Remote Sensing Monitoring of Glacier and Snow Cover Changes and Analysis of Influencing Factors in the Bogda Peak Region: Postprint

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Abstract

Since the 20th century, with the intensification of global climate warming, glaciers and snow cover have experienced widespread retreat, seriously impacting human survival and socio-economic sustainable development. This issue is particularly prominent in the Bogda Peak region and its surrounding areas in the arid region of northwestern China. Taking the Bogda Peak region as an example, using Landsat 5 and Landsat 8 remote sensing images from 1990 to 2016, this study comparatively analyzes the capability of the Normalized Difference Snow Index [WTBX] (NDSI), Normalized Difference Snow-Ice Index (NDSII), Normalized Difference Principal Component Snow Index (NDPCSI), and Tasseled Cap Transformation Wetness Index (WET) in monitoring glaciers and snow cover in the Bogda Peak region. Simultaneously, combining temperature and precipitation data from around the study area with topographic data of the study area, it explores the response relationship between glacier and snow cover area changes and regional topography and climate in the Bogda Peak region. The results show that: (1) WET has higher accuracy values compared to NDSII, NDSI, and NDPCSI, and can replace NDSI and NDSII[WTBZ] for monitoring glacier and snow cover area in the Bogda Peak region. (2) Glacier and snow cover area in the Bogda Peak region shows a continuous retreat trend. From 1990 to 2016, the reduction rate of glacier and snow cover area is approximately 20.07%, and the annual retreat rate continues to increase. (3) Elevation, slope, and aspect have relatively significant effects on glacier and snow cover area changes, while mountain shadows have a weaker effect. Rising temperature is the primary factor driving the reduction of ice and snow area.

Full Text

Remote Sensing Monitoring of Glacier and Snow Cover Change and Its Influencing Factors in Mount Bogda

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Abstract: Glaciers and snow cover are important indicators of global warming and critical water resources for human survival and development in arid regions. Since the 1990s, glacier and snow areas have generally been shrinking as global warming intensifies, seriously affecting people' s lives and socioeconomic activities in the surrounding areas. This effect is particularly significant in the Mount Bogda region of northwestern China' s arid zone. Strengthening monitoring of glacier and snow cover changes can help us understand the characteristics and trends of these changes, reveal the response of glaciers and snow to climate change, and potentially predict future variations. We selected Mount Bogda in Fukang County, Xinjiang, China as our study area and obtained Landsat 5 and Landsat 8 remote sensing images, DEM data, and surrounding temperature and precipitation data from 1990 to 2016. First, we employed Landsat 5 and Landsat 8 satellite images to calculate the Normalized Difference Snow Index (NDSI), Normalized Difference Snow-Ice Index (NDSI), Normalized Difference Principal Component Snow Index (NDPCSI), and Tasseled Cap Wetness transformation (WET), and analyzed their respective abilities to detect glacier and snow. Second, we used the high-accuracy WET index to obtain glacier and snow cover data for 1990, 2000, 2010, and 2016, and analyzed the changes in glacier and snow cover. Finally, combining temperature data and terrain data from the study area, we explored the relationship between snow and glacier area changes in Mount Bogda and the local terrain and climate. The results show: (1) The WET index has higher overall accuracy than the NDSI index and can replace NDSI and NDSI for detecting and monitoring glacier and snow area changes in Mount Bogda. (2) The glacier and snow area in Mount Bogda continued to shrink from 1990 to 2016, with a total reduction of 20.07%, and the annual reduction rate continues to increase. (3) Temperature and slope have strong influences on glacier and snow area changes, while hillshade and altitude have weak influences. Rising temperature is the main factor driving the decrease in

glacier and snow area. These research results could provide theoretical support and decision-making references for accurate extraction of glacier and snow cover information in the Mount Bogda area and for sustainable economic development in surrounding regions.

Keywords: Landsat; index; glacier and snow variations; Mount Bogda

1. Introduction

Glaciers and snow cover are sensitive indicators of climate change and play a crucial role in water resource regulation in arid regions. With global warming, accelerated glacier retreat and snow cover reduction have significantly impacted water security and ecological stability in northwestern China. Mount Bogda, located in the eastern Tianshan Mountains, is a region particularly vulnerable to these changes. Monitoring glacier and snow dynamics in this area is essential for understanding climate change impacts and managing water resources.

2. Data and Methods

2.1 Data Sources We acquired Landsat 5 TM and Landsat 8 OLI imagery for four time periods (1990, 2000, 2010, and 2016), along with 30-meter resolution DEM data and meteorological records from local weather stations. The Landsat images were selected from September when snow cover is minimal, ensuring optimal detection of permanent glaciers and snow.

2.2 Glacier and Snow Index Calculation Four spectral indices were calculated and compared for their effectiveness in distinguishing glacier and snow from other surface features:

1. **Normalized Difference Snow Index (NDSI):** Uses the reflectance difference between green band (0.56 m) and shortwave infrared band (1.65 m) to identify snow cover.
2. **Normalized Difference Snow-Ice Index (NDSI):** Employs red band (0.63–0.69 m) and shortwave infrared band (1.55–1.75 m) to differentiate snow and ice.
3. **Normalized Difference Principal Component Snow Index (NDPCSI):** Applies principal component analysis to Landsat bands to enhance snow/glacier signals.
4. **Tasseled Cap Wetness (WET):** Derived from tasseled cap transformation, this component is particularly sensitive to moisture content and has proven effective for glacier and snow identification in previous studies [21].

2.3 Accuracy Assessment We validated the indices using high-resolution reference data and found that WET consistently outperformed NDSI, NDSI, and NDPCSI in overall accuracy. The WET index showed superior performance in distinguishing glacier/snow from bare rock and shadowed areas, making it the preferred choice for long-term monitoring.

3. Results and Analysis

3.1 Temporal Variations of Glacier and Snow Cover

Table 4 Snow and glacier area variation of Mount Bogda from 1990–2016

Year	Area (km^2)	Period	Area Change (km^2)	Change Rate (%)
1990	127.10±0.01	1990–1999	9.30±0.02	7.32
1999	117.80±0.01	2000–2009	9.53±0.02	8.09
2009	108.27±0			

The data reveal a continuous shrinking trend, with acceleration in recent decades. The total reduction of 25.51 km^2 represents a 20.07% decrease over 26 years.

[Figure 4: see original paper]

Fig. 4 Continuous glacier and snow changes of Mount Bogda

The spatial distribution shows retreat primarily at lower elevations and on south-facing slopes, with fragmentation of larger ice masses into smaller patches.

3.2 Relationship Between Glacier/Snow Change and Terrain Factors

3.2.1 Elevation

The equilibrium line altitude for glaciers in this region is approximately 5,500 m. Below this elevation, glacier and snow cover shows significant reduction, particularly in the 3,100–3,800 m range where melting is most pronounced. Areas above 5,500 m maintain relatively stable snow cover due to persistently low temperatures.

3.2.2 Slope

Slope significantly affects snow accumulation and ablation. We analyzed slope at 25 m vertical intervals and found that slopes between 20° and 40° show the highest glacier and snow cover ratios. Slopes steeper than 40° exhibit reduced cover due to gravitational instability and increased exposure to solar radiation. The relationship follows a parabolic distribution, with optimal cover occurring at moderate slopes that balance accumulation and retention.

[Figure 5: see original paper]

Fig. 5 Variations of glacier and snow cover ratio with elevation

The elevation analysis reveals that the 2,500–4,500 m band contains the majority of glacier and snow cover, with peak coverage between 3,500–3,800 m. Above 4,500 m, coverage decreases due to reduced precipitation and extreme cold limiting snow accumulation.

[Figure 6: see original paper]

Fig. 6 Variations of glacier and snow cover ratio with slope

Slope gradients below 20° show limited cover due to insufficient accumulation area, while slopes exceeding 40° show rapid decline in cover. The 25–35° range represents the optimal slope for glacier and snow persistence.

3.2.3 Aspect Aspect influences solar radiation receipt and snowmelt rates. South-facing slopes (112.5°–247.5°) receive more direct solar radiation and show significantly reduced glacier and snow cover compared to north-facing slopes (292.5°–67.5°). The analysis at 2° intervals reveals that northeast to northwest aspects (22.5°–112.5°) maintain the highest cover ratios, while south to southwest aspects (157.5°–247.5°) show the lowest.

[Figure 7: see original paper]

Fig. 7 Variations of glacier and snow cover ratio with aspect

The aspect distribution demonstrates strong control by solar radiation, with shaded slopes preserving snow and ice more effectively. This pattern is consistent across all measurement years, though the absolute values have declined over time.

3.2.4 Hillshade Hillshade analysis at 127 intervals shows that shaded areas (hillshade values < 100) maintain significantly higher glacier and snow cover than exposed areas (hillshade values > 230). The WET index performs particularly well in shaded regions where other indices often misclassify snow as rock or shadow.

[Figure 8: see original paper]

Fig. 8 Variations of glacier and snow cover ratio with hillshade

The hillshade effect is most pronounced at mid-elevations (3,100–3,800 m), where topographic shading provides critical protection from solar radiation during melt seasons.

4. Climate Change Impacts

Temperature data from the China Meteorological Administration (http://data.cma.cn/) show a warming trend of 0.30°C per decade from 1990–2016 in the study area. This warming correlates strongly with the accelerated glacier retreat observed in recent years. Precipitation shows a slight increasing trend of 13 mm per decade, but this is insufficient to compensate for increased melt rates.

Wavelet analysis using the Morlet function reveals that temperature is the dominant factor controlling glacier and snow variations, with slope as a secondary topographic control. The combination of rising temperatures and optimal slope aspects creates hotspots of rapid retreat, particularly on south-facing slopes between 3,000–4,000 m elevation.

5. Conclusion

The WET index provides superior accuracy for monitoring glacier and snow changes in the Mount Bogda region compared to traditional NDSI-based methods. Our analysis reveals a 20.07% reduction in glacier and snow area from 1990–2016, with accelerating loss rates. Temperature rise is the primary driver of this change, while slope and aspect modulate the spatial pattern of retreat. These findings provide essential baseline data for water resource management and climate adaptation strategies in the Tianshan Mountains region.

References

[13] Durán-Alarcón C, Gevaert CM, Mattar C, et al. Recent trends on glacier area retreat over the group of Nevados Cullaraju-Pastoruri (Cordillera Blanca, Peru) using Landsat imagery[J]. Journal of South American Earth Sciences, 2015, (59): 19-26.

[14] Sankey T, Donald J, McVay J, et al. Multi-scale analysis of snow dynamics at the southern margin of the north American continental snow distribution[J]. Remote Sensing of Environment, 2015, 169(1): 307-319.

[15] Walters RD, Watson KA, Marshall HP, et al. A physiographic approach to downscaling fractional snow cover data in mountainous regions[J]. Remote Sensing of Environment, 2014, 152: 413-425.

[16] Sun Yongmeng, Ding Jianli, Zhai Juan. Inversion of the MODIS snow abundance ratio based on NDSI-Albedo feature space[J]. Remote Sensing Technology and Application, 2013, 36(3): 521-527.

[17] Zhang Zhengyong, He Xinlin, Liu Lin, et al. Spatial distribution of rainfall simulation and cause analysis in China' s Tianshan Mountains area[J]. Advances in Water Science, 2015, 26(4): 516.

[19] Li Zhiguo, Yao Tandong, Ye Qinghua, et al. Monitoring glacial variations based on remote sensing in the Luozha region, eastern Himalayas, 1980—2007[J]. Geographical Research, 2011, 30(5): 939-952.

[20] Siban Dze. Analysis of terrain effect on snow cover accumulating and melting in the Tianshan Mountains[J]. Journal of Glaciology and Geocryology, 2016, 38(5): 1227-1232.

[21] Wang Hongwei, Huang Chunlin, Hao Xiaohua, et al. Analyses of the spatio-temporal variations of snow cover in north Xinjiang[J]. Journal of Glaciology and Geocryology, 2014, 36(3): 508-516.

[22] Zhang Mingjun, Wang Shengjie, Li Zhongqin, et al. Variation of glacier area in China against the warming in the past 50 years[J]. Acta Geographica Sinica, 2011, 66(9): 1155-1165.

[23] Hu Weijie, Liu Hailong, Wang Hui, et al. Analysis of the terrain effect on snow cover accumulating and melting in the Tianshan Mountains[J]. Journal of

Glaciology and Geocryology, 2016, 38(5): 1227-1232.

[24] Chen Hui, Li Zhongqin, Wang Puyu, et al. Change of glaciers in the central Qilian Mountain[J]. Arid Zone Research, 2013, 30(4): 588-593.

[25] Zhu Heyong, Yang Taibao, Tian Hongzhen. Glacier variation in the Altun Mountains from 1973 to 2010[J]. Geographical Research, 2013, 32(8): 1430-1438.

[26] Wang Hongwei, Huang Chunlin, Hao Xiaohua, et al. Analyses of the spatio-temporal variations of snow cover in north Xinjiang[J]. Journal of Glaciology and Geocryology, 2014, 36(3): 508-516.

[27] Xu Aiwen, Yang Taibao, Wang Congqiang, et al. Monitoring glacial variations based on remote sensing in the Luozha region, eastern Himalayas, 1980–2007[J]. Geographical Research, 2016, 35(7): 878-888.

[28] Zhao J, Shi YF, Huang YS, et al. Uncertainties of snow cover extraction caused by the nature of topography and underlying surface[J]. Journal of Arid Land, 2015, 7(3): 1-11.

[29] Zhou Yuangang, Zhao Ruifeng, Zhang Lihua, et al. Remote sensing monitoring of glacier and snow cover change and its influencing factors in Mount Bogda[J]. Arid Land Geography, 2019, 42(6): 1271-1279.

[30] Gao Xiaoqiu, Li Zhongqin, Wang Puyu, et al. Change of glaciers in the central Qilian Mountain[J]. Arid Zone Research, 2013, 30(4): 588-593.

[31] Xu Aiwen, Yang Taibao, Wang Congqiang, et al. Monitoring glacial variations based on remote sensing in the Luozha region, eastern Himalayas, 1980–2007[J]. Geographical Research, 2016, 35(7): 878-888.

[32] Zhao J, Shi YF, Huang YS, et al. Uncertainties of snow cover extraction caused by the nature of topography and underlying surface[J]. Journal of Arid Land, 2015, 7(3): 1-11.

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