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# Analysis of Causes and Mesoscale Cloud Clusters of a Backflow Blizzard Process in Central Inner Mongolia

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**Abstract** Based on the conventional observation data, daily reanalysis data from NCAR/NCEP, and TBB data derived from FY-2G infrared cloud images in April 2018, a heavy snowfall weather process in central Inner Mongolia from April 4 to 6 in 2018 was analyzed. The results show that the low trough at 500 hPa, the southerly wind jet stream at 700 hPa, and the inverted trough on the ground were the main influencing systems causing this blizzard. The transportation of warm and humid air by the southerly wind jet stream at 700 hPa and intense water vapor convergence provided sufficient water vapor conditions for the blizzard, and the moist layer in the blizzard area was deep. The low-level MPV in the blizzard area was $<0$, and the atmosphere was in a conditional symmetric instability state. The coupling of the upper and lower-level jets induced strong ascending motion. With the invasion of cold air, a low-level cold pad was formed, so that the warm and humid air tilted upward. The secondary circulation updraft triggered by the wet Q vector system released the conditional symmetric instability energy, so that the sloping motion was more intense, and the heavy snowfall appeared. Meanwhile, there was a good correspondence relationship between the blizzard area and the large-value area of low-level wet Q vector divergence. The mesoscale cloud clusters continuously generating, merging, and moving eastward in Hetao area were the direct cause of this blizzard, and the TBB of the cloud clusters was $\leqslant -56$ ℃. The blizzard happened in the the edge gradient and large-value area of TBB.

**Key words** Blizzard; Cold pad; Conditional symmetric instability; Wet Q vector; Mesoscale cloud cluster

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The damage caused by blizzards to the national economy and people's lives is sometimes even greater than that of rainstorms. They often cause huge losses to urban transportation, forestry, and animal husbandry. Since blizzard weather is formed under the combined effect of multiple weather systems, its formation mechanism is complex, and it is difficult to predict. A large amount of research has been conducted worldwide on blizzards. Studies have shown that snowfall in Europe and America is closely related to the formation and development of temperate cyclones. In China, blizzards mostly occur in the northeastern regions, the northwestern regions, and their plateau mountainous areas[1]. The backflow weather in North China means that cold air moved southward from the northeastern plain and entered the North China Plain via a slightly eastern route through the Bohai Sea. The complexity of the path and intensity of cold air in the backflow weather in North China as well as the influence of terrain cause the diversity of the backflow weather[2–4]. Wu Qingmei *et al.*[5] proposed that the warm moist air moved on the dry cold air, which is the direct reason of the snowstorm in Beijing. There are many types of blizzard weather in Inner Mongolia[6], and the common types of blizzard weather are weak cold air types (trough-vortex type, shear type, and north trough-south vortex type) and strong cold air types (Mongolian trough (vortex) type, Baikal Lake trough (vortex) type, and westward baroclinic trough type), and backflow weather is also a type of blizzard weather in Inner Mongolia. Ma Suyan *et al.*[7] pointed out that low-level cold cushion is an important condition for the formation of blizzards, and the strongest snowfall occurs during the period when the front zone is the strongest and is beginning to weaken. In this paper, the causes of a backflow blizzard process and characteristics of mesoscale cloud clusters in central Inner Mongolia from April 4 to 6 in 2018 were analyzed to improve the forecasting and warning capability of backflow blizzards.

## 1 Data and methods

Based on hourly precipitation data and routine observational data from ground meteorological observation stations, NCEP/NCAR 1° × 1° reanalysis data, and TBB data derived from FY-2G hourly infrared cloud images, the weather dynamic method and satellite meteorology were employed to analyze the configuration of weather system, unstable conditions, triggering mechanisms, and the evolution characteristics of mesoscale cloud clusters during this blizzard, so as to provide a certain reference for the forecast of backflow blizzards in the future.

## 2 Weather conditions and circulation background

**2.1 Snowfall conditions** From April 4 to 6, 2018, a widespread snowfall process occurred in central Inner Mongolia, Shanxi, Hebei, Beijing, and Tianjin (North China). This process was characterized by extensive snowfall area, large snowfall, and concentrated heavy snowfall. The 24-hour snowfall from 08:00 on April 4 to 08:00 on April 5 reached the blizzard level, covering

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areas such as the southeast of Ordos, the south of Hohhot, the south of Ulanqab in Inner Mongolia, northern Shanxi, and the central and northern parts of Hebei. The blizzard areas were located near 40° N and distributed in a band-like pattern. Heavy blizzards (20 – 29.9 mm) appeared at 6 stations, and the maximum snowfall occurred in Huiren County in Shanxi, reaching 27 mm. In the center of Inner Mongolia, 12 stations experienced blizzards, and the snowfall in Yijinhuoluo Banner reached the heavy blizzard level (21 mm). From the distribution map of 3-hour snowfall (omitted), it can be seen that the heavy snowfall in the southeastern part of Ordos mainly occurred from 11:00 to 14:00 on April 4, and the maximum snowfall appeared in Yijinhuoluo Banner, up to 13.1 mm. In the other areas, the heavy snowfall mainly occurred from 14:00 to 17:00 on April 4, and snowfall was the maximum (13.6 mm) at Jining station, having characteristics of mesoscale snowfall. After 20:00 on April 4, the snowfall significantly decreased. From 08:00 on April 5 to 08:00 on April 6, there were still small amounts of snowfall in the west of Hohhot and Ulanqab with the intrusion of strong cold air, and then the snowfall gradually came to an end.

**2.2 Circulation situation** At 08:00 on April 4, there were two troughs and two ridges at 500 hPa in the middle and high latitudes of Asia, cutoff low pressure above the Sea of Okhotsk, a low trough on the western side of Baikal Lake, and a wide low trough on the eastern side of the Qinghai – Xizang Plateau, while the central and western regions of Inner Mongolia were under the control of the southwest airflow before the trough. A strong upper-level jet stream at 200 hPa and a low-level jet stream from the south wind cooperated to form a secondary circulation. At 850 hPa, the prevailing southerly airflow formed a cold layer, providing favorable dynamic uplift conditions for this snowfall weather. At 08:00 on April 4, the central region of Inner Mongolia was between the high and low pressure systems, and was controlled by southerly airflow. As the cold air from Xinjiang invaded, the trough in the west of Hetao area broke into two parts, and they moved southward and northward, respectively. The northern part moved to the Mongolian region and developed into a Mongolian cyclone. At 20:00 on April 4, the Mongolian cyclone passed over the blizzard area, and the snowfall significantly weakened.

## 3 Deep moist layers and intense water vapor convergence

The transport of warm and humid air currents plays a decisive role in the occurrence and persistence of blizzards, and the local aggregation of warm and humid air currents is of great significance for the occurrence of severe blizzards. When the thickness of the moist layer reaches 700 hPa, it can provide sufficient water vapor for the generation of rainstorms, and the moist layer of blizzards is even thicker. At 08:00 on April 4, 2018, a southerly jet stream was established at 700 hPa and persisted until 17:00 on April 4, and warm and humid air was transported to the blizzard area. At 14:00 on April 4, there was ≥6 g/(s · hPa · cm) water vapor flux at 600 and 500 hPa and strong southerly water vapor flux at 700 hPa in the central part of Inner Mongolia (Fig. 1a), and the southern part of the blizzard area (referring to the blizzard area in the central part of Inner Mongolia, hereinafter referred to as the blizzard area) was the large-value region of water vapor flux gradient, and warm and humid air was continuously transported to the blizzard area. There was wet advection in the time vertical section of dew point advection from 700 to 200 hPa. At 14:00 on April 4, the specific humidity at 850 – 500 hPa in the blizzard area remained above 2 g/kg, and a large and deep moist layer was maintained from the blizzard area to 300 hPa, with a relative humidity of over 90%. The zonal vertical cross-sectional diagram of water vapor flux divergence along the 113.4° E of the blizzard center (Fig. 1b) show that there was obvious convergence at 700 – 500 hPa in the blizzard area, and the convergence area shifted northward with height; the southerly warm and humid air flow at 700 hPa moved northward and rose along the cold layer at 850 hPa, gradually condensing water vapor to produce snowfall.

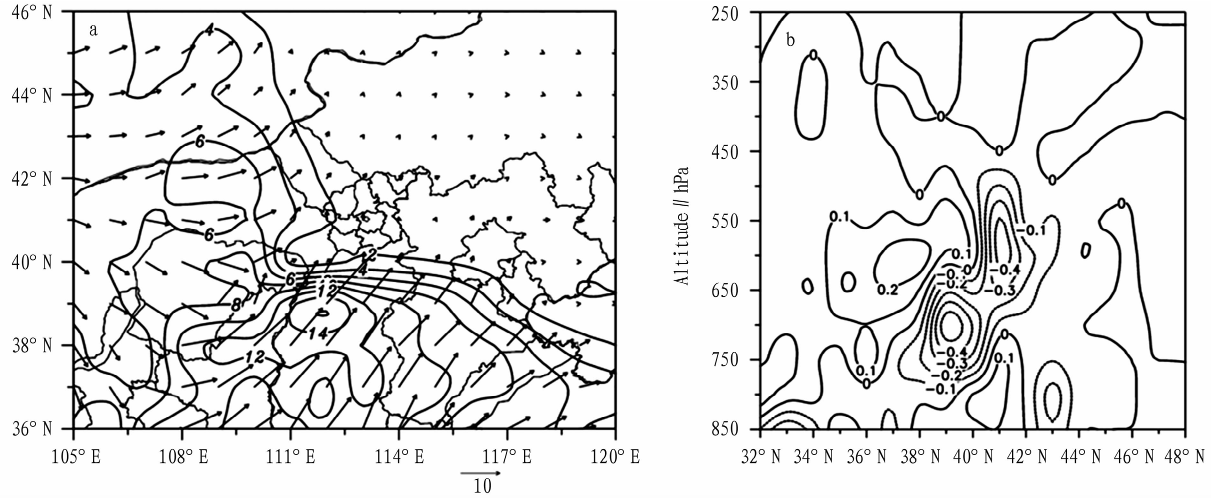

**Fig. 1 Water vapor fluxat 700 hPa (a) and zonal vertical cross-sectional diagram of water vapor flux divergence along 113.4° E (b) at 14:00 on April 14, 2018**

## 4 Conditional symmetry instability

Symmetry instability refers to a phenomenon of instability that occurs when there is a wind speed shear in the basic airflow, even if it is convective stable and inertial stable in vertical and horizontal directions, respectively, but when the air rises vertically, it may still occur due to the combined effect of buoyancy and rotation. In mesoscale weather, symmetry instability often develops, so it is also called mesoscale symmetry instability. Wet potential vorticity is widely used in the study of cyclones, rainstorms, and blizzards. The downward transport of high potential vorticity in the stratosphere can cause the development of ground cyclones, that is, there was an increase in cyclonic vorticity. In the p-coordinate system, wet potential vorticity can be expressed as the sum of the isobaric term and the inviscid term. $MPV < 0$ indicates conditional symmetry instability.

Before the snowfall began at 08:00 on April 4 (Fig. 2a), the horizontal distribution of MPV at 750 hPa reveals that MPV was $<0$ in the entire blizzard area and its adjacent regions, and they were controlled by weak conditional symmetry instability. At 14:00 on April 4 (Fig. 2b), the area with $MPV > 0$ in northeastern Hebei continuously expanded towards the southwest, while the area with $MPV > 0$ in the north of Hetao area expanded towards the southeast. Eventually, the stable zones in the east and west connected, so that the area with $MPV < 0$ was divided into northern and southern sections. The northern section was V-shaped, and covered the blizzard area from the west to the east of Ulanqab, while the blizzard area in the west of Hetao area was covered by the southern section ($MPV < 0$).

From the radial vertical section along 44.2° N at 14:00 on April 4 (Fig. 2c), it can be seen that the unstable zone ($MPV < 0$) of the blizzard area extended from 850 hPa to 700 hPa, and the unstable layer was deep, which was conducive to the generation of heavy snowfall. The distribution map of pseudo adiabatic temperature and pseudo potential temperature at 700 hPa at 14:00 (Fig. 2d) presents that the cross-product of pseudo adiabatic temperature and pseudo potential temperature in the blizzard area was positive, allowing the fluid to maintain $MPV < 0$. Humidity increased in the direction of thermal wind, and conditional symmetry instability still persisted. That is, it was still conducive to the generation of heavy snowfall after 14:00. At 20:00 (the figure is omitted), the snowfall significantly decreased in the blizzard area with $MPV > 0$.

## 5 Rising and triggering mechanisms

**5.1 Thermal convection** At 14:00 on April 4 (Fig. 3), there was a southerly airflow at 850 hPa in the blizzard area, and a cold advection zone (from $-1\times10^{-4}$ to $-3\times10^{-4}$ K/s) was formed. Relative humidity (RH) was $\geqslant 90\%$, and a low-level moist cold cushion was formed. A southward low-level jet stream was established at 700 hPa, and the front end of the jet stream extended to the north of Shanxi Province. Moreover, a warm advection zone ($1\times10^{-4}-4\times10^{-4}$ K/s) appeared. The warm advection zone extended to 500 hPa, and intensified with height. The warm and humid air in the middle and lower layers climbed along the cold cushion. On the one hand, the appearance of the cold cushion not only caused the temperature in the boundary layer to decrease; on the other hand, the constructed "wedge-shaped" triggering mechanism forced warm and humid air to climb northward and upward on it. Therefore, the appearance and intensity of the cold cushion were particularly important for the generation of the backflow blizzard[20]. Moreover, the cold advection center appeared before the heavy snowfall, which has predictive significance. By 20:00 on April 4, with the invasion of the strong cold air from the upper layer, the cold cushion gradually disappeared, and the snowfall significantly weakened. At 02:00 on April 5, there was cold advection in the entire layer, and the snowfall further weakened.

**5.2 Wet Q vector system** After the necessary water vapor conditions for heavy precipitation are met, strong upward motion is indispensable. Existing studies have shown that the non-geostrophic wet Q vector divergence has good physical significance for diagnosing mesoscale vertical motion and rainstorm, and good results has been achieved. However, there are few studies on the diagnosis of blizzards based on it. Next, it was used to diagnose the vertical motion and the falling area of the blizzard, providing new ideas for the prediction of blizzards. The results of non-geostrophic wet Q vector divergence show that at 08:00 on April 4 before the snowfall happened, there was a weak wet Q vector divergence convergence zone at the junction of Inner Mongolia and Shanxi. By 14:00 on April 4 (Fig. 4a), the wet Q vector divergence field at 600 hPa strengthened into a mesoscale band-like convergence zone. The blizzard area was near the convergence center of wet Q vector divergence, and the center value of wet Q vector divergence reached $-20\times10^{-16}$ $hPa^{-1}\cdot s^{-3}$. By 20:00 on April 4, the Q vector convergence zone significantly weakened, and moved southward out of the blizzard area, so the snowfall significantly weakened. Q vector divergence triggered secondary circulation. At 14:00 on April 4 (Fig. 4b), a vertical section was made along 113.4° E in the blizzard center, and there was a good correspondence relationship between the convergence zone and the negative-value area of vertical velocity. The convergence zone slightly moved northward with height, and slanting airflow and positive circulation were produced. The strong upward motion provided favorable dynamic conditions for the occurrence and development of the blizzard, and was extremely conducive to the release of conditional symmetric unstable energy, causing the mesoscale system to develop. The blizzard area had a good correspondence relationship with the large-value area of wet Q vector divergence convergence.

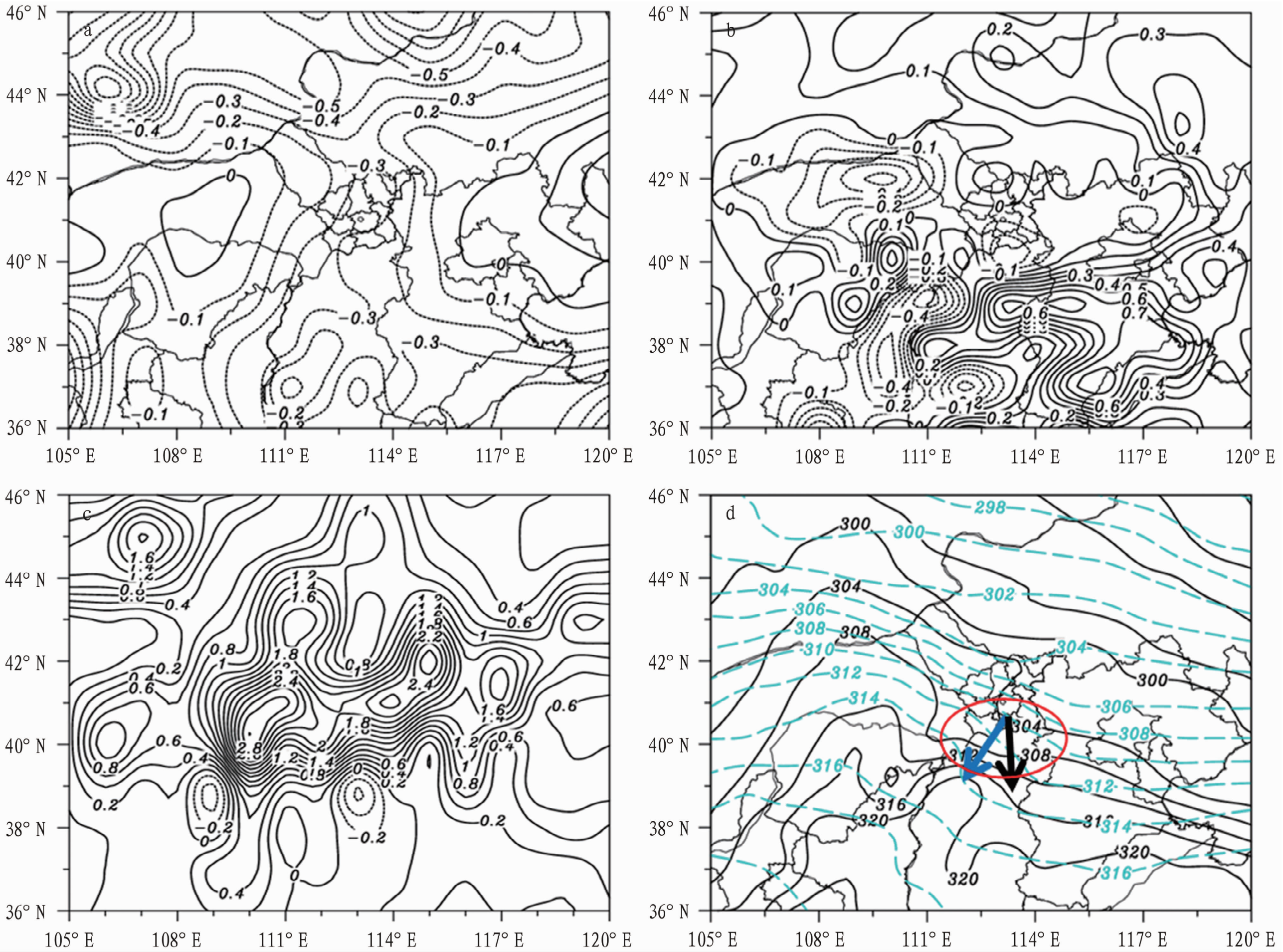

**Fig. 2** Distribution maps of MPV at 750 hPa at 08:00 (a) and 14:00 (b), radial vertical section of MPV along 44.2° N at 14:00 (c), potential temperature (dotted green line) and pseudo potential temperature (black solid line) at 14:00 (d) on April 4, 2018

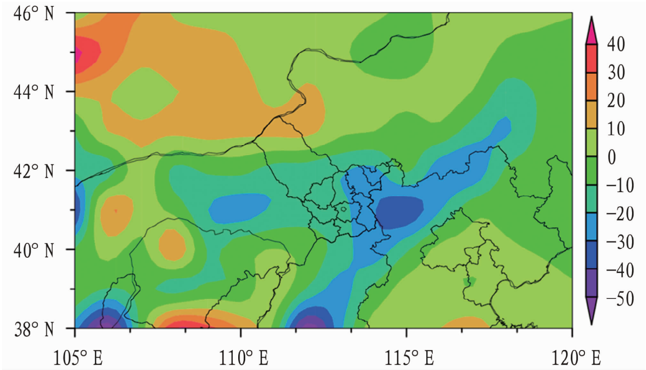

**Fig. 3** Distribution of temperature advection (unit: K/s) at 850 hPa at 14:00 on April 4, 2018

## 6 Mesoscale features

The TBB data derived from the FY-2G infrared cloud images during this heavy snowfall process were analyzed to identify the mesoscale systems during this snowstorm process. On the morning of April 4, 2018, as the northward movement of inverted trough in Hetao area and the establishment of low-level southerly wind jet stream, a cloud mass was generated in front of the inverted trough. At 10:00 on April 4 (Fig. 5a), two mid-β-scale cloud masses A and B (TBB ⩽ −56 ℃) were generated in the southeast of Ordos, and snowfall occurred. By 12:00 (Fig. 5b), as the low-level southerly wind jet stream strengthened, cloud masses A and B merged and moved eastward to the south of Hohhot, so the range of cloud masses expanded. TBB dropped to −64 ℃, and a band-shaped mid-β-scale cloud mass C with TBB ⩽ −56 ℃ was generated in the upstream area adjacent to cloud mass A. Under the influence of cloud masses A and C, the heavy snowfall with hourly snowfall of >2 mm occurred in the southeast of Ordos and the south of Hohhot from 12:00 to 13:00, and the maximum snowfall 5.0 mm appeared in Ejin Horo Banner. At 13:00 (Fig. 5c), cloud mass A continued to move eastward, and expanded to an approximately elliptical mid-α-scale cloud mass. The horizontal range of cloud mass C also expanded, and TBB of both cloud masses was −64 ℃. From 13:00 to 14:00, the range of strong snowfall expanded to the south of Zhangjiakou, and the snowfall was 5.5 mm at Dongsheng station and 4.2 mm at Liangcheng County. After 14:00, with the release of strong conditional symmetric unstable energy, the strengthening and eastward expansion of the

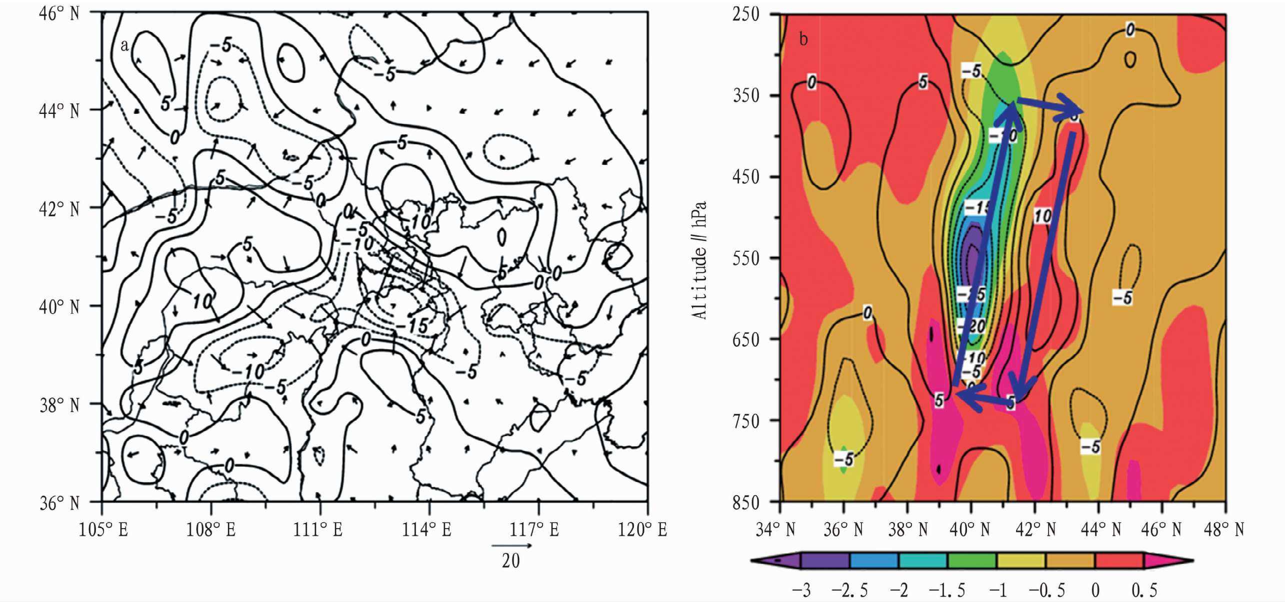

**Fig. 4** Distribution of wet Q vector divergence at 600 hPa (a) and latitudinal vertical profiles of vertical speed (color patches) and wet Q vector divergence (black solid line) along 113.4° E (b) at 14:00 on April 4, 2018

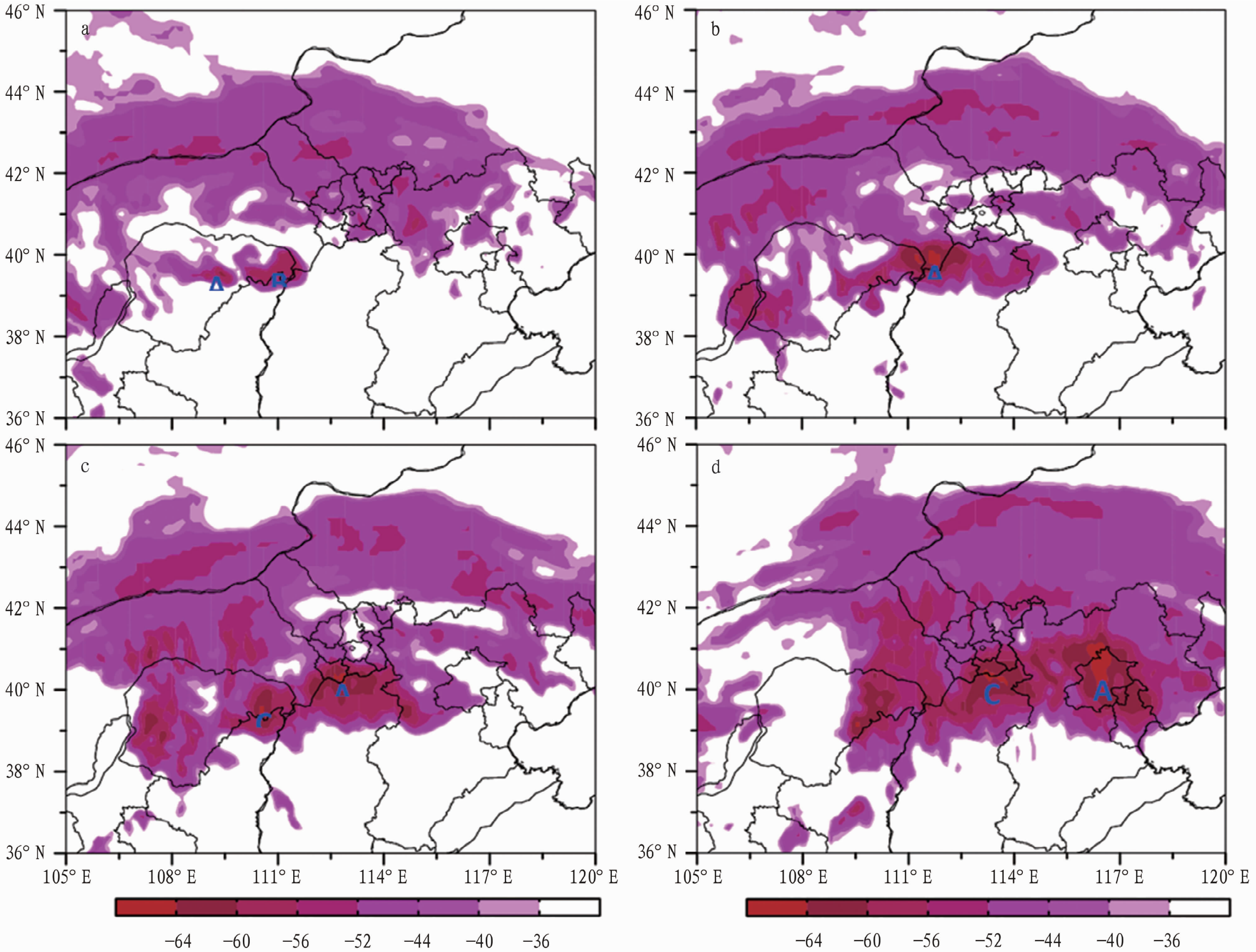

**Fig. 5** Distribution of TBB at 10:00 (a), 12:00 (b), 13:00 (c), and 15:00 (d) on April 4, 2018

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rience of this case indicates that the comprehensive control system centered on data driving is the key support for improving the efficiency of regional air environment governance in the current and future periods, and has a broad promotion value and application prospects.

## References

[1] HAO JM, CHENG SY, WANG SX. Air pollution control engineering [M]. Beijing: Higher Education Press, 2010.
[2] The 14th five-year plan for national economic and social development of the People's Republic of China and the long-range objectives in 2035.
[3] The construction plan for the national monitoring network for fine particulate matter and ozone control during the "14th Five-Year Plan" period (Huanbanjiancehan [2021] No.218).
[4] WANG ZF, LI J, WU JB, *et al.* Research progress on numerical forecasting technology for regional composite air pollution[J]. Research of Environmental Sciences, 2018, 31(1): 1 – 11.
[5] ZHENG C, ZHAO C, LI Y, *et al.* Spatial and temporal variations of $PM_{2.5}$ and its relation to meteorological factors in the urban agglomerations of China[J]. Urban Climate, 2018, 24: 26 – 37.

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low-level westerly jet stream of southerly wind at 700 hPa, and the strengthening of the cold cushion at 850 hPa, the mesoscale cloud masses further moved eastward and developed into mid-α-scale cloud masses (the inverted trough in Hetao area was affected by cold air and retreated southward). Along with the eastward movement of the heavy snowfall, the snowfall intensity in the southeast of Ordos weakened. At 15:00 (Fig. 5d), cloud mass A moved to Beijing, and cloud mass C moved to the junction of Ulanqab and Datong. From 15:00 to 16:00, the maximum snowfall occurred at Zhongning Station, up to 6.5 mm. As the cold air carried by the westerly airflow at 700 hPa infiltrated the cloud masses, gradually weakened and moved eastward, cloud mass D moved to the south of Ulanqab, and cloud mass C moved to the north of Hebei Province at 17:00. The intensity weakened significantly, and the lowest brightness temperature on the top of clouds was – 56 ℃. Afterwards, the snowfall weakened, and significantly decreased at 20:00. The blizzard in the southeast of Ordos was caused by the mid-β-scale cloud mass generated above the low-level southerly airflow, while the blizzard in other areas was caused by the continuous merging and eastward movement of mid-β and mid-α cloud masses, and the TBB of the cloud masses causing the blizzard was ≤ – 56 ℃. The blizzard occurred in the the edge gradient and large-value area of TBB.

## 7 Conclusions

(1) During this process, the presence of low trough at 500 hPa, the southerly wind jet stream at 700 hPa, easterly airflow at 850 hPa, cold high pressure and inverted trough on the ground provided favorable background conditions for this blizzard. The transportation of warm and humid air by the southerly wind jet stream at 700 hPa and intense water vapor convergence provided sufficient water vapor conditions for the blizzard. From the ground to 300 hPa over the blizzard area, there was a deep moist layer with relative humidity ≥90%, and the area of heavy snowfall corresponded to the low-level water vapor flux convergence zone.

(2) The blizzard occurred in the lower area with MPV <0, and the atmosphere was in a conditionally symmetric unstable state. The heavy snowfall ended with the release of the conditionally symmetric instability.

(3) The strong interaction between weather systems and the strong updraft induced by the low-level jet were one of dynamic factors contributing to the occurrence of the blizzard. With the invasion of cold air, a low-level cold pad was formed, so that the warm and humid air tilted upward along the cold pad. The secondary circulation updraft triggered by the wet Q vector system released the conditional symmetric instability energy, so that the sloping motion was more intense, and the heavy snowfall happened. At the same time, there was a good correspondence relationship between the blizzard area and the large-value area of low-level wet Q vector divergence.

(4) The blizzard in the southeast of Ordos was caused by the mid-β scale cloud cluster generated above the low-level southerly airflow, while the blizzard in other areas were caused by the continuous merging and eastward development of mid-β and mid-α cloud clusters, and the TBB of the cloud clusters was ≤ – 56 ℃. The blizzard appeared in the the edge gradient and large-value area of TBB.

## References

[1] GAO SY, LI HL, SUN LQ. A case study on an abrupt mesoscale heavy snow process in Dandong region[J]. Journal of Meteorology and Environment, 2006, 22(5): 32 – 35.
[2] LIU NH, QI LL, HAN JW. Analysis of a rare snowstorm event in Liaoning caused by a northward low-pressure system[J]. Chinese Journal of Atmospheric Sciences, 2009, 33(2): 275 – 284.
[3] WANG YC, QIAN TT, ZHENG YG. Primary analysis of the longest-lasting snowfall in Beijing[J]. Journal of Applied Meteorology, 2004, 15(1): 59 – 64.
[4] WANG JZ, DING YH. Research of moist symmetric instability in a strong snowfall in North China[J]. Acta Meteorologica Sinica, 1995, 53(4): 451 – 460.
[5] WU QM, YANG B, WANG GR. Analysis of the frontal characteristics of the backflow snowstorm process in Beijing area[J]. Plateau Meteorology, 2014, 33(2): 539 – 547.
[6] GU RY, *et al.* Handbook of weather forecasting in Inner Mongolia Autonomous Region[M]. Beijing Meteorological Press, 2012: 324.
[7] MA SY, ZHANG C, SHI JL. Analysis on two snowstorm events caused by reflow and inverted rough in Inner Mongolian Autonomous Region [J]. Journal of Meteorology and Environment, 2017, 33(1): 19 – 25.