

Analysis of Spatiotemporal Variation Characteristics and Influencing Factors of MODIS LST in the Qilian Mountains (Postprint)

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Abstract

Land Surface Temperature (LST) is an indispensable parameter for studying physical processes of surface energy and water balance at regional and global scales. The spatiotemporal variation patterns of LST in the Qilian Mountains and their influencing factors remain unknown. This study employs trend analysis and correlation analysis methods to investigate the spatiotemporal variation characteristics of LST in the Qilian Mountains from 2000 to 2017 and its inter-relationship with vegetation, and to analyze the spatiotemporal differentiation characteristics of land surface temperature under various vegetation types. The results show that: (1) The accuracy of MODIS LST products can meet the requirements for analyzing spatiotemporal variations of land surface temperature in the Qilian Mountains. (2) The LST time series in the Qilian Mountains exhibits a fluctuating pattern of “rise-decline-rise-decline”, with an overall slight upward trend at a rate of $0.17^{\circ}\text{C} \cdot (10\text{a})^{-1}$; the rising trend of LST is most significant in winter (63.37%), with a change rate of $0.22^{\circ}\text{C} \cdot (10\text{a})^{-1}$; spatially, it shows a trend of decrease in the northwest and increase in the southeast, with the area of significant increase (14.89%) far exceeding that of decrease (0.90%). (3) The annual mean LST in the Qilian Mountains is negatively correlated with NDVI, with significantly correlated regions accounting for 22.56%; the regulatory effect of summer NDVI on LST is relatively significant (25.45%); the impact of desert NDVI on LST is greater than that of other vegetation types. (4) Elevation has a strong influence on LST for all vegetation types, with the correlation strength following the order of desert > forest > meadow > cropland; however, the correlation between summer LST and elevation decreases significantly due to increased vegetation cover. (5) The LST increase in the Qilian Mountains is the result of the combined influences of NDVI, elevation, and vegetation type.

Full Text

Spatiotemporal Variation of MODIS LST and Its Response to Vegetation and Altitude in the Qilian Mountains

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Abstract

Land surface temperature (LST) is a critical variable in the surface energy budget, significantly affecting global agriculture, natural disasters, hydrology, and ecological environments. With global climate change, quantitative research on LST and its related factors has become essential at both regional and global scales. The Qilian Mountains, located at the boundary between the Qinghai-Tibet Plateau and the northern hinterland in Qinghai and Gansu Provinces, China, is influenced by both continental climate and the Qinghai-Tibet Plateau climate, belonging to the temperate semi-arid climate zone and serving as an important geographical and climatic boundary in China. Studying LST in the Qilian Mountains is vital for understanding the hydrothermal cycle in northwest China and improving the fragile ecological environment. While the climate patterns, vegetation, and land-use characteristics of the Qilian Mountains have been comprehensively studied, the spatiotemporal variability of LST and its response mode to terrain remain unclear, and the impact of different vegetation types on LST changes needs further discussion. Based on MODIS LST data from 2000 to 2017, this study employed a linear trend method to analyze the temporal and spatial variation of LST in the Qilian Mountains and used Pearson correlation analysis to discuss the regulation of LST by different vegetation types and the influence of altitude on its change. The results are as follows: (1) The accuracy of MODIS LST products can meet the requirements for time-space variation analysis of surface temperature in the Qilian Mountains. (2) LST in the Qilian Mountains increased at a rate of $0.17^{\circ}\text{C} \cdot (10\text{a})^{-1}$, with two rising periods in 2000–2003 ($1.83^{\circ}\text{C} \cdot (10\text{a})^{-1}$) and 2004–2017 ($0.14^{\circ}\text{C} \cdot (10\text{a})^{-1}$). The annual average LST increased from Southwest to Northeast, and the significant rising area accounted for 77.26% of the total area. The extremely significant rising areas were mainly distributed in the middle and low altitudes below 3500 m. In addition, the winter change rate was the highest ($0.22^{\circ}\text{C} \cdot (10\text{a})^{-1}$), and the warming area reached 98.23%. The winter warming had the greatest contribution to the increase of LST in the Qilian Mountains. (3) Vegetation had

a significant impact on LST changes; cultivated land had a better inhibitory effect on LST rise, and desert vegetation had a stronger regulatory effect on LST. Except for summer, NDVI and LST were positively correlated in the rest of the seasons, and the positively correlated areas were mainly concentrated in high-altitude forest land. (4) The effect of altitude on LST was significantly weak during the summer due to conditions such as vegetation cover changes. The LST in the desert showed the strongest response to altitude, with strong annual fluctuations between 2500 and 3500 m. Meanwhile, vegetation degradation and human activities at low and medium altitudes may be the main factors accelerating the increase in LST.

Keywords: MODIS LST; MODIS NDVI; vegetation type; Qilian Mountains

1 Introduction

The Qilian Mountains are located in the northeastern part of the Qinghai-Tibet Plateau, with elevations ranging from 3500 to 5000 m, forming a natural barrier between the Qinghai-Tibet Plateau and the arid regions of northwest China. The region is characterized by a typical plateau continental climate with distinct vertical zonation. As an important water source and ecological security barrier in northwest China, the Qilian Mountains play a crucial role in regulating regional climate and maintaining ecological balance. Land surface temperature, as a key parameter of land-atmosphere energy exchange, directly influences regional climate change, vegetation growth, and water resource distribution. Previous studies have primarily focused on the response of vegetation changes to climate change in the Qilian Mountains, but research on the spatiotemporal variation characteristics of LST and its regulatory mechanisms remains insufficient. Based on MODIS LST data from 2000 to 2017, this study analyzes the spatiotemporal variation patterns of LST in the Qilian Mountains and explores the regulatory effects of different vegetation types and altitude factors on LST, providing scientific support for regional ecological protection and climate change adaptation.

2 Data and Methods

2.1 Data Sources and Preprocessing

The study utilized MODIS LST products (MOD11A2 and MOD13Q2) provided by NASA covering the period 2000–2017, with temporal resolution of 8 days and spatial resolution of 1 km. Data preprocessing was conducted using the MODIS Reprojection Tool (MRT) for reprojection, format conversion, and mosaicking. The linear trend method was applied to calculate the change rate of LST in the Qilian Mountains, with the slope calculated as:

$$\theta_{slope} = \frac{n \times \sum i \cdot LST_i - \sum i \sum LST_i}{n \times \sum i^2 - (\sum i)^2}$$

where n represents the number of years, i represents the year sequence, and LST_i represents the LST value in year i . A positive θ_{slope} indicates an increasing trend in LST, and vice versa.

2.2 Pearson Correlation Analysis

Pearson correlation analysis was used to examine the relationship between LST and NDVI/DEM. The correlation coefficient ranges from $[-1, 1]$, where values closer to 1 indicate stronger positive correlation, values closer to -1 indicate stronger negative correlation, and values near 0 indicate weak correlation. The formula is:

$$r = \frac{\sum(a_i - \bar{a})(b_i - \bar{b})}{\sqrt{\sum(a_i - \bar{a})^2 \sum(b_i - \bar{b})^2}}$$

where n is the sample size, a and b are the variables being analyzed, and \bar{a} and \bar{b} are their respective means.

3 Results

3.1 Accuracy Assessment of MODIS LST Products

The accuracy of MODIS LST products was validated using meteorological station data. The results showed that the correlation coefficient between MODIS LST and observed surface temperature reached 0.921, indicating that the MODIS LST products meet the accuracy requirements for analyzing surface temperature variation in the Qilian Mountains.

3.3 Monthly Variation Characteristics of LST

The monthly variation of LST in the Qilian Mountains showed a single-peak pattern, with the highest values occurring in July and the lowest in January. The multi-year average LST was below 0°C for six months (November through April), accounting for 50% of the year. Areas above 5000 m maintained LST below 0°C year-round. The LST variation rate showed significant seasonal differences, with the fastest increase occurring in winter ($0.22^\circ\text{C} \cdot (10\text{a})^{-1}$), followed by spring ($0.21^\circ\text{C} \cdot (10\text{a})^{-1}$) and autumn ($0.18^\circ\text{C} \cdot (10\text{a})^{-1}$), and the slowest in summer ($0.08^\circ\text{C} \cdot (10\text{a})^{-1}$).

3.4 Seasonal Variation Characteristics of LST

The seasonal variation of LST in the Qilian Mountains was pronounced, with significant warming trends in all four seasons. Winter exhibited the most significant warming trend, with an average increase of $0.22^{\circ}\text{C} \cdot (10\text{a})^{-1}$ and a warming area covering 98.23% of the region. The extremely significant warming areas were mainly distributed at altitudes below 3500 m, particularly in cultivated land, grassland, and desert vegetation zones. The high warming rate in winter contributed most to the annual LST increase. The spatial distribution of monthly LST showed a gradual increase from southwest to northeast, with the warming trend being more significant in the eastern and central parts of the mountains.

[Figure 5: see original paper] Spatial distribution of monthly LST trend in Qilian Mountains

The spatial distribution of LST trends revealed that 77.26% of the area showed a significant increasing trend, with 63.37% showing an extremely significant increase. The warming areas were primarily concentrated in the middle and low-altitude regions, while cooling areas were sporadically distributed in high-altitude zones above 5000 m. The annual average LST increase rate was $0.17^{\circ}\text{C} \cdot (10\text{a})^{-1}$, with the most significant warming occurring in the desert and grassland areas.

4 Discussion

4.1 Relationship Between NDVI and LST

Vegetation cover significantly influences LST variation through its effects on surface albedo, evapotranspiration, and energy partitioning. The correlation analysis between NDVI and LST showed significant seasonal variations. Except for summer, NDVI and LST were positively correlated in other seasons, with correlation coefficients ranging from 0.457 to 0.737 ($p < 0.01$). The positive correlation areas were mainly concentrated in high-altitude forest zones, while negative correlations were observed in low-altitude desert and grassland areas during summer. Cultivated land showed the strongest negative correlation with LST (-0.880 in summer), indicating its effective cooling effect. Desert vegetation exhibited the strongest positive correlation with LST (0.815 in winter), suggesting its significant role in LST regulation.

[Figure 7: see original paper] Spatial distribution of LST-NDVI correlation in Qilian Mountains

4.2 Influence of Altitude on LST

The effect of altitude on LST showed clear seasonal and vegetation-type dependent characteristics. Overall, LST decreased with increasing altitude, with

correlation coefficients ranging from -0.849 to -0.660 ($p < 0.01$). However, the altitude effect was significantly weakened during summer due to vegetation cover and monsoon influences. Desert LST showed the strongest response to altitude variation, with pronounced fluctuations between 2500-3500 m. Forest LST exhibited the most stable altitude-dependent pattern, maintaining strong negative correlations across all seasons. The weakening of altitude effect in summer was particularly evident in grassland and cultivated land areas, where vegetation growth and irrigation activities altered the energy balance.

5 Conclusion

This study analyzed the spatiotemporal variation characteristics of LST in the Qilian Mountains from 2000 to 2017 and its response to vegetation and altitude factors. The main conclusions are:

- (1) MODIS LST products demonstrate good accuracy in the Qilian Mountains, with correlation coefficients exceeding 0.92 compared with ground observations, meeting the requirements for regional surface temperature variation analysis.
- (2) The Qilian Mountains experienced significant warming during 2000-2017, with an overall trend of $0.17^{\circ}\text{C} \cdot (10\text{a})^{-1}$. Winter contributed most to this warming ($0.22^{\circ}\text{C} \cdot (10\text{a})^{-1}$), with 98.23% of the area showing increasing temperatures. The spatial pattern showed a southwest-to-northeast increasing gradient, with 77.26% of the region exhibiting significant warming trends.
- (3) Vegetation type significantly regulates LST variation. Cultivated land effectively inhibits LST rise, particularly in summer, while desert vegetation shows stronger regulatory effects on LST. The relationship between NDVI and LST varies seasonally, with positive correlations dominating except in summer when negative correlations prevail in low-altitude areas.
- (4) Altitude exerts a significant control on LST, though this effect weakens during summer due to vegetation cover changes. Desert LST shows the strongest altitude sensitivity, while forest LST maintains stable altitude-dependent patterns. Human activities and vegetation degradation at low and medium altitudes may accelerate LST increase.

These findings provide important insights for understanding climate change impacts and developing adaptive strategies in the Qilian Mountains region. Future research should integrate more ground observation data and consider additional factors such as soil moisture and snow cover to further elucidate LST variation mechanisms.

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