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Urbanization effects on heat waves in Fujian Province, Southeast China

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ABSTRACT

Heat waves (HWs) exert increasingly profound effects on public health and ecosystems under global warming and regional urbanization. This study examines the changes in the frequency, duration, magnitude, and timing of HWs in Fujian, Southeast China during 1971–2014 and quantifies the possible effects of urbanization using a dynamical classification scheme for urban and rural stations. Considering that some rural stations could have been converted into urban types during the urbanization process, this scheme dynamically classifies urban and rural stations based on time-varying land use/cover maps in different subperiods, thus giving a better estimation of urbanization effects.

Our results show that HWs in Fujian are commencing earlier and ending later, and becoming more frequent, more intense, longer lasting. Particularly, severe (i.e., stronger and longer-lived) HW events have even stronger intensifying trends than regular ones. Moreover, we notice that the intensifying HW activities are especially prominent in densely populated and highly urbanized areas of Fujian. It is estimated that urbanization contributes to approximately half of the increasing HWs. Urbanization induces an additional increase of 0.15 events (3.78 days) per decade to HW frequency (participating days), accounting for 40.3% (57.5%) of the total trend. Meanwhile, 50.4% (60.8%) of the prolonging trend in the average (longest) duration and 27.0% (65.0%) of the intensifying trend in the average (strongest) magnitude are attributable to urbanization, i.e., 1.71 (1.19) days per decade and 0.18 (0.08) °C per decade, respectively. Moreover, urbanization induces further advancing (delaying) trend of 1.37 (1.39) days per decade for the onset (ending) date of HW in the calendar year. The findings presented here uncover the multi-faceted behaviors of HW and advance the existing research by providing a broader picture of this extreme event. It is also recommended to consider these various HW aspects in the research of climate change and extreme climate events.

1. Introduction

Heat wave (HW) is an extreme event that seriously threatens human and natural systems (Easterling et al., 2000b; Meehl and Tebaldi, 2004). With global warming, the HW activities in many parts of the world have been intensifying during the past decades and are projected to increase and pose increasingly severe threats to society in the future (Kunkel et al., 2010; IPCC, 2012, 2013; Cowan et al., 2014; Luo and Lau, 2018). The study on the long-term change of HWs is significant to detect the attribution of global and regional climate change and to assess the impacts of climate change on human society and natural systems.

China has been severely suffering from HWs and extremely high temperatures (Ding et al., 2010; Lu and Chen, 2016; Luo and Lau, 2017). 5758 HW-related illness cases have been reported during the summer of 2013 in China (Gu et al., 2015). Many studies have documented the warming trends in China during last decades (Ren et al., 2005; Liu et al., 2006; Zhang et al., 2011; Sun et al., 2016a; Wen et al., 2017; You et al., 2017). For instance, Ren et al. (2005) suggested that the mean temperature in China has increased by 0.22 °C decade^{-1} during 1951–2002. Cool nights (days) decreased by 28.23 (23.26) days decade^{-1} and warm nights (days) increased by 8.16 (5.22) days decade^{-1} (Zhou and Ren, 2011). These intensifying trends are particularly prominent in highly urbanized areas such as the North China (Ren et al., 2008; Wang et al., 2013; Zhang et al., 2015), the Yangtze River Delta (Gu et al., 2011; Guan et al., 2015), and the Pearl River Delta (Fischer et al., 2012; Luo and Lau, 2017). Thus, urbanization has been considered as an important factor in China's warming.

Ren and Zhou (2014) estimated that the urbanization effects on the annual mean of daily minimum (T_{min}) and maximum temperature (T_{max}) in China are 0.07 and 0.023 °C decade^{-1}, respectively. Sun et al.

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(2016b) further estimated that urbanization accounts for around one-third of the total warming trend in eastern China during 1961–2013. It has also been found that around half of the increasing HW frequency in southern China is induced by urbanization (Luo and Lau, 2017). Specifically, urbanization contributes about 44% and 35% to the total warming in the metropolis and large city areas, respectively (Fischer et al., 2012). For instance, a simulation study showed that urbanization induces 0.74 °C warming in Hangzhou of eastern China (Chen et al., 2014).

These previous studies mainly focused on the effects of urbanization on daily temperatures and daily extremes but neglect the effects on HW, a consecutive (e.g., three or more days) extremely high-temperature event (Robinson, 2001; Radinović and Ćurić, 2012; Perkins and Alexander, 2013; Zuo et al., 2015; You et al., 2017). The urbanization effects on HW activity have yet to be fully understood. Moreover, existing studies examined the urbanization effect on local climate at national or subregional scales (e.g., the Yangtze River Delta), and no systematic study has been conducted on the impacts of urbanization at the provincial scale. Therefore, this study selects the case of Fujian Province in southeast China to examine the trend of HW and the influence of urbanization on HW activity, by considering the local specific context. Such an investigation is essential for provincial government and related departments to adapt and mitigate climate change.

Fujian is located a joint region connecting the Yangtze River Delta and the Pearl River Delta, the most populated and developed regions in China. Though Fujian's urbanization level is not high as these two regions, it has been experiencing fast urbanization during the past decades (Zhu, 2000; Shen and Lin, 2017). As one of the most densely urbanized and populated areas in China, Fujian had a population of 36.9 million in 2010 (Fujian Office for Population Census, 2013). The urbanization level of Fujian was 20% in 1980, and it kept sustained growth in the reform era and exceeded 57% in 2010 (Shen and Lin, 2017).

It remains unknown how HW in Fujian changed during the last decades and whether, or to what degree, urbanization process in Fujian contributed to the long-term trends of the HW activity. Therefore, the primary purpose of this study includes a) to examine the long-term changes of various aspects of Fujian's HW including frequency, duration, magnitude, and timing, and b) to quantify the effect and contribution of urbanization to these changes.

2. Data and methodology

2.1. Study region

Fujian Province is located in the southeast coastal area of China (Fig. 1a), with a total area of 124,000 km^2. Fujian is characterized by a typical tropical climate, with hot summer and mild winter (Fig. 3). Mean T_{min} in peak summer (i.e., June–September) is higher than 20 °C (Fig. 3), and high temperatures and HWs regularly occur in this season. The densest population density appears in the southeastern coastal area (Fig. 2a). As shown in Fig. 2b, there is also a clear contrast between coastal and inland areas in terms of development and urbanization (Zhu, 2000; Shen and Lin, 2017). Such uneven spatial variation of urbanization level may induce different secular trend of summer climate and extremes, as discussed in our following analyses.

2.2. Data

Daily observations of T_{min} over the period of 1971–2014 at 65 state-level meteorological stations in Fujian Province are collected from the China Meteorological Data Service Center at http://data.cma.cn. Fig. 1b presents a map showing the locations of these stations. Excluded stations comprise those with missing observations for more than three days in any summer season (i.e., June–September) of 1971–2014.

Urbanization is expressed as the urban built-up area fraction (BAF) derived from the land use/cover maps (Liu et al., 2014, 2017). The land use/cover maps of China are available at eight episodes, i.e., 1980, 1990, 1995, 2000, 2005, 2008, 2010, and 2013. These maps were generated through visual interpretations of the Landsat TM/ETM+ images with a spatial resolution of 30 m (Liu et al., 2014), as provided by the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (http://www.resdc.cn).

2.3. Definition of HW

HW can be defined by either daily T_{max} or T_{min} series (Radinović and Ćurić, 2012; Perkins and Alexander, 2013; You et al., 2017). Consecutive hot days with or without limited nighttime relief can profoundly influence the rates of excess mortality and morbidity (Karl and Knight, 1997; Meehl and Tebaldi, 2004; Hansen et al., 2008). Therefore, we select daily T_{min} to define HW events in this study. For the selected variable, HW can be defined based on either absolute or relative threshold [the comparisons between different HW definitions can be referred to Robinson, 2001, Radinović and Ćurić, 2012, Perkins and Alexander, 2013, and You et al., 2017]. In this study, we follow Lau

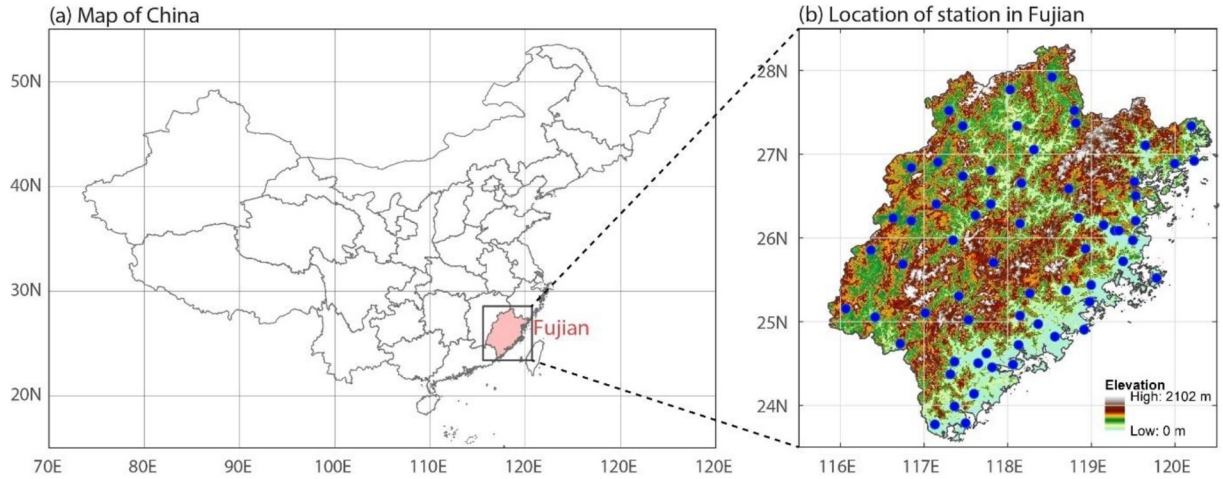

Fig. 1. Map of Fujian Province, Southeast China. Dots indicate the locations of weather stations. The pink shading in (a) denotes Fujian Province. Shading in (b) denotes elevation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)