Comparative Analysis of Two Heavy to Blizzard Processes in Beijing Area

Jixiong HUANG *

North China Air Traffic Management Bureau, CAAC, Beijing 100621, China

Abstract This paper conducted a more comprehensive review and comparative analysis of the two heavy to blizzard processes that occurred in the Beijing area during December 13 - 15, 2023, and February 20 - 21, 2024, in terms of comprehensive weather situation diagnosis, forecasting, and decision-making services, and summarized the meteorological service support experience of such heavy snow weather processes. It was found that both blizzard processes were jointly influenced by the 700 hPa southwesterly warm and humid jet stream and the near-surface easterly backflow; the numerical forecast was relatively accurate in the overall description of the snowfall process, and the forecast bias of the position of the 700 hPa southwesterly warm and humid jet stream determined the bias of the snowfall magnitude forecast at a certain point; when a deviation was found between the actual snowfall and the forecast, the cause should be analyzed in a timely manner, and the warning and forecast conclusions should be updated. With the full cooperation of relevant departments, it can greatly make up for the deviation of the early forecast snowfall amount, and ensure the safety and efficiency of people's travel.

Key words Heavy to blizzard process; Weather situation diagnosis; Forecasting and decision-making services; Review; Comparative analysis

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Heavy to blizzard is one of the common disastrous weather conditions in northern China in winter, which has great harm to people's production and life, as well as transportation. With the continuous development of the economy and the improvement of living standards, people's attention to disastrous weather such as heavy to blizzard has also increased. For transportation, heavy snowfall can lead to snow accumulation on roads, icy roads, aircraft icing, *etc.*, causing serious traffic accidents and even air disasters. In recent years, relevant scholars at home and abroad have conducted extensive research on the circulation characteristics, formation mechanisms, and water vapor sources of heavy to blizzard weather in Beijing, Hebei, Shandong, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Hunan, Xinjiang, Qinghai, and other regions, and accumulated some experience[1-12].

However, most of the above research focused on case analysis of a single heavy to blizzard weather event, lacking comparisons between different cases. This paper provided a comprehensive review and comparative analysis of the two heavy to blizzard processes that occurred in the Beijing area during December 13 - 15, 2023, and February 20 - 21, 2024, in terms of comprehensive weather situation diagnosis, forecasting, and decision-making services, and summarized the meteorological service support experience for such heavy snow weather processes.

1 Heavy to blizzard weather process during December 13 - 15, 2023

1.1 Overview of the weather process Starting from 05:00 on December 13, 2023, snowfall in the Beijing area gradually spread from southwest to northeast. At 12:00 on 13th, the average snowfall across the city reached 1 mm, and the ground was already covered with snow in most areas. Subsequently, the snowfall intensity increased. At 22:00 on 13th, the average snowfall across the city reached 2.5 mm, with the maximum snowfall of 5.8 mm occurring in Fenghuangling of Haidian, reaching the level of heavy snow. At 14:00 on 14th, the average precipitation across the city was 5.2 mm, with an average of 6.1 mm in urban areas. The maximum snowfall was 9.1 mm in Fenghuangling of Haidian, with snow depths reaching 5 - 9 cm in most areas. At 22:00 on 14th, the average precipitation across the city was 8.0 mm, with an average of 8.1 mm in urban areas. The maximum snowfall was 13.7 mm in Fenghuangling of Haidian. Afterward, the snowfall weakened, and the snowfall in the Beijing area basically ended in the early morning of 15th. Overall, the snowfall in Beijing lasted for nearly 48 h, with the average snowfall reaching the level of heavy to blizzard (Fig. 1).

1.2 Impacts of heavy snowfall weather Due to the heavy snowfall during December 13 - 15, 2023, all primary and secondary schools, kindergartens, and vocational schools in Beijing suspended in-person classes and transitioned to online learning. Multiple national scenic spots, such as Beijing Xiangshan Park and Tanzhe Temple, were temporarily closed. Some trains at Beijing West Railway Station and Beijing Fengtai Railway Station were temporarily suspended. On December 13, the number of scheduled flights at Capital Airport was reduced to 681, with a total of 465 flights canceled. Due to the slippery snow-covered roads, collision of two trains occurred up section between Xierqi

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* Corresponding author.

Station and Shengmingkexueyuan Station on the Changping Line of Beijing Subway at 18:52 on December 14, resulting in 3 serious injuries, 70 minor injuries, more than 500 people hospitalized, and direct economic losses of approximately RMB 9.508 million.

1.3 Weather situation analysis During December 13 – 15, 2023, under the combined influence of the strong northbound southwesterly warm and humid jet stream ahead of the southern branch trough and the near-surface easterly backflow bringing water vapor from Bohai Bay and Huanghuai, Beijing experienced a long-lasting and widespread heavy to blizzard. The strong southwesterly warm and humid jet stream at 700 hPa interacted with the significant near-surface southeasterly backflow, forming a stable overlay of a "warm cover" and a "cold cushion", which provided mature dynamic and thermodynamic conditions, as well as sufficient water vapor supply, for the occurrence and development of this widespread snowfall, leading to a larger snowfall area, stronger snowfall, and longer duration in Beijing (Fig. 2).

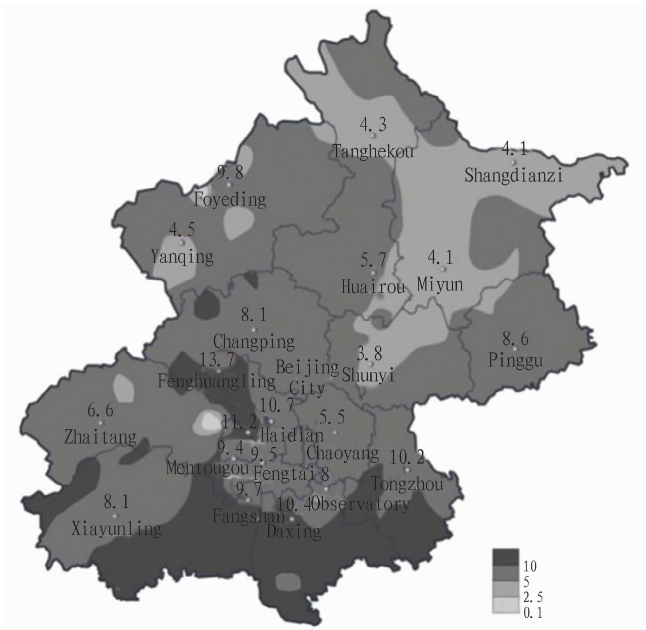


Fig.1 Distribution of precipitation in Beijing from 05:00 on December 13 to 22:00 on 14th, 2023 (Unit: mm)

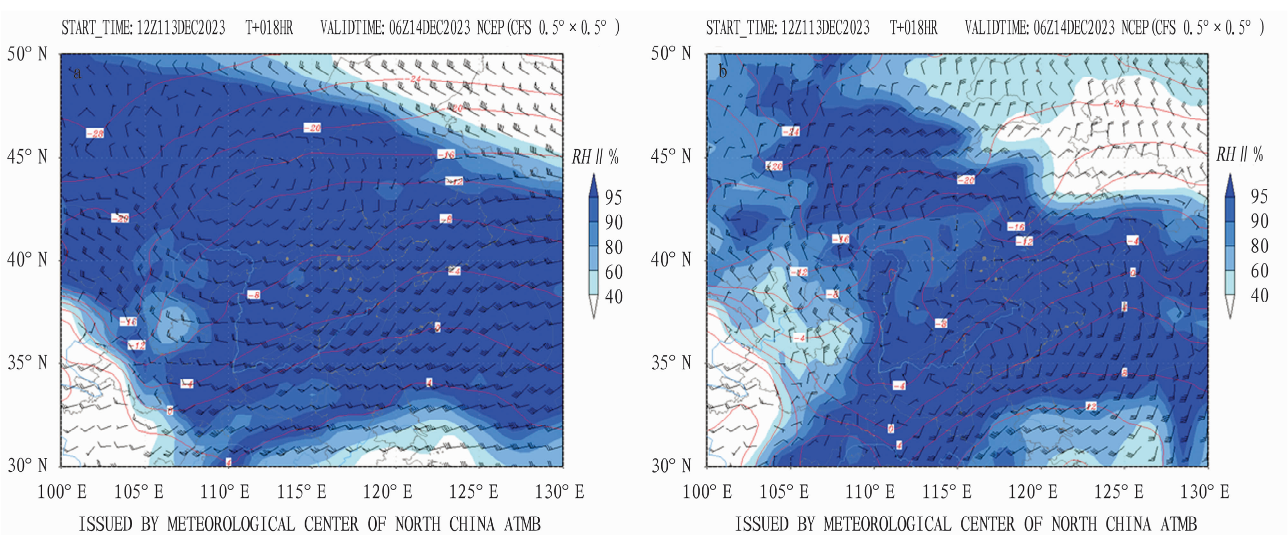


Fig.2 Wind and temperature chart at 700 (a) and 850 hPa (b) at 14:00 on December 14, 2023

1.4 Forecasting and decision-making services The meteorological departments in Beijing attached great importance to this heavy to blizzard process, organized technical teams for consultation, proposed a significant heavy to blizzard process in Beijing during December 13 – 15, 2023, a week in advance, and promptly submitted the latest forecast conclusions to relevant decision-making departments for reference.

At 16:30 on December 12, the Beijing Meteorological Observatory issued a yellow snowstorm warning (expecting snowfall ranging from heavy snow to blizzard from the morning of December 13 to the morning of December 15, with individual areas in Yanqing, Changping, Mentougou, Fangshan potentially experiencing extreme blizzard conditions), a blue cold wave warning, and a yellow road ice warning.

At 10:00 on December 12, the Beijing Meteorological Observatory upgraded the snowstorm warning signal to "orange", predicting snowfall ranging from heavy snow to blizzard from the morning of December 13 to the morning of 15th, with the strongest snowfall period expected from 10:00 to 20:00 on December 13. Some areas, including Yanqing, Changping, Mentougou, Fangshan, Huairou, Haidian, Shijingshan, Fengtai, Dongcheng, Xicheng, Chaoyang, Daxing, and Tongzhou, were expected to receive more than 10 mm of snowfall.

Multiple government departments in Beijing, including the Beijing Emergency Management Bureau and the Beijing Municipal Education Commission, jointly issued seven blizzard warning response measures, including advocating for staggered commuting times and flexible work arrangements, suspending classes for primary and secondary schools and kindergartens, temporarily closing scenic spots, increasing temporary trains on Beijing Subway, initiating a Level 1 response mechanism at Capital Airport, temporarily suspending some trains at Beijing South Railway Station, Beijing West Railway Station, and Beijing Fengtai Railway Station, and issuing a snow removal and ice melting initiative.

1.5 Review of experience The forecasting and early warning issuance for this heavy to blizzard process were highly accurate in terms of both timing and magnitude of snowfall, with sufficient lead time for predictions. Decision-making departments also promptly formulated contingency plans and issued multiple measures in response to the blizzard warning.

However, due to the large intensity, long duration, and extensive coverage of this blizzard, it still caused significant losses to people's lives and property when it struck. Therefore, it must attach great importance to such disastrous weather events, never take them lightly, and prevent the recurrence of production safety accidents caused by factors such as extended train braking distances during snowy days and inadequate snow response measures implemented by operating units, which have led to injuries to multiple people.

2 Heavy to blizzard weather process during February 20 – 21, 2024

2.1 Overview of the weather process Starting in the morning of February 20, 2024, Beijing experienced light snow or scattered snowflakes from west to east. The snowfall intensified significantly in the evening of 20th. By the morning of 21st, snowfall gradually weakened and ceased. From 05:00 on February 20 to 06:00 on 21st, the average precipitation across the city was 5.5 mm, with an average of 7.2 mm in urban areas. The maximum snowfall occurred at Qingta Station in Fengtai District, with a precipitation of 9.8 mm. During this snowfall event in Beijing, northern areas experienced less snowfall, while urban and southern areas saw heavier snowfall, with precipitation ranging from 6.5 to 9.8 mm and snow depths of 7 to 10 cm. The main snowfall period was within the 12 h from the evening of 20th to the morning of 21st. According to China's meteorological standards, snowfall with a 24-h precipitation of 10.0 to 19.9 mm or a 12-h precipitation of 6.0 to 9.9 mm is classified as a blizzard. Overall, northern Beijing received moderate-to-heavy snowfall during this snowfall event, while urban and southern areas experienced heavy-to-blizzard conditions (Fig. 3).

2.2 Impacts of heavy snowfall weather In the evening of February 20, as snowfall intensified, Beijing's overall traffic index reached 7.5, indicating moderate congestion, with an average speed of 21.6 km/h. Multiple highways and urban expressways, including Beijing – Harbin Expressway, Beijing – Shanghai Expressway, Beijing – Tianjin Expressway, and Beijing – Pinggu Expressway, successively implemented temporary closure measures. Some bus routes were temporarily suspended, rerouted, or had stops skipped due to snowfall and icy roads. A total of 48 trains were delayed at Beijing West Railway Station, Beijing South Railway Station, and Fengtai Railway Station, affecting more than 30 000 passengers. As of 12:00 on February 21, multiple flights were delayed at Capital Airport, and 111 flights were canceled.

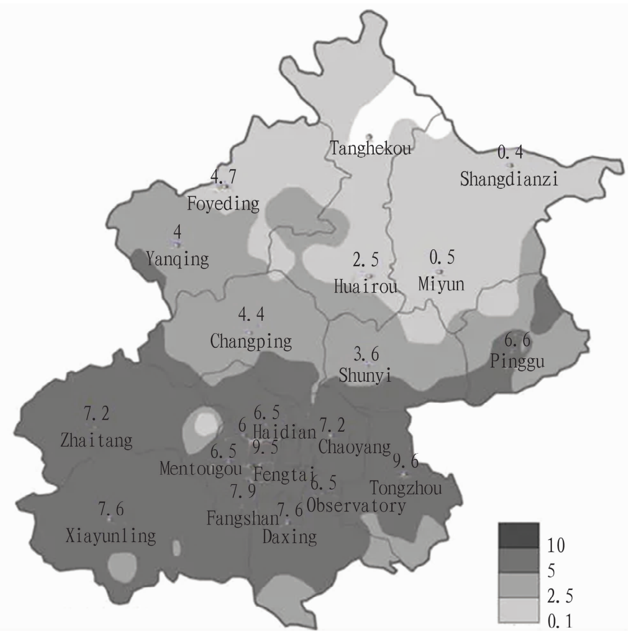


Fig. 3 Distribution of precipitation in Beijing from 05:00 on February 20 to 06:00 on 21st, 2024 (Unit: mm)

2.3 Weather situation analysis On February 20, 2024, Beijing gradually transitioned from the rear of a high-pressure system to the front of a low-pressure system, with weak cold air infiltrating from the northeast, dominated by northeasterly currents at 850 hPa. The inverted trough in the Hetao region slowly moved eastward from the low-value center. The water vapor in southern Beijing at 700 hPa rapidly accumulated under the transportation of the southwesterly warm and moist jet stream ahead of the trough (Fig. 4).

The intensification of this snowfall was primarily influenced by the eastward strengthening of the Hetao inverted trough and the southerly warm and moist jet stream ahead of the 700 hPa trough. In the evening of February 20, the rapid northward lifting of the southerly current at 700 hPa led to a rapid increase in water vapor in Beijing, resulting in a significant enhancement of snowfall. The slow eastward movement of the Hetao inverted trough also contributed to the prolonged snowfall. Snowfall in urban and southern Beijing was heavier, with deeper snow accumulation.

The reason for the underestimation of snowfall in initial forecasts was due to the southward bias in the position of the warm and moist jet stream ahead of the 700 hPa trough in initial numerical weather predictions, with a 50 – 100 km error compared to actual conditions. It led to an underestimation of overall water vapor conditions and snowfall amounts in Beijing.

2.4 Forecasting and decision-making services The initial snowfall forecast was underestimated. The Beijing Meteorological Observatory issued a weather forecast in the morning of February 20, 2024, predicting that most areas of Beijing City would experience light snow or scattered snowfall in the evening to overnight on 20th, with snowfall in mountainous areas continuing until the afternoon of 21st. Most plain areas were expected to receive less than 0.5 mm of precipitation, with relatively more significant precipitation in mountainous areas.

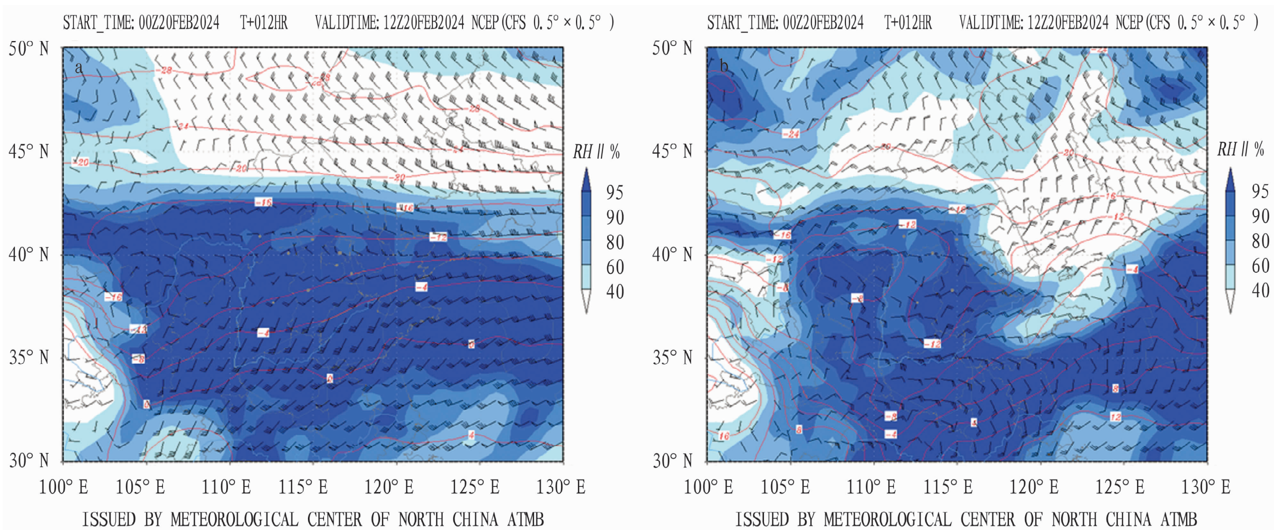


Fig. 4 Wind and temperature chart at 700 (a) and 850 hPa (b) at 20:00 on February 20, 2024

As snowfall gradually increased, Beijing issued a blue blizzard warning at 22:45 on February 20: currently, some areas of Chaoyang, Haidian, Fengtai, Shijingshan, Dongcheng, Xicheng, Mentougou, Fangshan, Daxing, and Tongzhou have already received 4 mm of snowfall, and snowfall was expected to continue in these areas until 08:00 on 21st. Please take precautions.

Meanwhile, the Beijing Municipal Government mobilized more than 45 000 professionals and over 6 000 snow removal and ice-clearing vehicles from various districts and operating units to work continuously through the night, intensifying efforts on highways, ring roads, and major urban roads to ensure smooth city traffic.

Forecasters at the Meteorological Center of North China Air Traffic Management Bureau of Civil Aviation closely monitored the evolution of the snowfall weather and promptly updated forecast conclusions when snowfall intensified, reminding relevant departments to prepare for support services (Fig. 5). At 06:00 on February 21, Capital Airport activated the level I response mechanism for collaborative operations of the operations management committee and simultaneously initiated a fixed-point de-icing mode. Daxing Airport activated its on-site command department at 07:00 to conduct joint command operations, ensuring the efficiency of aircraft de-icing and apron operations.

2.5 Review of experience The initial forecast for this heavy-to-blizzard event underestimated snowfall magnitudes, predicting only light snow or scattered snowflakes, with expected precipitation of less than 0.5 mm in most plain areas. However, forecasters on duty closely monitored the weather, promptly updated forecast conclusions after snowfall intensified, and actively issued snowfall alerts, snow condition bulletins, blue blizzard warnings, and road icing warnings. The rapid and coordinated response of relevant units greatly compensated for the initial underestimation of snowfall amounts, ensuring the safety and efficiency of people's travel during this heavy-to-blizzard event.

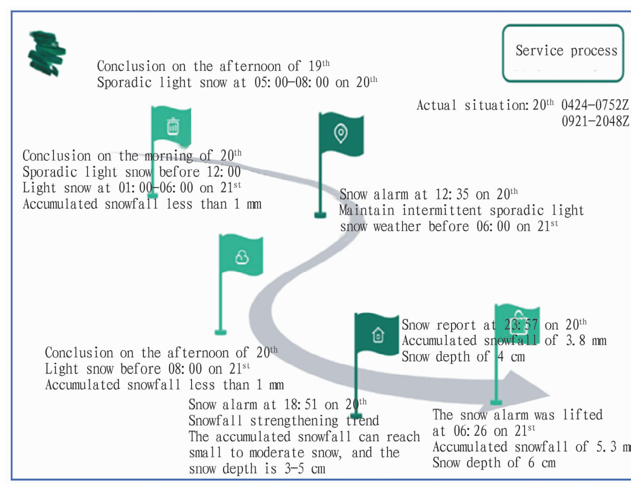


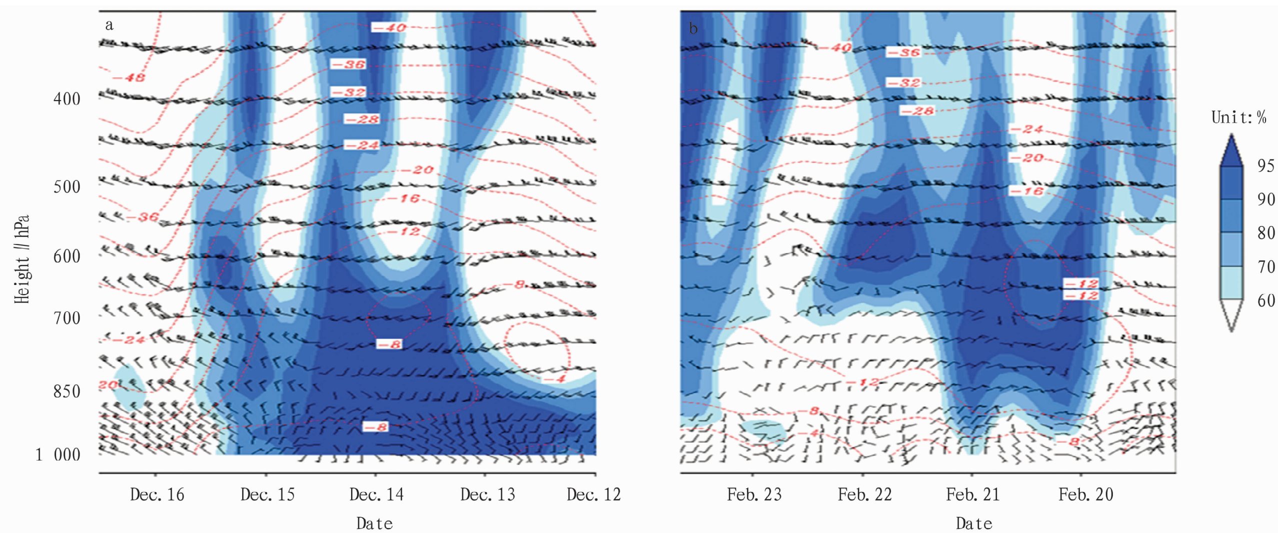
Fig. 5 Forecast service process at Capital Airport during February 20 – 21, 2024

3 Comparative analysis of two heavy to blizzard processes

A comparative analysis of the two heavy to blizzard processes in Beijing during December 13 – 15, 2023, and February 20 – 21, 2024, revealed the following:

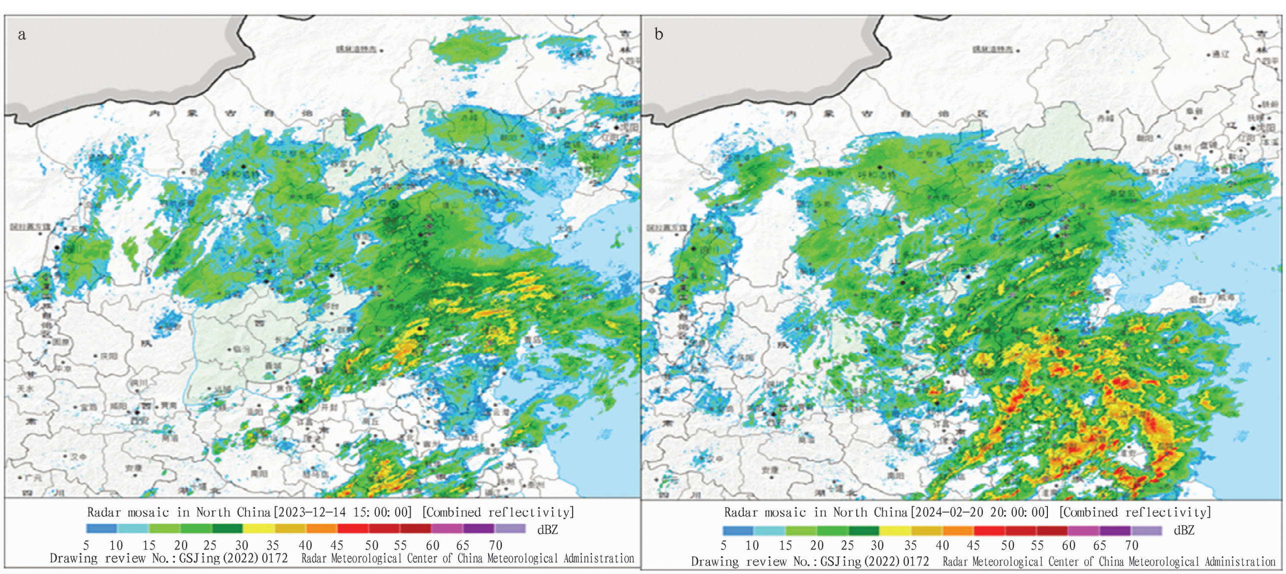
During December 13 – 15, 2023, there was a significant cold front passage, with a large-scale upper-level trough over a thousand kilometers wide. Ahead of the trough, there were deep warm and moist airflows, with sufficient water vapor content in the warm sector. From the surface to the upper atmosphere, the strong southwesterly warm and moist jet stream at 700 hPa interacted with significant near-surface southeasterly return flows, forming a stable overlay of a "warm cover" and a "cold pad", providing mature dynamic and thermodynamic conditions and adequate water vapor supply for the occurrence and development of this widespread snowfall. Cold air was evident behind the upper-level trough, with northwest winds and strong temperature drops of 10 – 15 ℃ within 24 h (Fig. 6a).

During February 20 – 21, 2024, the weather was dominated by the infiltration of a weak cold air, with the cold air behind the trough being insignificant, resulting in no significant wind or temperature drop. The main source of water vapor ahead of the trough was the rapid northward shift of the southwesterly warm and moist jet stream at 700 hPa, combined with a slight accumulation of weak return flows from the near-surface easterly winds. However, due to a 50 – 100 km discrepancy between numerical forecasts and actual observations regarding the final position of the northward-shifting southwesterly warm and moist jet stream at 700 hPa, there were significant deviations in the predicted overall water vapor content and transport in the Beijing area. As shown in Fig. 6b, water vapor conditions at the middle and lower levels were not favorable during this snowfall event, leading to a significant underestimation of the predicted snowfall amounts. Nevertheless, when comparing the radar composites of these two heavy snowfall events, the intensities of the radar echoes for both heavy snowfall events were not significantly different. Even for southern Beijing, the intensity of the radar echo during a certain period of snowfall on February 20 – 21, 2024, was stronger than that during the heavy to blizzard conditions during December 13 – 15, 2023 (Fig. 7).



Note: a. December 13 – 15, 2023; b. February 20 – 21, 2024.

Fig. 6 Comparison of spatio-temporal profiles of two snowfall processes in Beijing



Note: a. December 13 – 15, 2023; b. February 20 – 21, 2024.

Fig. 7 Comparison of radar images of two snowfall processes

Comparing these two heavy snowfall events, it was found that the heavy to blizzard conditions during December 13 – 15, 2023, featured a more pronounced cold air intrusion and a deeper upper-level trough system, with the snowfall lasting longer. In contrast, the heavy to blizzard event during February 20 – 21, 2024, was primarily driven by the infiltration of a weak cold air but shared similar near-surface easterly return flows and water vapor transport brought by the southwesterly warm and moist jet stream at

700 hPa. Consequently, it exhibited the same snowfall range and magnitude as the former event.

4 Discussion

The two snowstorm events in Beijing were both influenced by the combination of the 700 hPa southwesterly warm-wet jet stream and the near-surface easterly wind return flow. The overall description of snowfall process by numerical prediction was relatively accurate, and the deviations in the forecasted snowfall amounts were primarily due to the inaccuracies in predicting the position of the 700 hPa southwesterly warm-wet jet stream. When discrepancies between the observed and forecasted snowfall were identified, it should timely analyze the reasons, and update the warning and forecast conclusions. With the collaboration of relevant departments, the deviation in the initial snowfall forecasts could be significantly mitigated, ensuring the safety and efficiency of people's travel.

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S. glabra. Meanwhile, water accumulation may reduce the oxygen content in soil, resulting in breathing difficulties for *S. glabra* roots, which in turn affects its normal growth. Therefore, when *S. glabra* is planted, it is necessary to control soil moisture reasonably and choose areas with good drainage to avoid the occurrence of water accumulation.

In this study, based on meteorological data and climatic conditions for the growth of *M. officinalis* and *S. glabra*, the climate suitability zoning indicators of *M. officinalis* and *S. glabra* in Xinfeng County were established by relevant statistical methods, and the climate suitability zoning of *M. officinalis* and *S. glabra* planting in Xinfeng County was carried out based on geographic information system (GIS). However, in addition to the meteorological factors in this study, the growth of *M. officinalis* and *S. glabra* is also affected by factors such as concealability and soil, and the specific local conditions should be considered in actual application. In further studies, these indicators should be considered to make suitability zoning results more realistic and lay a foundation for the development of understory southern medicines.

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