Analysis of urban heat island (UHI) in the Beijing metropolitan area by time-series MODIS data

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1. Introduction

One of the most well-known climatic phenomenon in urban environment is the so-called "urban heat island" (UHI) effect, describing the phenomenon that temperatures in urban areas are higher than those in the nearby rural areas. Research works based on thermal remote sensing images with high temporal resolution have revealed that UHI has evident diurnal and seasonal properties, [1], [2], [3]. The objective of this paper is to investigate the relationships between UHI magnitude in the Beijing metropolitan area and the nearby rural surface temperature (RST) based on land surface temperature (LST) derived from the time series Terra/Aqua Moderate-Resolution Imaging Spectroradiometer (MODIS) data.

2. Study Area, data and methods

Beijing is selected as the study area in this research and analysis will be aimed at several typical sites of the urban and suburban areas of Beijing. The 8-day MODIS Terra/Aqua land surface temperature/emissivity products (MOD11A2 and MYD11A2) in version V005, [4],

during 2001-2008 are used to characterize UHI. The spatial resolution of this product is 1km. The Terra overpass time is around 10:30 and 22:30 local solar time, while the Aqua overpass time is around 13:30 and 01:30 local solar time. The yearly land cover type products MOD12Q1 from 2001 to 2004 are used to extract the urban and rural areas. The 16-day composite Terra MODIS vegetation indices products MOD13A2 with 1km spatial resolution for every year are also collected. In addition, meteorological data for every day observed at Beijing Weather Observatory (BWO, located at 39°48′N, 116°28′E) are collected.

UHI magnitude is defined as urban to rural temperature differences [5]. In this study UHI magnitude of a site is calculated as temperature difference between the temperatures of the site and the rural site. A Gaussian smoothing filter with window size as 9 is used to smooth the time series data.

3. Results and discussions

For the daytime, there were significant UHI effects in the summer in Beijing; while the UHI effects became weaker in the spring and autumn and urban heat sink appeared in the winter. It is observed that intra-annual changes of RST and UHI magnitude were not synchronous and a lag is found when comparing these two parameters in the summer. A lag-correlation was performed between these two parameters. For the area inside of Second Ring Road, when the lag-day of RST was 0, the correlation coefficients (R) were 0.59 and 0.58 for Terra and Aqua MODIS, respectively. However, R rose to 0.70 and 0.68 when the lag-day was 24. Then when the lag-day of RST increased to 48, R decreased to 0.65 and 0.65. All the correlation relationships were significant at 0.01 level. For Terra in the daytime, R ranged from 0.66 to 0.69 when the lag-day ranged from 24 to 48, much higher than that when the lag was 0. For Aqua, R ranged from 0.68 to 0.66 when the lag-day ranged from 24 to 48 and its highest value appeared when lag-day was 32; while R was 0.61 when lag-day was equal to 0. Lag-correlations were also found at other sites.

In the nighttime, there were nighttime UHI in all seasons. Intra-annual variations of the nighttime UHI magnitude were not as obvious as that in the daytime. The most significant UHI appeared in the winter night, while the weakest appeared in the summer night. Visual

interpretation on the seasonal changes of the nighttime UHI magnitude and RST suggested that there were significant negative correlation between these two parameters. An additional lag-correlation was also conducted. However, no lag relations were found for UHI 22:30 and 01:30 local time.

NDVI and the rainfall were selected as a main factor to analyzing the variations of daytime UHI magnitude. The annual NDVI shows that NDVI in the rural area reached its peak in DOY209~DOY225. The temporal change of NDVI in the urban area seemed much smoother than that of the rural areas, and a small peak appeared during DOY193~208. Difference between the multi-year averaged NDVI of rural area and urban area reaches its peak (around 0.47) during DOY209~DOY233, according with the time when the strongest daytime UHI appeared. On the other hand, examination on the temporal change of rainfall in the study area indicates that there were much rainfall during DOY180~240, and its peaks appeared during DOY193~DOY209 except 2003. The surface moisture is determined by rainfall. Therefore, it should be concluded that the surface moisture maybe another influencing factor to the lag relations between daytime UHI magnitude and RST.

4. Conclusions

The results from this work show the temporal relations between the UHI magnitude in Beijing city and the temperature of its rural background. Evident lag relations between daytime UHI magnitude and RST were found, indicating the dependence of UHI on the temperature itself was significantly influenced by the vegetation abundance and surface moisture. However, the nighttime UHI magnitude and RST change with the reverse phase. These results suggest cautions should be noticed when analyzing UHI at different temporal scales, especially for seasonal and intra-annual variations of UHI.

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