Spatiotemporal Variation Characteristics of Snow Cover Area in the Qilian Mountains from 2001 to 2017 (Postprint)

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Abstract

Scientific monitoring of snow cover area and its variation characteristics in the Qilian Mountains holds significant importance for climate research, development and utilization of snow water resources, environmental disaster forecasting, and ecological protection in this region. Based on MOD10A2 snow products and meteorological data from 2001 to 2017, we analyzed the dynamic variation characteristics of snow cover area in the Qilian Mountains and its relationship with temperature and precipitation. The results indicate that: (1) From 2001 to 2017, the interannual fluctuation trend of snow cover area in the Qilian Mountains was substantial, showing a decreasing trend, with the mean annual snow cover area being approximately 5×10^4 km², accounting for 25.9% of the total area of the Qilian Mountains; the intra-annual variation follows an "M"-shaped pattern, i.e., there are two peaks and troughs in a snow year, with peaks occurring in November and January, and troughs in July; the seasonal variation fluctuation trend is substantial, with the decreasing trend of snow cover area in summer and winter exceeding that in spring, while autumn shows a slight increasing trend. (2) Snow cover area in the Qilian Mountains is mainly distributed between 3,000–4,000 m and 4,000–5,000 m, with snow cover fraction showing a gradually increasing trend with rising altitude; there are significant differences in snow cover area among different aspects in the Qilian Mountains, but relatively small differences in snow cover fraction; high snow frequency zones exhibit a typical banded distribution, consistent with the topography of the Qilian Mountains, distributed in a northwest-southeast orientation, with the distribution of high snow frequency zones being larger in the west than in the east. (3) Preliminary analysis indicates that snow cover area variation in the Qilian Mountains is more sensitive to temperature factors.

Full Text

Abstract

To scientifically monitor snow cover and its changing characteristics in the Qilian Mountains—matters of significant importance for regional climate research, the development and utilization of snowmelt water, natural disaster forecasting, and ecological environmental protection—this study analyzes the dynamic changes of snow cover in the Qilian Mountains and its relationship with temperature and precipitation based on MOD10A2 snow products and meteorological data from 2001 to 2017. The results show: (1) The average snow cover area in the Qilian Mountains was approximately 5×10 km², accounting for 25.9% of the total area. Snow cover between 2001 and 2017 exhibited large inter-annual fluctuations following an "M" shaped pattern, indicating two peaks and one trough in annual snow cover. Peak positions occurred in November and January, while the trough appeared in July. Seasonal variation trends were substantial, with more pronounced decreasing tendencies in summer and winter than in spring, and a slight increasing trend in autumn. (2) Snow cover area was primarily located at altitudes between 3000–5000 m, tending to increase with elevation. Significant differences in snow cover area existed across different slope aspects, though with small snow cover ratios. High snow frequency zones displayed a typical banded distribution essentially consistent with the Qilian Mountains' topography, with high snow accumulation areas being far more numerous in the west than in the east. (3) Preliminary analysis indicates that snow area changes in the Qilian Mountains are more sensitive to temperature.

Keywords: Qilian Mountains; MODIS 10A2; snow cover area; temporal-spatial variation

1. Study Area

The Qilian Mountains (36°30 -39°30 N, 93°30 -103°E) extend in a NW-SE direction with a length of approximately 800 km and width of about 300 km [Figure 1: see original paper]. The mountain range features complex terrain with an average elevation of 3700 m [CITATION]. The region exhibits a typical continental alpine climate characterized by cold winters and cool summers, with annual precipitation of 250 mm and concentrated precipitation events primarily occurring as snowfall above 4100 m, earning it the designation as a "wet island" within the arid zone [CITATION].

[Figure 1: see original paper] Map showing the mountain range of Qilian

2. Data and Methods

2.1 Data Sources

Three primary data sources were employed: MOD10A2 snow products, Shuttle Radar Topography Mission (SRTM) elevation data, and meteorological obser-

vations.

(1) MOD10A2 Snow Products. The MOD10A2 snow cover dataset was obtained from the National Snow and Ice Data Center (NSIDC) at 500 m spatial resolution in HDF format, using Sinusoidal projection. The data covered the period from 2001 to 2017. Data preprocessing involved: using the MODIS Reprojection Tool for format conversion, reprojection to WGS84 geographic coordinate system, and clipping to the study area boundary. Quality control flags were applied to exclude pixels with cloud cover exceeding 10%. Snow cover classification values included: 200 (snow), 100 (lake ice), 25 (snow-free land), 37 (inland water), 11 (night), 1 (no decision), and 0 (missing data). The study utilized 17 years of data comprising 782 total scenes, with 12 scenes per year after excluding summer months (June–August), totaling 204 scenes for analysis [Figure 2: see original paper].

(2) Elevation Data. SRTM digital elevation data at 90 m resolution were resampled to 500 m to match MOD10A2 resolution and used to generate slope and aspect datasets.

(3) Meteorological Data. Temperature and precipitation data from 2001–2017 were obtained from national meteorological stations within the Qilian Mountains region.

[Figure 2: see original paper] Monthly variations of snow cover (a) and air temperature and precipitation (b)

3. Results

3.1 Temporal Variation Characteristics

Annual snow cover area showed significant inter-annual fluctuations from 2001–2017, ranging from 3.81×10 km² to 6.14×10 km² [Figure 3: see original paper]. The variation pattern exhibited a distinct "M" shape with two peaks and one trough. The first peak occurred in November, the second in January, and the trough in July. The period 2001–2004 showed a decreasing trend at 0.69 km² · a ^{1}, 2005–2008 remained relatively stable, 2009–2013 displayed a sharp decline from 4.94×10 km² to 3.81×10 km², and 2014–2017 showed an increasing trend.

Seasonal variations revealed: spring snow cover area of 6.91×10 km² (largest among seasons), summer 3.81×10 km² (smallest), autumn 5.23×10 km², and winter 5.67×10 km² [Figure 4: see original paper]. The decreasing trend was most pronounced in summer and winter, moderate in spring, while autumn showed a slight increase.

[Figure 3: see original paper] Annual variation of snow cover from 2001 to 2017 in the Qilian Mountains

[Figure 4: see original paper] Annual variations of snow cover in spring, summer, autumn and winter in the Qilian Mountains

3.2 Spatial Distribution Characteristics

3.2.1 Elevation Distribution Snow cover distribution varied significantly with elevation [Figure 5: see original paper]. Areas below 3000 m accounted for only 0.7% of total snow cover, 3000–4000 m comprised 12%, 4000–5000 m represented 57.5%, and above 5000 m contributed 29.8%. Snow cover ratio increased with elevation, from 9.7% at 2000–3000 m to 15.7% at 3000–4000 m, 8.9% at 4000–5000 m, and 9.7% above 5000 m [Figure 6: see original paper]. The 4000–5000 m zone showed the largest absolute snow area, while the 3000–4000 m zone exhibited the highest snow cover ratio.

[Figure 5: see original paper] Distribution characteristics of snow cover area (a) and snow cover ratio (b) at different elevations in Qilian Mountains from 2001 to 2017

[Figure 6: see original paper] Interannual variation characteristics of snow cover area (a) and snow cover ratio (b) at different elevations in Qilian Mountains from 2001 to 2017

3.2.2 Slope Aspect Distribution Snow cover distribution showed marked aspect-dependent patterns [Figure 7: see original paper]. North-facing slopes (315°–45°) had the largest snow area at 15.8%, followed by northeast (45°–90°) at 13.8%, east (90°–135°) at 8.7%, and southeast (135°–180°) at 17.7%. South-facing slopes (180°–225°) had the smallest coverage at 8.7%. Snow cover ratios were highest on north-facing slopes and lowest on south-facing slopes, reflecting the influence of solar radiation and wind patterns.

[Figure 7: see original paper] Distribution characteristics of snow cover area (a) and snow cover ratio (b) on each slope of Qilian Mountain

3.2.3 Snow Frequency Distribution High snow frequency zones (>60 days/year) exhibited a banded distribution pattern aligned with mountain orientation [Figure 8: see original paper]. These zones were concentrated primarily in the western Qilian Mountains, with frequencies decreasing from west to east. Areas with snow frequency exceeding 100 days/year were mainly located above 4000 m in the western section.

[Figure 8: see original paper] Variation characteristics of snow cover frequency in Qilian Mountains from 2001 to 2017

4. Discussion

4.1 Relationship with Climate Factors

Correlation analysis between snow cover area and meteorological factors revealed significant relationships . Temperature showed a negative correlation ($r = -0.67$, $p < 0.01$), while precipitation exhibited positive correlation ($r = 0.54$,

$p < 0.01$). The period 2008–2013 demonstrated the strongest temperature sensitivity, with snow cover decreasing sharply during warm years (2013, 2016) and increasing during cool years (2002). When winter temperature dropped below -8°C, snow cover area expanded significantly. The analysis indicates temperature is the dominant factor controlling snow cover variation, with precipitation playing a secondary role.

Correlation coefficients between snow cover area and meteorological factors

5. Conclusions

Based on MODIS 10A2 data from 2001–2017, this study analyzed snow cover variation characteristics in the Qilian Mountains:

(1) Average snow cover area was approximately 5×10 km² (25.9% of total area), showing significant inter-annual fluctuation with an "M" shaped pattern (peaks in November and January, trough in July). Seasonal trends revealed decreasing snow cover in summer and winter, contrasting with slight autumn increases.

(2) Snow cover was concentrated at 3000–5000 m elevation, increasing with altitude. Aspect distribution varied significantly, with north-facing slopes showing highest coverage. High snow frequency zones displayed banded distributions concentrated in western regions.

(3) Snow cover changes demonstrated greater sensitivity to temperature than precipitation, with significant negative correlations observed.

These findings provide scientific basis for water resource management, disaster prevention, and ecological protection in the Qilian Mountains region.

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