Meteorological and Environmental Research 2024, 15(1): 8 – 11

Analysis of a Strong Sandstorm Process in Ulanqab City

Biyun LI * , **Yu XUE**, **Yanni SONG**

Ulanqab Meteorological Bureau, Ulanqab 012000, China

Abstract Based on NCEP reanalysis data, EDAS data and ground observation data, the causes of a strong sandstorm process in Ulanqab City from March 14 to 15, 2021 were analyzed. The analysis shows that "3.15" sandstorm, a sandstorm process accompanied by northwest gale behind the front, was caused by strong cold air in the north. In the early stage, the Mongolian cyclone resulted in the increase of temperature and decrease of pressure on the ground. When a strong surface cold high pressure at the rear of the cyclone invaded the city, a strong pressure gradient between high and low pressure provided dynamic conditions for the sandstorm outbreak. The transit of the surface cold front was the sign of the sandstorm outbreak, and the downward transmission of momentum at high altitudes increased the wind speed near the surface.

Key words Cold front; Gradient wind; Downward transportation of momentum

DOI 10.19547/j.issn2152 – 3940.2024.01.002

Sandstorm refers to a disastrous weather phenomenon, meaning that strong winds sweep up a large amount of sand and dust from the ground to make horizontal visibility less than 1 000 m, which will bring great harm to social production and life as well as life and property safety. Located in the middle of Inner Mongolia, Ulanqab City has a semi-arid continental monsoon climate in the middle temperate zone. The annual precipitation is small, and has high variability. The frequency of sandstorm has decreased in recent years. On March 14, 2021, a large-scale sandstorm appeared in Mongolia, entered Inner Mongolia on the night of March 14, and moved rapidly eastward and southward, bringing a large-scale sandstorm weather phenomenon affecting northern China. The sandstorm weather was strong in intensity, wide in scope, long in duration and great in impact, and most parts of Ulanqab City suffered strong sandstorm, among which the lowest visibility was only 89 m. It was the strongest dust weather process in Ulanqab City in nearly 20 years.

1 Actual situation of the weather

1.1 Visibility On the night of March 14, sandstorm broke out in Ulanqab City. To 23:00 on March 14, the visibility of Siziwang Banner observation station dropped quickly from nearly 10 000 m to less than 500 m in less than an hour, and then sandstorm became strong from the northwest to the southeast in most areas of the city. At 01:00 on March 15, the minimum visibility of Xinghe County was only 89 m. The process was accompanied by force 5 – 6 northwest wind, and the force of instantaneous wind was up to 8 – 10. To 11:00 on March 15, the visibility of the city rose to more than 1 000 m, and it changed into blowing sand weather. The main body of sand dust moved southeastwards with the northwest wind, affecting Shanxi, Beijing and other places. On the night of March 15, the visibility in Ulanqab rose to more than 10 000 m, and the dust weather process ended in Ulanqab City.

1.2 Temperature Before the invasion of the sandstorm, Ulanqab was controlled by a warm ridge, and the ground was abnormally warm. The daily average temperature was 5.1 – 11.4 ℃ higher than that of the normal year. The warming and depressurization in the early stage and the clear and dry atmosphere were conducive to the development of the surface cyclone, and also accumulated heat energy for the formation of the sandstorm. In the early morning of March 15, the sandstorm weather entered Ulanqab, and the temperature dropped sharply, with a drop of 1.7 – 9.7 ℃ in 3 h. The surface pressure increased rapidly, and it was under the control of high pressure.

1.3 Wind direction and speed Before the passage of the cold front, the wind force decreased, and the surface wind direction changed from southwest to northwest. Afterwards, the wind force quickly increased. In Siziwang Banner, at 23:00 on March 14, strong sandstorm weather appeared, so that the visibility plummeted to less than 500 m. Meanwhile, the wind speed first dropped and then rose, and the wind direction changed from southwest to northwest. The maximum wind speed reached 16.1 m/s, indicating that there was a front crossing during this time (Fig. 1).

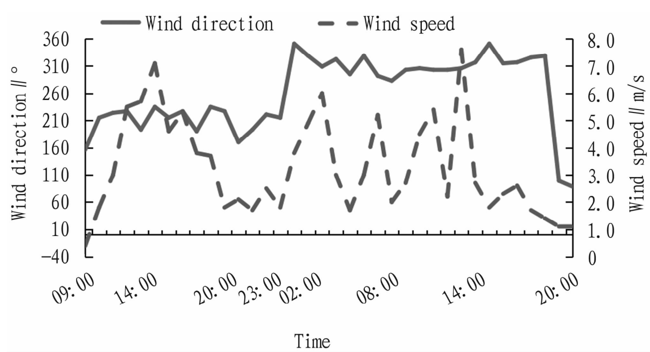

Fig. 1 Changes in hourly wind direction and speed in Siziwang Banner from 09:00 on March 14 to 20:00 on March 15

Received: December 11, 2023 Accepted: January 18, 2024

* Corresponding author.

2 Movement paths of dust

According to EDAS data, the backward trajectory of sandstorm in the city was analyzed. As shown in Fig. 2, there were representative airflow paths at an altitude of 500 and 3 000 m above the ground respectively. From 22:00 on March 14 to 08:00 on March 15, the track of the air flowing through Ulanqabu at 500 m was reversed hour by hour. It is obvious that there was southwest wind before 01:00 on March 15, and it suddenly changed to the northwest wind at 01:00 on March 15, which was consistent with the change of the surface wind direction and the time of dust outbreak, indicating that the low-altitude path represented by a height of 500 m was the main transmission path of dust. It can be seen that the dust of this sandstorm weather was mainly from central and eastern Mongolia. The track of the air flowing through Ulanqab City at a height of 3 000 m from 22:00 on March 14 to 08:00 on March 15 was reversed hour by hour, and the air path gradually changed from west to northwest. Compared with the jet stream zone and cold advection below, it can be seen that this path was the development path of high-altitude cold air.

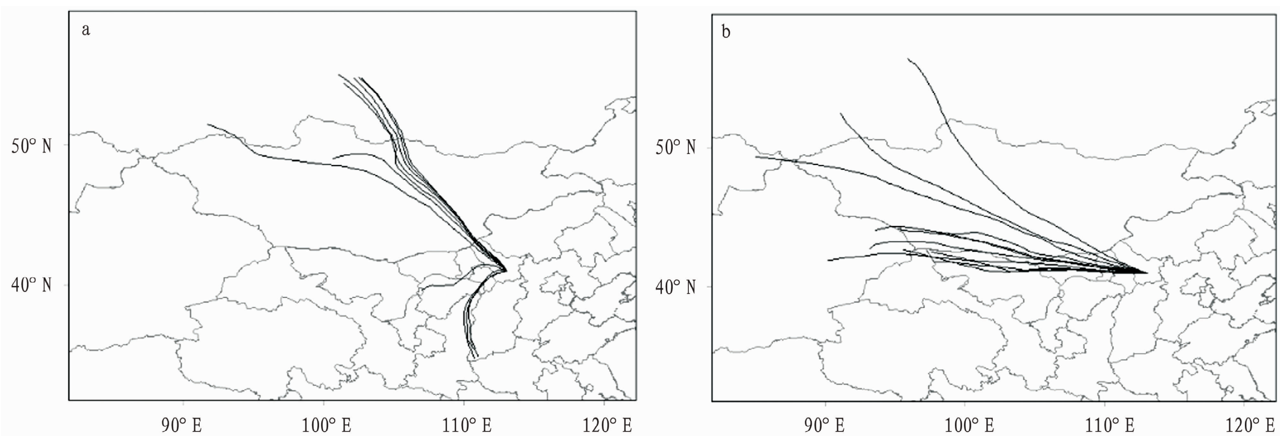

Fig. 2 Backward trajectory analysis at 500 (a) and 3 000 m (b) from 22:00 on March 14 to 08:00 on March 15

3 Circulation pattern

3.1 Middle troposphere In the early stage, the middle latitudes of Eurasia were controlled by the meridional circulation, and the circulation was flat. The Ural Mountains and eastern Asia were controlled by a long-wave high ridge, and there was a northeast – southwest long-wave trough in West Siberia. The central and eastern Inner Mongolia were controlled by a warm ridge, with clear weather and high temperature. At high latitudes, the polar vortex tended to the Eurasian continent, and formed a deep cold trough to the east of Novaya Zemlya. On March 14, the transverse trough in West Siberia moved eastward, moving more than 20° in 24 h, and the two westerly wind troughs in middle and high latitudes joined together into a deep East Asian trough. The high pressure ridge over the Ural Mountains strengthened, and the circulation pattern of Eurasia changed into a trough and a ridge. Due to the strong pressure gradient in the trough, the northerly air behind the trough was guided southwards[1].

3.2 Lower troposphere The contour lines in front of the cold trough diverged, and the temperature trough laged behind the height trough. The baroclinic structure was obvious. With the decrease of height and the eastward movement of cold trough, the intersection angle between the temperature and pressure fields increased, and the cold advection increased. In the early morning of March 15, a closed cold vortex formed in the middle and lower troposphere, and there was a closed high pressure center at the rear of the cold vortex. Isobaric lines between high and low pressure were dense, and the intersection angle with the isotherm was greater than 45°. The cold advection was strong (Fig. 1a).

3.3 Ground In the early stage, the cyclone over Lake Baikal developed and moved eastwards. By 20:00 on March 14, the central intensity reached 985 hPa. The cold high pressure behind the cyclone rapidly moved eastwards and developed. The high-pressure center rapidly moved eastwards from the north of Xinjiang to the west of Lake Baikal, and the central intensity reached 1 037.5 hPa[2]. Due to the development of surface cyclones and cold high pressure, the isobars between high and low pressure transition zones became denser and the pressure gradient increased (Fig. 1b).

4 Analysis of physical quantity field

4.1 High- and low-air jet stream zone From March 13 to 15, a continuous jet stream zone appeared from the west of Mongolia to the central and eastern parts of Inner Mongolia in the middle and lower troposphere. The central wind speed of the upper jet stream zone was more than 40 m/s at 500 hPa and over 20 m/s at 700 hPa. At 20:00 on March 14, the wind direction changed from a flat westerly air flow to a northwest air flow at 700 hPa, and the wind speed in the jet stream zone changed from southwest to northwest at 850 hPa. The jet stream zone covered the central part of Inner Mongolia to Ulanqab City.

4.2 Temperature advection On March 14, the high- and low-air cold advection over Mongolia developed strongly from west to east. At 20:00, it developed southeastwards, and entered China from the central and eastern part of Inner Mongolia to develop towards North China.

4.3 Horizontal divergence and downward transportation of momentum On the night of March 14, the horizontal divergence field over Ulanqab City showed a form of high-altitude convergence and low-altitude divergence, and there was a unified sinking movement area from high altitude to the ground (Fig. 4a). It can also be seen from the profile of wind speed that there was an obvious downward bulge in the wind speed line on the night of March 14, and upper-altitude momentum transmitted downward, so near-surface wind speed increased[3] (Fig. 4b).

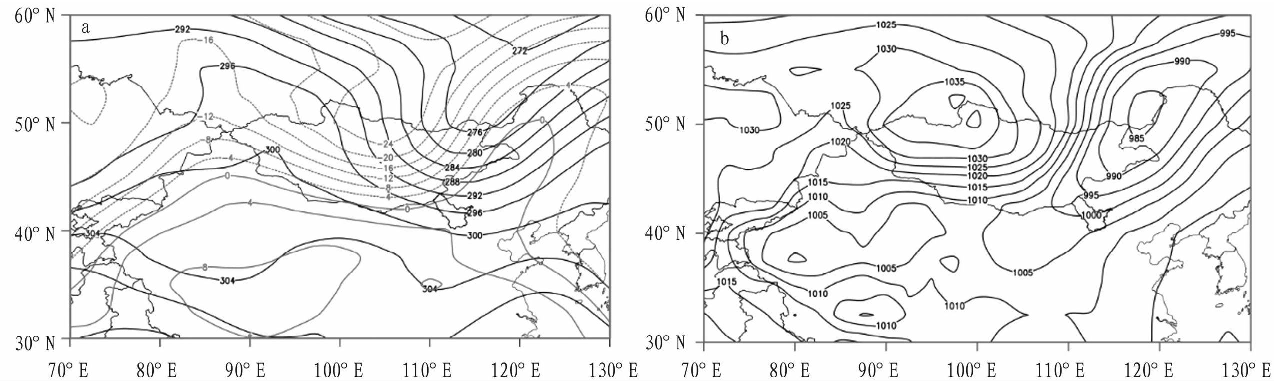

Fig. 3 Circulation field at 700 hPa (a) and sea level pressure field (b) at 20:00 on March 14

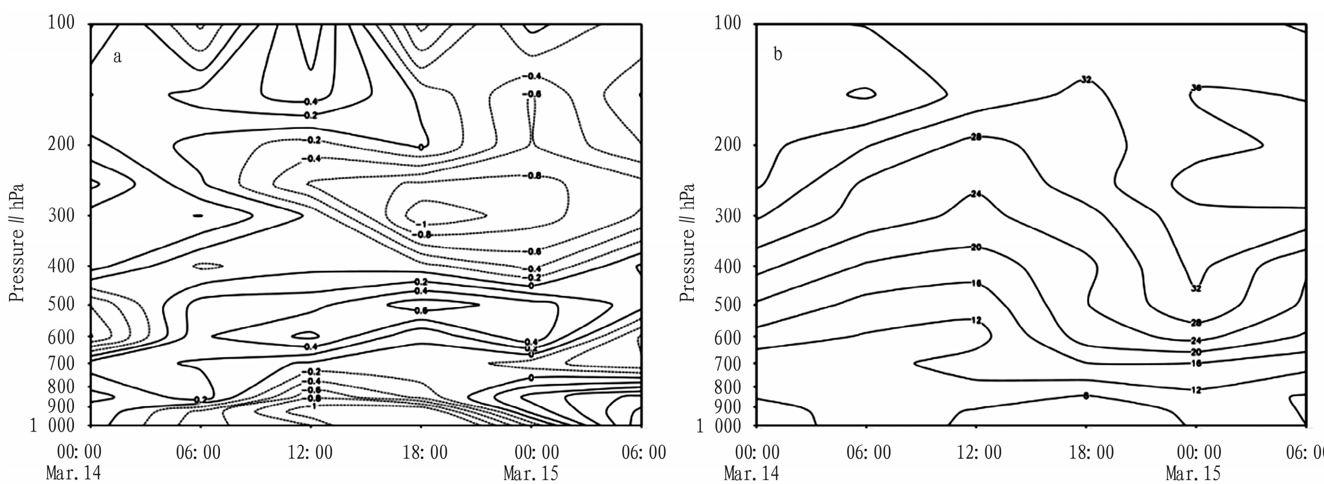

Fig. 4 Divergence (a) and wind speed profiles (b) over Ulanqab City

4.4 Vorticity Vorticity is a physical quantity that characterizes the rotation characteristics of air mass. In the early stage, there was a positive vorticity center and conversive upward motion in both high and low altitudes over Ulanqab City[4], which was conducive to the development of surface Mongolian cyclones. In the early morning of March 15, Wulanqab City was in the same negative vorticity area, with downdraft, which was conducive to the development of surface cold high pressure.

5 Influence systems

5.1 Mongolian Cyclone and Mongolian Cold High In the early period, the Mongolian cyclone developed in Ulanqab City, with high temperature and low pressure. Then, the surface cold high pressure moved eastward and strengthened. During the development of high and low pressure, the pressure gradient increased, and the isobars were more dense; the gradient wind was strengthened, and the combination of high and low pressure guided the northerly air flow between high and low pressure to move southwards. Ulanqab City was in the transition zone of high and low pressure; the pressure gradient was large, and the gradient wind was strong, which was conducive to the increase of the surface wind speed.

5.2 Polar vortex In the early stage, the polar vortex was biased to Eurasia, bringing polar cold air to Eurasia, so that high-latitude westerly trough deepened, and the cold air accumulated behind the trough, forming a cold center. When it merged with the mid-latitude westerly trough, the cold air slid down along the northwest air behind the trough, bringing gale and cooling.

5.3 Cold front system

5.3.1 High-altitude frontal zone. The isotherms were dense, and the temperature gradient was large; the front zone was strong and developed strongly. The front zone was nearly vertical below 700 hPa at 02:00 on March 15, and was over Ulanqab City.

5.3.2 Ground frontal zone. The isobaric lines were dense, and the gradient wind was strong. The thermal wind accelerated and strengthened the baroclinicity of the atmosphere, thus increasing the geostrophic deviation wind and aggravating the development of strong sandstorms. A cold front moved southeastwards on the ground. There was a large 3-h positive variation of pressure behind the front, and the barotropic wind was strong.

6 Conclusions

(1) The dust weather was a cold front type strong sandstorm process, and the main body of dust entered Ulanqab City from the central part of Inner Mongolia, and moved from the northwest to the southeast, resulting in a large range of dust weather in the north.

(2) The invasion of surface cold front was an important dynamic mechanism of sandstorm outbreak. When the visibility plummeted, the wind direction changed from southwest to northwest. The wind force first dropped and then rose, so the temperature plummeted. As the main body of cold high pressure affected our city after the transit of cold front, the wind force declined, and the dust weather basically ended.

(3) Downward transmission of upper-level wind momentum was the main reason for the development of dust weather. In the early stage, strong cold air accumulated in West Siberia. When the transverse trough turned to be vertical, the cold air moved rapidly eastwards along the westerly jet with the cold trough or the small trough in front of it. The subsidence motion combined with high-altitude convergence and low-altitude divergence made the high-altitude wind momentum pass down, and the near-surface wind increased, forming a strong frontal zone with a lot of wind and sand.

(4) Before the emergence of strong sandstorms, on the 500 hPa upper chart, there was a high-pressure ridge over the Ural Mountains or its west side, while a deep cold trough was formed in West Siberia, and a circulation pattern of a trough and ridge was formed in the middle and high latitudes of Eurasia.

References

[1] WANG KL, JIANG Y, WU H. Circulation dynamical structure in course of dust storm occurrence in North China in spring of 2001[J]. Plateau Meteorology, 2002(3): 303 –308.
[2] HU ZY, HUANG RH, WEI GA, *et al.* Variations of surface atmospheric variables and energy budget during a sandstorm passing Dunhuang on June 6 of 2000[J]. Chinese Journal of Atmospheric Sciences, 2002(1): 1 –8.
[3] SONG GY, LI ZJ, WANG DM, *et al.* Analysis on 3.19 sandstorm in mid-west area of Inner Mongolian[J]. Journal of Arid Land Resources and Environment, 2012, 26(6): 47 –51.
[4] AN TT, GUO PP, DING F, *et al.* Diagnostic analysis of a gale dust weather in Hexi Corridor[J]. Gansu Science and Technology, 2019, 36(22): 28 –30.

(From page 7)

[3] ZHI SL, BAO HM, ZHANG C. Convective conditions and characteristics analysis of regional torrential rain from midnight with flood hazards [J]. Torrential Rain and Disasters, 2017, 36(1): 42 –52.
[4] SUN SQ, ZHANG Y, ZHENG J, *et al.* Study on the causes of regional rainstorm in southern Jiangxi during 18 –19 May, 2015[J]. Meteorology and Disaster Reduction Research, 2017, 40(1): 15 –21.
[5] QIAN HC, MA ZY, HE W, *et al.* Diagnostic analysis of a heavy rain process on Meiyu front[J]. Jiangxi Science, 2022, 40(2): 283 –286.
[6] LONG YL, WU F, QUE ZP, *et al.* Analysis of a local heavy rainstorm process in northern Jiangxi[J]. Meteorological Science and Technology, 2018, 46(6): 1211 –1220.
[7] XU B, XIONG QF, ZHANG YT. Analysis of moisture source and transport pathways of a rainstorm with tropical cyclone in Nanchang[J]. Meteorological Monthly, 2019, 45(10): 1392 –1401.
[8] ZHOU Y, SHENG ZJ, XU AH, *et al.* Comparative analyses of two convective rainstorms in northern Jiangxi in June 2016[J]. Meteorology and Disaster Reduction Research, 2016, 39(4): 269 –276.
[9] WANG LY, WEN XL, XU WM, *et al.* Analysis on the characteristics of high-influence weather variation in Changbei International Airport from 1956 to 2019[J]. Meteorological and Disaster Reduction Research, 2021, 44(4): 311 –317.
[10] ZHANG FP, XU XF, CHENG JQ, *et al.* Variation characteristics of graded rainy days and rainfall amount in Poyang Lake area[J]. Journal of Yangtze River Scientific Research Institute, 2020, 37(7): 22 –28, 34.
[11] ZHENG J, XU AH, SUN SQ, *et al.* Forecast error analysis of extremely heavy rain under high-level northwest flow[J]. Meteorological Monthly, 2018, 44(1): 93 –106.
[12] WANG RL, WU F, LIU ZP, *et al.* Variation characteristics of urban meteorological disasters over the past 60 years in Nanchang[J]. Meteorology and Disaster Reduction Research, 2014, 37(2): 44 –49.
[13] CHEN YH, SHAN JS, LI J, *et al.* Causes and meso-scale characteristics of the short-duration rainstrom in Nanchang on 29 June 2022[J]. Torrential Rain and Disasters, 2023, 42(2): 124 –133.
[14] DENG HX, ZHI H, MA ZY, *et al.* Analysis on characteristics of rainstorm echo in flood season districts and cities of Jiangxi Province in 2017[J]. Journal of the Meteorological Sciences, 2019, 39(2): 274 –284.
[15] CHEN XX. Mesoscale analysis of heavy rainstorm in northern Jiangxi on May 12, 2012[C]// Chinese Meteorological Society. S1 Disaster weather research and forecast. 2012: 9.
[16] CHEN YH, CAI J, ZHI SL. The meso-scale characteristics and genetic analysis of a heavy rainstorm in Jiangxi Province[J]. Meteorology and Disaster Reduction Research, 2011, 34(2): 34 –42.
[17] XU AH, SUN JS, XU DB, *et al.* Basic synoptic situation classification and element character of severe convection in China[J]. Meteorological Monthly, 2014, 40(4): 400 –411.