P1.3 **ROLE OF TROPICAL CYCLONE IN SOUTHERN CHINA ON THE HEAVY RAINFALL OVER KOREA**

Kye-Hwan Kim and Song-You Hong*
Yonsei University, Seoul, Korea

1. Introduction

Heavy rainfall during the period of East Asian Summer Monsoon contributes to most of the annual precipitation over Korea, and the Korean peninsula experiences heavy precipitation events of about 6 times per year (Lee et al., 1998). These heavy rainfall events are climatologically related to three factors as follows; disturbances of quasi-stationary front named as "Changma" front in Korea, convective instability around western Pacific subtropical high, and tropical cyclone (hereafter, TC) directly or indirectly.

According to a climatological analysis, heavy rainfall events over the Korean peninsula recorded totally 317 cases during the period of 1980-1999, following a definition of heavy rainfall of Lee et al. (2002). Note that the definition of heavy rainfall event is different between Lee et al. (1998) and Lee et al. (2002). Among these cases, heavy rainfall events over the Korean peninsula caused by the TC located in southern China occupied about 75 percents.

Recent numerical studies associated with heavy rainfall over the Korean peninsula have suggested that the role of tropical cyclone located in southern China is important to the generation of heavy rainfall, together with a mid-latitude baroclinic system. For example, Park et al. (1986) suggested that a weakened typhoon landed on southern China intensifies convective instability over the Korean peninsula by transporting warm and moist air to Korea. Therefore, it contributes to the onset of heavy rainfall over the region. Lee et al. (1998) showed that a strong convergence ahead of the Low Level Jet (LLJ) on the right side of TC played a key role in producing the heavy rainfall. However, although these studies reported an importance of TC on heavy rainfall events over Korea, they have not been identified the impact of TC on heavy rainfall dynamically and in quantity.

In this study, we examine the role of TC in southern China and quantify the effect of TC on heavy rainfall over the Korean peninsula.

* Corresponding author address: Song-You Hong, Yonsei University, Dept. of Atmospheric Sciences
e-mail: shong@yonsei.ac.kr

The selected case is summarized in section 2. A description of the experimental setup and the Geophysical Fluid Dynamics Laboratory (GFDL) hurricane initialization algorithm is described in section 3. Simulated results of model are presented and interpreted in section 4. Section 5 presents our concluding remarks

2. Synoptic feaatures

2.1 The description of selected case

We selected a heavy rainfall case that produced a flooding northern part of South Korea (Fig. 1a). Daily precipitation from the 0000 UTC 5 to the 0000 UTC 6 August 1998 ranges from 100 to 600 mm over the peninsula. During the period, a record-breaking heavy rain of 619 mm occurred at a coastal station, Kanghwa (126.3 °E, 37.4°N). Most of rainfall was received at Kanghwa within the 12-h period of 1200 UTC 5 - 0000 UTC 6 August 1998 (Fig. 1b). The maximum hourly rainfall of 112 mm was observed between 1600 and 1700 UTC 5 August.

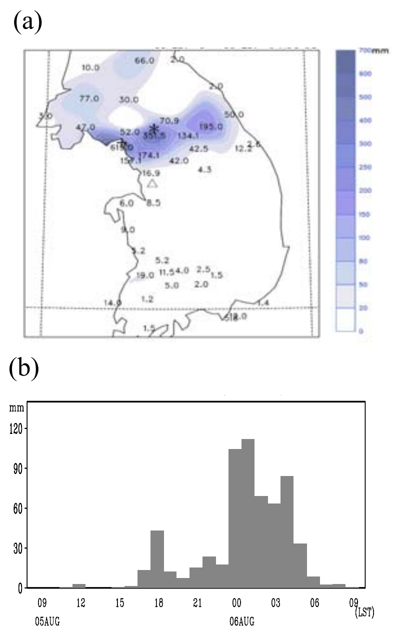
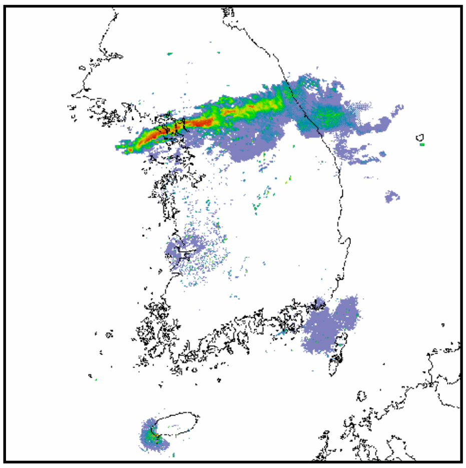


Fig. 1. (a) Observed 24-h accumulated precipitation (mm) from 0000 UTC 5 to 0000 UTC 6 August 1998. (b) The time series of observed hourly precipitation at Kanghwa. Adopted from Sun and Lee (2002).

2.2 Synoptic features

The Radar image shows that a short and narrow line of echo band is extended across the peninsula near the border between North and South Korea (Fig. 2). The convection band is 20 – 30 km wide, and about 300 km long at the mature stage. The convection cells move eastward along the band and new cells are continuously generated over the coastal region in the west.

(a)



(b)

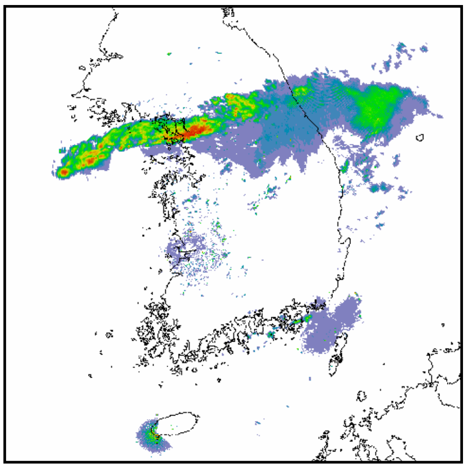


Fig. 2. Radar observation for (a) at 1500 UTC 5 August 1998, and (b) at 1800 UTC

Surface charts and enhanced GMS satellite infrared imagery show a synoptic-scale cyclonic system over northeastern China, its associated clouds (Fig.3a and 3b). Also, Fig. 3a represents tropical cyclone Otto in southern China, and western Pacific subtropical High (hereafter, WPSH) to the south of Japan. Figures. 3b and 3e show that the cold front of cyclone in northeastern China placed in the middle of Korean peninsula and represents that the edge of the WPSH is placed over the Korean peninsula. In Figs.3c and 3f, there is quasi-stationary front, Changma from central China to northern Japan.

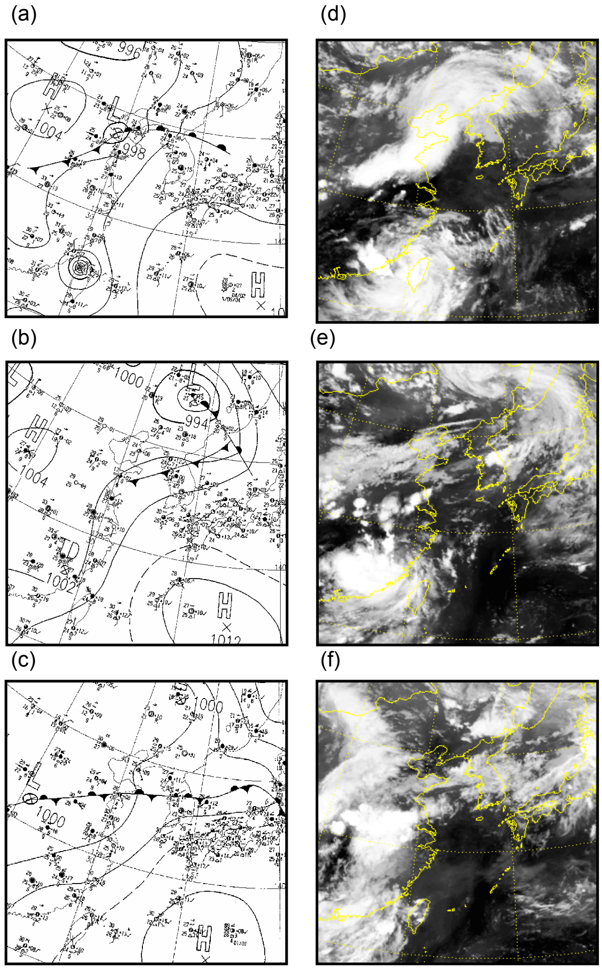
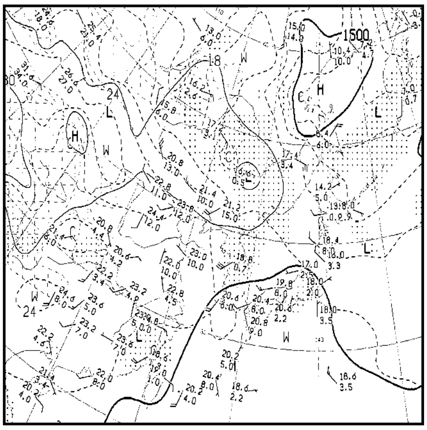


Fig. 3. Surface charts for (a), (b), and (c) at 1200 UTC 4, 1200 UTC 5, and 1200 UTC 6, respectively, GMS infrared satellite imagery at the same time.

At 1200 UTC 5 August, a major axis of synoptic-scale cyclone at 850 hPa was located over the north of the Korean peninsula (Fig. 4a). A minor ridge occupied the Korean peninsula and the East Sea on 4 August (not shown) and shifted eastward to the East Sea and Honshu on 12 UTC 5 August 1998. WPSH extended to the Kyushu Islands on 1200 UTC 5 August 1998. A strong south-westerly (i.e. LLJ) which was induced by TC and well organized baroclinic system was developed along the northwestern edge of the WPSH. Thus, warm and moist air was transported to the Korean peninsula by the strong low level southwesterly associated with TC, Otto.

Accordingly, the convection zone leading to heavy rainfall over Korea is generated in the area between the synoptic scale cyclone in the north of Korea and the WPSH, and enhanced by LLJ and advection of moisture due to TC. The 850 hPa height pattern at 1200 UTC 5 August indicates a converging air flow (southwesterly flow to the south and westerly flow to the north of the band) over the central part of the Korean peninsula.

(a)



(b)

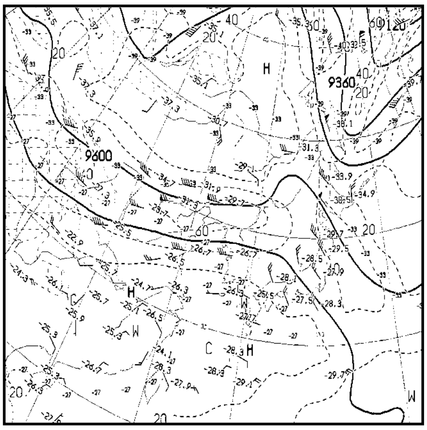


Fig. 4. The geopotential height(gpm), temperature (℃), and wind speed (ms^{-1}) 1200 UTC 5 August 1998 (a) at 850 hPa for (b) at 300 hPa.

3. The model and experimental designs

3.1, Model setup and experiment designs

The PSU-NCAR three-dimensional, non-hydrostatic mesoscale model (MM5 version3) is used for this study. The microphysics for explicit moisture process is treated using the mixed-phase micro physics scheme of Reisner et al. (1998), in which five prognostic equations are solved for mixing ratios of water vapor, cloud cumulus parameterization scheme of KF (Kain and Fritsch. 1993) is employed for subgrid-scale convection in coarse grids. Blackadar's high resolution scheme (Blackadar 1979; Zhang and Anthes 1982) is adopted to calculate the turbulent fluxes in the PBL. Physics options for the 15 km grid simulations are the same as the coarse grid simulation. The Five layer soil model of Dudhia (1996) is employed to predict soil temperature. Soil moisture is prescribed using the global land-use data in MM5.

3.2 GFDL hurricane initialization algorithm

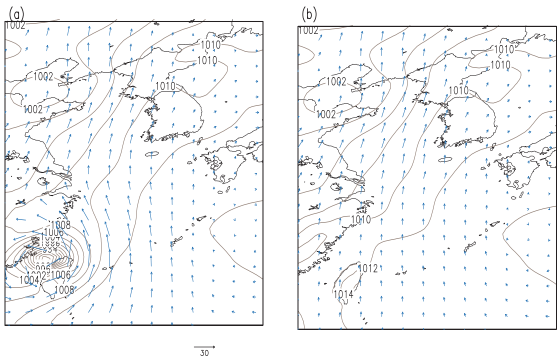
A bogussing algorithm originally developed at GFDL (Kurihara et al.1995, hereafter KBTR) and implemented into the MM5 (Kwon et al. 2002) was adapted to control the intensity of typhoon in southern China. In this method, winds are initialized in a straightforward manner within the filter region surrounded by 24 boundary points. To generate other variables, such as humidity, temperature, geo-potential height, etc., which are dynamically consistent with the prescribed winds, they use the built in function of MM5, the four dimensional data assimilation (FDDA).

3.3. Experimental design

A one-way interactive, nested grid system is used to include two domains. They consist of a 45-km grid domain (D01, 141 by 141 grid points), a 15-km grid domain (D02, 121 by 121 grid points). The model top is located at 100 hPa. The vertical sigma levels consist of 24 levels.

Initial conditions were obtained from the National Centers for Environmental Prediction (NCEP) reanalysis with 2.5° resolution. Global Telecomm-unication System (GTS) is used to improve initial condition. The lateral boundary and base fields were linearly interpolated in time from the 12 hourly reanalysis. The numerical simulation integrated from 1200 UTC 4 August 1998 to 1200 UTC 6 August 1998. Five experiments were conducted to examine role of tropical cyclone for heavy rainfall over Korean peninsula. A control experiment is the simulation of bogus which the central pressure of tropical cyclone Otto corresponds to observed (i.e. 980 hPa). The second experiment (i.e. T1000) is a simulation of no bogus which the central pressure of tropical cyclone

Otto is 1000 hPa . Others are performed to examine heavy rainfall intensity and distribution according to strengthen (i.e. T970, T960) and remove (i.e. NoTC) tropical storm Otto. Figure 5 represents CTL, NoTC, T960 experiments briefly.



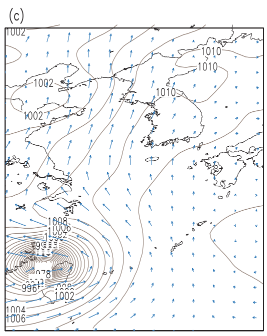


Fig. 5. Sea level pressure (contour) and wind vector of 850 hPa level obtained for the (a) control experiment (CTL), (b) NoTC, and T960 experiments at 1200 UTC 4 August 1998.

4. Results and discussions

4.1 Analysis of heavy rainfall

Figure 6a shows that CTL experiment with the central pressure of 980 hPa for Otto favorably reproduces convergence of water vapor mixing ratio and strong LLJ at the central part of the Korean peninsula. The NoTC experiment in Fig. 6b shows weak convergence of water vapor mixing ratio and weak LLJ compared to the features from the CTL experiment. In T960, although it's convergence and LLJ are stronger than those from the CTL run, but the convergence region is displaced too far to the north.

Figure 6d represents spatial distribution and amount of heavy rainfall for the control experiment, and winds at 850 hPa. The CTL experiment captures a band-type precipitation, although it underestimates the local maximum at Kanghwa with the amount of 156 mm, over the observed amount of precipitation in the amount of 619 mm. In Figs. 6e and 6f, spatial distribution and amount of rainfall for each experiment is compared to the CTL experiment.

Heavy rainfall over Korea is not simulated by the NoTC experiment (Fig. 6e). Thus, it is clear that the typhoon in South China plays a critical role in initiating the heavy rainfall over Korea. The T960 experiment also shows a little precipitation over Korea (Fig. 6f). Enhanced LLJ shifted the convergence zone northward, which results in more precipitation north of the Korean peninsula.

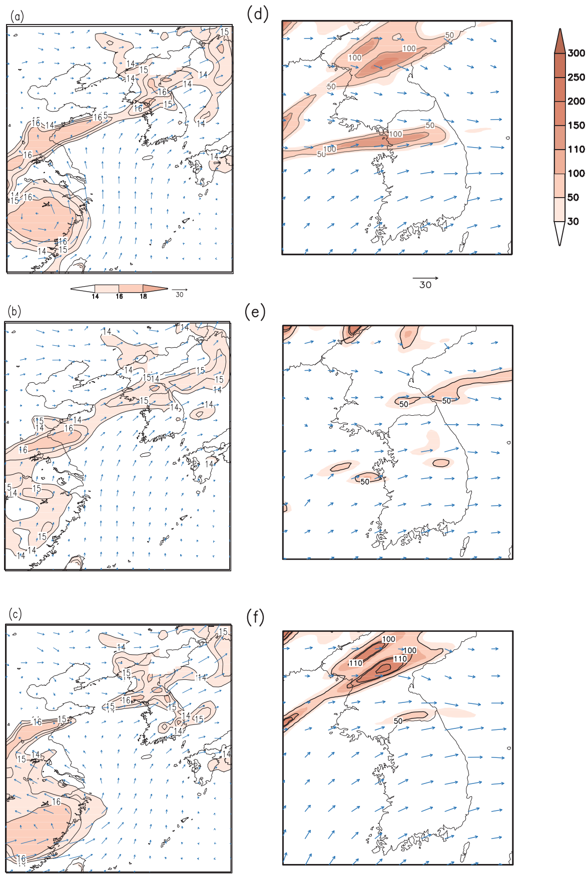


Fig. 6. Water vapor mixing ratio (shaded) and wind vector of 850 hPa level obtained from the control experiment (CTL), (b) NoTC, and (c) T960 experiments at 1200 UTC 4 August 1998, the 48-h accumulated precipitation (mm) ending at 1200 UTC 6 August 1998, obtained from the (d) CTL experiment, (e) NoTC, and (f) T960 experiments.

4.2 Moisture flux and quantification

Figure 7 shows the Convective Available Potential Energy (CAPE) of each experiment. The value of CAPE is 350, 701, 922, 933, and 1003 J kg^{-1}, respectively. This means that strong intensity of TC makes atmosphere to convectively unstable.

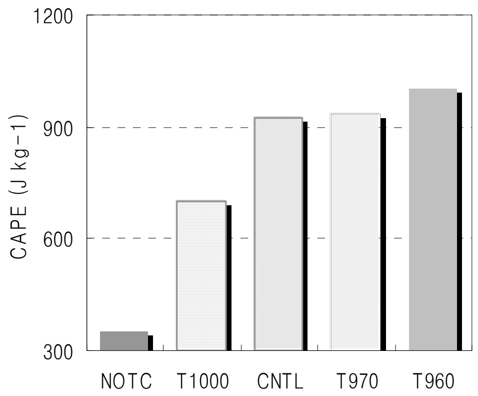


Fig. 7. The CAPE from the five experiments, averaged over South Korea (34-40° N, 125-130°E) at 2200 UTC 5 August 1998.

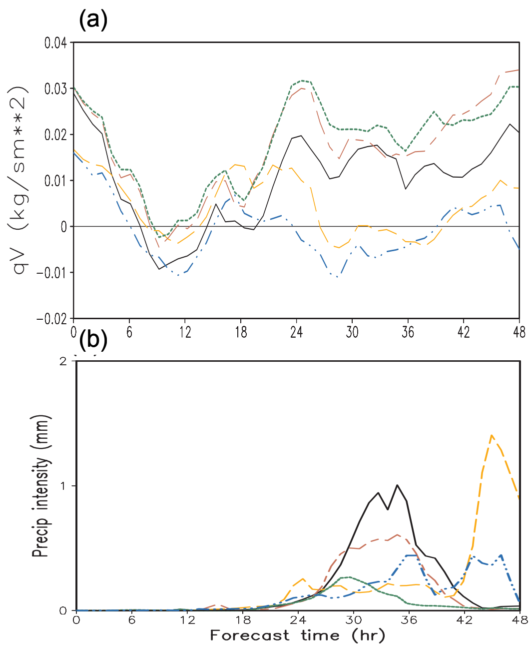


Fig. 8. The time series of (a) volume averaged moisture flux and (b) precipitation averaged domain 2 (32.5 - 49.7 °N, 110.5 – 135.8 °E) during the period of 1200 UTC 4 – 1200 UTC 6 August 1998, obtained from the T980 (solid), NoTC (dotted-dotted-dashed), T1000 (long-dashed), T970 (long-dashed short-dashed), and T960 (dotted) experiments.

Figure 8 shows that the inflow of moisture into nested domain is much larger as intensifying TC Otto. Those features are more notable for the time of 24 hour integration preceding 10-h to the time of maximum rainfall intensity.

5. Conclusion

In this study, we have investigated the role of tropical cyclone in southern China to heavy rainfall occurring over the Korean peninsula. A heavy rainfall case is selected to investigate the role of typhoon. The typhoon intensity is controlled by the use of the GFDL bogussing algorithm within the context of the MM5 system. Various experiments are designed with the different intensity of the typhoon in south China.

Numerical model results show that the effect of remote forcing due to the typhoon in southern China is crucial to the onset and maintenance of heavy rainfall over Korea. Without the tropical cyclone landed in China, the precipitation over Korea is significantly reduced. This indicates that the low-level jet on the right side of TC transports warm and moist air from southern China to the Korean peninsula. Interestingly, the typhoon with a stronger intensity than the observed central pressure is found to play a negative role in initiating the heavy rainfall over Korea. A stronger typhoon than the observed is found to be decoupled with a mid-latitude synoptic system over the heavy precipitation area in Korea since it tends to move further northward or westward.

Our results indicate that the success of the simulation of heavy rainfall over Korea is highly depends upon the accurate simulation of typhoon in southern China.

6. Acknowledgements

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7. References

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