Spatiotemporal Variation of Snow Cover in the Altai Mountains, Xinjiang, over the Past 20 Years and Its Influencing Factors: Postprint

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Abstract

Based on MOD10A2 snow product data for the Altai Mountains in Xinjiang from 2001–2020, combined with DEM and meteorological data, this study analyzes the spatiotemporal variation characteristics of snow cover over the past 20 years and the influence of topographic and meteorological factors on snow cover. The results show that: (1) The interannual variation of annual mean snow cover percentage (SCP) shows an overall non-significant decreasing trend, with a change rate of -0.88% · (10a)-1. Snow cover change exhibits obvious seasonality, with an increasing trend in autumn and a significant decreasing trend in winter. Snow cover begins to accumulate in October, with SCP values reaching their maximum in January. (2) SCP is positively correlated with altitude. SCP differs significantly among different slope aspects, with the highest value on the northwest slope at 28.45% and the lowest on the south slope at 18.36%. (3) Snow cover frequency (SCF) overall shows a distribution pattern of high in the northeast and low in the southwest, and is significantly positively correlated with altitude, with 67.65% of the area showing a decreasing trend in SCF. SCF shows an increasing trend in high mountain areas while decreasing in plains and river areas. (4) Temperature is the main factor affecting snow cover change in the Altai Mountains of Xinjiang, showing a significant negative correlation with SCF. As altitude gradually increases, the influence of temperature on snow cover gradually decreases. Annual mean precipitation in the Altai Mountains of Xinjiang shows a spatial distribution characteristic of gradually decreasing from northwest to southeast, and SCF is generally positively correlated with precipitation.

Full Text

Preamble

Spatio-temporal variation of snow cover in Altai Mountains of Xinjiang in recent 20 years and its influencing factors

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Abstract: Based on MOD10A2 snow product data from 2001 to 2020, combined with digital elevation and meteorological data, this study analyzes the spatiotemporal variation characteristics of snow cover in the Altai Mountains of Xinjiang and the influence of topographic and meteorological factors. The results show: (1) The annual average snow cover percentage (SCP) in the Altai Mountains of Xinjiang exhibited a non-significant decreasing trend from 2001 to 2020, with a change rate of -1.89% $\cdot$ $(10a)^{-1}$. Snow cover variation showed obvious seasonality, with an increasing trend in autumn and a significant decreasing trend in winter. The interannual variation showed an overall decreasing trend, with the lowest value of 41.55% in 2007 and the highest value of 48.84% in 2010. Snow cover began accumulating in October, reached its maximum in January, and then decreased sharply, melting gradually from May. (2) Snow cover frequency (SCF) showed a spatial distribution pattern of high values in the northeast and low values in the southwest, which was significantly positively correlated with altitude. Among different slope aspects, SCF values varied significantly, with the highest value on the northwest slope at 28.45% and the lowest on the south slope at 18.36%. (3) Temperature was the main factor affecting snow cover change in the Altai Mountains of Xinjiang, showing a significant negative correlation with SCF over an area of 9.08$×10^{3}$ km^2, accounting for 80.52% of the study area. With increasing altitude, the impact of temperature on snow cover gradually decreased. The annual average precipitation in the Altai Mountains of Xinjiang showed a spatial distribution pattern of gradually decreasing from northwest to southeast, and was positively correlated with SCF over 87.14% of the area.

Keywords: snow cover; MOD10A2; spatiotemporal variation; meteorological factors; Altai Mountains of Xinjiang

Snow cover is one of the main components of the cryosphere and one of the more active elements on the Earth's surface, playing an important role in regional and global energy and water balance. Snow cover and climate have a mutual feedback mechanism. Due to its high albedo, low thermal conductivity, and small latent heat of phase change, snow cover profoundly influences surface energy, hydrology, atmospheric circulation, and other elements. Meanwhile, snow cover is a product of climate, and long-term fluctuations in regional snow cover undoubtedly reflect long-term climate changes in that region. Over the past century, snow cover monitoring has been an important approach for diagnosing regional climate and studying the mutual influence between climate and snow cover. Since the 1980s, remote sensing technology has been widely applied in ice and snow research across different scales, providing effective means for obtaining long time series and large-area snow cover spatiotemporal dynamic change characteristics and snow monitoring.

In recent years, many scholars have conducted extensive research on snow cover based on remote sensing technology. For example, studies have used MODIS data to analyze the temporal and spatial variation patterns of snow cover and snow days in Xinjiang from 2002 to 2013, showing that seasonal snow cover in Xinjiang mainly occurs from November to March of the following year, with maximum snow cover in January and minimum in July. The special topography of Xinjiang has a significant impact on snow cover and climate change. Tian et al. used the Google Earth Engine cloud platform to process snow cover factors in northern Xinjiang, finding that the overall accuracy of snow products relative to meteorological station data reached 91.47%, making them suitable for spatiotemporal variation analysis of snow factors. The spatial distribution of snow cover days in northern Xinjiang varies greatly, with temperature having a greater impact on snow cover days than precipitation. Sa et al. used MODIS snow products to study the variation characteristics of snow cover area in Xinjiang and found a decreasing trend in snow area; in recent years, permanent snow cover areas in Xinjiang have been mainly distributed in the Altai Mountains, the northern foothills of the Tianshan Mountains, and along the southwestern Kunlun Mountains. Lou et al. used snow remote sensing data from 2002 to 2011 to explore the temporal variation characteristics and spatial distribution patterns of snow area in Xinjiang, finding that snow area in Xinjiang generally showed a decreasing trend, with permanent snow mostly distributed above 5000-6000 m.

The above studies mainly focused on the entire Xinjiang region, ignoring small-scale spatiotemporal snow cover changes, and there have been few studies on the spatiotemporal distribution characteristics of snow cover and its influencing factors in the Altai Mountains of Xinjiang based on snow remote sensing and meteorological grid data. The Altai Mountains are located in northern Xinjiang, deep inland, where snowmelt is an important freshwater resource. The large elevation difference and topographic influence result in obvious spatial heterogeneity in snow distribution characteristics. Therefore, analyzing snow cover changes and their influencing factors in the Altai Mountains can provide a theoretical basis for water resources and ecological environment protection in this region and has profound significance for climate change research. Meteorological stations in the Altai Mountains of Xinjiang are very limited. To better study the impact of spatial differences in temperature and precipitation on snow cover changes, this study selected 1 km resolution monthly climate datasets to avoid the limitation of station data representing spatial scope. Therefore, this paper uses MOD10A2 snow data combined with meteorological grid data to explore the spatiotemporal distribution characteristics of snow cover and their influencing factors in the Altai Mountains of Xinjiang.

1.1 Study Area Overview

The Altai Mountains within China (Fig. 1) are located in the northernmost part of Xinjiang, bordering Mongolia and Russia, with a length of about 500 km. The terrain is generally high in the north and low in the south, with elevations ranging from 320 to 4374 m. The geographical coordinates are 85°50 E to 91°00 E and 46°20 N to 49°10 N. The Altai Mountains are the main water source for the Irtysh River and its tributaries, with most areas above 3200 m being snow and ice accumulation zones. This region is a major animal husbandry base in China and has a continental cold temperate climate, with hot and dry summers and cold, snowy winters. The annual average temperature is about -8 to 4°C, and the annual average precipitation is about 300-500 mm. During the warm season, prevailing westerlies transport water vapor from the North Atlantic to this region, causing precipitation in the Altai Mountains to show a gradually decreasing trend from west to east. During the cold season, controlled by the Siberian High, snow disaster weather often occurs from November to March with low temperatures, resulting in a long snow season and most areas being covered by snow. The variation pattern of snow cover has an important impact on local agriculture and animal husbandry development, affecting the local economic lifeline.

1.2 Data Sources

1.2.1 MOD10A2 Snow Data The MOD10A2 snow data used in this study are 8-day composite snow product data from the new generation "Earth Observing System" satellite monitored by the National Snow and Ice Data Center (NSIDC) in the United States, reflecting the maximum snow cover extent with a spatial resolution of 500 m. The data format is HDF-EOS, with sinusoidal projection. MOD10A2 effectively avoids "cloud contamination" effects and can meet the requirements of long time series and high-precision snow research. Previous studies have shown that the snow identification accuracy of MOD10A2 in the Xinjiang region is 87.5%-94.0%, which can better present the actual snow distribution conditions in the Altai Mountains of Xinjiang. The MOD10A2 snow product data covering the study area consist of two images with track numbers h24v04 and h23v04. The MODIS Reprojection Tools (MRT) were used to batch mosaic and project the image data covering the study area, converting the geographic coordinates to WGS84, the projection to Albers, and the format to GeoTIFF. Finally, the data were clipped using the study area vector boundary for snow cover statistics.

1.2.2 Meteorological Data Meteorological data are derived from the 1 km resolution monthly climate dataset from the National Earth System Science Data Center (http://www.geodata.cn), with data from 2001 to 2020 selected. This dataset is generated by downscaling the CRU v4.02 climate dataset for China and has been validated with independent meteorological observation point data. It is currently the monthly climate dataset with the longest time series, highest spatial resolution, and widest coverage in China. Monthly average temperature and precipitation data from 7 meteorological stations on the China Meteorological Data Network (http://cdc.cma.gov.cn) were used to verify the applicability of this dataset in the study area. The results showed that the correlation coefficients between temperature data were as high as 0.98, and the correlation coefficients for precipitation data were between 0.64 and 0.70, indicating that the temperature and precipitation data have high accuracy in the study area and can meet research needs. In addition, the resolution was resampled to 500 m to match the snow data. The spatial distribution of the annual average temperature in the Altai Mountains of Xinjiang from 2001 to 2020 is shown in Fig. 2, and the average precipitation is shown in Fig. 3. The DEM data with 30 m spatial resolution from the Geospatial Data Cloud (http://www.gscloud.cn) SRTM V4.1 were resampled to 500 m and used for elevation zone and slope aspect division in this study.

1.3 Methods

1.3.1 Snow Cover Indices **Snow Cover Percentage (SCP)** is used to characterize relative snow area, which is the percentage of snow cover area to total regional area. The calculation formula is as follows:

$$SCP = \frac{P_s}{P} \times 100\%$$

where P_s is the snow cover area in the statistical region, and P is the total area of the region.

Snow Cover Frequency (SCF) is the ratio of the cumulative number of times snow pixels appear in each pixel during a snow year to the total number of statistical times, reflecting the overall characteristics of snow cover duration within the year. The calculation formula is as follows:

$$SCF_{i,j} = \frac{\sum_{i=1}^{n} ifsnow(i,j)}{n} \times 100\%$$

where $SCF_{i,j}$ is the snow cover frequency of pixel j in year i; $ifsnow(i,j)$ indicates whether the pixel is covered by snow (1) or not (0); and n is the total number of statistical times for pixel j during the statistical period.

1.3.2 Trend Analysis A univariate linear regression analysis method was used to analyze the trend of snow cover frequency changes in the Altai Mountains of Xinjiang from 2001 to 2020. The slope of the regression equation for individual pixels represents the interannual change rate. The calculation formula is:

$$Slope = \frac{n \times \sum_{i=1}^{n} i \times SCF_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} SCF_i}{n \times \sum_{i=1}^{n} i^2 - (\sum_{i=1}^{n} i)^2}$$

where *Slope* is the slope of the regression equation, and n is the cumulative number of years in the statistical period. If $Slope > 0$, it indicates an upward trend in snow cover frequency; if $Slope < 0$, it indicates a downward trend; and if $Slope = 0$, it indicates no change in snow cover frequency. The F-test was used to test the significance of the snow cover frequency change trend.

1.3.3 Correlation Analysis Correlation analysis was used to study the response relationship between snow cover characteristic indices and temperature and precipitation. The calculation formula is:

$$R_{xy} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}}$$

where n is the cumulative number of years in the statistical period; x_i and y_i are the two variables for correlation analysis; and $\bar{x}$ and $\bar{y}$ are the average values of the two variables over n years. When $R_{xy} > 0$, it indicates a positive correlation, and when $R_{xy} < 0$, it indicates a negative correlation. The higher the absolute value of R_{xy}, the stronger the correlation between the two elements. Since the sample correlation coefficient alone cannot determine whether there is a significant linear relationship between the two variables, this study also used the T-test to test the significance of the correlation coefficient.

2 Results and Analysis

2.1 Temporal Variation Characteristics of Snow Cover

2.1.1 Intra-annual Variation Characteristics of Snow Cover Percentage Using the maximum snow cover percentage (SCP) of each month as the monthly SCP, the intra-annual variation characteristics of SCP in the Altai Mountains of Xinjiang from 2001 to 2020 were analyzed (Fig. 4). The results show that snow cover in the Altai Mountains began to accumulate in October, reached its maximum in January of the following year, and then decreased sharply, with snow gradually melting from May. The monthly average SCP showed a single-peak pattern, with the lowest value of 2.27% in July and the highest value of 92.76% in January. The three winter months (December, January, and February) were the months with the largest snow cover, with coverage exceeding 81.85%. The uneven distribution of climate conditions such as temperature and precipitation within the year caused fluctuations in the timing of maximum annual snow cover occurrence. The maximum annual SCP in the Altai Mountains ranged from 96.45% to 99.92%, mainly appearing in January and December; the minimum coverage ranged from 0.84% to 2.27%, appearing in July and August. In recent years, the minimum SCP has shown an increasing trend, while the maximum SCP has shown a decreasing trend.

2.1.2 Interannual Variation Characteristics of Snow Cover Percentage

The interannual variation characteristics of SCP in the Altai Mountains of Xinjiang from 2001 to 2020 were calculated (Fig. 5). The results show that SCP in the Altai Mountains showed a non-significant decreasing trend, with a change rate of -0.88% $\cdot$ $(10a)^{-1}$, which is closely related to global climate warming, as rising temperatures lead to reduced snow cover in the study area. The interannual variation of snow cover in the study area showed stage-wise increasing or decreasing trends. Specifically, from 2001 to 2009, SCP showed a fluctuating downward trend with a change rate of -1.93% $\cdot$ $(10a)^{-1}$, reaching the lowest value in nearly 20 years in 2007 at 41.55%. From 2010 to 2015, the average SCP showed a clear upward trend with a change rate of 6.04% $\cdot$ $(10a)^{-1}$, with the highest average value in 2010 at 48.84%. From 2016 to 2020, SCP showed a downward trend with a change rate of -3.60% $\cdot$ $(10a)^{-1}$.

2.1.3 Seasonal Variation Characteristics of Snow Cover Percentage

Snow cover change showed obvious seasonality (Fig. 6). Except for autumn, which showed an increasing trend, the other three seasons all showed decreasing trends. Winter had the fastest decreasing rate, with a change rate of -3.23% $\cdot$ $(10a)^{-1}$. Autumn showed large interannual fluctuations but an overall increasing trend, with a change rate of -2.21% $\cdot$ $(10a)^{-1}$. Due to the complex climate changes as temperatures begin to drop in autumn, the interannual variation of snow cover percentage differs significantly. Spring and summer showed weak decreasing trends with relatively stable fluctuations. Winter SCP in the Altai Mountains of Xinjiang was the highest, caused by low winter temperatures and frequent snowstorms. Summer had the smallest coverage, mainly consisting of permanent snow at high altitudes.

2.2 Spatial Distribution Characteristics of Snow Cover

2.2.1 Snow Cover Variation Characteristics at Different Altitudes

Terrain is one of the important factors affecting the spatiotemporal distribution of snow cover in the Altai Mountains of Xinjiang. Temperature and precipitation vary at different altitudes, leading to differences in snow cover development and maintenance. To understand the relationship between snow cover and terrain factors, the study area was divided into different elevation zones (Table 2) and slope aspects, and the interannual average SCP of each elevation zone from 2001 to 2020 was calculated (Fig. 8). Overall, SCP in this region is positively correlated with altitude. Below 500 m, SCP is the lowest, with an average value of about 8.11%; at 1500-2000 m, SCP increases significantly, with a maximum value of 90.31%; above 2000 m, SCP can reach 99.08%, which is a perennial stable snow area. These areas are affected by westerlies and the Siberian High, with more snowfall. In addition, as altitude increases, temperature gradually decreases, creating conditions for snow cover development and maintenance.

2.2.2 Snow Cover Variation Characteristics on Different Slopes

Snowmelt is greatly affected by solar radiation, which varies with solar altitude and terrain, leading to significant differences in snowmelt across different regions. Sunny slopes receive stronger solar radiation and have higher temperatures, while shady slopes receive weaker radiation and have lower temperatures, so SCP on sunny slopes is smaller than on shady slopes. To better study the distribution and melting patterns of snow cover in different regions, the study area was reclassified into 8 slope aspects according to azimuth (Table 3), and the SCP of each slope was extracted. The results show significant differences in SCP among different slope aspects in the Altai Mountains of Xinjiang, with the highest value on the northwest slope at 28.45% and the lowest on the south slope at 18.36%. This is because under the influence of cold air from the northwest, the northwest slope has more water vapor, which is conducive to snow formation. Due to less solar radiation, north, west, northeast, and east slopes have higher SCP values of about 24%; while southwest and southeast slopes have lower SCP values, which is not conducive to snow accumulation.

2.2.3 Spatial Distribution Characteristics of Snow Cover Frequency

The spatial distribution of annual average snow cover frequency (SCF) in the Altai Mountains of Xinjiang varies significantly. As shown in Fig. 10a, high SCF values are mainly located in high-altitude mountainous areas, mostly perennial snow and glacier-covered areas, accounting for about 8.57% of the study area. The sub-high value area is distributed around the permanent snow area, accounting for 61.25% of the total area, and is the most widely distributed area. This area has abundant seasonal snow cover and is the ice and snow meltwater recharge area for river runoff. The SCF$ $30% area is mainly distributed in the Irtysh River plain area, accounting for 21.18% of the total area, where snow cover duration is short and contributes less to spring snowmelt runoff.

To analyze the interannual variation characteristics of SCF in the study area, a univariate linear regression analysis method was used to analyze the dynamic change trend of SCF from 2001 to 2020, and the significance of the trend was tested. Fig. 10b shows that SCF change has large spatial differences. Overall, SCF in high mountain areas shows an upward trend, while SCF in plain and river areas shows a downward trend. As shown in Table 4, 67.65% of the area shows a decreasing trend in SCF, of which 6.64% shows an extremely significant decreasing trend. Areas with significant decreasing trends are mainly distributed in plain areas. Areas with extremely significant increasing trends account for 0.60% of the area, mainly distributed in the high mountain areas of the Altai Mountains.

2.3 Relationship Between Snow Cover Frequency and Temperature/Precipitation

Temperature and precipitation are the two main meteorological factors describing snow cover change. Therefore, this study analyzed the spatial distribution of temperature and precipitation in the Altai Mountains of Xinjiang and calculated the correlation coefficients between SCF and average temperature and precipitation pixel by pixel to analyze their spatial correlation distribution. In low-altitude areas such as the Irtysh River plain, the correlation coefficient between temperature and SCF is mostly below -0.6, showing a strong negative correlation. Therefore, temperature is the main factor affecting snow cover change in this region. As altitude increases, temperature gradually decreases, and the impact of temperature on snow cover gradually weakens. In high mountain areas of the Altai Mountains, the annual average temperature is below 0°C, with some areas even below -8°C. Temperature changes have a relatively small impact on SCF in these areas, with correlation coefficients mostly between -0.2 and 0, showing a weak negative correlation. Overall, the area where temperature is significantly negatively correlated with SCF is about 9.08$\times10^{3}$ km^2, accounting for about 80.52% of the study area. In addition, 21.06% of the region shows a correlation coefficient below -0.6, especially in the southeastern Altai Mountains (Fig. 11).

The annual average precipitation in the Altai Mountains of Xinjiang from 2001 to 2020 shows a spatial distribution pattern of gradually decreasing from northwest to southeast. Precipitation is relatively high on the northwest side of the Kelan River, with annual average precipitation above 220 mm, especially in the north of the Haba River and Burqin River, where annual average precipitation reaches 300 mm. Precipitation is positively correlated with SCF over 87.14% of the area, with regions having correlation coefficients above 0.2 mainly distributed in the Irtysh River plain area, accounting for 8.56% of the total area. The correlation coefficients between SCF and precipitation in the Altai Mountains are mainly concentrated between 0.2 and 0.4. In addition, areas with lower correlation coefficients are mainly located in high-altitude mountainous areas. In high mountain areas, temperatures are relatively low, precipitation mostly occurs as snow, and the area is perennially snow-covered, weakening the impact of precipitation on SCF. In low-altitude areas without stable snow cover, snow mainly comes from precipitation, so the correlation between SCF and precipitation is more significant.

3 Discussion

Snow cover percentage in the Altai Mountains of Xinjiang is affected by terrain and meteorological factors, showing obvious spatial heterogeneity. SCP increases with altitude, with perennial snow accumulation in high-altitude mountainous areas forming stable snow cover, while inland plain areas have less snow cover. This is consistent with the research of Zheng et al. This is because as altitude increases, temperature decreases and snowfall increases, which is conducive to snow development and maintenance. Therefore, high-altitude areas are covered by deep snow that is not easy to melt, while snow cover in low-altitude areas is mostly shallow and melts quickly. From the perspective of SCF, the overall distribution pattern is high in the northeast and low in the southwest, which is significantly positively correlated with altitude. The SCF in the Altai Mountains has large spatial variability, with 67.65% of the area showing a decreasing trend. Overall, SCF in high mountain areas shows an upward trend, while SCF in plain and river areas shows a downward trend. Due to large differences in solar radiation on different slopes, the energy budget and snowmelt speed of snow cover are affected, leading to differences in snow cover distribution on different slopes.

Temperature is the main factor affecting snow cover change in the Altai Mountains of Xinjiang, with SCF being significantly negatively correlated with temperature. Previous studies have found that temperature is the main factor affecting snow cover change compared to precipitation. The results of this study show that the spatial distribution of temperature in the Altai Mountains of Xinjiang is significantly affected by elevation, and temperature is negatively correlated with SCF. In low-altitude areas, temperature rise accelerates snowmelt, so temperature is the main factor determining snow cover change, which is consistent with previous research results. However, as altitude increases, the impact of temperature on snow cover gradually weakens. This is because in high-altitude areas, temperatures are perennially below 0°C, making it difficult for snow to melt. At this point, the main factors affecting snowmelt are solar radiation, wind, and ground temperature under low-pressure conditions. The annual average precipitation in the Altai Mountains of Xinjiang shows a spatial distribution pattern of gradually decreasing from northwest to southeast, and 87.14% of the area shows a positive correlation between SCF and precipitation. The correlation between SCF and both precipitation and temperature decreases with increasing altitude.

This study only examined the variation characteristics of snow cover in the Altai Mountains of Xinjiang at different times and on different terrain, but snowmelt is also jointly affected by radiation, wind, and ground temperature. Due to the scarcity and uneven distribution of meteorological stations in the Altai Mountains, measured meteorological data in this area are relatively limited. The meteorological dataset has good continuity, but its accuracy is lower compared with measured data. Future research should strengthen the combination of field observations and remote sensing methods.

4 Conclusions

Based on MOD10A2 snow product data from 2001 to 2020, combined with DEM and meteorological data, this study analyzed the spatiotemporal distribution characteristics of snow cover in the Altai Mountains. The results show:

(1) The annual average SCP in the Altai Mountains of Xinjiang showed a

non-significant decreasing trend from 2001 to 2020, with a change rate of -1.89% · $(10a)^{-1}$. Snow cover variation showed obvious seasonality, with an increasing trend in autumn and a significant decreasing trend in winter. The interannual variation showed an overall decreasing trend, with the lowest value of 41.55% in 2007 and the highest value of 48.84% in 2010. Snow cover began accumulating in October, reached its maximum in January, and then decreased sharply, melting gradually from May. The uneven distribution of climate conditions such as temperature and precipitation caused fluctuations in the timing of maximum annual snow cover occurrence. The Altai annual SCP reached its peak between 96.45% and 99.92%, primarily observed in January and December. The lowest coverage range was 0.84% to 2.27%, which occurred in July and August.

(2) SCP in the Altai Mountains showed a positive correlation with altitude, with lower SCP values below 500 m (average of 8.11%) and higher values above 2000 m (average of 99.08% in an area with stable snow cover all year round). SCP varied depending on the slope aspect, with the northwest slope exhibiting the highest values (28.45%) and the south slope showing the lowest values (18.36%). SCF showed a spatial distribution pattern of high values in the northeast and low values in the southwest, which was significantly positively correlated with altitude. Among different slope aspects, SCF values varied significantly, with the highest value on the northwest slope and the lowest on the south slope.

(3) Temperature was the main factor affecting snow cover change in the Altai Mountains of Xinjiang, showing a significant negative correlation with SCF over an area of 9.08$×10^{3}$ km^{2}, accounting for 80.52% of the study area. With increasing altitude, the impact of temperature on snow cover gradually diminished. The annual average precipitation in the Altai Mountains showed a spatial distribution pattern of gradually decreasing from northwest to southeast, and precipitation was positively correlated with SCF over 87.14% of the area, with a weakened effect on SCF changes observed in high-altitude mountain areas and a more significant correlation observed in low-altitude areas.

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