P1.5 OROGRAPHIC EFFECT ON HEAVY RAINFALL IN THE EAST COAST OF THE KOREAN PENINSULA INDUCED BY A TROPICAL CYCLONE

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1. INTRODUCTION

Many meteorological phenomena passing over the Korean Peninsula are affected by its complex topography, sometimes causing localized orographic rainfall. Typhoon is one of the major meteorological phenomena whose circulation may interact with terrains to produce orographically-induced circulations and their associated local weather systems.

As a tropical cyclone moves onshore, the rainfall occurring in the vicinity of topography can be strongly controlled by orographic forcing, rather than being associated with the original rainbands accompanying the typhoon (Lin et al. 2002). In addition, heavy orographic rainfall may occur much earlier prior to the landfall of a tropical cyclone due to the influence of the mountain range in the conditionally unstable air stream associated with the outer circulation of the cyclone (Lin and Chiao 2000). When a cyclone approaches mountain range, it may decelerate and deflect due to orographic blocking (Lin et al. 1999). Furthermore, a weather system can be enhanced and persist due to the orographic channeling resulting from combined effect of terrain and synoptic-scale wind (Roebber and Gyakum 2003). Various issues on orographic precipitations are referred to Barros and Lettenmaier (1994).

An intense tropical cyclone, Typhoon Rusa, passed over the Korean Peninsula in late August 2002. It made landfall on the south coast of the peninsula and crossed over the central-east coast. The coastal areas of the central-eastern peninsula were devastated by this storm, mainly due to heavy rainfall, especially in the area located on the eastern side of the Taebaek Mountains Range (TMR) that has a north-south orientation. In contrast, the western side of the mountains had relatively small amount of rainfalls. This suggests that the localized heavy rainfall at the eastern side of the TMR was produced due partly to the orographic effect associated with the storm circulation, in addition to the rainfall accompanying the storm itself.

In this study, we investigate the orographic effect on this heavy rainfall event as well as dynamical and thermodynamical structure of the system, using a mesoscale numerical model.

2. SYNOPTIC ENVIRONMENT

Typhoon Rusa (2002) recorded a minimum central pressure of 960 hPa and a maximum wind velocity of 38 m s^{-1}. It stayed over the Korean Peninsula for 21 hours after it made landfall at Goheung, the south coast of the peninsula, around 1500 UTC 31 Aug 2002 (see Fig. 1). In 31 August 2002, it produced a record-breaking 24-hr accumulated rainfall at Gangneung (870.5 mm) and Daegwallyeong (712.5 mm), both located at the upstream (eastern) side of the TMR.

Prior to the landfall of the typhoon, southeasterly or easterly flows were predominant over the east coast of the Korean Peninsula, thus making warm and moist air converge in the coastal area located at the foot of the TMR (see Fig. 1). This moist flow was lifted along the eastern slopes of the TMR.

Figure 2 shows the skew-T log p analysis at Sokcho, located at the east coast of the peninsula just north of Gangneung (∼70 km apart), on 0000 UTC (blue) and 1200 UTC (red) 30 August 2002. It is clear that moist low-level jet and conditionally-unstable air were being enhanced by

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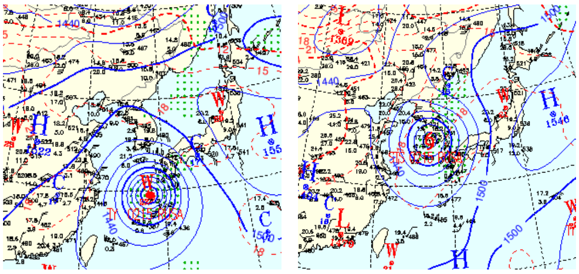

Fig. 1. 850 hPa map for 0000 UTC 30 August (left) and 1200 UTC 31 August (right) 2002.

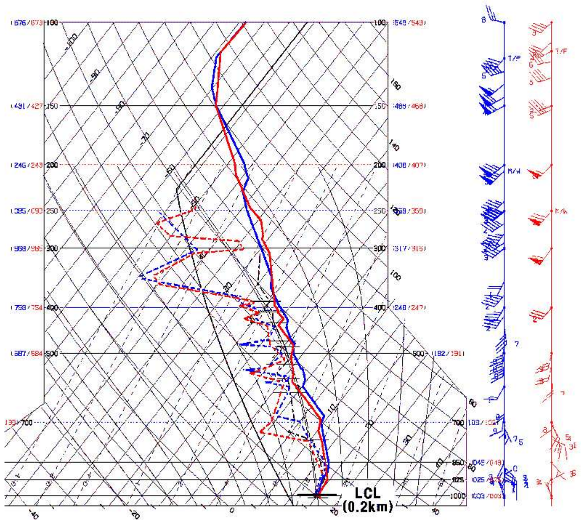

Fig. 2. The skew-T log p diagram at Sokcho on 0000 UTC (blue) and 1200 UTC (red) August 2002.

the outer circulation (easterly flow) of the storm at the east coastal area of the peninsula. The lifting condensation level was as low as 0.2 km at both times. This implies that a small amount of lifting would be sufficient to form clouds, and convective (potential) instability can be released due to strong orographic lifting.

3. EXPERIMENT DESIGN

For this study, the PSU/NCAR MM5 (version 3) is employed. The model is initialized at 0000 UTC 30 August 2002 with the NCEP global analysis data and synoptic observations. A triple nesting strategy is applied to the domains with horizontal resolution of 27 km, 9 km and 3 km, respectively. The model is integrated up to 48 hrs with a time step $\Delta t =$ 60 s. Physical processes include the mixed-phase for explicit moisture scheme, the Kain-Fritsch scheme for cumulus parameterization, and the MRF scheme for the PBL.

In order to investigate the orographic effect on heavy rainfall in this case, a set of sensitivity experiments is performed. A control (CON) run is made with terrain while a no-terrain (NT) run is performed by removing the model terrain. For the NT run, the initial conditions are regenerated based on the flat terrain with zero height.

4. RESULTS

Figure 3 depicts two experiments (i.e., CON and NT) for the 9 km and 3 km domain. In both experiments, compared to the observation, the typhoon made earlier landfall around 0600 UTC 31 August and stayed over the peninsula for a shorter time ($\sim$15 hrs) until 2100 UTC 31 August. The major difference between the two experiments was the pattern of the simulated rainbands. CON produced a highly-localized narrow rainband along the TMR on the upstream side (the east coastal area). Meanwhile NT produced less localized rainfall over a relatively broad rainband with an east-west orientation. In simulating the 24 hr accumulated rainfall, both the 9 km and 3 km runs underestimated the rainfall amount at Kangneung and overestimated at Sokcho. The 3 km run produced rainfall amount closer to the observation with more rainfall than the 9 km run.

Figure 4 shows the east-west vertical cross section, passing Gangneung, for wind vector and mixing ratios of cloud water and rainwater. It is evident that CON produced orographically-induced deep convective clouds while NT produced only typhoon-related clouds. This strongly implies that the heavy rainfall at the narrow upstream coastal area has occurred due to orographic effect enhanced by the typhoon outer circulation, in addition to the rainfall accompanying the storm itself.

5. CONCLUSIONS

In this study, using the PSU/NCAR MM5V3, numerical experiments are performed to investigate the orographic effect on the heavy rainfall event at the east coast of the Korean Peninsula, which was affected by a tropical cyclone – Typhoon Rusa (2002).

Prior to the landfall of the typhoon, condition-

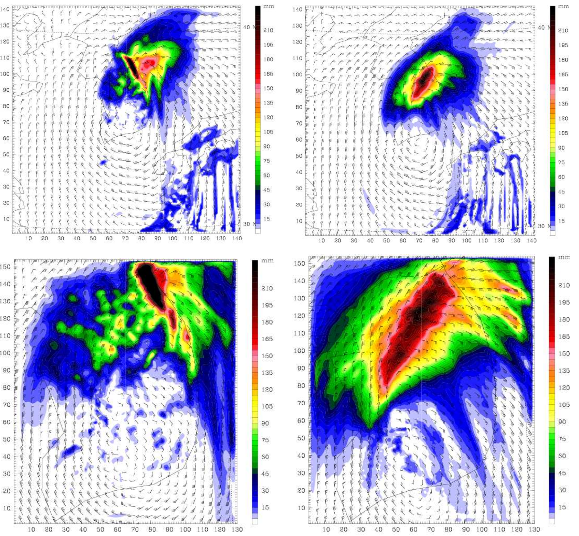

Fig. 3. The 6 hr accumulated rainfall valid at 1800 UTC 31 August 2002 for CON (left panel) and NT (right panel) runs with the 9 km (upper panel) and 3 km (lower panel) domain.

ally unstable atmosphere was established over the coastal area, located at the foot of the Taebaek Mountains Range (TMR), due to enhancement of the moist low-level jet. In the experiment with terrain (CON), compared to the observation, the typhoon track was simulated quite successfully with a 6 hr time shift in landfall. CON produced highly-localized heavy rainfall enhanced by the orographic lifting of the conditionally unstable atmosphere, induced by the typhoon outer circulation (easterly flow). Experiment with no terrain (NT) produced a rather broad rainband.

The simulation results confirm that strong easterly flow over the northern part of Rusa resulted in orographically-induced convective rainfall and greatly increased the amount of rainfall that would have occurred over flat terrain. The model predicted rainfall amounts that were sufficient to produce flooding over the eastern foothills of the TMR.

Although the current study is quite preliminary to investigate the complex mechanisms involved in the topography-typhoon interaction, it is evident that, in the existence of mountains range, synoptic flows and environmental conditions associated with the typhoon circulation were favorable to develop orographically-induced convective clouds and rainfalls at the upstream sides of the mountains range. More detailed analyses on dynamical

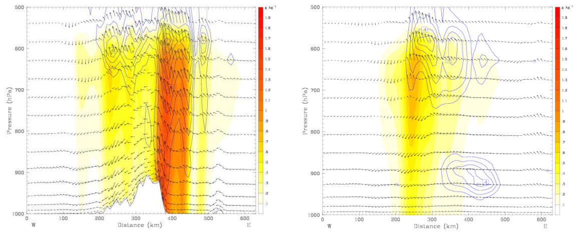

Fig. 4. East-west vertical cross section of wind vector and mixing ratios of cloud water (contoured) and rain water (color-filled) passing Kangneung with terrain (left) and without terrain (right) valid at 1800 UTC August 2002.

thermodynamical structures of this heavy rainfall system are undergoing.

Acknowledgments: This study is partly supported by the Meteorological Research Institute/Korea Meteorological Administration under a research grant on Improving Forecasting Ability Using Supercomputers.

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