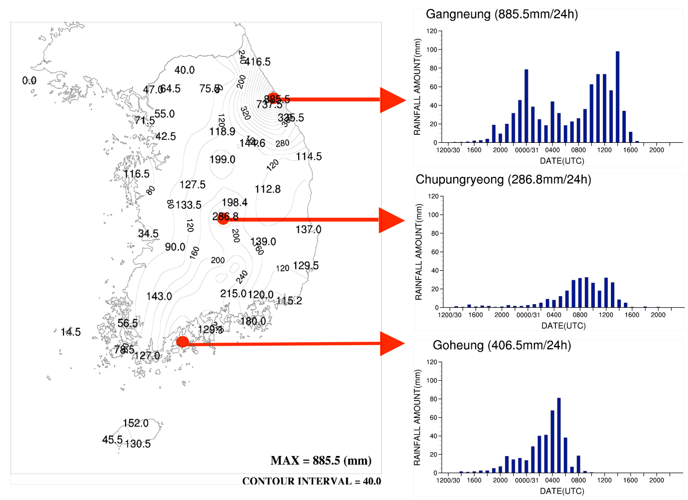

Figure1. 24h accumulated rainfall observed by surface station from 16 UTC 30 to 16 UTC 31 August 2002 with time series of hourly rainfall at Gangneung, Chupungryeong, and Goheung.

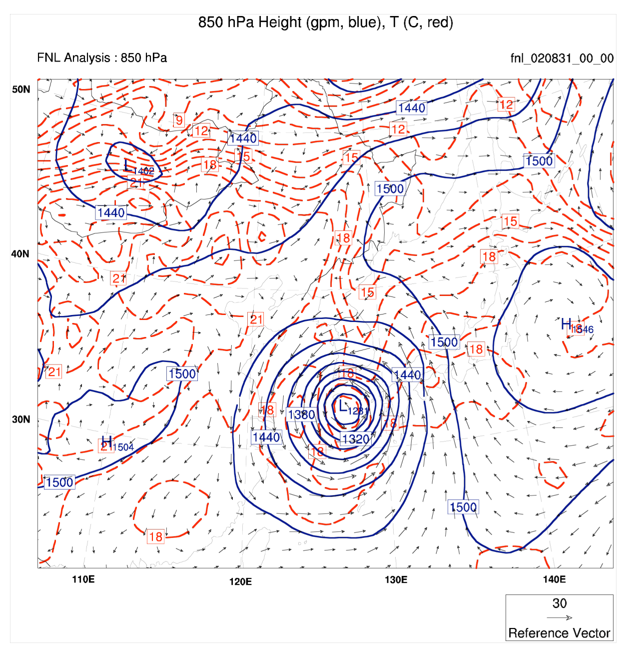

Figure 2. FNL analysis charts with geopotential height (solid; gpm), temperature (dashed; ^{o}C), and wind vectors at 850 hPa on 12UTC 30 August.

toward Korea by strong southerly flows of the typhoon locating in the East China Sea, upper-level westerly flows were prevailing north of Korea, and cold air originating from the Okhotsk Sea was dominated over the northern East Sea (Figure 2). A region of relatively strong north-south temperature gradient was developing over the East Sea. At 500 hPa westerly wind south of a weak upper-level trough over northeastern China and easterly wind north of the typhoon were developing a saddle area over Korea.

3. SIMULATIONS

We used the WRF version 2.1.2 to simulate the typhoon and heavy rainfall event at Gangneung. WRF model was run on a triple-nested domain using one-way nesting; the 30-km (EX30), 10-km (EX10), and 3.3-km (EX3.3) horizontal resolution. The model used 34 vertical layers with the model top of 50 hPa. In order to investigate how the topography of model gives an effect on the simulation of heavy precipitation, we also ran a sensitivity experiment (EX3.3TOPO) that was identical to EX3.3 except for that the model terrain of EX3.3TOPO used that of EX10. The Kain-Fritsch cumulus parameterization scheme for the 30 and 10 km horizontal resolution, WSM6 for microphysics scheme, the YSU scheme for planetary boundary layer physics, the NOAH land-surface model, and the RRTM long wave and Dudhia short wave schemes were used.

The simulation in the 30 km grid-mesh (EX30) started at 00UTC 29 August for 72 h forecasts, and the simulation in the 10 km (EX10) and the 3.3 km grid-mesh (EX3.3 and EX3.3TOPO) started at 00UTC 30 and 12 UTC 30, respectively. The initial and boundary conditions were obtained from the Final Global Data Assimilation System (FNL) analyses on 1.0 X 1.0 degree grids of NCEP including sea surface temperature (SST). No data assimilation was performed in this study.

4. RESULTS

In EX30, simulated track started to take a turn 12 h forecast, approximately 12 hours earlier than observation, so that the model simulated larger radius of curvature in track compared to observation. Accordingly the position error of simulated track was a minimum of 27 km at 12 h forecast and a maximum of 184 km at 48 h forecast, rapidly increasing after 36 h forecast. The typhoon track forecasts of EX10 and EX3.3 were similar to that of EX30.

Figure 3 shows the distribution of simulated total rainfall of EX10, EX3.3 and EX3.3TOPO. In the simulations, rainfall period extended for 36 hours, about 12 h longer than observation. The simulated maximum rainfall amount, 830.8 mm, and its location in EX10 were in good agreement with observation; however maximum amount, 1307.9 mm, in EX3.3 was much over simulated and its location occurred slightly northward compared to that of EX10. In EX3.3TOPO the maximum rainfall amount was 824.4 mm very analogous to 830.8 mm in EX10, and the

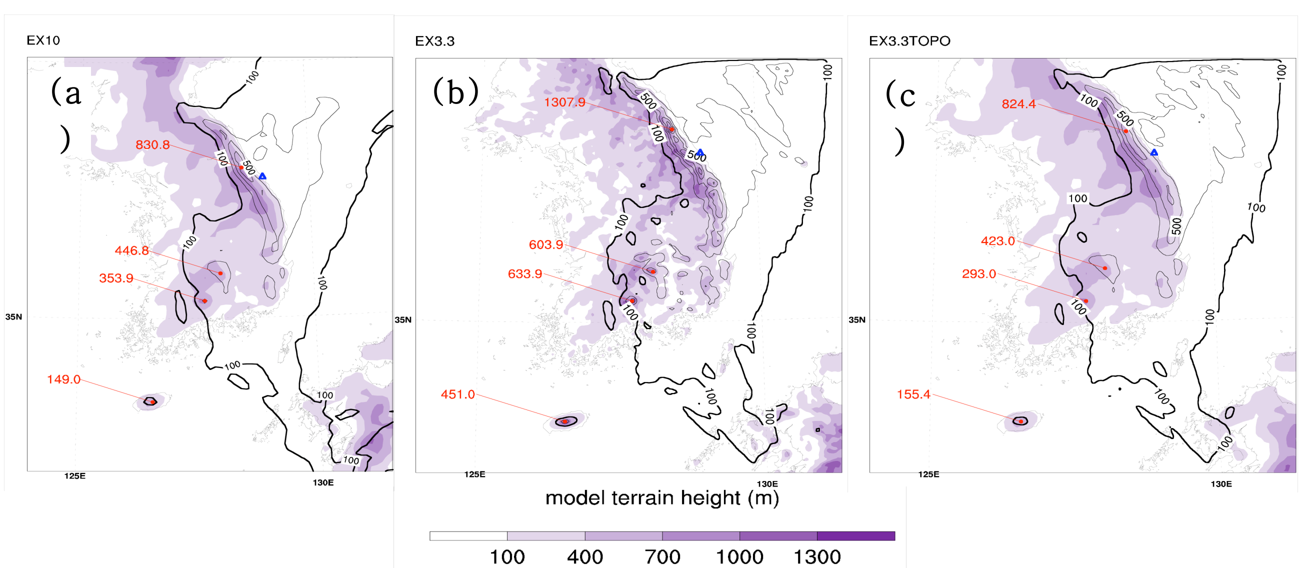

Figure 3. The simulated total accumulated total rainfall (mm, contours) with contour intervals of 200 mm and model terrains (m, shaded) for (a) EX10, (b) EX3.3, and (c) EX3.3TOPO. Triangles indicate the location of Gangneung.

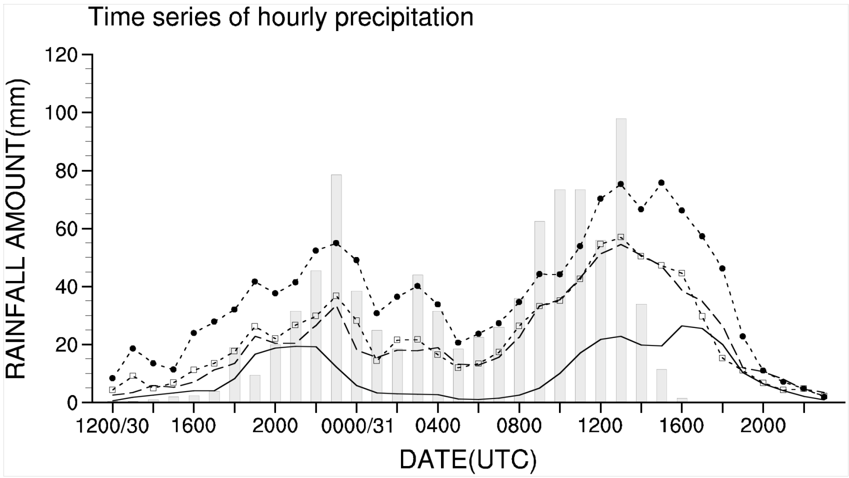

Figure 4. Time series of hourly precipitation for observation (bar), EX30 (solid line), EX10 (dashed), EX3.3 (dotted with hollowed squares), and EX3.3TOPO (dotted with filled circles).

rainfall distribution and maximum location appeared similar to those of EX10 and EX3.3, respectively. During the northeastward-moving typhoon approaching the Korean Peninsula, the eastern part of Korean Peninsula was influenced by easterly or northeasterly wind associated with the typhoon in lower troposphere, and vigorous convective activities were enhanced by an orographic lifting of the flows. Thus, the distribution of simulated rainfall followed that of the topography in the eastern part of the peninsula. The comparison between the results of EX3.3 and EX3.3TOPO well demonstrated the topographic effect which was one of the main factors for the extreme heavy rainfall at Gangneung.

The time series of hourly rainfall at Gangneung and the simulated maximum points are shown in Figure 4. The experiments in the nested models with higher horizontal resolution simulated well the two peaks of hourly rainfall and the timing of peaks, but more rainfall than observation after the second peak. The model simulated the mesoscale front induced by the typhoon and the northern air mass over the East Sea, and consequently the first peak of hourly rainfall resulting from the front. More rainfall after the second peak lasting approximately 6 hours was responsible for the slow movement of simulated typhoons, which contributed to the excessiveness of simulated rainfall. Figure 5 shows 850 hPa equivalent potential temperature (EPT), wind vectors and Omega in EX10. The mesoscale front was well characterized by the banded area of large gradient of EPT, upward motion, and convergence of horizontal wind at the time of the first peak, 00UTC 31. The frontal band starting near Gangneung was perpendicular to the Taebaek Mountain Range, a back-bone along the east coastline, whose slopes increase rapidly westward with an average slope of 800 m/30 km. The horizontal gradient of EPT was approximately 5 K/20 km. During the period of approximately from 16UTC 30 to 04UTC 31 associated with the first peak of rainfall before the typhoon landfall, the front interacted with the mountain ranges to produce concentrated heavy rainfall near the Gangneung area. Figure 6 shows the vertical cross section of relative humidity, EPT, and wind vectors of horizontal and vertical along the line shown in Figure 5. Cold and dry air north of the northward slantwise front with increasing height intruded down deeply near the surface, and very humid and warm air was rapidly overriding the frontal surface south of the front. In the cross-section, the gradient of potential temperature well delineates the frontal surface and relatively strong upward motion areas may indicate spiral bands of the typhoon.

5. SUMMARY

In this study the record-breaking rainfall was successfully simulated in the WRF; 830mm/30h in 10 km resolution being in good agreement with observation, 885.5mm/24h. The model simulated the development of a mesoscale front induced indirectly by the typhoon before the landfall, and the spiral bands of the typhoon, which were responsible for the heavy rainfall. The two factors took placed sequentially interacting with the effect of topography to produce torrential rainfall at Gangneung. EX3.3TOPO and EX10 simulated very similar rainfall amount, and EX3.3 simulated much more rainfall than EX3.3TOPO. The topography effect in the simulation played a significant role, but only high-horizontal resolution without high-resolution topography did not contributed to increased precipitation. The further study is needed to investigate the roles of precipitation physics processes and the effect of high resolution topography.

6. ACKNOWLEDEMENTS

This work was supported by the Korea Meteorological Administration Research and Development Program under Grant CATER 2006-2303. Authors are also grateful for computing support provided by the Korea Institute of Science and Technology Information (KISTI) through the Strategic Supercomputing Support Program.

7. REFENCES

Frank, W.M. and E.A. Ritchie, 1999: Effect of environmental flow upon tropical cyclone structure, *Mon .Wea. Rev.*, *127*, 2044-2061.

Harr, P.A. and R.L. Elsberry, 1996: Structure of a mesoscale convective system embedded in typhoon Robyn during TCM-93, *Mon. Wea. Rev.*, *124*, 634-652.

Romine, G.S. and R.B. Wilhelmson, 2006: Finescale spiral band features within a numerical simulation of hurricane Opal (1995), *Mon. Wea. Rev.*, *134*, 1121-1139.

Wu, C.-.C., T-.H. Yen, Y-.H. Kuo, and W. Wang, 2002: Rainfall simulation associated with typhoon Herb (1996) near Taiwan. Part I: The topographic effect, *Wea. And Forecasting*, *17*, 1001-1015.

Peng, M.S. and S.W. Chang, 2002: Numerical forecasting experiments on typhoon Herb (1996), *J. Atmos. Sci.*, *80*, 1325-1338.

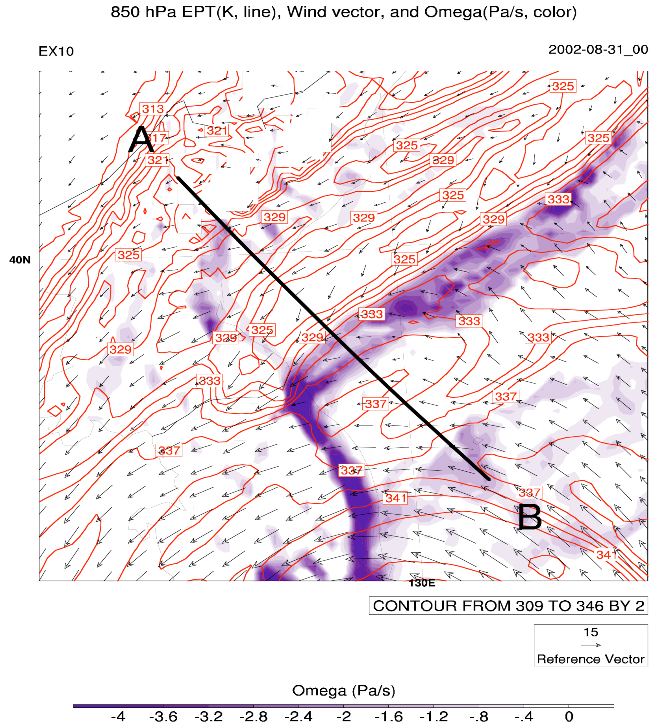

Figure 5. The EPT, wind, and omega at 850 hPa of 00UTC 31 from EX10.

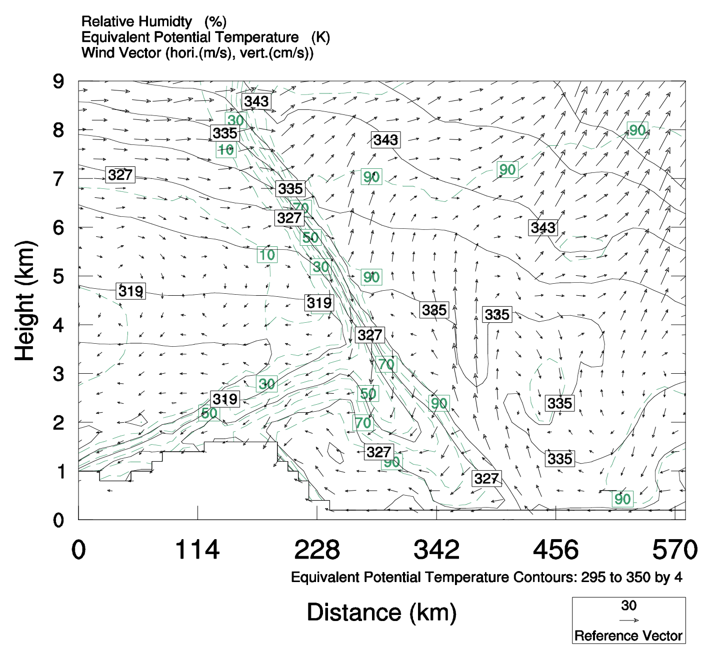

Figure 6. Vertical cross section of relative humidity (shaded), EPT (contour intervals 3 K), and wind vectors at 00UTC 31 August, 2002 along the line AB shown in Fig. 5.