Evolution and structure of cloud cluster occurred over the Korean peninsula on 16 July 2009

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1. INTRODUCTION

A significant portion (normally 53%, or about 700 mm) of the annual precipitation on the Korean Peninsula is due to heavy rainfalls during summer (KMA 2001). Heavy rainfalls over the Korean peninsula are produced by various types of precipitation systems.

To understanding various types of heavy precipitation systems (HPSs) better, Lee and Kim (2007) classified four types of heavy precipitation systems over Korean Peninsula. They identified four major types of HPSs which are squall line, isolated thunderstorm, convection band, cloud cluster by phenomenological analysis of HPSs during 2000-2006. According to their classification, the cloud clusters are generally identified in satellite imagery by their mesoscale cirrus shields, each shield being ~ 100-1000 km in dimension, and cold cloud-top temperature (Lee and Kim 2007). They may show the oval-shaped cloud mass region of T_B (equivalent black-body temperature) lower than -50℃ is about or larger than 100 km in diameter and horizontal gradient of T_B is large near the rim of the cloud mass.

They showed the cloud clusters are the most frequent type of HPS comprising about 47% of HPSs occurred during 2000-2006 and produce large amount of rainfall in significantly wider area than other HPSs. However, knowledge about the cloud cluster over the Korean peninsula is generally poor.

This study focuses on understanding the evolution and maintenance mechanism of the cloud cluster. Observational data and numerical simulation results are used to investigate evolution and maintenance mechanism of the cloud cluster.

2. Case and synoptic environment

Heavy rainfall associated with the cloud cluster occurred over Korean Peninsula during the 00 LST (15 UTC 15) – 12 LST (03 UTC 16) 16 July 2009. During this period, the 24-hourly accumulated rainfall amount exceeded more than 200 mm at the southern part of the Korean Peninsula (Fig. 1a). in the mature stage of the cloud cluster, one-hourly rainfall amount exceeded more than 90 mm at Pusan during 22 UTC – 23 UTC 15 July 2009.

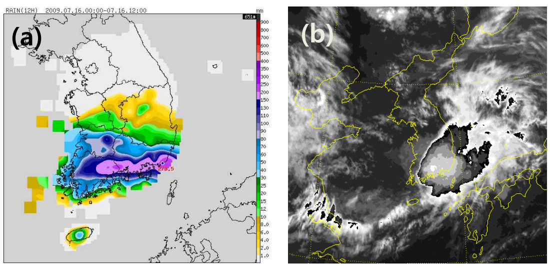

Fig. 1. (a) Accumulated rainfall amount (mm) for 00 LST 16 (15 UTC 15) ~ 12 LST 16 (03 UTC 16) July 2009 and (b) MTSAT enhanced infrared images for 23 UTC

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15 July 2009.

GMS IR imagery shows evolution processes of the cloud cluster (not shown). They show thin cloud belt associated Changma front extended from synoptic scale low in occlusion stage over the northeastern coast of the Asian continent to southern coast, and convective clouds developed near the Jindo, southwestern part of the Korean peninsula. After 1500 UTC 15 July 2009, two convective clouds developed near the Jindo, and they propagated eastward along the south coast of the Korean Peninsula. The convective system which extended from northwest to southeast appears at southern part of the peninsula at 1833 UTC. At 1933 UTC, a new convective cloud developed upstream of the convective system where the southwestern part of the peninsula. After 1933 UTC, the convective system moved inland area and developed rapidly. It merged with preexisted convective systems and then they formed a large cloud cluster at 2300 UTC (Fig. 1b).

The oval-shaped cloud mass region of T_B lower than -50℃ is larger than 200 km in diameter, and large horizontal gradient of T_B at the west part of the cloud cluster is shown. After 0100 UTC 16 July 2009, convective system narrowed south-north direction, and it dissipated and moved southeastward (not shown).

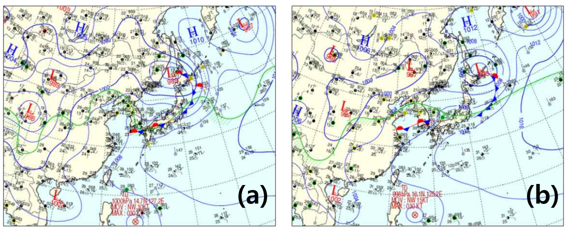

Fig. 2. Surface weather charts for (a) 12 UTC 15 July 2009, and (b) 00 UTC 16 July 2009.

The surface chart for 12 UTC 15 July 2009 shows the western Pacific subtropical high (WPSH) in the south of Japan. The WPSH is opposite to the lows which are located the north of the Japan and inland of the China. A quasi-stationary frontal system over the south coast of Korea extended from a weak, low center located in the northern East Asia. The frontal system moved northward and extended from Shandong peninsula to the south coast of the Japan. Tropical depression was approaching the southeast coastal area of China (Fig. 2)

High equivalent potential temperature more than 340K and strong equivalent temperature gradient located in the southern part of the Korean peninsula where south of the monsoon front was located (not shown). During 12 UTC 15 – 00 UTC 16, warm and moist air was transported to the Korean peninsula from the east coast of the China by strong southwesterly wind, and southwesterly wind and northwesterly wind conversed over the Korean peninsula. The large scale conditions provided a favorable environment for development of convection.

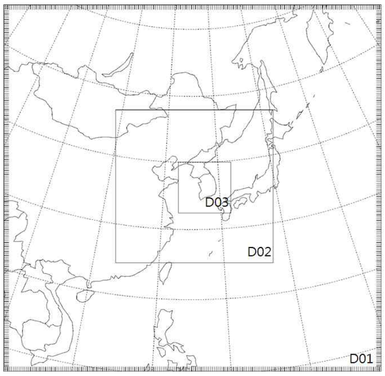

Fig. 3. The three nested domain (D01, D02, D03) for the simulation.

3. Numerical simulation

The WRF (Skamarock et al. 2005) model is a numerical weather prediction (NWP) and atmospheric simulation system designed for both research and operational applications. The model used in this study is the WRF version 3.1, which was released in April 2009. A one-way nested grid system is used. They consist of a 30-km grid domain (D01, 200×200 grid points), a 10-km grid domain (D02, 250×250 grid points) and a 3.33-km grid domain (D03, 250×250 grid points) with 41 vertical sigma levels to the model top, 50 hPa (Fig. 3). We will describe and discuss the present cloud cluster case using the results from the 3.33-km grid simulation. The model run is initiated using the GDAS data of NCEP.

The physics packages used in this study include the WRF single-moment 6-class (WSM 6) (Hong and Lim 2006) scheme, the Yonsei University planetary boundary layer (PBL) (YSU PBL) (Hong et al. 2006), and Kain-Fritsch scheme (Kain 2004), which is activated in the outer two domains.

Hong (1992) suggested that evaporative cooling at low level plays an important role in organization of precipitation system over the Korean peninsula. To investigate the role of low level evaporative cooling in cloud cluster organization, the experiment without evaporation from rain to vapor (NOEVP) in microphysics is compared with the CTL experiment.

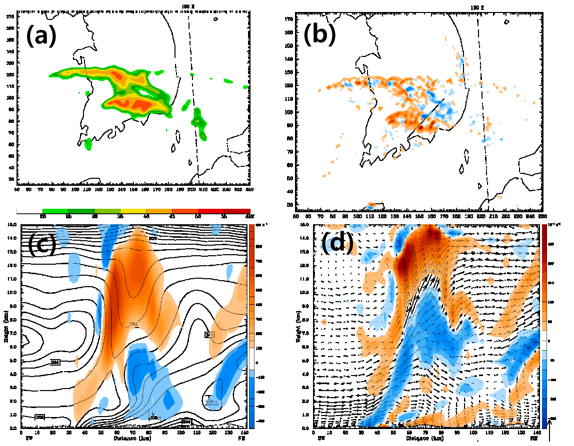

Fig. 4. (a) Simulated radar reflectivity (dBZ, shaded) at 850 hPa and simulated vertical velocity (ms^{-1} , shaded) at 700 hPa for 20 UTC 15 July 2009. Vertical cross sections of simulated (c) vertical velocity (ms^{-1} , shaded) and equivalent potential temperature (solid line), (d) divergence ($10^{-4}s^{-1}$, shaded) and circulation vector (arrow) along the line in (b) for 20 UTC 15 July 2009.

The simulated initiated location of the cloud cluster and the simulated precipitation pattern agrees well with the observation (not shown). 700 hPa vertical velocity field represents strong ascending (descending) motion at the upstream (downstream) of the southwesterly wind. There is wide updraft area whose length scale is about 60 km. And strong downdraft associated with the cold pool reveals at the low level (Fig. 4). Region of strong convergence is located at the low level where cold outflow and low level inflow converge. Widely tilted vertical structure plays an important role in development of precipitation system.

Strong convergence (divergence) at low level is intensified while the precipitation system develops. And lower and upper level jet are developed and intensified as precipitation develops (not shown). This secondary circulation associated convective activity is the important factor to develop and maintain precipitation system. This result agrees well with development mechanism of Sun and Lee (2002) and Shin and Lee (2005). They suggested that coupling between low level jet and upper level jet provides favorable condition for deep convection.

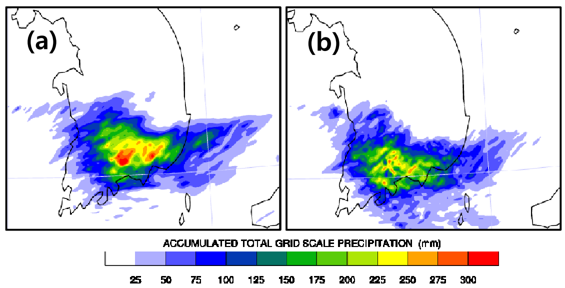

Fig. 5. Simulated 24h-accumulated rainfall amount ending at 12 UTC 16 July 2009 for (a) CTL and (b) NOEVP experiment.

Simulated 24h-accumulated rainfall amount shows similiar pattern between NOEVP and CTL experiments (Fig. 5). Domain averaged rainfall amount also shows almost the same amount (not shown). Since the convective system developed under strong large scale condition such as stationary monsoon frontal system, results represent almost no difference of location and intensity of the rainfall amount. However NOEVP experiment simulates more discrete and unorganized precipitation pattern comparing with CTL experiment. It seems that low level evaporative cooling is important to organize and maintain the structure of the cloud cluster type precipitation system.

4. Summary

Synoptic weather chart and analysis data showed that the stationary monsoon front and region of large convective instability was located at the southern part of Korean peninsula and warm and moist air was transported to the Korean peninsula by low level southwesterly wind. Korean peninsula was favorable condition for development of precipitation system.

Numerical simulation results show low level evaporative cooling plays an important role in develop and maintain the precipitation. Strong convection intensifies low and upper level jet and secondary circulation intensifies deep convection as positive feedback.

More studies are needed to generalize characteristics of the cluster type precipitation system over the Korean peninsula.

Acknowledgements

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