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Analysis of Environmental Conditions and Predictability of a Strong Wind Process in Shenyang City after the Cold Vortex

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Abstract:

Based on the ground and high-altitude conventional sounding data, LAPS multivariate fusion reanalysis data, Doppler weather radar and satellite cloud image data, a local strong wind process in Shenyangon May 8, 2021 was analyzed. The results show that this process took place in the rear of the upper cold vortex, and the instability of atmospheric stratification provided a favorable weather scale background for convection. The larger wind speed in the entrainment layer and the strong vertical wind shear of 0-6 Km promoted the development of convection. The development of convection in the west of Shenyang was triggered by the interaction of the ground trunk line, the ground convergence line and the cold pool outflow. The strong echo moves along the cold pool outflow direction, resulting in the local windy weather in Shenyang. The numerical forecast of this process all reported the existence of convective potential. The radar reflectivity forecast of Grapes_3KM and WRF mesoscale model has certain indication significance for this severe convective weather process. However, due to the strong locality and suddenness of convection triggered by the difference of underlying surface conditions, it is difficult to forecast, and it is still necessary to strengthen short-term imminent forecast and early warning.

Keywords: *Behind cold vortex, Local strong wind, Cold pool, Mesoscale model*

I. INTRODUCTION

Local extreme instantaneous strong wind has the characteristics of small occurrence range, short life history, strong extreme and serious disaster [1]. With the climate change and economical and urban development, the extreme strong convective events in Shenyang area pose a great threat to the urban drainage, transportation, communication, water supply and power supply systems, which attracts more and more attention from all walks of life, and also poses many problems and new challenges to our forecasting, early warning and disaster prevention and mitigation work. Strong convective weather may occur during the formation, development, maintenance and extinction of cold vortex [2-4], and the strong convective weather under the background of cold vortex has the characteristics of short duration and complex structure. Therefore, it is very difficult to predict the occurrence time and falling area of this kind of strong

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weather [5].

At noon on August 23rd, 2021, under the influence of the cold vortex system, there was a local thunderstorm and windy weather in Shenyang area, and the largest gust wind appeared in HunnanZhonghua Temple Scenic Area, with a wind force of 10 (24.6m/s). Coincidentally, on the evening of September 9th, 2021, there were 31 stations in Shenyang where gust wind reached level 8 or above. The largest wind force was in Faku Cien Temple, reaching level 11 (30.9m/s). Strong convective weather under the influence of cold vortex system is often accompanied by instantaneous strong wind. In recent years, strong convective weather frequently leads to serious disasters [5]. More and more experts and scholars have devoted themselves to the study of extreme strong convective weather, and the research results of local extreme strong wind are also increasing [6-7]. During the extreme strong wind on March 21st and the disastrous hail on April 24th in Guilin in 2019, the vertical shear between the cold pool outflow and the ambient wind keet a balance. Moderate cold pool outflow is beneficial for the echo band to maintain and move to the center of the cold pool front depression [8].

When the cold vortex system transits, it is obviously forced by the weather scale system due to the influence of the air flow behind the trough. The large-scale convergence and ascending movement in the lower layer with strong temperature rise in the afternoon is easy to trigger the organized convection system. The intrusion of dry and cold air in the middle layer is conducive to the occurrence of thunderstorms and strong winds, but it is often overlooked and missed after the system transits [9]. Therefore, it is of great significance to study different types of strong convective weather under the background of cold vortex by relying on the potential forecast information of large-scale environmental field [10].

There is little research on the local strong wind weather behind the cold vortex in Shenyang area. In this paper, the environmental conditions and predictability of the local strong wind weather behind the cold vortex, which is easy to be neglected, are preliminarily analyzed.

II. WEATHER PROFILE

From 18: 00 to 19: 00 on May 8, 2021, scattered showers or thunderstorms occurred in Kangping, Faku, northeast Xinmin and urban areas of Shenyang. The regional average precipitation (mm) was 0.5mm. The maximum value was 7.0 mm (Tiexi Shenyang Station in urban area), and the maximum hourly precipitation was 7.0mm. The local area was accompanied by thunderstorms, strong winds and hail. From 18: 00 to 19: 00, the gust wind of 55 regional automatic stations reached level 7 or above, and that of 19 regional automatic stations reached level 8 or above. Among them, the largest gust reached level 9 or above (26m/s), which appeared in Guanghui Street, Yuhong District.

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III. SYNOPTIC BACKGROUND ANALYSIS

2.1 Analysis of Circulation Situation

At 08:00on 8th (Figure 1), there was a deep cold vortex system at the junction of Jilin and Inner Mongolia at 500hPa. The temperature trough lagged behind the height trough, which was beneficial to the development of the high-altitude trough. Shenyang area was affected by the southwest airflow in front of the high-altitude trough at the bottom of the cold vortex, and there was a low vortex system at 700hPa and 850hPa. The low-level trough line and ground cold front pressure were in the central and eastern part of Shenyang area (figure omitted). Affected by this, there was a small shower from 10: 00 to 15: 00 on 8th in Shenyang area, with an average precipitation of 0.4mm.

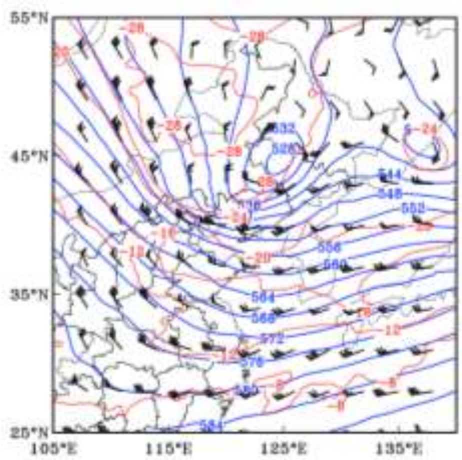

Figure 1 Comprehensive map of 500hPa at 08: 00 on May 8, 2021

At 20:00on 8th (as shown in Figure 2), the center of the cold vortex moved eastward and northward to the junction of Jilin and Heilongjiang at 500hPa. Shenyang area was affected by a strong northwest airflow with a wind speed exceeding 20m/s at the back of the cold vortex. This northwest jet guided the dry and cold air in the middle layer southward to Shenyang area. 700hPa and 850hPa also moved eastward and northward to the low-value system, all of which were affected by the northwest airflow behind the trough. Among them, the 850hPa cold center moved eastward rapidly, and Shenyang area was affected by the weak warm advection behind the temperature trough (as shown in Figure 3). The structure of upper dry and cold and lower warm and humid provides favorable weather scale conditions for the generation of atmospheric convection instability.

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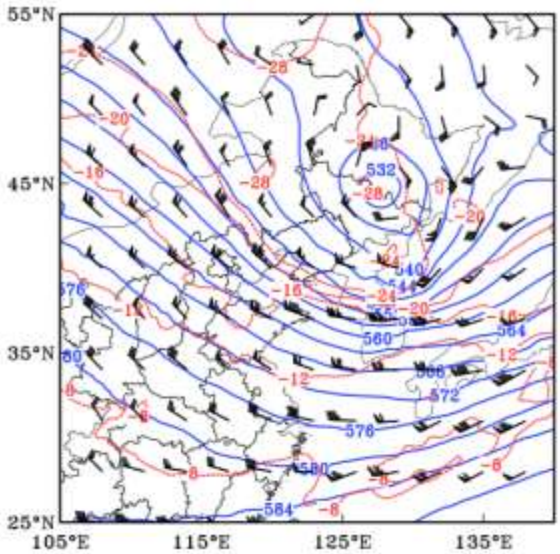

Figure 2 Comprehensive map of 500hPa at 20:00 on May 8, 2021

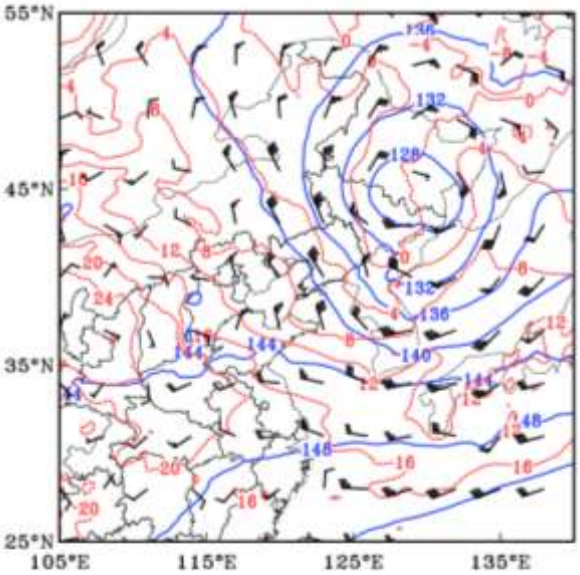

Figure 3 Comprehensive map of 850hPa at 20: 00 on May 8, 2021

2.2 Radar Echo and Cloud Picture Characteristics

2.2.1 Radar echo characteristics

The convection process was influenced by the eastward movement of small convective clouds, which lasted for less than one hour with a small range. It mainly affected the northeast of Shenyang, with local lightning and hail. At around 15: 00, there were sporadic counter flows in the central part of Tongliao (figure omitted). At around 17: 00, the main body of radar echo moved to the west of Shenyang area. After entering Shenyang area, it strengthened in the north of Xinmin area at around 17:42, and the echo intensity was greater than 45dBZ. At around 18:00, the range of strong echo entering the urban area decreased

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slightly, but there was still sporadic local convection development after entering the urban area, and the echo intensity was greater than 50dBZ (Figure 4). After 18:50, it gradually weakened and moved eastward, and Shenyang area was out of influence.

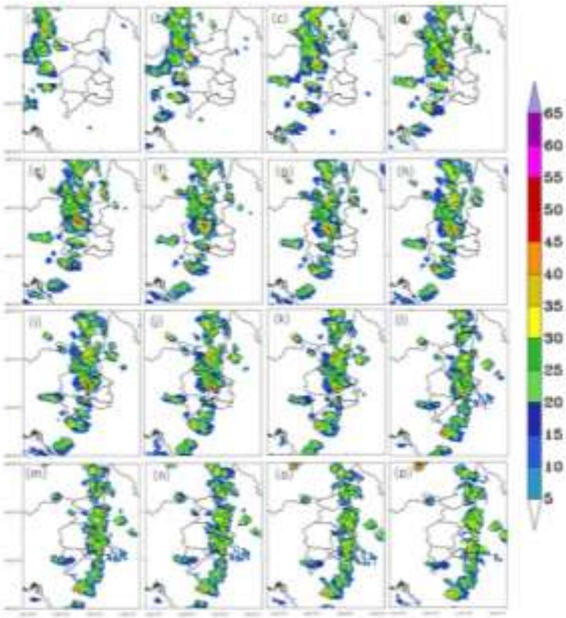
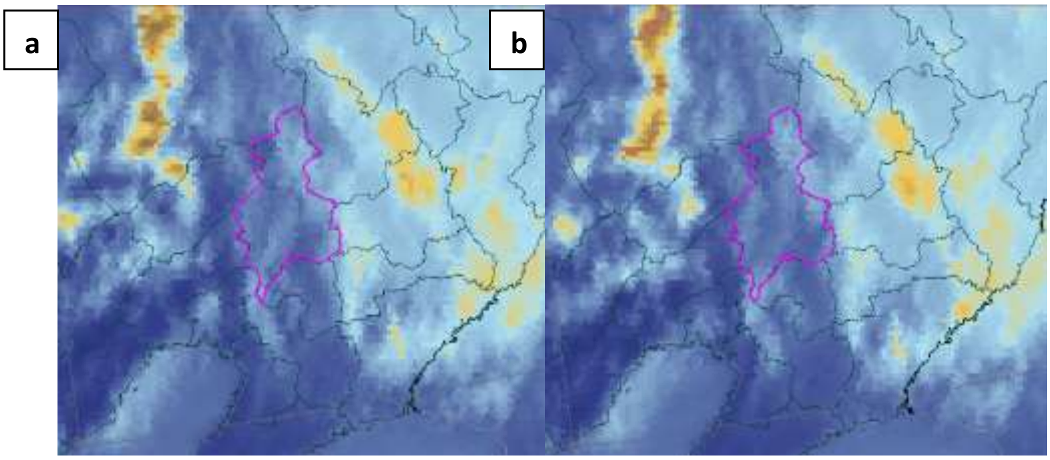


Figure 4 Concatenation of radar echo images from 16:30 to 18:48 ((a)16:30,(b)17:00,(c)17:30,(d)17:36,(e)17:42,(f)17:48,(g)17:54,(h)18:00,(i)18:06,(j)18:12,(k)18:18,(l)18:24,(m)18:30,(n)18:36,(o)18:42,(p)18:48)

2.2.2 Cloud Image Characteristics

At 15: 00 on 8th, the precipitation in Shenyang area basically ended, and the cloud cover over Shenyang decreased (as shown in Figure 5). From 15: 00 to 17: 00, during the precipitation rest period, the solar radiation increased significantly, which provided energy conditions for the convective weather in the evening.



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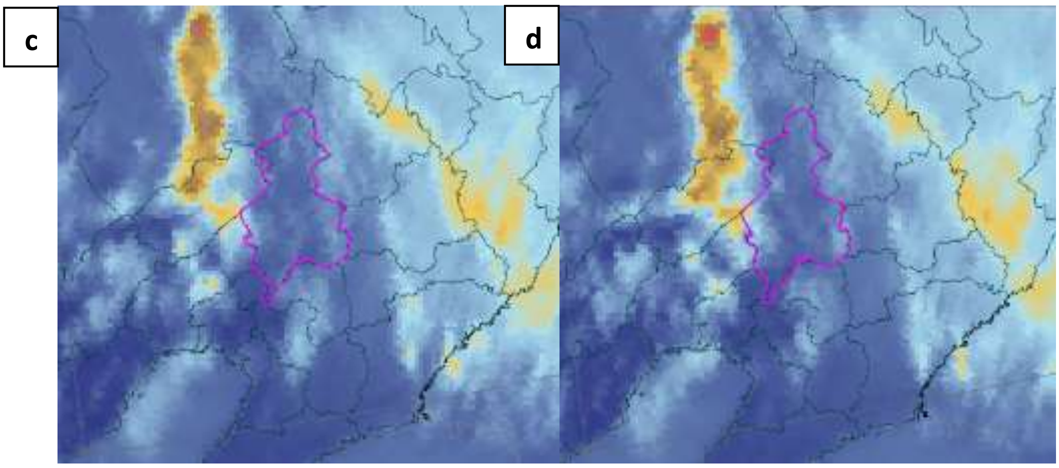
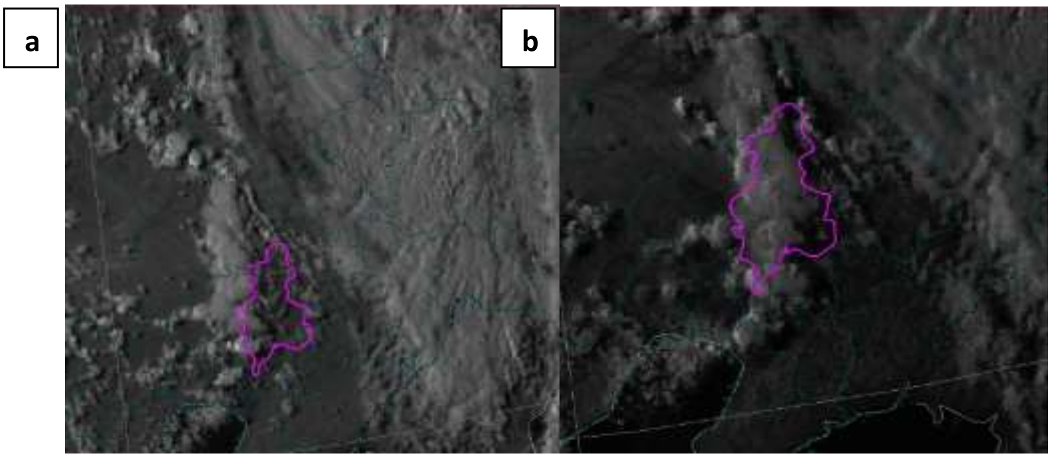


Figure 5 Infrared nephogram from 15: 45 to 16:45
((a)15:45,(b)15:53,(c)16:34,(d)16:45)

From the visible light cloud map (Figure 6), it can be seen that at 17:00, convective bubbles developed in the upper reaches of Tongliao area, with a horizontal scale of more than ten kilometers and a high development height. Obvious shadows can be seen in the cloud map. There is obvious thunder and hail strong wind weather in Tongliao area. The convective clouds in Shenyang area are obviously weaker than those in Tongliao area. There are bright spots in large stratiform clouds, that is, convective clouds with high development. But their horizontal scale is only a few kilometers, and their duration is less than 30 minutes.



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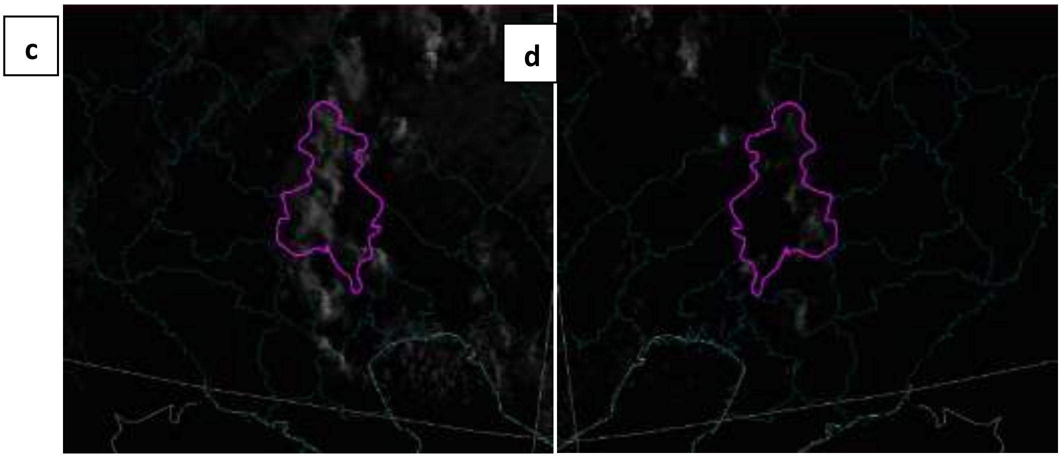

Figure 6 Visible light cloud picture from 17: 00 to 18:45
((a)17:00,(b)17:45,(c)18:30,(d)18:45)

2.3 Physical Environment Analysis

2.3.1 Water vapor analysis

At 17: 00 on 8th, the specific humidity in the lower layer was about 4g/kg, the precipitable water in the whole atmosphere was less than 20mm, and the water vapor condition was poor. The main source of water vapor in this process was local water vapor uplift, so the precipitation was not large.

2.3.2 Stratification conditions

According to thesounding chart (Figure 7) of reanalysis data of Shenyang Station at 17:00 on 8th, there was cold advection at 500hPa over Shenyang area, and the temperature dew point difference was above 6℃. The middle and upper layers were dry and cold, which was conducive to the accumulation of convective unstable energy in the lower layer. The release of unstable energy could transport the warm and humid air flow from the lower layer to the higher layer, which was conducive to the occurrence of precipitation. The temperature dew point difference between the middle and lower layers was 2℃-4℃, which was wet layer. The lower layer is a warm and dry air mass, and the stratification structure is "X"-shaped, which is conducive to the occurrence of thunderstorms and strong winds. The superposition of upper cold and lower warm aggravates the instability of atmospheric stratification in Shenyang, providing a favorable environmental background field for the occurrence of convection.

The wind speed at the 700hPa entrainment layer is more than 20m/s, and the downward momentum transmission is beneficial to windy weather. Besides, the vertical wind shear of 0Km -6Km is large, and the strong vertical wind shear environment is favorable to the development of storm airflow and the well-organized convective storm.

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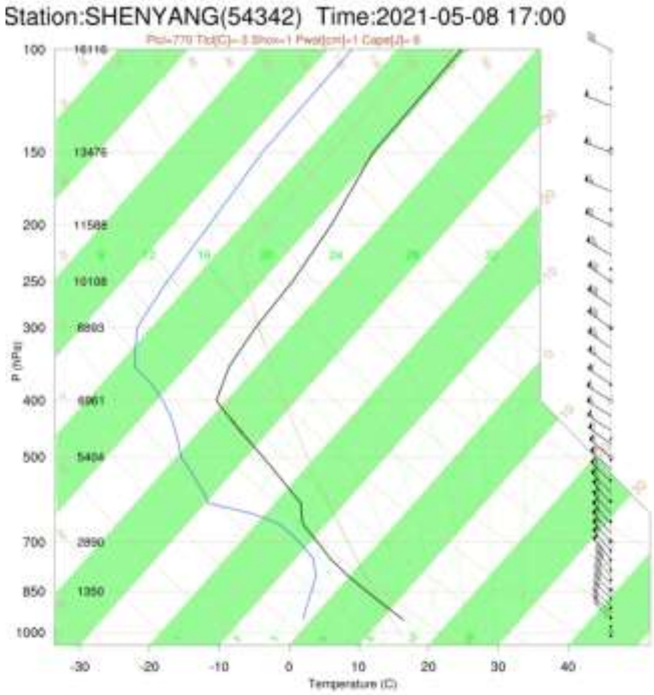

Figure 7 54342 Sounding chart of reanalysis data of Shenyang Station

2.3.3 Trigger conditions

From the morning of 8th to the afternoon of 8th, there was a shower in the eastern part of Liaoning, and the humidity in the eastern part was significantly higher than that in the western part.

At 17: 00 on 8th, the dew point temperature difference between the east and the west of Fuxin and Jinzhou areas was about 5℃, and there was an obvious trunk line. At around 18: 00, the ground trunk line moved eastward to the western part of Shenyang (as shown in Figure 8), which was in good correspondence with the radar echo positions in Liaoning area at 17: 00 and 18: 00.

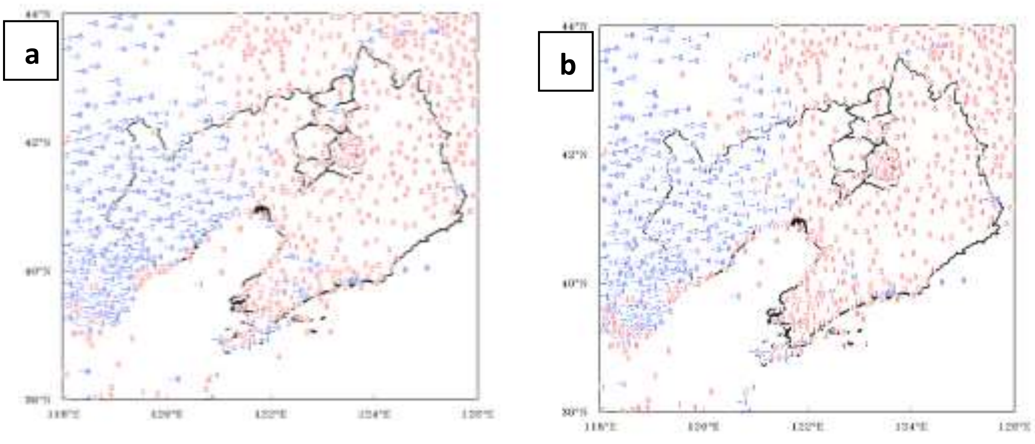

Figure 8 (a.17: 00 Ground dew point distribution diagram b.18:00 Ground dew point distribution diagram)

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At around 18: 00, there was an obvious ground convergence line in the central and western urban areas. The trunk line and the ground convergence line were the important triggering mechanisms of this urban convection process, and the establishment of the middle northwest jet promoted the unstable development of urban convection. As shown in Figure 9, at around 17: 25, due to the influence of precipitation, the raindrops evaporated and cooled, and the ground temperature dropped, forming a cold pool with a central temperature less than 13℃. The cold pool is about 4℃ different from the urban temperature. The ground wind field changed from prevailing southerly wind to northwest wind. In the front of the cold pool, the temperature gradient is large, which is in good correspondence with the strong echo position. The strong echo moved along the outflow direction of the cold pool. When the edge of the cold pool moved to the west of Shenyang city, the northwest wind from the cold pool and the westerly wind from the city formed a ground convergence line, which triggered the local heavy precipitation (5 minutes rainfall of 5 mm) and the instantaneous windy weather in the city. With the beginning of urban precipitation, the temperature dropped. The cold pool intensity and temperature gradient obviously weakened, and the convection also weakened and disappeared. At 17: 00 on 8th, there was a northeast-southwestwarm area in the central Liaoning Province. But how much it amplified the convection needs further study.

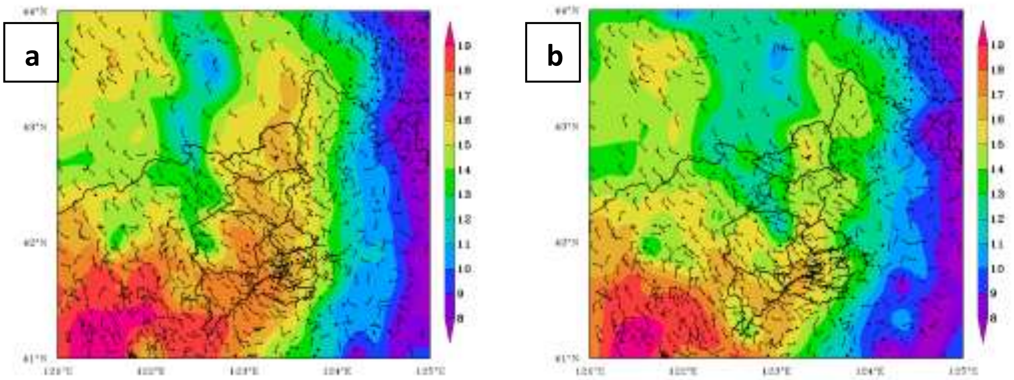

Figure 9 (a. Ground wind field and temperature analysis field at 17: 25 b. Ground wind field and temperature analysis field at 18: 05)

IV. PREDICTABILITY ANALYSIS

This convective weather happened at the back of the cold vortex, and the high and low layers turned into consistent northwest wind, with poor humidity conditions. It was very easy to ignore and miss the report just after a precipitation weather process during the day. The key point of this forecast is the triggering condition of boundary layer and the prediction of the propagation direction of upstream strong echo. The EC model (omitted) is basically accurate in forecasting the big situation field. From the profile at 20: 00 on 7th, it can be seen that the warming phenomenon began at around 17: 00 in the lower layer. Both the report at 20: 00 on 7th and the report at 08: 00 on 8th show that the temperature difference between 17: 00 850-500and 14: 00 850-500on 8th is obviously increased. The wind speed in the entrainment layer increased obviously around 700hPa, reaching more than 20m/s. This is basically consistent with the actual situation.

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From the forecast of WRF radiosonde chart (Figure 10) at 20: 00 on 7th and 17: 00 on 8th, it is predicted that the stratification structure is "X", which is consistent with the actual situation. However, from 20: 00 on 7th, the forecast of low layer and high layer is consistent cold advection. From 08: 00 on 8th, the forecast is adjusted to warm advection for lay layer and cold advection for middle and high layer. The near-time forecast adjusts the K index from 23 to 24, which is consistent with the actual situation. However, the mid-layer wind field forecast is weak, which is not as accurate as the EC wind field forecast. From the forecast of EC and WRF, we can predict certain convective potential.

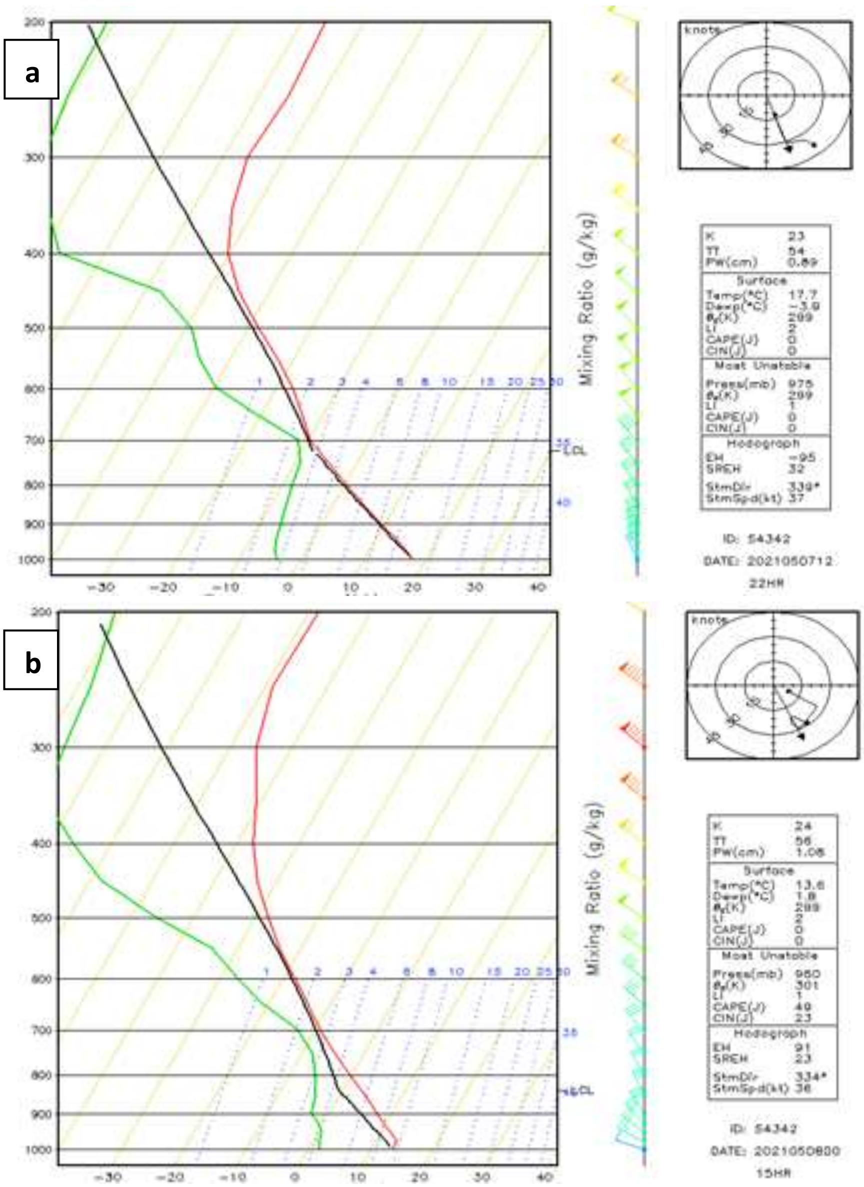

Figure 10 Forecast of WRF mode sounding chart (a: Forecast of the sounding chart for 22 hours (17: 00 on May 8th, 2021) at 20: 00. b: Forecast of the sounding chart for 15 hours (17: 00 on May 8th, 2021) at 08: 00 on May 8th, 2021)

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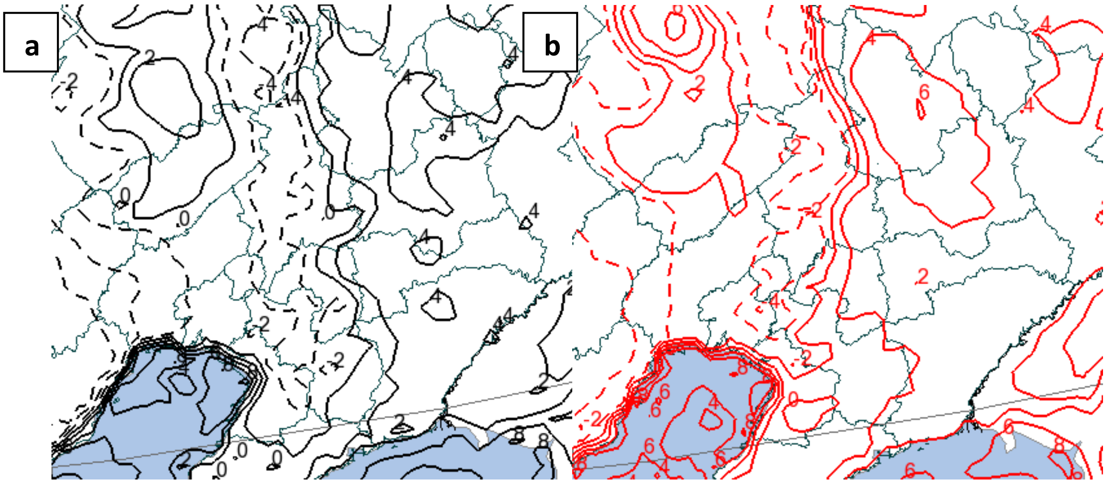
As for the trigger condition of this convection process, EC model (Figure 11) reported 2mdew point temperature at 20: 00 on 7th and at 17:00on 8th, both of which failed to predict the existence of trunk lines in western Liaoning. However, whether the dew point gradient increase in the eastern part of Shenyang forecast at the latest time has certain indication significance for short-term forecast of convective weather needs further study.



China Meteorological Administration

Figure 11 Forecast of ground dew point temperature in EC mode (a: Forecast of the ground dew point temperature for 21 hours (17: 00 on May 8th, 2021) at 20: 00. b: Forecast of the ground dew point temperature for 9 hours (17: 00 on May 8th, 2021) at 08: 00 on May 8th, 2021)

In the WRF mode (Figure 12) Liaoning 1KM,the forecast of the surface wind field at 20: 00 on 7th and at 8: 00 on 8th failed to predict the existence of the surface convergence line, and the triggering conditions of this convection process were extremely uncertain, which increased the difficulty of short-term period forecast.

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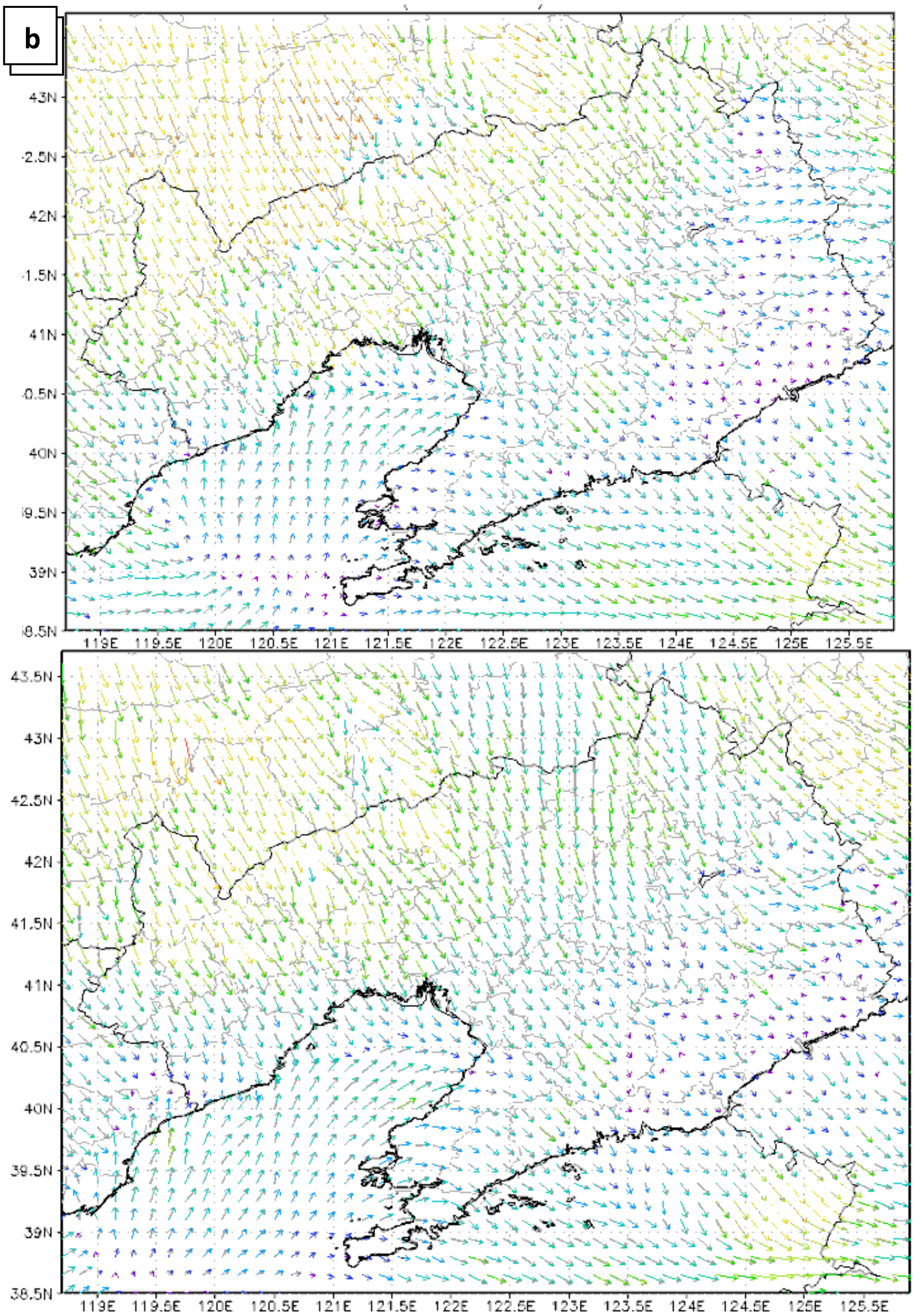

Figure 12 Forecast of surface wind field in WRF mode (a: Forecast of surface wind field for 22 hours (18: 00 on May 8th, 2021) at 20: 00. b: Forecast of the surface wind field for 10 hours (18: 00 on May 8th, 2021) at 08: 00 on May 8th, 2021)

According to the radar reflectivity forecast of WRF mode (Figure 13), WRF mode didn't forecast this convection process at 20: 00 on 7th. Radar echoes from Tongliao and western Liaoning were forecast at 08: 00 on 8th, with obviously insufficient intensity, but still better than the last time.

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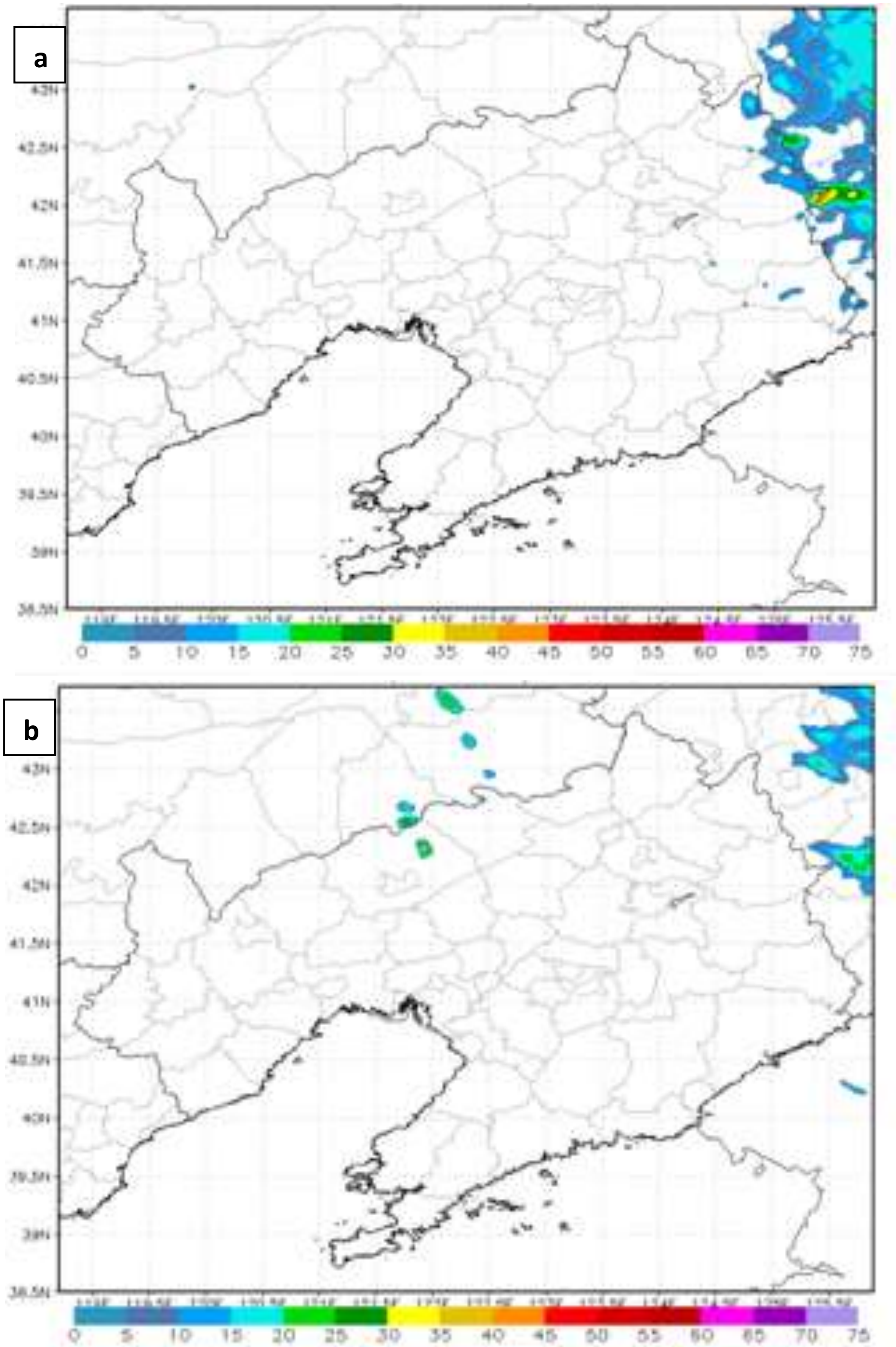

Figure 13 Radar reflectivity forecast of WRF mode
(a: Forecast of the radar reflectivity for 22 hours (18: 00 on May 8th, 2021) at 20: 00. b: Forecast of the radar reflectivity of 10 hours (18: 00 on May 8th, 2021) at 08: 00 on May 8th, 2021)

The Grapes_3KM model (Figure 14) performed well in this process. The radar reflectivity reported at 20: 00 on 7th and 08: 00 on 8th predicted the convection process. The intensity forecast is good and the position is slightly deviated, but it is of great significance to the forecast indication.

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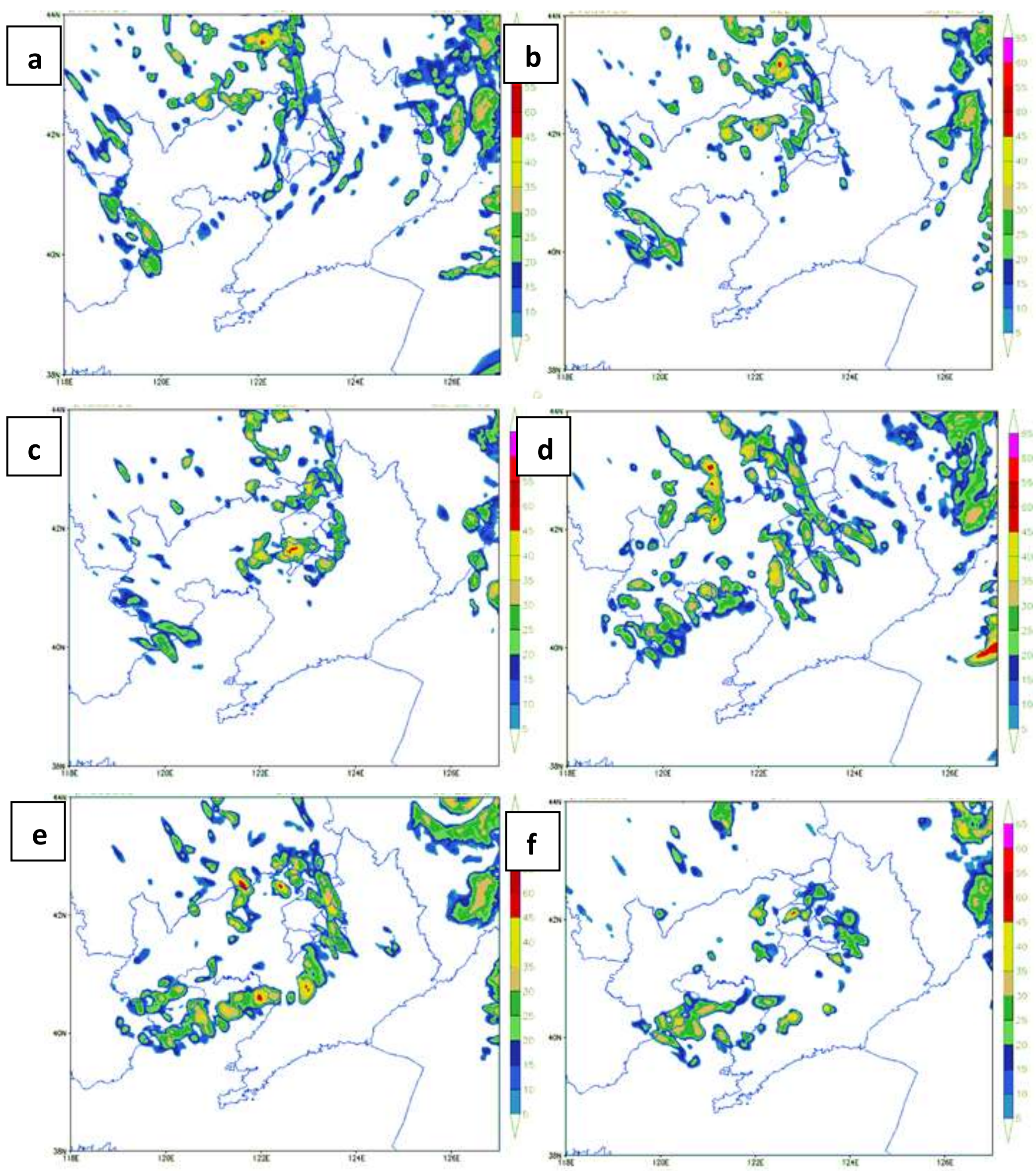

Figure 14 Radar reflectivity forecast of GRAPES _ 3 km model ((a, b, c: Forecast of the radar reflectivity for 21,22,23 hours (17:00,18: 00,19:00 on May 8th, 2021) at 20: 00. d,e,f: Forecast of the radar reflectivity of 9,10,11 hours (17:00,18: 00,19:00 on May 8th, 2021) at 08: 00 on May 8th, 2021)

To sum up, the model predicts the potential of convection, and there are some indications in the forecast of precipitation and radar reflectivity. However, there is great uncertainty in the area where strong convective weather occurs, which makes the forecast difficult.

V. CONCLUSION AND DISCUSSION

(1) Although the strong convective weather has a short duration and little rainfall, it has a strong wind, which should draw enough attention. Moreover, this convective weather happened behind the cold vortex,

and the high and low layers turned into consistent northwest wind, with poor humidity conditions. It is very easy to ignore and miss the report just after a precipitation weather process during the day.

(2) The structure of upper dry and cold and lower warm and humid provides favorable weather scale conditions for the generation of atmospheric convection instability. A strong northwest jet with a wind speed exceeding 20m/s behind the cold vortex leads the dry and cold air in the middle layer to the south, which aggravates the unstable stratification in Shenyang area. The larger wind speed in the entrainment layer and the vertical wind shear of 0km-6Km are beneficial to the development and organization of storm airflow. The interaction among the ground trunk line, the ground convergence line and the cold pool outflow triggered the convection activity. The strong echo moved along the cold pool outflow direction, resulting in the local windy weather in Shenyang area. The key point of this forecast is the triggering condition of boundary layer and the prediction of the propagation direction of upstream strong echo.

(3) When Shenyang area is located at the back of the cold vortex, the water vapor condition is not the necessary condition for strong convective weather, but the key point of forecast is whether there is unstable stratification, convective potential and uplift triggering conditions.

(4) The numerical forecasts of this process have all reported the existence of convective potential. The radar reflectivity forecast of Grapes_3KM and WRF mesoscale model has certain indication significance for this severe convective weather process, but it is necessary to pay attention to the short-term approaching actual situation analysis.

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REFERENCES

[1] Zhou Zhoufu, Fan Wei, Tao Yin, et al. A local strong wind observation in Anhui and its causes. Disaster Science, 2020, 35(2): 97-101.
[2] Sun Li, Zheng Xiuya, Wang Qi, 1994. Temporal and spatial distribution characteristics of northeast cold vortex and its relationship with large circulation system in East Asia. Journal of Applied Meteorological Science, 5(3): 297-303.
[3] Bai Renhai, Sun Yonggang. Background analysis of mesoscale weather in the northeast cold vortex process. Heilongjiang Meteorology, 1997, (3):6-12.
[4] Bai Renhai, Xie An. Analysis of squall line in the process of northeast cold vortex. Meteorology, 24(4): 37-40.
[5] Zhong Shuixin, Wang Donghai, Zhang Renhe, et al. Study on mesoscale convective system of a heavy rain in the development stage of cold vortex. Plateau Meteorology, 2013, 32(2): 435-445.
[6] Zheng Yongguang, Tao Zuyu, Yu Xiaoding. Some basic problems of severe convective weather forecast. Meteorology. 2017, 42(6): 641-652.
[7] Fu Danhong, Guo Xueliang, Xiao Wenan, et al. Numerical simulation of the formation mechanism of a strong wind and heavy precipitation in Beijing. Journal of Nanjing Institute of Meteorology, 2003, 26(2): 190-200.

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[8] Wu Hailang, Cao Wen, Yi Jun, et al. Multi-scale characteristics of the background of a microburst in July 2017. Meteorology Science and Technology, 2019, 47(1): 89-97.
[9] Wang Yanlan, Wang Juan, Wu Jing, et al. Comparative analysis of the characteristics of "March 21st" extreme strong wind and "April 24th" disastrous hail process in Guilin in 2019. Journal of Tropical Meteorology, 2021, 37 (2): 175-185.
[10] Zhang Yiping, Niu Shuzhen, Xi Shiping, et al. Analysis of synoptic characteristics of the strong convective process in Henan province behind the northeast cold vortex. Torrential Rain and Disasters, 2011, 30 (3): 193-201.
[11] Cai Xuewei, Zhuo Yun, Shen Xinyong, et al. Comparative analysis of the causes of different types of strong convective weather under the background of cold vortex. Meteorology, 2019, 45 (5): 621-631.