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Analysis of a Large-Scale Strong Convective Weather under a Weak Water Vapor Condition in Shanxi, China in Spring

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Abstract

This article uses NCEP 1˚ × 1˚ grid point reanalysis data, conventional meteorological observation data, FY2G satellite TBB data, radar combined reflectivity data, ground-encrypted automatic station observation data, etc., through the synoptic diagnostic analysis method for a comprehensive analysis of a large-scale underreporting of a strong convective weather process under weak water vapor conditions on the 13th April 2017. The results show that the severe convective weather process is affected by the short-wave disturbance in the northwesterly airflow, triggered by the uplift of the westerly trough, the mid-low shear line and the mesoscale front of the boundary layer in the dry northwest. The jet stream is also an important system for the development of this strong convective weather. In the case of weak water vapor and energy conditions, if there is strong dynamic uplift, vertical wind shear and large temperature differences, strong convection can still occur; the convection occurrence area corresponds to the high potential vorticity abnormal area. The movement speed and direction of the cloud cluster are also consistent with the movement of the high potential vorticity anomaly area; the potential vorticity anomaly will cause the cyclonic circulation to increase, and the upward movement will also increase, which is conducive to the development of strong convective weather. According to the position of the dew point front in the β mesoscale, the ground cold pool corresponds to the small value area of the convective cloud cluster TBB. The front of the cold pool is accompanied by a mesoscale ground convergence line, and the uplift is strengthened, which is conducive to the development and forward movement of thunderstorms; the outflow of the cold pool is guided by 700 hPa. When the wind direction is the same, the movement speed will increase, and the stronger the outflow, the faster the movement speed.

Keywords

Strong Convection, Mesoscale Boundary Layer Front, Potential Vorticity, Environmental Characteristics, Maintenance and Evolution

1. Introduction

Shanxi is located in North China, between 34˚34' - 40˚44' north latitude and 110˚14' - 114˚33' east longitude. It has a complex topography, a temperate continental monsoon climate, and many types of disastrous weather. Severe convective weather is one of the main disastrous weather in Shanxi. Severe convection is the disastrous weather caused by the strong development of atmospheric convection. It has the characteristics of strong suddenness, short duration, significant locality, and difficulty in forecasting. In my country's weather forecast business, severe convective weather mainly includes hail, thunderstorms, strong winds, short-term heavy precipitation and tornadoes.

In meteorology, Sun et al., (2016) are revealed the basic theories and concepts related to severe convective weather are introduced in detail, including thermal instability theory, dynamic instability theory and their analysis and application methods. Different severe convective weather phenomena correspond to different typical sounding characteristics, and have differences in thermal and dynamic structure on storm scale. An hour's precipitation of 20 mm or more is called short-term heavy precipitation; the instantaneous gale with wind >17.2 m/s that accompanies thunderstorm weather is called thunderstorm gale; In this case, thunderclouds develop strongly. The occurrence of solid precipitation is called hail, which can be divided into four categories according to its diameter (d). If 5 mm ≤ d < 20 mm, it is medium intensity hail; if 20 mm ≤ d < 50 mm, it is strong hail and if d ≥ 50 mm, it is extremely strong hail. Corfidi & Meritt (1996) refer to a procedure for operationally predicting the movement of the mesobeta-scale convective elements responsible for the heavy rain in mesoscale convective complexes is presented. Many meteorologists at home and abroad have conducted a lot of analysis on strong convective weather. Zhao et al. (2017) showed that the strong convective weather occurred under the circulation background of northwest airflow behind the vortex. The low-level shear line, surface convergence line and dry line were the main triggering factors of the strong convection weather. The instability of atmosphere increased due to invasion of the lower level cold air, which promoted the vertical upward motion and provided favorable conditions for the development of strong convective weather. Since strong convective weather in Shanxi usually occurs in summer, previous studies have focused on the analysis of strong convection in summer.

The temperature in Shanxi in April is generally low, the atmosphere is unstable and weak, the energy is insufficient, and the water vapor conditions are poor. Therefore, the probability of strong convective weather in Shanxi in April in spring is small, so it is easy to be ignored and underreport such weather processes Happening. However, once strong convection occurs in spring, it often has the characteristics of strong suddenness, wide range, and high intensity, which has a significant impact on spring agriculture, social activities, and personnel safety. Therefore, this article failed to report a large-scale severe convective weather on April 13, 2017 in Shanxi Province.

Through the weather diagnostic analysis method, the NCEP 1˚ × 1˚ grid was used to reanalyze data, conventional weather observation data, FY2G satellite TBB data, and radar combination. Reflectance data, ground-encrypted automatic station observation data, sounding data, etc., based on the three elements of convection formation (uplift conditions, water vapor conditions, and unstable conditions) to study its occurrence and development mechanism. The results can provide a reference for reducing the rate of under-reporting of strong convection in spring and improving the ability of meteorological disaster prevention and mitigation. At the same time, it is also of great significance for good spring agricultural meteorological services and social activities security services.

2. Data and Method

2.1. Data

This article uses NCEP 1˚ × 1˚ grid point reanalysis data from the NCEP, USA, conventional meteorological observation data, FY2G satellite TBB data, radar combined reflectivity data, ground-encrypted automatic station observation data come from the Shanxi Meteorological Bureau, China.

2.2. Method

This paper mainly uses synoptic diagnostic analysis methods (Zhu et al., 2007; Ding, 2005). Dynamic meteorology is a discipline that applies the laws of physics to study the dynamic and thermal processes of atmospheric motion and their mutual relations, and theoretically discusses the laws of atmospheric circulation, weather system and other atmospheric motion evolution. It's a branch of atmospheric science. Air is a fluid, and if fluid mechanics deals with the general laws of fluid motion, then dynamic meteorology deals with the special laws of air fluid motion that occur on a rotating earth and whose density decreases with height (Aylward & Dye, 2010; Chen et al., 2017).

3. Results and Analysis

On April 13, 2017, the Shanxi Meteorological Observatory's service forecast was "cloudy and cloudy in the north and central, with showers or light rain in some areas; cloudy and sunny in the south". In fact, there was a large-scale strong convective weather in Shanxi Province that day (**Figure 1(a)**), There were 69 stations of thunderstorms from 08 to 20:00; thunderstorms occurred at 36 stations in Datong, Xinzhou, Changzhi, and Jinzhong from 11 to 17: The maximum wind speed occurred at Xiangyuan station at 16:27 at 26 m/s; There were small

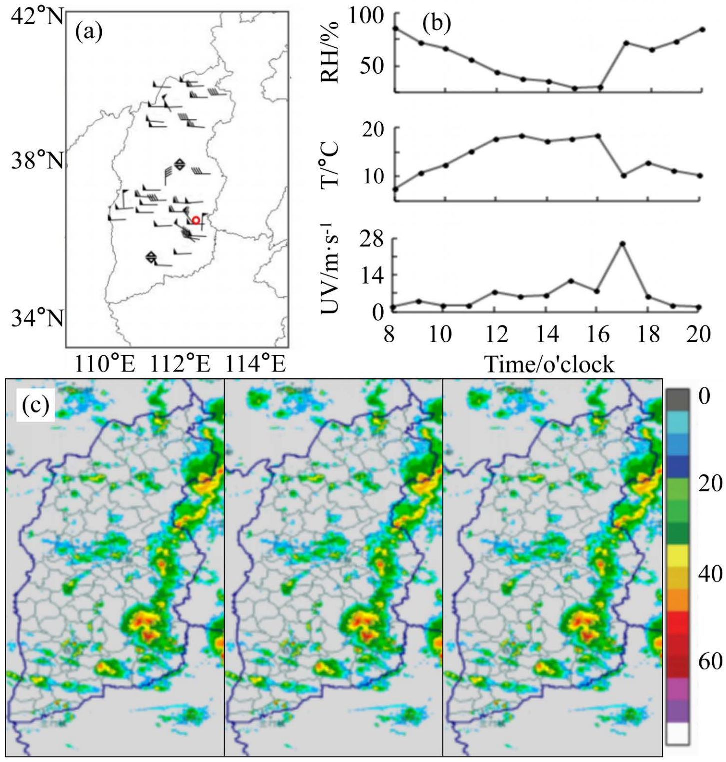

Figure 1. The actual distribution of strong convection on April 13, 2017 ((a), Xiangyuan), the change of elements of a single station at Xiangyuan station over time (b), and the combined reflectivity factor puzzle of 14 radars around Shanxi at different times ((c), unit: dBZ).

hailstones in Yangqu and Yicheng stations, with a maximum diameter of 10 mm. At the same time, there were showers in 69 stations in the province with a rainfall of 0.2 - 5.5 mm. From the changes of the elements of the single station at Xiangyuan Station over time (**Figure 1(b)**), it can be seen that when strong convection occurs, the station has a steep rise in relative humidity (RH) (affected by weak precipitation), a sharp drop in temperature (T) and wind speed (UV) Phenomenon such as rapid increase, the turning changes of meteorological elements have obvious suddenness.

On the radar echo (**Figure 1(c)**), it appears as two weak convective linear echoes, located in the northwestern part of Shanxi and the western part of the central part, which developed and merged into a north-south linear echo during the rapid eastward movement. The linear echo continued to move eastward, and the echo band moved to eastern Shanxi at 16:30, and the strong convective weather basically ended. The most obvious characteristics of the radar echo during the severe convective weather are: 1) The intensity is weaker than 35 - 40 dBZ, only partly greater than 45 dBZ, and the water vapor is not sufficient, so there is no short-term heavy precipitation, only showers; 2) It presents obvious linear echo, which is organized, and convection lasts for a long time, which brings thunderstorms and winds and small hail.

In summary, this process occurred under weak water vapor conditions, mainly thunderstorms and thunderstorms and gales, not accompanied by short-term heavy rainfall, and a long-lasting large-scale spring strong convective weather process. Then, according to the three elements of convection formation (water vapor conditions, uplift conditions, and instability), how did the strong convective weather process occur, evolve, and maintain under poor water vapor conditions? Below we will conduct a detailed analysis of its occurrence and development mechanism.

3.1. Influence System Analysis

At 08:00 on the 13th, 500 hPa (Figure 2(a)) in the mid-high latitudes of Asia and Europe were controlled by the northwest airflow. There were shortwave disturbances in central Inner Mongolia and eastern Shaanxi respectively, and the cold advection after the short wave trough was weak. On the ground map (Figure 2(b)), the center of cold high pressure is located to the west of Beihu Lake, and the cold high pressure and cold front are generally northerly. Shanxi is controlled by a weak pressure field and there is no dense zone of isobars. 700 hPa and 850 hPa have a north-south shear line corresponding to the 500 hPa groove line respectively (the figure is omitted). Based on the above analysis that day, Shanxi was affected by weak cold air and there will be weak precipitation weather in the future, and the occurrence of strong convective weather was not considered.

During this strong convective weather, there was an obvious dry northwest jet stream from eastern Xinjiang to eastern Shaanxi after the westerly trough, with a maximum wind speed of 24 m/s, accompanied by obvious small dew point and

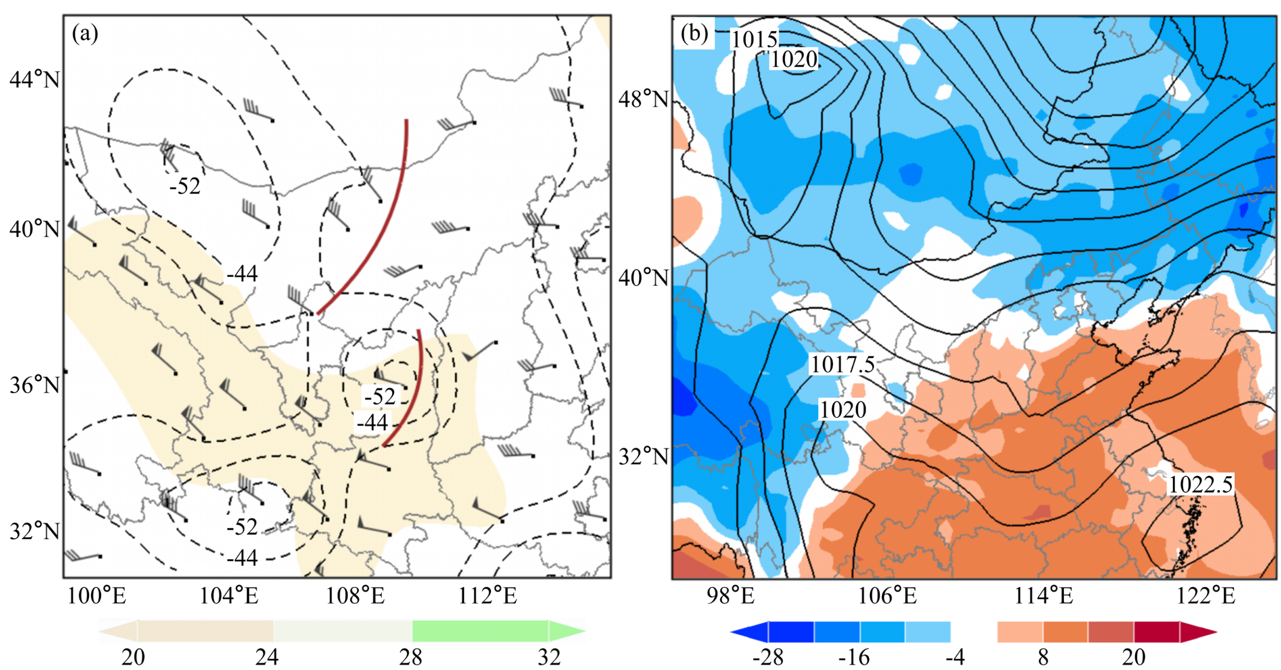

Figure 2. The 500 hPa situation diagram at 08:00 on April 13, 2017 ((a) Black dotted line denotes dew point, unit: ˚C, shadow denotes wind speed, unit: m/s) and the ground situation figure ((b) Black solid line denotes isobaric line, unit: hPa and shadow denotes dew point, unit: ˚C).

large temperature dew point difference areas **Figure 2(a)**), the minimum dew point reaches −53˚C, and the maximum temperature dew point difference is 30˚C. Corresponding to 700 hPa and 850 hPa, there is also a dry northwesterly high wind speed zone behind the upper shear line, and a cold center corresponding to it (picture omitted). During the rapid eastward movement of the Middle Northwest Jet, it will not only cause dry air intrusion, but also cause strong vertical wind shear and momentum downward transmission, which are conducive to the development, organization and maintenance of strong convective weather. At the same time, there is a clear trunk line in the central and eastern part of Shaanxi at 850 hPa (the figure is omitted), corresponding to the obvious dew point front in the upper reaches of Shanxi, and a clear dry area behind the front (**Figure 2(b)**). The future eastward movement of the two will affect Shanxi. Trunk lines and ground dew point fronts are mesoscale systems that are easily overlooked in forecasting, but they are actually important triggering mechanisms for strong convective weather.

For the influence of the mesoscale front in the boundary layer, analysis shows that the weather-scale trigger system that caused this large-scale strong convective weather process is the westerly trough and the mid-low altitude shear line, while the ground dew point front and trunk line in the boundary layer are the meso-scale trigger mechanism.

In the actual atmosphere, in addition to large-scale fronts, there are boundary layer mesoscale fronts with smaller scales and shorter lifetimes. They are closely related to the non-geostrophic deformation of the background field, and are also related to the dynamic and thermal characteristics of the underlying surface in local areas. The unevenness is related. Mesoscale fronts have an important impact on local weather changes and are an important research object for short-term forecasting. In convective weather forecasting, trunk lines are regarded as an important convective trigger mechanism (Shou, 2016). Trunk is also called trunk front or dew point front. In this article, the 850 hPa trunk line is called the trunk line, and the ground trunk line is called the dew point front.

At 14:00 there are 4 distinctly different-scale Td line dense areas in Shanxi (**Figure 3(a)**), corresponding to 4 different-scale ground dew point fronts. The α mesoscale dew point front at the junction of Shanxi and Shaanxi provinces. The largest dew point difference on both sides of the α mesoscale dew point front is 14˚C, and the largest dew point difference on both sides of the β mesoscale dew point front is 6˚C.

The trunk line is a warm and dry cover formed by the sinking airflow at the back of the low-pressure tank to form a sinking inversion temperature. It is a discontinuous line of humidity in the horizontal direction. One side is warm and dry, and the other side is wet and cold. Use 14 o'clock NCEP 1˚ × 1˚ Lattice point reanalysis data 1 is taken along the 37˚N vertical section of the dew point and temperature advection (**Figure 3(b)**). It can be seen that the middle and low layers of 108˚E (below 700 hPa) are dew point troughs and the sky above 117˚E is dew point ridge. There is a clear boundary between dry and wet between

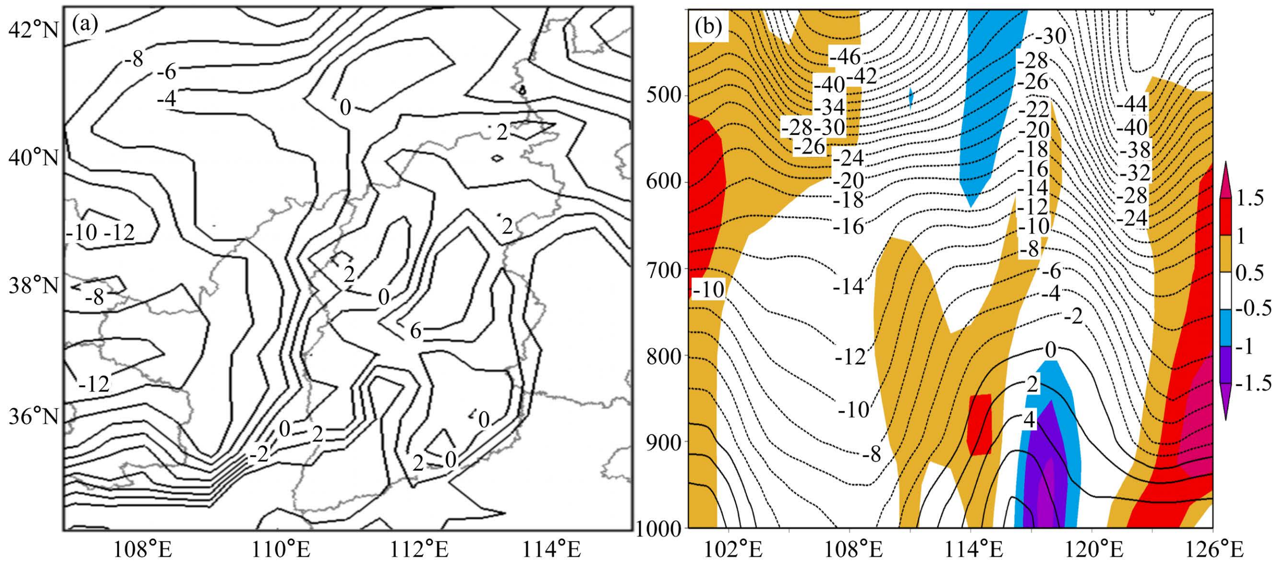

Figure 3. The contour map of the ground dew point at 14:00 on April 13, 2017 ((a) unit: ˚C) and the vertical section of the dew point and temperature advection along 37˚N ((b) the ordinate is the height, unit: hPa, the black contour is dew point, unit: ˚C, the shadow is temperature advection, unit: ˚C/s).

111˚E and 114˚E. At the same time, the dry zone corresponds to the positive temperature advection zone, that is, the dry zone corresponds to the warm advection, and the wet zone corresponds to the negative temperature advection zone, that is, the wet zone corresponds to the cold advection. There is a clear boundary between warm and dry and wet and cold.

3.2. Vorticity Analysis

Potential vorticity (PV), as a physical quantity that comprehensively reflects the dynamics and thermodynamic properties of the atmosphere, is a very useful tool for studying weather phenomena in the baroclinic atmosphere (Tao et al., 2012). According to the principle of potential vorticity conservation, the vorticity of the high potential vorticity airflow from the stable environment at the upper level will increase after reaching the unstable environment at the lower level, which will promote the occurrence and development of cyclones, which is conducive to the formation of heavy rain or strong convective weather. The unit of potential vorticity is PVU, 1 PVU is 10^{-6} $m^2 \cdot s^{-1} \cdot kg^{-1} \cdot K$ (Shou, 2010; Li et al., 2019).

There are many methods for potential vorticity analysis, the most commonly used is the isopotential vortex analysis method (IPV), that is, the isopotential vortex line is analyzed on the isopotential temperature surface (isoentropic surface). The basic expression of isentropic potential vorticity (IPV) is (Guo et al., 2010).

Isentropic potential vorticity IPV is not only conserved in adiabatic frictionless atmosphere, even when there are non-conservative effects of friction and dynamic wave drag or non-adiabatic heating, the concept of IPV is still applicable. On the isentropic surface, the evolution of atmospheric disturbances can be tracked by tracking the potential vortex anomaly area (i.e., the high or low value area of the potential vortex). High IPV corresponds to cyclonic circulation, and low IPV corresponds to anticyclonic circulation. The isentropic surface is generally taken as the isothermal surface that coincides with the top of the troposphere in the polar front. The northern hemisphere is generally 315 K in winter and 325 K in summer. In this paper, 320 K is used as the isentropic surface.

This paper uses NCEP 1˚ × 1˚ grid point reanalysis data to give the potential vorticity distribution on the 320 K isentropic surface from 08:00 to 20:00 on April 13th. It can be seen from **Figure 4(a)** that: For areas greater than 3.5 PVU, the high potential vortex center is located in the middle of Inner Mongolia to the northwest of Shanxi, with a center value of 5.0 PVU, and the 4.0 PVU contour is located in the west of central Shanxi. The area from eastern Inner Mongolia to Liaoning and Jilin has obvious low-potential vorticity areas with a large scale. The center of the potential vorticity is located in eastern Inner Mongolia with a center value of about 1.0 PVU. At 14:00 (**Figure 4(b)**), the high potential vorticity moves eastward to the south, and the center of the potential vorticity is located at the junction of Shanxi, Inner Mongolia and Hebei. The central value decreases slightly to 4.5 PVU. At 20 o'clock (picture omitted), the high potential vorticity center continued to weaken and moved east out of Shanxi, reaching the border between Hebei and Liaoning. From 08 to 14 o'clock, due to the blocking of the low potential vortex zone in front of the high potential vortex, the high potential vortex zone moved slowly and slightly southward. From 14 to 20 o'clock, due to the weakening of the low potential vortex zone, the high potential vortex moved quickly eastward, and the high potential vortex moved faster and slightly centered. Along with the movement of the high potential vortex region, it represents the movement trajectory of the dry and cold air in the middle and upper troposphere. Under the action of the northwest wind, the high potential vortex is transported eastward and downward, and the high-altitude low vorticity develops eastward and southward, which caused Shanxi's Strong convective weather process dominated by thunderstorms and gales.

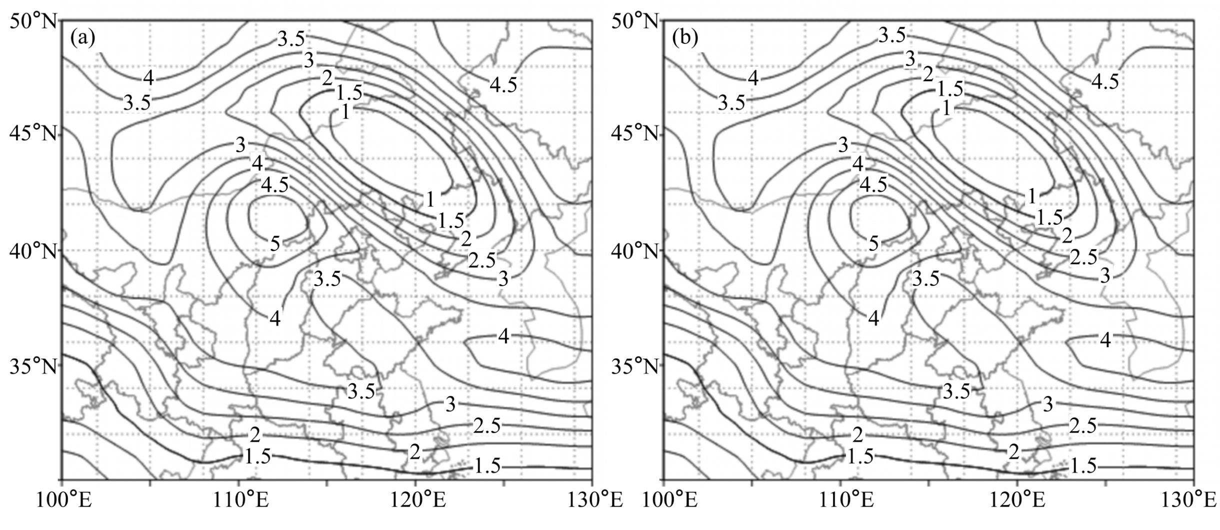

Figure 4. The 320 K isentropic potential vorticity distribution map at 08:00 (a) and 14:00 (b) on April 13, 2017 (unit: PVU).

The contour of PV = 1.5 PVU usually represents the boundary between the low tropospheric atmosphere from low latitudes and the high potential vortex atmosphere from the upper troposphere and stratosphere at high latitudes. In the area north of the subtropical jet, PV = 1.5 PVU, etc. The potential vorticity surface is close to the actual tropopause of the atmosphere, which is generally called "dynamic tropopause". The potential vorticity disturbances in the upper troposphere or stratosphere are transmitted downward, which can cause the development of cyclones in the lower troposphere and on the ground. The area greater than 1.5 PVU or 2.0 PVU in the troposphere is called potential vorticity anomaly.

At 14:00 on the 13th, along the vertical section of the 114˚E potential vorticity temperature (Figure 5), it can be seen that the high potential vorticity area between 35˚N and 40˚N extends downwards, presenting a funnel shape, presenting a high potential vortex. In the abnormal area, the high potential vortex center is above 250 hPa, and 1.5 PVU extends downward to below 350 hPa. Since the stratosphere is generally called the "high potential vortex reservoir", corresponding to the high potential temperature zone, the 1.5 PVU dynamic tropopause decreases, and the corresponding regional isopotential temperature becomes denser and will increase. If the stingy gas in the high-potential vortex column area quickly travels along the isopotential line from the upper layer to the lower layer and to the south, the isothermal line density in the gas block will decrease, and the static stability will decrease. According to the principle of

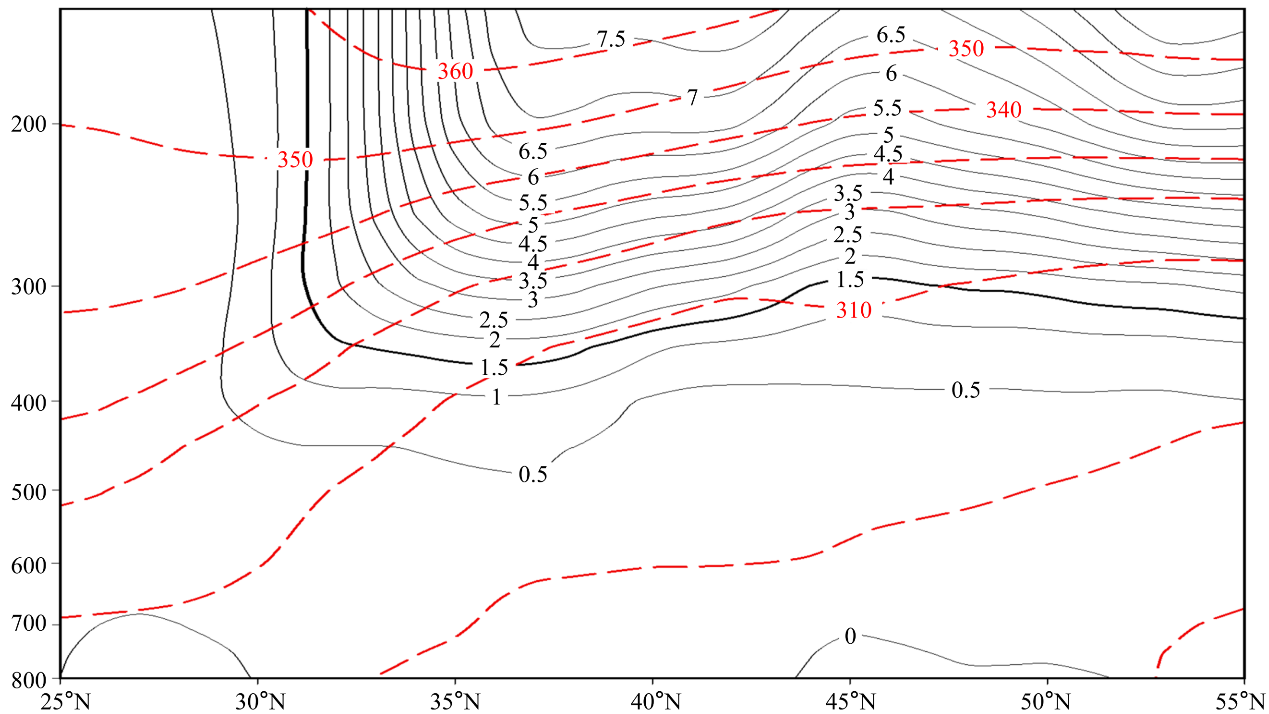

Figure 5. Vertical profile of the potential vorticity temperature along 114˚E at 14:00 on April 13, 2017 (The abscissa is latitude; the ordinate is isobaric surface, unit: hPa; the black solid line is Potential vortex (PV), unit: PVU; the red dotted line is potential temperature (θ), unit: K).

isentropic potential vorticity conservation, the rotation of dry and cold air in the high potential vorticity area should be strengthened, and the positive vorticity should be strengthened, causing the air mass to contract in the horizontal direction and elongate in the vertical direction, that is, the cyclonic circulation is strengthened, and the upward movement is strengthened. This condition is conducive to the occurrence and development of strong convective weather.

The cold air in this strong convective weather mainly comes from the upper and middle troposphere. The high potential vorticity representing the cold dry air moves eastward and downward under the action of the northwest wind, which increases the potential vorticity in the middle and low troposphere, reduces the static stability and reduces the positive vorticity. Intensified, so a large-scale strong convective weather appeared in the middle and low-level potential vortex increase area.

3.3. Analysis of Mesoscale Environmental Characteristics

From the perspective of forecast services, it is more meaningful to analyze the mesoscale environmental characteristics before the occurrence of strong convection, that is, the potential analysis of strong convection. The trigger time of strong convection in the north-central part is morning, and the south part mainly occurs in the afternoon. Therefore, according to the principle of time proximity, the environmental field characteristics at 08 o'clock are mainly studied in the north, while for the central and southern parts, the environmental field characteristics at 14 o'clock are more indicative. Since the sounding data is only at 08 o'clock, in order to meet the analysis requirements, the data is analyzed again at 14 o'clock with NCEP $1^\circ \times 1^\circ$ grid point.

Unstable conditions are the basic conditions for the formation of convective weather, and instability is divided into thermal instability and dynamic instability. As shown in **Table 1**, there is no obvious convective effective potential energy (CAPE) on the Taiyuan sounding (T-logP) at 08. The Dongsheng and Yan'an soundings in the upper reaches of Shanxi show that the convective effective potential energy is almost 0, but has a certain downward Shen effective potential energy (DCAPE), respectively, 316.5 J/kg, 545.4 J/kg. The ground temperature and dew point temperature at 14 o'clock were used to correct the convective effective potential energy of the three radiosonde stations. After the correction, there was a certain amount of convective effective potential energy. The energy

Table 1. Characteristics of mesoscale environmental conditions at 08:00 on April 13, 2017.

Station	CAPE/J·kg^{-1}	CAPE (Corrected)/J·kg^{-1}	DCAPE/J·kg^{-1}	K-index/°C	$\Delta T_{(850-500)\text{hPa}}$/°C	0 - 6 km Vertical wind shear/m·s^{-1}
Taiyuan	0	490.2	0.1	29	27	18
Dongsheng	1.1	813.7	316.5	25	31	18
Yanan	0	314.1	545.4	12	29	20

value of Dongsheng station reached 813.7 J/kg. It can be seen from the distribution of convective effective potential energy at 14:00 that the CAPE value in the southeastern part of Shanxi is about 200 - 400 J/kg, which has a certain amount of convective effective potential energy (**Figure 6(a)**).

The K index focuses on reflecting the 700 - 850 hPa humidity profile in the lower troposphere. The greater the humidity, the greater the K. At 08 o'clock, the K index of the three stations in Taiyuan, Dongsheng, and Yan'an are all less than 30˚C, and as the middle layer dry air behind the shear line moves eastward, the K index will continue to decrease in the future. At 14:00, the K index in Shanxi was ≤24˚C, and the K index in the northern and central-southern western regions was ≤20˚C. The K index has been small during this process (**Figure 6(a)**).

The temperature difference between 850 hPa and 500 hPa can reflect the stability of the atmosphere. The larger the temperature difference, the more unstable it is, and the more unstable convection is likely to occur. At 08 o'clock, the temperature difference between the three radiosonde stations including Taiyuan was the maximum 31˚C, which was quite large. By 14:00, the temperature difference in the province has increased, with a temperature difference of ≥34˚C, and atmospheric instability has increased (**Figure 6(a)**).

For Dynamic instability analysis, vertical wind shear is a key factor for the development and maintenance of convection. Strong vertical wind shear is conducive to the organization of thunderstorms and prolongs the life of thunderstorms. Generally, strong thunderstorms and gales usually develop in a strong vertical shear environment. At 08 o'clock, the 0 - 6 km vertical wind shear at the Taiyuan and Dongsheng stations were both 18 m/s, and the Yan'an station reached 20 m/s, which is a strong vertical wind shear. At 14:00, the vertical wind shear in the central part of the north decreased, but the magnitude of the wind shear in the south was 9 - 18 m/s, which was a medium-intensity vertical wind shear map (**Figure 6(b)**). It is still conducive to the occurrence and development of strong convection.

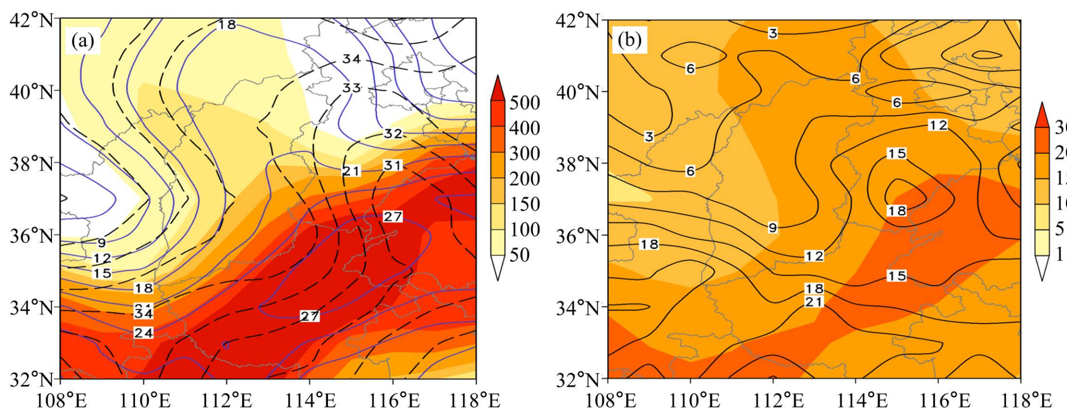

Figure 6. Thermal instability distribution map at 14:00 on April 13, 2017 (a) (CAPE (shaded, unit: J/kg), K index (blue solid line, unit: ˚C), ΔT (850 - 500) (black Dotted line, unit: ˚C)), distribution map of other elements (b) (PW (shaded, unit: mm), 0 - 6 km vertical wind shear (black solid line, unit: m/s)).

Water vapor conditions are also the basic conditions for the formation of convective weather. Affected by the weak precipitation at night on December 13th, at 8 o'clock on the 13th, Taiyuan sounding showed that the entire layer above Shanxi had better relative humidity conditions, with a low-level dew point of 7˚C, and local water vapor conditions, but because there was no water vapor transport, the overall water vapor conditions were poor. At 14:00, the whole layer of Shanxi's atmospheric precipitable water (PW) was only 10 - 20 mm, which was extremely low (**Figure 6(b)**), and the water vapor conditions were still poor.

The above analysis shows that in this severe convective weather process, the water vapor conditions and energy conditions (CAPE and K index) in the north central part of the northeast were poor before the strong convection was triggered. However, under the premise of dynamic uplift conditions and trigger conditions, Convection can still occur under strong vertical wind shear and large temperature differences. While in the south, although the overall water vapor conditions are poor, resulting in a small overall K index, the energy condition CAPE improves, the vertical wind shear and the large temperature difference are large, and convection occurs.

Judging from the above conditions, poor water vapor conditions are an important reason for the absence of short-term heavy precipitation in this process, and also the reason for the weak radar echo intensity. In addition to the basic conditions required for the occurrence of convection, the occurrence of large hail requires large convective effective potential energy (CAPE), strong vertical wind shear and a certain amount of dry and cold air. Although there is strong vertical wind in this process Shear and the invasion of dry and cold air, but there is no large convective effective potential energy, so there is no large hail, and only some small hail appears in some areas (Hou et al., 2018).

3.4. Evolution and Maintenance of the Mesoscale Convective System

The cognition of the strong convective weather process mainly relies on the analysis and discussion of small and medium-scale weather systems. This paper uses the distribution and change of the TBB value of the satellite FY2G cloud top brightness temperature to express the evolution characteristics of meso-scale convective system during the strong convective weather process.

From the perspective of cloud cluster intensity changes (**Figure 7**), at 11 o'clock on the 13th, precipitation cloud clusters basically moved out of Shanxi. At the same time, new convective cloud clusters a, b, and c were formed in central Inner Mongolia, eastern Hetao, and northwestern Shanxi, respectively, which were higher than their highs at 08 o'clock. Corresponding to the abnormal area of the vortex area (**Figure 4**), the area is small and the TBB value is large. Later, it develops eastward. At 13:00, the cloud cluster develops to the mature stage, and cloud clusters a and b continue to develop and the area increases. The cloud top TBB value continues Decrease, and a new convective cloud cluster d is

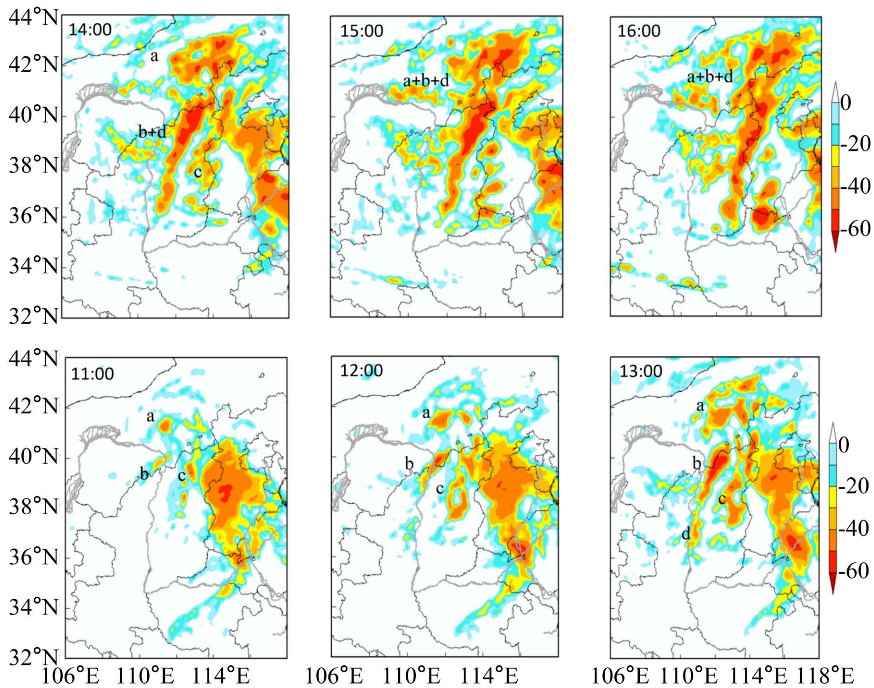

Figure 7. The TBB distribution map of Genting bright temperature on April 13, 2017 (Unit: ˚C).

formed in the southwest of Shanxi. After 14:00, the cloud clusters a, b, and d developed in the process of moving eastward and gradually merged into a continuous elongated convective cloud cluster, corresponding to the position of the ground dew point front (**Figure 3**) at 14:00, and was cut in a strong vertical wind. Under the effect of the change, the cloud appears to be clearly organized, and the cloud body is compact, reaching a mature stage at 15 o'clock, the minimum value of TBB reaches −57˚C, the TBB gradient at the edge of the cloud becomes larger, and the cloud top height develops to 150 hPa, and gradually moves out of Shanxi after 17:00. C cloud group has basically moved out of Shanxi after 14:00. Although the cloud body was continuously elongated >3 h during this process, the convective cloud cluster in this process did not belong to the MβECS in the mesoscale convective complex because the area of >−52˚C was less than 30,000 km^2 (Wang, Chen, Zhang et al., 2013).

From the perspective of cloud movement evolution (**Figure 7**), from 11 to 13 o'clock, the convective cloud cluster is smaller, but the moving speed is slower. From 14 to 16 o'clock, the convective cloud cluster merges and strengthens, but the moving speed increases, and the moving direction is basically easterly, slightly northward. The movement of the thunderstorm is consistent with the movement speed and direction of the high potential vortex anomaly area (**Figure 4**). So what is the reason that the convective cloud cluster continues to develop and move faster in the process of movement?

For maintenance of the mesoscale convective system, in the process of strong convection, weak precipitation occurs. Affected by the evaporation and heat absorption of weak precipitation in the dry air, the air becomes cold, which will accelerate the sinking of the dry air and diverge on the ground to form a cold pool density flow. During the evolution process, it was found that affected by weak precipitation, a clear cold pool appeared in the central part of Inner Mongolia corresponding to cloud cluster a at 11 o'clock (picture omitted), and the cold pool moved slightly eastward at 12 o'clock. At the same time, a cold pool appeared in the northwest of Shanxi at a cold pool to the south. The weak infiltration of cold air currents continue to be affected by weak precipitation at 13:00. A clear cold pool appears in the northwest of Shanxi. A westerly wind appears in the large temperature gradient area at the front of the cold pool. The outflow boundary interacts with the weak southerly wind in the front. Convergence in the front of the system is strengthened, forming an updraft, causing a meso-scale convergence line on the ground to appear in the front, pushing the system to move to the high temperature area, and the thunderstorm matrix moves to the direction of the convergence line. At 14 - 16, the cold pool continued to strengthen and merged with the cold pool at a during the eastward shift. The area increased (Figure 8), the front westerly wind increased, the front mesoscale convergence line strengthened, and the mesoscale convergence line merged. The distance between the cold pools is reduced, and the closer the convergence line is to the thunderstorm, the thunderstorm can be maintained for a longer period of time. At the same time, the thunderstorm can maintain a more consistent shape, so the convective cloud cluster will gradually become larger and move forward. This self-sustaining and self-feedback mechanism is conducive to the continuous maintenance and development of thunderstorms under poor energy conditions

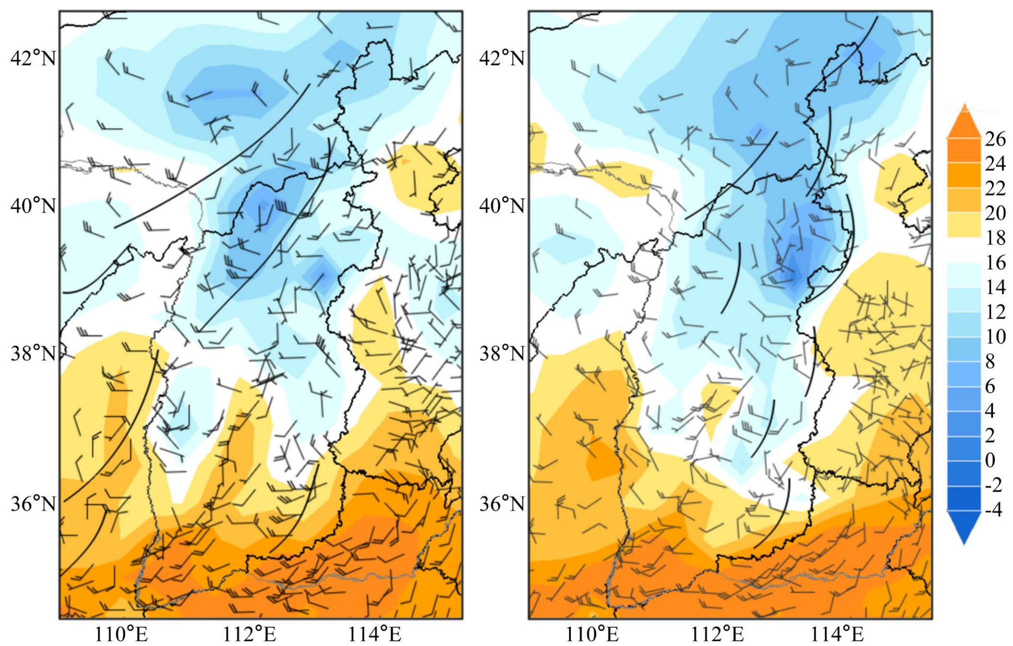

Figure 8. Wind field and temperature distribution map of automatic ground station on April 13, 2017 (14:00 (a), 16:00 (b)) Temperature T (shadow, unit: ˚C), mesoscale convergence line (black solid line).

and water vapor conditions. The analysis found that the cold pool always corresponds to the minimum cloud top brightness temperature TBB area (**Figure 7**) during this process, and the ground mesoscale convergence line is also located at the front of the convective cloud cluster.

Due to the strengthening of cloud development and the strengthening of the ground cold pool at 14 - 16, the outflow of the cold pool was strengthened, and the westerly wind speed increased significantly, and was consistent with the direction of the 700 hPa guided wind (westerly wind), so the speed of thunderstorms moved faster.

4. Conclusion and Discussions

This paper analyzes a large-scale underreporting of strong convective weather under weak water vapor conditions. From the aspects of influence system, potential vorticity, mesoscale environmental field characteristics, and the evolution and maintenance of convective system, the mechanism of its occurrence and development is studied, and the following conclusions are obtained. This severe convective weather process is affected by the short-wave disturbance in the northwestern airflow, and is triggered by the uplift of the westerly trough, the mid-low shear line, and the mesoscale front (main line and dew point front) of the boundary layer; The sexual northwest jet is also an important system for the development of this strong convective weather (Shou et al., 2001).

In the case of weak water vapor and energy conditions, if there is strong dynamic uplift, vertical wind shear and large temperature differences, strong convection can still occur; the convection occurrence area corresponds to the high potential vorticity abnormal area. The movement speed and direction of the cloud cluster are also consistent with the movement of the high potential vorticity anomaly area; the potential vorticity anomaly will cause the cyclonic circulation to increase, and the upward movement will also increase, which is conducive to the development of strong convective weather. It is corresponding to the position of the dew point front in the β mesoscale (Wang et al., 2013).

The ground cold pool corresponds to the small value area of the convective cloud cluster TBB. The front of the cold pool is accompanied by a meso-scale ground convergence line, and the uplift is strengthened, which is conducive to the development and forward movement of thunderstorms; the outflow of the cold pool is 700 hPa When the direction of the guiding wind is the same, the movement speed will increase, and the stronger the outflow, the faster the movement speed (Sun et al., 2016).

Due to the limitation of the time and space resolution of data, the study of small and medium-scale convective weather still faces many difficulties and constraints, especially the study of small-scale weather systems. Therefore, in subsequent studies, more real-life data with high temporal and spatial resolution and mesoscale model data will be used for relevant analysis, with the hope that the research results can provide a reference basis for spring severe convection forecasting, spring agricultural meteorological services, and social activity security services and improve local spring weather disaster prevention and mitigation capabilities (Li et al., 2019).

Conflicts of Interest

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

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