Analysis of a Type II Snowstorm Process in the Early Spring of 2022 in Ulanqab

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Abstract Based on the observation data of meteorological stations, Doppler radar observation data of Ulanqab City, and ERA-5 reanalysis data, a snowstorm process in Ulanqab City from March 17 to 18, 2022 was analyzed. The results show that this was a type II snowstorm process generated under the joint influence of upper trough and ground low inverted trough and frontal cyclone. The main period of snowfall can be divided into two time stages, and the total snowfall was more in the south and less in the north, which was consistent with that of average specific humidity field. Water vapor conditions provided by strong water vapor transport and convergence, strong upward movement shown by large vertical velocity field, and the suction action of high- and low-layer divergence and convergence were the reasons for the hourly heavy snowfall on the 18th. During the process, radar echoes were mainly sheet-shaped, and composite reflectivity was 15 – 25 dBZ in most areas. The zero speed line in the first period was positively "S"-shaped, and there was warm advection and southwest wind. On the morning of the 18th, after the cold front transited the city, Ulanqab City was gradually controlled by northwest wind, and the snow tended to end.

Key words Type II snowstorm; Influencing system; Diagnostic analysis; Radar echo characteristics

DOI 10.19547/j.issn2152 – 3940.2024.02.002

Snowstorm, the snowfall weather with snowfall of more than 10 mm in 24 h, is one of the major meteorological disasters in winter and spring in northern China, causes negative impacts on local transportation and people's life, and may even bring economic losses and security risks[1]. Chen Jie *et al.* studied the process of snowstorm in Ulanqab City, divided it into two types (the snowstorm in which the precipitation phase is pure snow is type I snowstorm, and the precipitation in which the precipitation phase is not pure snow (namely containing rain or sleet) is type II snowstorm, accounting for 70.2%), and classified the influencing system of snowstorm. In the high-altitude influencing systems. The upper-level trough accounted for 63.2%. When the upper air was affected by the trough, the surface was affected by the cyclone (accounting for 38.9%) and low-pressure inverted trough (accounting for 30.6%). This process was a typical type II upper trough snowstorm. The results of the first survey of snow disaster risk level show that among the western banner counties of Ulanqabu City, the level of snow disaster risk was mostly higher and locally high in the center and south of Siziwang Banner, the west and south of Chahar Right Wing Middle Banner, most of western Zhuozi County, and the west and south of Liangcheng County, and these areas were consistent with the areas with accumulated snowfall of more than 20 mm in the process. In this paper, the characteristics, influencing systems, snowfall conditions and radar echo characteristics of the snowstorm from March 17 to 18, 2022 were analyzed to supplement the case library of snowstorm research, strengthen the ability of snowstorm weather forecast and early warning, and provide scientific basis for disaster prevention and reduction.

Received: March 11, 2024 Accepted: April 18, 2024

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1 General situation and characteristics of the snowfall process

From March 17 to 18, 2022, strong snowfall weather appeared in 28 stations in Ulanqab City, and snowstorm happened in two consecutive days. From 20:00 on March 16 to 20:00 on March 18 in 2022, accumulated precipitation was greater than 20 mm in 5 stations, 5.0 – 9.9 mm in 16 stations, and 2.5 – 4.9 mm in 7 stations. According to the remote sensing monitoring after the snowfall, the area of accumulated snow accounted for 93.6% of the total area of the city, and the maximum snow depth appeared in Chahar Right Wing Back Banner and Shangdu County, reaching 16 cm. With the snowfall, the city's minimum temperature dropped by 8.0 – 19.5 ℃ within 48 h (March 17 – 19). The minimum visibility was 135 m (Xinghe County) – 650 m (Shangdu County), and the maximum wind speed was 10.7 – 15.9 m/s.

Seen from the temporal distribution (Fig. 1), snowfall mainly happened from the morning to the night of March 17 and from the morning to the afternoon of March 18. From 20:00 on the 16th to 20:00 on the 17th, snowstorm appeared in 12 stations, and heavy snow occurred in 5 stations; there was moderate snow in 6 stations and light snow in 5 stations. The maximum snowfall intensity was up to 3.3 mm/h in Liangcheng County from 09:00 to 10:00. From 20:00 on the 17th to 20:00 on the 18th, the number of stations with snowstorm, heavy snow or light snow was all 7, while the number of stations suffering moderate snow was 6, and the maximum snowfall intensity appeared from 07:00 to 08:00 in Siziwang Banner, reaching 5.9 mm/h. From the perspective of spatial distribution, the snowfall increased from north to south, and it was larger in the western, southern and southeastern regions (reaching more than 20 mm in Zhuozi County, Liangcheng County, Chahar Right Wing Middle Banner and Xinghe County). In general, the hourly precipitation intensity in the first period was small, but the duration was longer, and the spatial distribution was relatively uniform. In the second period, the precipitation intensity was large, but the duration was short, and the spatial distribution was relatively dispersed.

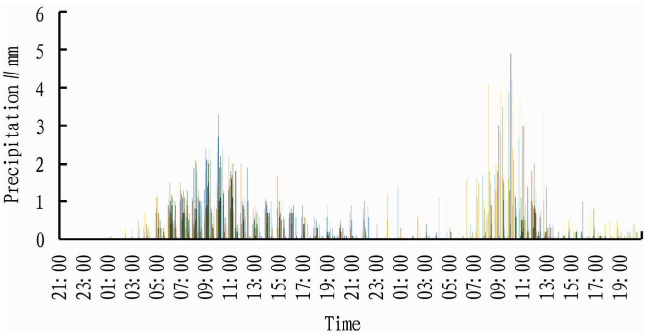

Fig. 1 Hourly precipitation in stations of Ulanqab from 20:00 on the 16th to 20:00 on the 18th (unit: mm)

2 Circulation characteristics and influencing systems

On the 17th (Fig. 2), on the 500 hPa weather chart, the cold center in the upper reaches of Ulanqab moved eastwards and southwards, and the temperature field was consistent with the height field. At 08:00, the short-wave trough in the westerly air flow affected the southern area of Ulanqab from west to east. At 700 hPa, Ulanqab was in front of the short-wave trough at 08:00 on the 17th. Due to the existence of weak ridge in the lower reaches of Ulanqab, there was a certain blocking situation, and the short-wave trough moved slowly. It continued to affect Ulanqab from 20:00 on the 16th to 14:00 on the 17th, which was the reason for the continuous precipitation. At 850 hPa, there was strong warm advection and warm ridge in the southern area of Ulanqab, which was affected by the southwest airflow. On the ground map, Ulanqab City was in front of the inverted trough, and seen from the infrared cloud image, there was southwest water vapor transport.

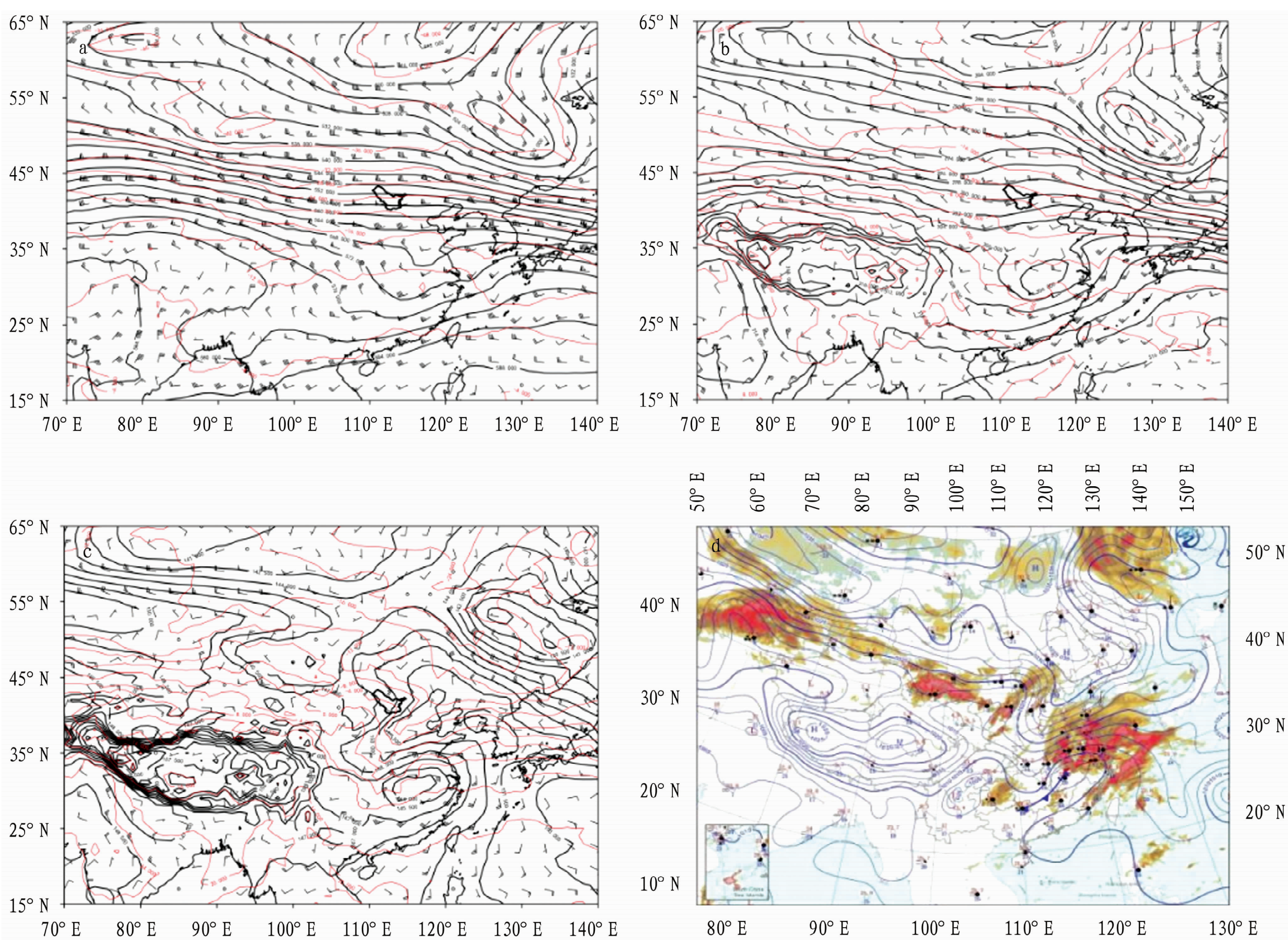

Fig. 2 Circulation situations at 500 (a), 700 (b) and 850 hPa (c) and superimposed infrared cloud image of surface pressure field (d) at 08:00 on the 17th

On the 18th (Fig. 3), the affected system at 500 hPa was a shallow trough, which affected Ulanqab from west to east. From the temperature field, the cold temperature trough moved southwards, and there was a cold advection in the north of Ulanqab; the temperature field lagged behind the height field, and the shallow trough showed a developing trend. At 700 hPa, there was a transverse trough in the north of Ulanqab City; the temperature field was almost perpendicular to the height field and the wind field, and there was cold air transport. At 850 hPa, with the development of the upstream trough, the contours formed a closed circulation, and Ulanqab City was affected by a low pressure system. On the surface map, the low value system strengthened to form a closed low pressure, and the cold front in front of the cold high pressure entered the inverted trough to form a frontal cyclone.

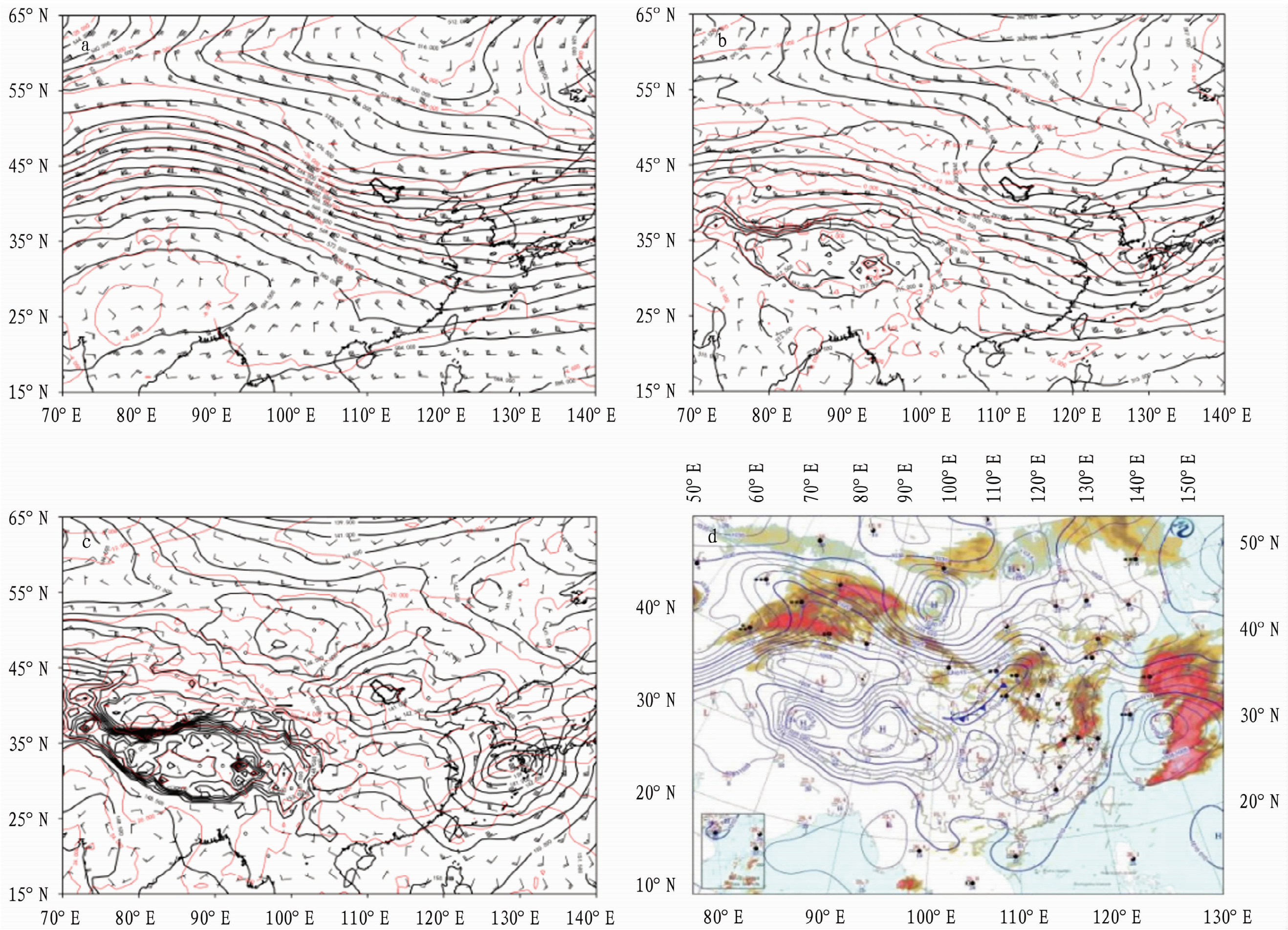

Fig. 3 Circulation situations at 500 (a), 700 (b) and 850 hPa (c) and superimposed infrared cloud image of surface pressure field (d) at 08:00 on the 18th

3 Diagnosis and analysis of precipitation conditions

3.1 Water vapor condition Water vapor condition is a necessary condition for precipitation. On the one hand, heavy precipitation needs water vapor transport; on the other hand, it needs water vapor convergence. According to the average specific humidity at 700 hPa from 20:00 on the 16th to 20:00 on the 18th (Fig. 4a), the trend of humidity was consistent with the falling area of rainfall, and the isocontour extended from east to west. The specific humidity in Ulanqab City ranged from 1.45 to 2.45 g/kg, decreasing from south to north. According to the hourly specific humidity field at 700 hPa (Fig. 1), the area with the specific humidity of above 2 g/kg was the large-value area of water vapor. In the first period, water vapor entered from the southwest of Ulanqab City and gradually moved to the northeast to control most areas in the center and south of Ulanqab City. Later it receded to the southeast, that is, the large-value area of water vapor lasted for a long time in the southern region, so the snowfall in the southern region was larger in the first period. In the second period, the water vapor became better from the northwest, moved southwards, and receded to the southeast. It lasted for a long time in the central and northern regions, and had a good supplement to the accumulated precipitation in the northern regions.

At 700 hPa at 08:00 on March 18, Ulanqab City was controlled by westerly wind (Fig. 4b). In the western region, there was the convergence of northwest and southwest winds, and the wind was relatively strong, while the wind in the eastern region was relatively small, with the maximum wind speed of 8 m/s. According to the specific humidity field, the wet tongue in the southwest of Ulanqab extended to the west-central area of Ulanqab City, with the maximum of 3 g/kg. At this time, the hourly precipitation in Siziwang Banner reached 5.9 mm/h. The water vapor flux divergence field in most areas of Ulanqab City was -5 g/(s · hPa · cm^2). Along the large-value area of specific humidity, the negative large-value area of water vapor flux divergence extended to the west of the central part of Ulanqab City, and it reached -40 g/(s · hPa · cm^2). There was a convergence center in Siziwang Banner, and it was up to -30 – -35 g/(s · hPa · cm^2) locally. The specific humidity field in the west of the region was perpendicular to the wind field, indicating that the larger water vapor flux corresponded with the stronger water vapor convergence.

3.2 Dynamic condition Strong upward motion is an important condition for the generation of snowstorm. On the one hand, the strong upward motion provides the dynamic condition for snowfall; on the other hand, the upward cooling effect makes the warm and wet air gradually saturated during the upward process, forming a deep column of wet air, which is conducive to the maintenance and strengthening of precipitation[2].

From the changes of velocity and divergence (unit: 10^{-4} s^{-1}) with time (Fig. 5a), it can be seen that at 08:00 on the 18th, the divergence at 500 hPa was 4×10^{-4} s^{-1}, and it was the center of divergence. There was a convergence center at 650 – 925 hPa, and the center value was -8×10^{-4} s^{-1}. The cooperation of the divergence and convergence fields at high and low altitudes had obvious suction effect, resulting in strong upward motion. Seen from the profile of vertical velocity in Siziwang Banner changing with time (Fig. 5b), there was ascending motion in Siziwang Banner from 02:00 to 08:00 on the 17th, appearing roughly from 800 to 350 hPa, but the intensity was not large, and the center value was -0.6 Pa/s. From 08:00 to 09:00 on the 18th, the rising move-

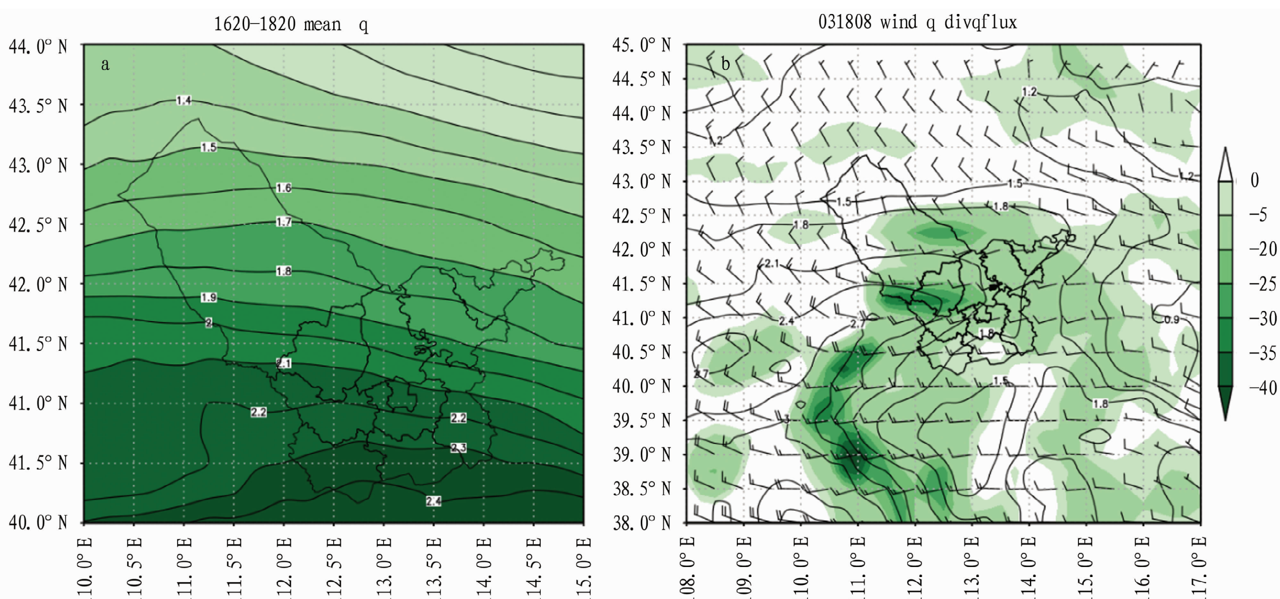

Fig. 4 Average specific humidity from 20:00 on the 16th to 20:00 on the 18th (a, unit: g/kg) as well as wind field, specific humidity (isocontour) and water vapor flux divergence (shadow) at 08:00 on the 18th [(b, unit: g/(s · hPa · cm^2)]

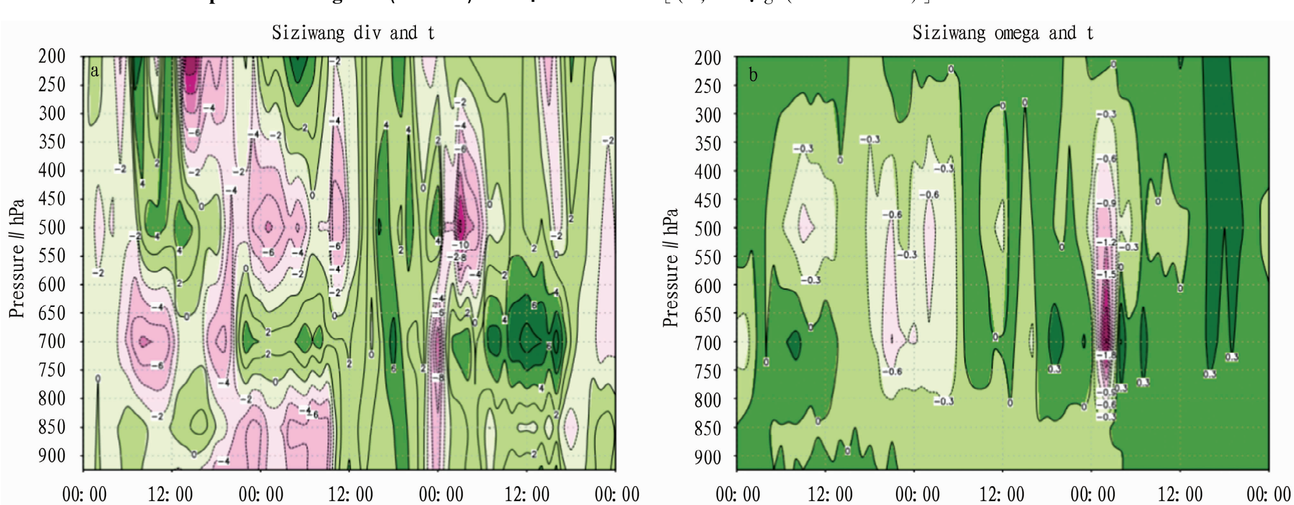

Fig. 5 Profiles of divergence (a, unit: 10^{-4} s^{-1}) and vertical velocity (b, unit: Pa/s) changing over time in Siziwang Banner

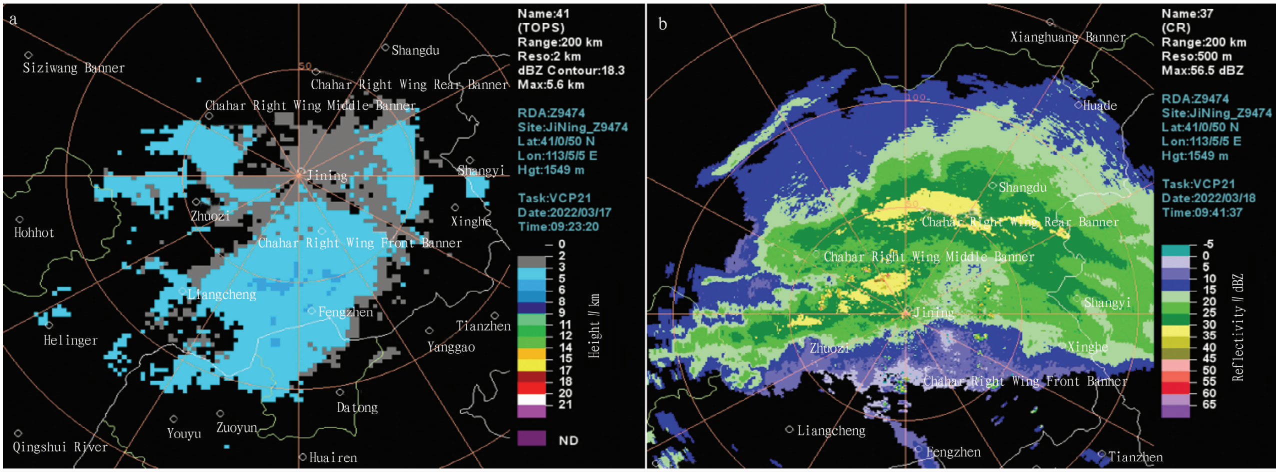

Fig. 6 Echo top height (a) and composite reflectivity (b) during the precipitation

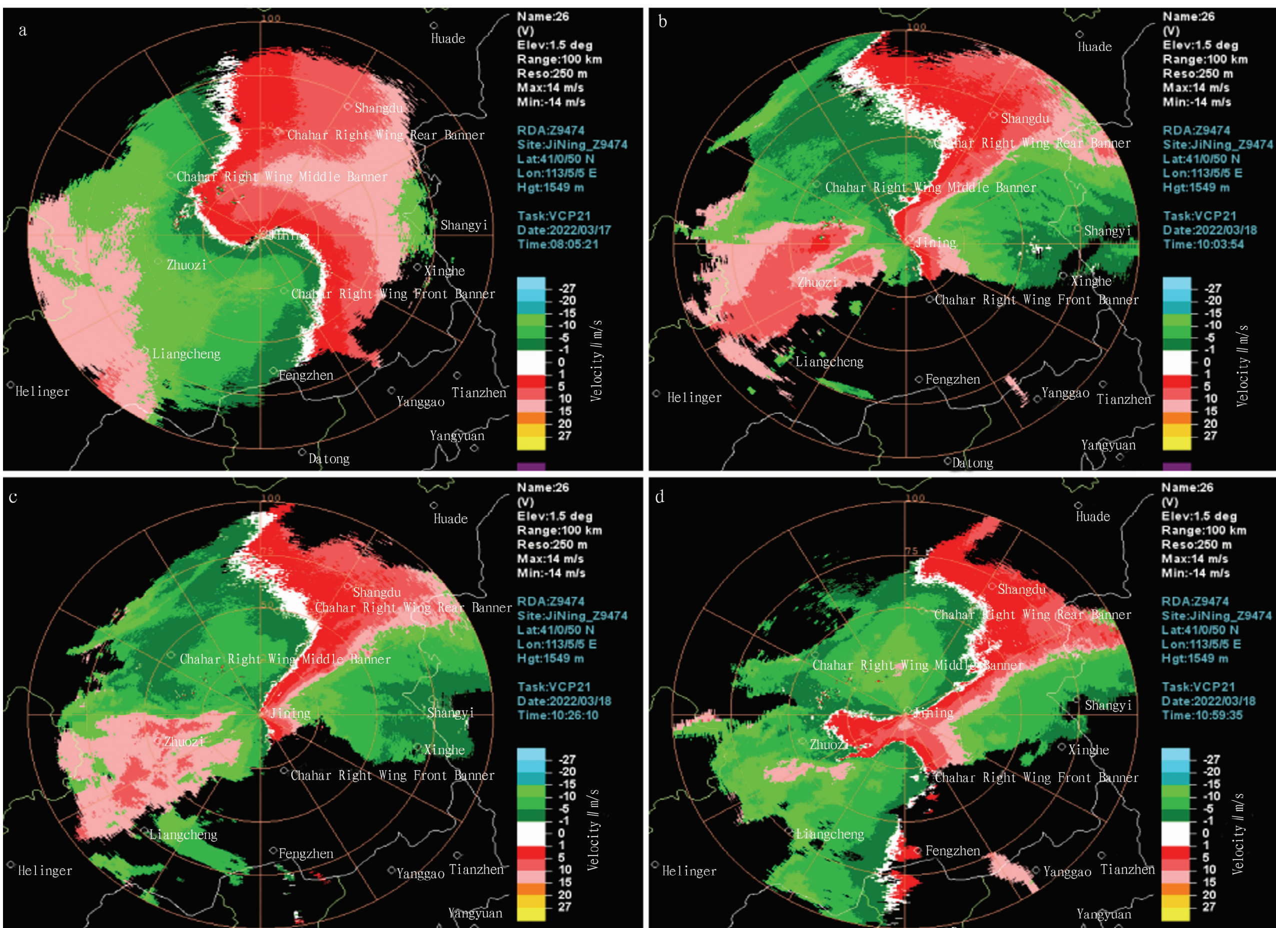

Fig. 7 Maps of radar radial velocity in Ulanqab City at 08:05 (a), before (b), during (c) and after (d) the transit of the front on the 17th

ment in Siziwang Banner was the strongest in the process, and occurred from 850 to 300 hPa. The large-value area of vertical velocity was at 700 hPa, and it was up to −1.8 Pa/s.

4 Characteristics of radar echoes

The top height of echoes in most areas was 3 – 5 km, reaching more than 5 km in local areas (Fig. 6a). From the perspective of combined reflectance, the precipitation echoes were mainly flaky from 08:00 on the 17th, affecting the central and southern regions, and scattered cotton echoes were dominant from evening to night. At about 08:00 on the 18th, the echoes reorganized into sheets, and gradually moved to the southeast. During the process, composite reflectivity ranged from 15 to 25 dBZ in most areas, reach 30 – 35 dBZ in local areas (Fig. 6b).

In the radial velocity field (1.5° elevation angle), from 08:00 on the 17th to 08:00 on the 18th, Ulanqap City was mostly controlled by southwest and westerly wind, and the zero velocity line was positively "S"-shaped; the wind turned along with the height, indicating warm advection. At 08:00 on the 18th, the wind first turned along with the height and then reversed in the northerly area (Fig. 7a), indicating that the warm and cold advection intersected. After 08:00, the zero velocity line gradually extended from northwest to southeast, that is, there was southwest wind at both high and low altitudes. As the cold front gradually moved eastwards and southwards, the velocity field showed a typical cold front shape. Around 10:00, the velocity was negative in the northwest and southwest at the rear of Jining station and positive in the northeast of Jining station, indicating that Jining station was located in front of the cold front (Fig. 7b). At around 10:26, the cold front passed through the city (Fig. 7c). Jining station was controlled by the northwest air flow, and negative speed changed into positive speed from southwest to northeast in the lower reaches (Fig. 7d). Then Ulanqab City was gradually controlled by northwesterly wind, and the snowfall tended to end.

5 Conclusions

Based on the observation data of meteorological stations, Doppler radar observation data, and ERA-5 reanalysis data of Ulanqab City, a snowstorm process in Ulanqab City in the early spring of 2022 was analyzed.

(1) This process involved a wide range, and had a long duration and large snowfall. It was accompanied by the transformation of rain, sleet, and snow, belonging to type II snowstorm. The main precipitation period can be divided into two stages: in the first stage, snowfall was small, lasted for a long time, and was distributed evenly in space; in the second stage, rainfall was heavy, lasted for a short time, and was dispersed in space. The snowfall in the process increased from north to south, and was larger in some areas.

(2) The snowfall process was formed under the combined influence of short-wave trough at 500 hPa, transverse trough 700 hPa, closed low-pressure system at 850 hPa, surface low-pressure inverted trough, frontal cyclone and other systems. The barrier of the downstream ridge of the trough on the 17th made the trough last longer, and the ground low-pressure inverted trough provided sufficient water vapor transport, so the duration was longer. On the 18th, there was a transverse trough at 700 hPa and a frontal cyclone on the ground. Overall, the system was stronger than that on the 17th, and the upward movement was strong, so the precipitation intensity was greater.

(3) During the process, the water vapor at 700 hPa was more in the south and less in the north, which tended to be consistent with the spatial variation of snowfall. At 08:00 on the 18th, a wet tongue in the southwest of Ulanqab extended to the west of central Ulanqab, and the negative large-value area of water vapor flux divergence corresponded to it. At the same time, the specific humidity field in the west of the region was perpendicular to the wind field, showing that sufficient water vapor and water vapor transport were compatible with strong water vapor convergence.

(4) The strong upward motion was one of the reasons for the high intensity of hourly precipitation on the 18th. In Siziwang Banner, when the hourly snowfall was strong, the ascending movement appeared from 850 to 300 hPa, and the large-value center of the ascending movement was near 700 hPa. There was a divergence field at 500 hPa and a convergence field from 700 hPa to the ground. A strong upward motion was formed under the cooperation of suction.

(5) During the process, the top height of echoes was 3 – 5 km in most areas and more than 5 km in local areas. The composite reflectivity ranged from 15 to 25 dBZ in most areas and from 30 to 35 dBZ in local areas. The echoes were mainly flaky and accompanied by scattered cotton echoes. The zero velocity line of radial velocity was "S"-shaped, indicating that it was controlled by southwest and westerly winds in most of the time, and there was obvious warm advection. There was cold advection in the northern area at about 08:00 on the 18th. Meanwhile, the cold front passed through the city on the morning of the 18th, and after the transit, Ulanqab City was gradually controlled by northwest wind, and the snowfall tended to end.

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air brought by the southward movement of the upper frontal zone and the warm and humid air outside the subtropical high.

(2) At 500 and 700 hPa, there were two troughs and one ridge, and the southwest jet existed at the lower level, which provided very favorable water vapor conditions and unstable energy conditions for the rainstorm process, and promoted the occurrence of upward movement.

(3) In terms of temperature conditions, the intrusion of strong cold air at the rear of the frontal zone after the precipitation was the main feature of the frost and cold wave weather process.

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