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Original Articles

The influence of different data and method on estimating the surface urban heat island intensity

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ABSTRACT

Few studies have examined the influence of different data and method on estimating the SUHIs. This study aims at analyzing the impact of different method (to define rural area) and different data (MODIS Terra and Aqua satellite data) on estimating the SUHI intensity (SUHII, LST in urban minus rural reference) in 31 cities of China. The major findings include: (1) For SUHII, ignoring the influence of elevation and water body will overestimate the SUHII by 1.68 °C (averaged for 31 cities, hereafter) and 0.28 °C, respectively, in summer days (SDs). Using nearby suburban area as reference will underestimate the SUHII by 1.48 °C in SDs. Different data and method have smaller impact on estimating the SUHII in summer nights (SNs) than in SDs. (2) For spatial variation of SUHII, ignoring the influence of elevation will influence the spatial variation of SUHII in SDs ($r = 0.3$, $p > .05$), but other methods have little impact on estimating the spatial variation of SUHII. (3) For interannual variation of SUHII, using nearby suburban area will underestimate the increasing rate of SUHII (SD: 0.106 °C/year, SN: 0.012 °C/year), whereas ignoring the influence of elevation and water body have little influence on the changing rate of SUHII. The changing rates of SUHII in SDs monitored by Terra satellite were 0.025 °C/year lower than Aqua satellite. In all, the present study can enhance our understanding of the influence of different data and method on estimating the SUHII, and provide a useful reference to study the SUHII.

1. Introduction

Urbanization is accelerating around the world and brings a large amount of natural and social problems, for example, urbanization can lead to higher temperature in urban area than the nearby rural area. This phenomenon is called urban heat island (UHI), which can bring a series of negative effects to human beings (e.g. influencing the human health (Goggins et al., 2012; Mohan and Kandya, 2015) and increase energy consumption (Akbari et al., 2015)) and surface ecological environment (e.g. changing land surface phenology (Yao et al., 2017b; Zipper et al., 2016) and damaging water and air quality (Grimm et al., 2008)). Therefore, UHI studies contribute to many fields, including atmospheric environment, ecology, natural landscape, architecture and climatology, which has attracted more and more attentions from general public and scientific experts in recent decades (Li et al., 2017a; Luo and Lau. 2017; Sun et al., 2016; Wang et al., 2015a, 2016b; Zhou et al. (2017a,b).

Generally, there are two kinds of UHIs: The first one was air UHI, which was detected by *in situ* data (including within and above the canopy layer) (Chen and Frauenfeld, 2015; Ren et al., 2008; Wang et al., 2015a). However, the measured data from weather stations have many limitations for estimating the UHIs. Firstly, the stations are sparsely distributed and cannot completely reflect the UHIs for a whole city (Zhou et al., 2014b). Secondly, most stations are located in urban area and it is difficult to select rural stations that have not been affected by UHIs (Wang et al., 2015a). Thirdly, the high-quality data from weather stations are not available for all users (Wang et al., 2015b). The second one was called surface UHI (SUHI), which was observed by remote sensing products. Because of the full and wide coverage, open and easy access, more researchers began to study the UHIs using remote sensing technology. Due to the high temporal resolution (four times per day by two satellite), MODIS land surface temperature (LST) data has been used to study the SUHIs worldwide in recent years (Bounoua et al., 2015; Du et al., 2016; Imhoff et al., 2010; Peng et al., 2012; Tran et al., 2006; Wang et al., 2015b, 2016; Yao et al., 2017a; Zhou et al., 2014b).

An important parameter for studying SUHI was SUHI intensity (SUHII), which was calculated as the LST in urban minus rural (Du et al., 2016; Peng et al., 2012; Wang et al., 2015b; Zhou et al., 2014b), therefore, it is necessary to select reliable rural references. However, the methods to define the rural area varied greatly in different studies.

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Most studies calculated the SUHII between urban and nearby suburban area (Clinton and Gong., 2013; Du et al., 2016; Li et al., 2017b; Liao et al., 2017; Peng et al., 2012; Shastri et al., 2017; Wang et al., 2015b; Zhao et al., 2016; Zhou et al., 2014b), whereas some studies calculated the SUHII between urban and far rural areas (Imhoff et al., 2010; Yao et al., 2017a–c; Zhang et al., 2014; Zhou et al., 2016b). Actually, some studies showed that LST decreased gradually with rising distances from urban area and the spatial extent of SUHIs was much greater than the actual size of urban area (Han and Xu. 2013; Yao et al., 2017b; Zhang et al., 2004; Zhou et al., 2015) and using nearby suburban area as references may underestimate the SUHII (Zhou et al., 2016a, 2015). In addition, it was necessary to exclude the impact of water body and elevation on LST when calculating the SUHII (Haashemi et al., 2016; Imhoff et al., 2010; Zhou et al., 2016a), but many studies have ignored this point, for example, Zhang et al. (2014) and Wang et al. (2015b) did not exclude the influence of water body, and almost all studies ignored impact of elevation when using nearby suburban area (Clinton and Gong., 2013; Du et al., 2016; Li et al., 2017b; Liao et al., 2017; Peng et al., 2012; Wang et al., 2015b; Zhao et al., 2016, 2014b). Therefore, the SUHII results may vary substantially in different cases, for example, Peng et al., (2012) used nearby suburban areas as references to study the SUHII and the results indicated that the mean summer SUHII during 2003–2008 averaged for 419 global big cities were 1.9 °C and 1.0 °C for daytime and nighttime, respectively; Zhang et al. (2014) used 15–20 km buffer as rural area and the mean summer SUHII during 2003–2005 averaged for more than 3000 global cities were 2.6 °C and 1.6 °C for daytime and nighttime, respectively. There are large differences of SUHII for above studies, therefore, it was necessary to comprehensively analyze the impact of different methods in estimating SUHII at regional scale.

In addition, MODIS LST data can be obtained from two satellites: Terra and Aqua. Some studies used the Terra satellite to analyze the SUHIs (Bahi et al., 2016; Du et al., 2016; Gawuc and Struzewska., 2016; Morabito et al., 2016; Wang et al., 2016a; Yao et al., 2017a–c), whereas other studies used the Aqua satellite (Imhoff et al., 2010; Peng et al., 2012; Wang et al., 2015b; Zhao et al., 2016; Zhou et al., 2016a, 2014b, 2015). Previous study showed that the daytime SUHII monitored by Aqua satellite was higher than the Terra (Clinton and Gong. 2013), but the impact of different data on estimating the spatiotemporal variations of SUHII remain unclear.

Therefore, to solve the above mentioned problems and fill the current research gaps, a series of experiments were performed in this study. Different methods (to define rural area) used by previous studies were first analyzed and an appropriate method was selected. The influence of different data and method on estimating the SUHII and spatiotemporal variations of SUHII were also examined. The order of the rest paper is organized as follows. Section 2 describes the study area, data and method in this study. Section 3 shows the main results of the influence of different data and method on estimating the SUHII. The discussion and conclusions are presented in Section 4 and 5, respectively.

2. Data and methods

2.1. Data

In this study, the 31 major cities in China were selected as study area because of the rapid urbanization and large variations in background climate and topography (Fig. 1). The 31 cities include 29 municipalities or provincial capitals, Pearl River Delta urban agglomeration (including Guangzhou, Shenzhen, Hongkong, Zhongshan, Dongguan, Foshan, Zhuhai and Jiangmen) and Yangtze River Delta urban agglomeration (including Shanghai, Wuxi, Suzhou and Changzhou). China has experienced rapid urbanization and socioeconomic development in recent decades (Liu et al., 2010, 2012), the total urban area in China increased from $4.85 \times 10^4\,km^2$ in 1990 to $9.08 \times 10^4\,km^2$ in 2010 according to Kuang et al. (2016), and the total urban population in China increased from 308 million in 1990 to 779 million in 2015 (United Nations, 2014). Deterioration of urban environment was observed in China in recent years (He et al., 2017; Yao et al., 2017c; Zhou et al., 2014a).

In this study, China's Land Use/Cover Datasets (CLUDs, derived from Landsat TM/ETM+ and HJ-1A/1B imagery, 5-year interval) for the year 2000, 2005, 2010 and 2015 were used to extract the urban and rural areas. The CLUDs were characterized by high spatial resolution (30 m), detailed classification (25 land cover types), high accuracy (overall accuracy was higher than 90% for the 25 land cover types) and wide coverage (for the whole China). Detailed information on the CLUDs can be found in Liu et al. (2010, 2014) and Kuang et al. (2016).

LST was obtained from MOD11A2 (Terra satellite, 8 day composite, 1 km spatial resolution, at 10:30 am and 10:30 pm local solar time, 2003–2016) and MYD11A2 data (Aqua satellite, 8 day composite, 1 km spatial resolution, at 1:30 am and 1:30 pm local solar time, 2003–2016) (Haashemi et al., 2016; Yao et al., 2017a). Both MOD11A2 and MYD11A2 have advantages: the MOD11A2 data have longer time series (available since 2000) than MYD11A2 (available since 2002); the monitoring time of MYD11A2 is closer to the time of occurrence of the highest and lowest temperature in the diurnal cycle than that of MOD11A2 (Clinton and Gong, 2013). In addition, the vegetation activity was quantified by the enhanced vegetation index (EVI) using MOD13A3 data (monthly composite, 1 km spatial resolution) (Liu et al., 2015; Wang et al., 2015b). The higher EVI represents higher vegetation coverage.

2.2. Methods

MODIS data (MOD11A2, MYD11A2 and MOD13A3) was first reprojected (to Albers Equal Area projection) and moisacked using MODIS Reprojection Tool (MRT). MOD11A2 data monitored at 10:30 am and 10:30 pm were used to represent the LSTs in daytime and nighttime, respectively. MYD11A2 data detected at 1:30 pm and 1:30 am were used to represent the LSTs in daytime and nighttime, respectively. We only studied the SUHII in summer since the SUHII was generally higher in summer than in other seasons (Peng et al., 2012; Wang et al., 2015b; Zhou et al., 2014b) and the UHIs in summer has the largest impact on human lives (Goggins et al., 2012). Therefore, this study mainly focused on two time periods: summer day (SD) and summer night (SN).

The CLUDs were first combined into three major types: built-up area (urban area, industrial land and rural settlement), water body and other types. Then we used a moving window method to calculate the urban development intensity (UDI, defined as the proportion of built-up area in each 1 km × 1 km pixel (Zhou et al., 2016a)) and proportion of water body (PWB, defined as the proportion of water body in each 1 km × 1 km pixel) maps. Finally, the areas with UDI more than 50% were aggregated with aggregation distance of 2 km to generate urban area (Liao et al., 2017; Zhao et al., 2016; Zhou et al., 2014b).

A total of 5 different methods were used in this study, including 4 different methods to define rural area according to previous studies (Table 1 and Fig. 2). Method 1 and Method 2 used the same method to define rural area but different data (Table 1). Rural areas in Method 1 and 2 were defined as Rural 1. Rural areas in Method 3, 4 and 5 were defined as Rural 2, 3 and 4, respectively (Table 1 and Fig. 2). The Rural 1 was generated in two steps. Firstly, we produced 20–25 km buffer based on the generated urban area previously. Secondly, the pixels meeting one of the following requirements were excluded from the 20–25 km buffer: a) UDI higher than 5%; b) classified as water body; and c) elevation outside the range of elevation of urban areas ± 50 m (Table 1). The resultant area was defined as Rural 1. The methods to define Rural 2, 3 and 4 can be found in Table 1. Note that the 20–25 km buffer was according to previous studies (Zhou et al., 2016c; Yao et al., 2017a,c), since the SUHI's footprint was much greater than the urban area size (Han and Xu. 2013; Yao et al., 2017b; Zhang et al., 2004; Zhou