Extreme Decrease of Air Temperature modified by a Typhoon Passage in the Korean Eastern Coast

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Abstract

The variations of air temperatures before and after the passage of a typhoon-TY21W (Rusa) were investigated in the coastal inland and sea using a 3D-WRF-2.2 with FNL initial meteorological data on August 29 ~ September 2, 2002. On August 29, 2002 with no influence of the typhoon, maximum air temperatures were 27 ^{o}C at Gangneung city, the Korean eastern coast and 34 ^{o}C at Wonju city in the 100 km west. Sea surface temperature in Gangneung coastal sea was 21 ^{o}C at 1600 LST on August 29 but 25.5 ^{0}C on August 28. Since the typhoon made a landfall in the southwestern part of Korea with a maximum sustained wind speed of 32 m/s at 1530 LST on August 31, precipitation amount at Gangneung city was 870 mm/day with a maximum value of 100.5 mm/hr at 2100 LST ~ 2200 LST. Maximum air temperatures at 1600 LST, August 31 were 23 ^{0}C at Gangneung city and 24 ^{0}C at Wonju city, showing the decreases of – 4^{0}C and – 10 ^{0}C respectively.

The decreases of air temperatures near the ground surface in the coast and further inland up to 23 ~ 24 ^{0}C should be significantly affected by extremely severe cold rain shower made by great cloud clusters of 9km ~ 10m height toward the ground surface of the city, due to a huge amount of water droplets supply by the typhoon itself and by cooling down and condensation of moistures intruded from the East Sea of Korea under a strong cyclonic circulation of the typhoon toward the coastal basin and further the steep mountain top. As sea surface temperature on August 31 was not detected by GOES satellite, due to cloud clusters and it was 22 ^{0}C on September 1, they could be also partially attributed to the decrease of sea surface temperature through the advection of relatively cool moist air masses on the sea surface toward the coast and further inland site.

Keywords: Air temperature, Sea surface temperature, GOES-MCSST satellite images, GOES infrared images, WRF model-2.2, Sea breeze and mixing ratio.

Introduction

In summer, north eastern Asian countries including Korea face of at least 5 or 7 typhoon invasions along with extreme rainfall and flood due to typhoon. Financial loss due to casualties of human beings, destructions of farm fields and industrial and economical infrastructures caused by typhoon reach more than billion US dollars[1]. For instance, since a typhoon Rusa (TY21W) with maximum sustained winds of 65 knots with gust of 80 knots had landfall 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 it the most powerful typhoon to hit South Korea since 1959[2]. Up to 870.5 mm/day of precipitation were dumped at Gangneung city of the Korean eastern coast for two days and the damage of farmland, tore apart bridges, ripped up sections of railway, caused by the typhoon could be as much as $750 million[3].

Especially, tropical cyclones in summer cause severe weather such as strong wind and heavy rainfall storm in the steep mountainous coastal areas, when they pass by[4-12]. In addition, the passage of typhoon causes not only a shortage of necessary solar radiation for the growth of vegetations and crops. Thus, to simulate the dramatic response of air temperature to the typhoon passage is a necessity to prevent from cold weather damage of the crops to some extent.

Study area and Numerical methods

Figure 1 describes topographical features around the Korean peninsula using a horizontal grid spacing of 27 km covering a 91 x 91 grid square in the coarse mesh domain. A small box as a study area covers the vicinity of Gangneung city of the Korean east coast in a fine-mesh domain consisting of a 3 km horizontal grid spacing again on a 91 x 91 grid square and the climate of the city is greatly affected by mountain and sea. In general, the city has a mild weather in winter due to the passage of the East Korea Warm Current following the east coast of the Korean peninsula as a branch current of Kuroshio Current.

A three dimensional meteorological grid point model called Weather Research and Forecasting Model (WRF)-version 2.2 with a terrain following coordinate system was adopted for the generation of wind, air temperature, relative humidity and so on in the vicinity of Korean peninsula and Gangneung city. Numerical simulation was carried out from 0000 UTC (0900 LST) on August 29, 2002 through 21 UTC to September 2, 2002. One way, triple nesting process from a coarse-mesh domain to a fine-mesh domain was performed using a horizontal grid spacing of 27 km covering a 91 x 91 grid square in the coarse mesh domain, a 9 km interval in the second domain and a 3 km in the third domain. NCEP/NCAR reanalysis

FNL (1.0^0 x 1.0^0) data was used as meteorological input data to the model[13].

Results and Discussion

Synoptic situation, wind, precipitation and air temperature with no typhoon effect: A tropical depression or tropical disturbance (later called typhoon TY21W, Rusa) with a central pressure of 950 hPa and maximum wind speed of 40 m/s for 10 minutes average was initially detected at about 1,900 km away from Guam Island, at 1130 LST on August 22, 2002 (Figure 2). Since the first warning on the tropical cyclone was given at 2100 LST on August 22 this cyclone tracked northwest toward Okinawa for 8 days before turning toward the Korea (Figure 3).

As the typhoon approached the southern Korean peninsula on August 29, surface wind speed increased to 10 m/s (Figure 4), but the wind speed in the Korean east coast of the study area was still weak less than 5 m/s. When it made a landfall in the southwestern part of Korean peninsula at 1530 LST on 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 40 m/s. At this time, the surface wind speed at Gangneung city by the typhoon-induced circulation was 22 m/s.

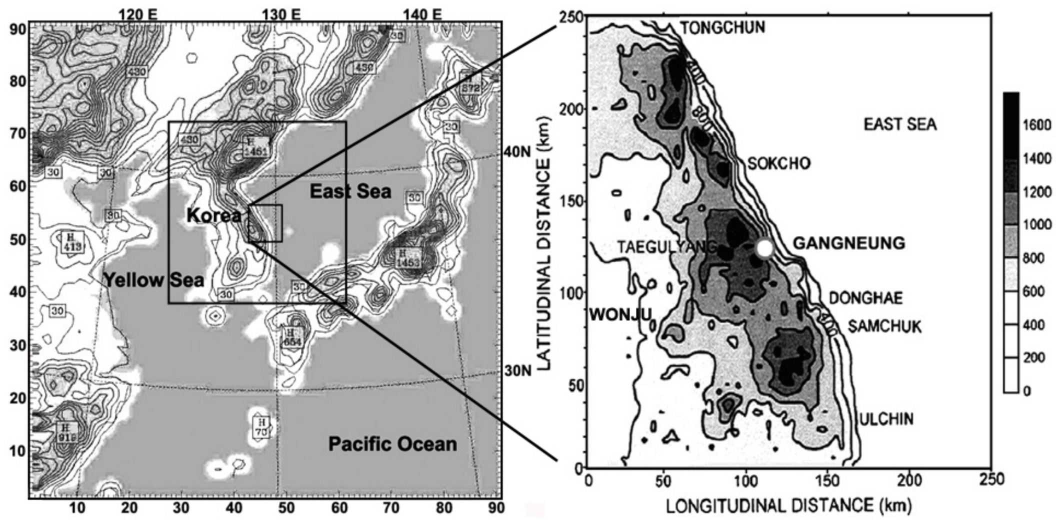


Fig. 1: Topographical features in the vicinities of Korean peninsula (large box) and Gangneung city in the Korean east coast (small box) for numerical simulation of WRF-2.2 model.

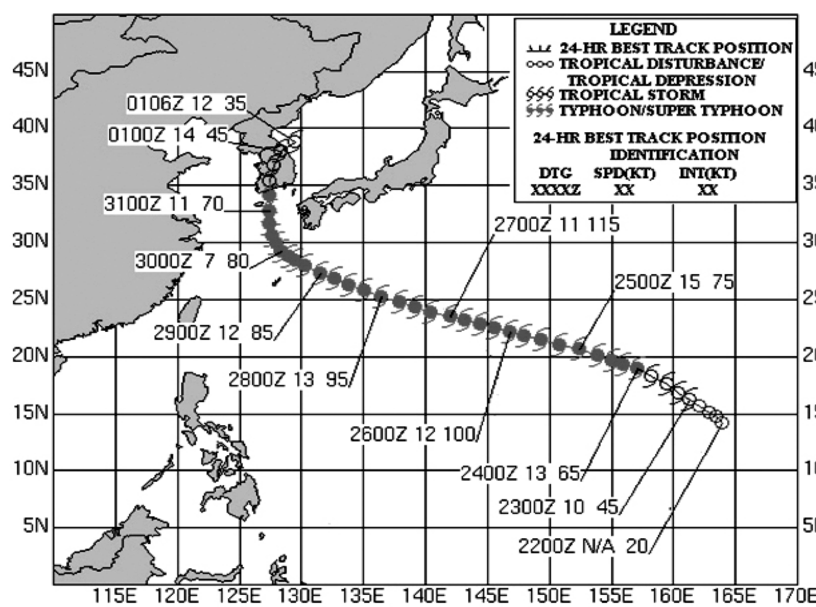
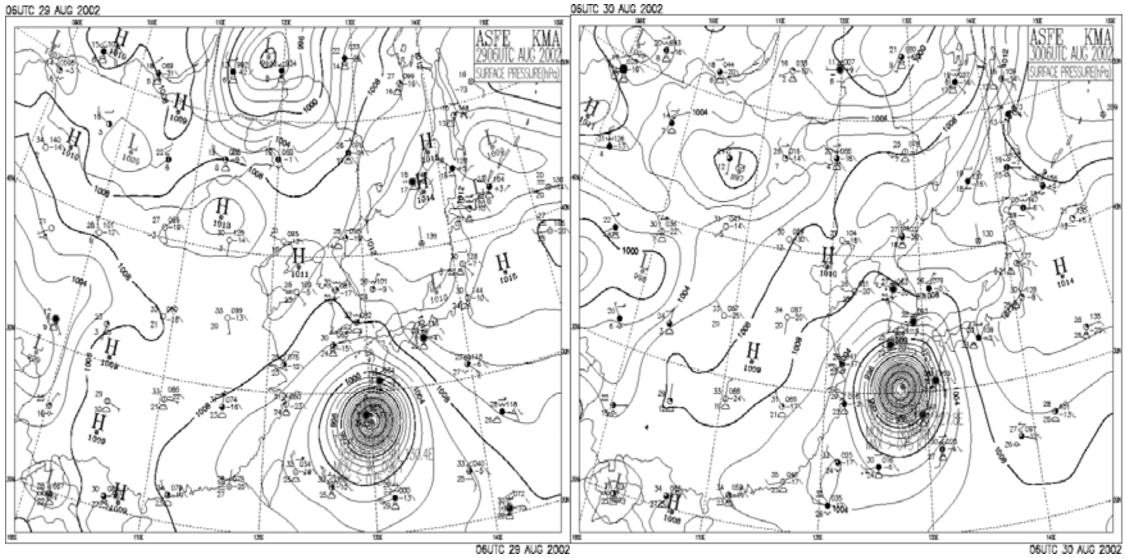
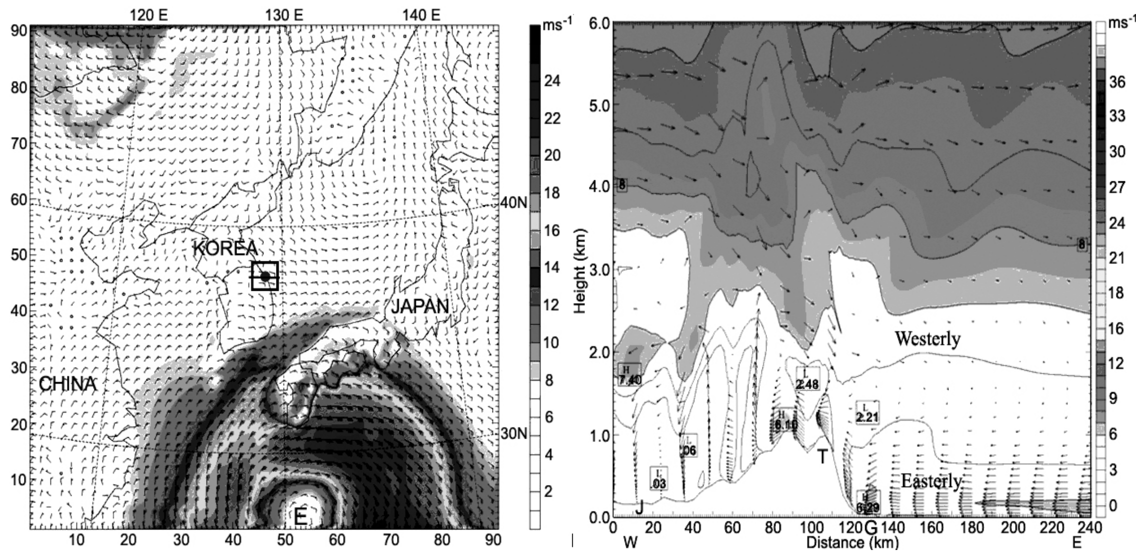


Fig. 2: Track of typhoon-TY21W (Rusa) from August 22 through September 1, 2002



(a) **(b)**

Fig. 3: Surface weather maps at (a) 1500LST, August 29, 2002 and (b) 1500LST, August 30



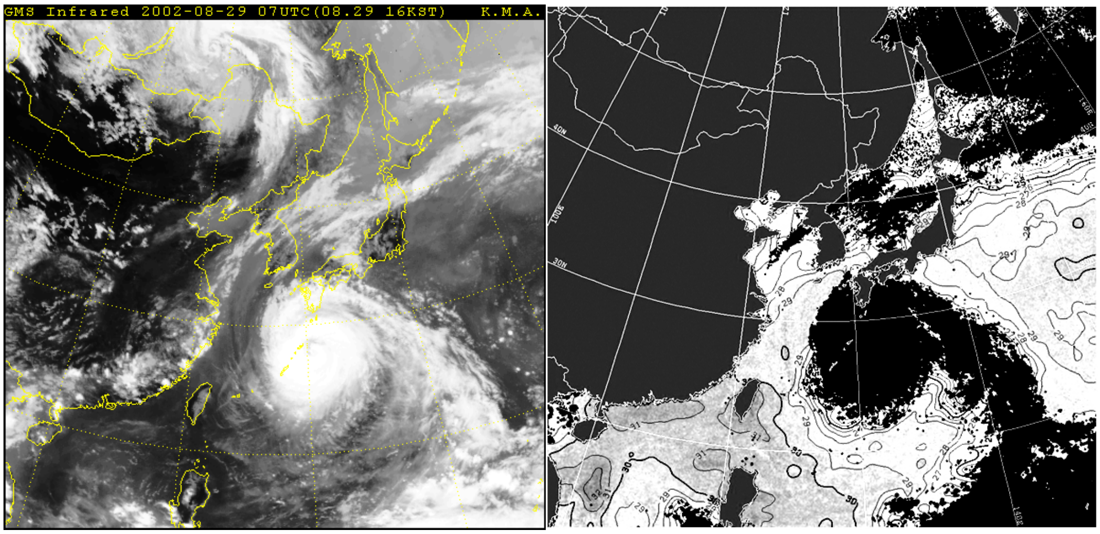
(a) **(b)**

Fig. 4: (a) Surface winds (m/s) in a coarse-mesh domain of 91 x 91 grids with a 27 km horizontal grid interval at 1600 LST on August 29, 2002, before typhoon Rusa passed by Korean peninsula. (b) Vertical profile of horizontal wind (m/s) in a fine-mesh domain with a 3 km horizontal grid near Gangneung city which lies on a straight cutting line in (a). Circle in (a) denotes Gangneung city and J, T and G in (b) denote Wonju city, Mt. Taegulyang (about 20km) and Gangneung city (about 100km) away from the east coast (G).

In summer, daytime maximum air temperature near the ground surface generally occurs at 1500 ~ 1600 LST. On August 29, 2002 before typhoon Rusa made landfall in the southern area of the Korean peninsula, Sea surface temperature in Gangneung coastal sea was 21 ^{0}C at 1600 LST on August 29 but 25.5 ^{0}C on August 28 (Figure 5). As resultant moderate easterly wind combined with both easterly sea breeze and synoptic scale easterly wind generated by the typhoon induced relatively cool moist air parcels toward the inland of the coast, maximum air temperature of Gangneung city at 1600 LST was 27 ^{0}C, but the maximum one at Wonju city in 100 km west was 34 ^{0}C due to the limited extension of easterly sea breeze (Fig. 6).

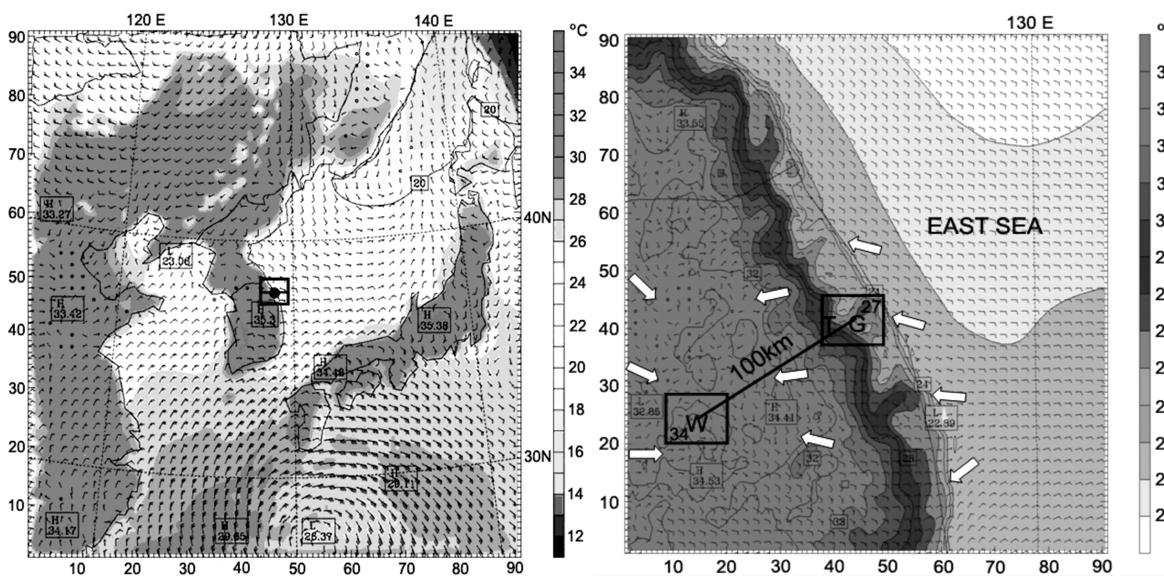
850 hPa level (approximately 1.5 km height)-air temperature change for 24 hours (^{0}C/day) at Gangneung city was further investigated whether dry cold air masses from the upper atmosphere of 6 km height toward 1 km height near the top of mountain (Mt. Taegulyang) in the west of the city could affect relatively cool surface air temperature in the city. As 850 hPa-air temperature change for 24 hours from 2100 LST on August 28 to 2100 LST on

August 29 reached – 0.5 ^{0}C/day (Figure 7a), where the decrease of surface air temperature of the city might be partially attributed to the falling of dry cold air masses with – 6 ^{0}C from the upper level of 6 km height toward the city and simultaneously, advection of relative cool moist air masses over the sea surface (SST; 21 ^{0}C) toward the coastal basin directly caused the decrease of surface air temperature of 27 ^{0}C in the coastal city much lower than 34 ^{0}C at further inland city, Wonju in the 100 km west (Figure 7b). It implies that cold moist air parcels induced by daytime sea breeze from the sea toward the inland could cool down air parcels in the coastal city but the intrusion of coastal cool air masses toward the inland could not reach Wonju city.



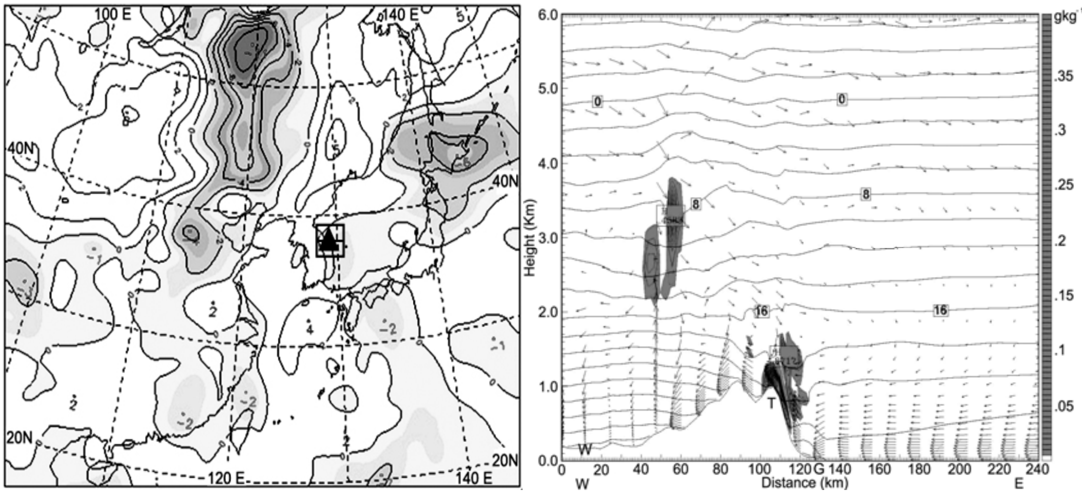
(a) (b)

Fig. 5: (a) GOES-9 satellite infrared image before typhoon Rusa made a landfall in the Korean peninsula at 1600 LST, August 29, 2002 and (b) sea surface temperature by GOES-9 MCSST satellite images at 1800 LST, August 29. Wide white area in (a) denotes cloud covered. The SST in the Gangneung coastal sea in (b) was 21 ^{0}C on August 29.



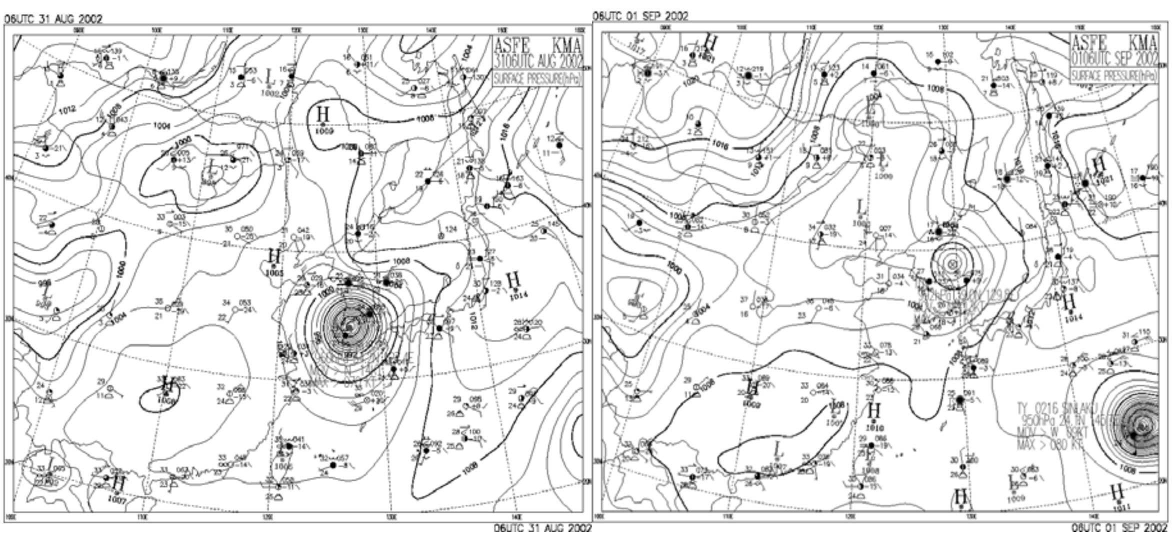
(a) (b)

Fig. 6: Air temperature (^{0}C) and wind vector (m/s) in (a) a coarse-mesh domain with a 27 km horizontal interval at 1600 LST, August 29, 2002 (occurrence time of daily maximum air temperature), before Rusa passed by Korean peninsula and (b) ones with a 3 km horizontal grid (Gangneung (45, 40)-27 ^{0}C; Wonju (15, 25)-34 ^{0}C). A small box with a circle in (a) denotes the vicinity of Gangneung city which is shown in (b). W, T and G in (b) denote Wonju city, Mt. Taegulyang and Gangneung city respectively.



(a) (b)

Fig. 7: (a) Air temperature change (^{0}C/day) at 850 hPa (about 1.5 km height) at 2100 LST, August 29, 2002, (five hours later). (b) Vertical profile of mixing ratio (g/kg; cloud) and air temperature (^{0}C) in a fine-mesh domain with a 3 km horizontal grid on a straight cutting line near Gangneung city [triangle in (a) and G in (b)]. Air temperature change at 850 hPa level near Gangneung city was – 0.5 ^{0}C/day in (a), where the falling of dry cold air masses of – 6^{0}C from the upper atmosphere toward 1 km height near the mountain top (Mt. Taegulyang; T) and the intrusion of easterly cold air from sea in (b). In (b), clouds near the mountain top and no cloud near G (Gangneung city), showing 27 ^{0}C of air temperature.



(a) (b)

Fig. 8: Surface weather maps at (a) 1600 LST on August 31, 2001 and (b) 1600 LST on September 1.

Synoptic situation, wind, precipitation and air temperature with the typhoon effect: After typhoon Rusa made landfall in the southern area of the Korean peninsula at 1530 LST on August 31, atmospheric pressure in the centre of the typhoon at 2100 LST became weaker with 975 hPa with maximum wind speed of 25 m/s (Figure 8). Wind speed near Gangneung city maintained to be in a range of 16 ~ 22 m/s before the typhoon getting out of the Korean peninsula (Figures 9, 10 and 11). At 0900 LST on 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 at 0900 LST on September 1 was about 18 hours. However, the typhoon effect with heavy precipitation and strong wind had still maintained until 1200 LST on September 1. The tropical depression became further extra-tropical cyclone in the northeastern area of the East Sea around 16000 LST on September 1.

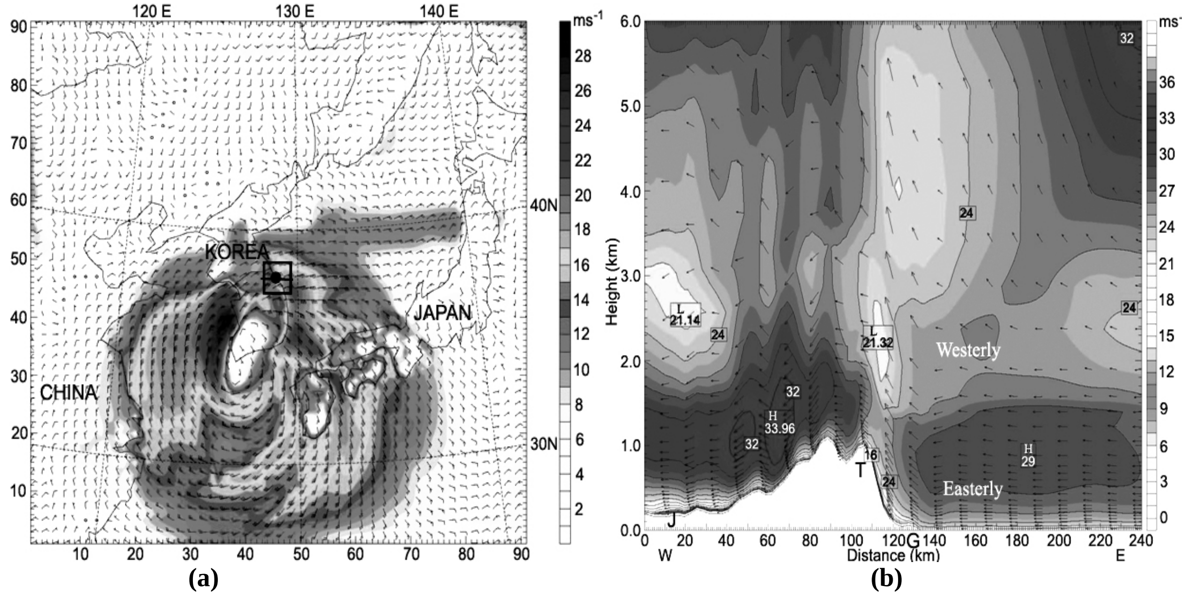


Fig. 9: Surface winds (m/s) in (a) a coarse-mesh domain with a 27 km horizontal grid interval at 1600 LST on August 31, 2002, for the passage of typhoon Rusa through Korean peninsula. (b) vertical profile of horizontal wind (m/s) in a fine-mesh domain with a 3 km horizontal grid on a straight cutting line in a small box near Gangneung city (circle). G, T and J in (b) denote Gangneung city, Mt. Taegulyang (about 20km) and Wonju city (about 100km) away from the Gangneung.

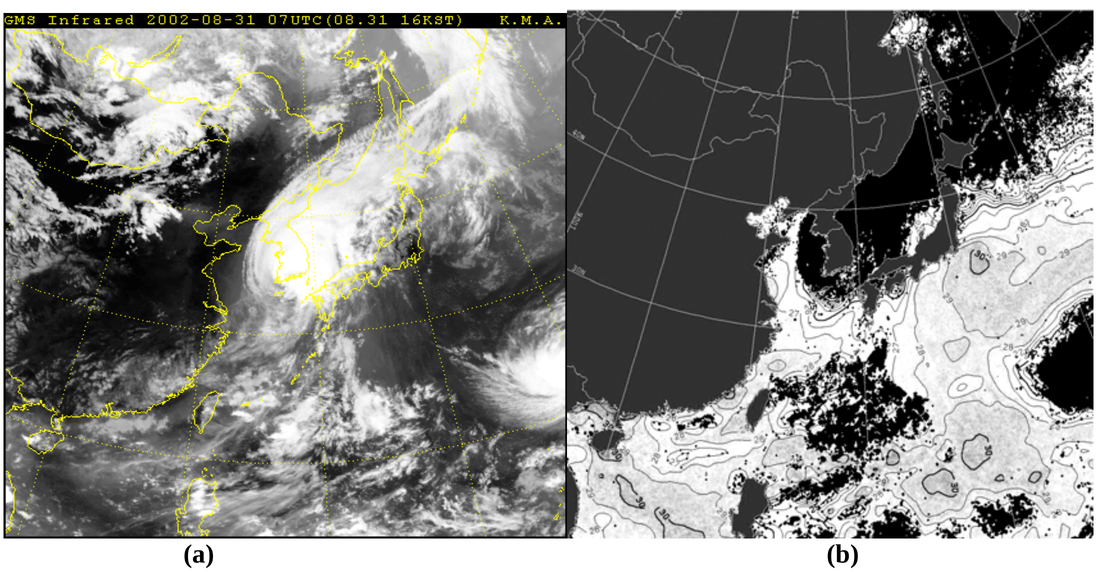
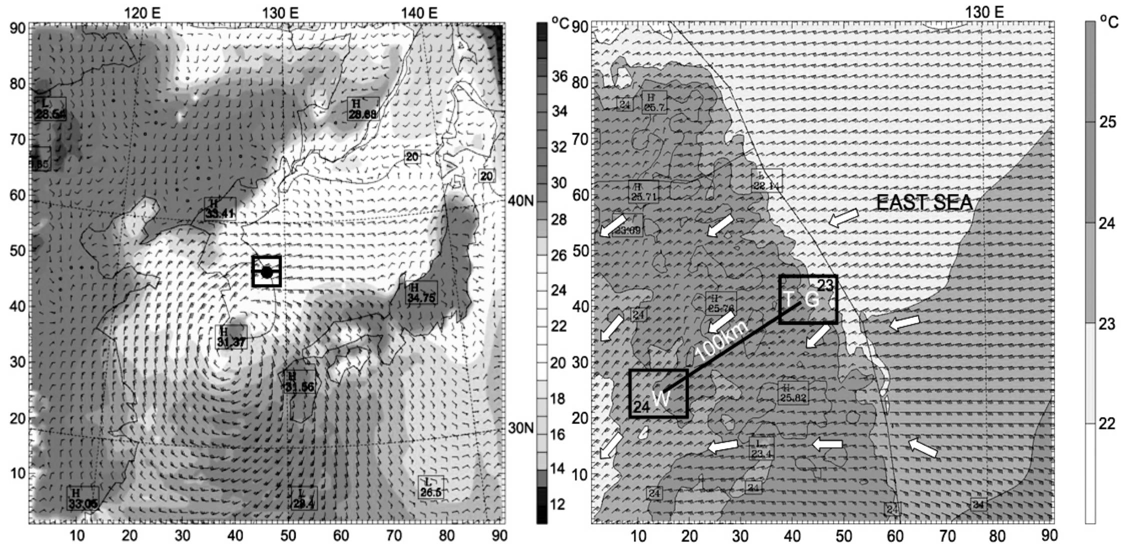


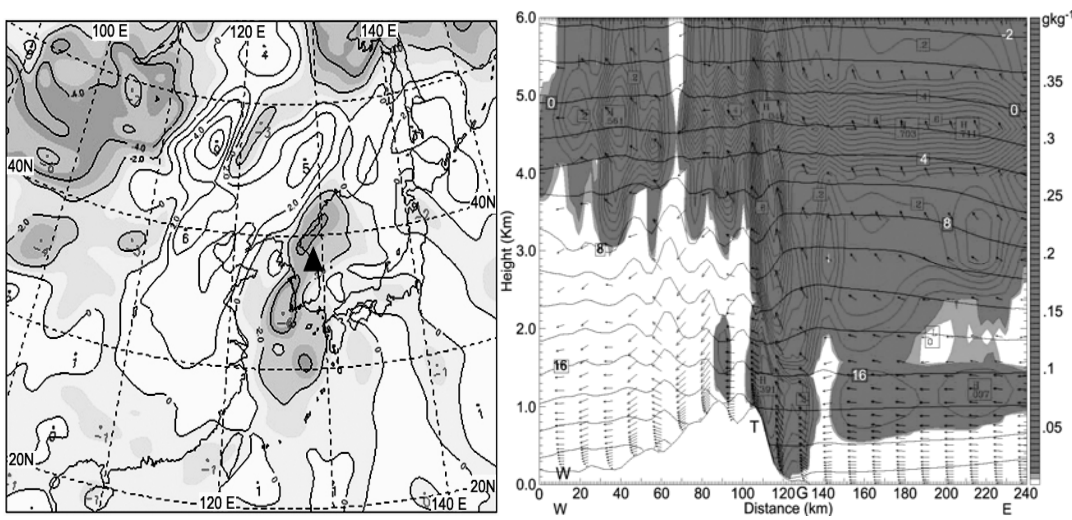
Fig. 10: (a) GOES-9 satellite infrared image of cloud after typhoon Rusa made a landfall in the southern Korean peninsula at 1600 LST on August 31, 2002 and (b) sea surface temperature by GOES-9 MCSST satellite images of Japan Meteorological Agency at 1800 LST on August 31. Wide white area denotes cloud covered area in (a) and SST near Gangneung coastal sea was 22 ^{0}C.

As shown in figure 10b, sea surface temperature (SST) on August 31 was not detected by GOES satellite image, due to cloud clusters, but it was 22 ^{0}C on September 1. On August 31, maximum air temperatures on August 31 were 23 ^{0}C at Gangneung city and 24 ^{0}C at Wonju city, showing maximum decreases of – 4 ^{0}C and – 10 ^{0}C, respectively (Figure 11). In figure 12a, air temperature change for 24 hours (^{0}C/day) at 850 hPa level (about 1.5 km height) at Gangneung city was – 3 ^{0}C/day at 2100 LST on August 31, which implied much cooling of air masses at about 1.5 km height for 24 hours.



(a) (b)

Figure 11: Air temperature (^{0}C) and wind vector (m/s) in (a) a coarse-mesh domain with a 27 km horizontal interval at 1600 LST on August 31, 2002, when typhoon Rusa made a landfall in the southern Korean peninsula and (b) ones with a 3 km horizontal grid [Gangneung (45, 40)-23 ^{0}C; Wonju (15, 20)-24 ^{0}C]. A small box in (a) denotes the vicinity of Gangneung city, which is shown in (b)



(a) **(b)**

Figure 12: (a) Air temperature change (^{0}C/day) at 850 hPa (about 1.5 km over the ground surface) at 2100 LST on August 31. (b) Vertical profile of mixing ratio (g/kg) and air temperature (^{0}C) at 1600 LST in a fine-mesh domain of a 3 km horizontal grid near Gangneung city, on a straight cutting line in a box in (a). Triangle in (a) denotes Gangnung city and W, T and G in (b) denote Wonju city, Mt. Taegulyang and Gangneung city. Air temperature change at 850 hPa level in Gangneung was – 3 ^{0}C/day in (a), under the intrusion of easterly moist cold air from sea and heavy rainfall from 9 km (here, 6 km) with – 4 ^{0}C super cooled water droplets supplied by the typhoon itself toward the ground in (b), causing air parcels to cool down to 24^{0}C (Wonju) and 23^{0}C (Gangneung)

In figure 12b, there was extremely severe cold rain shower with about 80 mm/hr, which was made by great cloud clusters of 9 km (here, 6 km) ~ 100 m height toward the ground surface of the city, due to a huge amount of water supply by the typhoon itself and by further cooling down and condensation of moistures intruded from the East Sea of Korea under a strong cyclonic circulation of the typhoon toward the coastal basin. Then moisturized and cooled down air parcels went up to the steep mountain top and further inland near Wonju city.

Thus, the decreases of air temperatures in the coastal city, Gangneung and further inland city, Wonju up to 23 ~ 24 ^{0}C should be primarily affected by cold rain shower by great cool cloud clusters of 9 km ~ 100 m height toward the ground surface. Secondary, it should be also due to the decrease of cool sea surface temperature in the coastal sea, inducing advection of relatively cool moist air masses over the sea surface toward the coast and further inland. Consequently, on August 31, air temperature in the Gangneung coastal sea was 23 ^{0}C and 24 ^{0}C in Wonju city.

Conclusion

With no influence of the typhoon, maximum air temperatures were 27 ^{0}C at 1600 LST on August 29, 2002 at a coastal city, Gangneung in the Korean eastern coast and 34 ^{0}C at an inland city, Wonju in the 100 km west. On the other hand, maximum air temperatures at 1600 LST on August 31 during the typhoon passage through the Korean peninsula were 23 ^{0}C at Gangneung and 24 ^{0}C at Wonju, showing the decreases of – 4 ^{0}C and – 10 ^{0}C respectively. The extremely decreases of air temperatures near the ground surface in coast and further inland up to 23 ~ 24 ^{0}C should be significantly affected by both extremely severe cold rain shower by great cloud clusters of 9 km ~ 100 m height over the ground surface and the westward intrusion of cool air masses by easterly wind from the sea, due to divergence of cold waters uplifted from the deep sea on the sea surface by strong cyclonic wind of the typhoon itself for all day long.

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