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An Analysis of a Meso-β System in a Mei-yu Front Using the Intensive Observation Data During CHeRES 2002

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ABSTRACT

The conventional and intensive observational data of the China Heavy Rain Experiment and Study (CHeRES) are used to specially analyze the heavy rainfall process in the mei-yu front that occurred during 20–21 June 2002, focusing on the meso-β system. A mesoscale convective system (MCS) formed in the warm-moist southwesterly to the south of the shear line over the Dabie Mountains and over the gorge between the Dabie and Jiuhua Mountains. The mei-yu front and shear line provide a favorable synoptic condition for the development of convection. The GPS observation indicates that the precipitable water increased obviously about 2–3 h earlier than the occurrence of rainfall and decreased after that. The abundant moisture transportation by southwesterly wind was favorable to the maintenance of convective instability and the accumulation of convective available potential energy (CAPE). Radar detection reveals that meso-β and -γ systems were very active in the MαCS. Several convection lines developed during the evolution of the MαCS, and these are associated with surface convergence lines. The boundary outflow of the convection line may have triggered another convection line. The convection line moved with the mesoscale surface convergence line, but the convective cells embedded in the convergence line propagated along the line. On the basis of the analyses of the intensive observation data, a multi-scale conceptual model of heavy rainfall in the mei-yu front for this particular case is proposed.

Key words: mei-yu front, heavy rainfall, mesoscale convergence line, conceptual model, Doppler radar

1. Introduction

It is well known that the majority of heavy rainfall is produced by mesoscale convective systems (MCSs). Since Maddox (1980) defined a relatively large-scale and severe convection system as a mesoscale convective complex (MCC), meteorologists have paid more attention to studying MCCs. Liang and Fritsch (2000) investigated the environmental conditions for the development of MCCs in Africa, Australia, China, South America, and the USA. They indicated that MCCs are initiated in the baroclinic region and that vertical wind shear in the lower troposphere and large convective available potential energy (CAPE) are favorable to the development of MCCs. Heavy rainfall events during the mei-yu season usually appear in relation to the passage of MCSs. The floodings due to heavy rainfall over the Huaihe River basin in 1991 and over the Yangtze River basin in 1998 were produced by MCSs; in particular, the severe heavy rainfall in Wuhan City and Huangshi City, Hubei Province, China, during 20–21 July 1998 resulted from MβCSs (Zhang et al., 2002; Bei and Zhao, 2002). The MβCSs that produced heavy rainfall in 1991 developed along the shear line and mei-yu front, and some MβCSs are associated with vortices (Ding, 1993). Only conventional data have been employed to analyze the synoptic conditions of vortices and MCSs that occurred along mei-yu fronts in China in previous studies (Zhang et al., 2002; Zhang and Zhao, 2004), in addition, some simulation results have been used to study the structure (Bei et al., 2002; Xu and Gao, 2002; Cheng and Feng, 2001).

Several field experiments have been carried out during recent years in East Asia to study the structure and mechanism of MCSs that produce heavy rainfall, such as the observation of the structure of a mei-yu-

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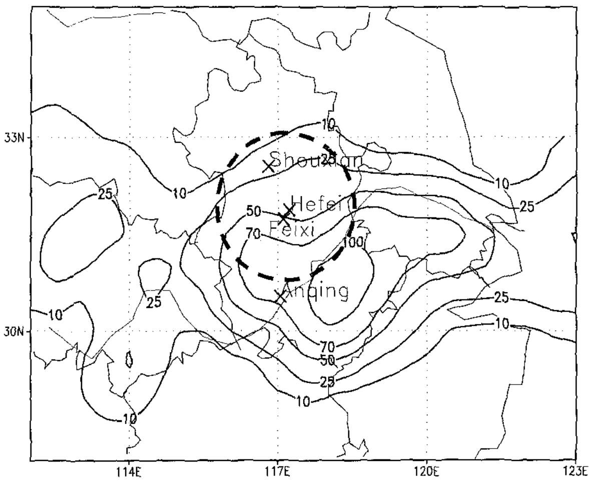

Fig. 1. The observed 36-h precipitation of 0800 LST 20 June–2000 LST 21 June 2002. The cross marks indicate the location of Shouxian, Hefei, Feixi and Anqing stations. The dashed circle shows the observation area by the Hefei radar. (units: amm)

frontal convective system during the Taiwan Area Mesoscale Experiment (TAMEX, Kuo and Chen, 1990). Intensive field experiments were also conducted on Kyushu Island and in the East China Sea between 1998 and 2002 (Yoshizaki et al. 2002). In particular, the China Heavy Rain Experiment and Study (CHeRES) field experiment on heavy rainfall in the mei-yu front, which was to acquire intensive observational data for studying the structure and evolution of mesoscale convective systems, was conducted in the middle and lower reaches of the Yangtze River in June and July in 2001 and 2002.

The CHeRES field experiment in China covers two regions: the middle reaches of the Yangtze River, including southern Hunan Province and most of Hubei Province, and the lower reaches of the Yangtze River, including most of Anhui Province, southern Jiangsu Province, and northern Zhejiang Province. The field experiment includes 15 radiosondes, 120 surface intensive observation stations, 9 weather Doppler radars, 8 GPS stations, 2 wind profilers, 1 boundary layer observation system, and 114 automatic weather stations (AWS). The Yichang and Jingzhou Doppler radars in Hubei Province and the Wuwei and Ma'anshan Doppler radars in Anhui Province provided two dual Doppler radar observations systems, respectively (Ni, 2001). During the field experiment, a severe MCS with a life cycle longer than one day developed over southern Anhui Province during 20–21 June 2002, which produced heavy rainfall in southern Anhui Province and Jiangsu Province (Fig. 1) with a maximal rainfall of 180.8 mm d^{-1} occurring over Huangshan. In this paper, intensive observation data—especially the radar data of Hefei station, GPS, and wind profiler data—are used to reveal the features of the MCS.

2. The synoptic conditions for MCS development

The synoptic weather patterns at 2000 LST 20 and 0800 LST 21 June 2002 are shown in Fig. 2. At 200 hPa,the northeastern rim of the South Asia high is located at the Yangtze River basin (Figs. 2a, b), which is the upper-level divergence area. At 500 hPa, a trough is located in the western part of China at 2000 LST 20 June and travels eastwards a little by 0800 LST 21 June (Figs. 2c, d). The MCSs developed in the warm region to the south of the shear line (Figs. 2e, f), which is located between the southern edge of the westerlies and the northern periphery of the western Pacific subtropical high. At the same time, the mei-yu front is located at the Yangtze River basin to the north of 30°N, which is the left side of the exit of the lower level jet (LLJ) and the right side of the entrance of the upper level jet (ULJ). Development of the convective system in the mei-yu front seems to be significantly related to the moisture transported by the LLJ. Backward propagation or redevelopment of the cell occurs when unstable moist air continuously feeds into the southwest boundary of the active convection. In conclusion, the weather pattern and synoptic condition over the middle and lower reaches of the Yangtze River basin are favorable to the formation and development of convective systems from 20 to 21 June 2002. The convection along the mei-yu front is extraordinarily active, especially over the lower reaches of the Yangtze River basin.

3. The formation and development of the MCS

3.1 MCS features

It can be seen in Fig. 3 that the MCS formed in southern Anhui Province (near Dabie Mountains) at 2000 LST 20 June and developed into a meso-α system at 0200 LST 21 June with a minimum TBB (black body temperature) less than −70°C. The system produced weak rainfall at that time, and afterwards, the hourly rainfall during 0200–0800 LST 21 June was greater than 10 mm. The system split at 0900 LST 21 June, and consequently, it weakened gradually and part of the severe convection stagnated over southern Anhui Province. Almost at the same time, a new meso-β convective system was generated at (116°E, 31.5°N) (Dabie mountains), and merged with the old convection at 1600 LST 21 June. This system dissipated at 2000 LST 21 June over southern Anhui

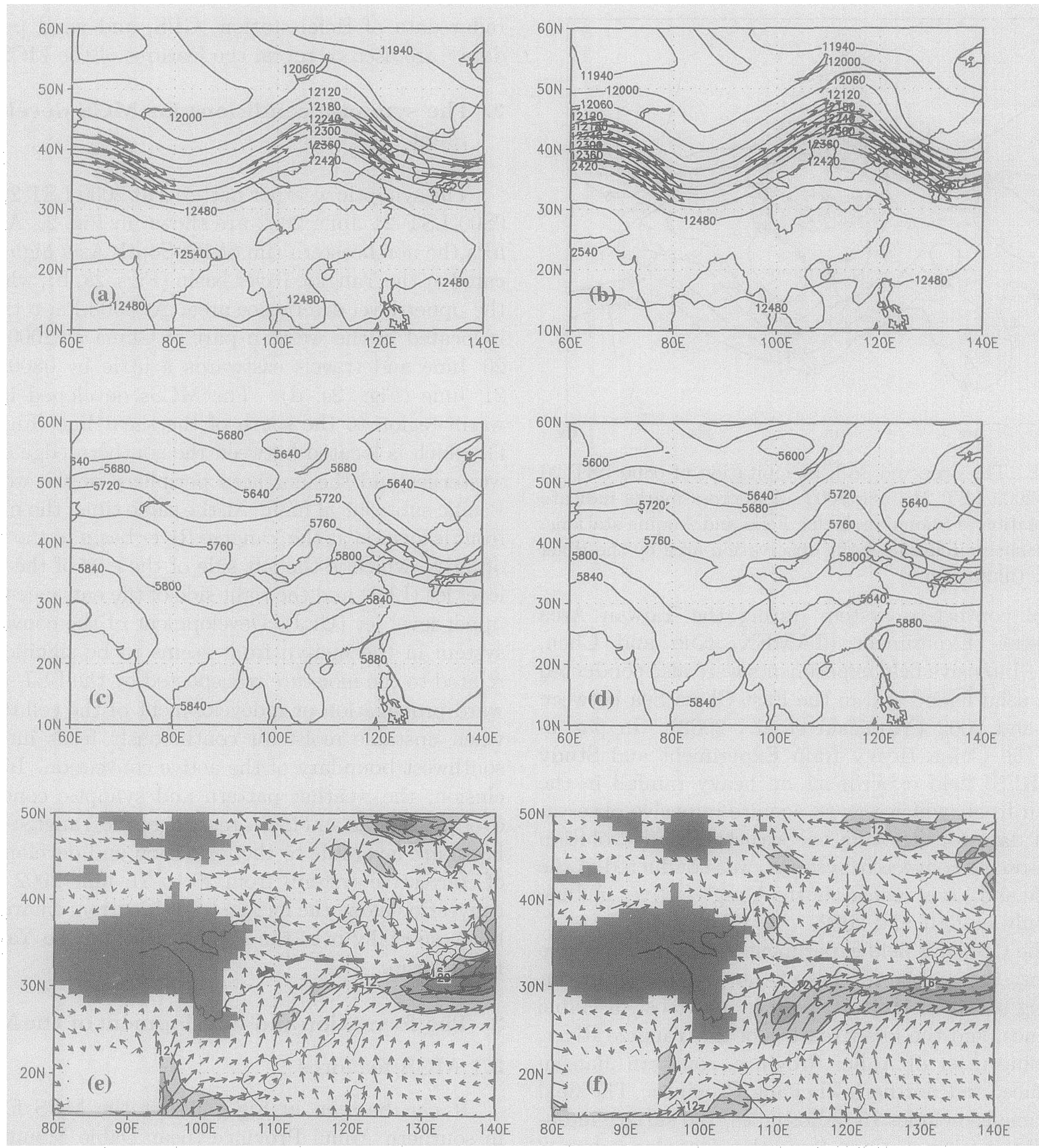

Fig. 2. Geopotential height in gpm and wind greater than 40 m s^{-1} at 200 hPa (upper panel), Geopotential height in gpm at 500 hPa (middle panel), and wind field at 850 hPa with wind greater than 12 m s^{-1} being shaded (lower panel, the deep shaded area is topography greater than 1500 m, bold dashed line is the shear line). (a), (c), (e) are at 2000 LST 20 June and (b), (d), (f) are at 0800 LST 21 June 2002.

Province. According to the variation of hourly precipitation and TBB, precipitation was produced over a large area at the rearward portion of the MCS with a strong TBB gradient.

In addition, along the mei-yu front, the moisture was generally transported to the south of the MCS, which induced a new convection triggered in the rearward portion of the old convection. Shi et al. (1996) indicated that in this situation, the cold cloud shield would be extended to the region of the strong TBB gradient around the cold cloud shield and dissipate in the region of the weak TBB gradient. The features of this system are thus consistent with the results of Shi et al. (1996).

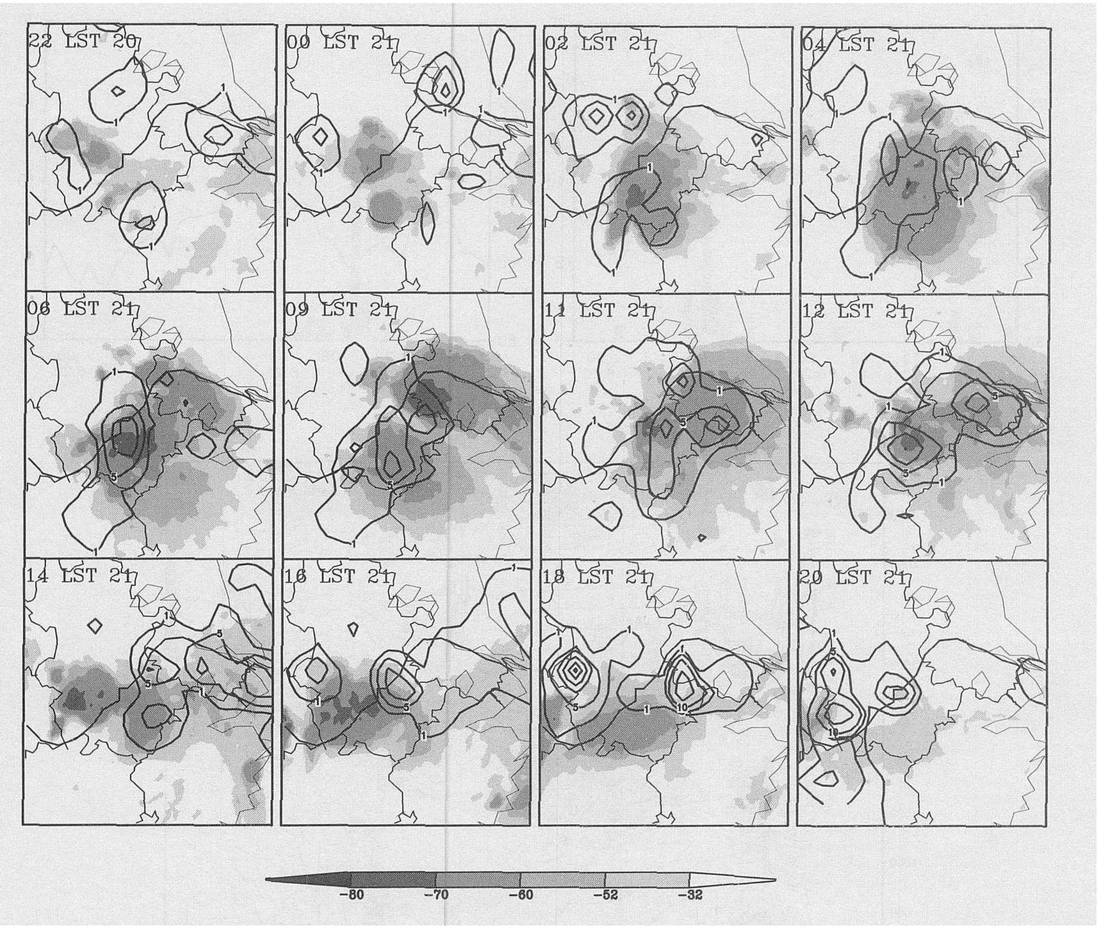

Fig. 3. TBB from GMS satellite (shaded, Units: °C) and hourly precipitation (solid line, Units: mm) of 2200 LST 20 June–2000 LST 21 June 2002 (isolines at 1, 5, 10, 20, 30, 40, 50 mm).

From the above analyses, the lifetime of the convective system is about one day. During the evolution of the system, two systems originated over the Dabie Mountains and traveled eastwards. The first system moved eastwards quickly, whereas the second system stagnated and developed deeply. Severe rainfall occurred at the rearward portion of the MCSs. The frequent occurrence of convection over the Dabie Mountains may be caused by the climbing of the easterly.

Abundant moisture is necessary for the development of an MCS. The precipitable water and wind in the lower and middle troposphere can reveal the variation of moisture transportation to some extent. In the field experiment, there were six GPS stations and the Feixi wind profiler in Anhui Province, and their observations made available during the propagation of the MCS in Anhui Province.

The precipitable water from the GPS and hourly precipitation in Feixi county (31°44′N, 117°08′E) and Shouxian county (32°33′N, 116°47′E) are given in Figs. 4a, b. Precipitable water in Feixi county increased twice during 1200 LST 20 June–0000 LST 22 June, reaching as high as 75 mm at both 2300 LST 20 June and 1500 LST 21 June. After the rainfall of 1100–1500 LST 20 June, precipitable water did not decrease because of strong moisture transportation (Fig. 4c). The precipitation with a maximum of 12 mm h^{-1} in Shouxian county lasted from 0200 to 1100 LST 21 June. The precipitable water was as high as 72 mm two hours earlier than the occurrence of rainfall, and it decreased rapidly after the beginning of the rainfall. Other cases of this experiment also show a significant increase of precipitable water 2–3 hours earlier than the rainfall and a decrease after the beginning of the rainfall.

Although the precipitable water is not proportional to the vertical moisture flux, it increases obviously before the rainfall from the GPS observation, and can be employed as a sensitive indicator of rainfall in real-time prediction.

Wind profiler data in Feixi county is shown in Fig. 4c. After 1800 LST 20 June, the southwesterly wind

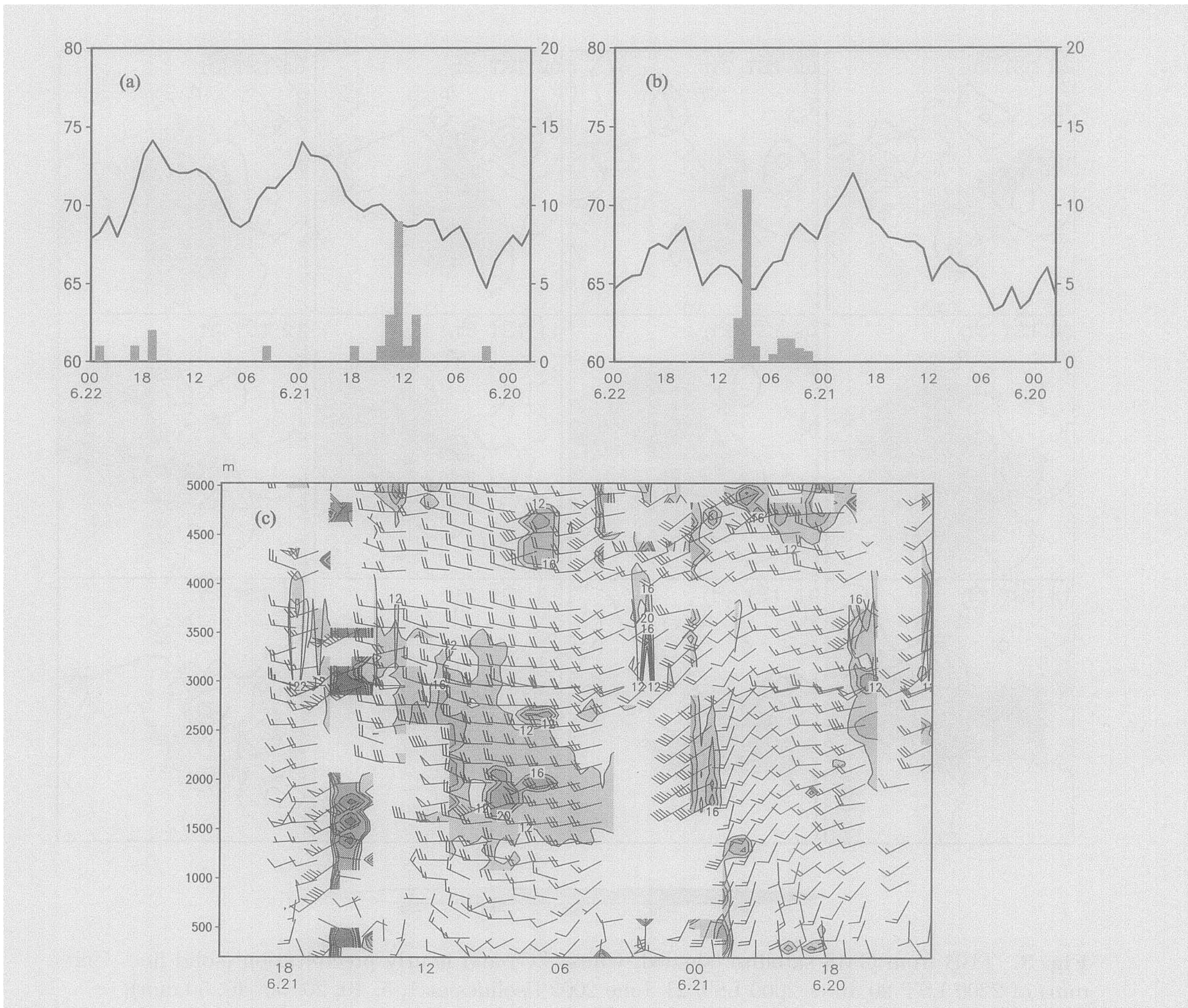

Fig. 4. Hourly precipitation in mm (bar, left ordinate) and precipitable water in mm from GPS (line, right ordinate) of 0000 LST 20 June–0000 LST 22 June 2002 at (a) Feixi county and (b) Shouxian county, (c) wind vector and speed of 1400 LST 20 June–2100 LST 22 June 2002 from the wind profiler at Feixi county (the shading is wind speed exceeding 12 m s^{-1}).

increased and the low-level jet (LLJ) extended gradually from 2000 m upward to the middle troposphere (about 4000 m). The LLJ was below 2000 m and 4000 m at 0400 LST 21 June and 1800 LST 21 June, respectively. The prevailing westerly or southwesterly wind below 5000 m transported moisture to the MCS from 2000 to 0600 LST 21 June. The northwesterly wind, which was caused by the invasion of cold air or outflow of the MCS in the boundary layer, was below 1000 m during 1000–1200 LST 21 June.

Since there was an intensive observation period (IOP) during the evolution of the MCS, 6-h interval radiosonde data are available. The sounding of Anqing station (location shown in Fig. 1) is employed to analyze the variation of stratification during the development of the MCS. Anqing station, located in southwestern Anhui Province, was affected by the MCS. Table 1 lists the physical quantities calculated by the sounding data at Anqing station from 2000 LST 20 June to 0200 LST 22 June. These physical quantities include convective available potential energy (CAPE), convective inhibition energy (CIN), lifting index (LI), K index, precipitable water (PWAT) and surface equivalent potential temperature θ_e). From Table 1, it is clear that CAPE was as high as 1981 J kg^{-1} at 2000 LST 20 June, but it was reduced to 718 J kg^{-1} at 0200 LST 21 June, releasing about 1200 J kg^{-1}. The satellite image shows that the MCS had already traveled eastwards, so the instability of stratification was not as strong as that at 2000 LST 20 June. However, the CAPE accumulated again after 0200 LST 21 June and increased to 2455 J kg^{-1} at 1400 LST 21 June, which was favorable to the regeneration of convection. After the convection reinitialized, most of the CAPE

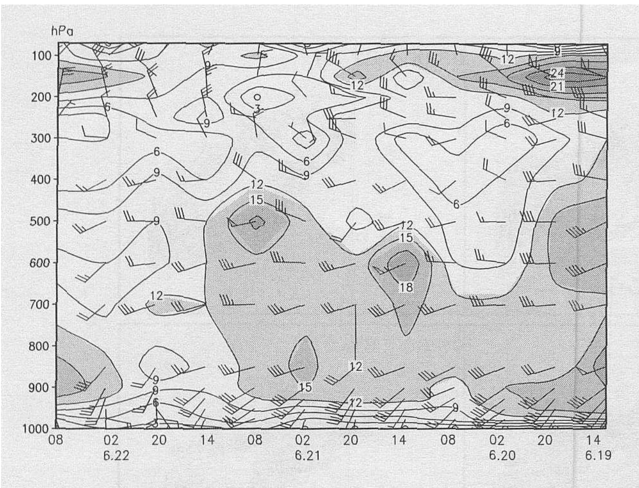

Fig. 5. 6-h wind vector and speed in m s^{-1} (isolines, shading for wind speed greater than 12 m s^{-1}) from intensive observation sounding at Anqing station for 0800 LST 19 June–0800 LST 22 June 2002.

was released while the CIN increased to 345 J kg^{-1}. The changes of LI and surface θ_e were more significant from 1400 LST 21 June to 2000 LST 21 June, being –6 and 370 K at 1400 LST 21 June and –1 and 352 at 2000 LST 21 June, respectively. There were two periods of precipitation (2200 LST 20 June–0800 LST 21 June and 1500–1800 LST 21 June, not shown) during the two days at Anqing, which correspond to the development of the convection events. As mentioned above, 6-h interval radiosonde observations were able to capture the variation of CAPE and other features between the initialization of the two convection events.

The sounding wind direction and speed from Anqing station is shown in Fig. 5. The prevailing southwesterly wind remained from 0800 LST 19 June to 0800 LST 22 June, while the LLJ was only maintained until 1400 LST 21 June. The LLJ intensified twice (at 1400 LST 20 June and 0800 LST 21 June) with a maximal speed of 18 m s^{-1} in the middle troposphere,

Table 1. The physical quantities calculated by sounding data at Anqing station from 2000 LST 20 June to 0200 LST 22 June.

Time/Variable	2000 LST 20	0200 LST 21	0800 LST 21	1400 LST 21	2000 LST 21	0200 LST 22
CAPE (J kg^{-1})	1981	718	1748	2455	67	86
CIN (J kg^{-1})	2	14	5	0	345	300
LI	–5	–3	–5	–6	–1	–1
K	37	40	42	36	40	39
PWAT (mm)	65.4	71.1	69.4	60.4	68.1	70.1
θ_e (K)	365	360	364	370	352	352

which reveals that the southwesterly wind transported a large amount of moisture to the convection area. In addition, the continuous moisture transportation was the main reason for the re-accumulation of CAPE after the first development of convection.

3.2 *Analysis of radar data at Hefei*

Hourly TBB and precipitation data indicate that the rainfall area was significantly less than the convection areas (Fig. 3), and severe precipitation generally occurred in special places, which reveals the severe precipitation produced by the meso-β and -γ convective systems. Considering that the radar data are very helpful to the analysis of the MβCS, and that the Hefei radar adequately revealed parts of the evolution of the MCS, the radar data and hourly surface observations can be used to identify the characteristics of the meso-β and -γ convective systems. The observation area covered by the Hefei radar is shown in Fig. 1. The scan radius of the radar is 150–200 km.

The variation of radar reflectivities during the evolution of the MCS reveals that meso-β and -γ systems are very active in the MαCS. The reflectivity is block- or line-shaped. The convection lines will be investigated in detail in the following. The two 200-km long mesoscale convection lines (MCLs) developed continuously during 0000–1000 LST 21 June, with the strongest reflectivity at 40 dBZ (Fig. 6). We refer to them here as MCL1 and MCL2. The MCL1 developed in the southeast of Hefei first, and was gradually extended from southeast to northwest. A 20-km wide convection line with a southeast-northwest orientation formed at 0300 LST 21 June. Afterwards, convective cells of the western MCL1 weakened with the northwestward propagation, and consequently, the length of MCL1 did not increase but the width grew wider and wider. The width of MCL1 was about 40–50 km during 0500–0700 LST 21 June and a new convection line (MCL2) was triggered while MCL1 moved into its mature stage. Nevertheless, the MCL1 dissipated as MCL2 intensified. The formation of MCL2 may be related to the development of MCL1, and a convergence

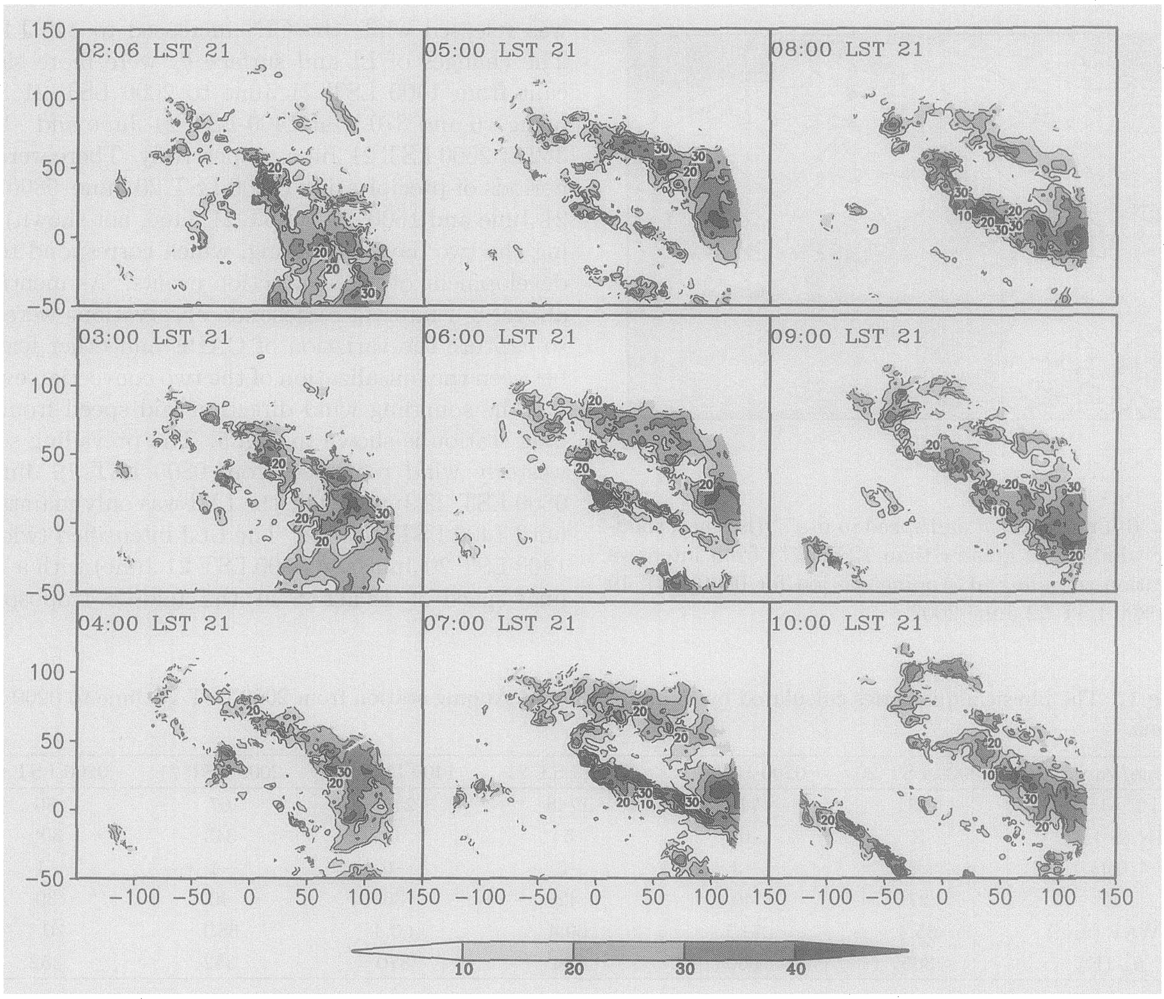

Fig. 6. The reflectivity in dBZ at 2 km ASL by the Hefei radar during 0200–1000 LST 21 June 2002. The origin (0,0) represents the location of the Hefei radar.

line may have appeared between the boundary outflow of MCL1 and the southwesterly current. However, the formation of MCL1 was somewhat different from that of MCL2. The northwestward propagation of convection cells formed MCL1, and the convection cells to the south of MCL1 were initiated by it, and these connected together to form MCL2. During the evolution of the two convection lines, the lines were almost stagnant, but the convective cells embedded in the lines propagated from southeast to northwest.

Even though the length of the convection was as long as 200 km, the width was very narrow, being less than 50 km. This kind of meso β convection cannot be revealed distinctly by synoptic map. However, a surface convergence line between the southeasterly and northeasterly wind can be found at a location 100 km to the north of Hefei (Fig. 7). After the formation of the convergence line at 0100 LST 21 June, the convection cells were triggered along the line in a dispersed manner, and then MCL1 formed at 0300 LST 21 June (Fig. 6). A vortex can be found in the western convergence line, which may be associated with the effect of the Dabie Mountains. The convergence line moved slowly southward from 0500 to 0700 LST 21 June, which may have reduced the intensification of MCL2 and caused the dissipation of MCL1. It should be emphasized that two convection lines were observed by the Hefei radar, but only one surface convergence line was found probably because of the limited spatial and temporal resolution of the surface observation.

The surface streamlines in Fig. 7 reveal that the southwesterly wind shifts to a southeasterly wind after it passes through Dabie and the gorges between the Jiuhua and Mufu mountains, and the convergence line formed between the southeasterly wind and the northeasterly wind, thereby the formation of the local convergence line may be related to the special topography in southern Anhui Province. The vertical cross

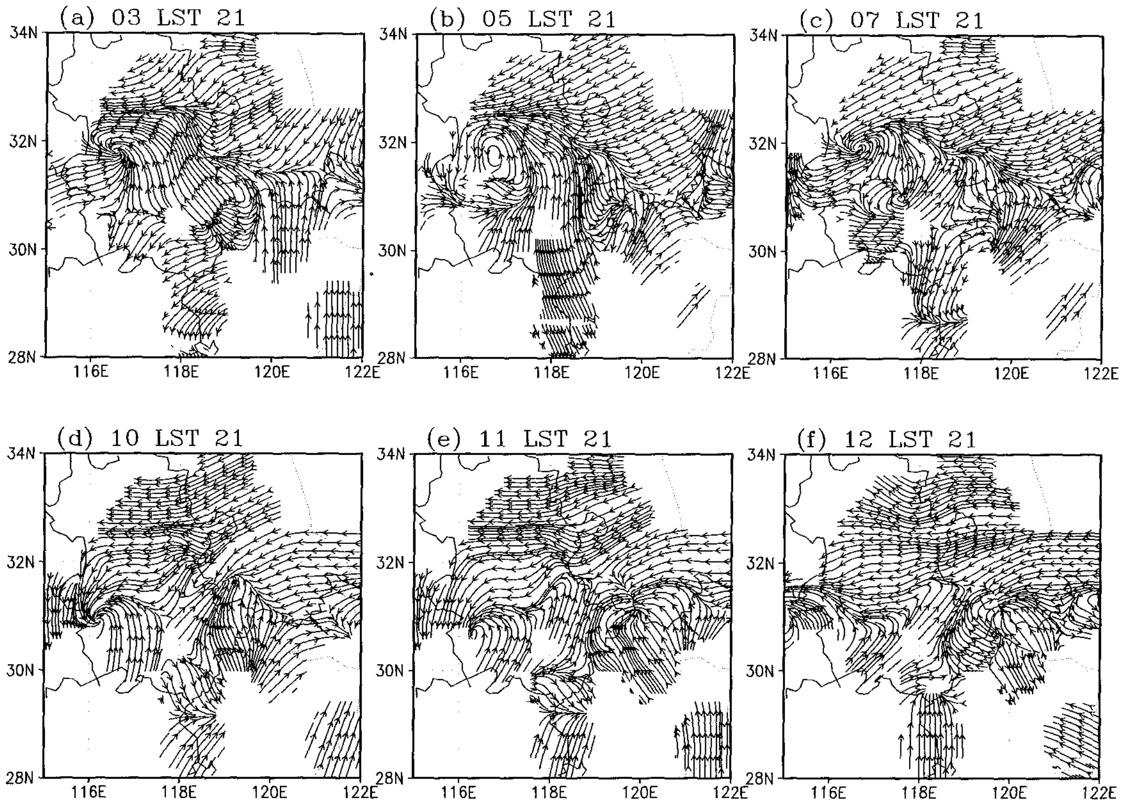

Fig. 7. Surface streamlines on 21 June 2002, (a) 0300 LST, (b) 0500 LST, (c) 0700 LST, (d) 1000 LST, (e) 1100 LST, (f) 1200 LST.

section of convection lines (not shown) shows that strong reflectivity is located in the middle and lower troposphere with the top at 10 km, and a reflectivity greater than 30 dBZ is below 7 km. The distance between the two convection lines is around 20–30 km. Three dimensional retrieval wind from the Doppler radar is needed to confirm whether or not the boundary outflow could trigger another convection line. Unfortunately, dual Doppler radar data is not available from that period.

Another convection line (MCL3) appeared to the south of Hefei while MCL1 and MCL2 were dissipating (Fig. 8). The evolution of MCL3 was significantly different from the previous lines. A meso-γ cell was initiated at Huoshan at 0829 LST 21 June and intensified with eastward propagation after its initiation. New convective cells formed to the northwest of the old cell, and all of these convective cells organized into a convection line. The convection line moved northeastward while the convective cells embedded in the convergence line propagated southeastward along the line. The surface streamline during 1000–1200 LST 21 June (Figs. 7d–f) shows that the convergence line is located to the south of Hefei, and that it was associated with the development of MCL3.

Although the Hefei radar could not detect the whole evolution process of the MCS, the convection lines and their embedded cells can be distinctly revealed. The distribution of radar reflectivity and surface streamlines indicates that the convection line traveled with the surface convergence line and the cells embedded in it propagated along the convection line.

Bluestein and Jain (1985) studied 150 cases of mesoscale convection lines of radar echoes in eastern, central, and western Oklahoma during the springs of 1971–1981. They classified the squall lines associated with severe weather reports into four types: broken line formation, back-building, broken-areal formation and embedded-areal formation.

According to the characteristics of the three aforementioned MCLs, the formation of MCL1 and MCL2 is similar to the broken-areal type, that is, the development of an amorphous area of moderate-to-intense cells into a solid line of convection. MCL3, on the other hand, is to a certain extent, similar to the back-building type, that is, the periodic appearance of a new cell upstream, relative to cell motion, from an old

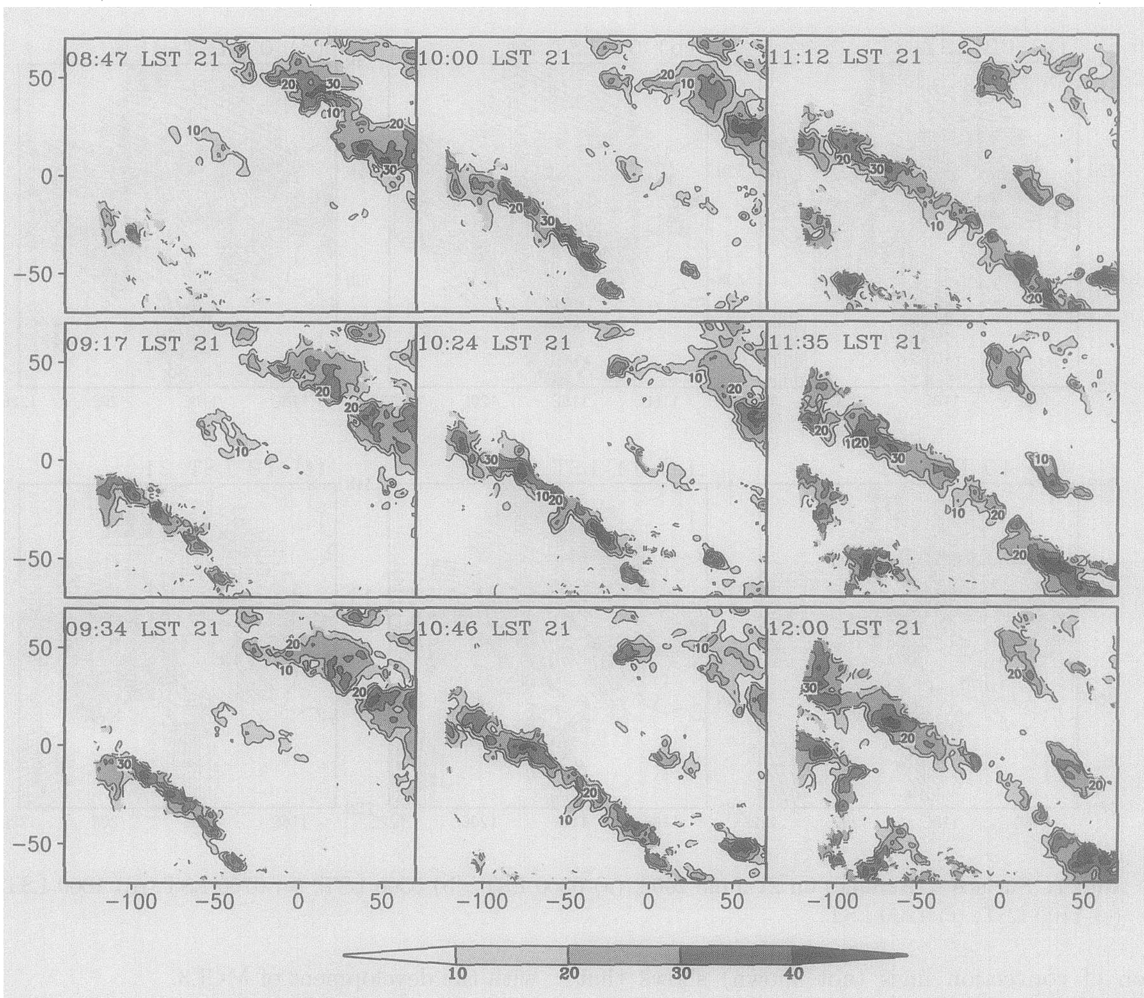

Fig. 8. As in Fig. 6 for 0800–1200 LST 21 June 2002.

cell, and the resulting merger of the two cells as the new cell expands in area and moves into the old one. The radiosonde station data at Anqing station shows that the CAPE during the evolution of MCL1–3 was about 2000 J kg^{-1}. The wind shear from the low- to middle-level troposphere was significant. However, the different environmental conditions for the two types of MCLs cannot be analyzed because the sounding observation is limited. The conditions of CAPE and vertical wind shear for the convection in Anhui Province are similar to those in Oklahoma. The results from Bluestein and Jain (1985) reveal that large CAPE (mean value: 2090 J kg^{-1}) and strong vertical wind shear (mean value: 4.8×10^{-3} s^{-1}) are favorable for the formation of the back-building type, while the broken-areal type occurs in an environment of large CAPE (mean value: 2120 J kg^{-1}) and weak vertical shear (mean value: 3.3×10^{-3} s^{-1}). However, the obvious difference between the lines in Anhui Province and Oklahoma is the moisture content in the air, given that the precipitable water values in Anhui Province and Oklahoma are greater than 65 mm and less than 30 mm, respectively. Therefore, the convection lines along the mei-yu front occur in wet air, while those in Oklahoma occur in relatively dry air. The composite sounding of Oklahoma lines indicates that CAPE (positive area above the level of free convection-LFC) is markedly large and that dry air covers the whole troposphere. It is reasonable because squall lines in Oklahoma are mainly related to the dry lines. The sounding at Anqing shows a large CAPE and wet air in the whole air column (Fig. 9).

4. Multi-scale conceptual model of heavy rainfall in the mei-yu front

In section 2, the intensive observation data from the CHeRES experiment are employed to analyze the MCS that occurred over southern Anhui Province on 20–21 June 2002. Based on the above-mentioned fea-

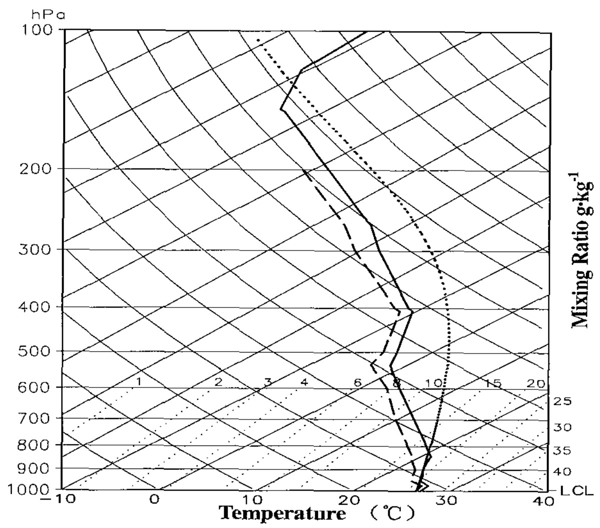

Fig. 9. Composite sounding on skew T-log$p$ diagrams, temperature (solid line), dew point (dashed line), and path in (T, p) space taken by surface parcel as it ascends (dotted line). The pressure is plotted in hPa on the ordinate and temperature is plotted on a skewed abscissa in °C at Anqing station for 0800 LST 21 June 2002.

tures obtained in the present case and previous studies (Tao, 1980; Tao et al., 2001; Ding, 1993; Zhang et al., 2004), a multi-scale conceptual model of the heavy rainfall in the mei-yu front for present case will be proposed in the following. The model includes a synoptic scale model, meso-α scale model and meso-β scale convection line model.

4.1 *Synoptic model*

The synoptic systems associated with the mei-yu include the southwesterly and southeasterly monsoon in the middle and lower troposphere, the mei-yu front, shear line, subtropical high, middle level trough, cyclones or vortices along the mei-yu front in the middle and lower troposphere, the South Asia High, the subtropical westerly, and the easterly jet in the upper troposphere. The case in this paper is not associated with the development of a cyclone, but only with a meso-α convective system. The allocation of the systems is shown in Fig. 10a.

The southeasterly wind along the northwestern rim of the Western Pacific Subtropical High (WPSH) and southwesterly wind from the Bay of Bengal transport abundant moisture to the lower and middle reaches of the Yangtze River basin while heavy rainfall occurs. A weak trough travels eastward in the middle troposphere in the middle latitude areas, and weak cold air invades the Yangtze River basin. The appropriate activities of weak cold air from middle latitudes and warm, moist air from lower latitudes are favorable to maintain the mei-yu front and trigger convection.

The westerly jet and easterly jet can provide a divergence condition at upper levels for the formation of the MCS. The allocation of the above-mentioned upper and lower level systems and the middle and lower latitude systems is propitious to the development of heavy rainfall producing systems along the mei-yu front. The heavy rainfall systems are mainly mesoscale systems, which may be triggered by the streak of a jet. The small figure in the bottom right of Fig. 10a reveals the relationship between precipitable water and rainfall. Precipitable water increases 2–3 hours earlier than the occurrence of the rainfall, and decreases after the beginning of rainfall.

The MCSs that produce heavy rainfall generally develop in the high θ_e area to the south of the mei-yu front. The MCS along the mei-yu front develops from a meso-γ or -β system to a meso-α system, some of them relating to vortices and some of them not. The following meso-α and meso-β models are only concluded from the case occurring in southern Anhui Province on 20–21 June 2002, and they do not relate to vortices.

4.2 *Meso-α model*

The spatial scale of the MαCS along the mei-yu front is about 200–500 km (Fig. 10b), and the lifetime is about one day. The satellite image and radar monitoring show that meso-β block- and line-shaped convections with spatial scales of 20–200 km develop continuously in the MαCS system. The MαCS forms according to one of the following two ways: several meso-β systems merge into one meso-α system, or one meso-β system grows up into a meso-α system under advantageous synoptic conditions.

4.3 *Meso-β scale convection line model*

Meso-β convection lines often develop in the meso-α MCS, and these convection lines are composed of meso-γ convective cells. The convection lines are about 20–50 km in width and 200 km in length with a lifetime of several hours. The convection line generally forms along the convergence line in the boundary layer. The process of one MCL triggering another MCL is shown in Fig. 10c. First, the meso-γ convective cells dispersedly develop to the south of the old MCL. These convective cells organize into a line accompanying the formation of a boundary convergence line. How can the boundary convergence line form? The outflow boundary of the old convection line with the original inflow could form another boundary convergence line, which may organize into a new convection line. The convection line moves with the mesoscale surface convergence line, but the convective cells embedded in the convergence line propagate along the line.

The detailed formation types of convection lines are classified into two types: back-building and broken-areal formations. The formation of these two types of convection lines is, to a certain extent, similar to the definition described by Bluestein and Jain (1985).

Since these physical models are concluded from some previous studies and the present study, and in particular the meso-β convective line model is only from the present case, the characteristics of meso-α and meso-β models indicated in this section may not be consistent with other cases along a mei-yu front. The multi-scale conceptual model of heavy rainfall in a mei-yu front should be further improved according to results from other case studies in the future.

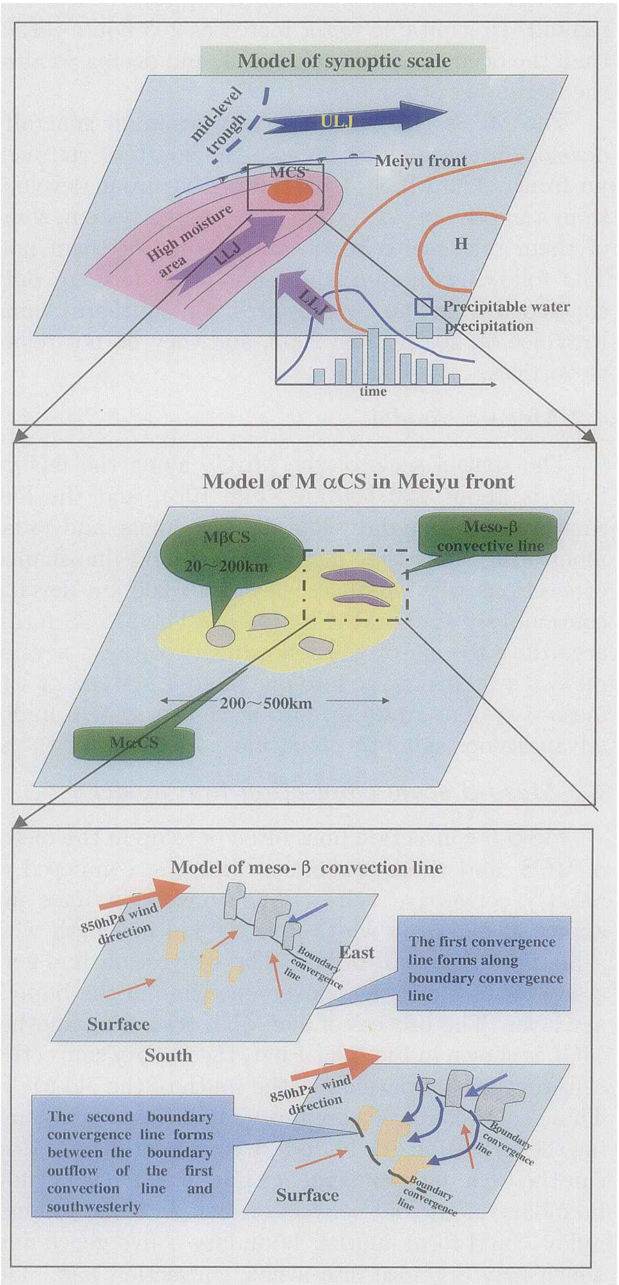

Fig. 10. Multi-scale conceptual model of heavy rainfall in the mei-yu front: (a) Synoptic model, (b) Meso-α model, and (c) Meso-β convection line model.

5. Conclusions

In this paper, the MCS that was triggered in southern Anhui Province and produced heavy rainfall during 20–21 June 2002 is analyzed by using the conventional and intensive observational data of the CHeRES. The main results are the following:

(1) The MCS formed in the warm-moist southwesterly wind to the south of the shear line over Dabie Mountain and the gorge between the Dabie and Jiuhua Mountains. During the evolution of the MCS, two systems originated over the Dabie Mountain area and traveled eastwards. The first system moved eastwards quickly, whereas the second system stagnated and developed deeply. The severe rainfall occurred in the rearward portion of the MCSs.

(2) The GPS observation data indicate that precipitable water increased obviously about 2–3 earlier than the occurrence of rainfall and decreased after that, which may be a sensitive indicator of rainfall in real-time prediction.

(3) The wind profiler data reveal that the LLJ extended to the middle troposphere and was accompanied by the development of convection. The analysis of sounding data from Anqing station at 6-h intervals captured the release and accumulation of CAPE during the evolution of convection. The abundant moisture transportation by the southwesterly wind was very favorable to the maintenance of the convective instability and accumulation of CAPE.

(4) The radar image reveals that meso-β and -γ systems were very active in the MαCS. Several convection lines developed during the evolution of the MCS, which were associated with the surface convergence lines. The boundary outflow of one convection line can trigger another convection line. The convection line moved with the mesoscale surface convergence line, but the convective cells embedded in convergence line propagated along the line.

(5) The convection lines in the mei-yu front occurred in wet air, while those in Oklahoma occur in dry air.

(6) A multi-scale conceptual model of the heavy rainfall in the mei-yu front for this particular case is proposed.

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