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Temporal trends of surface urban heat islands and associated determinants in major Chinese cities

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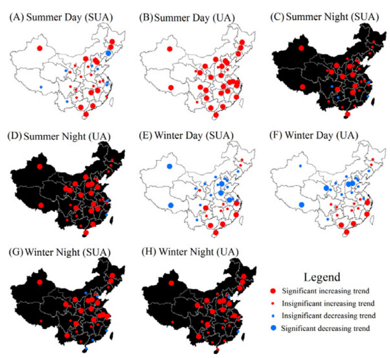
HIGHLIGHTS

- It is first time to study the temporal trends of SUHI at national scale.
- The surface urban heat island is intensifying in China.
- SUHII in SUA and UA was correlated with LST and urbanization, respectively.

GRAPHICAL ABSTRACT

Temporal trends of surface urban heat island intensity in China during 2001–2015. SUA: stable urban area. UA: urbanized area.



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ABSTRACT

There are many studies focusing on spatial variations of surface urban heat islands (SUHIs) in literature. In this study, MODIS land surface temperature (LST) data and China's Land Use/Cover Datasets (CLUDs) were used to examine the temporal trends of SUHIs in 31 major Chinese cities during 2001–2015 using three indicators: SUHI intensity (SUHII), area of the SUHI ($Area_{SUHI}$) and percentage of area with increasing SUHII (PAISUHII). Correlation analyses between SUHII and background (rural) LST (extracted from MODIS LST), vegetation coverage (reflected by MODIS EVI data) and anthropogenic heat release (reflected by nighttime light data) were performed from temporal rather than spatial perspectives. Our findings showed that the SUHII and $Area_{SUHI}$ in urbanized areas increased significantly in most cities in summer days, whereas they increased significantly in approximately half and more than half of the cities in summer and winter nights, respectively. In summer days, summer nights and winter nights, the PAISUHII was approximately 80% and over 50% in union areas and the 20 km buffer, respectively. Correlation analyses indicated that the SUHII in stable urban areas was negatively correlated with the background LST in summer and winter days for most cities, especially in northern China. A reduction in vegetation contributed to the increasing SUHII in urbanized areas in summer days and nights. The increasing anthropogenic heat release was an important factor for increases in the SUHII in urbanized areas.

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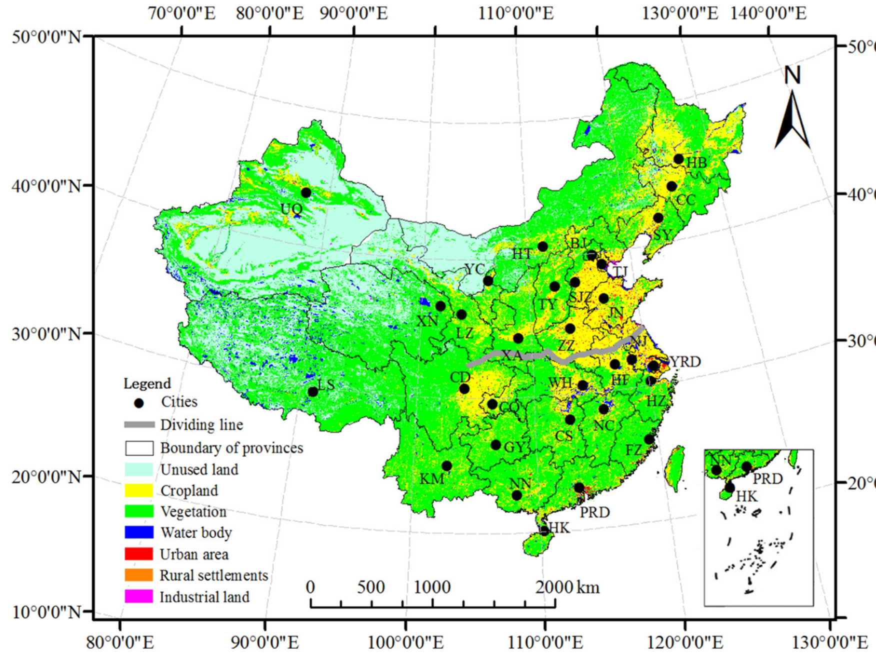

Fig. 1. The 31 selected Chinese cities in this study. The northern cities included Harbin (HB), Changchun (CC), Urumqi (UQ), Shenyang (SY), Hohhot (HT), Beijing (BJ), Tianjin (TJ), Yinchuan (YC), Shijiazhuang (SJZ), Taiyuan (TY), Jinan (JN), Xining (XN), Lanzhou (LZ), Zhengzhou (ZZ) and Xi'an (XA). The southern cities included Nanjing (NJ), Yangtze River Delta (YRD), Heifei (HF), Hangzhou (HZ), Wuhan (WH), Chengdu (CD), Chongqing (CQ), Nanchang (NC), Changsha (CS), Fuzhou (FZ), Guiyang (GY), Kunming (KM), Nanning (NN), Pearl River Delta (PRD) and Haikou (HK). Another city was Lhasa (LS). The background map was the China's Land Use/Cover Datasets (CLUDs) in 2010.

1. Introduction

Urbanization is accelerating all over the world. The urban population accounted for 30% and 54% of the total world population in 1951 and 2015, respectively, and this percentage is expected to reach 60% by 2030 (United Nations, 2014). Urbanization can cause a series of environmental issues that have profound impacts on human life, including the urban heat island (UHI) effect, which is defined as a higher temperature in urban areas than in rural areas (Peng et al., 2012; Zhou et al., 2015). This phenomenon can be attributed to: a) the increases in impervious surfaces can lead to the transformation from latent heat flux into sensible heat flux; b) the low albedo and high heat storages of urban roads and buildings; c) anthropogenic heat release. The UHI effect can influence human life by increasing the risk of exposure to health-threatening heat (Zhou et al., 2015) and energy consumption (Akbari et al., 2015), and it can also reduce water and air quality (Grimm et al., 2008; Zhou et al., 2014), change land surface phenology (Zhou et al., 2016c; Yao et al., 2017) and decrease net primary production (Chen et al., 2017; Imhoff et al., 2004). Therefore, both the magnitude and temporal trends of UHIs must be comprehensively studied.

UHIs include atmospheric UHIs monitored by weather stations and surface UHIs (SUHIs) estimated by remote sensing (Zhou et al., 2014). Although the atmospheric UHIs is more closely related to human health, Both types of UHIs are still highly related (Arnfield, 2003; Zhou et al., 2016b). The use of remote sensing to monitor SUHIs has attracted increasing attention around the world in recent decades because of its free access and broad spatial coverage. Studies have used Landsat TM/ETM+ to study the time series of SUHI in a single city because of the high spatial resolution and long time series of products, and results have indicated that the SUHI has been intensifying or expanding in certain cities of China, including Beijing (Qiao et al., 2014), Shanghai (Zhao et al., 2016), Nanjing (Tu et al., 2016), Wuhan (Shen et al., 2016) and Lanzhou (Pan, 2015). Studies have also used MODIS land surface temperature (LST) data to study the spatiotemporal variations of SUHIs at regional or global scales (Clinton and Gong, 2013; Peng et al., 2012; Wang et al., 2015a; Zhou et al., 2016a; Zhou et al., 2014; Weng et al., 2014). The results of such studies have indicated that SUHIs were characterized by large spatial, diurnal and seasonal heterogeneity. For example, Peng et al. (2012) studied the SUHI intensity (SUHII, temperature difference between urban and rural areas) in 419 large cities worldwide for the period 2003–2008, and the results showed that the daytime SUHII was higher than the nighttime SUHII (1.5 ± 1.2 °C vs. 1.1 ± 0.5 °C, $p < 0.01$). Zhou et al. (2014) and Wang et al. (2015a) investigated the SUHII in 32 major Chinese cities for the period 2003–2011 and 67 large Chinese cities for the period 2003–2010, respectively, and results showed that the daytime SUHII was higher in summer and lower in winter while the nighttime SUHII was relatively stable across seasons. The daytime SUHII in southern cities was higher than that in northern cities, although the opposite occurred at night. Zhou et al.

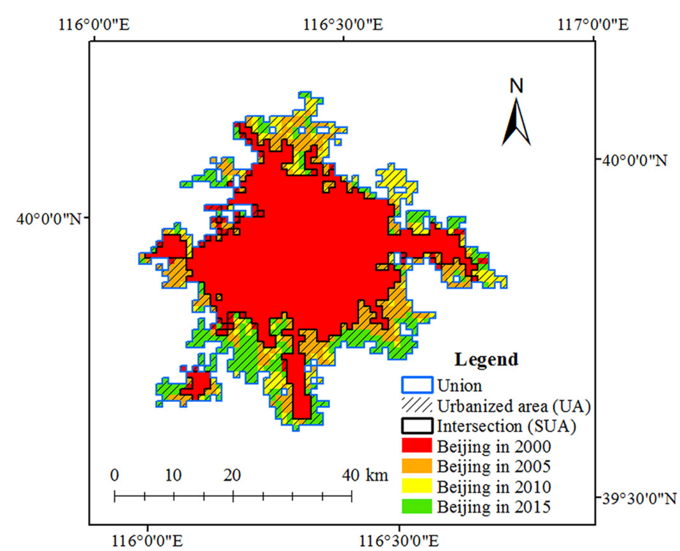

Fig. 2. The schematic diagram of old urban areas (SUAs) and urbanized areas (UAs), using BJ as an example. The background maps were CLUDs in 2000 (red), 2005 (orange), 2010 (yellow), 2015 (green). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)