Humidity Distribution Determining the lifetime of Convective Cells within Mesoscale Convective Systems, Observed near Shanghai during Meiyu Period in 2001.

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1. Introduction

The relation between environment and types of Mesosclae 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; Bluestein and Marx, 1987). In a moist environment, a humidity distribution, as well as CAPE and vertical wind shear, is focussed as an important parameter for maintenance of supercell (Shimizu et al., 2001). Shimizu et al. (2002) investigated the structures of three rainbands observed in field experiment in the downstream region of Yangtze River during Baiu/Meiyu season in 2001 (Geng et al., 2002), and revealed that two back-building rainbands (Bluestein and Jain, 1985) developed in strong vertical-wind-shear environment, a broken rainband (Bluestein and Jain, 1985) developed in weak vertical-wind-shear environment. The two back-building rainbands developed in environments possesing different distributions of mid-level humidity. The back-building rainband developed in a moist mid-level environment on 19 Jun 2001 caused continous rainfall for long time, while the other back-building rainband developed in a dry mid-level environment on 24 Jun 2001 caused intensive rainfall in short time (Shimizu et al., 2002). In this study, in order to explain the different rainfall type between the two back-building rainbands, we investigate the lifetime and strength of downdraft of convective cells within two back-building rainbands by dual-Doppler radar analysis, and estimate three-dimensional humidity distribution by using Regional objective ANALysis (RANAL) and Regional Spectral Model (RSM), which are produced by the Japan Meteorology Agency.

2. Data and analysis method

Two X-band Doppler radars (at Wuxian and Zhouzhuang, covering the downstream of the Changjiang river with 64 km in radius) obtained sets

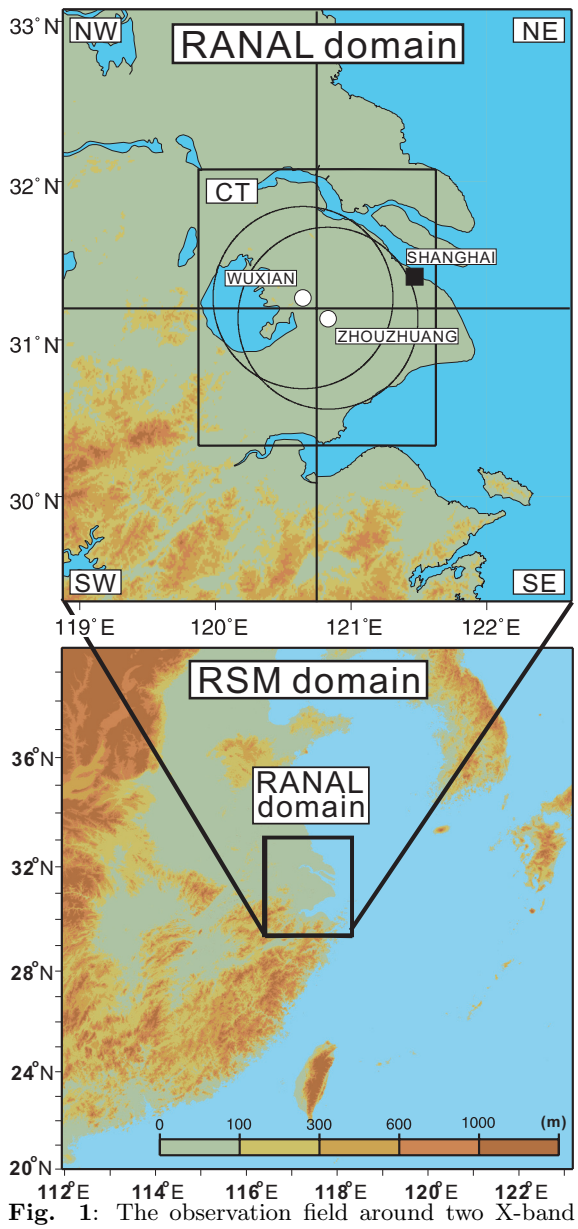

Fig. 1: The observation field around two X-band Doppler radars at Wuxian and Zhouzhuang. Five of 2°×2° regions (NW,NE,SW,SE, and CT) indicate analysis regions for estimating environmental parameters (Table 1) using RANAL and RSM.

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Table 1: Definitions of five environmental parameters estimated by using RANAL data.

$$CAPE = -R \int_{p_{LFC}}^{p_{top}} (T_p - T_e)\, d(\ln p)$$

$$CIN = -R \int_{p_{base}}^{p_{LFC}} (T_p - T_e)\, d(\ln p)$$

$$VISH = -\frac{1}{g} \int_{surf}^{850hPa} q\, dp$$

$$HUDE = -\frac{1}{g} \int_{850hPa}^{500hPa} (q_s - q)\, dp$$

$$VFC = -div(-\frac{1}{g} \int_{surf}^{850hPa} q\vec{V}\, dp)$$

T_e :temperature of environment
T_p :temperature of parcel $\vec{V}$:wind vector
q :specific humidity q_s :saturated specific humidity

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 within the overlapped observation area of the two radars (Fig. 1).

In order to evaluate the environment around the observation area, we divided the 4° × 4° region (depicted in Fig. 1) into four regions (2°×2° quadrants centering at the two radars) named as NE, NW, SE, SW. We added 2°×2° region named as CT just over the observation area. We investigated the each environment in the five regions using RANAL data.

The time resolution of RANAL is 6 hours (02, 08, 14, 20 LST*). The horizontal resolution of RANAL is 20 km. In the vertical direction, RANAL contains 20 levels.

The mean of four environmental parameters (Table 1) in the each region are calculated: CAPE, CIN, vertical integrated specific humidity from surface to 850 hPa (VISH), vertical integrated specific humidity deficit from 850 hPa to 500 hPa (HUDE), and vertical integrated vapor flux convergence from surface to 850 hPa (VFC). For accurate calculation of these parameters, in this study, we converted the vertical 20 levels data to 211 levels data (5 hPa interval) by linear interpolation. VISH and HUDE are indices wetness of lower layer, and for dryness of midlevel layer, respectively.

In order to investigate the time variation of humidity distribution, we used the forecast of RSM within approximately 2000 km × 2000 km region (Fig. 1). 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.

3. Characteristics of convective cells

In order to reveal lifetime and the maximum downdraft velocity of convective cells within two back-

*LST = UTC + 8 hours

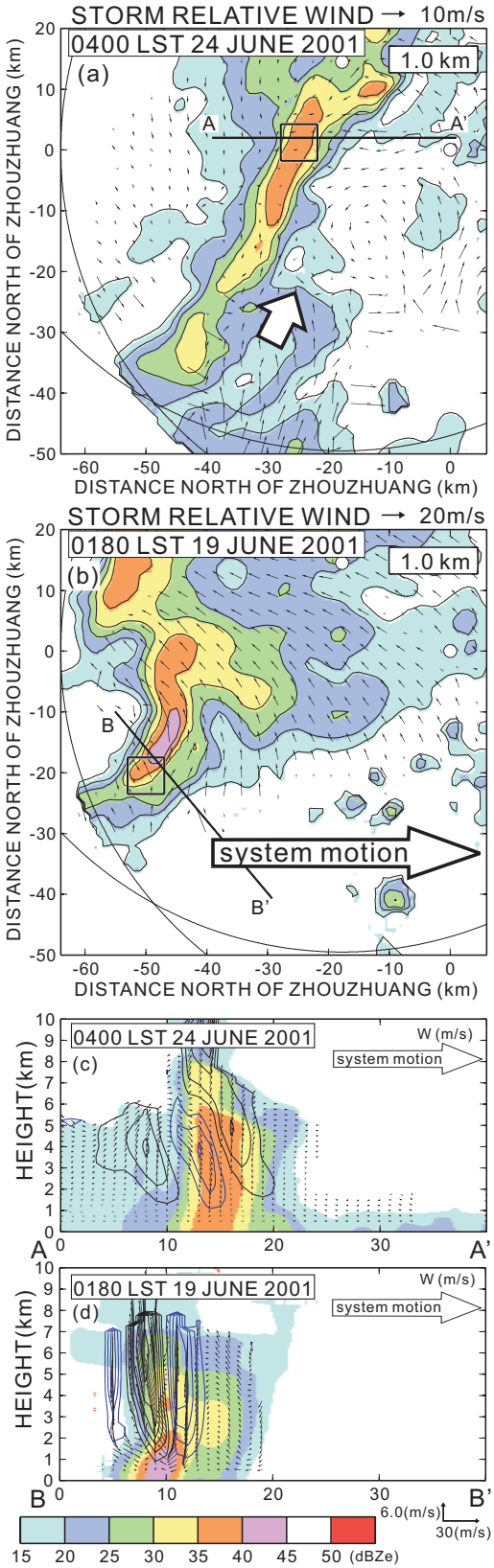

Fig. 2: Radar reflectivity overlaid with storm-relative wind vectors at 1 km ASL of CASE1 (a), CASE2 (b). Open arrows indicate system propagation speed and the direction. Vertical cross sections along A-A'(c), B-B'(d) lines are indicated. Black (Blue) contours indicate updraft (downdraft) velocity every 1 m s^{-1} (3 m s^{-1}) in CASE1 (CASE2).

building rainbands (CASE1: 0400 LST 24 June, CASE2: 0118 LST 19 June), we investigate radar reflectivity fields at 1.0 km Above Sea Level (ASL) in Figs. 2a,b. The back-building rainband in CASE1 moved to the northeast at a speed of 2.4 m s^{-1}, while, the back-building rainband in CASE2 moved to the east at a speed of 13.0 m s^{-1}. We defined lifetime of convective cell as the period during the maximum reflectivity at 4 km 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 had steady structure, because the BBL was maintained by the steady convective cell. On the contrary, the BBS was maintained by repeated replacement of the convective cells.

We observed remarkable difference in not only the lifetime but also maximum downdraft velocity. Vertical cross sections along the A-A' and B-B' lines in Figs.2a,b are shown in Figs. 2c,d. The maximum downdraft velocity at 4 km ASL in CASE1 and CASE2 was 3.0 m s^{-1} and 12.0 m s^{-1}, respectively. A strong downdraft causes a strong outflow cutting warm and moist air supply to an updraft of convective cell (Weisman and Klemp, 1982). In present cases, acctually we observed the short lifetime of convective cell corresponding to the strong downdraft in CASE2. The location of downdraft core differed from the location of the reflectivity core in two cases. 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). We investigate which environmental parameters determine the efficiency of evaporative cooling in next section.

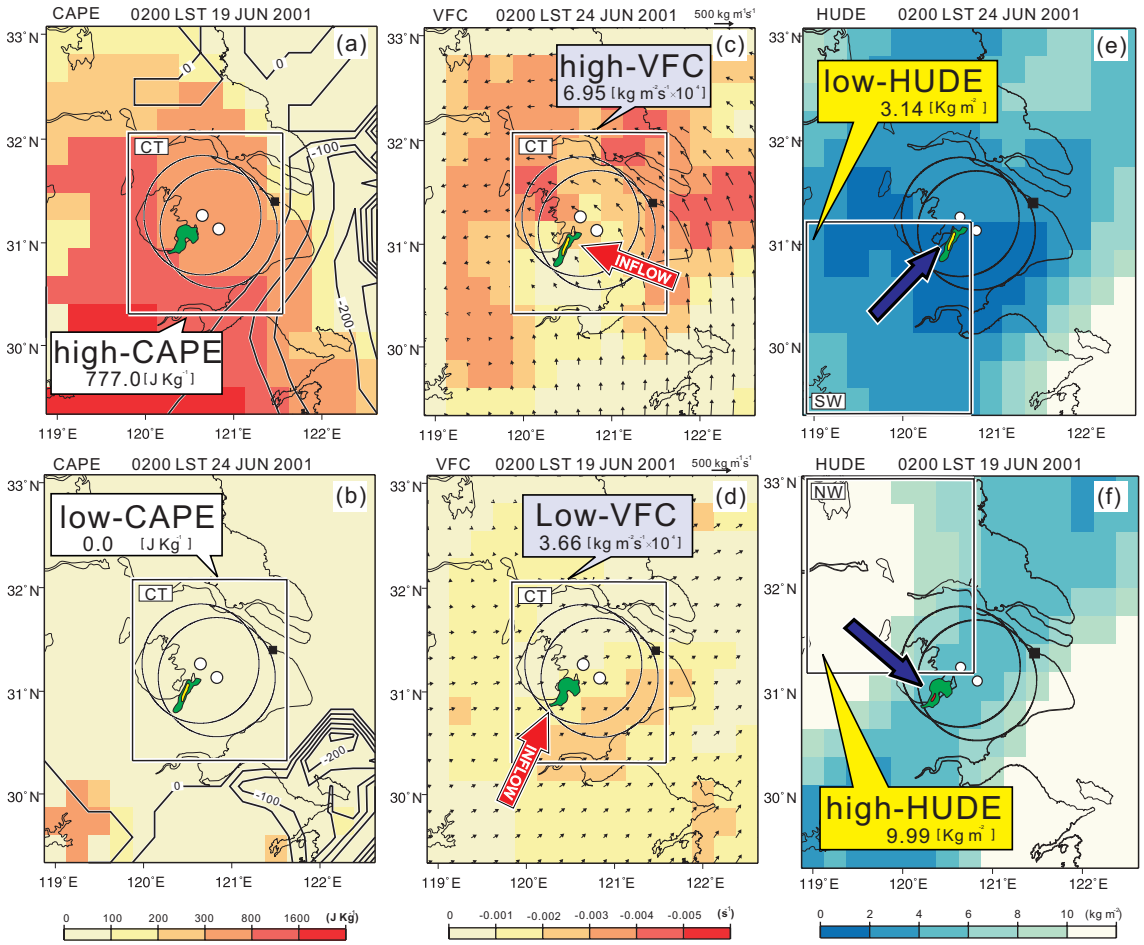

Fig. 3: Distributions of CAPE and CIN on 19 Jun (a) and 24 Jun (b), VFC and vapor flux integrated from surface to 850 hPa on 19 Jun (c) and 24 Jun (d), HUDE on 19 Jun (e) and 24 Jun (f). Contours in Fig. 3a,b indicate CIN every 50 J kg^{-1}. Vectors in Fig. 3c,d indicate the vapor flux vertically integrated from surface to 850 hPa. The mean value of each environmental parameter is calculated from RANAL data within five regions in Fig. 1. Blue (Red) arrow indicates storm relative wind at a height of 4(1) km ASL. The location of two rainbands are shown by conceptual illustration in the center.

4. Environments of two rainbands

We investigate the environment around the two rainbands, in order to find useful 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.

Distribution of five environmental parameters are shown in Fig. 3. In order to evaluate the environment quantitatively, and to compare two cases, we calculated the mean value of the five environmental parameters in five regions. We select a region from five regions by following rules. CAPE, CIN, and VFC are calculated only in CT region. The mean value of VISH (HUDE) is selected in the region which the storm-relative wind at 1 km (4 km) ASL blew from. In Fig. 3, distributions of CAPE and CIN (Figs. 3a,b), VISH and VFC (Fig. 3c,d), HUDE (Fig. 3e,f) in two cases are indicated.

In CASE1, Mean value of CAPE was 0 kg J^{-1} (Fig.3a), CIN over the ocean restrained vertical transport of vapor, thus abundant vapor in lower layer (VISH in SE region was 24.1 kg m^{-2}, not shown) was horizontally transported from ocean to the observation area (Fig.3c). The transported abundant vapor was accumulated at lower layer because the VFC had high value (6.95×10^4 kg m^{-1} s^{-1} in Fig. 3c). In the midlle layer, a moist air (HUDE was 3.14 kg m^{-2} in Fig. 3e) existed over the windward region of storm-relative wind at the mid-level (SW region).

In CASE2, CAPE was higher (777 J kg^{-1} in Fig. 3b) than that of CASE1. A little vapor at lower layer (VISH in SW region was 18.5 kg m^{-2}, not shown) was supplied from mountain region to the observation area. Therefore, Vapor flux was smaller than that of CASE1 (Fig3. d). In addition, the transported vapor was not accummulated efficiently at lower layer (VFC was 3.66 $\times 10^4$ kg m^{-1} s^{-1} in Fig. 3d) In the midlle layer, a dry air (HUDE was 9.99 kg m^{-2} in Fig. 3f) existed over the windward region of storm-relative wind at the mid-level (NW region).

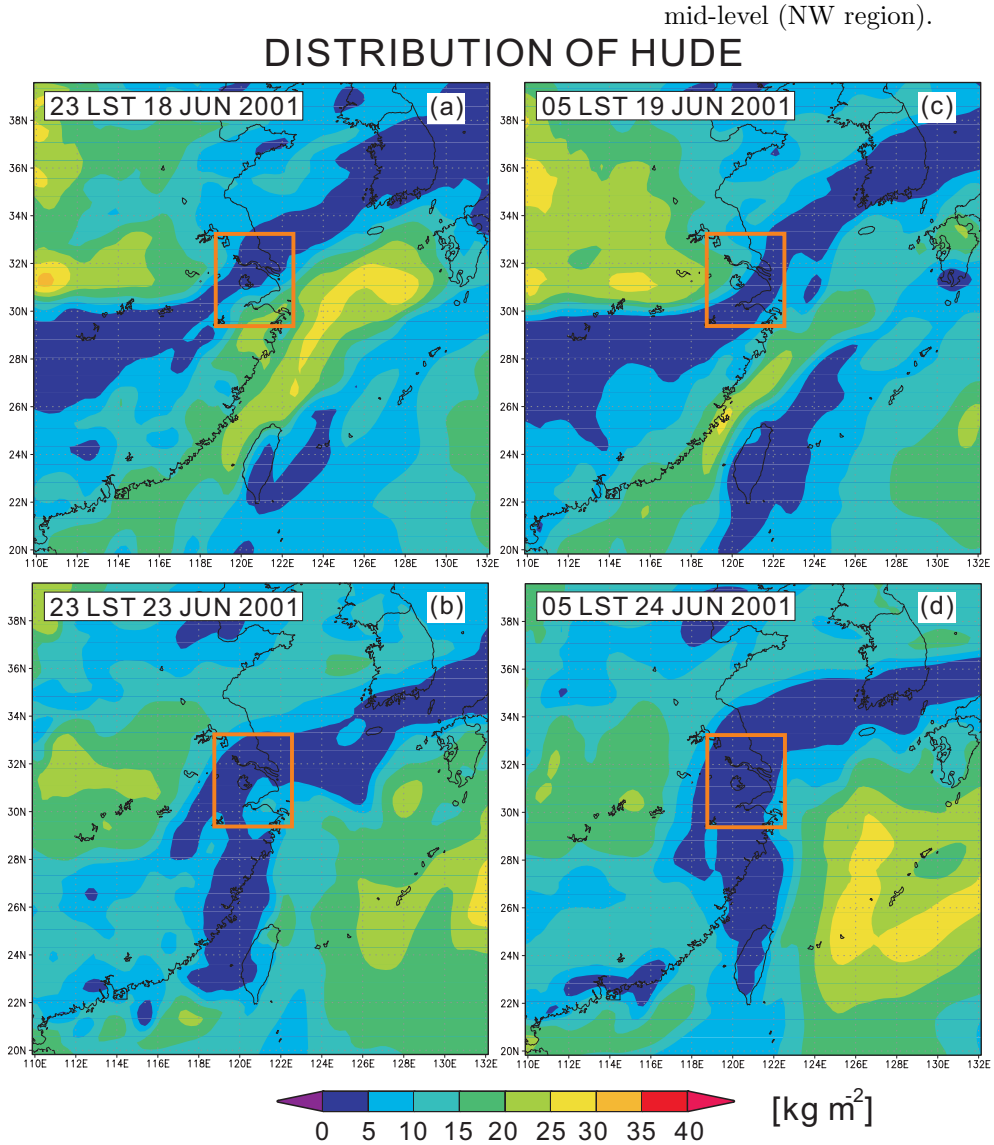

Fig 4: HUDE distribution at 23 LST 18 Jun (a), 23 LST 23 Jun (b), 05 LST 19 Jun (c), and 05 LST 24 Jun (d) within RSM domain in Fig.1. Red square indicates the RANAL domain.

CAPE was important parameter to transport vapor from lower layer to middle layer in CASE2. In fact, maximum updraft in CASE2 was more that 12 m s^{-1}, and maximum reflectivity was more than 42 dBZe corresponding to high-CAPE. On the contrary, in CASE1, VFC, instead of CAPE, was impotant parameter to transport vapor vertically. Although the maximum updraft was less than 3 m s^{-1}, and maximum reflectivity was less than 40 dBZe corresponding to low-CAPE, the updraft was well maintained for more than 90 minutes (Shimizu et al., 2001), it caused much amount of rainfall (Geng et al., 2002) corresponding to high-VFC. CAPE and VFC would be important environmental parameter to determine the amount of vapor transported in vertical.

The strength of downdraft, caused by evaporative cooling of the vapor transported vertically, was determined by HUDE. In a dry mid-level environment (high-HUDE environment), the vapor was evaporated well and caused strong downdraft in CASE2. The strong downdraft cut off warm and moist air supply in the lower layer, and caused the short-lived convective cell in CASE2. On the contrary, in a moist mid-level environment (low-HUDE environment), the most long-lived convective cell had the lifetime more than 90 minutes in CASE1. HUDE was important environmental parameter to determine the efficiency of evaporation of vertically-transported vapor.

We proposed that the combination of HUDE, CAPE, VFC determined the downdraft strength and lifetime of convective cells within the rainbands.

5. Discussion

We described the lifetime and maximum downdraft velocity of convective cell within two back-building rainbads in Section 3, and revealed that the relation between the characteristics of convective cells within rainbands and the environment in Section 4. In this section, we discuss the difference of humidity distribution in synoptic scale by using the forecast of RSM.

The two rainbands formed within the region of Baiu/Meiya front, judging from surface weather map (not shown). However, the humidity distributions around the Baiu/Meiyu front were very different. HUDE distribution around RANAL domain is shown in Fig. 4. From 23 LST 23 Jun to 05 LST 24 Jun (three hours before and after Fig.3e), a dry air (HUDE was more than 5 kg m^{-2}) advected from northwest to the RANAL domain. On the contrary, From 23 LST 18 Jun to 05 LST 19 Jun (three hours before and after Fig.3f), a moist air (HUDE was less than 5 kg m^{-2}) advected from southwest to the RANAL domain.

The research on environmental parameters focussed on mid-level humidity distribution, such as the HUDE give us strong possibility to predict the lifetime of convective cell or downdraft strength by using regional objective analysis, for preventing disaster and to understand the development mechanism of rainbands in a moist environment.

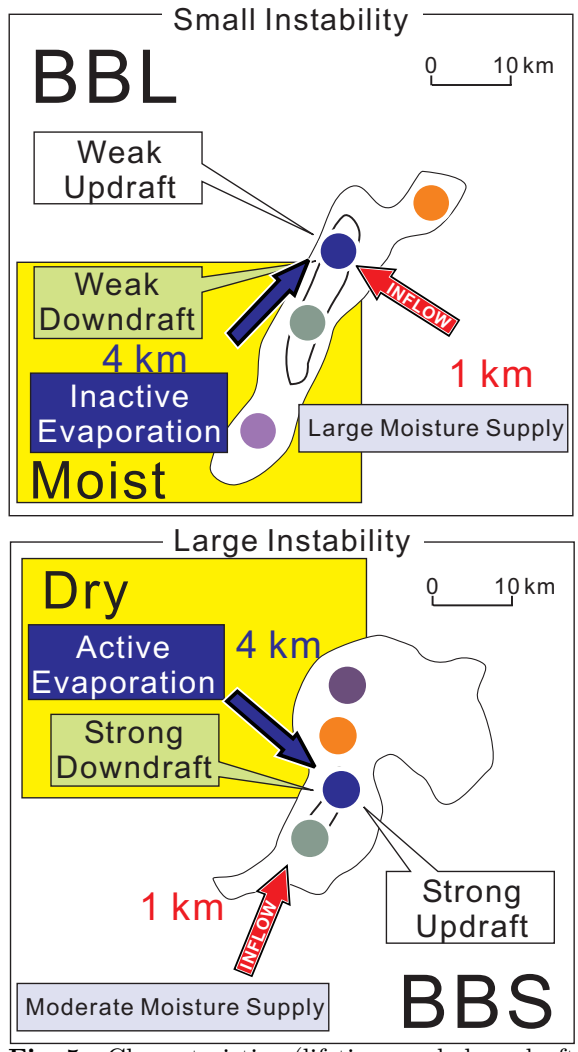

Fig 5: Characteristics (lifetime and downdraft velocity) and schematic models of two rain bands developed in different distribution of mid-level humidity on 24 Jun (CASE1:upper) and 19 Jun (CASE2:lower), 2001. Blue-colored dot indicates the longest-lived convective cell (90 minutes in CASE1, 42 minutes in CASE2). In a moist mid-level environment (CASE1), evaporative cooling was inactive, therefore, weak downdraft could not cut off a moist and warm air supply from lower layer, therefore convective cells were maintained well. On the contrary, in a dry mid-level environment (CASE2), convective cells were not maintained well. BBL was formed in the environment possessing small instability and large vapor convergence. BBS was formed in the environment possessing large instability and small vapor convergence.

6. 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 by using dual-Doppler radar analysis, RANAL, and RSM. We summarized our results in Fig. 5. Mid-level dryness (HUDE) behind a rainband would determine the efficiency of evaporative cooling of rain. A moist mid-level environment causes weak downdraft because of inactive evaporative cooling. The weak downdraft would not cut off a moist and warm air supply to an updraft, therefore, convective cells within MCS could be maintained for long time. The amount of vapor supplied from lower layer can be estimated from the combination of CAPE, VFC, and VISH in the windward region of lower layer inflow.

More case studies and statistically studies on rainbands in a moist environment with focusing on humidity distribution would lead to more accurate prediction of heavy rainfall for preventing disaster, and a clear understanding of the rainbands in a moist environment.

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