Extremely Heavy Precipitation by Typhoon Rusa and Orography in the Korean Eastern Coast

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Abstract

Heavy precipitation under the influence of typhoon 21W-Rusa at Gangneung city in the Korean eastern coast was investigated from August 29 through September 1, 2002, using Weather Research & Forecasting Model (WRF)-2.2, GOES-IR satellite images and radar echo. The typhoon of 950hPa at its centre with maximum wind speed of 40m/s for 10 minutes average was originally generated in the northeastern sea of 1800km away from Guam Island. At 1530 LST, August 31, it made a landfall near the Goheung city of the southern Korean peninsula with a maximum sustained wind speed of 32m/s and gusting to 40m/s. When it made a landfall, atmospheric pressure in the centre of the typhoon was 960 hPa with a maximum wind speed of 32 m/s and gusting to 40m/s. When the typhoon centre just passed by the central part of Korean peninsula near Chungcheng province at between 2200 LST ~ 2300 LST, August 31, relatively strong easterly wind generated by cyclonic circulation of the typhoon could induce a grater amounts of moisture from the East Sea of Korea into the coastal inland, Ganenung city and the moistures were uplifted by easterly upslope wind toward the top of the higher mountains than 1 km height, resulting in extreme heavy rainfall through cooling and condensation processes of moisture, making a huge size of cloud clusters. Especially, the precipitation was 98 mm/h for 2100 LST ~ 2200 LST and 100.5 mm/h for 2200 LST ~ 2300 LST. During the slowly passing of the typhoon by the Korean peninsula after its landfall, accumulated precipitation amount for one day on August 31 was 870.5 mm/day at Gangneung city, 712.5 mm on Mt. Taegualyang and 404.0 mm in Goheung city. At 1500 LST on August 31, observed precipitation amount for past 3 hours in Gangneung city was 120mm. At 0600 LST, September 1, it entered the East Sea and was changed into extra-tropical cyclone and precipitation for past 3 hours at Gangneung city reduced to 20 mm. Primary, heavy rainfall was due to directly supply of waters accompanying by a great cloud cluster of the typhoon. Secondary, as large amounts of moisture intruded from the East Sea of Korea by strong cyclonic circulation of the typhoon went into the coastal basin and further went uplifted to the top of mountains of about 1 km height along their slope, most of moisture should be cool down and condensed, resulting in the formation of large cloud clusters and heavy precipitation in the mountainous coastal region. Extreme heavy precipitation was attributed to directly supply of water vapors by the typhoon and multi-combination processes among typhoon itself, condensation of moisture induced from sea and steep orography in the Korean eastern coast.

Keywords: Precipitation, Typhoon Rusa, WRF model, GOES-IR satellite images, Radar echo, Orography

Introduction

In the mountain and coastal regions, the occurrence of severe precipitation and wind storm occurs frequently in the case of typhoon passage. Typhoon Rusa was the most powerful hurricane to strike the Korean Peninsula since Typhoon Sarah in 1959. Up to 870.5 mm/day of precipitation were dumped on some parts of South Korea over a two-day period and the resulting floods left 113 dead and another 71 missing[1]. The storm destroyed hundreds of acres of farmland, tore apart bridges, ripped up sections of railway, and cut off fresh water to 400,000 people. Altogether, officials estimate that the damage caused by the hurricane could be as much as $750 million[2]. After hitting the Korean peninsula, the typhoon moved north to Sakhalin Island in Russia in Far East in the north of Japan, where it brought torrential rains that destroyed houses and flooded streets.

The term of typhoon is used in the north-western Pacific Ocean, while it is called hurriciane in the North America, willy willy in Australia and severe tropical cyclone in the rest of the world[3]. In summer, tropical cyclones cause severe weather of strong wind and heavy rain in the coastal areas, when they pass by[4]. In general, typhoon has been classified into three catagories as tropical depressions with maximum sustained surface winds less than 17m/s and tropical storm with ones reaching 17m/s and typhoon with ones more than 33 m/s, respectively[5].

During last several decades, many a meteorologists, even oceanographers have investigated the evolution of gust wind, torrential precipitation, storm surges, cold water outbreak and flood by tropical cyclones. Typically typhoons or hurricanes have radical scales of several hundred kilometers and bring about hazardous weather including strong winds and heavy rain associated with the outer rain bands[6-10]. Since a typhoon Rusa (TY21W) with maximum sustained winds of 65 knots (gusting to 80 knots) had landfall at Goheung coastal city in the south of Korean peninsula, there were 113 fatalities and 71 missing in South Korea and a total of 88,625 people in all were evacuated, showing the most powerful typhoon to hit South Korea since 1959[1].

The main purpose of this study is to investigate the reason why extreme heavy precipitation of 870.5 mm/day took place at Gangneung city in the Korean eastern coast and to understand possible mechanisms to forecast heavy precipitation using Weather Research & Forecasting Model through numerical simulation.

Numerical Method and Input Data

For the generation of heavy rainfall amount and strong wind, a three-dimensional, grid point Weather Research & Forecasting Model (WRF) version 2.2 model was adopted from 0000 UTC (Local Standard Time (LST) = 9h + UTC; 0900 LST), August 30 through 12 UTC, September 1, 2002 (Fig.1). One way, triple nesting was performed using a horizontal grid spacing of 27 km covering a 91 x 91 grid square in the coarse mesh domain and a 9 km interval also covering a 91 x 91 grid square in the second domain. The third and final nesting consisted of a 3 km horizontal grid spacing again on a 91 x 91 grid square. NCEP/NCAR reanalysis FNL (1.0^0 x 1.0^0) data was used for meteorological input to the model and was vertically interpolated onto 36 levels with sequentially larger intervals increasing with height from the surface to the upper boundary level.

WSM 6 scheme for heat budget, the YSU PBL scheme for the planetary boundary layer, Kain-Fritsch (new Eta) for cumulus parameterization, the five thermal diffusion model for land surface, and the RRTM long wave radiation scheme and dudhia short wave radiation schemes were used. For calculating 3 hrs accumulated precipitation amount, a mixed phase of both ice and water was considered. Hourly archived wind, air temperature and relative humidity by Gangwon Meteorological Administration were used for the verification of numerical results of the meteorological elements, in addition to GOES-9 DCD satellite images by the Japan Meteorological Agency.

Results and Discussion

Synoptic situation, wind and precipitation: Prior to the heavy precipitation in the Korean east coast, Gangneung city, on August 31, 2002, the precursor of a tropical depression or tropical disturbance (later called typhoon TY21W, Rusa) with a central pressure of 950hPa and maximum wind speed of 60m/s for one minute average and 40m/s for 10 minutes average was initially detected in the north-northeastern part at about 1,900 km away from Guam Island, the western Pacific Ocean 0230Z (1130 LST), August 22, 2002 (Fig. 1)[5]. Since the first warning on the tropical cyclone was given at 1200Z (2100 LST) August 22, this tropical depression developed southwest of Wake Island. This tropical cyclone tracked northwest toward Okinawa for approximately 8 days before turning toward the Korean Peninsula.

When it made a landfall near the Goheung city in the southwestern part of Korean peninsula at 0530 UTC (1530 LST), August 31, atmospheric pressure in the centre of the typhoon was 960 hPa with a maximum sustained wind speed of 32 m/s and gusting to 40m/s. At 2100 LST, atmospheric pressure in the centre of the typhoon was 960 hPa became weak with 975 hPa with maximum wind speed of 25 m/s. Then, at 0900LST, September 1, the typhoon Rusa entered the East Sea of Korea (Japan Sea) and wind speed generated by typhoon reached 17 m/s, becoming Tropical Depression. The sustaining period of the typhoon Rusa in the Korean peninsula from its landfall at 1530 LST on August 31 through its entering the East Sea of Korea (Japan Sea) at 0900 LST on September 1was about 18 hours. At 0900 LST, September, the typhoon Rusa became weak and changed into Tropical Depression (Figs. 2 and 3). The effect of the typhoon with heavy precipitation and strong wind had still maintained until 1200 LST (noon), September 1. The tropical depression became further extra-tropical cyclone in the northeastern area of the East Sea around 16000 LST, September 1.

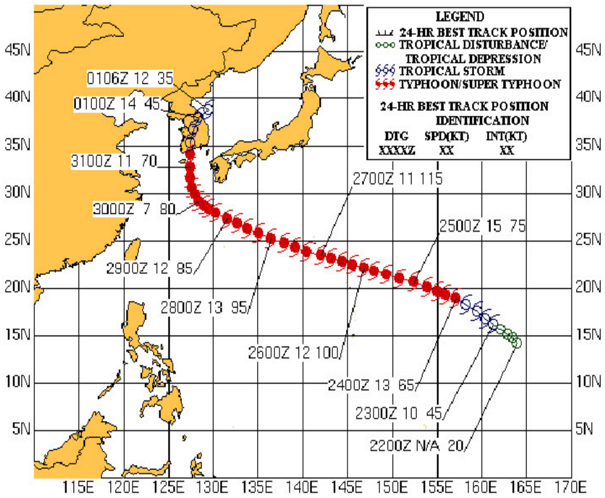

Figure 1: Track of typhoon Rusa (TY 21W) from August 22 through September 1, 2002.

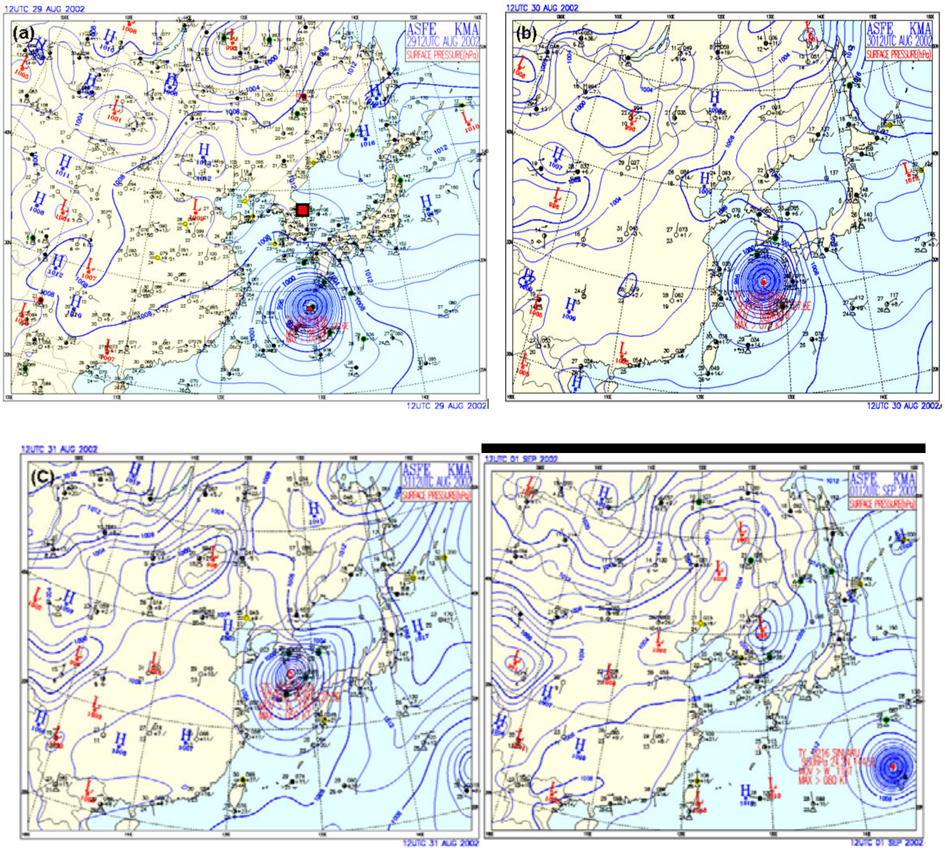

Figure 2: Surface maps at (a) 1200 UTC (0900 LST) on August 29, 2002, (b) August 30, (c) August 31 and (d) September 1, respectively. A small rectangle denotes Gangneung city, in the Korean eastern coast. After Typhoon Rusa made a landfall in the southern Korea on August 31, it became Tropical Depression. At 0900 LST on September 1, after it entered the East Sea, it became extra-tropical cyclone.

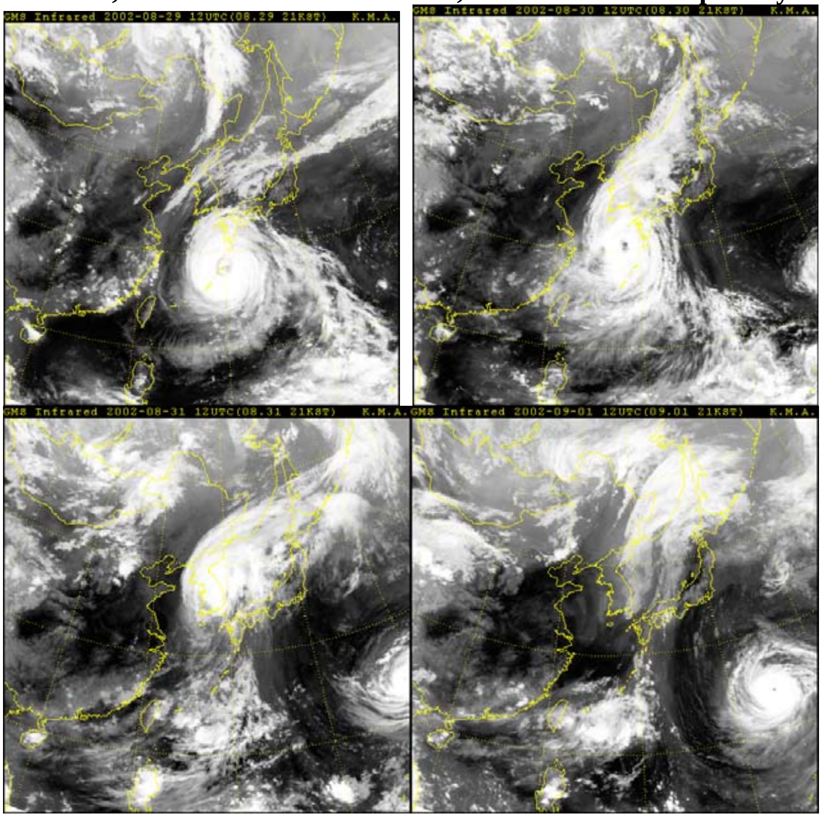

Figure 3: GOES-9 DDCD satellite images at 1200 UTC (0900 LST) on (a) August 29, 2002, (b) August 30,(c) August 31(tropical depression after its landfall) and (d) September 1 (extra-tropical cyclone), respectively.

Wind and precipitation: As typhoon is basically a low pressure system without front systems, its development energy comes from evaporation of water partcles from sea surface, condensation from convective clouds and deepening atmospheric pressure, and it dimishes the deficit of supply of water vapor passing through the island or inland area. In Figs. 5a and 5b, surface winds in a coarse-mesh domain with a 9 km horizontal interval and vertical profiles of horizontal wind in a fine-mesh domain of a 3 km interval, which covers a 91 x 91 grid square in the model at 2100 LST, August 30, 2002 before the typhoon passage across Cheju Island.

At this time, as the typhoon centre was still located about 200 km south away from Cheju Island (a small circle) in the south of Korea, Gangenung city was out of its powerful wind and large amounts of moisture supplied directly from the typhoon, resulting in moderate surface wind and strong wind over 10 m/s to be confined only in the west of the mountain top (Fig. 5b) and no precipitation (Figs. 4a and 5c) under the small cloud clusters (colorful area) just in the lower atmosphere over Gnagneung coastal city (Fig. 5d), respectively. In Fig 5a, very weak winds were detected in the center of the typhoon ("eye") in the coarse-mesh domains (Figs. 4a) and strong wind band existed in the distance of about 200 km away from the center, but weak winds were detected again in the outside area, 200 km away from the center.

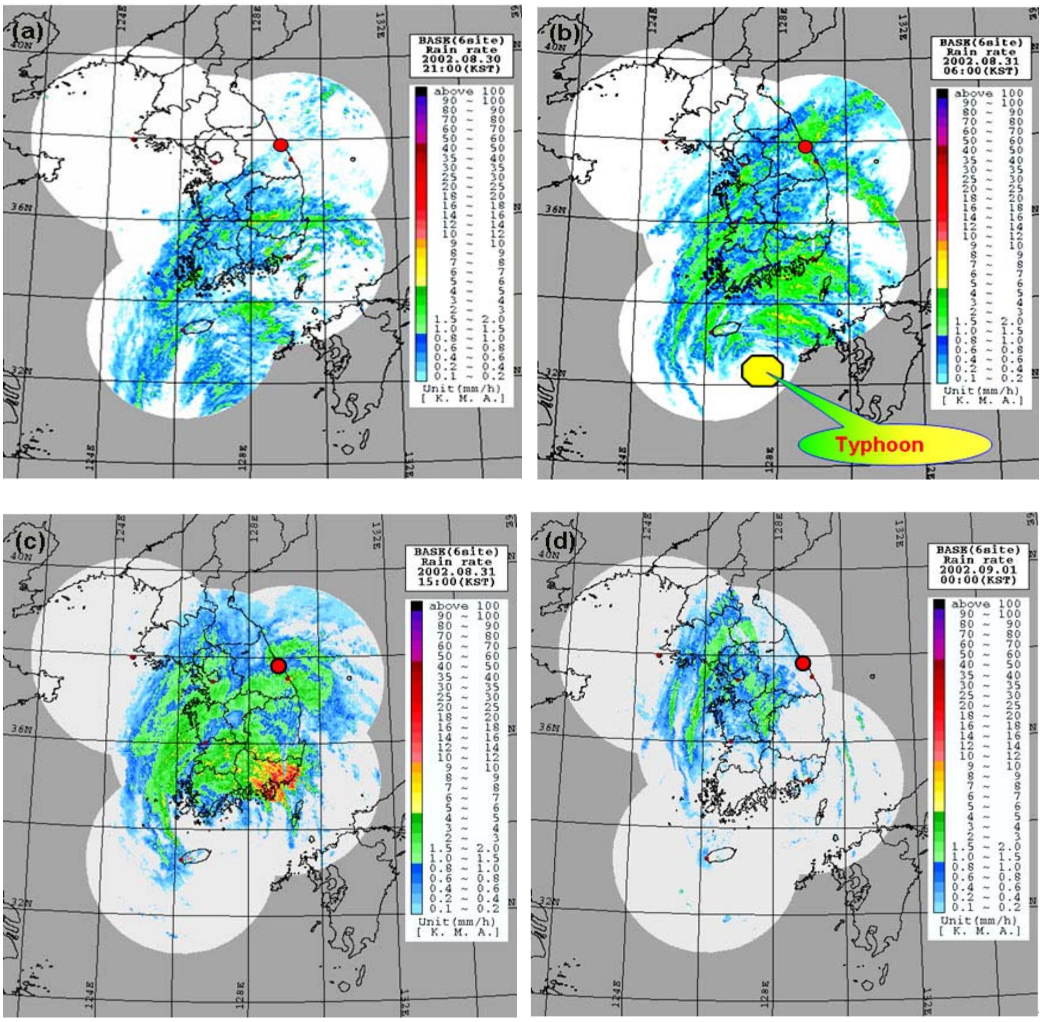

Figure 4: GOES-9 DCD satellite images at (a) 2100 LST August 30, 2002, (b) 0600 LST, August 31, (c) 1500 LST, August 31 and (d) 0000 LST, September 1, respectively. A small circle denotes Gangneung city with maximum precipitation amount of 870.5 mm/day in the Korean eastern coast. Typhoon Rusa made a landfall at 1530 near Gohung city in the southern city of Korean peninsula and left for the East Sea of Korea at 0900 LST, September 1.

On the other hand, at 0800 LST ~ 0900 LST, in the morning of August 31, even though the typhoon centre was still located at about few hundred km away from Cheju Island, in the south of Korea, large amounts of warm and moist masses directly supplied through converge zone in the front of the typhoon encountered cold core in the upper level of atmosphere (500 hPa) and cooled down and condensed, resulting in spread out of rains in the whole Korean peninsula, especially, showing precipitation amount of 80 mm/hour at Gangenung city in the eastern coast of Korea.

At 1200 LST, August 31, about 3 hours before the typhoon Rusa made a landfall near Gonhyung city in the southern region of Korean peninsula, Gangneung city in the Korean east coast was seriously under the influence of the typhoon (Figs. 6a and 6b). Surface wind speeds in the coastal areas in the southwestern peninsula of Korea were over than 20 m/s, but over than about10 m/s in the eastern coast. Surface wind within 200 m depth over the open sea surface near Gangneung city was about 10 m/s and ones in the higher altitude than 200 m height to about 1 km height were about 20 m/s. Strong wind sector over 20 m/s was also detected in the west of the mountain top and this strong wind sector extended toward the east, compare to one at 0000 LST, August 31.

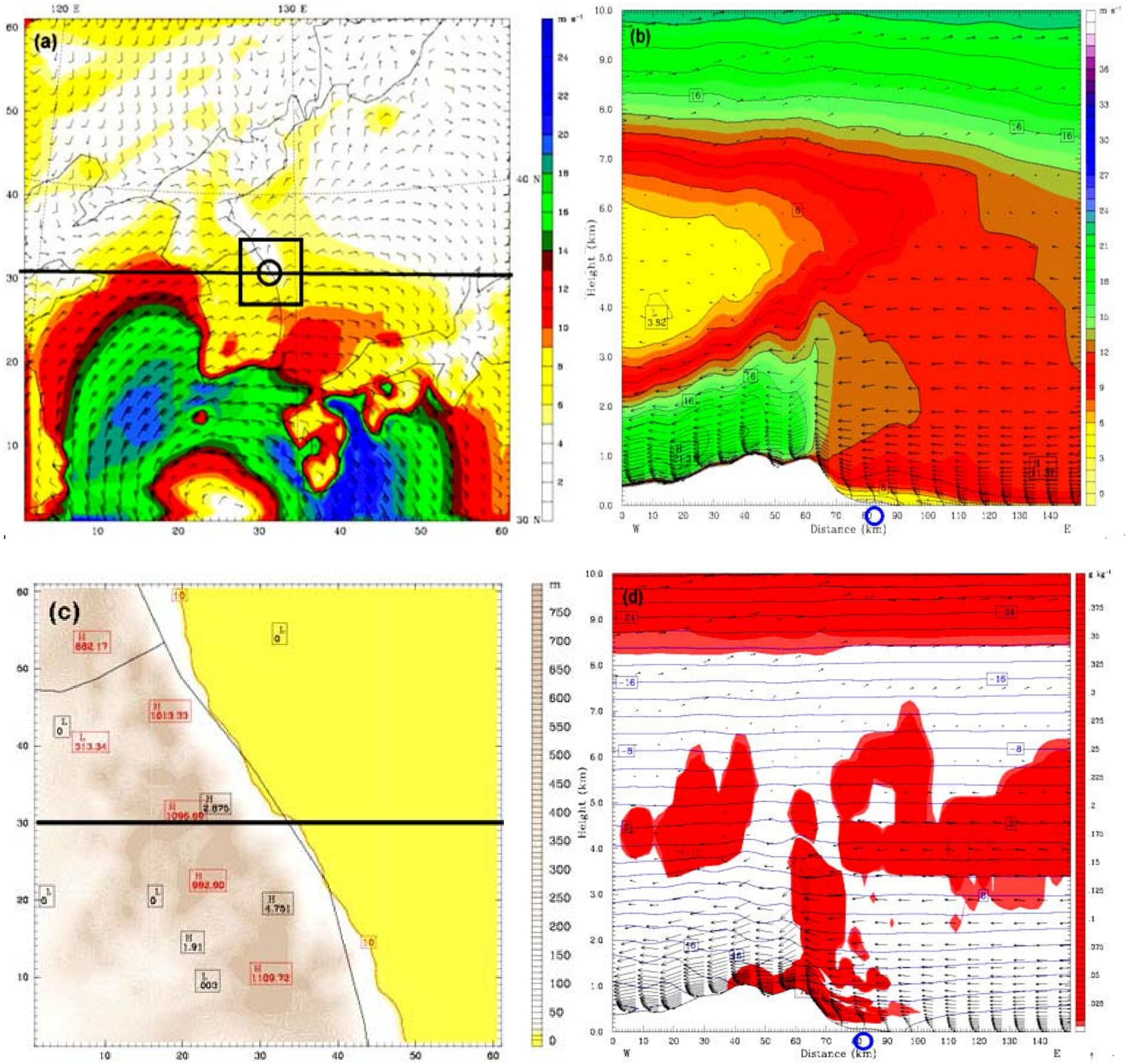

Figure 5: Surface winds (m/s) in (a) a coarse-mesh domain with a 9 km horizontal interval and (b) vertical profiles of horizontal wind (m/s) in a fine-mesh domain of a 3 km interval on a straight cutting line from west to east in (a) at 2100 LST, August 30, 2002 before the typhoon passage across Cheju Island. (c) and (d) denote total precipitation for 3 hours and mixing ratio (g/kg), at the same time, respectively. Box and circle in (a) denote a fine-mesh domain of 3 km horizontal grid interval and Gangneung city in the Korean eastern coast, which was not directly affected by Typhoon Rusa in about 100 km south away from Cheju Island, Korea. Colorful area in (d) indicates cloud clusters. Very weak winds were detected in the center of the typhoon ("eye") in the coarse-mesh domains (Figs. 4a) and strong wind band existed in the distance of about 200 km away from the center, but weak winds were detected again in the outside area, 200 km away from the center..

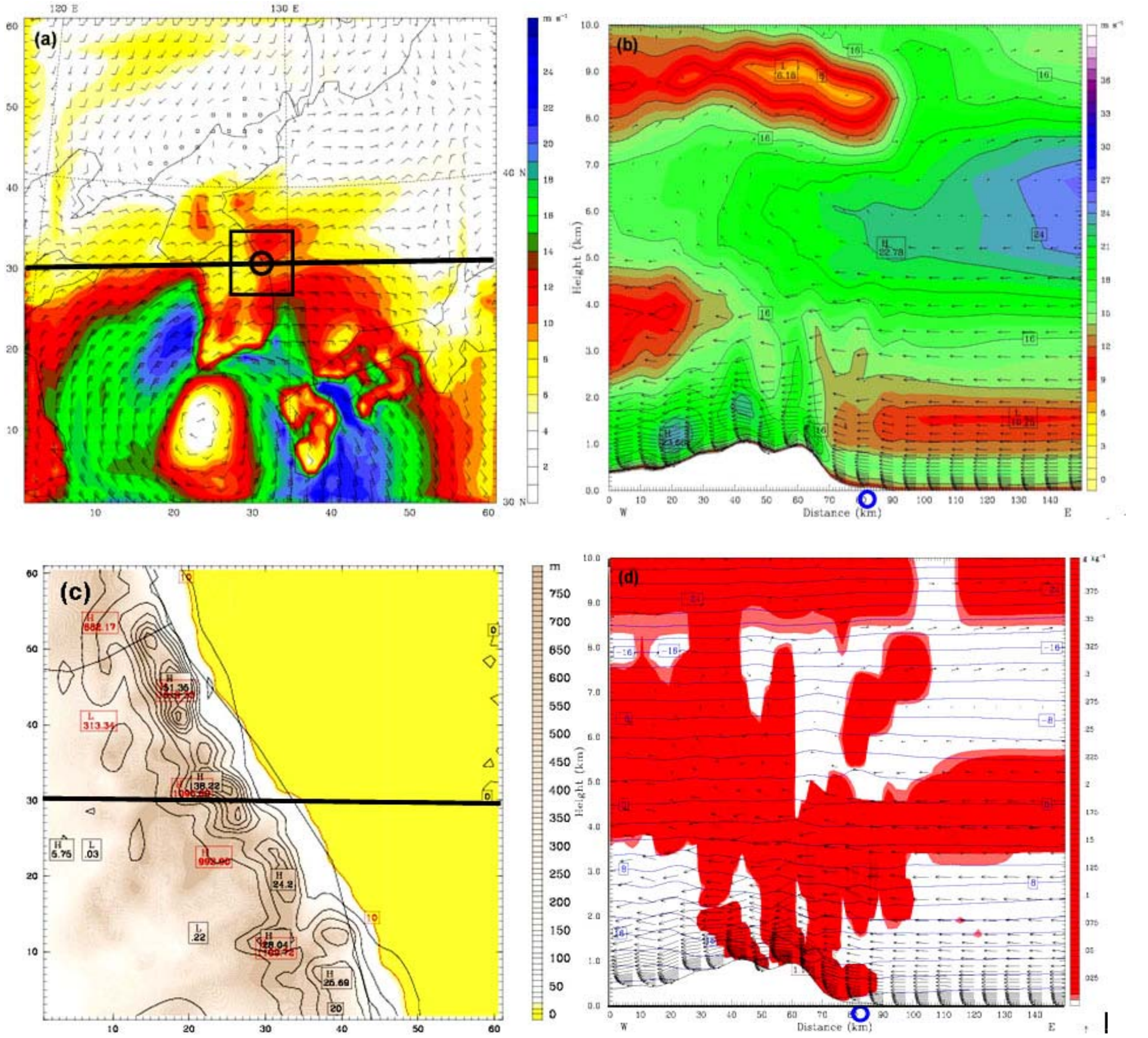

Figure 6: As shown in Fig. 5, except for 1200 LST, August 31, 2002. Box and circle in (a) denote a fine-mesh domain of 3 km horizontal grid interval and Gangneung city. Gangneung city was under direct influence of the typhoon Rusa and a large amounts of cloud clusters existed from the lower atmosphere over the Gangneung city toward Mt. Taegulyang in the west of the city and vertically extended to higher altitude than 10 km height, resulting in heavy precipitation in the eastern mountainous coastal region of Korea.

Under this situation, synoptic scale easterly wind over than 10 m/s generated by cyclonic circulation of the typhoon could induce a large amounts of moisture from the sea into the coastal basin and further went uplifted to the top of mountains of about 1 km height along their slope and then most of moisture should be cool down and condensed, resulting in the formation of large cloud clusters and heavy precipitation in the mountainous coastal region (Figs. 4c, 6b, 6c and 6d). As shown in Fig. 6d, Gangneung city was under direct influence of the typhoon Rusa and a large amounts of cloud clusters generated by easterly moisture advection from the sea existed from the lower atmosphere over Gangneung coastal city toward Mt. Taegulyang in the west of the city and vertically extended to higher altitude than 10 km height, resulting in heavy precipitation in the eastern mountainous coastal region of Korea. It means that extreme heavy precipitation was attributed to directly supply of water vapors by the typhoon itself and multi-combination processes among typhoon, condensation of moisture induced from sea by strong easterly wind and condensation by orography in the Korean eastern coast.

When Typhoon Rusa made a landfall near the Goheung city in the southwestern part of Korean peninsula at 0530 UTC (1530 LST), August 31, atmospheric pressure in the centre of the typhoon was 960 hPa with a maximum sustained wind speed of 32 m/s and gusting to 40m/s. After its landfall, wind speed and precipitation amount could be more intensified.

As time went on, atmospheric pressure in the centre of the typhoon at 2100 LST was 960 hPa became weak with 975 hPa with maximum wind speed of 25 m/s. When the typhoon centre just passed by the central part of Korean peninsula near Chungcheng province at between 2200 LST ~ 2300 LST, August 31, relatively strong easterly wind generated by cyclonic circulation of the typhoon could induce a grater amounts of moisture from the East Sea of Korea into the coastal inland, Ganenung city. The moistures uplifted by easterly upslope wind toward the top of the higher mountains than 1 km height should be condensed to much bigger cloud clusters horizontally and combine with a great amounts of waters directly accompanied by the typhoon itself, resulting in their extension toward the upper atmosphere up to 11 km height and extreme heavy precipitation at Gangneung coastal city (Figs. 4d, 7a, 7a, 7c and 7d). Especially, the precipitation was 98 mm/h for 2100 LST ~ 2200 LST and 100.5 mm/h for 2200 LST ~ 2300 LST.

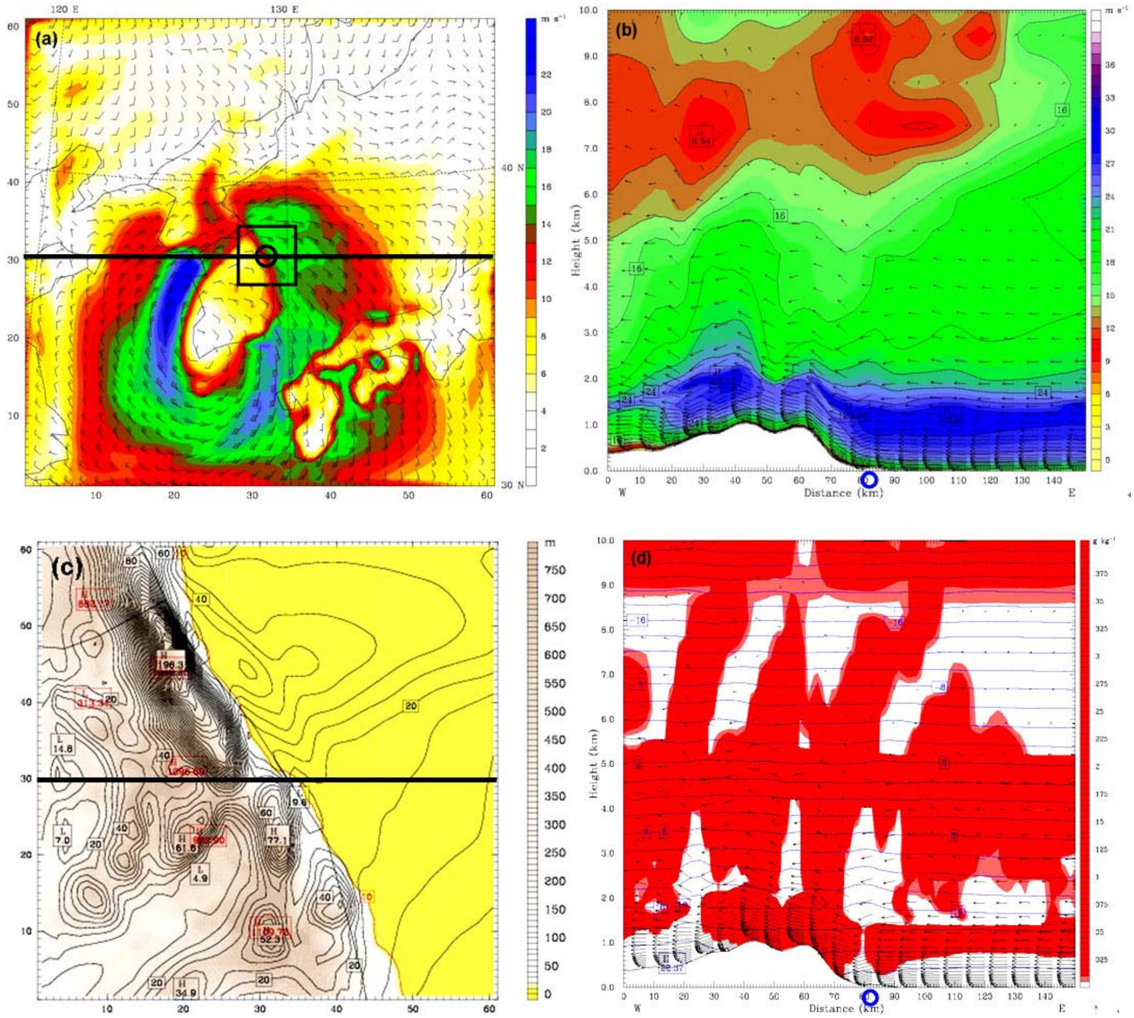

Figure 7: As shown in Fig. 5, except for 0000 LST, September 1. As typhoon Rusa became Tropical Depression during its passage inside the Korean peninsula, and Gangneung city was under strongly influence of the typhoon and bigger cloud clusters existed from the lower atmosphere toward the upper atmosphere up to 11 km height under their extension of horizontally and vertically, resulting in heavy precipitation in the eastern mountainous coastal region of Korea, especially 100.5 mm/hr from 2200 LST to 23 LST, August 31, 2002.

At 0900LST, September 1, the typhoon Rusa entered the East Sea of Korea (Japan Sea) and wind speed generated by typhoon reached 17 m/s, becoming Tropical Depression. The sustaining period of the typhoon Rusa in the Korean peninsula from its landfall at 1530 LST on August 31 through its entering the East Sea of Korea (Japan Sea) at 0900 LST on September 1was about 18 hours. The effect of the typhoon with heavy precipitation and strong wind had still maintained until 1200 LST (noon), September 1. The tropical depression became further extra-tropical cyclone in the northeastern area of the East Sea around 16000 LST, September 1.

Conclusions

Heavy precipitation under the influence of typhoon 21W-Rusa at Gangneung city in the Korean eastern coast was investigated from August 29 through September 1, 2002, using Weather Research & Forecasting Model (WRF)-2.2, GOES-IR satellite images and radar echo. Typhoon is basically a low pressure system without front systems, its development energy comes from evaporation of water partcles from sea surface, condensation from convective clouds and deepening atmospheric pressure, and it dimishes the deficit of supply of water vapor passing through the island or inland area. Actually, Korean peninsula had been influenced by the typhoon from 0000 LST, August 31 (13 hours before its landfall in the southern Korean peninsula) until 1200 LST, September (3 hours after its left from the Korean peninsula).

From the analysis of numerical simulation and observed archived data of wind and rainfall amount, primary, heavy rainfall was due to directly supply of waters accompanying by a great cloud cluster of the typhoon. Secondary, as large amounts of moisture intruded from the East Sea of Korea by strong cyclonic circulation of the typhoon went into the coastal basin and further went uplifted to the top of mountains of about 1 km height along their slope, most of moisture should be cool down and condensed, resulting in the formation of large cloud clusters and heavy precipitation in the mountainous coastal region. Extreme heavy precipitation was attributed to directly supply of water vapors by the typhoon and multi-combination processes among typhoon itself, condensation of moisture induced from sea and steep orography in the Korean eastern coast.

Acknowledgement

This work was funded by the Korea Meteorological Administration Research and Development Program under Grant CATER 2006-2308-“Generation mechanism and prediction of wind storm in the mountainous coast”.

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