The heterogeneity of urban thermal environment during summertime as observed by *in situ* and remotely sensed measurements

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1. Introduction

The well known phenomenon associated with urban thermal environment is urban heat island (UHI), which is urban areas are generally warmer than its surrounding rural areas. Currently, many studies have been conducted with a focus on general UHI intensity. However, landscape complexities over urban areas may result in non-uniformity of thermal environment. It is a critical question that whether the heterogeneity is inclined to highlight (be obvious) under heat extreme events. As projected, global warming resulted from the raise of anthropogenic greenhouse gases will possibly/likely increase the incidence, intensity, and duration of summertime heat wave events (IPCC, 2013; Meehl and Tebaldi, 2004). Urban area, which holds large amounts of wealth and population, with large energy consumption is potentially sensitive to these related changes (Adger et al., 2014; Fischer et al., 2012; Oleson, K., 2012; Uejio et al., 2011).

According to our previous investigation, thermal heterogeneity over urban areas was generally obvious under the condition of heat wave event, as measured by remotely sensed land surface temperature (LST), which suggests that proper and effective counter measures for heat wave events are location-dependent (Chen and Yang, 2014). However, due mainly to the uncertainties both in quality and quantity of the remotely sensed LST records, further investigation is necessary to be done more than the preliminary findings.

2. The abstract

To fully understand the thermal heterogeneity over urban areas at summertime, especially during heat wave event, hourly records of whether stations were primarily collected, in addition to the MODIS remotely sensed LST products and GHCN CAMS gridded land air surface temperature data. In this paper, specific attention is given to the case study of Shenzhen City in summer 2007, which is located in the South China and is characterized by rapid urbanization and developed economy (http://english.sz.gov.cn/gi/). Totally 140 automatic weather stations (AWSs) were primarily included. However, after checking the raw data, only 45 stations having full records of hourly air temperature were selected in August. By the way, only 6 stations have full records for July, and even no station has full records for June. Therefore, the main parts of this presentation are based on the hourly records of 45 stations in August 2007. Actually, over the South China, air temperature anomaly in August 2007 is less obvious than the situation in July, as recorded by MODIS LST and GHCN CAMS gridded land air surface temperature. The urban thermal heterogeneities over Shenzhen City are compared and discussed in view of the anomalies of LST and air temperature. The relationship between thermal heterogeneity and urban landscape complexity is desired to be investigated.

3. Data sets

3.1 AWS records

Totally 140 automatic weather stations (AWSs) were primarily included. However, after checking the data, only forty five stations provided with full records of hourly air temperature were selected in August. By the way, only 6 stations have full records for July, and even no station has full records for June. Forty five AWSs as well as the National Climate Station (No.59493) are finally selected. The underlying map in Fig. 1 is the World Topographic map service obtained from ESRI (www.arcgis.com). For these AWSs hourly temperature is provided, and for the National Climate Station the daily temperatures are acquired including daily maximum (Tmax), daily minimum (Tmin), and daily mean temperatures (Tmean).

3.2 MODIS LST

MOD11A2/MYD11A2 is the level-3 MODIS global LST and Emissivity 8-day product, which is composed from the daily 1 km LST product (MOD11A1/MYD11A1) and stored on a 1 km Sinusoidal grid as the average values of clear-sky LSTs during an 8-day period. Five calendar collections of MOD11A2/MYD11A2 (four composites for each set) were processed for further analysis, and the specific calendar beginning days are Julian 209, Julian 217, Julian

225, Julian 233, and Julian 241, mainly covering August. In addition, the level-3 MODIS global LST and Emissivity Monthly Climate Modeling Grid (CMG) product—MOD11C3/MYD11C3, which is a monthly composited average and is stored as clear-sky LST values during a month's period in a resolution of 0.05º geographic CMG. The MOD11C3/MYD11C3 is used for the comparison with GHCN CAMS monthly gridded land air surface temperature.

3.3 Gridded land air surface temperature

The GHCN CAMS gridded land air surface temperature is an analyzed global land air surface temperature with high spatial resolution (0.5º×0.5º) from 1948 to near present. This data set can be regularly updated in near real time with plenty of stations (Fan and van den Dool, 2008). The dataset is provided at http://www.esrl.noaa.gov/psd/.

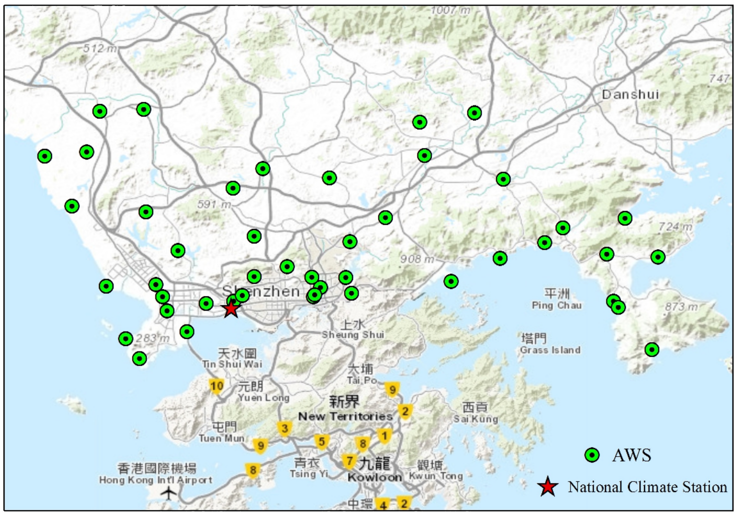

Fig.1 Selected stations including 45 AWSs and a National Climate Station

4. Main findings

Generally, the land surface anomaly shows accordance with air anomaly (Fig. 2). Thermal anomaly during the summer of 2007 is observed by monthly GHCN CAMS and MODIS LST products. Warm anomalies are obviously seen in July and August 2007. Meanwhile, cool anomalies are also recorded in June and July, which are located around over the north of 30ºN. Significantly warm anomalies in July 2007 are recorded by both air temperature and LST over the South China and the Yangtze River Delta. However, because of the limited data records collected by AWSs over Shenzhen City for July 2007, the urban thermal heterogeneity in August 2007 is investigated instead.

In Fig. 3, hourly anomaly of an AWS is defined as its difference from the hourly average of Shenzhen City, while the hourly average is calculated from the hourly records at 45 AWSs. By the way, the hourly average is obtained through a simple way, which takes each station with equal weights. Generally, the heterogeneity of thermal environment is obvious, with the temperature anomaly mainly ranges -2 ~ 2°C. Even worse, significant variation larger than 4°C is seen under some conditions (Fig. 3). Seemingly, the temperature anomaly generally shows accordance with the variation of the hourly average (Fig. 3). However, the hourly average alone is only able to explain a small part of the temperature heterogeneity, according to detailed investigations.

Daily temperatures including Tmax, Tmin, and Tmean are obtained from the hourly records correspondingly for all AWSs. The variation of daily temperature over Shenzhen City is obvious in August 2007. The inner-city heterogeneity of daily temperature varies with time, evidently showing daily variation. Compared with the Tmax and Tmean, the Tmin shows more significant heterogeneity with steady magnitude. Furthermore, the similarity between the records at the National Climate Station (No.59493) and the averages of AWSs is seen (Fig. 4).

Significant thermal heterogeneity is also shown in view of the occurrences of time for Tmax and Tmin (Fig. 5). However, the variation of the Tmin occurrences is generally more visible in comparison with the variation of the Tmax occurrences.

As presented in Fig. 6, the heterogeneity of LST is prevailing in both daytime and nighttime. However, the MODIS LST only records surface temperature under the clear-sky situation, thus the cloudy conditions are generally missed in this product (Fig. 6). The limitation is obvious over both tropical and sub-tropical regions, where absolutely cloudy-free condition is always scarce, especially in Boreal summer. Meanwhile, given the daily variation of surface temperature, the 8-day MODIS LST products may potentially filter the details of surface thermal environment. The data availability is a big challenge for thermal environment monitoring.

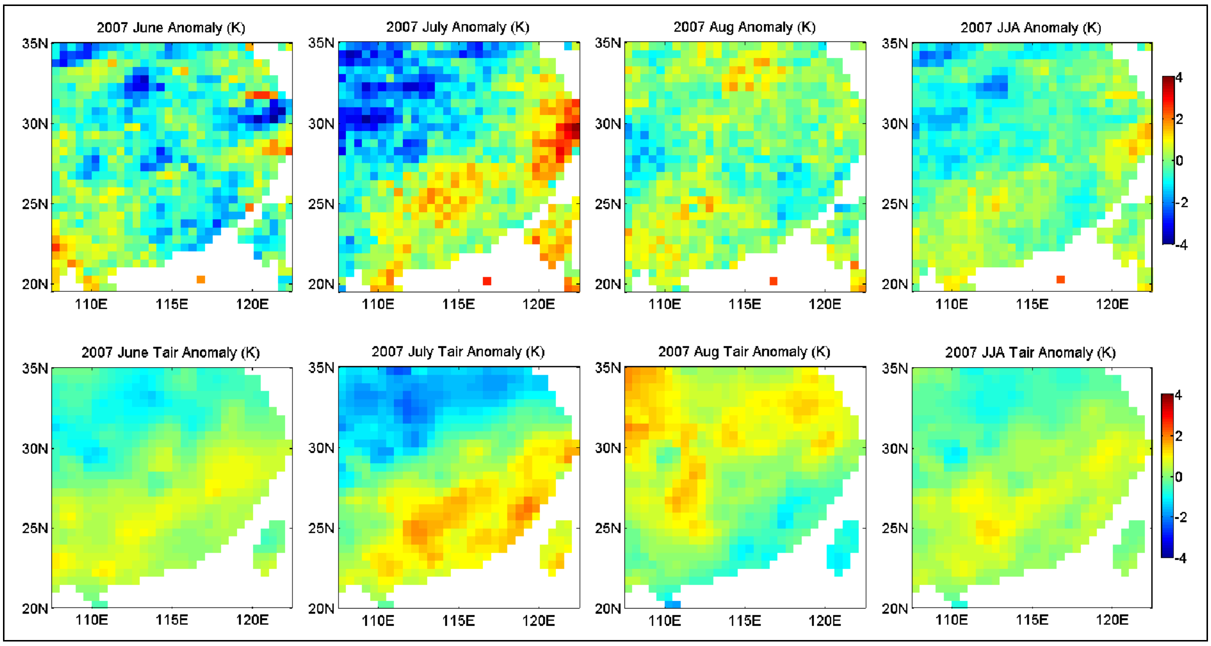

Fig. 2 The monthly and seasonal temperature anomaly of summer 2007: the land surface temperature (the Top panel) and surface air temperature (the Bottom panel), and the reference period is 2002-2013.

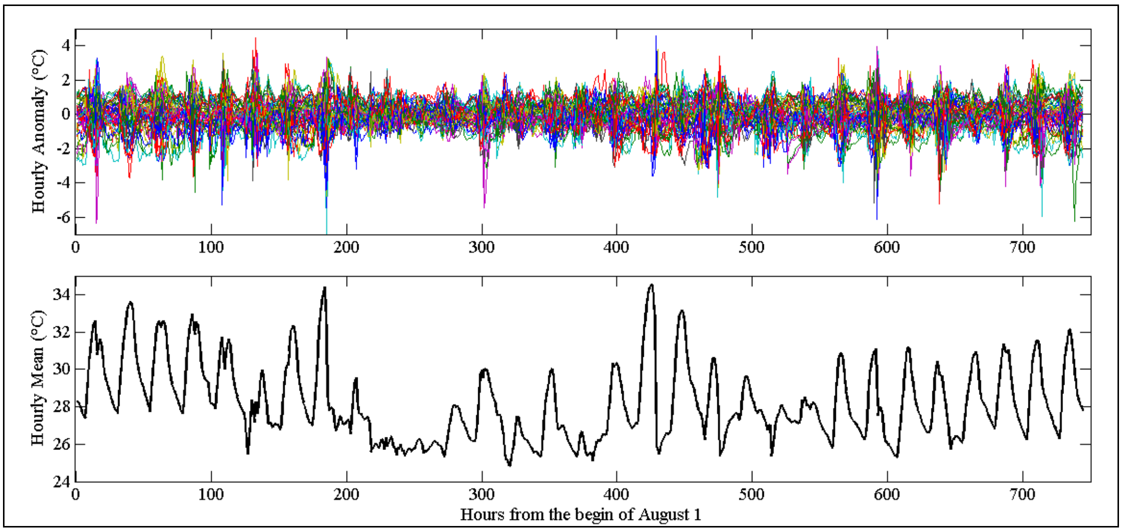

Fig. 3 Hourly anomaly recorded at the 45 AWSs (the Top panel) and the hourly average of temperature (the Bottom panel) in August 2007.

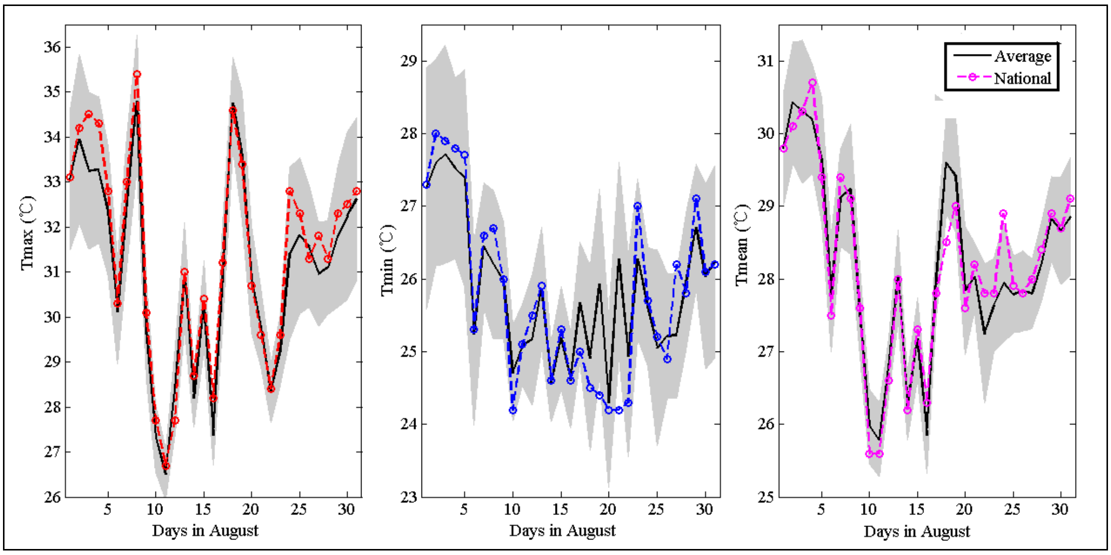

Fig. 4 The urban thermal heterogeneity in view of daily temperatures: daily maximum (left), daily minimum (center) and daily mean (right).The black line shows the average records of the AWSs, while the colored dot dash line shows the daily record at the National Climate Station (No.59493).The gray shadow shows the boundary of temperature variation (±1.5 standard deviation). Cautions the temperature in range in different figures.

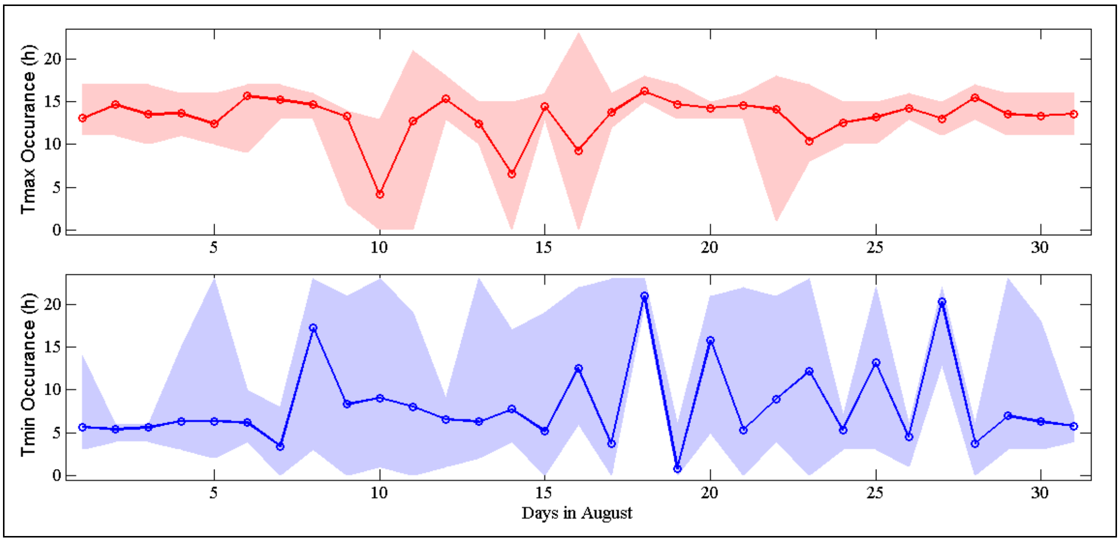

Fig. 5 The urban thermal heterogeneity in view of the occurrence of time. The daily maximum and daily minimum temperatures are presented at top and bottom panels respectively. The shadow shows the boundary of the variation of occurrence, while the upper and the lower boundaries are the earliest and latest occurrences. The dotted line represents the mean values of the occurrence of time.

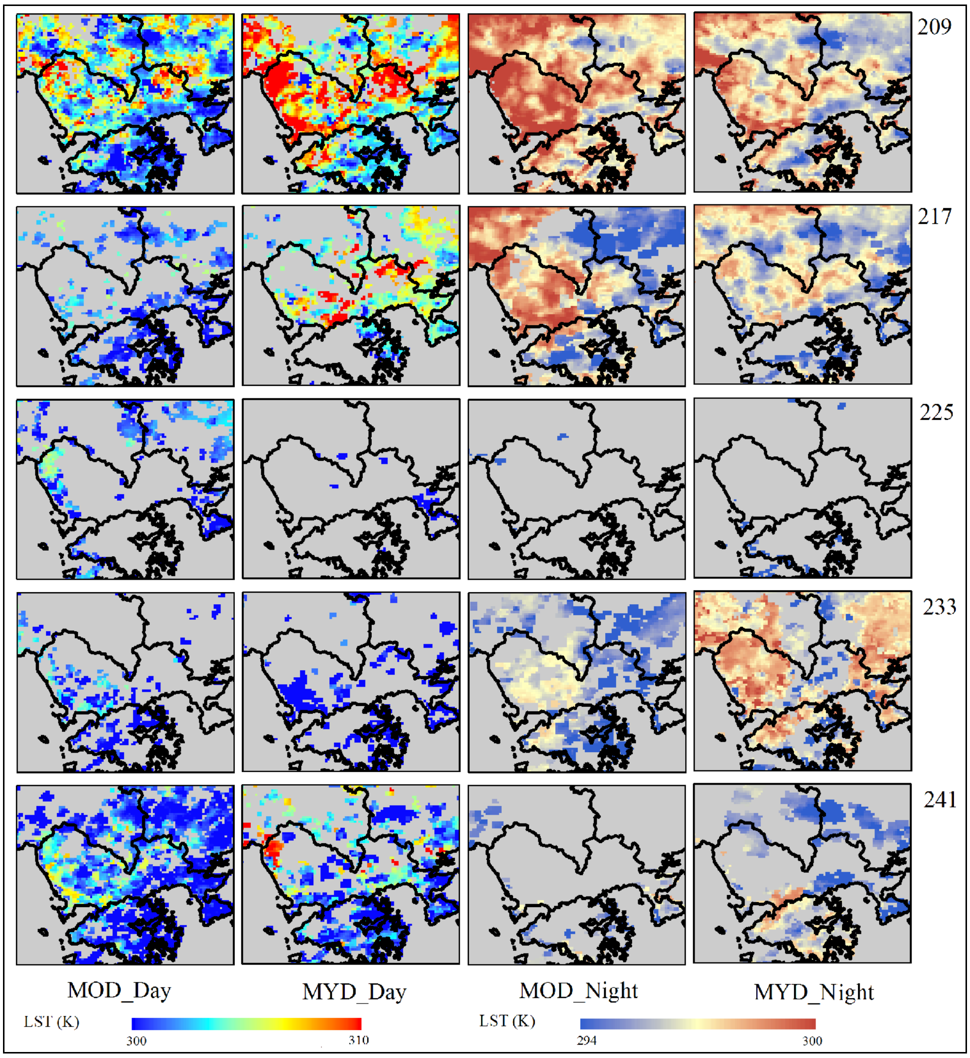

Fig. 6 The urban thermal heterogeneity recorded by MODIS LST, the gray color shows the invalid LST. Day and night records are stretched using Min-Max strategy, and different color bars are used.

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