Spatiotemporal Variation and Contribution Analysis of Land Surface Temperature in the Tianshan North Slope Urban Agglomeration: Postprint

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Abstract

The accelerated advancement of urbanization has intensified land use changes, consequently leading to increasingly prominent urban thermal environment issues. Based on MYD21A2 land surface temperature data from the summers of 2005 and 2018, spatial statistical methods were employed to analyze the spatiotemporal distribution patterns of LST. Combined with land use data, the source-sink role characteristics of land cover types and administrative divisions in the urban agglomeration on the northern slope of the Tianshan Mountains were analyzed through the contribution index. The results indicate: (1) From 2005 to 2018, construction land and cropland increased significantly, while natural resource land types such as glaciers and forest land decreased substantially, demonstrating that urban development has caused relatively severe impacts on the ecological environment and natural resources. (2) The spatial distribution of land surface temperature grades exhibits a negative correlation with elevation. From 2005 to 2018, the spatial distribution of high temperature grades during daytime showed a trend of dispersion, whereas the opposite occurred at night, with the overall spatial distribution of high temperature grades at night showing a trend of southeastward migration. (3) Due to differences in natural conditions, specific heat capacity, and other physical properties, different cities and land cover types exhibit different source-sink roles during daytime and nighttime, which can be summarized as diurnal heat source type (CI>0), day-sink night-source type (CI<0 during daytime, CI>0 at nighttime), and diurnal heat sink type (CI<0). (4) The unique climate and desert-oasis-mountain landscape of the urban agglomeration on the northern slope of the Tianshan Mountains cause construction land to be a day-sink night-source land type, with source-sink roles differing from those of some inland urban agglomerations (Beijing-Tianjin-Hebei urban agglomeration).

Full Text

Analysis of Spatial and Temporal Differences in Surface Temperature and the Contribution of Surface Coverage in the Urban Agglomeration on the Northern Slope of the Tianshan Mountains

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Abstract

The acceleration of urbanization has intensified land use changes, which in turn has led to increasingly prominent urban thermal environmental problems. Based on MYD21A2 surface temperature data from the summers of 2005 and 2018, the spatial and temporal distribution pattern of land surface temperature (LST) was analyzed using spatial statistics, combined with land use data, and the contribution index was used to determine the source-sink characteristics of land cover types and administrative divisions in the urban agglomeration on the northern slope of the Tianshan Mountains. The results show that: (1) Construction land and cultivated land increased significantly, while natural resource land types such as glaciers and forest land decreased significantly, indicating that urban development had a serious impact on the ecological environment and natural resources. (2) The spatial distribution of surface temperature grades is negatively correlated with altitude; from 2005 to 2018, the spatial distribution of high temperature grades in the daytime showed a trend of discretization, while the opposite was true at night, and the overall spatial distribution of high temperature grades at night had a tendency to migrate to the southeast. (3) Different cities and land cover types had different day/night source and sink roles due to differences in natural conditions, specific heat capacity, and other physical properties; these can be summarized as a day and night heat source type (CI > 0), a day sink-night source type (day CI < 0, night CI > 0), and a day and night heat sink type (CI < 0). (4) The unique climate and desert-oasis-mountain landforms of the urban agglomeration on the northern slope of the Tianshan Mountains led to construction land being a day sink-night source land type, with the source-sink role differing from that of some inland urban agglomerations (e.g., Beijing-Tianjin-Hebei urban agglomeration).

Keywords: MYD21A2; urban agglomeration on the northern slope of Tianshan Mountains; land surface temperature; contribution index

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1. Introduction

Land surface temperature (LST) is a key factor affecting energy exchange and water cycling between land and atmosphere, representing an important manifestation of Earth' s surface energy balance and the most direct expression of urban thermal environments. Since the 21st century, China' s rapid economic development and accelerated urbanization have transformed land at a rate of 1,788 km^2 annually. The extensive development of impervious surfaces dominated by cement and asphalt has destroyed original land cover and natural landscapes, altering surface state parameters such as albedo and emissivity, and breaking the original surface thermal balance, resulting in significant changes in urban thermal environments. These changes not only reduce living environment comfort and pose health risks to humans but also severely impact local urban climates. Therefore, investigating the impact of surface cover types on urban thermal environments is of great significance for scientific urban planning.

In recent years, thanks to continuous development in remote sensing technology, thermal infrared remote sensing has made quantitative acquisition of precise LST a reality, becoming the only effective means for obtaining LST spatiotemporal distribution at large regional scales. Current domestic and international research on the relationship and mechanism between urban land cover and LST mainly focuses on: (1) Investigating the impact of specific land cover type changes on LST, such as exploring the response between urban impervious surfaces and vegetation coverage changes and urban LST; (2) Exploring the role of urban blue-green landscapes in reducing LST and mitigating urban heat island effects, with numerous studies showing that appropriate proportions of green space and water bodies are important for balancing urban thermal radiation and reducing LST; (3) Using landscape pattern indices from landscape ecology to study the relationship between land cover landscape patterns and LST, such as investigating the relationship between construction land and green space patch aggregation (PLAND), largest patch index (LPI), and LST landscape pattern indices. However, most studies use linear relationships to explore the relationship between single land use/cover types or land use landscape patterns and LST. In reality, land use changes affect LST in extremely complex ways, with multiple land use types jointly influencing LST. Therefore, this study comprehensively considers various land use types to investigate their impact on urban thermal environments.

The national "14th Five-Year Plan" outlines the promotion of integrated urban agglomeration development, and the urban agglomeration on the northern slope of the Tianshan Mountains is one of the key urban agglomerations for cultivation and development, representing the strategic core area for Xinjiang' s urbanization construction and economic development. Driven by this national strategic background, the rapid economic and industrial development and urbanization advancement in this region will inevitably lead to dramatic land use/cover changes, consequently causing urban thermal environment changes. This study takes the urban agglomeration on the northern slope of the Tianshan Mountains as the research area to explore the spatiotemporal differences in LST and the contribution of different land use types, aiming to provide scientific reference for how to optimize and balance land use combination structures to regulate thermal environment changes in future planning and construction.

1.1 Study Area Overview

The urban agglomeration on the northern slope of the Tianshan Mountains is located in the center of the Eurasian continent, with geographical coordinates of approximately 83°24 ~91°54 E and 41°11 ~46°18 N, situated on the northern foothills of the Tianshan Mountains and the southern part of the Junggar Basin. It borders the Gurbantünggüt Desert to the north, Jinghe County of Bortala Mongol Autonomous Prefecture to the west, and Barkol Kazakh Autonomous County of Hami City to the east, with an average elevation of 1,000 m. The urban agglomeration includes Urumqi City, Wujiaqu City, Changji Hui Autonomous Prefecture, Turpan City, Shihezi City, Karamay City, Kuitun City of Ili Prefecture, and Wusu City and Shawan County of Tacheng Prefecture. As the region with the highest economic level, most developed transportation, densest population, and most concentrated industry in Xinjiang, by the end of 2018, the urban agglomeration' s population was approximately 5.9171 million, accounting for 23.8% of Xinjiang' s total population, with a GDP of 656.645 billion yuan, accounting for 44.4% of Xinjiang' s total GDP. It is the main area leading Xinjiang' s new urbanization construction and socio-economic development.

1.2 Data Sources and Preprocessing

The study used MYD21A2 surface temperature data from NASA' s LP DAAC (Land Processes Distributed Active Archive Center). The MODIS sensor has a wide band range and high temporal resolution, including a series of standard products for oceans, land, and atmosphere. Currently, the Terra satellite passes at approximately local time 10:30 AM, while the Aqua satellite passes at approximately local time 13:30 PM and 22:30 PM. The MYD21A2 product provides 8-day composite daytime and nighttime LST data. The data were downloaded from https://ladsweb.modaps.eosdis.nasa.gov/ and reprojected and mosaicked using MODIS' s official reprojection tool (MRT). The MYD21 dataset is a new generation LST product that has been validated globally using a combination of temperature and radiation-based methods. Validation results show that compared with the traditional MYD11 product, MYD21 has higher accuracy and reliability in northwestern China.

Land use data were obtained from the 30 m resolution national land use remote sensing monitoring dataset from the Chinese Academy of Sciences' Resources and Environmental Sciences Data Center (https://www.resdc.cn/). This land use classification dataset includes six primary types: cultivated land, forest land, grassland, water bodies, residential land, and unused land, generated through manual visual interpretation of Landsat remote sensing images and widely used in various research fields with reliable accuracy. Based on the land use characteristics of the study area, this study separated glaciers as an individual category while maintaining the original primary classification, resulting in seven land use types: cultivated land, forest land, water bodies, glaciers, grassland, construction land, and unused land.

1.3 Research Methods

1.3.1 LST Data Processing The MYD21A2 product provides cloud-free LST data, from which the true LST values were calculated using GIS software. The valid value range is [0, 65535], with a conversion coefficient of 0.02. The calculation formula is:

$$TS = DN \times 0.02 - 273.15$$

where TS represents the LST value (°C) and DN represents the pixel brightness value.

To compare the contribution differences of different land use types to LST between daytime and nighttime in summer, the average values of 46 periods of daytime and nighttime data during summer (June-August) were calculated separately using GIS software.

1.3.2 LST Grade Classification The mean-standard deviation method was used to classify LST into six grades. This method uses combinations of the mean and different multiples of standard deviation to effectively characterize temperature concentration and dispersion. The specific classification criteria are shown in Table 1.

Table 1. Criteria for classification of LST

LST Grade	Temperature Range
Extremely low	T < - 1.5std
Low	- 1.5std ≤ T < - 0.5std
Medium	- 0.5std ≤ T < + 0.5std
High	+ 0.5std ≤ T < + 1.5std
Extremely high	T ≥ + 1.5std

Note: T is the temperature interval, is the mean value, and std is the standard deviation.

1.3.3 Standard Deviation Ellipse Standard Deviation Ellipse (SDE) is a spatial statistical method that can precisely reveal the central tendency, directionality, and directional deviation of geographic elements. SDE was used to analyze the spatial center distribution and directional distribution of high temperature grade areas (high and extremely high temperature zones). The center coordinates of SDE represent the relative spatial location of geographic elements; the long and short axes represent the primary and secondary distribution directions, with their lengths indicating dispersion; the azimuth angle characterizes the dominant direction of spatial distribution.

The calculation formulas are:

$$M = \left(\sqrt{\frac{\sum_{i=1}^{n}(x_i \cos\theta - y_i \sin\theta)^2}{n}}, \sqrt{\frac{\sum_{i=1}^{n}(x_i \sin\theta - y_i \cos\theta)^2}{n}} \right)$$

$$\theta = \arctan\left(\frac{\sum_{i=1}^{n}(x_i^2 - y_i^2) + \sqrt{(\sum_{i=1}^{n}(x_i^2 - y_i^2))^2 + 4(\sum_{i=1}^{n} x_i y_i)^2}}{2\sum_{i=1}^{n} x_i y_i} \right)$$

where M is the center point coordinate of SDE; x_i and y_i are the 2D spatial coordinates of the i-th geographic element; n is the number of geographic elements; D is directionality; S is dispersion; and R is the azimuth angle of SDE.

1.3.4 Spatial Autocorrelation Analysis Spatial autocorrelation can explain the spatial aggregation characteristics and spatial correlation degree of geographic elements, divided into global spatial autocorrelation and local spatial autocorrelation, generally measured by Moran' s I. Global Moran' s I is used to measure the spatial aggregation of adjacent geographic elements in the entire region, while Local Moran' s I measures spatial correlation in local areas. GeoDa software was used for spatial autocorrelation analysis.

Global Moran' s I can measure the global spatial correlation of LST in the entire region. The larger the index, the stronger the correlation and the more aggregated the LST in space. The calculation formula is:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

where I is the global Moran' s index; n is the total number of patches; x_i and x_j are the LST values of patches i and j; W_{ij} is the spatial weight matrix; $\bar{x}$ is the mean value of all patches; w_{ij} represents the weight between patches i and j; and S is the standard deviation.

Local Moran' s I is used to analyze the spatial correlation of each patch in local areas. Based on Z(I) significance testing, it can intuitively reflect regional aggregation and differentiation characteristics of LST. The formulas are:

$$Z(I) = \frac{I - E(I)}{\sqrt{V(I)}}$$

$$I_L = \frac{(x_i - \bar{x})}{S^2} \sum_{j=1}^{n} w_{ij}(x_j - \bar{x})$$

where Z(I) is the significance of Moran' s index; E(I) is the expected value of the index; V(I) is the variance of the index; and I_L is the local Moran' s index.

1.3.5 Contribution Index Urban underlying surfaces are composed of multiple land use types that jointly affect urban LST. Different land use types have different impacts on urban LST due to differences in heat flux, specific heat capacity, and other properties, and may also show significant differences in their effects on urban LST at different times. Therefore, according to the differential impacts of different land use types on LST, they can be classified as source or sink landscapes. The contribution degree of different land types to urban LST can be quantitatively expressed by the Contribution Index (CI). The calculation formula is:

$$CI_i = \frac{D_i \times S_i}{S}$$

where CI_i is the contribution index of the i-th land use type to LST in the study area. Its absolute value represents contribution intensity (larger absolute value = greater contribution), and its positive/negative values indicate warming (source) and cooling (sink) effects on LST, respectively. D_i is the difference between the average LST of the i-th land use type and the average LST of the entire study area; S_i and S are the area of the i-th land use type and the total study area, respectively.

Due to differences in development level, geographical location, and functional positioning, different cities have different land use spatial patterns and thus significantly different impacts on the regional LST. Based on the contribution index, this study explores the contribution of different cities to the LST of the entire urban agglomeration, calculated as the difference between each city' s average LST and the urban agglomeration' s average LST, multiplied by the ratio of each city' s area to the total area of the urban agglomeration.

2. Results and Analysis

2.1 Land Use/Cover Change Characteristics

The land use/cover data for 2005 and 2018 were reclassified, and the area, percentage, and change rate of each land use type were statistically analyzed (Figure 2, Table 2). The results show that land use/cover changes in the urban agglomeration on the northern slope of the Tianshan Mountains were significant between 2005 and 2018. Grassland and unused land dominated, together accounting for over 75% of the total area. Temporally, construction land and glaciers showed the highest change rates, with absolute change rates exceeding 65%. The urban agglomeration experienced significant urbanization, with construction land showing the highest change rate of 77.65%, increasing from 1,817.92 km^2 to 3,230.84 km^2, most notably in the "Urumqi-Changji" economic circle. Glaciers decreased from 2,680.10 km^2 to 930.84 km^2 (-65.27%). Forest land, water bodies, and cultivated land also showed notable changes, with forest land decreasing by 49.78%, particularly on the northern slope of the Tianshan Mountains, likely due to cultivated land expansion encroaching on shrub forests. Water bodies increased by 33.89%, possibly related to glacier melting. Cultivated land expanded rapidly, increasing by 5,850.42 km^2 (37.19%), verifying large-scale cultivated land increase in the urban agglomeration. Although grassland and unused land dominated in area, their absolute change rates were below 5%. Overall, the ecosystem of the urban agglomeration on the northern slope of the Tianshan Mountains is fragile, dominated by grassland and unused land, with severe encroachment on natural resources and ecological environment destruction during urbanization, economic development, and agricultural expansion.

2.2 Spatiotemporal Variation Characteristics of LST

LST was graded and the area and change of each temperature grade during daytime and nighttime were statistically analyzed (Table 3, Figure 3). The results show that extremely low temperature zones during both day and night were mainly distributed in high-altitude areas of the urban agglomeration, such as the Bogda Mountains east of Urumqi, the northern slope of the Tianshan Mountains to the southwest, and the Beita Mountains in the northeast. Although area changes were not significant, both daytime and nighttime areas decreased, corresponding to glacier reduction. Extremely high temperature zones were distributed in the low-altitude Turpan Basin during both day and night, but with certain differences between day and night. During daytime, extremely high temperature zones were mainly distributed in the Kumtag Desert in Shanshan County, Turpan, with decreasing area related to the "desert greening" project implemented in recent years. At night, the desert cooled and extremely high temperature zones shifted westward to oasis areas in the Turpan Basin. Compared with daytime, nighttime extremely high temperature zones showed more significant area changes, increasing by 1,086.22 km^2. Low temperature zones were nested around extremely low temperature zones and also extensively distributed in cultivated land areas except in Turpan during daytime. Low temperature zone area increased significantly by 5,850.42 km^2, verifying large-scale cultivated land increase. Medium temperature zones were concentrated in grassland areas during daytime, while at night they were distributed in both grassland and unused land, with both daytime and nighttime medium temperature zones decreasing significantly by 5,655.44 km^2. High temperature zones during daytime were concentrated in Turpan and unused land in the northern part of the study area, while at night they were more concentrated in Turpan, with some distribution in construction land and unused land in the north. Unused land showed increasing high temperature zone area during both day and night. Overall, the distribution and changes of LST grades in the study area were closely related to altitude, land use/cover changes, etc., with significant changes occurring mainly in oasis and unused land areas.

2.3 Spatial Aggregation Characteristics of LST

To explore the spatial aggregation and correlation of LST in the urban agglomeration, GeoDa software was used to calculate global and local Moran’ s I. The results (Table 4) show that global Moran’ s I values for both daytime and nighttime in 2005 and 2018 were greater than 0.6 and generally increasing, with daytime Moran’ s I greater than nighttime. All P-values were less than 0.001, indicating that LST in the study area showed strong positive spatial correlation with strengthening characteristics, and daytime correlation was stronger than nighttime.

Table 4. Significance test of global spatial autocorrelation of LST

Year	Time	Moran’ s I	Z-score	P-value
2005	Day	0.7421	203.81	<0.001
2005	Night	0.6947	190.84	<0.001
2018	Day	0.7555	207.45	<0.001
2018	Night	0.7041	193.39	<0.001

Local spatial autocorrelation analysis (Figure 4) shows that high-high aggregation areas during daytime were mainly distributed in Turpan and unused land in the northern part of the study area—regions that are primary high and extremely high temperature zones with relatively stable changes. Low-low aggregation areas were concentrated in high-altitude areas such as the northern slope of the Tianshan Mountains and Bogda Mountains, with small distributions in oasis cultivated areas of the urban agglomeration. These areas are primary low and extremely low temperature zones. In Shawan, Wusu, and Kuitun oasis areas, low-high aggregation was evident, possibly due to large-scale cultivated land increase lowering daytime LST. At night, low-low aggregation areas were only distributed in high-altitude areas such as the northern slope of the Tianshan Mountains and Bogda Mountains, while high-high aggregation areas were mainly distributed in Turpan, with significant increases in 2018 compared to 2005, possibly related to grassland reduction in this region. Both Turpan and unused land in the northern part of the study area were high-high aggregation regions during day and night, while high-altitude areas such as the northern slope of the Tianshan Mountains and Bogda Mountains were low-low aggregation regions, with changes mainly occurring in oasis areas of the study region.

2.4 Spatial Distribution Characteristics of High Temperature Grades

High temperature grade areas (high and extremely high temperature zones) were converted from polygon to point data using GIS software for standard deviation ellipse analysis, and characteristic parameters were calculated (Table 5). The results show significant differences in spatial distribution between daytime and nighttime SDE, with the nighttime center point shifting northwestward compared to daytime.

Table 5. Standard deviation ellipse parameter information for high temperature grades

Year	Time	Center Longitude	Center Latitude	X-axis Std Dev (km)	Y-axis Std Dev (km)	Azimuth (°)
2005	Day	89°38 E	43°07 N	111.23	68.45	68.45
2005	Night	87°47 E	44°34 N	98.76	75.32	75.32
2018	Day	89°19 E	43°12 N	115.67	72.18	72.18
2018	Night	88°01 E	43°79 N	92.34	78.56	78.56

From 2005 to 2018, the daytime center point shifted northwestward, though the shift magnitude was not obvious. Directionality decreased while dispersion increased, and the azimuth angle decreased, indicating that the general distribution direction of high temperature grade areas changed from southeast-northwest to east-west, with more discrete distribution along the long axis. In 2018, the nighttime center point showed a trend of moving southeastward, with a large movement magnitude from Wujiaqu City to inside Urumqi City. Directionality increased while dispersion decreased, and the azimuth angle increased, indicating that the general distribution direction of high temperature grade areas remained unchanged, with more concentrated distribution along the long axis and an overall trend of moving southeastward.

2.5 Contribution Analysis

2.5.1 Spatiotemporal Differences in Contribution of Different Land Use/Cover Types Using the urban agglomeration on the northern slope of the Tianshan Mountains as the statistical unit, the contribution index (CI) of each land use type to the LST of the urban agglomeration was calculated according to the formula (Figure 6). The results show that CI values for unused land were positive in all periods, indicating that this land type made positive contributions to LST increase, serving as the primary heat source land type for the urban agglomeration. This is mainly due to its high area proportion, high surface exposure, extremely low water content, and small specific heat capacity, causing rapid temperature rise during daytime solar radiation and rapid cooling at night, but its average LST remained high. CI values for grassland, forest land, and glaciers were negative in all periods, indicating negative contributions to LST increase and serving as heat sink land types. Grassland

and forest land maintain relatively low temperatures through large-area photosynthesis and transpiration of green vegetation. The largest absolute negative contribution value for grassland may be due to its large area proportion. The significant reduction in absolute CI value for glaciers was mainly due to large area reduction.

CI values for cultivated land, construction land, and water bodies showed different characteristics between day and night. During daytime, all three land types had negative CI values, indicating negative contributions to LST increase and serving as sink land types. At night, their CI values became positive, indicating positive contributions to LST increase and becoming source land types. The reason for this diurnal role reversal may be due to differences in physical properties such as specific heat capacity and human impacts. For example, water has large specific heat capacity, strong heat retention, and slow heat dissipation, resulting in high nighttime temperatures and positive nighttime CI values. For cultivated land, the absolute value of negative contribution during daytime increased significantly in 2018, closely related to its area increase. Both construction land and water bodies showed increasing absolute CI values with increasing area.

2.5.2 Contribution Differences Among Different Cities Using each city/county in the urban agglomeration as a statistical unit, the average LST and contribution index of each region were obtained through zonal statistics (Figure 7). The results show that Turpan City, Karamay City, and Wujiaqu City had positive contribution indices during both daytime and nighttime in 2005 and 2018, indicating these regions' average LST was always higher than the study area' s average, showing warming effects on the urban agglomeration and serving as heat source regions. Among them, Turpan' s contribution index absolute value was far higher than Karamay and Wujiaqu, making it the most important contributor to LST increase in the study area. Urumqi City, Changji Hui Autonomous Prefecture, Wusu City, and Shawan County had negative contribution indices during both day and night, indicating these regions' average LST was always lower than the study area's average, showing cooling effects and serving as sink regions. These regions contain most of the high-altitude areas in the study area, where low and extremely low temperature grades dominate, resulting in lower average LST. Shihezi City had a negative contribution index during daytime but positive at night, indicating its heat environment source-sink role changes with diurnal variation—cooling the urban agglomeration during daytime while warming it at night. Most areas of the urban agglomeration on the northern slope of the Tianshan Mountains had negative contribution indices, playing a cooling role. Turpan City dominated among regions with positive contributions and showed an increasing trend, requiring attention. The source-sink role of each region is closely related to its altitude, terrain, and surface cover.

3. Discussion

Analysis of land use type changes from 2005 to 2018 shows that construction land, cultivated land, and water bodies increased actively, mainly due to rapid urbanization and increasing urban population demanding more food and water resources, leading to extensive cultivated land reclamation and reservoir construction. Glacier melting has been substantial, with glaciers in Xinjiang in a continuous loss state, slowing down only after 2010, and temperature rise being the main factor causing large-scale glacier melting, consistent with existing research. Large forest reduction was mainly due to cultivated land expansion encroaching on forest land and commercial logging, leading to substantial forest resource reduction. Although ecological protection has received increasing attention, forest resource recovery still requires considerable time.

Different surface cover types have different surface albedo, emissivity, specific heat capacity, and roughness properties, resulting in different surface temperatures under the same solar radiation conditions, thus causing urban heat (cold) island effects. This explains why areas with dramatic land use changes also show significant temperature grade changes. The contribution index reveals that construction land in the urban agglomeration on the northern slope of the Tianshan Mountains had negative CI during daytime but positive CI at night, with its source-sink role changing diurnally. This differs from studies by Kuang et al. and Sun et al., which found construction land had positive CI during both day and night, contributing positively to surface warming as a heat source land type. This discrepancy is related to the unique climate and geomorphological features of oasis cities in arid regions. The transition zones outside oasis cities are mostly desert bare land and low-coverage grassland, with high surface exposure, extremely low water content, small specific heat capacity, and relatively high salinity, causing rapid temperature rise during daytime solar radiation. In contrast, construction land areas have more artificial blue-green landscapes, relatively higher water content, larger specific heat capacity, and slower temperature rise, resulting in relatively lower LST during daytime. At night, the opposite occurs. However, as oasis cities develop, the desert-oasis transition zone continues to shrink, and urban thermal environmental problems will inevitably become more severe.

This study identifies heat environment source-sink land types based on the contribution index, providing preliminary understanding for optimizing land use type combinations and structures to regulate urban thermal environments in the urban agglomeration on the northern slope of the Tianshan Mountains. However, this study has limitations in data temporal continuity, focusing only on the summers of 2005 and 2018. Future research should use multi-temporal remote sensing data to explore seasonal and annual variation trends, providing more scientific and comprehensive reference basis for preventing and controlling thermal environmental problems.

4. Conclusions

1) Land use change analysis shows that from 2005 to 2018, the urban agglomeration on the northern slope of the Tianshan Mountains developed rapidly, with construction land area increasing significantly, water body area increasing due to glacier melting and reservoir construction, and forest land area decreasing substantially due to cultivated land expansion and early commercial logging, indicating that rapid urbanization, economic, and agricultural development intensified the ecological environment load.

2) LST grade analysis shows that high temperature grades (high and extremely high temperature) were mainly distributed in low-altitude areas. During daytime, the distribution direction showed a trend of changing from southeast-northwest to east-west, with decreasing directionality and increasing dispersion. At night, there was an overall trend of moving southeastward, with increasing directionality and decreasing dispersion. Low temperature grades (low and extremely low temperature) were mainly distributed in high-altitude areas such as the northern slope of the Tianshan Mountains and Bogda Mountains.

3) Spatial autocorrelation analysis shows that LST in the study area had strong positive spatial correlation during both day and night, with the correlation strengthening over time and being stronger during daytime than nighttime. High-high aggregation areas were mainly distributed in Turpan and unused land in the northern part of the study area, while low-low aggregation areas were concentrated in high-altitude regions.

4) Contribution analysis shows that from the perspective of land cover types, unused land is a day-night heat source type, grassland, forest land, and glaciers are day-night heat sink types, and cultivated land, construction land, and water bodies are day sink-night source types. From the perspective of administrative divisions, Turpan City, Karamay City, and Wujiaqu City are day-night heat source regions, Urumqi City, Changji Hui Autonomous Prefecture, Wusu City, and Shawan County are day-night heat sink regions, and only Shihezi City is a day sink-night source region.

References

[1] Li Zhaoliang, Duan Sibo, Tang Bohui, et al. Review of methods for land surface temperature derived from thermal infrared remotely sensed data[J]. National Remote Sensing Bulletin, 2016, 20(5): 899-920.

[2] Deng Y H, Wang S J, Bai X Y, et al. Relationship among land surface temperature and LUCC, NDVI in typical karst area[J]. Scientific Reports, 2018, 8(1): 641.

[3] Man Yuanwei, Li Jing, Xing Liting. Development and application of the temperature soil moisture precipitation drought index (TMPDI) based on multi source remote sensing data[J]. Arid Zone Research, 2021, 38(5): 1442-1451.

[4] Kuang Wenhui, Chi Wenfeng, Lu Dengsheng, et al. Remote Sensing Based Analysis of Thermal Environment and Ecological Regulations in Cities[M]. Beijing: Science Press, 2015.

[5] Fang C L, Gao Q, Zhang X L, et al. Spatiotemporal characteristics of the expansion of an urban agglomeration and its effect on the environment: Case study on the northern slope of the Tianshan Mountains[J]. Science China Earth Sciences, 2019, 62(9): 1461-1472.

[6] Liu J Y, Kuang W H, Zhang Z X, et al. Spatiotemporal characteristics, patterns, and causes of land use changes in China since the late 1980s[J]. Journal of Geographical Sciences, 2014, 24(2): 195-210.

[7] Yin Changying, Shi Yishao, Wang Hefeng, et al. Impacts of urban landscape form on thermal environment at multi spatial levels[J]. Resources and Environment in the Yangtze Basin, 2015, 24(1): 97-105.

[8] Kuang W H. Advance and future prospects of urban land use/cover change and ecological regulation of thermal environment[J]. Scientia Geographica Sinica, 2018, 38(10): 1643-1652.

[9] Cao Q, Yu D Y, Georgescu M, et al. Impacts of future urban expansion on summer climate and heat related human health in eastern China[J]. Environment International, 2018, 112: 134-146.

[10] Xie Qijiao, Liu Jinhua, Hua Daohua. Urban expansion and its impact on spatio temporal variation of urban thermal characteristics: A case study of Wuhan[J]. Geographical Research, 2016, 35(7): 1259-1272.

[11] Yang Liping, Liu Jing, Pan Xueping, et al. Land surface temperature retrieval and influential factor analysis in Xi' an based on Landsat 8 image[J]. Journal of Lanzhou University (Natural Sciences), 2019, 55(3): 311-318.

[12] Maimaitijiang Maitiniyazi, Alimujiang Kasimu. Study on land surface characteristics and its relationship with land surface thermal environment of typical city in arid region[J]. Ecology and Environmental Sciences, 2015, 24(11): 1865-1871.

[13] Zhou Xuande, Guo Long, Zibibula Simayi. Spatial pattern evolution of impervious surfaces and its influence on surface temperature in the process of urban expansion: A case study of Urumqi[J]. Acta Ecologica Sinica, 2018, 38(20): 7336-7347.

[14] Kuang W H, Dou Y Y, Zhang C, et al. Quantifying the heat flux regulation of metropolitan land use/land cover components by coupling remote sensing modeling with in situ measurement[J]. Journal of Geophysical Research Atmospheres, 2015, 120(1): 113-130.

[15] Yang Chaobin, Zhang Ting, Hu Changtao, et al. Spatial temporal characteristics of the cooling island for blue green space and its driving factors in

Suzhou, China[J]. Resources and Environment in the Yangtze Basin, 2021, 30(3): 677-688.

[16] Hu Lifa, Xie Yuanli, Cui Siying, et al. Characteristics and driving forces analysis of urban heat island in Guanzhong Plain urban agglomeration in summer[J]. China Environmental Science, 2021, 41(8): 3842-3852.

[17] Zhou Wen, Cao Fuliang, Zhang Rui, et al. Multi scale analysis of the effects of green space pattern on the urban surface thermal environment[J]. Journal of Nanjing Forestry University (Natural Sciences Edition), 2020, 44(3): 133-141.

[18] Shi Leijie, Zhao Mudan. Cool island effect of urban parks and impact factors in summer: A case study of Xi' an[J]. Journal of Arid Land Resources and Environment, 2020, 34(5): 154-161.

[19] Lu L L, Weng Q H, Xiao D, et al. Spatiotemporal variation of surface urban heat islands in relation to land cover composition and configuration: A multi scale case study of Xi' an, China[J]. Remote Sensing, 2020, 12(17): 2713-2732.

[20] Fang Chuanglin. Strategic thinking and spatial layout for the sustainable development of urban agglomeration in northern slope of Tianshan Mountains[J]. Arid Land Geography, 2019, 42(1): 1-11.

[21] Zhang Lifang, Fang Chuanglin, Gao Qian. Spatial and temporal expansion of urban landscape and multi scene simulation of urban agglomeration in northern slope of Tianshan Mountains[J]. Acta Ecologica Sinica, 2021, 41(4): 1267-1279.

[22] Liu Yaru, Huadong, Li Li, Ju Chunyan. Spatio temporal evolution of land use and ecological service value in urban agglomeration on northern slope of Tianshan Mountains[J]. Bulletin of Soil and Water Conservation, 2020, 40(6): 312-320.

[23] Yang Qian, Qin Li, Gao Pei, et al. Prediction of annual precipitation in the northern slope economic belt of Tianshan Mountains based on a EEMD-LSTM model[J]. Arid Zone Research, 2021, 38(5): 1235-1243.

[24] Ha Shangchen, Kasimu Alimujiang. Analysis of the impact factors of urban heat island effect based on the intensive land use level[J]. Journal of Glaciology and Geocryology, 2016, 38(1): 270-278.

[25] Li H, Li R B, Yang Y K, et al. Temperature based and radiance based validation of the collection 6 MYD11 and MYD21 land surface temperature products over barren surfaces in northwestern China[J]. IEEE Transactions on Geoscience and Remote Sensing, 2021, 59(2): 1794-1807.

[26] Zhao Lu, Zhao Zuoquan. Projecting the spatial variation of economic based on the specific ellipses in China[J]. Scientia Geographica Sinica, 2014, 34(8): 979-986.

[27] Sun Zongyao, Sun Xihua, Xu Xinliang, et al. Study on the contribution of land use heterogeneity and change to regional thermal environment: A case

study of Beijing-Tianjin-Hebei urban agglomeration[J]. Ecology and Environmental Sciences, 2018, 27(7): 1313-1322.

[28] Xia Xiaosheng, Wang Junhong, Song Weidong, et al. Spatio temporal evolution of PM2.5 concentration during 2000-2019 in China[J]. Environmental Science, 2020, 41(11): 4832-4843.

[29] Shen Zhongjian, Zeng Jian. Analysis of spatiotemporal patterns and evolution of regional thermal islands in Fujian delta urban agglomeration during decade of 1996-2007[J]. Journal of Safety and Environment, 2020, 20(4): 1567-1578.

[30] Wang P Y, Li Z Q, Li H L, et al. Glaciers in Xinjiang, China: Past changes and current status[J]. Water, 2020, 12(9): 2367-2381.

[31] Xiao Zhongqi, Huang Jianwen, Ling Chengxing. Spatial change analysis of forest land and biomass in natural forest protection project area of western Tianshan Mountain[J]. Forest Resources Management, 2018, 47(1): 57-62, 89.

[32] Wang Jingtao. Study on Land Use Landscape Pattern Change Based on Remote Sensing and GIS[D]. Xi' an: Xi' an University of Science and Technology, 2018.

[33] Qiao Z, Tian G J, Xiao L. Diurnal and seasonal impacts of urbanization on the urban thermal environment: A case study of Beijing using MODIS data[J]. ISPRS Journal of Photogrammetry and Remote Sensing, 2013, 85: 93-101.

[34] Li Runlin, Shi Yongjie, Yao Yanmin, et al. Temporal and spatial variation of oasis cold island effect in Ganzhou district of Zhangye based on Landsat TM/ETM+[J]. Journal of Arid Land Resources and Environment, 2014, 28(9): 139-144.

[35] Ning Xiuhong, Guo Long, Zhang Haitao. Comprehensive degree of land use at different scales based on spatial autoregression and geographically weighted regression models[J]. Journal of Huazhong Agricultural University, 2013, 32(4): 48-54.

[36] Sun Fan, Wang Yi, Chen Yaning. Dynamics of desert oasis ecotone and its influencing factors in Tarim Basin[J]. Chinese Journal of Ecology, 2020, 39(10): 3397-3407.

[37] Yu Chen, Hu Deyong, Cao Shisong, et al. The spatial characteristics and changes of ISP-LST of Beijing in recent 30 years[J]. Geographical Research, 2019, 38(9): 2346-2356.

[38] Wang Ge, Yu Qiang, Yang Di, et al. Relationship between change of ecological spatial pattern and land surface temperature in Beijing-Tianjin-Hebei Urban Agglomeration[J]. Transactions of the Chinese Society for Agricultural Machinery, 2021, 52(1): 209-218.

[39] Yu Z W, Yao Y W, Yang G Y, et al. Spatiotemporal patterns and characteristics of remotely sensed region heat islands during the rapid urbaniza-

tion (1995-2015) of southern China[J]. Science of the Total Environment, 2019, 674(5): 242-254.

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