MAINTENACE MECHANISM OF CONVECTIVE CELLS WITHIN MESOSCALE CONVECTIVE SYSTEM IN HUMID SUBTROPICAL REGION

*Shingo Shimizu[1], Hiroshi Uyeda[1], Taro Shinoda[1], Kazuhisa Tsuboki[1]
H. Yamada[2], B. Geng[2], and T. Kato[3]
(1: HyARC, Nagoya University, 2: Frontier Observational Research System for Global Change,
3: Meteorological Research Institute, Japan Meteorological Agency)
HyARC, Nagoya University, Japan, 464-8601, Furo-cho, Chikusa Nagoya, Japan.
e-mail: shimizu@rain.hyarc.nagoya-u.ac.jp

Abstract

In oder to reveal relation between maintenance mechanism and storm environment, two back-building rainband observed near Shanghai during Meiyu season in 2001 which had different lifetime of convective cell were investigated using variational dual-Doppler radar analysis and regional objective analysis data. The lifetime of convective cells within MCS in a moist mid-level environment (90 min) was longer than that in a dry mid-level environment (42 min). The moist environment caused evaporative cooling of rain to be inactive and caused a weak downdraft. The weak downdraft did not cut off a moist air supply to the long-lived convective cell.

Keyword: MCS, Lifetime of convective cell, mid-level humidity, dual-Doppler radar analysis, CReSS

1. Introduction

The relation between environment and types of Mesoscale Convective System (MCS) has not been documented well in a moist environment such as that of East Asia. On the contrary, in a dry environment such as that of the Great Plains in U.S., it is well known that Convective Available Potential Energy (CAPE) and vertical wind shear are important environmental parameters for determining formation types of MCS (Bluestein and Jain, 1985). In a moist environment, a humidity distribution, as well as CAPE and vertical wind shear, is now focused as an important parameter for maintenance of convective cell within MCS.

In order to reveal maintenance mechanism of convective cells within linear MCS in a moist environment, we selected two back-building rainbands with distinct characteristics of convective cells observed during a field experiment in the downstream region of Yangtze river during Baiu/Meiyu season in 2001 (Yamada et al., 2004). We investigated the lifetime and downdraft strength of convective cells within the two back-building rainbands by dual-Doppler analysis, and estimated three-dimensional humidity distribution by using Regional objective ANALysis (RANAL), Regional Spectral Model (RSM), which are produced by the Japan Meteorology Agency. To confirm the relation between mid-level humidity and downdraft strength, we performed a numerical simulation with Cloud Resolving Storm Simulator (CReSS) (Tsuboki and Sakakibara,2002).

2. Data

Two X-band Doppler radars (at Wuxian and Zhouzhuang, covering the downstream of Yangtze river with 64 km in radius) obtained sets of volume scan data of reflectivity and Doppler velocity every six minutes.

We analyzed lifetime and three dimensional structure of convective cells within two back-building rainbands by using dual-Doppler radar analysis with variational method (Gao et al.,1999) within the overlapped radar observation area of the two radars (Fig. 1a).

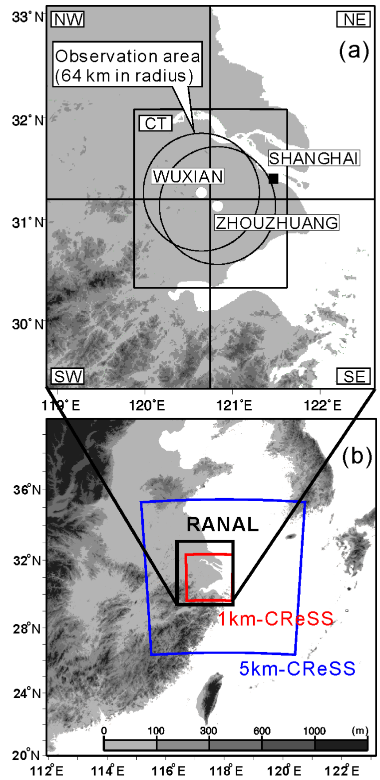

Fig. 1: The observation field around two X-band Doppler radars at Wuxian and Zhouzhuang (Fig. 1a). Two circles in Fig. 1a show the radar observation area (64 km in radius). Five of 2° x 2° regions (NW,NE,SW,NE,and CT) in Fig. 1a indicate analysis regions for estimating environmental parameters using RANAL. The RSM calculated the parameters within the 10° x 10° region shown in Fig. 1b. Domains for 1km-CReSS and 5km-CReSS are shown in Fig. 1b.

In order to evaluate the environment around the observation area, humidity distribution is investigated in the five regions ($2^o \times 2^o$ regions: NE, NW, SE, SW, and CT (covering the radar observation area)) using RANAL data (Fig. 1a). The time resolution of RANAL is 6 hours (02, 08, 14, 20 LST (LST = UTC + 8 hours)). The horizontal esolution of RANAL is 20 km. In the vertical direction, RANAL contains 20 levels. The mean value of environmental parameters in the each region is calculated: vertical integrated specific humidity deficit from 850 hPa to 500 hPa (HUDE), and vertical integrated vapor flux convergence from surface to 850 hPa (VFC), vertical integrated specific humidity from surface to 850 hPa (VISH), CAPE and CIN. HUDE is an index for dryness of midlevel layer. In order to investigate the time variation of humidity distribution, we used the forecast of RSM within $10^o \times 10^o$ region (Fig. 1b). The time resolution of RSM is 1 hour. The horizontal resolution is 20 km. The RSM was run for 24 hours from 20 LST 18 Jun and 20 LST 23 Jun.

The numerical simulations were conducted with a 1km-resolusion CReSS (1km-CReSS). The 1km-CReSS was one-way nested within the outputs of a 5km-CReSS (Fig.1b). The 5km-CReSS was also nested within the outputs of RSM.

3. Result

3.1 Dual-Doppler analysis

We investigated lifetime and the maximum downdraft velocity of convective cells within two back-building rainbands (CASE1: 0348 LST 24 June, CASE2: 0118 LST 19 June). We defined lifetime of convective cell as the period when the maximum reflectivity at 4 km above sea level (ASL) was over 30 dBZe. The longest lifetime of convective cell was 90 minutes in CASE1 (0318 LST - 0448 LST), and 42 minutes in CASE2 (0106 LST - 0148 LST). The maximum reflectivity during the lifetime was 39 dBZe at a height of 4 km ASL in CASE1, and 44 dBZe at a height of 2 km ASL in CASE2 (not shown). We named the back-building rainband with long-lived convective cells as BBL, and the back-building rainband with short-lived convective cells as BBS. The BBL consists of steady convective cells. On the contrary, the BBS was maintained by repeated replacement of the convective cells.

We observed a remarkable difference in the maximum downdraft velocity. Reflectivity at a height of 1 km ASL of CASE1 and CASE2 is shown in Fig. 2. Vertical cross sections along the A-A' and B-B' lines in Fig. 2a and Fig. 2b are shown in Fig. 2c and Fig. 2d, respectively. The maximum downdraft velocity at 2 km ASL was 2.0 m s^{-1} (CASE1) and 5.0 m s^{-1} (CASE2), respectively. The location of downdraft core differed from the location of the reflectivity core in two cases (not shown). The cause of the downdraft seems to be mainly due to evaporative cooling in two cases because the downdraft core located at the confluence of the wind at a height of 4 km ASL and the edge of strong echo in two cases (not shown).

It is known that a strong downdraft of a convective cell causes a strong outflow cutting warm and moist air supply to an updraft of the convective cell (Weisman and Klemp, 1982). In present cases, actually short-lived convective cells were observed corresponding to the strong downdraft in CASE2, and long-lived cells were obserbed corresponding to the weak downdraft in CASE1.

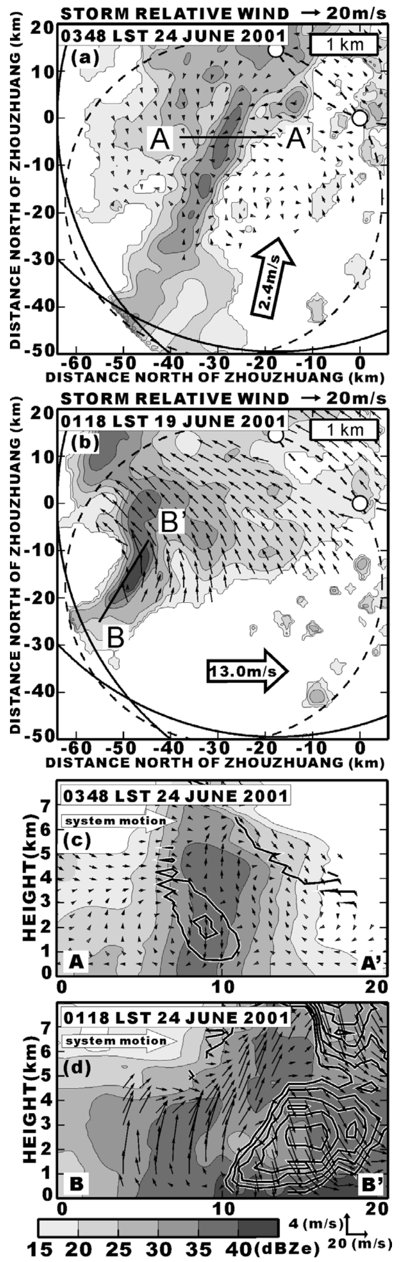

Fig. 2: The radar reflectivity overlaid with storm-relative wind vectors at a height of 1 km ASL of CASE1(a),CASE2 (b). Vertical cross sections along A-A' (Fig. 2c) and B-B' (Fig. 2d) lines are indicated. Thick contours show downdraft every 1 m s^{-1}. Open arrows show system movement speed.

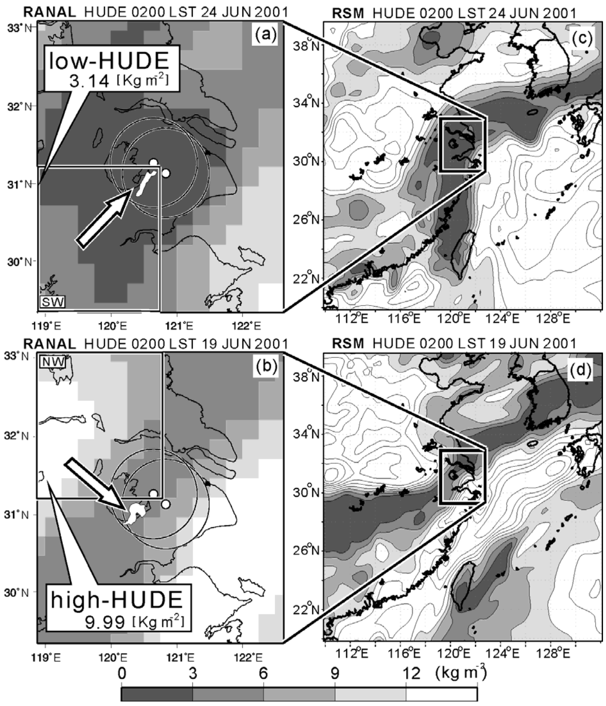

Fig. 3: The distribution of HUDE on 19 Jun (a) and on 24 Jun (b) calculated by RANAL data, and those of 19 Jun (c) and 24 Jun (d) estimated by RSM. In Fig. 3a and Fig. 3b, the locations of two rainbands are shown by open area within radar range (over 30 dBZe). Open arrows indicate storm-relative wind at 4 km ASL estimated by dual-Doppler analysis. The mean value of HUDE is calculated in SW (a) and NW (b) region. Contours in Fig. 3c and Fig. 3d show HUDE every 3 kg m^{-2} estimated by RSM.

3.2 Environments of two rainbands

We investigated the environment around the two rainbands, in order to find environmental parameters to determine lifetime and downdraft velocity of convective cell, and to understand the maintenance mechanism of convective cells within a rainband in a moist environment. We compared the two cases, and calculated the mean value of HUDE in the region where the storm-relative wind at 4 km ASL blew from. The other parameters were calculated in CT region. In Fig. 3, HUDE distributions in two cases are indicated. In CASE1, low CAPE (0 J kg^{-1}) in CT region and large CIN (104 J kg^{-1}) over the ocean restrained vertical transport of vapor, thus abundant vapor in lower layer (VISH in SE region was 24.1 kg m^{-2}) was horizontally transported from ocean to the observation area. The transported abundant vapor was accumulated in lower layer because the VFC had high value (6.95 × 10^4 kg m^{-1} s^{-1}). In the middle layer, a moist air (HUDE was 3.14 kg m^{-2}) existed over the windward region of storm-relative wind at the mid-level (Fig. 3a). In CASE2, CAPE (777 J kg^{-1}) and HUDE (9.99 kg m^{-2} in Fig. 3b) were higher, and VFC (3.66 ×10^4 kg m^{-1} s^{-1}) was lower than that of CASE1. A mid-level layer in CASE2 was drier than that of CASE1 (Fig. 3b).

CAPE was important parameter to transport vapor from lower layer to middle layer in CASE2. In fact, maximum

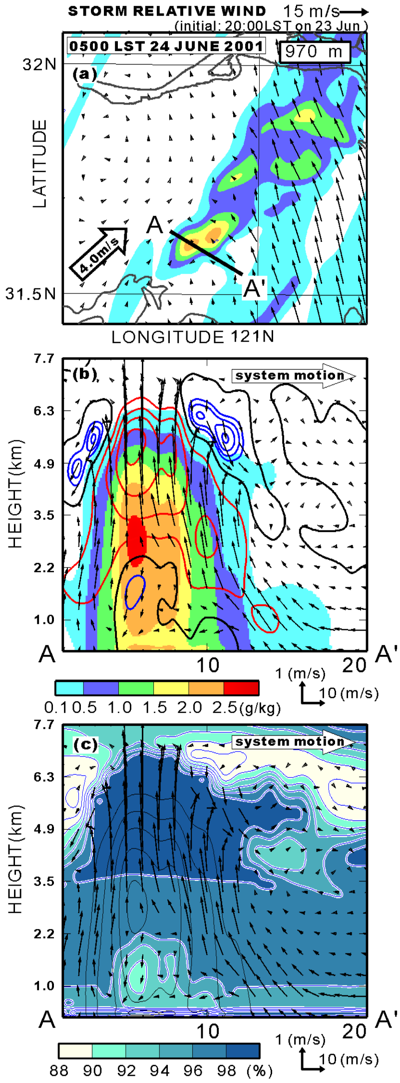

Fig. 4: The simulated mixing ratio of rain and storm-relative wind at a height of 970 m (a), and vertical cross section of mixing ratio of rain (b) and relative humidity(c) along A-A' line at 0500 LST on 24 JUN 2001. In Fig.4b, the black contour indicates 0 m/s vertical velocity. Red (blue) contour shows updraft (downdraft) evrery 1 m/s (0.2 m/s). In Fig. 4c, blue contour shows relative humidity evrery 2 %, and black contour shows mixing ratio of rain every 1 g/Kg.

updraft in CASE2 was more that 7 m s^{-1}, and maximum reflectivity was more than 42 dBZe (Fig. 2d) corresponding to high CAPE. On the contrary, in CASE1, VFC, instead of CAPE, was important parameter to transport vapor vertically. The maximum updraft was less than 2 m s^{-1}, and maximum reflectivity was less than 40 dBZe (Fig. 2c) corresponding to low CAPE. The weak updraft was quasi-steady during 90 minutes. It caused a large amount of rainfall corresponding to high VFC.

Distributions of HUDE in Fig. 1b are shown in Fig. 3c and Fig. 3d, respectively. The belt of HUDE less than 6 kg m^{-2} from east to west (Fig. 3a and Fig. 3b) approximately corresponded to the Baiu/Meiyu frontal zone. In both north and south sides of the Baiu/Meiyu front, HUDE was more than 20 kg m^{-2}. From 23 LST 23 Jun to 05 LST 24 Jun (three hours before and after Fig. 3c), a dry air (HUDE was more than 5 kg m^{-2}) advected from northwest to the NW region in Fig. 3b. On the contrary, from 23 LST 18 Jun to 5 LST 19 Jun (three hours before and after Fig. 3d), a moist air (HUDE was less than 5 kg m^{-2}) advected from southwest to SW region (Fig. 3a.).

3.3 Numerical simulations

We conducted numerical simulations with the 1km-CReSS in order to confirm the relation between the downdraft strength and the mid-level humidity (we show only CASE1 here). Figure 4a shows the horizontal distribution of mixing ratio of rain (QR) corresponding to reflectivity distribution observed at 0348 LST (Fig.2a). The orientation of rainband and the wind field at a height of 1 km around rainband were well simulated. A new convective cell generated to the southwest of the old convective cell as well as observation. The lifetime of convective cell was long-lived (about 1 hour).

The pattern of vertical wind was well simulated (Fig. 4b). The storm-relative inflow from southeast turned to weak updraft (2-3 m/s) below the melting layer. Little snow and graupel were formed above the melting layer (about 1 g/Kg). Therefore, the height of QR more than 0.5 g/kg well corresponds to the echo top height (Fig. 2). The maximum downdraft was very weak (about 0.2 m/s). The weak downdraft core was located in the moist region more than 90 % (Fig. 4c). The moist environment caused evaporative cooling to be inactive, and caused the weak downdraft.

4. DISCUSSION

We summarized our results in Fig. 5. In a dry mid-level environment (high HUDE environment (Fig. 5b)), the vapor was evaporated well and caused strong downdraft in CASE2. The strong downdraft cut off warm and moist air supply to the updraft of convective cells in the lower layer, and caused the short-lived convective cells in CASE2. The vertical vapor transportation in CASE2 is explained by high CAPE. On the contrary, in a moist mid-level environment (low HUDE environment (Fig. 5a)), the evaporative cooling is inactive, therefore, long-lived convective cells with weak downdraft velocity were observed in CASE1. The vertical vapor transportation in CASE1 is explained by high VFC in spite of low CAPE.

We propose that HUDE is a parameter to determine the lifetime of convective cells within MCS and the strength of downdraft caused by evaporative cooling of rain. CAPE and VFC would be important environmental parameters to determine the amount of vertical vapor transportation.

The research on environmental parameters focused on mid-level humidity (HUDE and VFC), such as these two case studies, gives us strong possibility to understand the maintenance mechanism of MCS in a moist environment.

5. CONCLUSIONS

We investigated the humidity distribution for determining the lifetime of convective cell within two rainbands observed near Shanghai during Baiu/Meiyu period in 2001

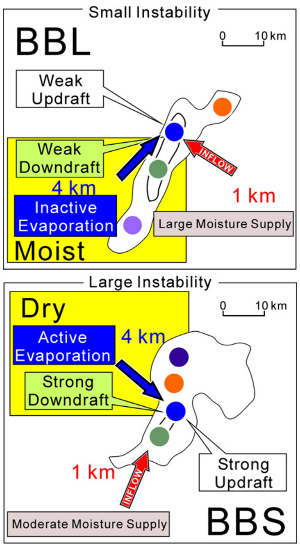

Fig. 5: Characteristics (lifetime and downdraft velocity) and schematic model of two rainbands developed in different distribution of mid-level humidity on 24 Jun 24 (CASE1: Fig. 4a) and 19 Jun (CASE2: Fig. 4b), 2001. Black dot indicates the longest-lived convective cell (90 min in CASE1, 42 min in CASE2). In a moist mid-level environment (CASE1), evaporative cooling was inactive and a weak downdraft could not cut off warm and moist air supply to the convective cell.

by using dual-Doppler radar analysis with variational method, RANAL, and RSM. We propose that mid-level dryness between 850hPa and 500 hPa (HUDE) behind a rainband determines the maximum downdraft velocity and lifetime of convective cell within MCS. More observational and numerical study on the relation between this HUDE and MCS would lead to a clear understanding of maintenance mechanism of MCS in a moist environment.

References

Bluestein, H. B. and M. H. Jain, Formation of Mesoscale Lines of Precipitation: Severe Squall lines in Oklahoma during the Spring.J.Atmos.Sci.,**42**,1711-1733,1985.

Gao, T., M. Xue, A. Shapiro, K. K. Droegemeier, A variational method for the analysis of three-dimensional wind fields from two Doppler radars. Mon. Wea. Rev.,**127**, 2128-2142, 1999.

Tsuboki K., A. Sakakibara, Large-scale Parallel computing of cloud resolving storm simulator. High Performance Computing., Springer,243-359.

Weisman, M. L., J. B. Klemp, 1982: The dependence of numerically simulated convective storms on vertical wind shear and buoyancy. Mon. Wea. Rev.,**110**, 504-520.

Yamada, H., B. Geng, K. K. Reddy, H. Uyeda and Y. Fujiyoshi 2003: Three-dimensional structure of a mesoscale convective system in a Baiu-frontal depression generated in the downstream region of the Yangtze river. J. Meteor. Soc. Japan, **81**,1243-1271.