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Research paper

Impacts of urban biophysical composition on land surface temperature in urban heat island clusters

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HIGHLIGHTS

- We extracted urban heat island (UHI) clusters using an innovative approach.
- We examined the nonlinear relationships between the LST and urban biophysical composition in UHI clusters.
- The spatial heterogeneity of the landscape within UHI results in the complexity of LST.
- Both NDVI and NDBI are great indicators for predicting the variations of LST in UHI clusters.

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ABSTRACT

The spatio-temporal pattern of biophysical composition significantly affects land surface temperature (LST). Previous studies, however, mostly characterized urban heat island (UHI) clusters being spatially homogeneous. The landscape spatial heterogeneity in urban across UHI clusters challenges us to more accurately characterize the relationships between LST and corresponding urban biophysical composition. In this study, we introduced an innovative integrated approach that combined object-oriented image segmentation with local indicators of spatial autocorrelations (LISA) to extract UHI clusters from an LST image. We used a regression tree model to examine the nonlinear relationships between LST and each of three satellite-based indices within the UHI clusters: normalized differential vegetation index (NDVI), normalized differential build-up index (NDBI), and normalized difference bareness index (NDBaI). We found that both NDVI and NDBI are strongly correlated with the variations of LST whereas NDBaI has a weaker correlation with LST. We also found that the regression tree model built in this study enabled us to effectively detect the nonlinear relationship between LST and biophysical composition. Furthermore, based on a set of rules derived from a regression tree analysis, we found that urban landscapes strongly affect LST and its spatial heterogeneity within a UHI. These rules were used to detect the nonlinear impacts of complex urban biophysical composition on LST. The results of this study provided insights into how LST within UHI varies with urban surface characteristics at fine spatial scale and also a new method for investigating effects of land surface composition on LST in urbanized areas.

1. Introduction

Urbanization is considered to be one of the most evident aspects of human impacts on the earth in terms of greenhouse gas emissions and land use changes (e.g., road and building construction), both of which can in turn affect daily mean surface temperature (Gallo & Owen, 1999; Owen, 1998). It is well documented that urban centers experience higher temperature than surrounding

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suburban/rural areas, and this phenomenon is known as the urban heat island (UHI) (Voogt & Oke, 2003). Traditionally, UHI was often identified using in-situ weather station networks or mobile measurements of the urban canopy layer (Li et al., 2011). With the development of remote sensing (RS) technology, RS-based data – such as surface radiative temperatures derived from remote imagery thermal bands – are increasingly used to examine UHI. RS-based technology enables us to thoroughly characterize LST distribution in urban areas and thus contribute us to explicit revealing spatial patterns and variations of UHI although LST only provides a snapshot of temperature during the day (Li et al., 2011). As a result, RS-based LST have been widely used to examine the relationship between UHI and surface biophysical parameters (e.g., Weng, 2009; Arnfield, 2003).

Previous studies that focused on the relationship between urban thermal behavior and landscape patterns indicated that LST is strongly subject to both the composition and configuration of land cover/use (Buyantuyev & Wu, 2010; Li et al., 2011; Weng, Liu, & Lu, 2007; Zhou, Huang, & Cadenasso, 2011). RS-based urban surface biophysical composition – such as vegetation abundance, impervious surface and soil fractions – were found to be the best indicators of LST variations across space (Deng & Wu, 2013; Xiao et al., 2007; Zhang, Odeh, & Han, 2009). The relationship between biophysical composition and LST also varies with seasons and is thought to be nonlinear (Chen, Zhao, Li, & Yin, 2006; Owen, Carlson, & Gillies, 1998). Based on landscape metrics derived from different LST zones, Liu and Weng (2008) found that the seasonal variations in landscape pattern was correlated with LST. Buyantuyev and Wu (2010) linked LST variations with changes in land covers as well as socioeconomic features (i.e., family income, population density and age). Nevertheless, the results from these studies were based on urban-wide scale and ignored the spatial heterogeneity of compositions and configurations of urban landscapes at fine spatial scales. The neglect of spatial heterogeneity of urban landscapes across space is likely to disable these studies to accurately predict LST variations through space and time. Given the spatial heterogeneity and nonlinear interactions among urban ecological systems (Wu & David, 2002) and their significance for urban landscape management and planning, it is essential to improve our understanding of the relationship between urban thermal behavior and its surface biophysical composition at fine spatial scales.

Therefore, the objectives of this study are to (i) introduce an integrated and object-oriented segmentation approach for extracting the UHI clusters from LST image, (ii) quantify the relationship between LST and each of three urban biophysical compositions, and (iii) explore the spatial heterogeneity of LST in UHI clusters. To achieve these ends, we selected the center of Guangzhou in China, an area characterized by strong spatio-temporal variability in UHI, as the study region. Specifically, we focused on UHI clusters in the Central Urban Districts of Guangzhou City to investigate impacts of three selected urban biophysical compositions (i.e., NDVI, NDBI, and NDBaI) on LST in UHI clusters. The results from this study will improve our understanding of how LST varies across urban landscapes at fine spatial scale characterized by different surface conditions.

2. The study site

Guangzhou is the capital of Guangdong province of China. It is situated on the broad flat alluvial plain of the Pearl River Delta of southern China, and has a total area of approximately 7434.40 km^2 (Fig. 1). The climate condition in Guangzhou is characterized by the typical subtropical monsoon maritime climate of Southern Asia, with annual mean temperature about 23.2 °C and maximum temperature about 38.7 °C (based on long-term climate records from the Wushan weather station that is located at 23.17°N and 113.33°E and operated by Guangzhou Meteorological Bureau). Guangzhou has been one of the fastest urbanizing cities in China since the 1980s and its GDP reached 1.35 trillion RMB in 2012, a 10.5% increase compared to that in 2011. The population in the core

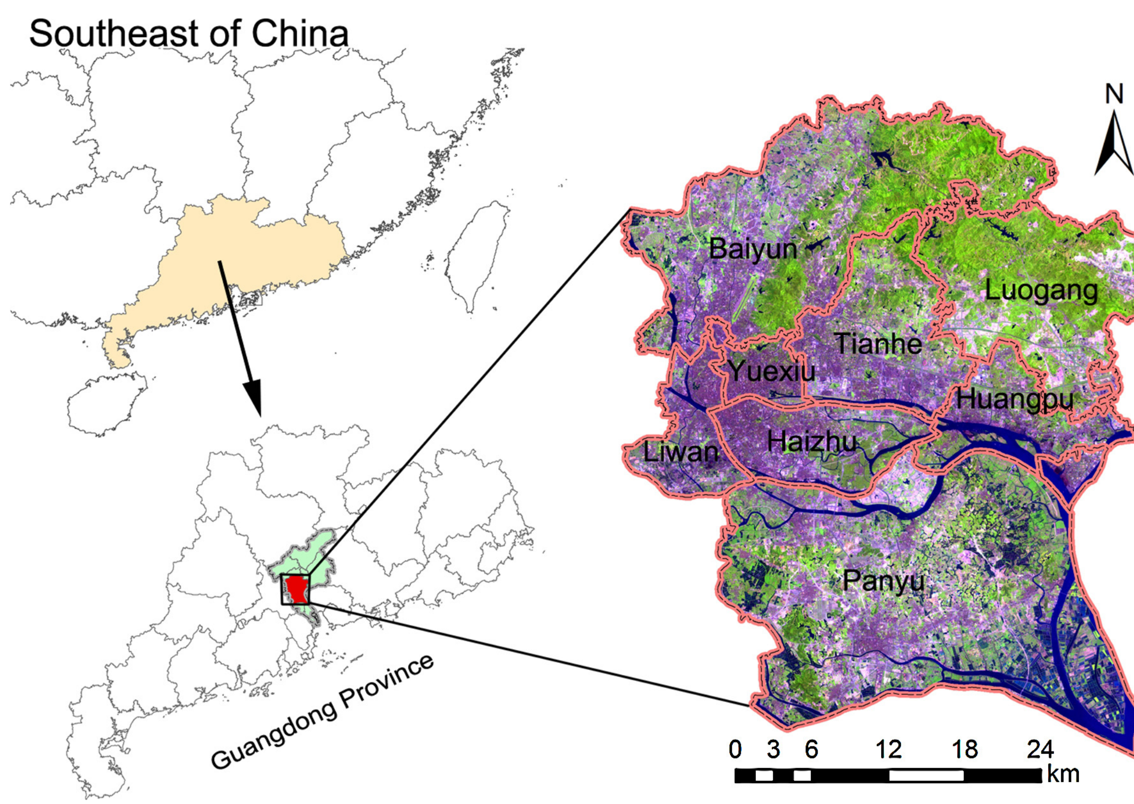

Fig. 1. Geographic location of the Guangzhou Central Urban Districts.