Numerical Case Study of Heavy Rainfall Occurred in the Central Korean Peninsula on July 26-28, 1996

Young-Ah Kim and Jai-Ho Oh

Meteorological Research Institute, KMA
2 Waryong-dong, Chongno-gu, Seoul 110-360, Korea

(Manuscript received 14 November, 1998)

Abstract

The numerical simulation of heavy precipitation event occurred in the central Korean Peninsula on July 26-28, 1996 was performed using the fine mesh model, ARPS (Advanced Regional Prediction System) developed by the CAPS (Center for Analysis and Prediction of Storms). Usually, the heavy rainfalls occurred at late July in the Korean Peninsula were difficult to predict, and showed very strong rainfall intensity. As results, they caused a great loss of life and property. As it usual, this case was unsuccessful to predict the location of rain band and the precipitation intensity with the coarse-mesh model. The same case was, however, simulated well with fine-mesh storm-scale model, ARPS.

Moisture band at 850 hPa appeared along the Changma Front in the area of China through central Korea passed Yellow Sea. Also the low-level jet at 700 hPa existed in the Yellow Sea through central Korea and they together offered favorable condition to induce heavy rainfall in that area. The convective activities developed to a meso-scale convective system were observed at near the Yangtze River and moved to the central Korean Peninsula. Furthermore, the intrusion of warm and moist air, originated from typhoon, into the Asia Continent might result in heavy rainfall formation through redistribution of moisture and heat.

In the vertical circulation, the heavy rainfall was formed between the upper- and low-level jets, especially, the entrance region of the upper-level jet above the exit the region of the low-level jet. The low level convergence, the upper level divergence and the strong vertical wind were organized to the very north of the low level jet and concentrated on tens to hundreds km horizontal distance. These result represent the upper- and low-level jets are one of the most important reasons on the formation of heavy precipitation.

1. Introduction

The Changma - known as the wet monsoon in Korea - brings a significant amount of rainfall during late June and July and is the major supplier of water resources in Korea. Also, it causes natural disaster time to time due to too much rainfall within a short time period. The annual-averaged property loss due to the heavy rainfall reaches to about 280 million US dollars. It takes about 30% among all natural disasters, and it reaches up to 70% of total loss in Korea (from KORMEX Science Plan, 1997). Based on the eleven years data (1980-1990) Lee (1993) reported that about five to six heavy rainfall events have visited to Korea in each year and they are concentrated in summer season (June, July and August). Recently a significant heavy rainfall event occurred at the central part of the Korean Peninsula on 26-28 July 1996, it took 89 human lives and the property loss reached to about 650 million US dollars. It has been recorded as the second largest flood damage in Korean history. To abate casualties from the severe weather events it is absolutely necessary to monitor and forecast them properly.

The heavy rainfall phenomena are closely related to the synoptic condition, the meso-scale processes and their interactions. Climatologically, the local heavy rainfall events frequently occur by the meso-scale disturbances developed on the Changma Front in Korea. These disturbances are located in the domain between north of the low-level jet stream at 800~700 hPa and south of the upper-level jet stream near 200 hPa (Park et al., 1986). Kim et al. (1983) reported that heavy rainfalls associated with the Changma were accompanied with the low-level jet (LLJ) at 850~700 hPa levels to its south and the upper-level jet to its north. Hwang and Lee (1993) also found that the most heavy rainfall cases are related to LLJ through the analysis of Changma for the period from 1980 to 1990. Under this circumstance precipitation has usually developed by the eastward propagating disturbances originated over the Yangtze region, where the west edge of the Changma Front is located.

Numerical model is an important tool not only to understand the meso-scale features but also to forecast precipitation quantitatively. In this study, synoptic characteristics of heavy precipitation are surveyed, and a numerical experiment is performed using the Advanced Regional Prediction System (ARPS) (Xue et al., 1995) of the Center for Analysis and Prediction of Storms (CAPS) for the case of heavy precipitation events occurred in the central Korean Peninsula on July 26-28, 1996.

2. Overview of a heavy rainfall event occurred in the central Korean Peninsula on July 26-28, 1996

Fig. 1 illustrates accumulated total precipitation during the heavy rainfall event occurred

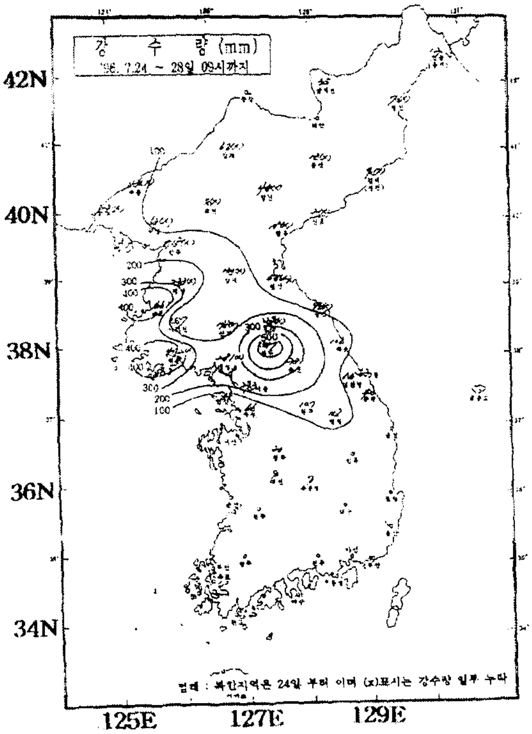

Fig. 1. Distribution of the observed accumulated rainfall during 12 UTC 24~00 UTC, July 28, 1996

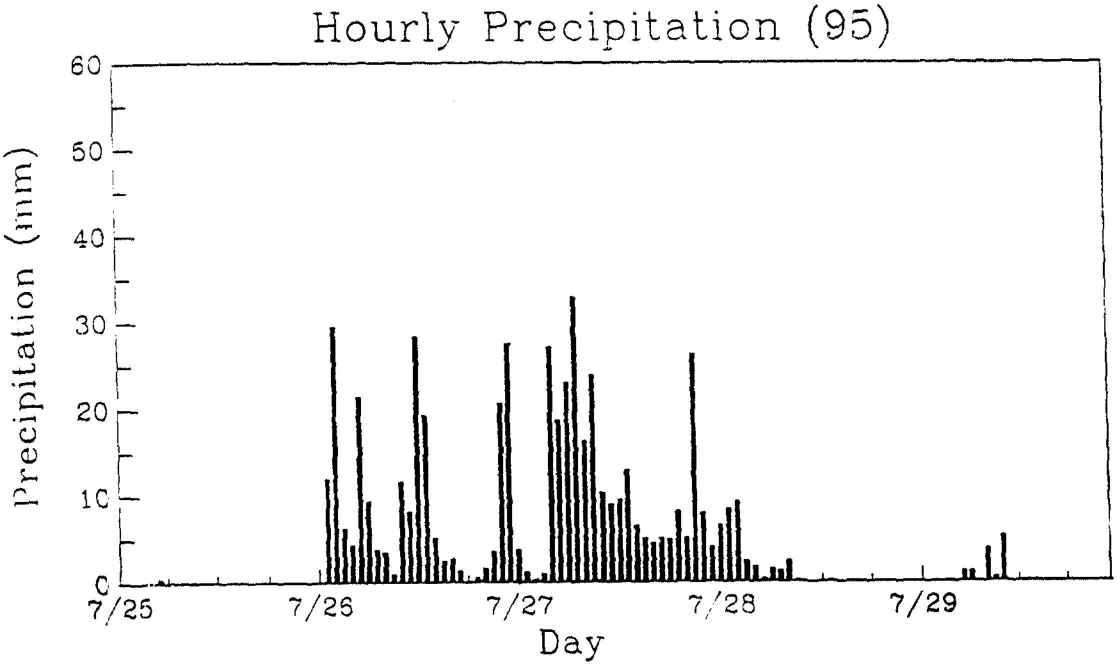

Fig. 2. Time series of the observed hourly rainfall at Cheolwon (95 is station number) for the duration of the heavy rainfall event.

July 24-28, 1996 over Korea. The maximum rainfall area includes Cheolwon sat which the total precipitation amount records more than 500 mm. Fig. 2 shows the hourly precipitation during this heavy rain at Cheolwon. The precipitation was started at early morning hours of July 26 and continued until July 28 at the central part of the Korean Peninsula. The total precipitation amount during July 26-28 at Cheolwon reached 527.2 mm, and the daily precipitation amount of 268.1 mm on 27 July was a record break. The convective precipitation amount is usually about 150 mm/day, but it can be reached more than 250 mm/day at late July (Lee, 1993).

As shown in Fig. 3a, significant convective activities are observed at near the Yangtze river by GMS-5 on 12 UTC, July 25, 1996. These convective activities have been developed to a meso-scale convective system, which might be directly related to this heavy rainfall case. It is located along the central part of the Korean Peninsula at 00 UTC, July 26 (Fig. 3b). At the western Pacific, meanwhile, Typhoon Gloria was landed at southern China, then dissipated at there (Fig. 3a-3f). As a result, the intrusion of warm and moist air into Asia continent contributes to redistribution of moisture and heat.

The Changma Front was located in Manchuria on 12 UTC July 25 as shown in the surface chart (Fig. 4), then it moved southward to the Korean Peninsula on 00 UTC July 26.Under this circumstance, it might be related to the revival of the Changma Front in the Korean Peninsula. Also, it might partly be caused by a significant moisture advection from China (Fig. 5, 850 hPa mixing ratio distributions) resulting from the movement of Typhoon Gloria in land and following Typhoon Herb (Dillon and Andrew, 1997). The intrusion of tropical storm or depression into southern China may play an important role on large inland fluxes of moisture and convectively unstable over southern China (Park, 1988). In general, the typhoon activity characteristics at late July in the western Pacific are closely related to supply a significant moisture to China and Korea.

3. Numerical Experiment

The heavy rainfall event on July 26-28 is one of interesting cases to simulate due to not only its significant casualties and property losses but also its improper forecast at that time in terms of on-set, duration and amount of precipitation. The predicted precipitation zone by KLAM (Korea Limited Area Model: Cho and Chung, 1993), which is one of the operational NWP models at KMA with 40 km horizontal resolution, was located at the further northern part of Korean peninsula compared to the actual event. The predicted 12 hour accumulated precipitation amount was less than 24 mm as shown in Fig. 6b so that it did not alert to forecaster at all, although it turned to unexpected heavy rain phenomena. This underestimated precipitation amount by the operational model, KLAM, might be caused from both its coarse horizontal resolution and treatment of physical processes. It is one of motivations to utilize the ARPS to simulate this heavy rainfall case since the ARPS is non-hydrostatic includes many enhanced physical treatment of precipitation process as well as.

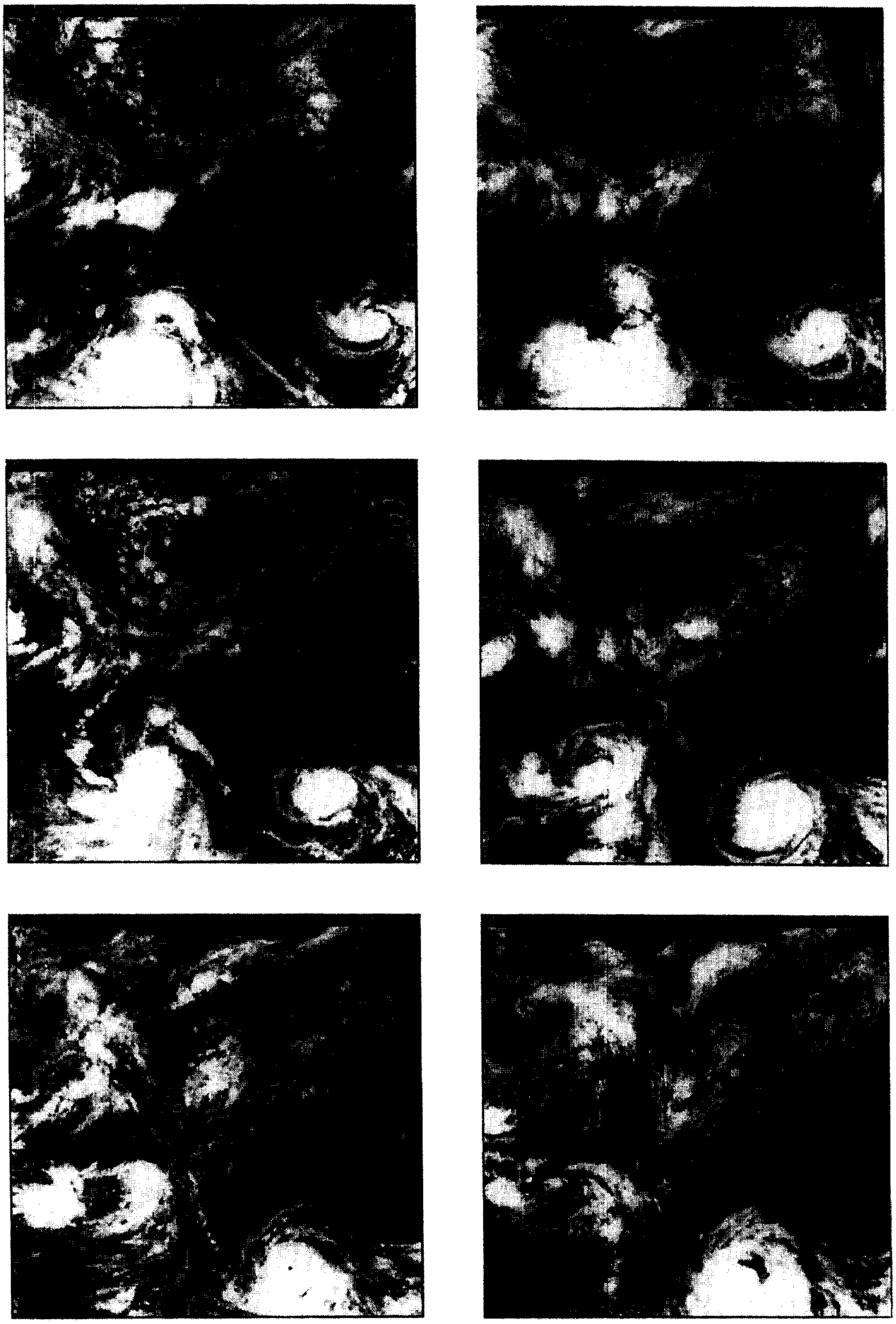

Fig. 3. GMS IR images every 12hour from July 12 UTC 25 (a) to 00 UTC 28 (f) 1996.

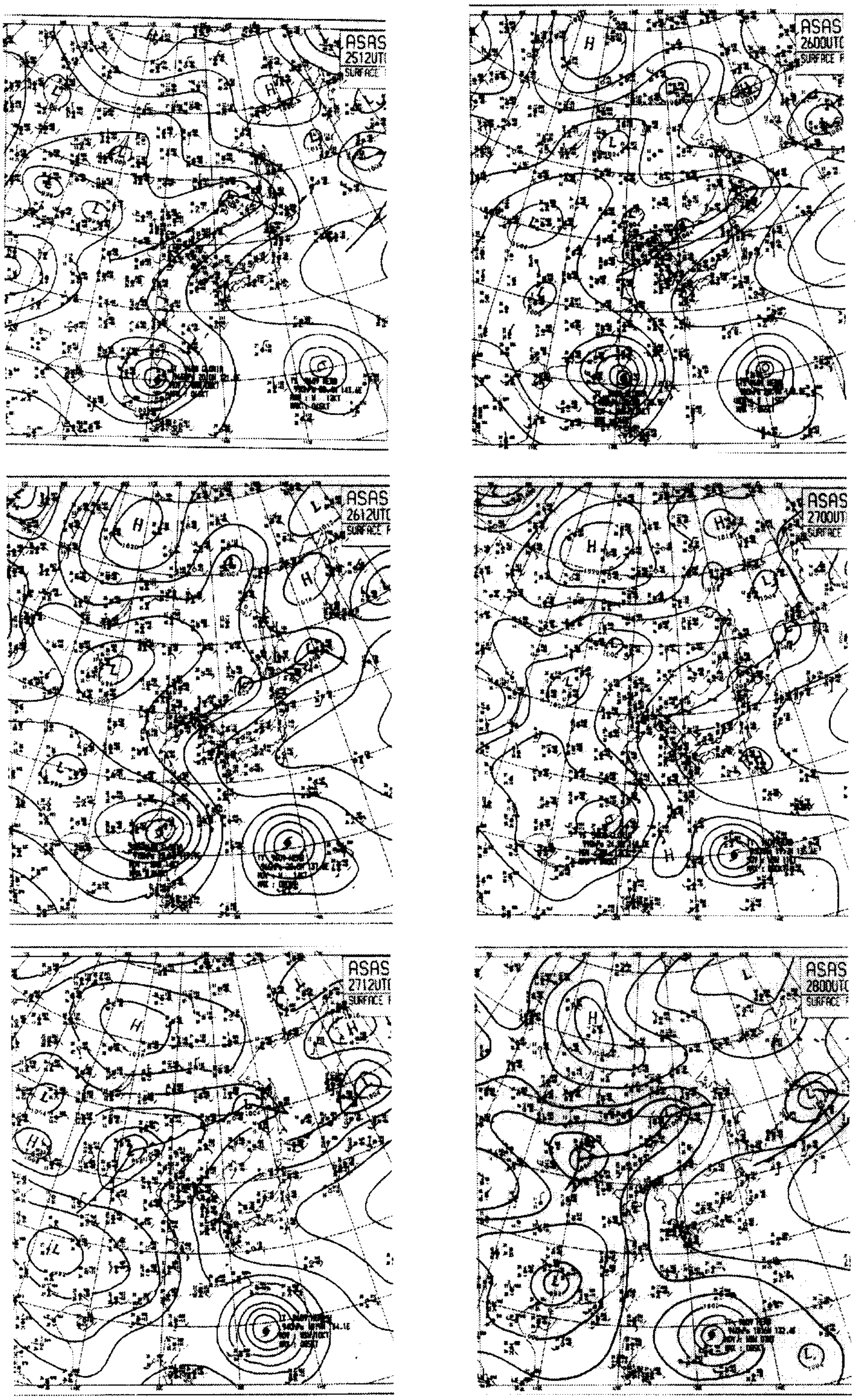

Fig. 4. Surface pressure analysis chart published by KMA from 12 UTC 25 (a) to 00 UTC 28 (f) July 1996.

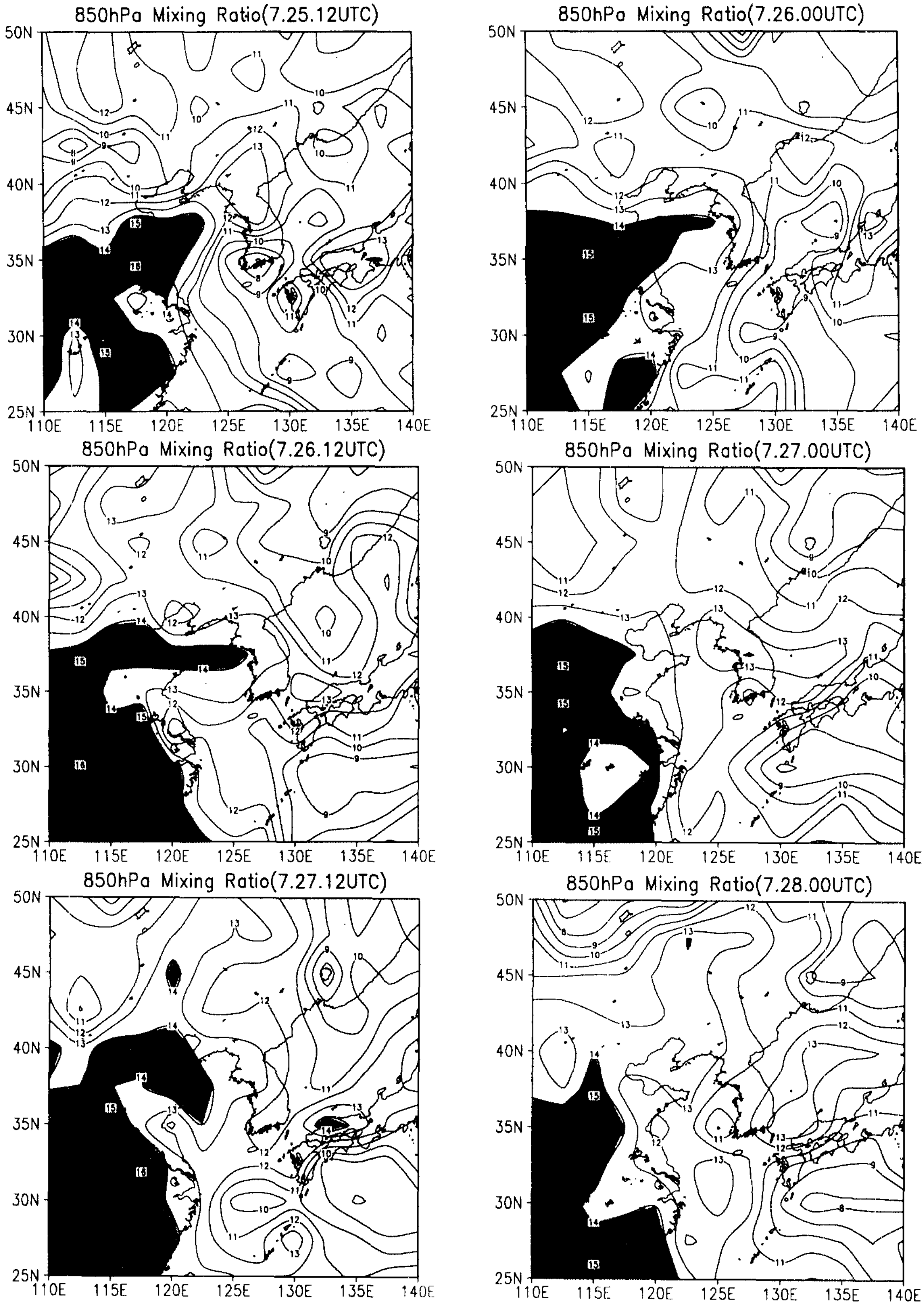

Fig. 5. 850 hPa mixing ratio analysis of gpv data (Japan) from 12 UTC 25 (a) to 00 UTC 28 (f) July 1996 (shaded area ≥14 g/kg).

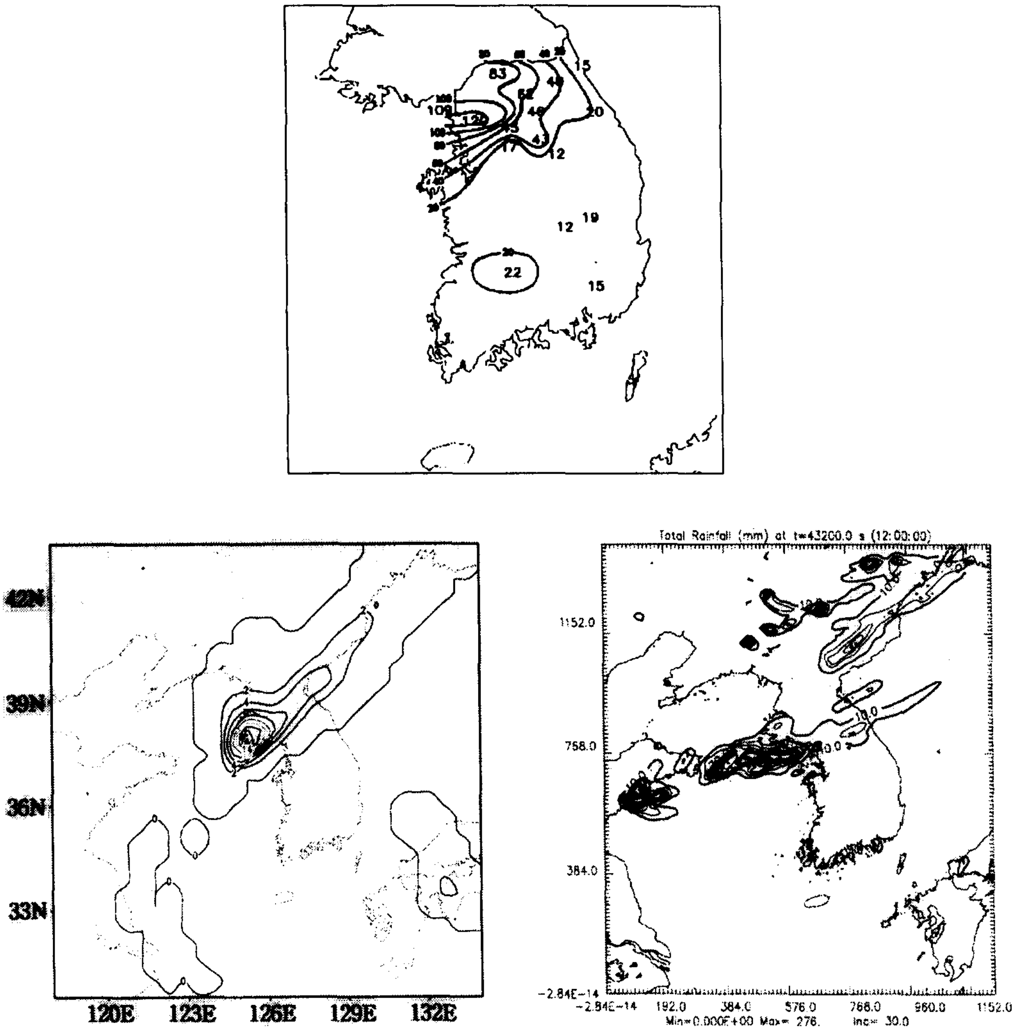

Fig. 6. The 12-hour accumulated precipitation amount during 00~12 UTC 26 July 1996 from observation (a), KLAM (b), and ARPS (c).

In this study, we examined the predictability of heavy rainfall and precipitation formation mechanism related to the development of convective cluster using the fine-resolution model, ARPS, output. The relatively dense simulated data in space compared to the conventional operational model may provide a better opportunity to study such storm-scale weather phenomena.

3.1 Model description

The ARPS, 3-dimensional non-hydrostatic storm-scale model, is used to simulate this heavy rainfall case. The model predicts Cartesian velocity components (u, v, w), perturbations of potential temperature (θ') and pressure (p'), mixing ratios of water vapor (Q_v), cloud water (Q_c), and rain water (Qr), and turbulent kinetic energy, on the Arakawa C grid. The advective modes are computed on big time steps with the leap-frog time scheme and second-order centered space differencing, whereas the acoustic modes are integrated on small time steps with the Crank-Nicolson method. Turbulent mixing is parameterized using 1.5 order turbulent kinetic energy based closing scheme. Schultz NEM ice microphysics are employed. An extensive description of the model can be found in Xue et al. (1995).

3.2 Experimental design

The initial data were obtained by interpolating the 12-hour forecasting result of the coarse resolution model, KLAM. The lateral boundary conditions were also obtained from the every 3-hour KLAM output. It means that the proposed experiment is a kind of nested ARPS experiment within spatial and temporal domain provided by the KLAM. Fig. 7 shows themodel domain of the KLAM and the ARPS for this experiment. The target model domain over the Korean Peninsula has been selected in the area from 119°E to 133°E in longitude and 30°N to 43°N in latitude. It covered by 99 x 119 horizontal grids with 12 km interval and 43 vertical sigma layers. In this study, the results of numerical experiment with the ARPS were examined only for 12-hour integration starting from 00 UTC July 26, 1996. Accordingly it concludes only the beginning point of this heavy rainfall case in the central part of the Korean Peninsula.

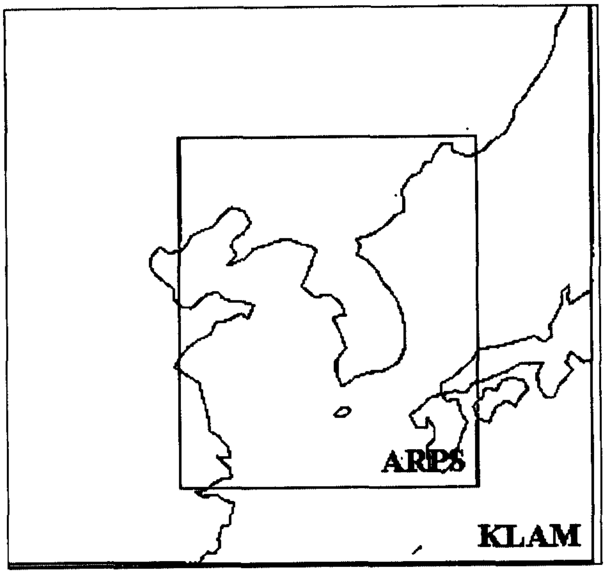

Fig. 7. Predicted domain of coarse-resolution model (KLAM) and nested fine-resolution model (ARPS).

3.3 Results and Discussion

3.3.1 Prediction of precipitation

The 12-hour precipitation amounts during 00~12 UTC July 26, the 1996 from observations in south Korea, the coarse mesh model (KLAM) output, and the fine mesh model (ARPS) output are presented in Fig. 6. The observed rainfall areas more than 100 mm are located at the central western part of the Korean Peninsula near the Yellow Sea (Seoul and Kanghwa). The coarse-resolution model, KLAM, results show that the precipitation amount is less than 24 mm and the predicted rain-band location centered at the Ungjin Peninsula was shifted toward north compared to the observation. As a result, coarse resolution model was not successful to predict this heavy rainfall case.

With the fine-resolution model, ARPS, the predicted precipitation maxima appeared across the eastern Yellow Sea and western part of the Korean Peninsula and the precipitation amounts are about 100~250 mm at these areas. To compare more precisely, we select two points; one near Kanghwa located at the coastal region of the Yellow Sea (Point 1), and the other near Cheolwon the located at central area in the Korean Peninsula (Point 2). Table 1 shows the latitude and the longitude of each location, respectively. Fig. 8 shows time series of 12-hour accumulated precipitation amount. The simulated precipitation at the Point 1, near Kanghwa, records 197.5 mm about twice larger than the observation 109.0 mm at Kanghwa. It might be caused by the location of Point 1 which is the Yellow Sea, the west of Kanghwa. At the point 2, near Cheolwon, however, has only the half precipitation amount compared to the observation and on-set time is delayed about 6 hour. There is time lag between simulation and observation especially in land area, although the fine-mesh model result is much improved compared to the coarse-mesh model. The fine-resolution storm-scale model could significantly improve local precipitation predictions in the limited time period.

Table 1. Latitude and longitude at each location

	Name	Latitude(°N)	Longitude(°E)
Observational station	Kanghwa	37.7	126.5
	Cheolwon	38.2	127.3
Selected point	Point 1 (near Kanghwa)	37.3	125.4
	Point 2 (near Cheolwon)	38.2	127.8

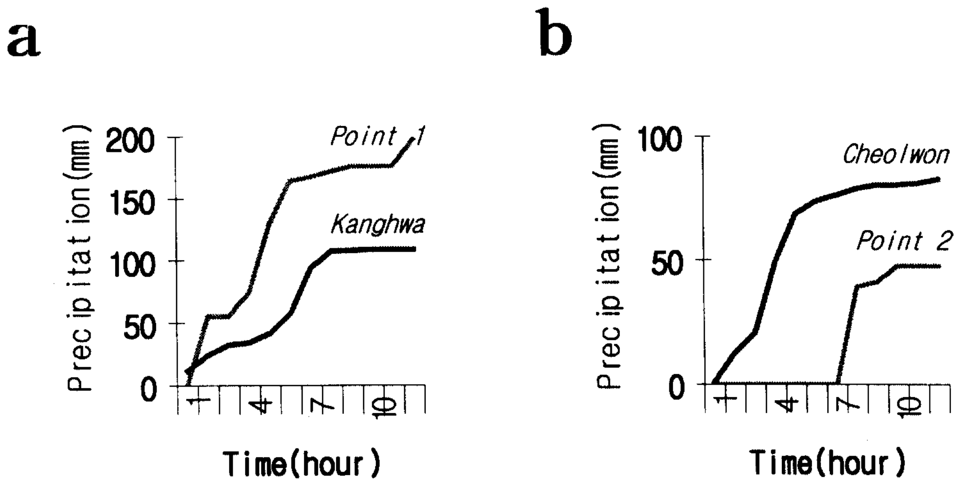

Fig. 8. Comparison of observed precipitation amount with fine-resolution model (ARPS) output at Kanghwa (a) and Cheolwon (b).

3.3.2 Initial condition

First of all, the initial synoptic condition has been analyzed to understand how the convection is well simulated respectively. Fig. 9 shows the upper and lower level jets and

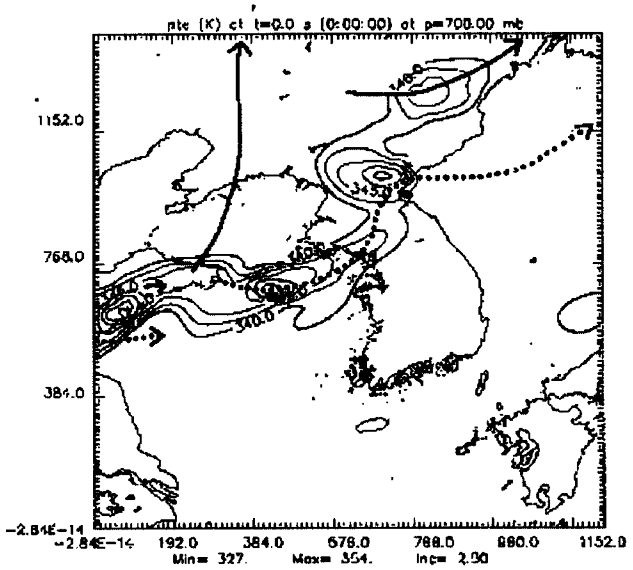

Fig. 9. The initial fields (00 UTC 26 July) of model simulation: The contours that equivalent potential temperature is more than 340 °K are drawn. Thick and dotted arrows indicate the upper-level (200 hPa) jet and the low-level (700 hPa) jet, respectively.

relative-high equivalent potential temperature area(≥ 340°K) in the initial fields of model simulation. The feature of equivalent potential temperature field represents the air mass caused the convection came from the Yangtze river. The belt shape of high equivalent potential temperature region has extended from China to middle and the northern part of the Korean Peninsula through the Yellow Sea. It might be followed the moisture advection, which is not shown in here. The low level jet at 700 hPa also existed along this belt. It seems that the high potential temperature and low level jet offer a favorable condition for developing the convective clusters in that area. In simulation, the precipitation has been developed by the meso-scale convective cells in the size of several tens to hundreds km. It also can be observed in simulation that the precipitation is related to the lower level jet.

3.3.3 Vertical cross-section

To understand how the convection is organized, we examined the vertical circulation in the cross-section along the core of the jet after 6 hour integration. Fig. 10 represents latitudinal-vertical cross-sections of horizontal wind (Fig. 10a), of cloud water mixing ratio, rain water mixing ratio and meridional-vertical wind vector (Fig. 10b), of vertical velocity(Fig. 10c), of vorticity (Fig. 10d), of divergence (Fig. 10e), and of equivalent potential temperature (Fig. 10f) obtained after 6-hour integration. As shown in Fig. 10, there is the upper-level jet located at about 11 km altitude extends downward and southward to the low-level jet (Fig. 10a). The precipitation formation area, according to Fig. 10b, might be closely related to the location of two jets, especially the very north of the low-level jet where the horizontal wind variation is very large. The distribution of vorticity (Fig. 10d) illustrates anticyclonic vorticity at the upper level while cyclonic vorticity at the low level in the precipitation area. For the divergence field (Fig. 10e), there are upper-level divergence and low-level convergence which are consistent with vorticity field. The strong rising motion also exists (Fig. 10c) at the precipitation area and is confined to within one hundred km, the very north of the low level jet. The rising of warm, humid air with the large degree of convective instability results in the release of convective instability, and there is a nearly moisture-neutral layer (Fig. 10f).

The upper-level anticyclonic vorticity above the low-level cyclonic vorticity is a popular feature in a severe storm environment (Park and Sikdar, 1982). With abundant low-level moisture supplies the vertical motion associated with the upper and lower vorticity, and the divergence fields can provide an enough precipitation to be heavy rainfall. Such a vertical circulation has been organized within a tens to hundreds km horizontal size.

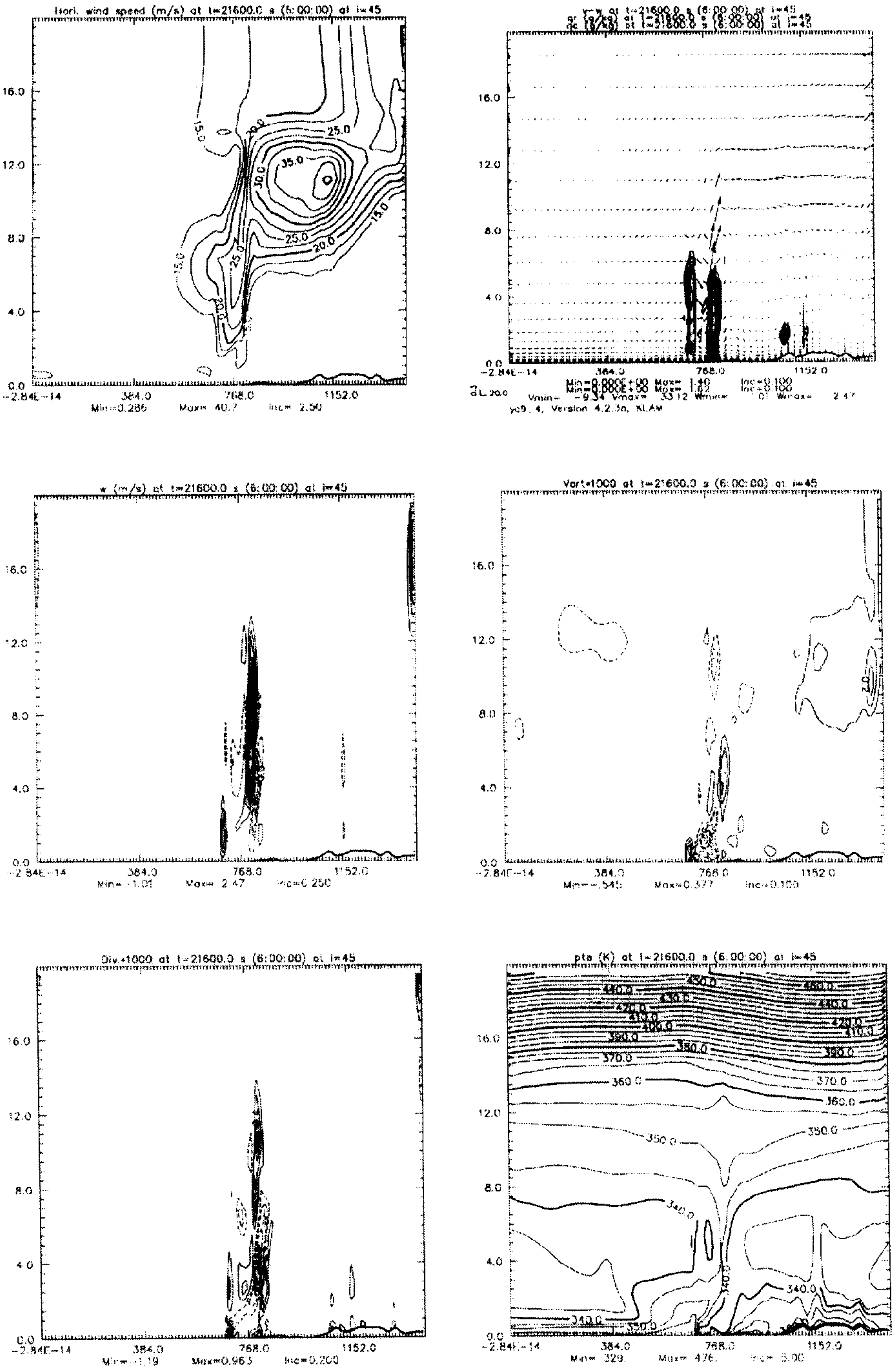

Fig. 10. The latitudinal-vertical plane (i=45) for horizontal wind distribution (a), cloud-water and rain-water mixing ratio and v-w wind vector (b), vertical wind (c), vorticity (d), divergence (e) and equivalent potential temperature (f) after 6-hour model integration.

4. Summary

The simulation of heavy rainfall event occurred on July 26, 1996 with the ARPS is relatively successful at least for the 12 hour integration started on 00 UTC July 26 in terms of the precipitation amount compared to the coarse resolution model. Although the on-set of precipitation is somewhat delayed compared to the observation, the location and intensity of heavy rainfall is much closer to the observation than the simulation with the KLAM. This partial success on the simulation of the heavy rainfall event may provide a necessary information on the dynamical and physical processes related to the development of convective clusters near the Korean Peninsula. We summarize the findings through this study as: The belt shape moisture distribution located along the Changma Front and the organized upper- and low-level jets provide a favorable condition for a strong convection. The heavy precipitation associated with this convection has concentrated on tens to hundreds km horizontal distance and the location of the low-level jet nearly coincide with the location of heavy rain. In addition, the typhoon after inland arriral plays as one of the major suppliers of moisture associated with the low-level continental-scale cyclonic monsoon circulation at the East Asia.

Acknowledgements

This work is supported by Ministry of Science and Technology of Korea under the grant PD 01-01-01.

References

Cho, J.Y. and Chung, J.S., Structure and Operational Process of KLAM (Korea Limited Area Model). KMA/NWPD TN 93-1, 36pp, 1993.

Dillon, C.P. and Andrews, M.J., Annual Tropical Cyclone Report. Joint Typhoon Warning Center, 331pp, 1996.

Hwang, S.O. and LEE, D.K., A Study on the Relationship between Heavy Rainfalls and Associated Low-Level Jets in the Korean Peninsula. *J. Korean Meteor. Soc.*, 29, 2, 133-146, 1993.

Kim, S.S., Joung, C.H., Park, S.U., and Lee, B.S., The characteristic structural differences of the rainy front (Changma front) between the wet and dry seasons. *J. Korean Meteor. Soc.*, 19, 1, 12-32, 1983.

Lee, D.K., Numerical Simulation of Heavy Rainfall in Korea. Korea Science and Engineering Foundation, Research Report, 509pp, 1993.

Park, S.U., Joung, C.H., Kim, S.S., Lee, D.K., Yoon, S.C., Jeong, Y.K., and Hong, S.G., Synoptic scale features of the heavy rainfall occurred over Korea. *J. Korean Meteor. Soc.*, 22, 1, 42-81, 1986.

Park, S.U., Ann, H.J., and Chun, Y.S., Evolutionary of the large scale circulation over East Asia during the Changma period of 1985. *J. Korean Meteor. Soc.*, 24, 3, 22-43, 1988.

Park, S.U. and Sikdar, D.N., Evolution of the dynamics and thermodynamics of a mesoscale convective system: A case *Mon. Wea. Rev.*, 110, 1024-1040, 1982.

Xue, M., Droegemeier, K.K., Wong, V., Shapiro, A., and Brewster, K., ARPS4.0 User's Guide. Center for Analysis and Prediction of Storms, University of Oklahoma, 380pp, 1995.