Spatiotemporal Distribution Characteristics and Impact Assessment of Snow Disasters in the Ili Region, Xinjiang, 1990-2020: Postprint

Authors: fiery red, Liu Yan, Mawulaxia Mubarek, Liu Yan

Date: 2024-12-04T00:00:00+00:00

Abstract

Snow disasters have inflicted significant economic and social impacts on the Yili region, primarily manifested in reductions in agricultural production and destruction of ecosystems. To quantify and evaluate the impacts of snow disasters on the Yili region, based on 95 snow disaster events in the Yili region from 1990 to 2020, disaster loss indices were calculated through indicator selection, dimensionless processing, and weight allocation. Using the percentile method, snow disaster severity was classified into four levels: general, relatively severe, severe, and extremely severe. The results indicate: (1) The frequency of snow disasters in the Yili region from 1990 to 2020 exhibited a bimodal distribution, with November and January-February being peak incidence periods, correlating with seasonal climate characteristics. Since 2014, the frequency of snow disaster occurrences has decreased significantly. (2) From 1990 to 2020, general-level snow disasters were most common in the Yili region, accounting for 49.4%, while relatively severe, severe, and extremely severe levels accounted for 23.2%, 24.2%, and 5.0%, respectively. (3) Nilka County experienced the most severe disaster losses, followed by Xinyuan County and Yining County, while Zhaosu County was the least affected. (4) The occurrence and severity of snow disasters are influenced by meteorological factors including cumulative snowfall, maximum snow depth, minimum temperature, and snowfall duration. These factors exhibit significant inter-county variations but overall concentrated trends. The research findings can provide a scientific basis for snow disaster risk assessment and management in the Yili region.

Full Text

Preamble

ARID LAND GEOGRAPHY
Vol. 47 No. 11 Nov. 2024

Spatiotemporal Distribution Characteristics and Impact Assessment of Snow Disasters in the Ili Region of Xinjiang from 1990 to 2020

HUO Hong[1,2,3], LIU Yan[1,3,4], Maiwulaxia MUBAREKE[1,2,3]

[1] Institute of Urumqi Desert Meteorology, China Meteorological Administration, Urumqi 830002, Xinjiang, China
[2] Wulanwusu Ecology and Agrometeorology Observation and Research Station of Xinjiang, Urumqi 830002, Xinjiang, China
[3] Field Scientific Experiment Base of Akdala Atmospheric Background, China Meteorological Administration, Urumqi 830002, Xinjiang, China
[4] Xinjiang Desert Meteorology and Sandstorm Key Laboratory, Urumqi 830002, Xinjiang, China

Abstract: Snow disasters have caused significant economic and social impacts in the Ili region, primarily through reduced agricultural production and ecosystem damage. To quantify and assess these impacts, this study analyzed 95 snow disaster events in the Ili region from 1990 to 2020. A disaster loss index was calculated through indicator selection, dimensionless processing, and weight allocation, with disaster severity classified into four levels (mild, moderate, severe, and extreme) using the percentile method. The results show: (1) Snow disasters exhibited a bimodal temporal distribution, with peak occurrence periods in November and January-February, correlating with seasonal climate characteristics. Since 2014, the frequency of snow disasters has significantly decreased. (2) Mild snow disasters were most common, accounting for 49.4% of events, while moderate, severe, and extreme disasters represented 23.2%, 24.2%, and 5.0%, respectively. (3) The most severe losses occurred in Nilka County, followed by Xinyuan County and Yining County, while Zhaosu County was least affected. (4) Snow disaster occurrence and severity were influenced by meteorological factors including cumulative snowfall, maximum snow depth, minimum temperature, and snowfall duration. These factors showed significant regional variation but overall concentrated trends. The findings provide a scientific basis for snow disaster risk assessment and management in the Ili region.

Keywords: snow disaster; disaster loss index; intensity and frequency; spatial pattern; Ili region

1 Introduction

Snow disasters, as natural hazards triggered by extreme snowfall events, pose severe challenges to human society and the natural environment. They manifest in various forms including blizzards, snowdrifts, and avalanches, causing widespread destruction that can rapidly disrupt transportation, damage infrastructure, and threaten human safety. With intensifying global warming, changes in global climate patterns and increasing frequency and intensity of extreme climate events such as snow disasters have attracted worldwide attention. China’ s vast geographical distribution and diverse climatic conditions make it particularly susceptible to frequent snow disasters across multiple regions. For instance, significant snow disasters occurred in Inner Mongolia in 2000, the Sunit grassland in 2016, the Haixi area of Qinghai in 2017, Chifeng City in Inner Mongolia in 2020, and pastoral areas in southern Huangnan Prefecture, Qinghai in 2021. In 2023, Xinjiang experienced snow disasters that caused substantial economic and social harm. Specifically, in 2022, low-temperature freezing and snow disasters in China caused direct economic losses of ¥1.25\$×10$^{\{10\}}, whiletheUnitedStatessufferedseveresnowdisastersthatsameyear, causingmulti-statewaterandpoweroutages, tra$

The Ili region holds a critical position in snow disaster research due to its unique geographical location and humid continental climate conditions. The region experiences long winters with heavy snowfall, where snow depth and frequency often exceed other parts of Xinjiang, making it a high-risk area for snow disasters. According to collected disaster records, the Ili region experiences snow disasters of varying scales almost annually. Compared with areas such as the Sunit grassland in Inner Mongolia, snow disasters in the Ili region exhibit distinct seasonal characteristics with high frequency and intensity, particularly concentrated during winter months. These features pose special challenges for snow disaster risk assessment and management in the region. For example, in 2009-2010, severe snow disasters heavily impacted Zhaosu and Yining Counties, affecting 4.2\$×10^{5}\$ people and causing direct economic losses of ¥1.60\$×10^{9}\$, revealing deficiencies in early warning and emergency response measures.

Given the prevalence and severity of snow disasters in China, researchers are developing comprehensive assessment models to enhance understanding and response capabilities. These models integrate multi-dimensional data including disaster records, meteorological observations, remote sensing, geographic information, and socioeconomic factors to accurately predict disaster impacts. For example, Liu et al. established grassland livestock snow disaster evaluation and loss estimation models for the Altay pastoral area using satellite data and ground observations. Zhuang et al. analyzed multiple meteorological datasets from 1961-2013, including maximum snow depth and monthly precipitation, to examine snow disasters, sunspots, and forage availability in northern Xinjiang pastoral areas. Wang et al. constructed a disaster loss index based on affected livestock numbers, crop areas, and economic losses to reveal spatiotemporal distribution characteristics of snow disasters in Xinjiang. Xu et al. analyzed Xinjiang snow disaster monitoring data from 2000-2010 using spatiotemporal autocorrelation methods. Wei et al. identified 23 warm-sector blizzard events in the Tacheng area using various observational data and NCEP reanalysis data.

While existing studies provide basic understanding of snow disaster frequency and impacts in different regions, they often focus on single influencing factors such as snowfall or temperature, limiting comprehension of disaster complexity. For the Ili region specifically, despite frequent and far-reaching snow disasters, comprehensive analysis of their spatiotemporal distribution characteristics remains insufficient. This study addresses this gap by focusing on snow disasters directly caused by blizzard processes, particularly events triggered by heavy snowfall in short periods and associated adverse weather conditions. By constructing a disaster loss index that integrates six key factors including affected population, fatalities, and crop damage, this research analyzes spatiotemporal distribution characteristics, severity levels, and impact scope of snow disasters. The findings will provide robust data support for developing effective disaster prevention measures and emergency response strategies.

2 Data and Methods

2.1 Study Area Overview

The Ili region (80°09 42 -84°56 50 E, 42°14 16 -44°53 30 N) is located in northwestern Xinjiang. Surrounded by mountains on its eastern, southern, and northern sides with a trumpet-shaped topography opening westward, the region forms unique natural landscapes and ecological environments. Together with the Tarim Basin in southern Xinjiang and the Hami-Turpan Basin in eastern Xinjiang, the Ili region constitutes Xinjiang' s distinctive natural geographical pattern. The region features a cold temperate semi-arid continental climate with short summers and long winters, with annual average temperatures of 2.9-9.1°C, annual precipitation of 200-800 mm, and annual sunshine hours of 2700-3000 h. Precipitation varies significantly across monthly, seasonal, and annual timescales, with mountain areas typically receiving more precipitation than plains and substantial differences between local areas. Particularly during late autumn and early spring, frequent cold air invasions cause sharp temperature drops, potentially triggering rain or snow events accompanied by blizzards with wind speeds exceeding 10 $\mathrm{m \cdot s^{-1}}$. These extreme weather conditions create favorable conditions for snow disasters, making the Ili region highly vulnerable.

2.2 Data Sources

Disaster data were obtained from the *China Meteorological Disaster* 大典 · *Xinjiang* 卷 and snow disaster records provided by the Xinjiang Uygur Autonomous Region Department of Civil Affairs. By collating snow disaster data from 1990-2020 in the 大典 and civil affairs records, 95 snow disaster events in the Ili region were identified. These records include key indicators such as disaster occurrence time, affected area, impacted population, fatalities, collapsed houses, and damaged crop area. Data completeness was relatively good, with direct economic loss data available for 75.5% of events, and population impact, fatalities, house collapse, livestock deaths, and crop damage data fully available.

2.3 Methods

2.3.1 Calculation of Disaster Loss Index The disaster loss index calculation involved four steps: First, six key disaster indicators were selected from snow disaster events, including affected population, fatalities, collapsed houses, direct economic losses, livestock deaths, and crop damage area. Second, average and maximum values were calculated for each indicator per event, followed by dimensionless processing to eliminate scale differences. Third, weights (a) were assigned to each dimensionless indicator. Finally, the disaster loss index was computed for each event.

The disaster loss index formula is:

$$Z_i = \sum_{j=1}^{m} a_j \times X'_{ij}$$

where Z is the disaster loss index for event i; a represents the weight of indicator j; X is the dimensionless value of indicator j in event i; and m is the total number of indicators.

Weights were determined using a ratio method that reflects each indicator’ s relative importance in historical snow disasters:

$$a_j = \frac{\sum_{i=1}^{n} X_{ij}}{\sum_{j=1}^{m} \sum_{i=1}^{n} X_{ij}}$$

where a is the weight of indicator j; n is the total number of snow disaster events; m is the total number of indicators; X is the recorded value of indicator j in event i.

2.3.2 Classification Standards for Disaster Severity The percentile method was used to classify snow disaster severity in the Ili region. All disaster loss indices were sorted ascendingly, with the 25th, 50th, 75th, and 95th percentiles established as thresholds for different severity levels. The classification standard is: events below the 25th percentile are mild; between 25th–50th percentile are moderate; between 50th–75th percentile are severe; and above the 75th percentile are extreme. This method provides clear quantitative standards for disaster management and assessment.

The percentile calculation formula is:

$$P_r = X_{[d]} + (d + 1 - [d]) \times (X_{[d+1]} - X_{[d]})$$

where P is the rth percentile; d is the specific position of percentile r in the sample; [d] is the integer part of d; X_{[d]} and X_{[d+1]} are values at positions [d] and [d+1]; n is the total number of snow disaster events; and r is the percentile value.

2.3.3 Spatial Distribution Mapping and Analysis GIS technology was employed to analyze spatial distribution characteristics of snow disasters in the Ili region from 1990–2020. A standardized dataset was constructed containing disaster indicators (affected area, fatalities, collapsed houses), disaster loss indices, and severity levels. All data were formatted consistently and stored as Excel files. ArcMap software was then used to import the data and generate intuitive spatial distribution maps clearly showing disaster loss indices and snow disaster intensity levels.

---

3 Results and Analysis

3.1 Construction of Disaster Loss Index and Weight Determination

In snow disaster assessment, when using all six disaster indicators, affected population, direct economic losses, and fatalities showed relatively high weights (Table 1). Livestock deaths and crop damage area had lower weights and low correlation with the disaster loss index, so these two indicators were excluded. After indicator selection, the weights for affected population, direct economic losses, and fatalities were basically consistent, while collapsed houses had lower weight but showed improvement compared to before indicator removal.

Correlation coefficients between the disaster loss index and different indicator combinations were all positive with significance levels $\alpha < 0.01$, demonstrating that the index effectively integrates various indicator combinations and quantitatively reflects snow disaster intensity. Using extreme snow disasters as an example, comparison of severity levels classified by different indicator combinations (Table 2) revealed that after removing the two low-correlation indicators (livestock deaths and crop damage area), although the disaster loss index and severity levels were adjusted, the overall trend remained stable. This indicates that key indicators can effectively assess disaster intensity even with incomplete records.

Analysis of extreme snow disaster events based on different indicators (Table 3) showed that after removing livestock deaths and crop damage area, the disaster loss index and disaster severity levels were adjusted but remained stable overall. This demonstrates that key indicators can still effectively evaluate disaster intensity when indicator records are incomplete.

Comprehensive analysis of snow disaster events from 1990–2020 revealed certain patterns. Mild snow disasters occurred most frequently (47 events), followed by moderate and severe levels (24 and 18 events respectively), with extreme disasters being least common (6 events). These data reveal the frequency distribution of snow disasters and emphasize the importance of key indicators in the assessment process, showing that using more indicator types and complete records significantly improves the accuracy of the disaster loss index.

3.2 Temporal Characteristics

3.2.1 Monthly Patterns of Snow Disaster Frequency and Intensity

Snow disaster frequency in the Ili region showed a significant bimodal distribution (Figure 1), with two main peak periods: November, marking the beginning of winter, recorded 25 events; and January-February, the core winter months, with cumulative events reaching 46, accounting for nearly half of annual occurrences. In contrast, summer and autumn had relatively low incidence rates. This pattern is crucial for targeted disaster prevention, particularly during these high-incidence months when enhanced risk management is needed.

[Figure 1: see original paper]

Snow disaster intensity levels also showed monthly variation (Figure 2). November and December had relatively mild intensity, mainly mild-level disasters with annual frequency below 1.5 events. January-February saw increased intensity levels, including mild and moderate categories, though overall frequency remained relatively low. March-April showed no severe-level disasters, with mild-level events dominant, correlating with gradually colder but not yet extreme winter conditions. Winter months (November-February) exhibited significantly elevated intensity levels, with frequent severe and extreme disasters across all categories (Figure 2). This seasonal characteristic aligns with winter’ s low temperatures and heavy snowfall, indicating the need for enhanced monitoring and early warning systems during this period. Additionally, as the number of disaster indicators increased, identification accuracy for severe and extreme snow disasters improved, with 4-indicator combinations more effectively identifying severe and extreme events than 3-indicator combinations.

[Figure 2: see original paper]

3.2.2 Monthly Characteristics of Disaster Indicators

To visualize the specific contribution of each disaster indicator to snow disaster severity across different months and reveal seasonal patterns, a percentage stacked chart of monthly indicator contributions was created (Figure 3). During the critical crop growth period of April-May, direct economic losses and crop damage area showed higher percentages, reflecting the potential threat to agricultural production and significant economic impact. During the peak disaster period of November-February, indicators such as affected population and collapsed houses increased, highlighting concerns for residents’ lives and infrastructure safety.

March primarily impacted animal husbandry. These seasonal differences help identify high-risk months and provide scientific basis for targeted preventive measures.

[Figure 3: see original paper]

In summary, snow disasters in the Ili region exhibit significant seasonal distribution, and assessment of disaster intensity levels becomes more precise as more comprehensive disaster indicators are considered. This finding has important guiding significance for developing early warning systems and disaster management strategies.

3.2.3 Annual Patterns of Snow Disaster Frequency and Intensity

Building on monthly analysis, this study further examined annual variation characteristics of snow disasters, intensity levels, and key indicator contributions. From 1990-2020, the Ili region experienced 95 snow disasters, averaging 3.1 events annually, indicating continuous impact. Notably, 1999-2000 and 2009-2010 showed significant increases, becoming prominent high-incidence periods.

[Figure 4: see original paper]

Annual distribution of snow disaster intensity levels (Figure 5) revealed that 1990-1999 generally had low intensity, mainly mild-level events. 2000-2009 saw increased intensity with more uniform distribution across levels, reflecting widespread impacts. 2010-2014 experienced decreased frequency and intensity, representing a relatively low-disaster period, though extreme-level events still caused significant impacts. 2015-2019 showed another increase in both frequency and intensity. After 2020, data indicate decreased frequency and intensity, with no severe or extreme disasters recorded, suggesting reduced overall impact. These trends relate to climate change, regional development, and disaster prevention measures, requiring further analysis to identify specific influencing factors.

[Figure 5: see original paper]

3.2.4 Annual Characteristics of Disaster Indicators

The annual contribution percentage stacked chart of disaster indicators from 1990-2020 (Figure 6) clearly revealed cumulative impacts. From 1990-1999, fatalities were the main impact factor. 2000-2009 showed the most significant impact on animal husbandry, with maximum livestock deaths. After 2010, although casualties decreased, the proportion of economic losses increased, along with affected population and collapsed houses. Analysis of annual indicator contributions revealed variations—for example, affected population and collapsed houses dominated in some years, while in others, direct economic losses and livestock deaths were primary factors. These trends relate to regional development, population distribution, economic structure, and disaster prevention capacity changes.

[Figure 6: see original paper]

3.3 Spatial Characteristics

3.3.1 Spatial Patterns of Disaster Loss Index Using natural breaks classification, cumulative disaster loss index values from 1990-2020 for nine counties (cities) were mapped (Figure 7). Nilka County showed the most severe losses with a cumulative value of 0.92. Xinyuan County and Yining County also had high indices of 0.64 and 0.63 respectively. In contrast, Horgos City had a relatively low index of 0.03, indicating lighter impacts. The analysis revealed that while disaster levels varied with different indicator combinations, overall spatial distribution showed certain stability.

[Figure 7: see original paper]

3.3.2 Spatial Patterns of Snow Disaster Frequency and Intensity The nine counties (cities) in the Ili region experienced 95 total snow disasters. Nilka County had the highest frequency with 18 events. Yining County and Tekes County each had 15 events, followed by Xinyuan County and Qapqal Xibe Autonomous County with 13 events each. Huocheng County, Yining City, Zhaosu County, and Horgos City had fewer events.

[Figure 8: see original paper]

Spatial distribution of snow disaster intensity levels (Figure 9) showed that Horgos City experienced only one mild-level disaster. Xinyuan County had the widest distribution across levels, with mild, moderate, severe, and extreme events accounting for 27.3%, 18.2%, 36.4%, and 18.5% respectively. Yining County did not show extreme-level disasters under 4-indicator conditions. Qapqal Xibe Autonomous County, Nilka County, and Tekes County mainly had mild, moderate, and severe disasters. The remaining counties (cities) primarily experienced mild and moderate disasters, with mild-level events being most common.

[Figure 9: see original paper]

3.3.3 Spatial Characteristics of Disaster Indicators By comprehensively considering average annual snow disaster frequency and multi-year averages of six key indicators (affected population, fatalities, collapsed houses, direct economic losses, livestock deaths, and crop damage area), annual disaster conditions were assessed for each county (city) (Figure 10). Yining County ranked first in affected population (1.01$\times10^{5} persons), followed by Nilka County (0.92$\times10^{\{5\})andXinyuanCounty(0.91\times10}\{5\}).XinyuanCountyhadthehighestaverageannualfatalities(25.7person$
demonstrating significant economic impact per event. These data highlight spatial heterogeneity of snow disaster impacts and provide important support for regional disaster management.

[Figure 10: see original paper]

3.4 Comprehensive Assessment of Meteorological Factors

Meteorological factors are direct drivers of snow disaster occurrence and intensity. In-depth analysis helps comprehensively understand disaster mechanisms. This study analyzed meteorological factors for 95 snow disaster events from 1990–2020. Key factors included cumulative snowfall, maximum snow depth, minimum temperature, and snowfall duration within each event period. Cumulative snowfall quantifies total precipitation, maximum snow depth reveals ground impact, minimum temperature records extreme conditions, and duration reflects persistence and cumulative effects. These indicators are crucial for assessing disaster severity and closely related to spatiotemporal distribution, index construction, and risk assessment.

Meteorological factors causing snow disasters showed obvious regional differences but relatively concentrated overall distribution trends (Figure 11). Zhaosu Station recorded the highest maximum snow depth (31.7 cm), showing that high snowfall intensity can cause severe disasters even without extreme duration or total amount. Xinyuan Station recorded the most snowfall days (4.3 days) and largest cumulative snowfall (31.7 mm), while Tekes Station had generally lower values. The median cumulative snowfall across the region was 14.0 mm with a standard deviation of 16.4 mm, indicating significant fluctuations. Xinyuan Station ranked first in average cumulative snowfall, while Tekes Station ranked last at 9.7 mm, reflecting substantial regional differences. Average snowfall duration was 3.6 days, concentrated between 2.0–4.3 days at most stations. For maximum snow depth, Huocheng Station showed the largest standard deviation (20.8 cm), while Zhaosu Station had the smallest (3.7 cm). Minimum temperatures averaged -10.3°C across stations, ranging from -28.4°C to 3.4°C, with Tekes Station recording the lowest and Horgos Station the highest. Huocheng Station had the largest standard deviation for minimum temperature (10.03°C), while Zhaosu Station had the smallest (2.18°C).

Analysis revealed that high-incidence counties (Nilka, Xinyuan, Yining, and Tekes) had higher mean maximum snow depth values, distinguishing them from other regions. Nilka, Xinyuan, and Yining counties also had higher maximum cumulative snowfall values. These findings provide crucial meteorological evidence for understanding spatiotemporal distribution characteristics and offer scientific basis for risk assessment and management. Identifying regional meteorological characteristics enables more precise disaster risk prediction and supports effective prevention measures.

[Figure 11: see original paper]

---

4 Conclusions

This study analyzed spatiotemporal distribution characteristics and impact assessment of snow disasters in the Ili region from 1990–2020, yielding four main conclusions:

(1) Snow disasters showed a bimodal distribution and periodic variation, concentrated in November and peaking in January-February. Spring and autumn had relatively low occurrence. High-incidence months also exhibited more diverse disaster types and severe levels. From 1990–2020, the region averaged 3.1 snow disasters annually, with 1999–2000 and 2009–2010 recording 6 and 7 events respectively—significantly above average. Disaster frequency was high during 2000–2014, then decreased further after 2015, indicating periodic changes possibly related to climate change and regional adaptation measures.

(2) Snow disaster impacts showed significant spatial heterogeneity. Nilka County, Xinyuan County, and Yining County were most severely affected, while Zhaosu County was relatively less impacted. Disaster management and planning should consider region-specific risk characteristics.

(3) Multi-indicator combination assessment effectively improved identification accuracy for severe and extreme snow disasters. Results show that increasing the number of assessment indicators significantly enhances disaster loss index accuracy, particularly when using 4 indicators compared to 3, enabling more precise intensity classification. This finding emphasizes the importance of comprehensive assessment in disaster management and provides more reliable basis for risk evaluation.

(4) Key meteorological factors influencing snow disaster risk in the Ili region are cumulative snowfall, maximum snow depth, minimum temperature, and snowfall duration. These factors show significant regional differences but relatively concentrated overall distribution, providing crucial indicators for risk assessment and solid scientific basis for establishing disaster thresholds. Using these indicators enables more accurate severity assessment and supports effective disaster prevention strategies.

Based on these findings, we recommend that relevant departments establish more refined early warning systems and improve emergency plans to enhance response capabilities for extreme snow disasters. Particularly during November-February, region-specific differentiated prevention measures should be implemented. Additionally, we recommend using these key meteorological factors to establish and optimize disaster risk assessment models to provide scientific data support for more effective disaster risk management.

References

[1] Gao J M. Analysis and assessment of the risk of snow and freezing disaster in China[J]. International Journal of Disaster Risk Reduction, 2016, 19: 334-340.

[2] Han Yanli. Spatiotemporal distribution characteristics of snow disasters in

Sunit grassland[J]. Modern Salt and Chemical Industry, 2023, 50(1): 89-91.

[3] Li Xing, Li Jinfeng, Chen Hongsong, et al. Temporal and spatial distribution characteristics of snow disasters in Haixi area of Qinghai Province in recent 41 years[J]. Journal of Qinghai Environment, 2022, 32(2): 90-95.

[4] Ge Haiyan. Analysis on temporal and spatial distribution characteristics of snow disaster in Chifeng area in recent 60 years[J]. Agricultural Technology & Equipment, 2022(1): 146-148.

[5] Peng Yingchao, Chen Jing, Tang Zhongtao. A study on the characteristics of snow disasters in the pastoral areas of southern Huangnan Prefecture in recent 60 years[J]. Journal of Agricultural Catastrophology, 2021, 11(9): 84-86.

[6] Wang Xiuqin, Lu Xinyu, Ma Yu, et al. Study on snow disaster assessment method and snow disaster regionalization in Xinjiang[J]. Journal of Glaciology and Geocryology, 2019, 41(4): 836-844.

[7] Xiao Pengfeng. Analysis and recommendations on the response to the 2022 snow disaster in the United States[J]. Disaster Reduction in China, 2023(3): 36-39.

[8] 2006 national situation on low temperature freeze and snow disasters[J]. Disaster Reduction in China, 2007(2): 16.

[9] Wang Xu, Chu Changjiang, Mou Huan. Spatial pattern and interannual variation characteristics of snow disaster in Xinjiang[J]. Arid Zone Research, 2020, 37(6): 1488-1495.

[10] An Ying, Li Shengcai. Statistics of environmental events in China during period from November to December in 2013[J]. Journal of Safety and Environment, 2014, 14(6): 348-351.

[11] Yang Dengxing, Liu Fenggui, Yan Junping, et al. A risk assessment of snow disaster along Qinghai-Tibet railway[J]. Geographical Research, 2021, 40(5): 1223-1238.

[12] Ma Heng, Zhang Gangfeng, Shi Peijun. Advances and prospects of livestock snow disaster mechanism research and risk assessment[J]. Progress in Geography, 2021, 40(12): 2116-2129.

[13] Zhao Huixia, Zhou Lilong, Yuan Huimin, et al. Comprehensive assessment model of heavy snow process in northeast China[J]. Meteorological and Environmental Sciences, 2021, 44(3): 1-7.

[14] Wang Xiuqin, Wang Yun, Wang Xu. Variation characteristics of wind disasters at different levels in Xinjiang from 1990 to 2019[J]. Meteorological Science and Technology, 2022, 50(2): 273-281.

[15] Liu Xingyuan, Liang Tiangang, Guo Zhenggang, et al. Assessment and monitoring of snow disaster effect on grassland livestock industry in the Aletai

region using remote sensing technology[J]. Acta Prataculturae Sinica, 2003(6): 115-120.

[16] Zhuang Xiaocui, Zhou Hongkui, Wang Lei, et al. Evaluation and cause study on the snow disasters in pastoral areas of northern Xinjiang[J]. Arid Zone Research, 2015, 32(5): 1000-1006.

[17] Guo Wei, Xie Haitao, Wang Xu, et al. Spatiotemporal variation of rainstorm flooding disaster events in northern Xinjiang from 1981 to 2019[J]. Torrential Rain and Disasters, 2022, 41(1): 101-108.

[18] Xu Jianhui, Shu Hong, Liu Yan. Spatiotemporal autocorrelation of snow disasters in Xinjiang from 2000 to 2010[J]. Journal of Catastrophology, 2014, 29(1): 221-227.

[19] Wei Juanjuan, Wan Yu, Zhang Junlan, et al. Circulation classification and cause analysis of the warm area blizzards in Tacheng area in recent 20 years[J]. Arid Land Geography, 2022, 45(6): 1718-1728.

[20] Li Yanhua, Gao Rucun, Zhang Ying, et al. Comparison analysis of snow change characteristic in Yili region in recent 35 years[J]. Desert and Oasis Meteorology, 2007(2): 26-28.

[21] Chen Ying, Ma Yu. Spatial and temporal characteristics of flood and rainstorm disaster in Xinjiang[J]. Arid Land Geography, 2021, 44(6): 1515-1524.

[22] Han Minghua, Xiao Jidong, Li Zhanling. Effects of two uncertainty sources on drought index of SPEI and on drought assessment[J]. Arid Land Geography, 2022, 45(5): 1392-1401.

[23] Changnon S A, Changnon D, Karl T R. Temporal and spatial characteristics of snowstorms in the contiguous United States[J]. Journal of Applied Meteorology and Climatology, 2006, 45(8): 1141-1155.

[24] Cohen J, Pfeiffer K, Francis J A. Warm Arctic episodes linked with increased frequency of extreme winter weather in the United States[J]. Nature Communications, 2018, 9(1): 869, doi: 10.1038/s41467-018-02992-9.

[25] AghaKouchak A, Chiang F, Huning L S, et al. Climate extremes and compound hazards in a warming world[J]. Annual Review of Earth and Planetary Sciences, 2020, 48(1): 519-548.

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