Meteorological and Environmental Research 2024, 15(3): 1 –5, 15

Analysis of a Large-scale Hail Process in Ulanqab City

Yanni SONG[1], Xuetong WU[2], Zetao ZHANG[1]*

1. Ulanqab Meteorological Bureau, Ulanqab 012000, China; 2. Fengzhen Meteorological Bureau, Fengzhen 012100, China

Abstract Based on the weather monitoring data, NCEP/NCAR reanalysis data and Doppler weather radar data, the circulation background, atmospheric stability and changing characteristics of radar echoes of a large-scale hail weather process in Ulanqab City on July 5, 2021 were analyzed. The results show that this hail weather process occurred in the summer afternoon of the hail-prone period in Ulanqab City, and was formed under the influence of upper trough and the circulation background of "two troughs and one ridge", which was conducive to the occurrence of strong convection weather. The low-level shear line provided the dynamic and water vapor conditions for the occurrence of the hail. In strong convection weather, water vapor was transported mainly from the Bay of Bengal, India and Nepal over the Himalayas. Before the occurrence of strong convection weather, water vapor transport increased significantly, and the low-level water vapor concentrated below 400 hPa, with obvious convergence and vertical transport. The characteristic parameters of radar echoes, such as combined reflectivity, vertically integrated liquid, and echo top height, increased significantly before and during the occurrence of hail, which had good indicative significance for the prediction and early warning of hail.

Key words Hail; Upper trough; Shear line; Convection cell

DOI 10.19547/j.issn2152 –3940.2024.03.001

Severe convection weather, especially hail, is a kind of serious catastrophic weather in summer and autumn in Inner Mongolia, and is characterized by strong local nature, short duration and great destructive power, causing serious losses to local agriculture and animal husbandry production. Therefore, the forecast and early warning services of hail weather is of great practical significance to the disaster prevention and reduction of hail prevention[1]. Hail, a solid precipitation with a diameter greater than 5 mm, is one of the main disastrous weather in Ulanqab City. Affected by the terrain, hail appears frequently in the middle of Ulanqab City, especially in June and July. During a day, hail mainly occurs from 13:00 to 17:00, and is often accompanied by thunderstorm, gale and short-term heavy precipitation. Hail often comes with fierce force, high intensity, short duration and serious harm, so it has great harm to agricultural production and brings economic losses to people's production and life in the city. Hence, it is needed to study the causes of hail weather, and analyze the background field, physical field and radar echo characteristics of its occurrence and development, so as to provide certain reference for the short forecast and early warning of Ulanqab City in the future.

The generation of hail is closely related to high-altitude cold vortex, low trough, cold advection and small- and medium-scale weather system. The occurrence of hail is affected by these weather systems, and changes with season and terrain. Hail is the product of hail clouds. It is generally believed that the formation of hail requires three basic conditions: unstable atmospheric stratification, abundant water vapor and lifting force. Many studies have been conducted on the mechanism of hail occurrence. Hail is usually directly generated by small- and medium-scale systems under the background of favorable large-scale weather conditions. Lu Dejin *et al.*[2] analyzed the radar echo characteristics of hail clouds in Anhui Province in spring and summer. It is pointed out that the echo intensity of hail clouds reached at least 55 dBZ, and the maximum vertically integrated liquid (VIL) of a monomer should be no less than 30 kg/m^2, generally 40 –80 kg/m^2.

In this paper, based on weather monitoring data, NCEP/NCAR reanalysis data and Doppler weather radar data, the fields of physical quantities such as high-altitude, low-altitude and ground circulation, relative humidity, specific humidity, and false equivalent potential temperature in Ulanqab City on July 5, 2021 were analyzed, and the environmental background conditions, triggering mechanism, changing characteristics of physical quantities and radar echo characteristics of the large-scale hail were discussed, so as to provide certain reference for short-term forecast and early warning of Ulanqab City in the future.

1 Weather facts and disasters

From 07:00 on July 5 to 07:00 on July 6 in 2021, rainfall appeared 219 monitoring stations (241 stations in total) in Ulanqab City. Among them, 2 stations suffered rainstorm (50.0 –99.9 mm), of which the accumulated precipitation of Hongshaba in Fengzhen City was 59.2 mm, and the maximum hourly rainfall intensity 48.3 mm/h occurred in Hongshaba from 14:00 to 15:00 on the 5th; the accumulated precipitation of Gaowusu in Shangdu County was up to 53.7 mm. Heavy (25.0 –49.9 mm), moderate (10.0 –24.9 mm) and light rain (0.1 –9.9 mm) appeared in 20, 59, and 138 stations, respectively.

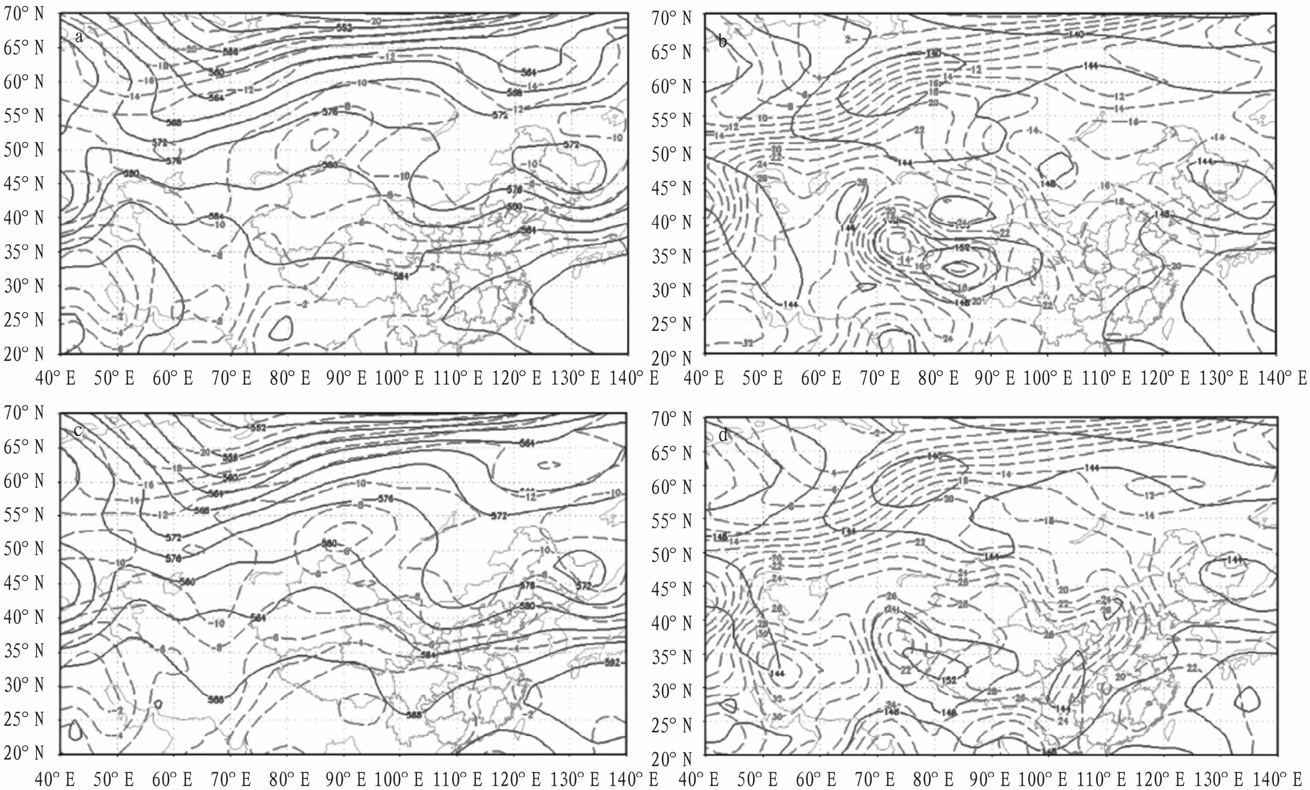
The precipitation process was a convective precipitation process, and was accompanied by lightning, hail and short-term strong precipitation and other convective weather. Hail happened in most of Ulan-

Received: April 10, 2024 Accepted: May 14, 2024
* Corresponding author.

qab City, and was the largest range of hail weather since the flood season in 2021. According to statistics, a total of 3 787 people and 2 993 hm^2 of crops were affected by the hail weather process, and the direct economic loss reached 14.901 9 million yuan.

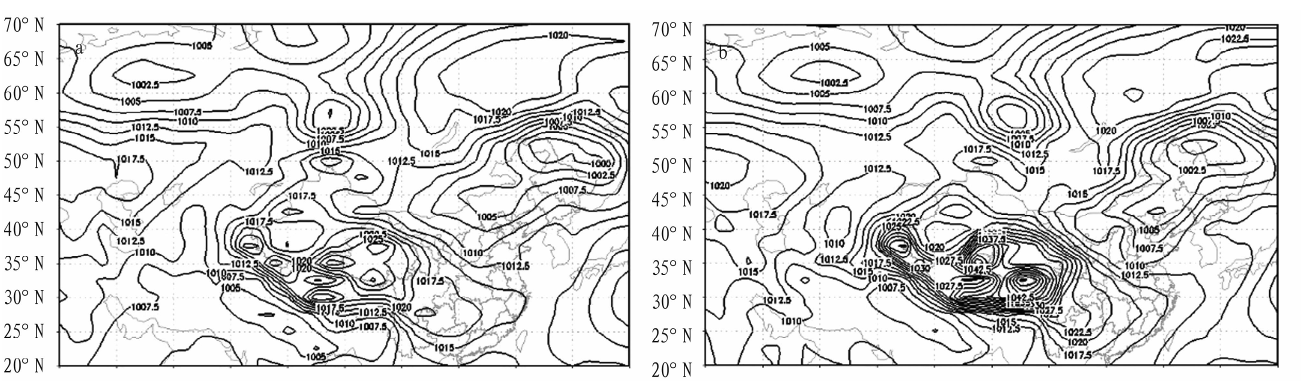
2 Circulation situation

At 08:00 on July 5, the upper 500 hPa of the city was affected by the upper short-wave trough, and was controlled by the southwest air flow in front of the trough (Fig. 1a). The lower 850 hPa was controlled by the warm ridge, and the temperature was high (Fig. 1b). At 14:00, 500 hPa temperature field and height field were superimposed in reverse phase (Fig. 1c). There was an intrusion of dry and cold advection over the city. The lower warm ridge strengthened and developed, and the unstable energy was enhanced (Fig. 1d). The circulation configuration of dry and cold upper air and warm and wet lower air was conducive to the occurrence of hail. In the sea level pressure field (Fig. 2), Ulanqab City was located behind the bottom of the hot low pressure, which provided unstable energy for the occurrence of strong convection weather.



Note: a. 08:00 at 500 hPa; b. 08:00 at 850 hPa; c. 14:00 at 500 hPa; d. 14:00 at 850 hPa. The blue contours represent the height field, with an interval of 10 gpm; the red contours represent the temperature field, with an interval of 2 ℃.

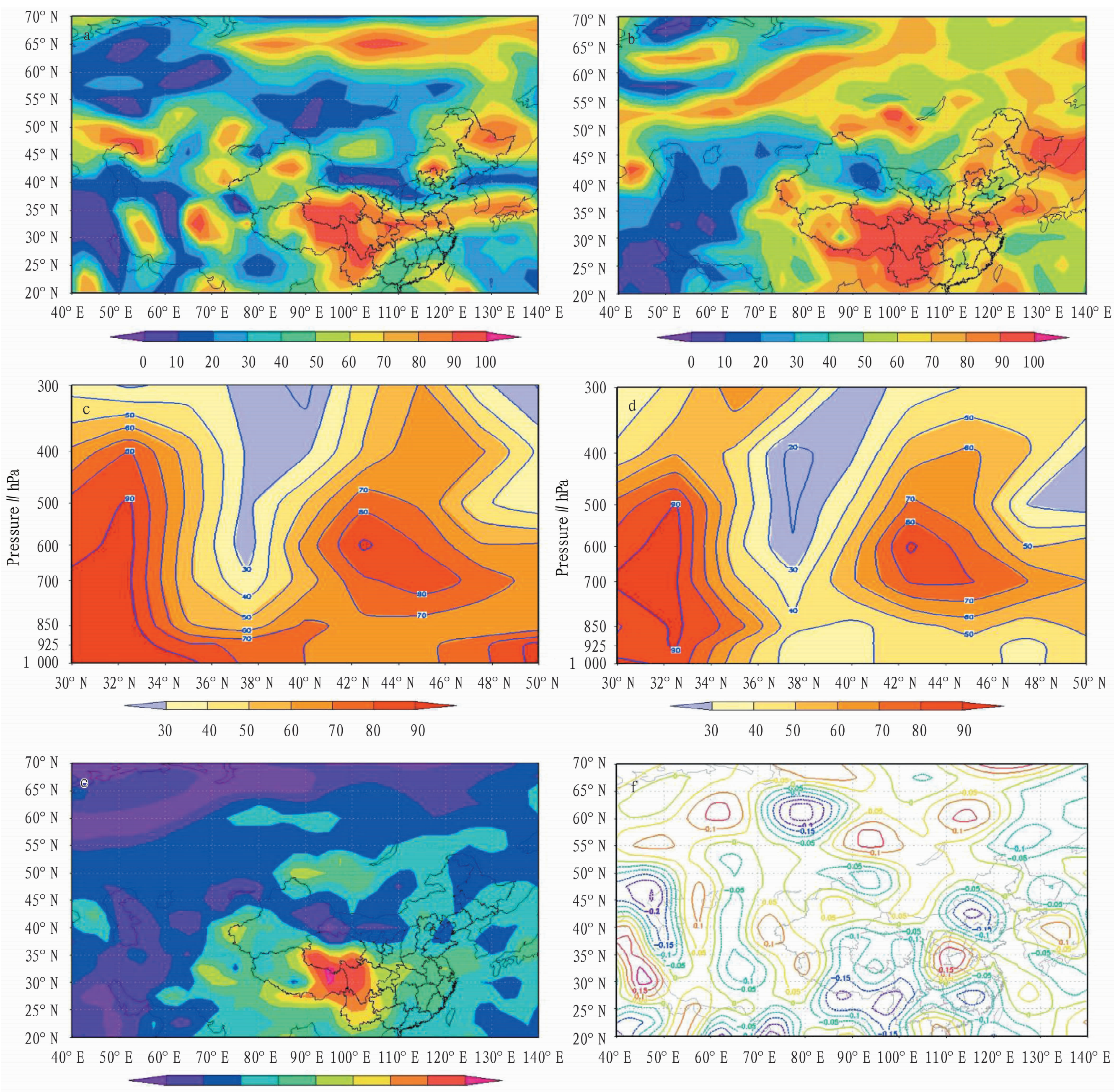
Fig. 1 Superposition diagrams of potential height field (unit: gpm) **and temperature field** (unit: ℃) **in the Northern Hemisphere (20° – 70° N, 40° – 140° E) on July 5, 2021**



Note: a. 08:00; b. 14:00.

Fig. 2 Sea level pressure field in the Northern Hemisphere (20° – 70° N, 40° – 140° E) on July 5, 2021 (unit: gpm)

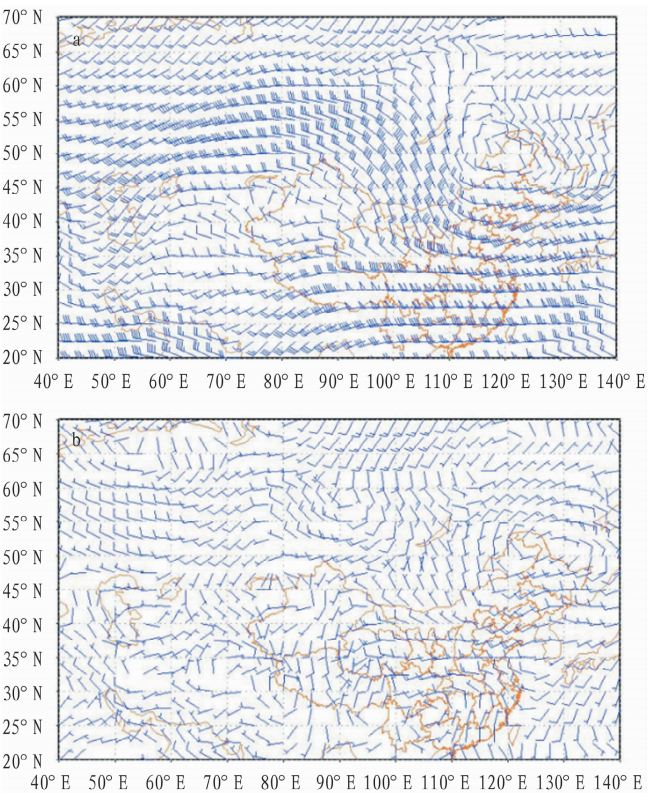
On July 5, the large-scale hail in the whole city was accompanied by short-term heavy precipitation. Under the good system configuration, the water vapor conditions were good during the process. As can be seen from the relative humidity field at 14:00, the relative humidity of Ulanqab City at 850 hPa was relatively high (Fig. 3a), and the water vapor condition was relatively abundant. At 500 hPa, the relative humidity was relatively low (Fig. 3b), and the air was relatively dry. The configuration of dry upper air and wet lower air enhanced the instability of stratification, and was conducive to the occurrence of convection weather. From the comparison between the profiles at 08:00 (Fig. 3c) and 14:00 (Fig. 3d), it is found that the lower humidity condition in the city was mostly very good, and the water vapor in most of the whole layer was warm and wet at 08:00. At 14:00, the dry cold air invaded the middle layer, forming an unstable stratification of dry and cold upper air and warm and wet lower air, and hail gradually developed. At the same time, the specific humidity of the city also increased significantly at 14:00, and it was about 12 g/kg at 850 hPa (Fig. 3e), providing sufficient water vapor conditions for the formation of hail clouds.



Note: a. Relative humidity at 500 hPa at 14:00; b. Relative humidity at 850 hPa at 14:00; c. Profile along the latitude circle at 08:00; d. Profile along the latitude circle at 14:00; e. Specific humidity at 850 hPa at 14:00; f. Vertical speed at 700 hPa at 14:00.

Fig. 3 Maps of physical quantities in the Northern Hemisphere (20° −70°N, 40° −140°E) on July 5, 2021 (unit: gpm)

The occurrence of severe convection weather such as hail requires certain triggering conditions. At 14:00 on July 5, Ulanqab City was located on the right side of the entrance area of the high-altitude jet stream at 200 hPa, and there was divergence air (Fig. 4a). The suction effect was conducive to the strengthening of upward movement. At 850 hPa, it was located to the right of the shear line between the northerly and southwesterly winds (Fig. 4b), and the convergence uplift of the shear line strengthened the upward movement. In the vertical speed field at 14:00 on July 5 (Fig. 3f), the city was in an obvious negative speed zone, and there was an upward movement. The occurrence of hail requires a certain upward movement. On July 5, the high- and low-layer wind field and vertical velocity cooperated well. The existence of upper-level jet stream and shear line increased the upward movement, and played a good role in triggering the lifting effect.



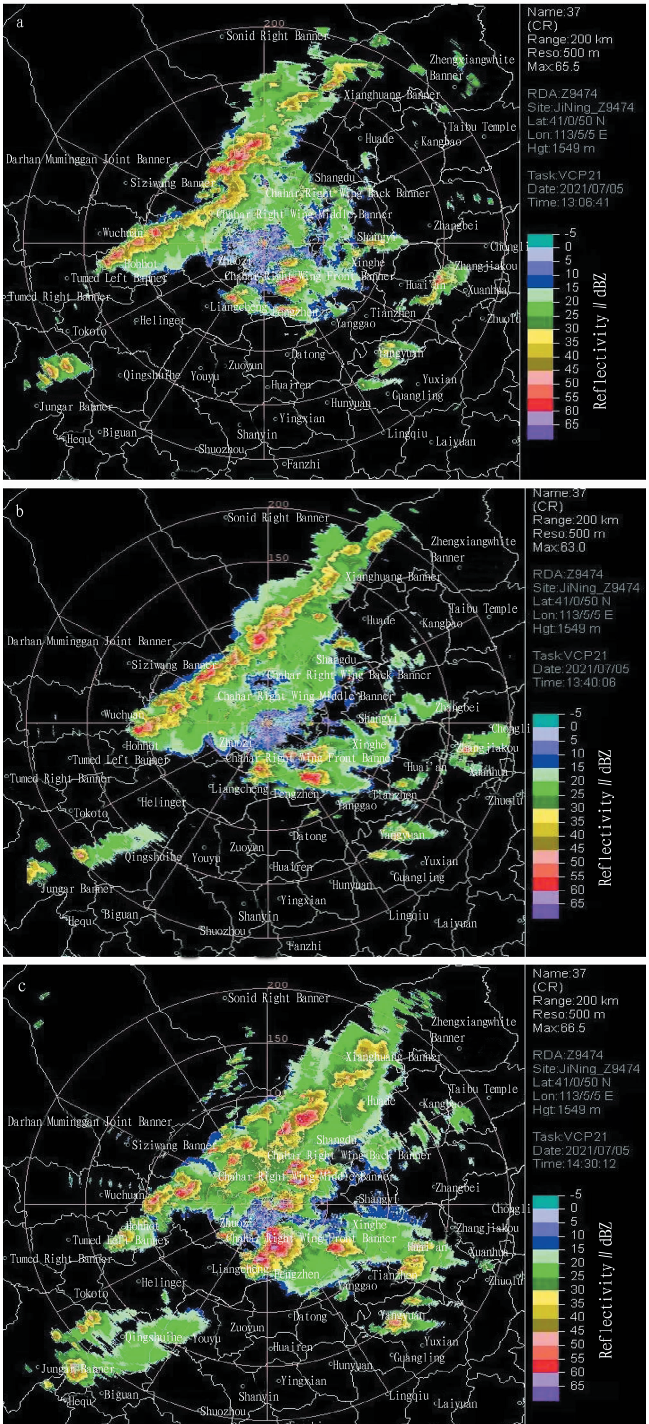
Note: a. 14:00 at 200 hPa; b. 14:00 at 850 hPa.

Fig. 4 UV wind fields over the Northern Hemisphere (20° – 70° N, 40° – 140° E) on July 5, 2021 (unit: gpm)

In summary, in the afternoon of July 5, the upper and lower systems were well configured, with abundant water vapor conditions, and the systematic upward movement provided a trigger condition for lifting. There was obvious convective unstable stratification and convective unstable energy accumulation in the lower layer, and there were stratification characteristics of strong convection weather such as hail and short-term heavy precipitation.

3 Characteristics of radar echoes

The maps of combined reflectivity factor, echo top height and radial velocity of the multi-cell thunderstorm process are given respectively. At 13:06, an obvious hook echo developed in the center of the city (Fig. 5a). At 13:40, the hook echo developed into a strong band echo in the center of the city (Fig. 5b), and the maximum reflectivity factor reached 60 dBZ. At the same time, several strong convection cells were generated in the southeast of the city. At 14:30, the band echo split into strong dispersed

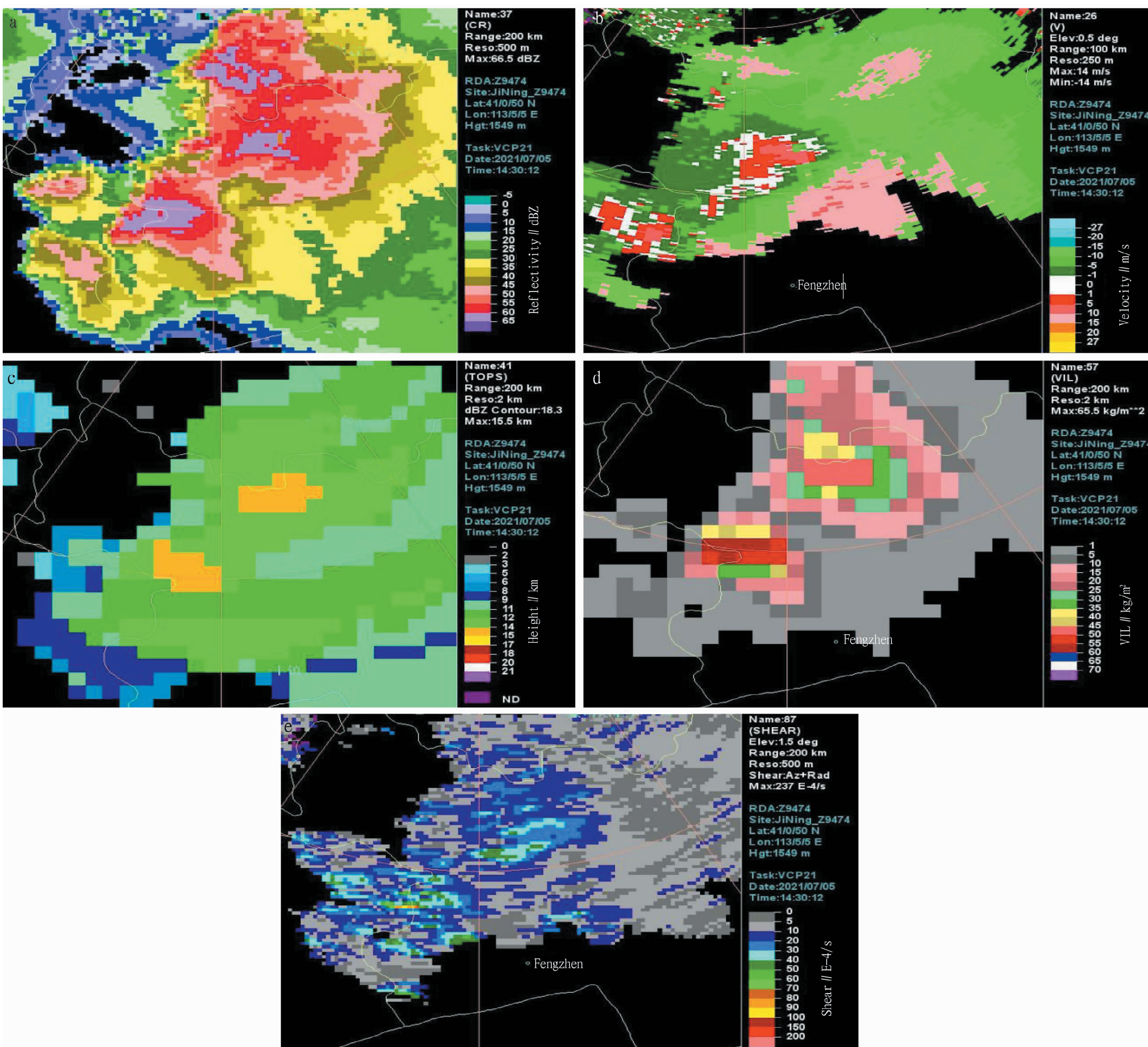


Note: a. 13:06; b. 13:30; c. 14: 30.

Fig. 5 Maps of combined reflectivity factor of Ulanqab City on July 5, 2021

blocky echoes to affect most of the city (Fig. 5c). The maximum reflectivity factor of the strong convection cell located in the northwest of Fengzhen City was up to 65 dBZ. The development of echoes was an indicator of hail occurrence. The strong echo continued to propagate to the east, forming an obvious train effect across most areas of the city. The echo was very strong, and there were multiple strong echo centers, with high centroid, which was conducive to the generation of hail.

For the strong convection echo in the northwest of Fengzhen, the maximum echo intensity was 65 dBZ (Fig. 6a). The echo top height developed into 14.5 km (Fig. 6c), and VIL also had a significant jump, with a maximum of 58.5 kg/m^2 (Fig. 6d). The reflectivity factor had front inflow gap and rear inflow gap. The front inflow gap indicated there was updraft, and strong updraft was conducive to the growth of large hailstones in the air. The rear inflow gap showed there was downdraft, which might cause destructive winds. The basic radial velocity had obvious convergence of wind direction (Fig. 6b), which was conducive to the further development of upward motion of convection storm. At the rear of the convection storm, the diverging downdraft descended to the ground, and the diffusive wind outflow forced the warm and wet airflow at the front of the convection storm to uplift, which further strengthened the upward movement. There was obvious storm top divergence at the echo top, which was also an important indicator of hail weather. Strong vertical wind shear is also an important indicator of hail production. The wind shear diagram shows that the wind shear of the strongest echo was above 30 m/s, and it belonged to strong vertical wind shear, which was conducive to the occurrence and development of hail.



Note: a. Combined reflectivity; b. Basic speed; c. Echo top height; d. VIL; e. Wind shear.

Fig. 6 Radar maps of Fengzhen at 14:30 on July 5, 2021

(To page 15)

identified as the mutation point by sliding t-test and pettitt test.

(4) After the abrupt change, the precipitation in Shandong Province increased significantly. In terms of time series, SPI index changed from decreasing to increasing. In terms of spatial distribution, after the abrupt change, the areas with normal and wet years increased, while the areas with dry years decreased, and the frequency of wet years rose greatly. The characteristics of dry and wet climate changed from gradually drying to wetting.

References

[1] Intergovernmental Panel on Climate Change (IPCC). Sixth Assessment Report of IPCC: Natural Science Basis[R]. 2021.
[2] ZHAO HH, CAO J, PAN L, et al. Spatio-temporal distribution of short-time severe precipitation in Shandong from 2007 to 2019[J]. Journal of Marine Meteorology, 2021, 41(2): 149-155.
[3] GUO FY, ZUO WQ, GUO FL, et al. The impacts of ENSO for accompanied with IOD type and isolated type on the interannual climate variability in Shandong[J]. Journal of Marine Meteorology, 2017, 37(4): 34-48.
[4] Grades of meteorological drought (GB/T 20481-2017)[S]. 2017.
[5] MCKEE TB, DOESKEN NJ, KLEIST J. The relationship of drought frequency and duration to time scales[R]. California: Proceedings of the 8th Conference on Applied Climatology, 1993.
[6] VICENTE-SWRRANO SM, BEGUERIA S, LOPEZ-MORENO JI. A multiscalar drought index sensitive to global warming: The standardized precipitation evapotranspiration index[J]. Journal of Climate, 2010, 23(7): 1696-1718.
[7] PALMER W. Meteorological drought[R]. U. s. department of Commerce Weather Bureau Research Paper, 1965.
[8] JU XS, YANG XW, CHEN LJ, et al. Research on determination of station indexes and division of regional flood/ drought grades in China[J]. Journal of Applied Meteorological Science, 1997(1): 27-34.
[9] AFRIN R, HOSSAIN F, MAMUN SA. Analysis of drought in the northern region of Bangladesh using Standardized Precipitation Index (SPI)[J]. Journal of Environmental Science and Natural Resources, 2019, 11(1/2): 199-216.
[10] YU JR, AI P, YUAN DB, et al. Spatial-temporal characteristics of drought in Heilongjiang Province based on standardized precipitation index[J]. Arid Land Geography, 2019, 42(5): 1059-1068.
[11] LI M, WANG GW, CHAI XR, et al. Climate regionalization and temporal evolution of meteorological drought in Northeast China based on spatial clustering[J]. Journal of Natural Resources, 2019, 34(8): 1682-1693.
[12] WAN MB, DONG XG. Nonuniformity characteristics of precipitation in Shandong Province during 1961-2010[J]. Journal of Arid Meteorology, 2015, 33(4): 566-573.
[13] LU GR, ZHENG MQ, ZHOU XJ, et al. Application and comparison of two kinds of drought indices in Rizhao of Shandong Province[J]. Journal of Arid Meteorology, 2010, 28(1): 102-106.
[14] WEI FY. Modern climate statistical diagnosis and prediction techniques (2nd ed.): China Meteorological Press, 2007: 63-65.
[15] ZHANG YL, LIU PX, WANG Y. Temporal and spatial variations of the drought in Ningxia based on aridity index and Morlet wavelet analysis. Chinese Journal of Ecology, 2015, 34(8): 2373-2380.
[16] CHEN C, ZHANG LD, LI JD, et al. Analysis of meteorological drought in Kunming based on Pa and SPI indexes[J]. Acta Agriculturae Jiangxi, 2021, 33(6): 78-84.
[17] CUI JT. Introduction to wavelet analysis[M]. Xi'an Jiaotong University Press, 1995.
[18] REN JC, ZHANG TT. Evolution characteristics of drought and flood in Shandong Province in recent 45 years based on Standardized Precipitation Index[J]. Research of Soil and Water Conservation, 2019, 28(2): 149-154, 162.
[19] HUANG WH, YANG XG, LI MS, et al. Evolution characteristics of seasonal drought in the south of China during the past 58 years based on standardized precipitation index[J]. Transactions of the Chinese Society of Agricultural Engineering, 2010, 26(7): 50-59.
[20] XIAO NS, LIU BC, YIN H, et al. Drought risk assessment of table grapes in the Bohai Rim Region based on crop water deficit index[J]. Chinese Journal of Agrometeorology, 2019, 43(5): 380-391.

(From page 5)

4 Conclusions and discussion

(1) The hail weather mainly occurred during the eastward movement of the upper air trough accompanied by the shear line. The shear line presented a forward tilt, and the forward tilt situation intensified. As a result, the cold dry air behind the upper shear line was placed on top of the warm and humid air in front of the lower shear line, and the wind shear in the vertical direction strengthened, increasing the convective instability of the air column over Ulanqab City, which was conducive to the triggering and development of hail weather with strong convection.

(2) The water vapor channel of this hail and other strong convection weather was the main transport channel for water vapor in summer: water vapor was transported northeastwards from the Bay of Bengal, India and Nepal over the Himalayas. Before the strong convection occurred, the specific humidity increased obviously. The relative humidity was better in the lower layer, and the dry cold air was invaded in the upper layer.

(3) From the configuration of upper and lower wind fields, and profiles of vertical velocity and relative humidity, it can be seen that the suction effect of the upper-level jet stream in Ulanqab City strengthened upward movement, and the negative vertical velocity indicates that there was a strong upward movement. The profile of relative humidity shows that there was obvious convective unstable stratification

(4) It can be seen from the radar echo maps that the hook echo gradually split into several strong convection cells, and moved eastwards to gradually affect most of the city and bring a large-scale hail to the city. It was accompanied by short-term heavy precipitation. The parameters of radar echo characteristics, such as combined reflectivity, vertically integrated liquid, and echo top height, increased significantly before and during the occurrence of hail, which had good indicative significance for the prediction and early warning of hail.

References

[1] ZHANG GL, LIU LC, ZHAO F, et al. Weather causes for a heavy hail under the background of the forward trough in Hetao area[J]. Desert and Oasis Meteorology, 2019, 13(4): 1-8.
[2] LU DJ, CHEN ZR, YUAN Y, et al. Analysis on radar echo characteristics of hail clouds in spring and summer of Anhui Province[J]. Meteorological Monthly, 2015(9): 1104-1106.