Academic Journal of Earth Sciences
ISSN: 2960-0162
DOI: https://doi.org/10.61784/ajes3008

CAUSE ANALYSIS OF A FLOOD-CAUSING RAINSTORM PROCESS IN THE MIDDLE REACHES OF THE YANGTZE RIVER

LiTian Xing
Xianning Meteorological Bureau, Xianning 437100, Hubei, China.
Corresponding Email: xiliti2006@163.com

Abstract: Conventional meteorological observation and 6-hour re-analysis data of NCEP1°×1° were used to analyze the cause of the process from July 18 to 19, 2020. The results showed that the "07.18" process had the characteristics of mixed precipitation, the circulation pattern was double resistance, and the southwest and northeast winds were strongly converging in the middle and low levels, which was conducive to the generation of systematic heavy precipitation. The middle-scale convergence system is at least 3h earlier than the occurrence of heavy precipitation, which can be used as a reference for this kind of weather forecast. The water vapor condition and dynamic condition are good, but the energy condition is general, which is not conducive to the occurrence of short-term heavy precipitation with heavy rain intensity. The rise of the cold air in the boundary layer and its above strong convergence and high altitude strong divergence are one of the main reasons for the occurrence of this heavy precipitation. In addition, the MPV center has a good indication of the rainstorm center.
Keywords: Rainstorm; Boundary layer; Middle-scale system; Mold rain front

1 INTRODUCTION

The middle reaches of the Yangtze River are densely covered with water systems, and there are many large and small reservoirs, and it is a key area for flood control in China. The major rainfall that has the greatest impact on the middle reaches of the Yangtze River is concentrated in the mold rain Period of the Yangtze River from mid-June to mid-July every year. During this period, the Yangtze River Basin is a zone where polar cold air and tropical warm and humid air frequently intermingle. The middle-scale weather systems on the mold rain front are active, and their activities not only maintain the continuous precipitation in the mold rain Period, but also maintain the continuous precipitation in the mold rain Period. It also creates very favorable conditions for the production of heavy rain [1]. Many scholars at home and abroad have conducted some studies on heavy rainfall in the Yangtze River Basin. Wang Xiaofang et al. [2-3] statistically analyzed the types and activity characteristics of the scale convective systems in the middle and lower reaches of the Yangtze River during the mold rain period, and found that the linear middle-scale convective systems in the middle and lower reaches of the Yangtze River during the mold rain period can be divided into 8 typical linear middle-scale convective systems. The vertical distribution of ambient wind relative to convective line components is an important factor determining the organization model of linear middle-scale convective systems. Zhang Shunli et al. [4] made a detailed analysis of the large-scale, synoptic and medium-alpha scale systems of the three floods and rainstorms in the middle and lower reaches of the Yangtze River in 1991, 1996 and 1998. Liu Danni et al. [5] analyzed the characteristics and evolution of mold rain circulation in the Jianghuai River Basin. Zhang Ruiping et al. [6] analyzed the main influencing systems of heavy rainfall during the mold rain period of Jianghuai River in June 2011, and believed that the change of the ridge of the Northwest Pacific subtropical high was the decisive factor for the development of heavy rainfall during the mold rain period. Yao Xiuping et al. [7] analyzed the structure and evolution of easterly disturbances over the tropics related to the east-west movement of the subtropical high. Qiu Hui et al. [8] studied the rainstorm characteristics of the Yangtze River Basin during the main flood season in 2020, and found that from June to July, two ridges and one trough in the middle and high latitudes of Eurasia, and the subtropical ridge line continued to be abnormal, and several northward trips failed to occur, resulting in the shear line and mold rain front remaining near the Yangtze River main stream for a long time, and the southeast air flow from the South China Sea and the Pacific Ocean was unusually strong, coupled with frequent cold air activities. Resulting in frequent heavy rains in the middle and lower reaches of the Yangtze River. At 10:00 on July 17, 2020, the second flood of the Yangtze River in 2020 was formed, and the first flood peak was still slowly subsiding, and the overall water level in the middle and lower reaches of the Yangtze River was still high, and the flood control situation was very severe. The rainstorm process in the middle and lower reaches of the Yangtze River from July 18 to 19, 2020 (referred to as the "07.18" process, the same below) is crucial to flood control. In this paper, conventional meteorological observation data and NCEP 1°×1° re-analysis data for 6 hours are used to analyze the cause of this process from the aspects of weather overview, weather system, environmental characteristics and physical quantity characteristics, so as to provide some reference for the forecast and service of extreme flooding rainstorm in the middle reaches of the Yangtze River.

2 WEATHER OVERVIEW

During the "07.18" process, the accumulated precipitation of national stations in the Yangtze River Basin is shown in Figure 1(a). In the middle reaches of the Yangtze River, there was heavy rain and local heavy rain, mainly located in the area from north-central Hunan to south-eastern Hubei, with the maximum precipitation of 140mm, which occurred in Macheng, Huanggang, Hubei (31.12°N, 114.93°E). Figure 1(b) shows hourly precipitation at three major precipitation points. From west to east, the precipitation in Xiantao, Hubei Province (30.31°N, 113.49°E), Wuhan, Hubei Province (30.60°N, 114.03°E) and Macheng, Hubei Province (31.12°N, 114.93°E) was mainly concentrated from 18:00 on 18th to 08:00 on 19th.

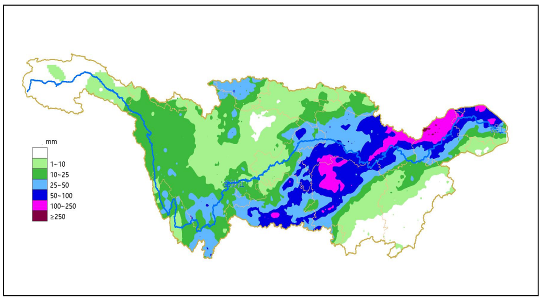

Figure 1(a) Cumulative Rainfall of the Yangtze River Basin During "07.18"

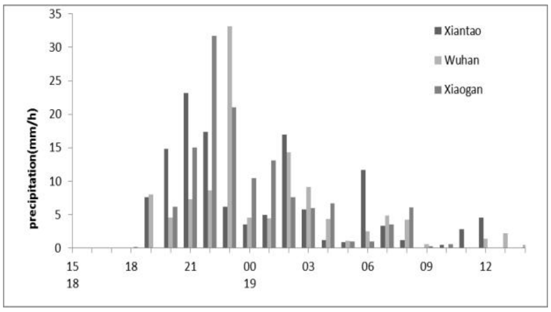

Figure 1(b) Hourly Precipitation at 3 Sites During "07.18"

3 CIRCULATION PATTERNS AND INFLUENCING SYSTEMS

3.1 Circulation Situation

According to the analysis of the 500hP situation field, at 20 o 'clock on July 18 (Figure 2(a)), there was a high pressure ridge near the Ural Mountains and the Sea of Okhotsk in the middle and high latitudes, and a deep low trough from the north of Lake Baikal to the north of the Yellow River, forming a double resistance situation of "two ridges and one trough". There was an obvious northwest jet behind the deep low trough, guiding cold air southward. In the western part of the lake, there are low troughs in the middle and low latitudes moving eastward, and they are superimposed with low troughs in the middle and high latitudes, forming a deep low value system. The sub-high ridge line is located near 20°N, and the western extension ridge point is near 105°E. The southwest air flow in front of the trough and behind the sub-high transport a large amount of warm and humid air to the middle and lower reaches of the Yangtze River, and the northwest air flow in the back of the trough intersects with the obvious northwest air flow in the middle and lower reaches of the Yangtze River, forming a circulation condition conducive to heavy precipitation in the middle and lower reaches of the Yangtze River. From the analysis of 200hPa, at 20:00 on July 18 (Figure 2(b)), the upper westerly jet core was located near 40°N, the South Asian High Pressure ridge line was located near 28°N, and the middle reaches of the Yangtze River was located in the distribution area of southwest winds and west winds to the northeast of the South Asian High Pressure, which was conducive to strengthening the upward movement in this region. Therefore, the "07.18" process is a double-resistance type, in which the northwest jet stream at the back of the deep trough and the southwest jet stream to the northwest of the subtropical high strongly confluent in the middle and lower reaches of the Yangtze River, which is conducive to the generation of systematic heavy precipitation.

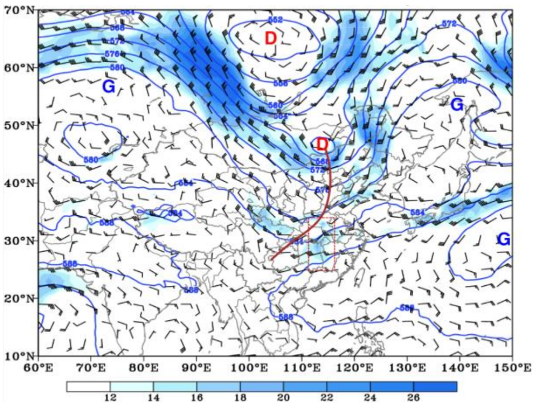

Figure 2(a) Height Field (Solid Blue Line), Wind Field and Jet Stream (Shaded Area) at 20:00:500hPa on July 18

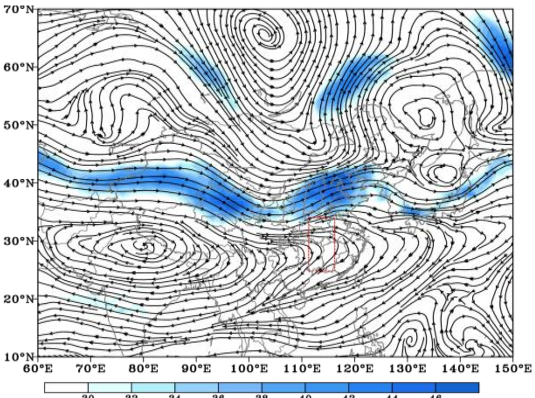

Figure 2(b) 200hPa Flow Field (Solid Black Arrow) and Jet Stream (Shaded Area) at 20:00:500hPa on July 18

3.2 Affecting the System

According to the analysis of the influence system in the middle and low levels, at 08:00 on the 18th (omit the picture), over 700hPa and 850hPa, the shear line gradually shifted eastward to the south over Chongqing -- northwest Hunan, and an obvious low-level jet was established over Hunan-north-central Jiangxi -- south-southeastern Hunan -- southern Anhui. As the precipitation approached, at 20:00 on the 18th (Figure 3(a)), Over 850hPa, a low vortex appeared in the central and southern parts of Hubei province, and the shear line moved to the central part of Hubei, showing a southwest-northeast track, and there was obvious convergence of southwest winds (maximum wind speed 18m·s^{-1}) and northeast winds (maximum wind speed 16m·s^{-1}). In addition, there are obvious near-formation low vortex shear lines Over 925hPa. Similarly, at 02:00:925hPa on the 19th, the southwest to northeast shear line in the eastern part of Hubei moved eastward, the southwest jet core was located in the central south of Hunan to the northwest of Jiangxi, the maximum wind speed reached 16m·s^{-1}, and there was an obvious northeast jet on the north side of the shear line, the maximum wind speed reached 14m·s^{-1}, forming an obvious convergence with the southwest jet. According to the analysis of water vapor flux and water vapor flux divergence at 20:00, over 850hPa (Figure 3(c)), the water vapor in the "07.18" process mainly came from the southwest airflow of the Bay of Bengal, and there was obvious convergence of water vapor flux from northern Hunan to most of Hubei. Therefore, there was strong convergence of southwest wind and northeast wind in the middle and low levels of this process, and water vapor transport was significant, and there were systematic dynamic conditions and water vapor conditions for generating strong precipitation.

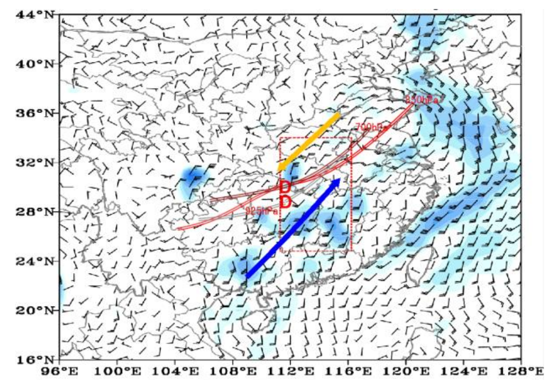

Figure 3(a) 850hPa Wind Field (Wind Pole), Jet Stream and System Configuration at Each Layer at 20:00 on July 18

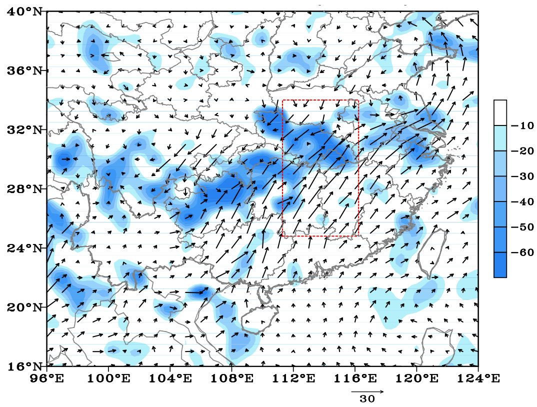

Figure 3(b) 850hPa Vapor Flux (Vector Arrow) Vapor Flux Divergence (Shaded Area) at 20:00 on July 18

3.3 Terrain Impact

The analysis of the superimposed map of the surface middle-scale system and terrain (Figure 4) between the rain area with rain intensity ≥30mm at the maximum of the "07.18" process and the 12 o 'clock of the 18th shows that obvious middle-scale shear lines had appeared on the ground three hours before the appearance of the heavy rainfall, and the northward air flow entered the Jianghan Plain along the foothills of western Hubei Province. Due to the influence of friction, the northward air flow was weak. The southwest air flow in the southern part of the convergence line is stronger, by puding Mufu-Mountain in the southeast of Hubei Province. Due to the dynamic uplift and blocking effect of the terrain, there is strong precipitation along the foothills of Mufu-Mountain in the north side. Therefore, the topographic effects further strengthen and maintain the convergence of northeast and southwest winds, providing favorable dynamic convergence conditions for heavy precipitation[9], and indicating the fall area of heavy rain area at least 3 hours in advance, which can be used as a reference for forecasting.

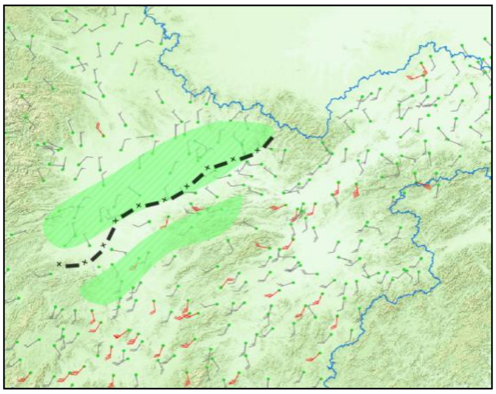

Figure 4 Surface Wind Field and Middle-Scale Shear Line at 12:00 on 18 July Superposition Diagram of Rain Area (Green Shaded Area) and Terrain at the Maximum Rain Intensity of "07.18" Process ≥30mm

3.4 Radar Reflectivity Factor

From 09:00 on July 18 (Figure 5(a)), the combined radar reflectance analysis (Figure 5(a)) shows that the 07.18 "process has the characteristics of stratosphere-cumulus mixed type precipitation echo, and the vertical profile is carried out along the precipitation echo center (Figure 5(b)). Echoes with center intensity of 40dbz are located in the north of Hunan and the southeast of Hubei, and the echo centroid is about 4.5km. The maximum intensity is 45dbz, and the precipitation efficiency is high. Therefore, this process has mixed precipitation characteristics and high precipitation efficiency.

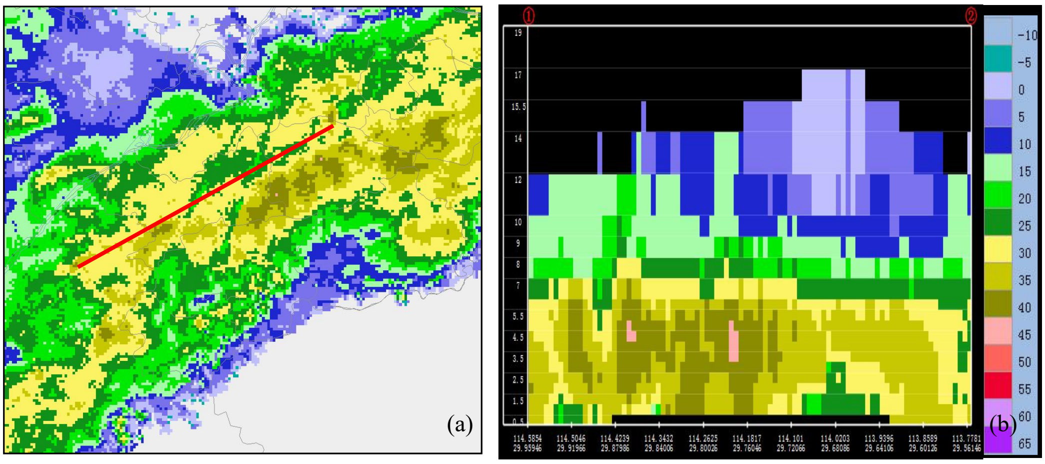

Figure 5 Combined Reflectance (a) and Profile (b) of Weather Radar at 09:00 on July 18

4 PHYSICAL QUANTITY ANALYSIS

4.1 Horizontal Structure of Water Vapor, Heat and Power Factors

4.1.1 Analysis of water vapor characteristics

From 20:00 on July 18, the whole layer precipable water (PWAT), 850hPa specific humidity and wind field analysis (Figure 6(a)) showed that PWAT was greater than 70mm and specific humidity was greater than 13g/kg in the northern Hunan-Central and eastern Yangtze River region, while the specific humidity reached more than 18g/kg in the northeast Hunan-Xianning, Wuhan and Xiaogan regions of Hubei Province, and the iso-specific humidity line was dense. There is a clear intersection of dry and wet advection. Therefore, this process has water vapor conditions conducive to the occurrence of heavy precipitation.

4.1.2 Thermal condition analysis

From the analysis of thermal conditions at 20pm on July 18 (Figure 6(b)), there is a certain amount of unstable energy in the northern part of Hunan and Jiangxi, CAPE is 600-1000j /kg, and the vertical decline rate of false equivalent potential temperature (θse) (the difference between 850hPa and 500hPa false equivalent potential temperature) reaches 12-20K, indicating that both have convective unstable stratification. It is conducive to the occurrence of strong convective weather[10], and the K value (figure omitted) reaches 38 ~ 40℃. Therefore, these processes have certain convective unstable energy and unstable stratification, but they are not particularly favorable for the occurrence of strong convective precipitation.

4.1.3 Analysis of dynamic conditions

From the analysis of the vorticity and θse at 20:00:850hPa on July 18 (Figure 6(c)), the θse values range from 340 to 364K, and the iso-θSe lines are dense and have a very obvious θse horizontal gradient, that is, there is a clear front region. Most of the vorticity reaches 70×10-5 s-1, indicating strong dynamic conditions. In addition, from the analysis of the 850hPa and 200hPa divergence fields (Figure 6(d)), the convergence center value of the middle and low layers is -4×10-5 s-1, and the divergence center of the high layers is 7×10-5 s-1. It shows that the upper level divergence is stronger than the convergence of the middle and lower levels, and the upper level suction is conducive to strengthening and maintaining the ascending motion.

In summary, from the horizontal characteristics of water vapor, thermal and dynamic conditions, the "07.18" process has very favorable water vapor and dynamic conditions for the occurrence of heavy precipitation, but the energy conditions are general, which is not conducive to the occurrence of short-term heavy precipitation with very strong rainfall.

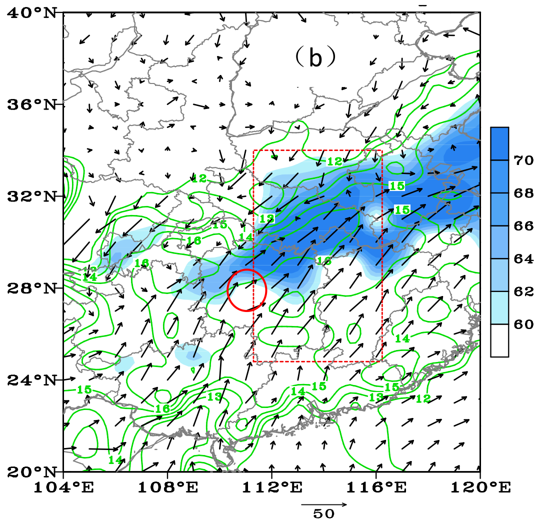

Figure 6(a) Specific Humidity of 850hPa (Solid Green Line), Wind Field (Vector Arrow) and Precipitable Water of the Whole Layer (Shaded Area) at 20:00 on July 18

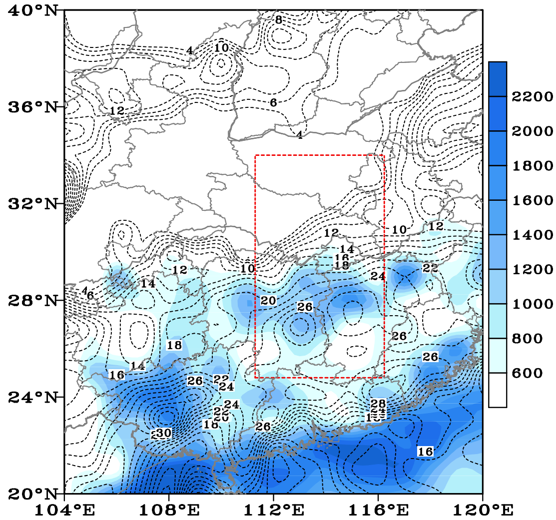

Figure 6(b) 850hPaθse Vertical Decline Rate (Black Dashed Line) and CAPE (Shaded Area) at 20:00 on July 18

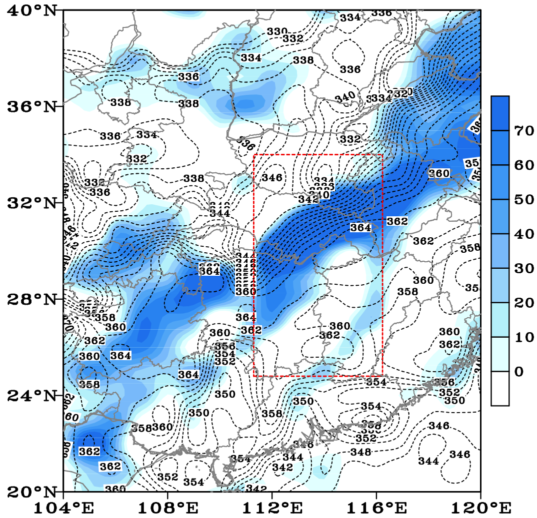

Figure 6(c) 850hPaθse (Black Dashed Line) and Vorticity (Shaded Area); Vorticity (Shaded Area) at 20:00 on July 18

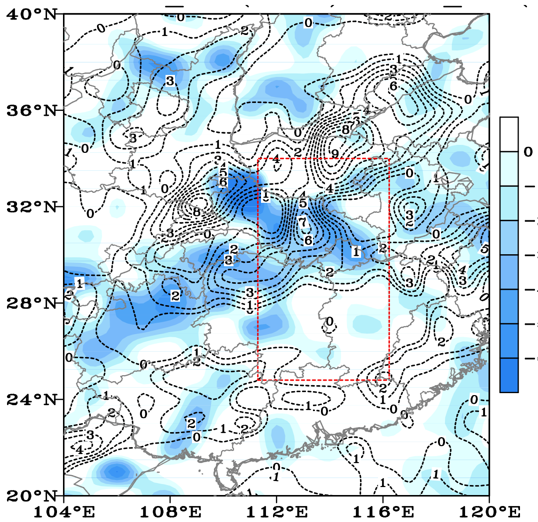

Figure 6(d) 850hPa (Shaded Area) and 200hPa Divergence (Black Dashed Line) at 20:00 on July 18

4.2 Vertical Distribution of Water Vapor, Heat and Dynamic Conditions

4.2.1 Vertical distribution of relative humidity and θse

The vertical profile of the precipitation center along 30°N and longitudinally 108 ~ 118°E (the same below) was made. From the analysis of the vertical distribution of relative humidity and θse at 20pm on July 18 (Figure 7(a)), there is a deep wet layer nearly saturated, and the relative humidity of more than 90% reaches 200hPa. The high value area of θse represents the high temperature and high humidity area, while the low value area represents the low temperature and low humidity area (Meng Yingjie, Li Liping, Wang Shanshan, et al., 2010). According to the vertical distribution analysis of θse (Figure 7(b)), there is an obvious dense band of is θse lines below 900hPa between 110 and 113°E, indicating that there is an obvious intersection of cold and warm. Corresponding to the heavy precipitation center, there is a θse gradient large value zone in the 700-800hPa east of 112°E, indicating that the zonal Mold rain front has obvious characteristics. Therefore, this process has deep wet layer and obvious Mold rain front characteristics.

4.2.2 Temperature advection, wind and vertical velocity are distributed vertically

From the analysis of the vertical distribution of temperature advection, wind and vertical velocity at 20:00 on July 18 (Figure 7(b)), the wind below 800hPa to the west of 114°E was northerly, with obvious cold advection (the extreme value center was above -12×10-5K·s-1), and there should be obvious sinking movement, indicating that there was strong cold air intrusion at the lower level. Between 800 and 600hPa above the cold pad near 110°E, there is a warm advection center with an extreme value of 10×10-5K·s-1, and there should be a vertical velocity center with an extreme value of $-1.6Pa \cdot s^{-1}$. Near and east of 114°E, almost the whole layer is warm advection, corresponding to the whole layer is updraft, but the intensity is weak. From the vertical wind shear analysis of the precipitation center, the wind vector difference between the ground and 500hPa near 114°E is about $12m \cdot s^{-1}$, which has a certain convective organization and is more conducive to the generation of convective heavy precipitation. Therefore, the process of "07.18" has obvious convergence of cold and warm air, strong upward movement and certain convective organization conditions, which is more conducive to the occurrence of heavy precipitation.

4.2.3 Vertical distribution of divergence and vorticity

According to the analysis of the vertical distribution of divergence and vorticity (Figure 7(c)) at 20:00 on July 18, negative vorticity and divergence subsidence were observed below 950 from 110 °E to 113°E, which is consistent with the conclusion of the previous analysis that there is an obvious uplift of cold air near the surface. In addition, there is a small and medium scale vertical circulation below 900hPa in the near formation at 112°E. The convergence center with a central value of -6×10-5 s^{-1} is located above the divergence center with a central value of $3\times10^{-5}\ s^{-1}$, which may be related to the middle-scale system in the boundary layer except for the lifting of cold air. 900 ~ 500hPa is the positive vorticity region, the above is the negative vorticity region, 900 ~ 700hPa is the convergence region, corresponding to 110° ~ 112°E near the 400hPa height, there is a center of divergence value of $3\times10^{-5}\ s^{-1}$, 800 ~ 700hPa convergence is weak, this vertical structure is exactly corresponding to the precipitation center. Therefore, the strong boundary layer convergence and high altitude divergence in the process of "07.18" are the main reasons for the dynamic conditions for the occurrence of this heavy precipitation.

4.2.4 Wet potential vortex positive pressure terms (MPV1) and baroclinic pressure terms (MPV2) are vertically distributed

Wet-potential vorticity not only characterizes the dynamic and thermal properties of the atmosphere, but also considers the effect of water vapor. Wet-potential vorticity has a good correspondence with symmetric instability. The analysis of wet-potential vorticity can describe the occurrence and development of convection more comprehensively and effectively. MPV1 is the vertical component of the wet potential vortex (positive pressure term), when the atmosphere is convective instability, MPV1 < 0; If the atmosphere is convective stable, MPV1 > 0. MPV2 is the horizontal component of the wet potential vorticity (baroclinic term), which represents the wet baroclinic property of the atmosphere. The increase of vertical shear of wind or the increase of horizontal wet baroclinic can cause the increase of vertical vorticity due to the tilt of wet isentropic surface, which is conducive to the occurrence or intensification of heavy precipitation. The unit of wet potential vortex is PVU, 1PVU = $10^{-6}m^2 \cdot s^{-1} \cdot K \cdot kg^{-1}$[11]. Figure 7(d) shows the longitudinal vertical profile of MPV1 and MPV2. It can be seen that MPV1 < 0 below 700 hPa and the maximum value of the center is -1.4PVU, which is consistent with the dense band of is θse lines near the ground in Figure 7(a). This region is very conducive to the growth of vertical vorticity, and at the same time, the negative MPV1 region overlaps with the positive MPV2 region with a central value greater than 1.2PUV, which is conducive to the occurrence or intensification of heavy precipitation[12]. Therefore, MPV can better explain the occurrence mechanism of the strong convective rainstorm and determine the location of the center of the strong convective rainstorm.

In summary, from the analysis of vertical distribution of physical quantities, the process of "07.18" has deep wet layer and obvious characteristics of Mold rain front, and a medium and small-scale vertical circulation in the boundary layer. The uplifting of the cold air in the boundary layer and its strong convergence above and strong divergence in the upper air are the main dynamic conditions for the occurrence of the heavy precipitation. In addition, the MPV center has a good indicator significance for the rainstorm center.

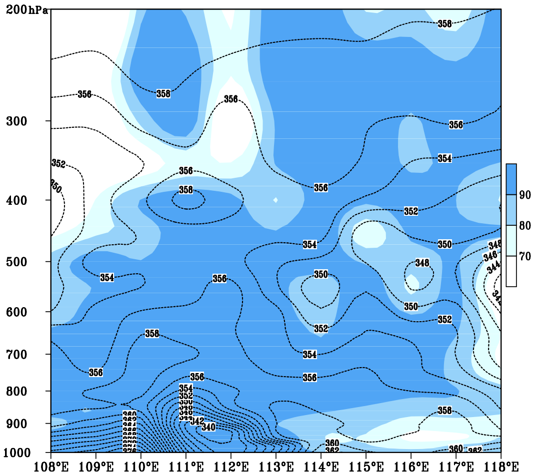

Figure 7(a) The Longitudinal Vertical Profile of Physical Quantities: θse (Black Dashed Line) and Relative Humidity (Shaded Area) at 20:00 on July 18

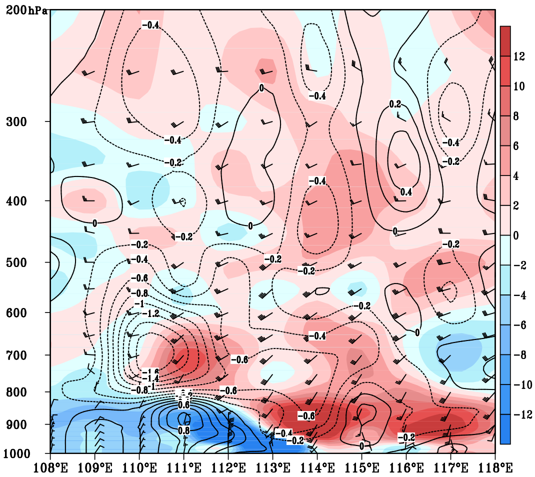

Figure 7(b) Vertical Velocity (Black Dashed Line), Temperature Advection (Shaded area) and Wind at 20:00 on July 18

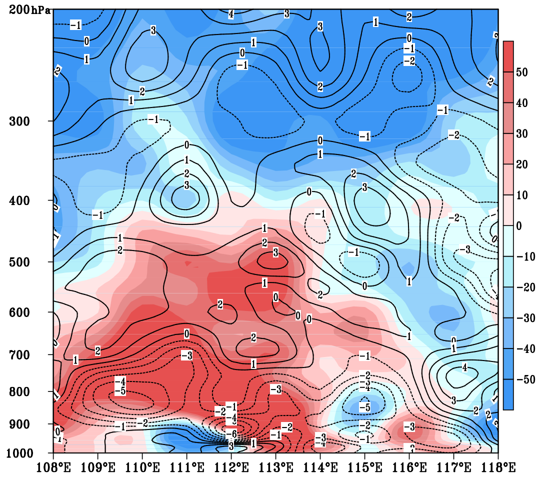

Figure 7(c) Divergence (Black Line) and Vorticity (Shaded Area) at 20:00 on July 18

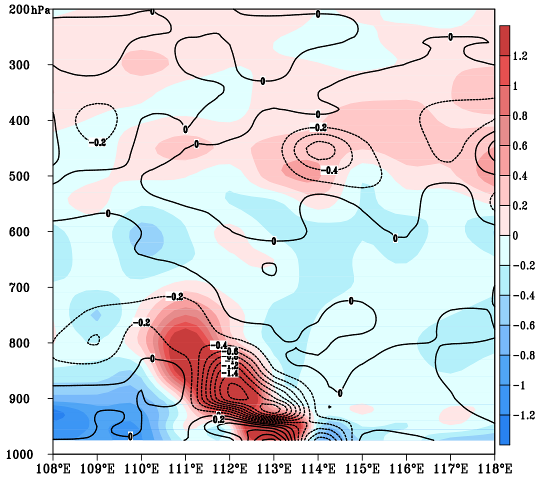

Figure 7(d) MPV1 (Contour Line) and MPV2 (Shaded Area) at 20:00 on July 18

5 SUMMARY AND DISCUSSION

(1) The "07.18" process has the characteristics of mixed precipitation, and the circulation situation is double-resistance type. The northwest jet stream at the back of the deep trough and the strong southwest jet stream to the northwest of the subtropical high converge in the middle and lower reaches of the Yangtze River, forming circulation conditions conducive to the generation of systematic heavy precipitation.
(2) In the process of "07.18", there was strong convergence of southwest wind and northeast wind at the low level, and water vapor transport was significant, which had systemic dynamic conditions and water vapor conditions for generating strong precipitation.
(3) Topographic effects further strengthen and maintain the convergence of northeasterly and southwesterly winds, providing favorable dynamic convergence conditions for heavy precipitation. The middle-scale convergence system on the ground is at least 3h earlier than the occurrence of heavy precipitation, indicating the occurrence time and falling area of heavy rain, which can be used as a reference for such weather forecast.
(4) From the perspective of the horizontal characteristics of water vapor, thermal and dynamic conditions, the "07.18" process has very favorable water vapor and dynamic conditions for the occurrence of heavy precipitation, but the energy conditions are general, which is not conducive to the occurrence of short-term heavy precipitation with large rainfall intensity.
(5) From the analysis of vertical distribution of physical quantities, the process of "07.18" has deep wet layer and obvious characteristics of Mold rain front, and a small and medium scale vertical circulation in the boundary layer, which may be related to the ground middle-scale system. The rise of the cold air in the boundary layer and its above strong convergence and high altitude strong divergence are the main dynamic conditions for the occurrence of the heavy precipitation. In addition, the MPV center has a good indication of the rainstorm center.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

REFERENCES

[1] Tao Shiyan. Torrential Rain in China. Beijing: Science Press, 1980.
[2] Wang Xiaofang, Cui Chunguang. Analysis of linear middle-scale convective system during mold rain Period in the middle and lower reaches of Yangtze River I: Characteristics of organization types. Acta Meteorologica Sinica, 2012, 70(5): 909-923.
[3] Wang Xiaofang. Analysis of linear middle-scale convective system during mold rain Period in the middle and lower reaches of Yangtze River II: Environmental characteristics. Acta Meteorologica Sinica, 2012, 70(5): 924-935.
[4] Zhang S L, Tao S Y, Zhang Q Y, et al. Multi-scale conditions of flood-causing rainstorm in the middle and lower reaches of Yangtze River. Chinese Science Bulletin, 2002, 47(6): 467-473.
[5] Liu Danni, He Jinhai, Yao Yonghong, et al. Structural characteristics and evolution of mold rain circulation in Jianghuai River Basin. Journal of Tropical Meteorology, 2011, 27 (4): 465-474.
[6] ZHANG R P, Ma X L, Sheng W B, et al. Characteristics of main influencing system of mold rain rainstorm in Jianghuai River in June 2011. Journal of Atmospheric Sciences, 2014, 37 (3): 366-377.
[7] Yao Xiuping, Wu Guoxiong, Liu Huanzhu. Structure and evolution characteristics of easterly disturbances over the tropics related to the east-west movement of the West Pacific subtropical high during the mold rain Period of 2003. Journal of Tropical Meteorology, 2008, 24(1) : 20-26.
[8] Qiu H, Xiong Y, Xing W H, et al. Characteristics and causes of rainstorm in the Yangtze River Basin during the main flood season in 2020. People's Yangtze River, 2020, 51, 673(12):108-114.
[9] Li Qingchun, Cheng Conglan, Quan Jiping, et al. Comparison of Characteristics and Effects About Low-Level Jet in Two Rainstorm Processes with Different Intensities in Summer. 2022, 48(11): 1384-1401.
[10] National material. Severe convection weather and forecast. Beijing: China Meteorological Press, 2011: 94-105.
[11] Meng Yingjie, Li Liping, Wang Shanshan, et al. Analysis of topographic uplift during middle-scale rainstorm. Anhui agricultural science, 2010, 38(12): 6333-3666.
[12] Gao Wanquan, Zhou Weican, Li Yu, et al. Wet potential vorticity diagnosis of a severe convective rainstorm in North China. Journal of Meteorology and Environment, 2011, 27(1): 1-6.