Analysis of Winter Snowfall Variation and Its Influencing Factors on the Northern Slope of the Central Tianshan Mountains: Postprint

Authors: Miao Yunling, Yongbo Yu, Huo Da, Pan Cunliang, Li Ruqi, Li Ruqi

Date: 2023-03-13T00:00:00+00:00

Abstract

Based on observational data of daily precipitation and temperature elements in winter from 17 national meteorological stations on the northern slope of the Central Tianshan Mountains from 1978 to 2020, and using various statistical methods, this study analyzes the spatiotemporal variation characteristics of winter snowfall and its relationship with meteorological factors. The results indicate that: the regional distributions of snowfall days and snowfall amount are similar, both exhibiting a distribution pattern of "more in urban areas, less in mountainous areas" ; the decrease in light snow days is the direct cause of the reduction in total snow days, while the significant increase in moderate and heavy snow is the main reason for the increase in total snowfall amount; precipitation events lasting 1 day constitute the main snowfall process in winter, and as the duration increases, precipitation events decrease significantly, with events lasting $ $5 days accounting for only 2.8%; over the past 43 years, the climate on the northern slope of the Central Tianshan Mountains has shown a relatively obvious warming and humidification trend, with abrupt changes occurring in 1987 and 1994 when snowfall amount shifted from less to more and mean temperature shifted from low to high, respectively; snowfall amount shows a significant positive correlation with annual precipitation, winter average minimum temperature, and snowfall days—the greater the annual precipitation, the lower the winter minimum temperature, and the more snowfall days that occur, the larger the winter snowfall amount, and vice versa.

Full Text

Analysis of Winter Snowfall Variability and Its Influencing Factors on the North Slope of the Middle Tianshan Mountains

MIAO Yunling[1], YU Yongbo[1], HUO Da[1], PAN Cunliang[2], LI Ruqi[3]
[1]Urumqi Meteorological Bureau, Urumqi 830002, Xinjiang, China
[2]Hami Meteorological Bureau, Hami 839000, Xinjiang, China
[3]Xinjiang Meteorological Observatory, Urumqi 830002, Xinjiang, China

Abstract

Based on winter daily precipitation and temperature observation data from national meteorological stations on the north slope of the middle Tianshan Mountains from 1978 to 2020, this study uses various statistical methods to analyze the spatiotemporal variation characteristics of winter snowfall and its relationship with meteorological factors. The results show that: The regional distribution of snowfall days and snowfall amount is similar, both showing a distribution pattern of "more in urban areas, less in mountainous areas." The decrease in light snow days is the direct cause of the reduction in total snow days, while the significant increase in moderate snow and blizzard events is the main reason for the increase in total snowfall amount. Precipitation processes lasting days are the main snowfall processes in winter. With increasing duration, precipitation processes decrease significantly, with precipitation processes accounting for only %. Over the past 43 years, the climate on the north slope of the middle Tianshan Mountains has shown a significant warming and humidifying trend, with abrupt changes in snowfall amount from less to more in 1987 and in average temperature from low to high in 1994. Snowfall amount shows a significant positive correlation with annual precipitation, winter average minimum temperature, and snowfall days. The greater the annual precipitation, the lower the winter minimum temperature, and the more snowfall days, the greater the winter snowfall amount, and vice versa.

Keywords: different magnitude snowfall; spatiotemporal distribution; persistence; north slope of the middle Tianshan Mountains

Introduction

Snowfall is solid precipitation formed by condensation of water vapor in winter air and represents one of the most active natural processes on the Earth's surface, constituting an indispensable component of hydrological systems in arid regions. Stable snow cover formed by snowfall in high-altitude areas provides material for alpine glaciers. In Northeast China, snowfall exhibits a pattern of more in the north and less in the south, more in the east and less in the west, with snowfall days showing a significant decreasing trend. The Tibetan Plateau shows a "less-more-less"trend in snowfall, with snowfall days significantly decreasing, although no significant trend is observed in snowfall days in the northern plateau. In the eastern Hexi Corridor, snowfall days are more in the southwest and less in the northeast. In Ningxia, snowfall days are fewer in the north and more in the south, while in southeastern Shandong they are more in the west and less in the east, but all show a decreasing trend over time. For Xinjiang, snowfall days gradually increase from south to north, with significantly more snowfall days in northern Xinjiang than in southern Xinjiang. Both northern Xinjiang and the Tianshan Mountains show increasing trends in snowfall days, especially for moderate and heavy snowfall.

Snowmelt water is the main source of agricultural irrigation and domestic water use in arid and semi-arid regions, helping to alleviate water shortages and improve ecological environments. However, prolonged and large-scale snowfall often causes significant disasters to agriculture, animal husbandry, and transportation. Thus, snowfall is closely related to people' s production and daily life. Therefore, strengthening research on winter snowfall is highly necessary.

Xinjiang is one of China' s three major snowfall regions, with snowfall mainly occurring on the southern slope of the Altai Mountains and the northern slope of the Tianshan Mountains. The north slope of the middle Tianshan Mountains is Xinjiang' s primary economic belt and the region with the highest frequency of blizzards in the province. The amount of snowfall has important impacts on local industrial and agricultural production. Analyzing the spatiotemporal distribution and variation characteristics of local snowfall is of great significance for improving snowfall forecasting capabilities, disaster prevention and mitigation, and scientific water resource utilization.

Recent studies show that the proportion of snowfall days at different levels to total snow days varies by region, and snowfall days are closely related to geographical location. For Xinjiang, water resource shortage is a prominent problem restricting local economic development and the biggest bottleneck constraining agricultural and pastoral development. Therefore, this paper uses winter daily precipitation data from 1978 to 2020 on the north slope of the middle Tianshan Mountains to conduct in-depth analysis of the spatiotemporal distribution, variation trends, and contributions of different magnitude snowfall, aiming to provide technical support for improving snowfall forecasting and prediction levels, water resource evaluation, and effective implementation of artificial snow enhancement in this region, while also promoting sustainable social and economic development and water resource utilization.

1.1 Data Sources and Precipitation Classification

Considering data completeness, continuity, temporal sequence, station relocation, and geographical conditions, 17 national meteorological stations in the core cities of the economic belt on the north slope of the middle Tianshan Mountains (Urumqi and Changji) were selected for analysis. Daily precipitation, temperature, and weather phenomenon data from these stations were used, all of which have undergone strict quality control with high data integrity and accuracy. For consistency, liquid precipitation and sleet processes occurring in winter were excluded. Winter is defined as December to February of the following year, with a time series from 1978 to 2020.

According to the "Code for Automatic Surface Meteorological Observation (First Edition)" , weather phenomenon records use Beijing time with 20:00 as the daily boundary. When precipitation crosses days (or months), it is counted as two separate precipitation events. Due to Xinjiang' s special climate and forecasting needs, precipitation is classified according to Xinjiang standards into six magnitudes: trace snow ($R < 0.1$ mm), light snow (0.1 mm $\leq R \leq 3.0$ mm), moderate snow (3.0 mm $< R \leq 6.0$ mm), heavy snow (6.0 mm $< R \leq 12.0$ mm), blizzard (12.0 mm $< R \leq 24.0$ mm), and heavy blizzard ($R \geq 24.1$ mm). This paper only counts effective precipitation with $R \geq 0.1$ mm. Snowfall days refer to days with snowfall weather phenomena in winter, and snowfall intensity refers to the ratio of snowfall amount to snowfall days.

Based on population, altitude, and geographical environment, the north slope of the middle Tianshan Mountains is divided into urban areas (representative stations: Urumqi, Changji, Midong), mountainous areas (representative stations: Xiaoquzi, Mushizhan, Tianchi, Beitashan, Daxigou), and suburban areas (stations surrounding the city). The specific station distribution is shown in [Figure 1: see original paper].

1.2 Research Methods

Conventional analysis methods including linear trend, polynomial fitting, and anomaly analysis were used for trend analysis. Inverse Distance Weighted (IDW) average interpolation was applied for spatial analysis. The Mann-Kendall test was used for mutation analysis. To verify whether turning points represent true mutations, signal-to-noise ratio testing was applied using the formula $S/N = |Xb - Xa| / (Sa + Sb)$, where Xa, Xb, Sa, and Sb are the means and standard deviations of the observation elements before and after the turning year. When $S/N > 1.0$, the year is considered a mutation year.

2.1 Basic Characteristics of Snowfall

Statistics show that winter snowfall on the north slope of the middle Tianshan Mountains from 1978 to 2020 has the following characteristics: (1) The average snowfall amount is 23.5 mm and average snowfall intensity is $1.24\ \text{mm} \cdot \text{d}^{-1}$. As snowfall magnitude increases, snowfall days decrease faster than snowfall amount. Light snow contributes most to total snowfall days, while blizzard days contribute least. (2) Winter snowfall shows large interannual fluctuations, with maximum snowfall being 10.8 times the minimum. The maximum number of snowfall processes is 5.6 times the minimum. (3) Both maximum snowfall days and amount occur in urban areas, while minima occur in mountainous areas. (4) During the study period, Dabancheng did not experience heavy snow or blizzards, while Mosuowan, Beitashan, and Daxigou did not experience blizzards. (5) In the past 20 years, heavy snow occurred but blizzards did not, meaning blizzards occur on average once every 20 years.

2.2.1 Spatial Distribution of Snowfall Days

As shown in [Figure 2: see original paper], winter total snow days on the north slope of the middle Tianshan Mountains gradually decrease from urban centers outward, with maximum values in Urumqi (urban area) and minimum values in Dabancheng (suburban area). Other stations range from 13 to 24 days. Regional differences are significant, following the pattern: urban areas > suburban areas > mountainous areas. Urban areas have the most winter snowfall, with all 5 stations exceeding 20 days, while mountainous areas, despite abundant precipitation during flood season, have the least winter snowfall at only about 13 days. Among them, 4 stations did not experience blizzards within 43 years.

From the regional distribution of snowfall days at different magnitudes, maximum values all appear in urban areas, but minimum values appear in different regions: light snow days, moderate snow days, and blizzard days in mountainous areas, and heavy snow days in suburban areas. Light snow days show similar spatial distribution to total snow days, gradually decreasing from urban centers outward. Except for Dabancheng in suburban areas, other stations have 10-20 light snow days, but their proportions differ significantly. Urumqi in urban areas has the most light snow days (18 days) but the smallest proportion (83.9%), while Dabancheng has the fewest light snow days (13 days) but the largest proportion (97.3%).

Moderate snow days and blizzard days show relatively consistent spatial distribution with two high-value centers in urban Urumqi and suburban Manas and Mulei, gradually decreasing outward. Maximum values still appear in Urumchi. Except for Dabancheng and Daxigou, other stations have 1-3 moderate snow days.

2.2.2 Spatial Distribution of Snowfall Amount

Winter total snowfall amount on the north slope of the middle Tianshan Mountains ([Figure 3: see original paper]) shows similar spatial distribution to total snow days, gradually decreasing from urban centers outward. Maximum snowfall occurs in Urumqi (97.3 mm), while minimum occurs in Dabancheng (3.8 mm), a 25-fold difference. Other stations range from 15 to 30 mm. Regional distribution follows the same pattern as snowfall days: urban areas (34.4 mm) > suburban areas (21.0 mm) > mountainous areas (18.5 mm).

Analysis of light snow amount proportions shows Urumqi, with the largest snowfall amount, has the smallest proportion of light snow (37.7%), while Daxigou in high mountainous areas has the largest proportion (81.6%). Other stations differ little, ranging from 87.0% to 92.8%.

Monthly distribution shows snowfall days and amounts peak in December and January, accounting for 41.5% and 36.2% of winter totals respectively. Light snow occurs mainly in December and January (31.7%), moderate and heavy snow mainly in January, and blizzards mainly in January and February. The distribution of snowfall amount by magnitude differs from snowfall days, with maximum values all appearing in January, accounting for 29.8%, 27.5%, and 30.9% of winter totals for different magnitudes.

In summary, the spatial distribution characteristics of snowfall days and amount differ markedly from flood season precipitation. While maximum flood season precipitation occurs in mountainous areas, winter maximum occurs in urban areas and minimum in mountainous areas, with the highest values in Urumqi. This is related to Urumqi' s geographical environment, altitude, atmospheric circulation, and inversion layers. Urumqi is surrounded by mountains on three sides with higher terrain in the southeast and lower in the northwest. The forcing uplift of low-level jets by southern mountainous terrain destroys the inversion layer on the north slope of the Tianshan Mountains, intensifying the convergence of cold and warm air and facilitating snowfall formation.

2.3.2 Interannual Variation

The average snowfall days on the north slope of the middle Tianshan Mountains is 18.9 days, decreasing at a rate of -0.52 $d \cdot (10a)^{-1}$ (not statistically significant). Over 43 years, snowfall days decreased by 2.2 days, consistent with trends in the Tianshan Mountains but opposite to northern Xinjiang. Maximum snowfall days occurred in 1988 (27 days) and minimum in 2008 (10.4 days), showing obvious interannual fluctuations.

Average snowfall amount is 23.5 mm, increasing at a rate of 2.52 $mm \cdot (10a)^{-1}$ (significant at the 0.05 level), a rate significantly higher than in Liaoning Province. Snowfall amount increased by 10.8 mm over 43 years, with maximum in 1988 (62.9 mm) and minimum in 1985 (9.5 mm), accounting for only one-fifth of the maximum.

Extreme snowfall events cannot be ignored. For example, on January 23, 2018, Urumqi experienced a blizzard (17.7 mm) with snow depth reaching 25 cm, causing 97 flight delays, 57 flight cancellations, and stranding approximately 8,000 passengers, while significantly impacting urban transportation and facility agriculture. This event was listed among Xinjiang' s "Top Ten Climate Events of 2018."

2.3.3 Interdecadal Variation

Using polynomial fitting to analyze interdecadal variation, total snow days show a double-peak/three-valley distribution over the past 43 years ([Figure 5: see original paper]), reaching the first peak around 1988, then gradually declining to a trough around 1998, rising sharply to the maximum peak around 2005, then declining sharply to the lowest value around 2015 before rising again.

Total snowfall amount shows a different single-peak/single-valley pattern, with low values around 1985, then gradually rising with small fluctuations but an overall upward trend continuing to 2020.

Different magnitude snowfall days and amounts show varying rates of change. Light snow days show a decreasing trend, making them the main cause of reduced total snow days. Other magnitudes show increasing trends, with moderate snow days significant at the 0.05 level and heavy snow days at the 0.01 level. All magnitudes of snowfall amount show increasing trends, with moderate snow and blizzard amounts significant at the 0.01 level, indicating they are the main contributors to increased total snowfall.

Light snow days account for the largest proportion of total snow days at 88.8%, contributing most to total snow days while blizzard days contribute least. In the past 43 years, blizzards occurred in 29 years, indicating that extreme precipitation events have significantly increased under climate warming. Light snow amount accounts for the largest proportion of total snowfall but is significantly smaller than the contribution of light snow days.

2.4 Precipitation Persistence

Precipitation duration is an important characteristic reflecting regional water cycle impacts. This study defines precipitation persistence by duration length, classified into five categories: 1 day, 2 days, 3 days, 4 days, and $ $5 days. Precipitation frequency refers to the ratio of a certain precipitation type' s occurrence to total precipitation events.

Analysis shows that 1-day precipitation processes dominate, accounting for 54.8% of total processes, with frequencies decreasing sharply as duration increases. Processes lasting $ $5 days account for only 2.8%. Spatial distribution shows all stations and regions are dominated by 1-day processes, with maximum frequency in Dabancheng (69.4%) and minimum in Xiaoquzi (46.6%). Suburban areas have about 60%, while urban areas have approximately 54.8%.

For 2-day processes, the spatial pattern is opposite, with maximum frequency in Xiaoquzi (38.4%) and minimum in Dabancheng (21.3%). Mountainous areas exceed 30%, while urban areas are below 27%. Other duration categories show similar spatial patterns, with high-value centers in urban areas gradually decreasing outward, maximum values in Urumqi, but minimum values at different stations. Urban areas are the main regions for these persistent precipitation processes, followed by suburban areas.

2.5 Mutation Analysis

Mann-Kendall tests were applied to analyze climate warming and humidifying trends. Snowfall days show intersection of UF and UB curves in 1993 but fail the signal-to-noise ratio test, indicating no significant mutation. Snowfall amount shows intersection in 1987, passing the signal-to-noise ratio test, indicating 1987 as the mutation year when snowfall increased from less to more, consistent with northern Xinjiang and Tianshan Mountains trends. The UF curve exceeds the critical line after 1999, indicating significant increase.

Average annual temperature shows UF and UB curves intersecting in 1994, passing the signal-to-noise ratio test, indicating 1994 as the mutation year when temperature increased from low to high, consistent with Xinjiang warming in the early 1990s. The UF curve exceeds the critical line after 1996, showing obvious warming.

Analysis of different magnitude snowfall shows light snow days, moderate snow days, and heavy snow days intersecting in 1993 (more to less), 2005 (less to more), and 1998 (less to more) respectively, but only moderate snow amount and heavy snow amount show significant mutations from less to more in 1987. Blizzard days and amount show no mutations due to low frequency. Overall, the climate on the north slope of the middle Tianshan Mountains shows significant warming and humidifying trends.

2.6 Climate Characteristics of High and Low Snow Years

Using absolute anomaly values exceeding 1.0 standard deviation as criteria, years with positive anomalies are high snow years and negative anomalies are low snow years. High snow years occurred mainly after 2000 (8 years), with 1988 as an extremely high year (+1.5 standard deviations). Low snow years occurred mainly before 2000 (6 years), with 1985 as an extremely low year (-1.5 standard deviations). Under global warming, extreme precipitation events are likely to increase.

Analysis shows significant differences in proportions of different magnitude snowfall between high and low snow years. Light snow amount accounts for 37.2% in high snow years versus 62.3% in low snow years. Moderate snow amount proportions are similar (28-30%). Heavy snow amount in high snow years is 1.4 times that in low snow years (19.9% vs. 14.5%), while blizzards occur only in high snow years. Light snow days account for 82.2% in high snow years and 92.8% in low snow years. Thus, light snow is the main form in both, but low snow year precipitation is dominated by light snow, while high snow years have more balanced contributions from all magnitudes.

2.7 Relationship Between Snowfall and Meteorological Factors

Temperature and precipitation are the main factors affecting climate change, with low environmental temperatures being crucial for snowfall formation. Under global warming, correlation analysis shows snowfall amount is positively correlated with various temperature elements, precipitation days, and precipitation amount (). Significant positive correlations exist with annual precipitation ($r = 0.58$), snowfall days ($r = 0.85$), and winter average minimum temperature ($r = 0.33$). Other elements show no significant correlations.

Climate tendency rates show that annual mean, maximum, and minimum temperatures, as well as winter mean and minimum temperatures, are increasing. The annual mean temperature increase is significantly higher than national and global rates, being 5.6 times the national average. Annual precipitation days show a significant decreasing trend while annual precipitation amount increases, indicating that reduced winter snowfall days contribute to decreased annual precipitation days, while increased winter snowfall contributes to increased annual precipitation.

3 Conclusions

Based on winter daily precipitation and temperature data from 17 national meteorological stations on the north slope of the middle Tianshan Mountains from 1978 to 2020, this paper analyzes spatiotemporal variation characteristics of winter snowfall and their relationship with meteorological factors, yielding the following conclusions:

1) Spatial distribution of winter snowfall days and amount from 1978 to 2020 shows a "more in urban areas, less in mountainous areas" pattern, gradually decreasing from urban centers outward, which differs completely from flood season precipitation distribution. Maximum values of different magnitude snowfall days and amount occur in urban Urumqi, while minima occur in suburban Dabancheng. Regions with more snowfall also have larger snowfall amounts.

2) Interannual trends show snowfall days decreasing at -0.52 d $\cdot$ $(10a)^{-1}$, similar to Tianshan Mountains trends, while snowfall amount increases at 2.52 mm $\cdot$ $(10a)^{-1}$, significantly higher than Liaoning' s rate. Except for light snow days, all other magnitude snowfall days show increasing trends, making light snow day reduction the direct cause of decreased total snow days. All magnitude snowfall amounts show increasing trends, with moderate snow and blizzard increases being the main causes of total snowfall increase.

3) No mutation occurs in winter snowfall days, but snowfall amount shows a significant mutation from less to more in 1987, indicating increasing humidification. Average temperature shows a mutation from low to high in 1994, indicating warming. Influenced by multiple factors, the north slope of the middle Tianshan Mountains has experienced significant warming and humidifying changes in recent years.

4) Under global warming, high snow years mainly occurred after 2000 (8 years) and low snow years before 2000 (6 years). Light snow days are the main form in both high and low snow years, but light snow amount contributes most to precipitation in low snow years (62.3%), while high snow years have more balanced contributions from all magnitudes.

5) Snowfall amount shows significant positive correlations with annual precip-

itation, winter average minimum temperature, and snowfall days. Greater annual precipitation, lower winter minimum temperatures, and more snowfall days lead to greater winter snowfall amount.

References

[1] Jiang Wenxuan, Jia La, Xiao Tiangui, et al. Climate change and spatial distribution of winter snowfall over the Tibetan Plateau during 1971-2010[J]. Journal of Glaciology and Geocryology, 2016, 38(5): 1211-1218.

[2] Chuduo, Luosangquzhen, Yang Zhigang, et al. Characteristics of temporal and spatial evolution of snowfall in the Tibetan Plateau during 1971-2010[J]. Journal of Applied Meteorological Science, 2017, 28(3): 292-305.

[3] Liu Yihua, Lu Yanrong, Zhou Qiang, et al. Research on the spatiotemporal variation characteristics of snowfall in the Qinghai Plateau from 1961 to 2017[J]. Journal of Glaciology and Geocryology, 2019, 41(4): 809-817.

[4] Ding Yonghong, Feng Jianmin, Ma Shaiyan, et al. Climatic characteristics and circulation structure of snowfall days in Ningxia[J]. Meteorological Monthly, 2012, 38(12): 1523-1531.

[5] Lu Guirong, Yang Chengfang, Cheng Pan, et al. Analysis of the climate characteristics of snowfall in southeastern Shandong Province from 1961 to 2015[J]. Journal of Glaciology and Geocryology, 2018, 40(3): 492-500.

[6] Yang Xiaoling, Guo Limei, Zhang Chunyan, et al. Characteristics of snowy days in east Hexi Corridor: Temporal and spatial variations[J]. Journal of Glaciology and Geocryology, 2018, 40(6): 1133-1140.

[7] Zhang Zhifu, Xi Shuang, Liu Na, et al. Snowfall change characteristics in China from 1961 to 2012[J]. Resources Science, 2015, 37(9): 1765-1773.

[8] Zhou Xiaoyu, Zhao Chunyu, Cui Yan, et al. Analyzing the characteristics of temporal and spatial evolution of snowfall in Northeast China from 1961 to 2017[J]. Journal of Glaciology and Geocryology, 2020, 42(3): 766-779.

[9] Liu Yulian, Ren Guoyu, Yu Hongmin. Climatology of snow in China[J]. Scientia Geographica Sinica, 2012, 32(10): 1176-1185.

[10] Zhou Gang, Cui Manyi, Li Zhe, et al. Dynamic evaluation of spring snowmelt flood hazard in Xinjiang[J]. Arid Zone Research, 2021, 38(4): 950-960.

[11] Gao Jing, Jing Lihong, Qin Rong, et al. Characteristics of heavy blizzard in Tacheng area of Xinjiang and its relationship with atmospheric circulation and SST[J]. Arid Zone Research, 2021, 38(2): 359-368.

[12] Li Xiaoshou, Wang Baolong, Wang Shengjie, et al. The change characteristics of winter snowfall, snow concentration degree and concentration period in the Tianshan Mountains[J]. Resources Science, 2012, 34(8): 1556-1564.

[13] Liu Chengwu, An Dawei, Zhang Junlan, et al. Variation characteristics of different grades of winter snowfall in Northern Xinjiang from 1961 to 2019[J]. Desert and Oasis Meteorology, 2021, 15(4): 115-122.

[14] Qin Yan, Ding Jianli. Change characteristics of different types of snowfall event in China' s Tianshan Mountains from 1961 to 2016[J]. Advances in Water Science, 2019, 30(4): 457-466.

[15] Zhao Yong, Cui Caixia, Li Xia. Climatic characteristics of winter precipitation in Northern Xinjiang region[J]. Journal of Glaciology and Geocryology, 2011, 33(2): 292-299.

[16] China Meterological Administration. Code for Automatic Surface Meteorological Observation[M]. Beijing: Meteorological Publishing House, 2020: 1-2.

[17] Xiaokaiti Duolaite. Division of precipitation magnitude standard in Xinjiang[J]. Xinjiang Meteorology, 2005, 28(5): 7-8.

[18] Li Jinglin, Zheng Yuping, Li Yue, et al. Influence of urbanization on temperature and heat island effect in Urumqi-Changji area[J]. Plateau Meteorology, 2010, 29(6): 1609-1618.

[19] Gao Lijun, Sun Huilan, Lan Xiaoli, et al. Spatio-temporal evolution of the extreme dry and wet events in Tianshan Mountains, Xinjiang, China[J]. Arid Zone Research, 2021, 38(1): 188-197.

[20] Zhou Xiaoyu, Zhao Chunyu, Cui Yan, et al. Variation characteristics of different levels of snow in Liaoning Province[J]. Journal of Glaciology and Geocryology, 2017, 39(4): 720-732.

[21] Wei Fengying. Modern Climate Diagnosis and Prediction Technology[M]. Beijing: Meteorological Publishing House, 2007: 63-66.

[22] Miao Yunling, Zhang Yunhui, Zheng Yuping, et al. Variation characteristics of different magnitudes precipitation days over the Urumqi-Changji region in flood seasons of 1978-2018 and its relationship with precipitation[J]. Meteorological and Environmental Sciences, 2020, 43(4): 97-104.

[23] Yao Junqiang, Li Moyan, Dilinuer Tuoliewubieke, et al. The assessment on warming-wetting trend in Xinjiang at multi-scale during 1961-2019[J]. Arid Zone Research, 2022, 39(2): 333-346.

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