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Characteristic Analysis of Short Time Heavy Rain in Yulin, China

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Abstract

National Centers for Environment Prediction (NCEP) reanalysis data, automatic observation data, FY-2E satellite data and Doppler radar data are used to analyze a short-time local heavy rain in Yulin city, Shaanxi, China on August 7, 2018. The result shows that the strong convective weather occurred in peripheral subtropical high over west pacific, being caused by short wave disturbance, and surface convergence lines with positive pressure variation are corresponding to areas of short-time heavy precipitation. The degree of temperature change in cold pool caused by thunderstorm may decide the intensity of a short-time rainfall, and local topography plays an important role in extreme precipitation. Local water vapour accumulation and water vapour flux convergence in the middle and lower layers support adequate moisture condition in the process. Moving direction and development direction of mesocale convective cloud are in a line to develop the train effect, leading to local short-time heavy rain in Yulin city, Shaanxi, China.

Keywords

Short-Time Rain Storm, Precipitable Water, Vapor Flux Divergence, Train Effect

1. Introduction

Short-term heavy rainfall will bring the surge of surface runoff, easy to cause urban waterlogging, farmland water, in mountainous areas prone to debris flow, mountain landslide and other disasters. Heavy rain is one of the major catastrophic weather in summer in Shaanxi Province in China, attracting many scholars to study it. For example, Bi et al. (2011) analyzed a rare regional rainstorm weather process in northern Shaanxi; Yuan et al. (2008) conducted diagnostic analysis of a heavy rain process in Yulin City, northern Shaanxi; Zhao et al. (2017) diagnosed the thermal dynamic mechanism of two rainstorm processes in northern Shaanxi. The convective rainstorm with hourly precipitation exceeding 30 mm or three hours of accumulated rainfall exceeding 50 mm has the characteristics of small spatial scale, short life span and sudden burst. Many scholars have studied the physical mechanism, environmental parameters, multi-scale, and early warning of short-term heavy precipitation. For example, Hao et al. (2012) established a model of short-term heavy precipitation, and concluded that it is conducive to the two structural features of the weather system and radar echoes that occur in short-term heavy precipitation. It is believed that the rapid current in the boundary layer half an hour before the occurrence of heavy precipitation is an important indicator of early warning; Tian et al. (2015) believe that short-term heavy precipitation on water vapor The correlation quantity is the most sensitive, and the indications of the secondary thermal conditions, dynamic conditions and vertical wind shear are not significant; Fan & Yu (2013) have studied the characteristics of environmental parameters of short-term heavy precipitation, and pure short-term heavy precipitation The T-logP map can be divided into two types. The temperature difference between the middle and lower layers and the upper layer is small, and the height of the lifted condensation and the height of the free convection are low.

Located in the Loess Plateau in northern Shaanxi, the annual precipitation is less and unevenly distributed. In case of heavy rain, soil erosion is very serious, and heavy rains often cause geological disasters such as flash floods, landslides and mudslides, causing serious casualties and property losses, especially a short rainstorm (Liu & Du, 2006). Zhang et al. (2006) analyzed the heavy rain in northern Shaanxi, and considered that the mesoscale convergence system on the ground flow field and the mesoscale convective system on the satellite cloud map are the causes of the short-term heavy precipitation system (Liu, 2008). The study of sudden heavy rains in northern Shaanxi shows that the mid-storm cloud and wet convective echoes directly affect the system. The southwest low-level jet along the periphery of the subtropical high provides sufficient energy and water vapor conditions for the rainstorm area. The occurrence of secondary circulation in the upper and lower atmospheres means that there is a strong upward movement and divergence field in the atmosphere. Other scholars have conducted a diagnostic analysis of the causes of heavy rain in northern Shaanxi (Liu et al., 2014).

In recent years, in the context of global warming, extreme weather is frequent, and the heavy rains in northern Shaanxi have also increased significantly, causing serious urban floods, flash floods and other disasters, and direct economic losses of over 100 million yuan for people's lives. It poses a serious threat, so it is necessary to further study the causes of short-term heavy rain and heavy rain to improve the accuracy of forecasting.

Compared to other studies mentioned in this paper, the issues discussed in this paper are linked to existing research, highlighting its similarities or differences with existing research, which reflects the novelty of this paper.

2. Date and Methods

NCEP reanalysis data, automatic observation data, FY-2E satellite data and Doppler radar data are used to analysis a short-time local heavy rain. By transmitting radio electromagnetic wave signals to the atmosphere, receiving the reflected signals of precipitation particles at different levels in the atmosphere, obtaining the precipitation structure information of different levels in the vertical direction, and realizing the detection of vertical precipitation. The key of radar detection principle lies in the reflection and scattering phenomenon of electromagnetic wave. When electromagnetic wave meets the target, the scattering and reflection phenomenon will occur, which will cause the propagation method and speed of electromagnetic wave to change. We also use analysis methods such as actual situation analysis, mesoscale analysis, water vapor condition analysis, satellite cloud image analysis and radar monitoring analysis.

3. Results and Analysis

3.1. Actual Situation Analysis

At 16 o'clock on the afternoon of August 7, 2018, Yulin City experienced a short-term heavy precipitation process. The accumulated rainfall from 16:00 to 26:00 shows that there were 8 stations in the storm and 1 heavy rain. It is 103.4 mm in Yulin District of Xiangyang District. It can be seen that the main rainstorm area is in the middle of Yulin, the precipitation center is located in the center of Yulin, and the precipitation period is the peak of the evening hours, which causes serious urban shackles and traffic jams, giving people life. Property poses a great threat. Among them, 23 stations with short-term heavy precipitation (>20 mm/h) were obtained. The distribution map is shown in **Figure 1**. The main precipitation period is 17 - 19, and the maximum hourly precipitation is Mengjiawan Township, Xiangyang District, 16 to at 17 o'clock, the precipitation reached 66.3 mm.

From the precipitation and temperature changes from 15:00 to 22:00 on August 7th in Mengjiawan Township and Yulin City (**Figure 2**), it can be seen that when the hourly precipitation reaches a maximum value, it is also the minimum value of temperature. From the temperature before the occurrence of short-term

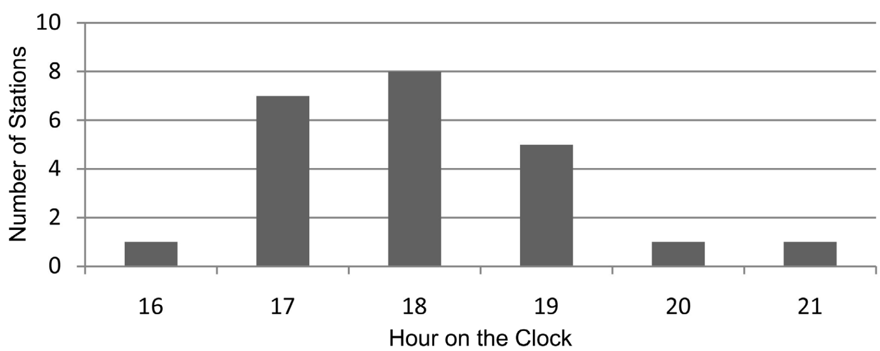
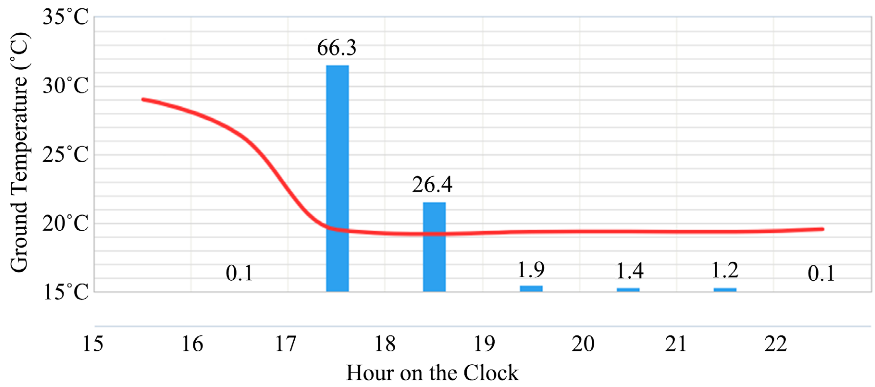
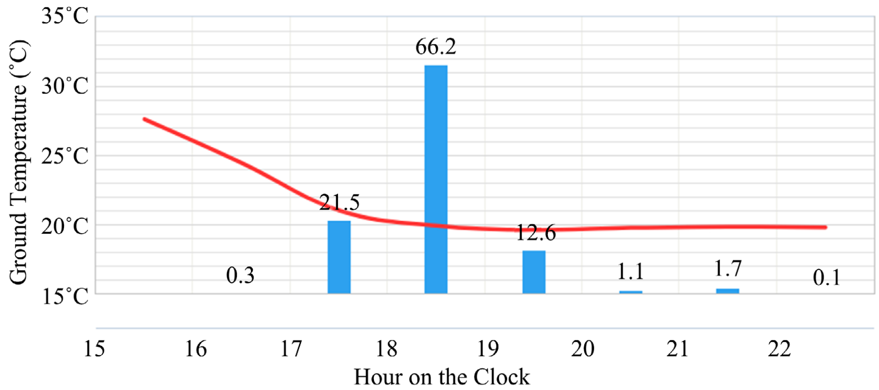


Figure 1. Time distribution of precipitation stations greater than 20 mm/h.



(a)



(b)

Figure 2. Hour precipitation and ground temperature. (a) Mengjiawan Township; (b) Yulin City. The number above the column represents the amount of precipitation in millimeters.

heavy precipitation, Mengjiawan Township's temperature at 15:00˚C was 29.5˚C, and short-term strong precipitation occurred at 17:00, the temperature dropped to 19˚C, and the temperature dropped to 10.5˚C in 2 hours. At 15 o'clock in Yulin City, the ground temperature was 28.1˚C. At 17 o'clock, the temperature of the strong precipitation began to decrease to 20.1˚C. At 18 o'clock, the maximum temperature reached 19.6˚C, and the temperature decreased by 8.5˚C in 3 hours.

The statistics of other nearby stations with short-term heavy precipitation are shown in **Table 1**. The results show that short-term heavy precipitation occurs in a short time (about 2 - 3 hours). Strong thunderstorm activity causes local formation of cold pools and cooling in cold pools. The magnitude of the precipitation and the intensity of precipitation have a certain proportional relationship, indicating that the strength of the cold pool activity may determine the intensity of short-term heavy precipitation.

In addition, there are extreme precipitation sites > 60 mm/h, Mengjiawan Township, Yulin City and Central Square. From the topographic map, it is located in the basin zone in Yulin, along the basin line with rivers and small watersheds. It may also be the cause of extreme short-term heavy precipitation.

Table 1. Hourly rain intensity and the first 2 hours of cooling.

Station name	Hourly rain intensity (mm/h)	First 2 hours of cooling (˚C)
Bolo	44.6	11.9
Balasu	35.9	10.8
Baijie	35.8	10
Qinhe	35.4	9.1
Shimawa	35	8.1

3.2. Mesoscale Analysis

At 08 o'clock, the situation shows that the high-altitude 500 hPa has a short-wave trough eastward in the upper reaches of Shaanxi Province, and the northern part of Yulin is controlled by the westward airflow in front of the trough, and there is continuous short-wave disturbance; the subtropical high is a block-like northward elevation, and the ridgeline latitude is near 35˚N. The west extension ridge point is located at 105˚E, and the Yulin forest is under the influence of the southwest airflow around the subtropical high. Affected by 500 hPa short-wave trough, there is a small cyclone circulation in the 700 hPa Hetao area. There is obvious shear from the low-pressure center to the north, affecting to the northern part of Yulin. The 850 hPa shear line is northeast-southwest and directly runs through the Yulin area. The ground is located in the pressure equalization field, and there are obvious ground convergence lines in the Yulin area. In terms of water vapor conditions, the dew point difference between 700 hPa and 850 hPa in Yulin area is ≤3˚C. The water vapor from the east road has obvious conveying path to the area along the periphery of the subtropical high. The dynamic conditions and water vapor conditions are very favorable for the occurrence of strong convective weather.

From the sounding of the Dongsheng area at 08:00, the water vapor conditions in the middle and lower layers are better, and the effective energy of the convection is fine and high, with a value of about 300 J/kg. The free convection height LFC is located at 700 hPa, and there is weak convective suppression effective potential energy at 700 - 850 hPa. That is, when the convective height is less than LFC, it is difficult to form strong convective weather, but the mesoscale analysis shows that both 850 hPa and 700 hPa are affected. The shearing effect and the dynamic lifting condition are better. Therefore, the convective suppression effective energy has energy accumulation, which is conducive to the development of strong convective weather. The low-level wind rotates with the height, and there is weak warm advection. The middle and upper-level winds are reversed with height, and there is weak cold advection. There is no particularly strong wind shear in the whole layer, which is conducive to the convective development of convection. In addition, the K index is 40.5˚C, and the Si index is −1.72˚C, indicating that the atmosphere is in a strong stratification instability.

The vertical distribution of relative humidity shows that the medium and low humidity conditions are very good, both >90%, and the relative humidity above

500 hPa drops rapidly. The distribution of high-level dry cold and low-level warm and wet is very conducive to the development of strong convective weather. From the vertical distribution of the pseudo-equivalent temperature, it can be seen that the 700 - 850 hPa layer has a convective neutral balance, 700 hPa - 500 hPa is convectively unstable, and convection is stable above 400 hPa. The high convective instability layer height is also conducive to the development of convection once it is triggered.

The sea level pressure field (Figure 3) shows that Yulin is in the pressure equalization field. The hourly pressure change in the strong precipitation area is positive, and due to thunderstorms, there is continuous sinking cold air accumulation on the ground, and the positive pressure change strengthens with time, indicating the enhancement of convection and the triggering of new convection. According to the ground wind field, there is a very obvious ground convergence line at the junction of positive and negative pressure, and the location of the convergence line is the area generated by strong convection. After 19:30, the convergence line is basically removed from the Yulin area, strong precipitation. It has gradually turned smaller. This shows that the ground convergence line is the mechanism for the convective maintenance of this short-term rainstorm.

3.3. Analysis of Water Vapor Conditions

We first analyze the entire layer of atmospheric precipitation. Due to the large

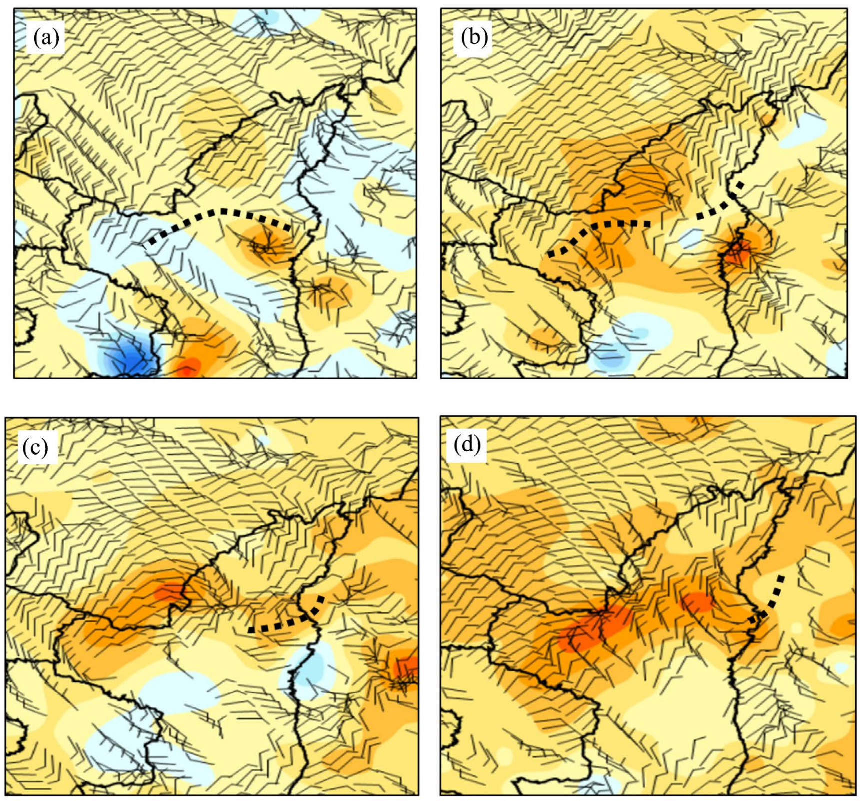


Figure 3. Sea level wind field and 1 hour transformer. (a) 16:30; (b) 17:30; (c) 18:30; (d) 19:30 (red is positive pressure, blue negative pressure, interval 1 hPa).

amount of precipitation in the early period of northern Shaanxi, the water vapor content of the local atmosphere is relatively high. The atmospheric precipitation in the Yulin area from 14:00 to 20:00 is greater than 40 kg·m^{-2}, moving eastward with time. The center increased from 45 kg·m^{-2} to over 47 kg·m^{-2}. The significant increase in atmospheric precipitation (shown in **Figure 4**) corresponds to the location of the short-term heavy precipitation area, and there are no other areas with increased precipitation. This indicates that the water vapor source of this process is mainly local water vapor accumulation. There is no obvious water vapor transport channel.

Next, the analysis of water vapor flux and its divergence shows that there is a distinct water vapor flux convergence zone at 850 hPa (**Figure 5**) above the Yulin at 14:00, and the most convergent center is located on the northwest side of the strong precipitation. It is 16 × 10^{-5} kg·m^{-2}·s^{-1}. By 20:00, the water vapor flux divergence rapidly increased to 50 × 10^{-5} kg·m^{-2}·s^{-1}, and the convergence center was located in the main precipitation area. 700 hPa also has obvious water vapor flux convergence in the strong precipitation area, and the convergence center also moves to the precipitation center with time, but the value is smaller than 850 hPa, about 20 × 10^{-5} kg·m^{-2}·s^{-1} (figure omitted). It can be seen that the small-scale small-scale water vapor flux convergence in the middle and lower layers also plays an important role in short-term heavy precipitation, and the water vapor flux convergence in the lower layer is more significant.

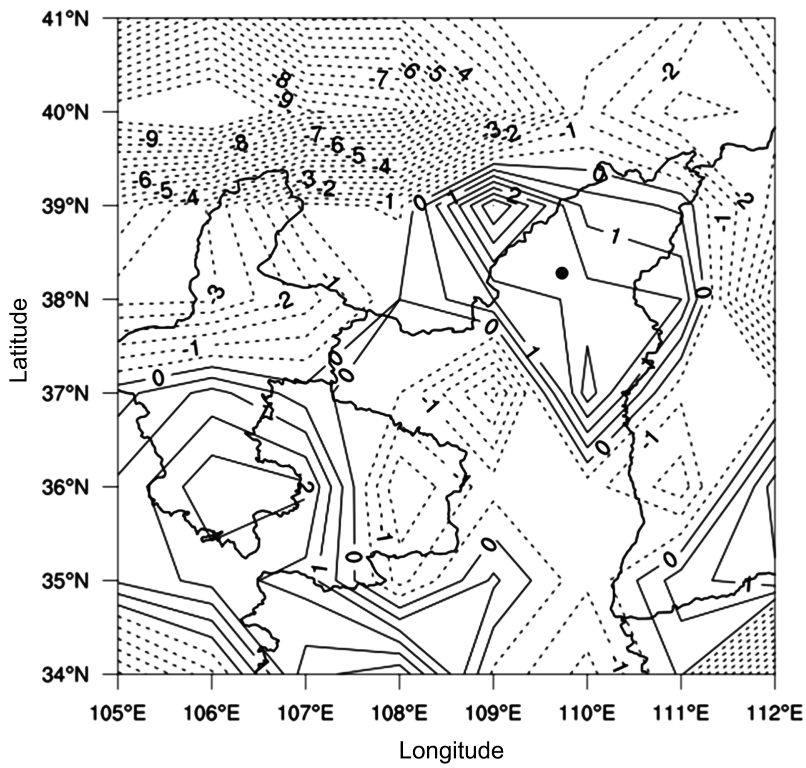


Figure 4. Change in atmospheric precipitation from 14:00 to 20:00 (unit: kg·m^{-2}, black spot is Yuyang District, Yulin City).

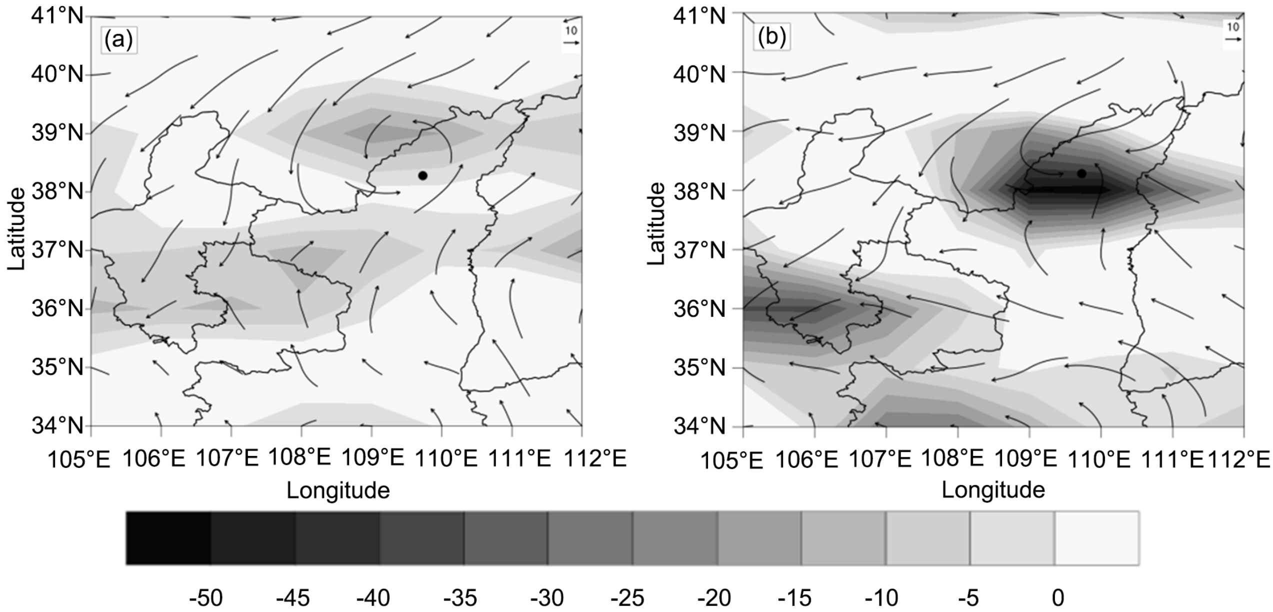


Figure 5. Water vapor flux (vector, unit: kg·m^{-1}·s^{-1}) and its divergence distribution (unit: 10^{-5} kg·m^{-2}·s^{-1}) (a) 14:00; (b) 20:00 (black spots are Yuyang District, Yulin City).

3.4. Satellite Cloud Image Analysis

It can be seen from the evolution of TBB satellite cloud map that most of Shaanxi was under the control of sub-high in 2008, and northern Shaanxi was at the periphery of the sub-high 588 line. There were weak clouds in the eastern part of Yulin and northeast of Yan'an. At 10 o'clock, the cloud group moved over the east of Shaanxi. At 11 - 12 (**Figure 6(a)**), several small-scale convective clouds began to appear in the southern part of Yulin, over Yan'an, and in the northern part of Guanzhong. At 14:00 (**Figure 6(b)**), the development of small-scale convective clouds increased and northeast. mobile. At 16:00 (**Figure 6(c)**), the cloud group continued to develop and strengthen, and the area further increased. The cloud group is located in most of Yulin and Yan'an, and the cloud center below −52˚C is located in the central and southeastern part of Yulin, west of Yan'an. At 17 o'clock (**Figure 6(d)**), the cloud area continued to increase. The cloud group in the west of Yan'an expanded westward, the cloud group in the east developed eastward, and the cloud group structure was dense. The strong center of −72˚C is located in the western part of Fuyang caused heavy precipitation in the Fuyang area. At the same time, there are convective clouds in the Dingbian area in the west of Yulin. At this time, the convective cloud group has the largest area and the strongest intensity. At 18 o'clock (**Figure 6(e)**), the temperature center area of the cloud cluster at −62˚C in the west of Yan'an and the eastern part of Yulin began to weaken, and the southern structure of the cloud cluster became loose. The cloud area at −62˚C in the northern part of Yulin began to increase, however, the strong center of −72˚C is still located in the western part of Fuyang, slightly moving westward, and continues to bring short-term heavy precipitation to the western part of Fuyang. At 1900, the cloud group in the western part of

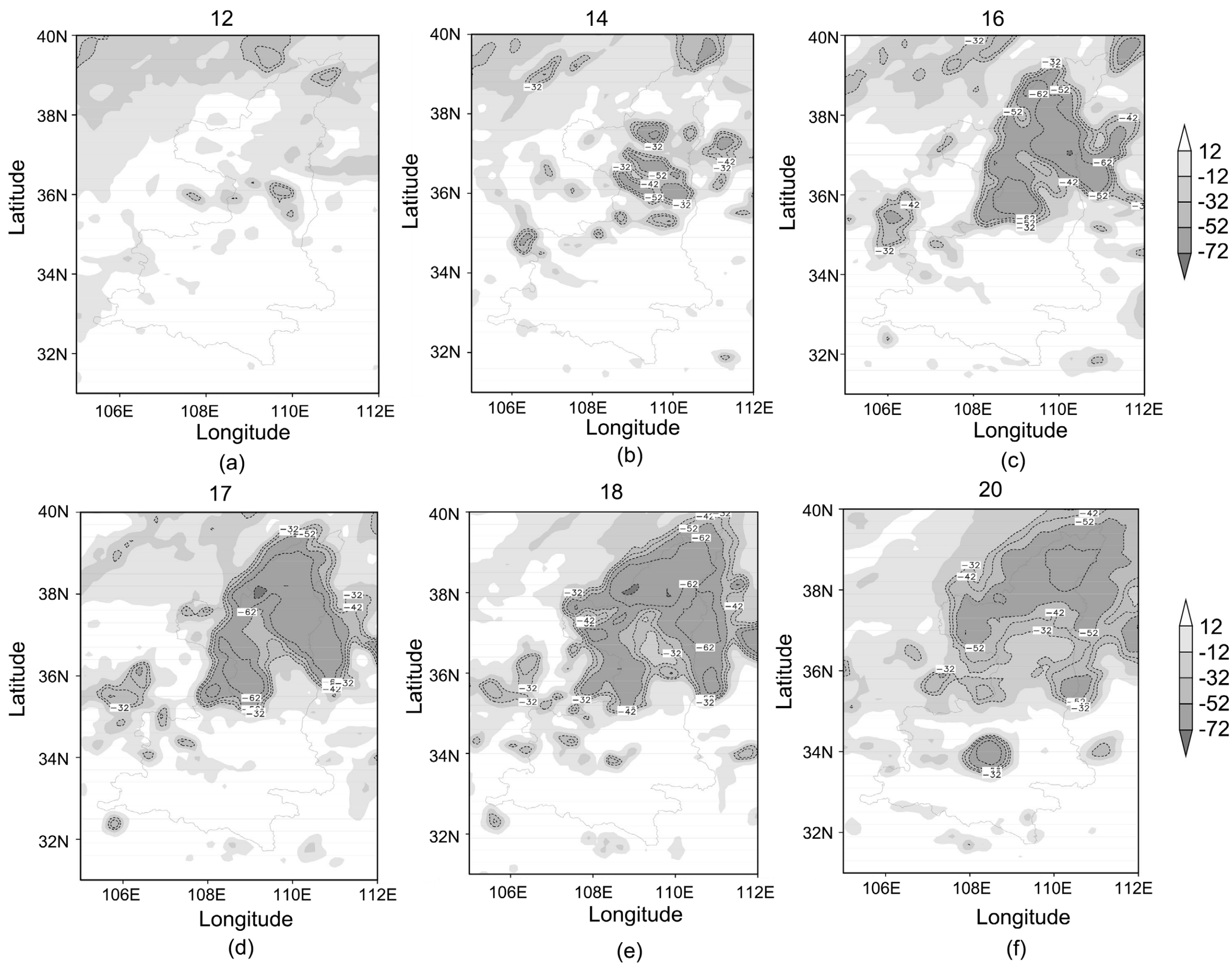


Figure 6. TBB cloud evolution ((a) is 12:00, (b) is 14:00, (c) is 16:00, (d) is 17:00, (e) is 18:00, (f) is 20:00).

Yan'an moved westward and rapidly weakened. The intensity of the cloud group moving eastward in eastern Yanan also weakened. The intensity of the cloud center in the northern part of Yulin is less than −62˚C, mainly located in the northern part of Yulin. The strong center continues to bring short-term heavy precipitation to the Fuyang area. As the cloud begins to weaken, the submerged airflow is mainly caused by thunderstorms. Therefore, the region has also brought short-term windy weather. At 20 o'clock (**Figure 6(f)**), the cloud group obviously turned to the east-west direction, and the strong center−62˚C area decreased, and then the cloud group rapidly weakened.

It can be seen that this is a small-scale convective cloud excited by the southwest warm and humid airflow in the process of moving along the ambient airflow to the northeast. In the process of short-wave trough, short-term strong precipitation and strong winds in the Yulin area are caused. Strong convective weather.

3.5. Radar Monitoring Analysis

The strong precipitation in Yulin City mainly occurs at 17:00-19:00, corresponding to the combined reflectivity. It can be seen that there are strong echoes above 45 dBZ in Yulin City during this time period. 16:11-16:30 has a strong echo development above 60 dBZ. A multi-monomer echo zone in the northeast-southwest direction is formed over the Yulin at 16:30, and a strong convective echo is embedded in the echo zone. At 17:12, as the northeast of the echo zone moves, it can be found back. Even if the echo area above 45 dBZ is not large, it continues through the Yuyang District. Over the sky, it caused 16:00-17:00 Menglin Bay Township in Yulin, an hour of 66.3 mm, 17:00-18:00 Yulin City 66.2 mm, and a central square 62.7 mm short-term heavy precipitation.

According to the radial velocity of the elevation angle of 0.5˚, the wind field near the ground level in the Xiangyang District is rotated from the height of 17:25 to 18:00, and there is warm advection. The circle on the 17:25 is able to see the development of the convergence zone. The height is about 1.4 km, and the convergence angle is presented at different elevation angles, indicating that the vertical rise condition is very favorable and the convection is developed. It is worth noting that the positive and negative velocity zones in the circle all have velocity ambiguity, and after de-blurring, they can reach above 18 m/s, which further indicates that the wind field in the convergence zone is very strong, and the distance from the radar is very close. At about 1.4 kilometers, it indicates that there is a short-term wind. The live show shows that there is a short-term wind of 20.8 m/s in the central square of Xiangyang District from 17:00-18:00. At 17:55, the convergence area continued to move closer to the radar station, so that the convergence of the lower layer was strengthened and the convection continued to develop until the 19:00 convergence zone gradually moved to the northeast, leaving the Yuyang District, and the wind stopped.

4. Conclusion

Thunderstorms cause the sinking airflow to form a cold pool on the ground. The degree of temperature reduction in the cold pool is directly proportional to the magnitude of short-term heavy precipitation, and the terrain also plays an important role in the formation of extremely short-term heavy precipitation.

This process occurs in the periphery of the subtropical high, and the strong convective weather caused by short-wave disturbances provides a dynamic condition for the cut of the middle and lower layers into short-term rainstorms. The warm and humid transport around the subtropical high provides water vapor, energy and Unstable stratification. The ground convergence line is the triggering and maintenance mechanism of short-term heavy precipitation, and the positive pressure-variable area represents the penetration of cold air, which is better than the strong precipitation area.

The continuous local precipitation in the previous period provided sufficient water vapor source for this short-term heavy precipitation. The significant increase in the whole-layer precipitation is just a short-term heavy precipitation area; the small-scale water vapor flux convergence centers in the middle and lower layers basically coincide with the strong precipitation centers. The center also has a good correspondence, which can be used as a forecast indicator for short-term heavy precipitation.

The small and medium-scale convective cloud clusters develop and merge along the process of moving the ambient airflow to the northeast, and the moving direction and development direction are basically in a straight line, thus forming a "train effect", which leads to the local short-term heavy rain in this process.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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