Postprint: Correlation Analysis of Vegetation-Water Vapor-Land Surface Temperature in Typical Deserts and Oases of Xinjiang

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Date: 2022-04-14T00:28:15+00:00

Abstract

To investigate the correlation among land surface temperature (LST), normalized difference vegetation index (NDVI), and atmospheric water vapor content in desert and oasis areas of different regions in Xinjiang, this study utilized MOD13C3 vegetation index data, MOD11C3 land surface temperature data from 2001-2019, and Suomi NPP VIIRS water vapor content data from 2013-2017, employing the Slope trend analysis method. The results indicate: (1) From 2001 to 2019, the annual average NDVI in Xinjiang showed an overall increasing trend, with particularly significant increases in oases. The annual average LST exhibited changes characterized by daytime decrease and nighttime increase in oases, resulting in a reduced annual temperature range; while in deserts, both daytime and nighttime temperatures increased, leading to an increased annual temperature range. (2) Monthly data of NDVI, atmospheric water vapor content, and LST across Xinjiang were positively correlated with each other. Increased vegetation can reduce surface temperature differences and atmospheric water vapor differences, which was particularly evident in high vegetation cover areas of northern Xinjiang oases. Oases demonstrate superior ecological regulation compared to deserts, with northern Xinjiang oases outperforming those in southern Xinjiang. (3) The Taklamakan Desert exhibited pronounced nighttime surface temperature inversion and humidity inversion phenomena from March to October each year, causing nighttime atmospheric water vapor content to exceed daytime levels. Southern Xinjiang oases, under the dual influence of the desert environment and vegetation increase, have shown a gradual reduction in months where nighttime water vapor content exceeds daytime content in recent years, primarily concentrated in summer. These findings contribute to a macroscopic understanding of climate change in Xinjiang and provide valuable references for ecological environmental protection in the region.

Full Text

Vegetation-Water Vapor-Land Surface Temperature Correlation Analysis of Typical Deserts and Oases in Xinjiang

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Abstract: To explore the correlations among land surface temperature (LST), normalized difference vegetation index (NDVI), and atmospheric water vapor content in different regions of Xinjiang, this study utilized MOD13C3 NDVI and LST data from 2001 to 2019 and Suomi NPP VIIRS water vapor content data from 2013 to 2017, applying trend analysis methods. The results indicate: (1) From 2001 to 2019, the annual average NDVI in Xinjiang showed an overall increasing trend, with particularly significant increases in oases. The annual average LST changes exhibited daytime decreases and nighttime increases in oases, reducing the diurnal temperature difference, while desert areas showed increases during both day and night, expanding the annual temperature differential. (2) Monthly data for NDVI, atmospheric water vapor content, and LST were positively correlated with each other. Increased vegetation can reduce both surface temperature differences and atmospheric water vapor differences, an effect particularly evident in high vegetation coverage areas of northern Xinjiang oases. Oases demonstrate superior ecological environment regulation compared to deserts, with northern Xinjiang oases outperforming those in southern Xinjiang. (3) In the Taklimakan Desert, nighttime surface temperature inversion and humidity inversion phenomena are pronounced from March to October each year, resulting in higher atmospheric water vapor content at night than during the day. The oases in southern Xinjiang, influenced by both the desert environment and increasing vegetation, have experienced a gradual reduction in months where nighttime water vapor content exceeds daytime levels in recent years, primarily concentrated in summer. These findings contribute to macro-level understanding of climate change in Xinjiang and provide valuable references for ecological environmental protection.

Keywords: normalized difference vegetation index (NDVI); land surface temperature; atmospheric water vapor content; temperature inversion; humidity inversion

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Introduction

Vegetation changes can directly reflect regional environmental variations. Vegetation plays a crucial role in climate regulation and maintaining surface environmental stability. The normalized difference vegetation index (NDVI) effectively reflects vegetation changes and coverage extent, and has been widely applied in studying spatiotemporal vegetation dynamics and ecological environment monitoring. Land surface temperature and atmospheric water vapor content are closely related to vegetation; higher vegetation coverage strengthens the regulatory effect on land surface temperature and improves atmospheric water vapor regulation.

Previous studies have yielded valuable insights into local areas of Xinjiang, including surface temperature in Shihezi, vegetation in the Tianshan Mountains, and vegetation changes in the Hotan region. Using MODIS datasets and trend analysis, researchers have identified significant increasing trends in vegetation along the Tianshan Mountains oasis belt in Xinjiang. Analysis using MODIS land surface temperature products with maximum value compositing and long-term trend analysis has revealed increasing vegetation trends and significant summer surface temperature decreases in these regions. Yang et al. studied water vapor content in the Ili River Basin, finding that water vapor concentrates in summer. Yao et al. analyzed water vapor content in the Tianshan Mountains and surrounding areas using meteorological station observations and sounding data, revealing distinct seasonal variations with highest levels in summer and lowest in winter. Cai et al. calculated vegetation coverage from MOD13Q1 data, concluding that increased vegetation coverage plays an important role in slowing surface temperature rise. Lei et al. used Landsat TM imagery and daily surface temperature data from Yutian meteorological stations, finding positive correlations between NDVI and surface temperature.

However, comparative studies between desert and oasis systems in Xinjiang remain limited, and correlation analyses of vegetation-water vapor-temperature across northern and southern Xinjiang are particularly scarce. Therefore, this paper selects typical habitats in Xinjiang deserts and oases to compare vegetation index, atmospheric water vapor content, and land surface temperature changes between northern and southern Xinjiang, revealing the intrinsic relationships among these three factors under current environmental changes and providing valuable references for better understanding Xinjiang' s ecological environment changes.

1.1 Study Area Overview

Xinjiang is located deep within the Eurasian continent, far from oceans, and features a typical temperate continental climate. The Tianshan Mountains divide Xinjiang into northern and southern regions. Northern Xinjiang contains the fixed and semi-fixed Gurbantunggut Desert with vegetation coverage around 15-30%, while southern Xinjiang has the mobile Taklimakan Desert with vegetation coverage near zero. Northern Xinjiang has lower elevation than southern Xinjiang, receives more precipitation, and has better overall vegetation conditions. These significant climatic differences between northern and southern Xinjiang create substantial ecological environment variations, offering high exploration, comparison, and research value.

1.2 Data and Processing

The NDVI and land surface temperature data from MOD13C3 and MOD11C3 have spatial resolutions of 5.5 km and temporal resolutions of one month. The Suomi NPP VIIRS water vapor data has a spatial resolution of 5.5 km and temporal resolution of one month. Data from 2001 to 2019 were obtained from https://ladsweb.modaps.eosdis.nasa.gov. Using Interactive Data Language (IDL) programming, data quality information from MOD13C3 and MOD11C3 was applied for cloud removal. Pixels affected by aerosols were also processed to ensure data accuracy and reliability for subsequent calculations. The NUCAPS (NOAA Unique Combined Atmospheric Processing System) water vapor product from VIIRS was used to obtain daytime and nighttime global monthly average values, compensating for missing total precipitable water vapor (TPW) data. Study area data were extracted using vector maps of typical habitats.

1.3 Research Methods

Trend analysis was applied to annual average NDVI and LST sequences using the slope calculation formula:

$$\text{Slope} = \frac{j \times \sum x_j - \sum j \times \sum x_j}{j \times \sum j^2 - (\sum j)^2}$$

where j represents the year, x_j is the annual average value of NDVI or LST for year j, and n is the total number of years. When Slope > 0, the factor shows an upward trend over n years; when Slope < 0, it shows a downward trend.

2.1 NDVI Change Trends in Xinjiang

Trend analysis results (Fig. 2) reveal significant vegetation increase in Xinjiang oases. This increase is closely related to saline-alkali land improvement and farmland development. On one hand, Xinjiang’ s agricultural production model transformation, particularly drip irrigation implementation, has created semi-conical soil wetting bodies beneath drip emitters. Soil salts move with water and are leached to the periphery of the wetting body, resulting in reduced salinity in the tillage layer and promoting crop growth, thereby utilizing large areas of saline-alkali land. On the other hand, drip irrigation improves water use efficiency and significantly increases cultivated land area. Influenced by increased regional precipitation in recent years, Xinjiang’ s natural vegetation has shown an overall increasing trend, though vegetation has decreased in parts of Ili, Tacheng, and Altay regions, particularly in Ili. Research indicates this decline relates to population growth, human disturbance, summer overgrazing, precipitation reduction, and invasive plant species.

2.2 Land Surface Temperature Change Trends in Xinjiang

Land surface temperature trend analysis (Fig. 3) shows that in oases with significant vegetation increase, daytime LST clearly decreases while nighttime LST increases, reducing the diurnal temperature difference. This demonstrates that vegetation increase regulates LST and reduces temperature amplitude. Influenced by global warming, both daytime and nighttime LST have increased in low vegetation coverage areas like the Gurbantunggut and Taklimakan Deserts, increasing diurnal temperature differences. Although vegetation in both deserts has slightly increased in recent years, sparse vegetation provides weak temperature regulation, and desert LST changes are more controlled by underlying surface conditions and air temperature variations. This analysis indicates that high vegetation coverage areas have stronger regulatory effects on LST changes than low vegetation coverage areas.

2.3 Overall Vegetation-Water Vapor-LST Correlations in Xinjiang

The relationships among NDVI, LST, and atmospheric water vapor content show positive correlations. Vegetation increase raises both daytime and nighttime water vapor content, increasing water vapor differences (Fig. 4). With NDVI increase, both daytime and nighttime LST increase, and when NDVI peaks in summer, the diurnal surface temperature difference gradually decreases (Fig. 4). Comparing the effects of vegetation increase on temperature and water vapor differences reveals that LST is highly sensitive to vegetation changes, while atmospheric water vapor content shows low sensitivity. At the regional level, the relatively low average vegetation coverage cannot effectively reduce water vapor differences. Additionally, as LST increases, both daytime and nighttime water vapor content increase, and larger diurnal surface temperature differences correspond to larger water vapor content differences (Fig. 4).

2.4 Vegetation-Water Vapor-LST Correlations in Northern Xinjiang Desert and Oasis

In the Gurbantunggut Desert of northern Xinjiang, vegetation, atmospheric water vapor content, and LST show clear seasonal variations, with all parameters and their differences reaching annual maxima in summer and minima in winter (Fig. 5). Daytime water vapor content and LST are higher than nighttime values (Fig. 5). NDVI peaks occur in spring (Fig. 5). Due to low vegetation coverage and weak regulation, annual increases in desert vegetation do not reduce temperature and water vapor differences (Fig. 6). LST significantly affects atmospheric water vapor content (Fig. 6), and vegetation changes have minimal impact on LST (Fig. 6).

In northern Xinjiang oases, high vegetation coverage reduces both temperature and water vapor differences compared to the adjacent Gurbantunggut Desert (Fig. 7, Table 1). As vegetation increases annually, both water vapor and temperature differences decrease (Fig. 8), demonstrating vegetation' s environmental regulation and oasis effects. Since oases are primarily cropland, NDVI peaks in summer (Fig. 7). The influence of LST on atmospheric water vapor content is significant (Fig. 8), and vegetation changes clearly affect LST (Fig. 8).

2.5 Vegetation-Water Vapor-LST Correlations in Southern Xinjiang Desert and Oasis

In the Taklimakan Desert of southern Xinjiang, daytime LST is significantly higher than nighttime (Table 2), creating huge diurnal temperature differences (Fig. 9). Atmospheric water vapor content shows higher nighttime than daytime values during March-October (Fig. 9), with nighttime surface temperature and humidity inversion phenomena being pronounced. Due to lack of vegetation regulation, the desert heats and cools rapidly. Nighttime surface radiation cooling causes the lower air layer near the ground to cool rapidly while the upper layer cools more slowly, creating temperature inversion. A large amount of water vapor accumulates at the bottom of the inversion layer, forming a distinct humidity inversion layer. With weak turbulent exchange, the atmosphere remains basically stable, while daytime heating creates unstable stratification that weakens the inversion humidity. Therefore, the Taklimakan Desert exhibits this anomalous pattern mainly in warmer months. Additionally, vegetation changes under extremely low coverage have almost no regulatory effect on LST, though LST significantly affects atmospheric water vapor content, with nighttime water vapor content being more sensitive to temperature regulation than daytime (Fig. 10).

In southern Xinjiang oases, high vegetation coverage significantly reduces diurnal temperature differences (Fig. 11), showing the same characteristic as northern Xinjiang oases where temperature differences decrease with vegetation increase (Fig. 12). However, atmospheric water vapor content changes differ from northern Xinjiang oases. Southern Xinjiang oases, heavily influenced by the surrounding desert environment, also exhibit nighttime water vapor content exceeding daytime values, but mainly concentrated in summer months (Fig. 11, Fig. 12). This analysis again demonstrates that vegetation changes affect LST more strongly than water vapor, and LST clearly controls atmospheric water vapor content (Fig. 12).

3 Discussion

The finding that Xinjiang NDVI showed an overall increase from 2001 to 2019 aligns with Zhou et al.' s research results. The significant increasing trend in Xinjiang oases is consistent with studies showing rapid oasis area expansion in northern and southern Xinjiang in recent years. The LST trend results are similar to those of Han et al. and Hu et al., showing rising temperatures in desert areas and decreasing temperatures in oases. The positive correlation between NDVI and LST in the Taklimakan Desert is consistent with Reyi et al.' s findings. Calculations show the Taklimakan Desert has higher LST than the

Gurbantunggut Desert, with daytime and nighttime averages of 31.32°C and 20.87°C respectively, compared to 26.41°C and 15.96°C for the Gurbantunggut Desert, aligning with Zhao et al.' s research.

The positive correlation between increased vegetation coverage and atmospheric water vapor content is consistent with Zhang et al.' s conclusion that the correlation between NDVI and water vapor strengthens with NDVI increase. Water vapor content is significantly affected by underlying surfaces; oasis farmland irrigation and crop evapotranspiration produce high atmospheric water vapor content, while desert areas with low precipitation and vegetation coverage have relatively low water vapor content. The finding that water vapor content in southern Xinjiang oases exceeds that in the Taklimakan Desert aligns with existing research.

The diurnal surface temperature differences in oases are clearly different from those in deserts. The conclusion that LST increase leads to atmospheric water vapor content increase is consistent with Wei et al.' s findings. Northern Xinjiang shows higher daytime than nighttime water vapor content, following the general pattern that higher temperatures correspond to higher water vapor content. The anomalous pattern in southern Xinjiang from March to October, where nighttime exceeds daytime water vapor content, relates to the Taklimakan Desert' s low vegetation coverage and scarce precipitation. During daytime solar radiation, desert surfaces heat up, but at night they rapidly cool through longwave radiation. The Gurbantunggut Desert' s vegetation coverage provides some regulation, preventing rapid temperature drops and making inversion phenomena less obvious. The nearly vegetation-free Taklimakan Desert experiences rapid surface cooling at night, creating pronounced temperature and humidity inversion that leads to higher nighttime water vapor content. Cui et al.' s study based on GPS observations in the Taklimakan Desert hinterland found nighttime water vapor content exceeded daytime values throughout the year, slightly different from this study' s temporal pattern, likely due to data sources and methodology differences requiring further investigation.

4 Conclusions

From 2001 to 2019, Xinjiang' s vegetation increased overall with local decreases, with the most significant increases in oases. Increased vegetation reduced daytime LST, increased nighttime LST, decreased diurnal temperature differences, and stabilized the environment. Vegetation increase also raised atmospheric water vapor content, showing positive correlation. The regulatory effect of vegetation on water vapor content is only evident in high vegetation coverage oases. Vegetation affects LST more strongly than atmospheric water vapor content. Increased vegetation helps reduce both temperature and water vapor differences. The Taklimakan Desert shows higher nighttime than daytime water vapor content from March to October. Southern Xinjiang oases, influenced by both recent vegetation increase and the Taklimakan Desert, exhibit this phenomenon mainly in summer. Enhancing vegetation coverage in Xinjiang will be beneficial for addressing global climate change.

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