Circulation Patterns and Genesis of Warm-Sector Heavy Snow in the Tacheng Region over the Past 20 Years: Postprint

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Date: 2023-02-02T00:00:00+00:00

Abstract

Using daily precipitation, temperature, conventional surface and upper-air observation data from 7 national meteorological stations in the Tacheng region from November to March of the following year during 2000–2019, as well as NCEP reanalysis data from the U.S. National Centers for Environmental Prediction, warm-sector blizzard weather processes in the Tacheng region over the past 20 years were identified and analyzed. The results show that: (1) Warm-sector blizzards in the Tacheng region occurred at the Tacheng, Yumin, and Emin stations in the Ta-E Basin, with the highest frequency at the Tacheng station. In terms of temporal distribution, the highest frequency of warm-sector blizzards occurred in November and December, mainly concentrated from mid-November to early December, followed by January, and the lowest in February. (2) Warm-sector blizzards in the Tacheng region are classified into three types: pre-trough type, transverse trough bottom type, and northwesterly jet type, with surface low-pressure systems following western and northwestern paths. The pre-trough type is the most typical warm-sector blizzard pattern, occurring mainly from November to early December, developing in the convergence zone between the frontal zone ahead of the West Siberian trough and the southern branch mid-latitude short-wave trough, with surface low pressure following a northwestern path. The transverse trough bottom type occurs mainly from November to January of the following year, developing in a strong frontal zone where the westerly flow at the bottom of the polar front meets the warm and moist southwesterly flow from mid-latitudes, with surface low pressure following a western path. The northwesterly jet type occurs mainly in November–December, developing within the northwesterly flow of the polar front, with surface low pressure following a northwestern path. (3) The overlapping region of strong northwesterly or westerly jets at 500–300 hPa, westerly low-level jets at 700 hPa, and warm shear at 850 hPa coincides with the warm-sector blizzard impact area. The pre-trough and northwesterly jet types produce blizzards in the warm sector ahead of the front, while the transverse trough bottom type generates blizzards along the warm front to the right front of the low-pressure system. (4) The water vapor for both the pre-trough and transverse trough bottom types follows a westerly path, with moisture from the Mediterranean Sea and Arabian Sea intensified after passing over the Caspian Sea and Aral Sea before being transported to the blizzard area. The northwesterly jet type has two water vapor transport pathways: westerly and northwesterly. Moisture from the high-latitude Barents Sea converges with moisture from the mid- and low-latitude Caspian Sea, Aral Sea, Mediterranean Sea, and Arabian Sea near Lake Balkhash before being transported to the blizzard area. Strong water vapor transport is accompanied by significant moisture convergence in the lower troposphere, with the strong convergence center located between 850–700 hPa.

Full Text

Circulation Classification and Cause Analysis of Warm-Sector Blizzards in Tacheng Area in Recent 20 Years

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Abstract

Using daily precipitation, temperature, conventional surface and upper-air observation data from seven national meteorological stations in Tacheng area, Xinjiang, together with NCEP reanalysis data from November 2000 to March 2019, this study identifies warm-sector blizzard events in Tacheng area over the past 20 years and analyzes their characteristics. The results show that: (1) Warm-sector blizzards in Tacheng area occurred exclusively at Tacheng, Yumin, and Emin stations in the Tacheng-Emin Basin, with the highest frequency at Tacheng station. Temporally, these events peaked in November and December, primarily concentrated from mid-November to early December, followed by January, with the lowest frequency in February. (2) Three synoptic types are identified: low-trough front type, horizontal trough bottom type, and northwest jet type, with surface lows following either western or northwestern tracks. The low-trough front type represents the most typical warm-sector blizzard pattern, occurring mainly from November to early December within the confluence zone between the frontal zone ahead of a West Siberian low trough and a mid-latitude short-wave trough, with the surface low taking a northwestern path. The horizontal trough bottom type occurs primarily from November to January in the strong frontal zone where the westerly flow at the bottom of the polar front merges with warm, moist mid-latitude southwesterlies, with the surface low following a western path. The northwest jet type occurs mainly from November to December within the northwesterly flow of the polar frontal zone, with the surface low taking a northwestern path. (3) The overlapping region of a strong northwest or westerly jet at 500–300 hPa, a westerly low-level jet at 700 hPa, and warm shear at 850 hPa coincides with the warm-sector blizzard precipitation area. The low-trough front and northwest jet types produce blizzards in the pre-frontal warm sector, while the horizontal trough bottom type generates blizzards along the warm front to the right of the low-pressure center. (4) Water vapor for both the low-trough front and horizontal trough bottom types follows a westerly path, originating from the Mediterranean Sea and Arabian Sea, intensifying over the Caspian Sea and Aral Sea before reaching the blizzard area. The northwest jet type features two water vapor pathways: westerly and northwesterly. Water vapor from the high-latitude Barents Sea converges with that from the mid- and low-latitude Caspian Sea, Aral Sea, Mediterranean Sea, and Arabian Sea near Lake Balkhash before being transported to the blizzard area. Strong water vapor transport is accompanied by significant low-level moisture convergence, with the strongest convergence center located between 850 hPa and 700 hPa.

Keywords: warm-sector blizzard; temporal and spatial distribution characteristics; synoptic classification; three-dimensional configuration of weather systems

1. Study Area Overview

Xinjiang is located deep within the Eurasian continent, featuring vast territory and complex terrain. The Kunlun Mountains lie to the south, the Altai Mountains to the north, and the Tianshan Mountains stretch across central Xinjiang, creating a distinctive "three mountains surrounding two basins" topography and a unique temperate continental arid climate. Winters are cold with frequent snowfall and deep snow cover, making blizzard weather a significant meteorological disaster. Xinjiang blizzards concentrate in the western and northern regions of northern Xinjiang and along the northern foothills of the Tianshan Mountains. Blizzard events in Xinjiang are classified into warm-sector blizzards and cold-front blizzards based on influencing weather systems. Typically, blizzards along the northern Tianshan foothills are cold-front blizzards, while those in Tacheng and Altay areas are predominantly warm-sector blizzards. Because warm-sector blizzards feature heavy snowfall and long duration, they severely impact agriculture, animal husbandry, transportation, power systems, and people' s livelihoods.

Tacheng area is situated in northwestern Xinjiang. The West Junggar Mountains lie to the north, the North Tianshan Mountains to the south, the Tacheng-Emin Basin to the west, and the Junggar Basin to the central-east. The terrain is highly distinctive, with the Tacheng-Emin Basin surrounded by mountains on three sides, sloping from high in the northeast to low in the southwest. The Tarbagatay Mountains stretch across the north, and the Wuerkashier Mountains extend northeast-southwest to the east, forming a "horn-shaped" topography opening westward (known as the Tacheng-Emin Basin) [Figure 1: see original paper].

2. Data and Methods

This study uses daily precipitation and temperature data from seven national meteorological observation stations in Tacheng area, along with conventional surface and upper-air observations and NCEP reanalysis data (2.5°$×$2.5° resolution) to classify the influence systems of warm-sector blizzards in Tacheng area based on atmospheric circulation characteristics. Synoptic-dynamic analysis methods are employed to diagnose physical quantities including water vapor flux, water vapor flux divergence, frontogenesis function, and pseudo-equivalent potential temperature, revealing structural characteristics of different warm-sector blizzard types.

The Xinjiang snowfall standard is applied: 12.0 mm $<$ 24-hour snowfall $\leq$ 24.0 mm constitutes heavy snow, 24.0 mm $<$ 24-hour snowfall $\leq$ 48.0 mm constitutes a blizzard, and 24-hour snowfall $>$ 48.0 mm constitutes a severe blizzard. A warm-sector blizzard is defined as a snowfall event with decreasing surface pressure and increasing temperature (referred to as "decompression warming") during the 24-hour period when 12.0 mm $<$ 24-hour snowfall.

3. Results

3.1 Spatial and Temporal Distribution Characteristics

Based on daily precipitation and temperature data from seven national meteorological stations in Tacheng area from November 2000 to March 2019, 20 typical warm-sector blizzard events were identified. Warm-sector blizzards occurred exclusively at Tacheng, Yumin, and Emin stations in the Tacheng-Emin Basin, with the highest frequency at Tacheng station (12 cases, accounting for 60%), followed by Yumin station (6 cases, 30%), and the lowest at Emin station (2 cases, 10%). In terms of temporal distribution, warm-sector blizzards peaked in November and December (9 cases each), primarily concentrated from mid-November to early December, followed by January (2 cases), with none occurring in February. The average daily snowfall during warm-sector blizzards was highest at Yumin station (24.3 mm), followed by Emin station (19.7 mm), and lowest at Tacheng station (19.4 mm). Interannual variation showed a jump increase after 2009, with 2010 being a particularly prominent year when northern Xinjiang experienced multiple warm-sector blizzard events, including a once-in-50-years continuous blizzard process with cumulative snowfall exceeding historical extremes (>50 mm) at many stations, causing severe disasters.

3.2 Synoptic Classification

Based on 500 hPa circulation patterns and surface pressure fields, the 20 warm-sector blizzard cases in Tacheng area are classified into three main types: low-trough front type, horizontal trough bottom type, and northwest jet type. Surface lows follow either western or northwestern tracks. The low-trough front type is the most typical warm-sector blizzard pattern.

3.2.1 Low-Trough Front Type This type occurs under a two-trough-two-ridge meridional circulation pattern in the mid-high latitudes, with high-pressure ridges over Europe and from northern Xinjiang to Lake Baikal, and a low trough over West Siberia extending southward to 45°N. Mid-latitude short-wave disturbances exist upstream. As an unstable short-wave trough attacks, the European ridge declines southeastward, pushing the West Siberian low trough eastward. The mid-latitude short-wave trough merges with the West Siberian low trough during its northeastward movement, strengthening the frontal zone at the trough base. Due to the strong high-pressure ridge downstream over Lake Baikal, the low trough moves northeastward slowly, with its main body located at 70°–85°E. The strong frontal zone created by the southwest-westerly flow ahead of the trough affects northern Xinjiang [Figure 3: see original paper], producing warm-sector blizzards.

A typical case occurred on December 15–16, 2009, when the Tacheng-Emin Basin experienced heavy snowfall. Daily snowfall (20:00–20:00 UTC) reached 19.4 mm at Tacheng, 14.6 mm at Yumin, and 7.5 mm at Emin, with Yumin meeting the Xinjiang blizzard standard. At Tacheng station, surface pressure began decreasing from 08:00 on the 15th, reaching a minimum of 969.1 hPa at 12:00 on the 16th, while nighttime surface temperature rose by 7.5°C. During the snowfall period, pressure showed a decreasing trend while temperature increased, characteristic of a warm-sector blizzard. At 20:00 on the 15th, northern Xinjiang was situated within a high-altitude northwesterly jet stream (>36 $m \cdot s^{-1}$ at 300 hPa), with the jet core maximum wind speed reaching 40 $m \cdot s^{-1}$. The 500 hPa strong westerly frontal zone (>26 $m \cdot s^{-1}$) was located at 45°–50°N, and a southwesterly low-level jet at 700 hPa extended from east of Lake Balkhash to Tacheng area. At 850 hPa, a warm shear line existed between southwesterly and southeasterly winds over northern Xinjiang, with a warm temperature ridge over the western and northern regions. The surface low moved eastward along a northwestern track, with its center (1005 hPa) over West Siberia and a high-pressure center (1030 hPa) over Mongolia. The southeastern periphery of the low affected northern Xinjiang, with frontogenesis occurring north of Tacheng area, placing Tacheng in the pre-frontal warm sector.

Analysis of the vertical cross-section along 83°E shows a dense zone of pseudo-equivalent potential temperature concentrated below 600 hPa north of Tacheng, with a frontogenesis function of 0.5$×10^{-9}$ $K \cdot m^{-1} \cdot s^{-1}$. At Tacheng, the pseudo-equivalent potential temperature contours show a downward concave trend, indicating its location in the pre-frontal warm sector. Abundant warm, moist air is transported northward under southwesterly flow, producing warm-sector blizzards. The three-dimensional conceptual model shows the superposition of a strong northwesterly or westerly jet at 500–300 hPa, a westerly low-level jet at 700 hPa, and warm shear at 850 hPa, coinciding with the warm-sector blizzard area.

Water vapor analysis using vertically integrated water vapor flux vectors from 1000–500 hPa reveals that water vapor from the Mediterranean Sea and Arabian

Sea moves northward, intensifies over the Black Sea, and is transported along westerly flow through Eastern Europe, the Ural Mountains, and Lake Balkhash to northern Xinjiang. Water vapor flux values remain small during transport but increase rapidly near Lake Balkhash, forming a large-value center (20 $g \cdot cm^{-1} \cdot hPa^{-1} \cdot s^{-1}$) west of Tacheng area. Significant water vapor convergence occurs between 850-700 hPa, with the strong convergence center at 700 hPa (-5×10^{-5} $g \cdot hPa^{-1} \cdot cm^{-2} \cdot s^{-1}$). When the convergence layer thickness decreases and intensity weakens, the warm-sector blizzard ends and cold-front snowfall begins.

3.2.2 Horizontal Trough Bottom Type This type occurs under a two-trough-two-ridge meridional circulation pattern, with a shallow ridge over southern Europe, a low trough over the Ural Mountains extending to 50°N, and a high-pressure ridge from West Siberia to northern Xinjiang. Under the influence of an eastward-moving short-wave trough, the high-pressure ridge gradually weakens and disappears. A polar high-pressure system over Europe moves eastward and southward, strengthening the European ridge. The northerly flow ahead of the ridge guides polar cold air southward to West Siberia, where a vortex is cut off or an east-west oriented horizontal trough forms near 60°N. Northern Xinjiang is controlled by westerly flow at the bottom of the horizontal trough. A mid-latitude short-wave trough exists north of the Caspian and Aral Seas, with its pre-trough warm, moist airflow merging with the westerly flow at the bottom of the horizontal trough, creating a strengthened frontal zone that produces blizzards. As the high-pressure ridge declines southeastward and the northeasterly flow ahead of the ridge shifts to northwesterly, cold advection appears ahead of the trough, the horizontal trough turns vertical and moves southeastward, ending the warm-sector blizzard. Since the horizontal trough turning vertical is influenced by the eastward-moving low trough, cold-front snowfall occurs subsequently, making this a type with coexisting warm-sector and cold-front blizzards [Figure 4: see original paper].

A typical case occurred on November 29-30, 2015, when the Tacheng-Emin Basin experienced a blizzard. Cumulative snowfall reached 22.5 mm at Tacheng, 21.8 mm at Yumin, and 19.5 mm at Emin, with new snow depths of 39 cm, 32 cm, and 13 cm, respectively. At Tacheng station, the main snowfall period was from 20:00 on the 29th to 08:00 on the 30th, with maximum hourly intensity of 2.7 mm. Surface pressure decreased while temperature increased, but with smaller amplitude than the low-trough front type. At 20:00 on the 29th, northern Xinjiang was located within a high-altitude northwesterly jet stream (maximum wind speed 44 $m \cdot s^{-1}$ at 300 hPa). The 500 hPa strong westerly frontal zone (>32 $m \cdot s^{-1}$) was situated at the bottom of a West Siberian horizontal trough at 45°-52°N, and a southwesterly low-level jet at 700 hPa extended from east of Lake Balkhash to Tacheng area. At 850 hPa, a warm shear line existed between southwesterly and southeasterly winds, with a warm temperature ridge over western and northern Xinjiang. The surface low moved eastward along a western track to near Lake Balkhash (center pressure 1007.5

hPa), while the Mongolian high was 1032.5 hPa. The southeastern periphery of the low expanded to western Xinjiang, with the low' s inverted trough beginning to affect Tacheng. Strong warm air continuously pushed the cold air eastward and northward, with warm frontogenesis occurring to the right front of the low.

Analysis of the vertical cross-section along 83°E shows a dense pseudo-equivalent potential temperature zone concentrated below 700 hPa, tilting northward (toward cold air). The frontogenesis position is lower and more southerly than the first type, indicating warm frontogenesis, with a frontogenesis function of 1.5$×10^{-9}$ K · m^{-1} · s^{-1}. Abundant warm, moist air climbs northward and upward along the cold air under southerly flow guidance, producing warm-sector blizzards.

Water vapor analysis shows that water vapor from the Mediterranean and Arabian Seas moves northward along southwesterly flow, converges and intensifies south of the Caspian and Aral Seas, and is transported along southwesterly-westerly flow to near Lake Balkhash, then reaches the blizzard area along westerly flow at the bottom of the horizontal trough. Water vapor flux values are large throughout transport, with a large-value center reaching 30 g · cm^{-1} · hPa^{-1} · s^{-1}. Significant water vapor convergence occurs between 850–700 hPa, with the convergence center at 700 hPa. When the convergence layer thickness decreases below 700 hPa and intensity weakens, the warm-sector blizzard ends and cold-front snowfall begins.

3.2.3 Northwest Jet Type This type occurs under a two-trough-two-ridge pattern in the mid-high latitudes, with a shallow ridge over southern Europe and a low vortex over the Ural Mountains to West Siberia centered at 60°N. As the ridge develops, the strong northerly flow ahead of it transports polar cold air southward to Siberia. The Siberian low vortex is positioned far north, and Xinjiang is controlled by northwesterly flow ahead of the ridge, producing warm-sector blizzards [Figure 5: see original paper].

A typical case occurred on December 11–12, 2010, when the Tacheng-Emin Basin experienced a blizzard. Cumulative snowfall reached 52.3 mm at Tacheng, 44.2 mm at Emin, and 41.4 mm at Yumin, with new snow depths of 44 cm, 22 cm, and 15 cm, respectively. At Tacheng station, the main snowfall period was from 14:00 on the 11th to 08:00 on the 12th, with maximum hourly intensity of 2.7 mm. Surface pressure decreased while temperature increased, but with the largest pressure drop and smallest temperature rise among the three types. At 20:00 on the 11th, northern Xinjiang was situated within a high-altitude northwesterly jet stream (maximum wind speed >36 m · s^{-1} at 300 hPa). The 500 hPa strong northwesterly frontal zone (>32 m · s^{-1}) was located at the bottom of the West Siberian low vortex at 45°–52°N. A northwesterly low-level jet at 700 hPa extended from east of Lake Balkhash to Tacheng area, with wind speeds >30 m · s^{-1}. At 850 hPa, a warm shear line existed between northwesterly and southeasterly winds at Tacheng and Altay stations. The surface low moved southeastward along a northwestern track to affect Xinjiang, with frontogenesis occurring north of Tacheng area, placing Tacheng in the pre-frontal warm sector.

Analysis of the vertical cross-section shows a dense pseudo-equivalent potential temperature zone concentrated below 600 hPa, nearly vertical to the surface north of Tacheng, with a frontogenesis function of 2.0×10^{-9} $K \cdot m^{-1} \cdot s^{-1}$. Tacheng area is located in the pre-frontal warm sector, with warm, moist air transported northward under weak southerly flow, producing warm-sector blizzards.

Water vapor analysis reveals two pathways: water vapor from the high-latitude Barents Sea is transported southeastward along northwesterly flow to Lake Balkhash, while water vapor from the mid-latitude Caspian Sea, Aral Sea, and low-latitude Mediterranean Sea and Arabian Sea moves northward along southwesterly flow, intensifies over the Black Sea and Caspian Sea, and is transported eastward through Eastern Europe and the Ural Mountains to Lake Balkhash. These two branches converge near Lake Balkhash, forming a large-value center of 30 $g \cdot cm^{-1} \cdot hPa^{-1} \cdot s^{-1}$, then are transported to northern Xinjiang along westerly flow. Significant water vapor convergence occurs below 600 hPa, with the convergence center at 850 hPa (-2.5×10^{-5} $g \cdot hPa^{-1} \cdot cm^{-2} \cdot s^{-1}$). The three-dimensional conceptual model shows the superposition of a strong northwesterly jet at 500–300 hPa, a northwesterly low-level jet at 700 hPa, and warm shear at 850 hPa, though the temperature ridge is less pronounced than in the other two types.

4. Conclusions

(1) Warm-sector blizzards in Tacheng area occur exclusively at Tacheng, Yumin, and Emin stations in the Tacheng-Emin Basin, with the highest frequency at Tacheng station, followed by Yumin and Emin stations. Temporally, events peaked in November and December, primarily concentrated from mid-November to early December, with the lowest frequency in February. However, the average daily snowfall during warm-sector blizzards was highest at Yumin station, followed by Emin station, and lowest at Tacheng station.

(2) Warm-sector blizzards in Tacheng area are classified into three types: low-trough front type, horizontal trough bottom type, and northwest jet type, with surface lows following northwestern or western tracks. The low-trough front type is the most typical pattern, occurring mainly from November to early December in the confluence zone between the frontal zone ahead of a West Siberian low trough and a mid-latitude short-wave trough, with the surface low taking a northwestern path. The horizontal trough bottom type occurs primarily from November to January in the strong frontal zone where westerly flow at the bottom of the polar front merges with warm, moist mid-latitude southwesterlies, with the surface low following a western path. The northwest jet type occurs mainly from November to December within the northwesterly flow of the polar frontal

zone, with the surface low taking a northwestern path.

(3) The overlapping region of a strong northwest or westerly jet at 500–300 hPa, a westerly low-level jet at 700 hPa, and warm shear at 850 hPa coincides with the warm-sector blizzard precipitation area. The low-trough front and northwest jet types produce blizzards in the pre-frontal warm sector, while the horizontal trough bottom type generates blizzards along the warm front to the right of the low-pressure center.

(4) Water vapor for the low-trough front and horizontal trough bottom types follows a westerly path, originating from the Mediterranean Sea and Arabian Sea, intensifying over the Caspian Sea and Aral Sea before reaching the blizzard area, though the horizontal trough bottom type has a slightly more southerly transport channel. The northwest jet type features both westerly and northwesterly water vapor pathways. Water vapor from the high-latitude Barents Sea converges with that from the mid-latitude Caspian Sea, Aral Sea, and low-latitude Mediterranean Sea and Arabian Sea near Lake Balkhash before being transported to the blizzard area. Strong water vapor transport is accompanied by significant low-level moisture convergence, with the strongest convergence center located between 850 hPa and 700 hPa.

Warm-sector blizzards represent a unique weather phenomenon in Xinjiang, characterized by heavy snowfall and severe disasters. While previous research has focused primarily on Altay area, studies on Tacheng area warm-sector blizzards are scarce. This systematic analysis of the temporal-spatial distribution, circulation characteristics, and formation mechanisms establishes conceptual models for different warm-sector blizzard types in Tacheng area, enhancing understanding of their formation mechanisms and providing key technical support for refined forecasting. However, due to sparse surface observations, the mesoscale system structure of warm-sector blizzards remains unclear. Future research should employ radar and other mesoscale numerical simulations to investigate microphysical processes and evolution patterns of various particles during blizzard events, improving the precision of operational blizzard location and intensity forecasting.

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Note: Figure translations are in progress. See original paper for figures.