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Less sensitive of urban surface to climate variability than rural in Northern China

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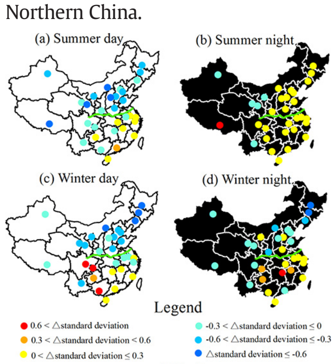
HIGHLIGHTS

- SUHII in summer days and winter days was significantly negatively correlated with background LST
- The SUHII generally decreased in hot summers, while increased in cold winters
- The standard deviations were used to reflect the interannual stabilities of LST, EVI and WSA
- Urban LST, EVI and WSA (in winter) were generally more stable than in rural areas.

GRAPHICAL ABSTRACT

The land surface temperature in summer days and winter days in urban cores was more stable than rural in Northern China.



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ABSTRACT

In this study, the relationships between interannual variations of surface urban heat islands (SUHIs) and climate variability were studied in 31 cities of China for the period 2001–2016. For cold and dry Northern China, it was found that the interannual variations of SUHI intensity (SUHII, land surface temperature (LST) in urban minus rural) in urban cores was significantly ($p < 0.05$) and negatively correlated with rural LST in 9 (in summer days (SDs)) and 8 (in winter days (WDs)) of the 15 northern cities, respectively. In addition, the daytime LST differences between hot summers and other summers and between cold winters and other winters were generally lower in urban cores (1.141 °C for SDs and 2.535 °C for WDs) than in rural areas (1.890 °C for SDs and 3.377 °C for WDs). The standard deviation was further used to reflect the interannual stabilities of LST, enhanced vegetation index (EVI) and white sky albedo (WSA). Interestingly, the standard deviations of LST across 2001–2016 were generally lower in urban cores (0.994 °C for SDs and 1.577 °C for WDs) than in rural areas (1.431 °C for SDs and 2.077 °C for WDs). Similar results were observed for EVI and WSA (winter). The results suggested that the urban surface is less sensitive to climate variability than rural areas in Northern China. Comparatively, most findings were less evident in hot and humid Southern China. Despite the whole world would become warmer or colder in future, the insensitivity of urban surface may mitigate its impacts in cold and dry Northern China. However, it does not mean that urbanization is totally good due to its environmental problem.

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1. Introduction

One of the important issues that human being is facing is the rapid urbanization, especially in developing countries (United Nations, 2014). A major effect of urbanization is urban heat island (UHI), which refers to higher temperature (including both land surface and air temperatures) in urban area than in rural surrounding and is a prevalent phenomenon that has been observed in hundreds of cities (Peng et al., 2012; Santamouris, 2015). UHIs has many negative impacts on human beings and surface environment: a) it can affect human health, for example, increasing the natural mortality (Goggins et al., 2012; Mohan and Kandya, 2015); b) it can increase energy consumption by increasing cooling needs in summer (Akbari et al., 1992); and c) it can reduce air and water quality (Grimm et al., 2008). Thus, it is necessary to comprehensively study the UHI, including its magnitude, spatiotemporal variations and driving forces.

Another important problem that human being is facing is climate change. It is generally believed that the earth surface is warming (Brown et al., 2017; Sun et al., 2016; Huang et al., 2017a, 2017b; IPCC, 2015). However, the earth may cool in the future due to reductions in solar activities (Shepherd et al., 2014; Landscheidt, 2003; Nevett, 2016). Although future climate change remains controversial, both extreme high and low temperatures have negative impacts on human beings, for example increasing mortality and energy consumption (Kolokotroni et al., 2012; Linares et al., 2015; Schatz and Kucharik, 2015). Therefore, both climate and UHI can significantly alter the urban thermal environment, and have negative impacts on human society, it is important to systematically study the relationships between them.

However, the relationships were still poorly understood at a regional scale. Certain studies analyzed the relationships between UHI and heatwaves using in situ data or model simulations in single city or a few cities in a small region, the results indicated that the UHI intensity (UHII, urban temperature minus rural) was enhanced by heatwaves, especially at night (Founda et al., 2015; Li et al., 2016; Li et al., 2015; Ramamurthy and Bou-Zeid, 2017; Ramamurthy et al., 2015). For example, Founda et al. (2015) showed a significant amplification of nighttime UHII under heat waves in Athens (Greece); Ramamurthy and Bou-Zeid (2017) showed that the UHII was amplified more strongly during heat waves in bigger cities (e.g. New York City, 2 °C) compared to smaller cities in Western United States. Detailed studies for a large area and across different climate regions are needed. Additionally, few studies have analyzed the relationships between UHI and climate in winter. Schatz and Kucharik (2015) showed that the air UHII in winter was negatively related to the daily minimum temperature in Madison (USA), similar results were found in Northern China according to Yao et al. (2017c), however, they did not find the detailed reasons. Furthermore, data from weather stations have some disadvantages in terms of studying the UHI: a) weather stations are spatially scarce and air temperature data from one or few stations cannot be used to represent the whole city; and b) it is hard to choose a reference rural station that immune to UHI, since most stations are located in urban areas (Sun et al., 2016; Wang F. et al., 2015a; Yao et al., 2017b).

Satellite remote sensing provides a new and objective way to monitor the UHI. It has wide spatial coverage and can cover the whole city. The UHI monitored by satellite remote sensing is called surface UHI (SUHI) since satellite data reflect heat information of land surface. Moderate Resolution Imaging Spectroradiometer (MODIS) LST data have wide coverage and can be easily used to study the UHI at national and continental scales (Imhoff et al., 2010; Wang J. et al., 2015b; Ward et al., 2016; Zhou et al., 2015, 2016a, 2016b), which overcomes the drawback (strait coverage) of traditional methods (in situ measurement and model simulation). For instance, Peng et al. (2012) showed that the SUHI intensity (SUHII, urban LST minus rural) is positive in 92% and 95% of the 419 global big cities for daytime and nighttime, respectively.

China has large temperature and precipitation gradients since it covers a large area for about 9.6 million km^2. In addition, China has undergone rapid urbanization in terms of population growth (United Nations, 2014) and urban expansion (Kuang et al., 2016). All of these make China an ideal region to study the SUHI and its relationships with background climate variability. Thus, this study aims at: a) exploring the correlations between interannual variations of SUHII and climate variability in 31 cities in China for the period 2001–2016; b) analyzing the SUHII and LST changes in hot summers and cold winters; c) studying the stabilities of LST, enhanced vegetation index (EVI) and white sky albedo (WSA) in urban and rural areas. The main novel elements of this study includes: a) systematically analyzing the relationships between SUHII and climate variability for a large area and across different background climate zones; b) comprehensively studying the relationships between SUHII and climate in winter; and c) revealing an interesting characteristic of urban surface: the stabilities of LST, EVI and WSA.

2. Data

In this study, the experiments were performed in Yangtze River Delta urban agglomeration (including Shanghai, Suzhou, Changzhou and Wuxi), Pearl River Delta urban agglomeration (including Shenzhen, Dongguan, Guangzhou, Foshan, Zhongshan, Zhuhai, Xianggang and Jiangmen) and other 29 municipalities or provincial capitals (Fig. 1) (Yao et al., 2017c). Due to different geographical locations and climate, the whole China was divided into southern part (including 15 cities, humid climate) and northern part (including 15 cities, semi-humid, semi-arid and arid climate) using Qinling Mountain-Huaihe River Line (Wang J. et al., 2015b). Because of its special location (away from the Qinling Mountain-Huaihe River line) and plateau climate, Lhasa was not classified into any of them (Fig. 1) (Yao et al., 2017c).

China's Land Use/Cover Datasets (CLUDs, produced from Landsat TM/ETM+ and HJ-1A/1B imagery using human-computer interactive interpretation) in the year 2000, 2005, 2010 and 2015 were used to delineate urban and rural areas in this study. The CLUDs have many advantages, for example, high spatial resolution (30 m), high overall accuracy (over 90%) and long time series (5-year interval since the late 1980s). Detail information (e.g. data processing and accuracy assessment) can be found in Liu et al. (2010), Liu et al. (2014) and Kuang et al. (2016).

Terra MODIS LST data (MOD11A2, 8-day composite, 1 km spatial resolution, version 6, for the period 2001–2016) was used to extract LST in this study. The LST data was retrieved using generalized split-window algorithm and improved by correcting noise due to topographic differences, cloud contamination, and zenith angle changes. The accuracy of this data had been widely validated in a wide range (−10 to 58 °C) and different land cover types (Wan, 2008, 2014). This data had been widely used to study the SUHI (Imhoff et al., 2010; Peng et al., 2012; Zhang et al., 2014; Zhou et al., 2014; Wang J. et al., 2015b; Ward et al., 2016; Yao et al., 2017c). Vegetation information was quantified by MODIS MOD13A3 EVI data (1 km spatial resolution, monthly composite, version 6, for the period 2001–2016), with higher value representing higher vegetation activity (pixels with negative value were considered as water bodies and excluded in this study). In addition, albedo information was derived from MCD43B3 shortwave WSA data (1 km spatial resolution, 8-day composite, version 5, for the period 2001–2016), respectively. Finally, precipitation data for the period 2001–2015 from weather stations (obtained from China Meteorological Administration) in and around the city were used in the present study (Fig. 1). EVI and WSA data had been widely validated and used by previous studies (Liang et al., 2002; Huete et al., 2002; He et al., 2012; Peng et al., 2012; Zhou et al., 2014).

3. Methods

Fig. 3 shows the flow chart of the methodologies in this study. The CLUDs were first merged into three broad types: built-up area