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Influence of urbanization on the thermal environment of meteorological station: Satellite-observed evidence

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Abstract

In this paper, five national meteorological stations in Anhui province are taken as typical examples to explore the effects of local urbanization on their thermal environment by using Landsat data from 1990 to 2010. Satellite-based land use/land cover (LULC), land surface temperature (LST), normalized difference vegetation index (NDVI) are used to investigate the effects. The study shows that LULC around meteorological stations changed significantly due to urban expansion. Fast urbanization is the main factor that affects the spatial-temporal distribution of thermal environment around meteorological stations. Moreover, the normalized LST and NDVI exhibit strong inverse correlations around meteorological stations, so the variability of LST can be monitored through evaluating the variability of NDVI. In addition, station-relocation plays an important role in improving representativeness of thermal environment. Notably, the environment representativeness was improved, but when using the data from the station to study climate change, the relocation-induced inhomogeneous data should be considered and adjusted. Consequently, controlling the scale and layout of the urban buildings and constructions around meteorological stations is an effective method to ameliorate observational thermal environment and to improve regional representativeness of station observation. The present work provides observational evidences that high resolution Landsat images can be used to evaluate the thermal environment of meteorological stations.

Keywords: Urbanization; Thermal environment; Representativeness; Land surface temperature; Normalized difference vegetation index (NDVI)

1. Introduction

Driven by the recent thirty-year economic booming, China has undergone rapid development and urbanization. Many meteorological stations used to be in rural area now are in urban area and their observational environments have changed dramatically (Ren et al., 2010; Zhang et al., 2010; Ren and Ren, 2011; Shao et al., 2011; Yang et al., 2011, 2013; Li et al., 2015). The changed thermal environment around meteorological stations significantly influences the observations (Yan et al., 2010; Li et al., 2012; Shao et al., 2011; Ren and Ren, 2011), which will further disturb local weather and climate analysis, such as the evaluation of heat island effect, one of the main features of a modern city (Kalnay and Cai, 2003; Li et al., 2004; Zhou et al., 2004; Chen et al., 2007; Ren et al., 2007, 2008; Shi et al., 2011a; Zhao et al., 2013; Yang et al., 2013). For these reasons, objectively quantifying changes in thermal environment is crucial to evaluate the representativeness of meteorological stations.

Land surface temperature (LST) is an important index to represent the thermal environment around meteorological

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stations. Satellite remote sensing, as a recently developed technique, provides a unique opportunity to monitor and study macroscopical and dynamic-continuous LST in different spatial scales. Satellite-derived LST images have been widely used in land use classification, urban heat island research, thermal environment and hydrological investigation in an urban or even larger scales (Yang, 2000; Weng, 2001; Zhang et al., 2005, 2011; Hung et al., 2006; Shi et al., 2011b, 2013). However, only in recent years have satellite-derived LST data been used specifically for evaluating thermal environment and observational stations' representativeness in China. For example, by using 1-km resolution MODIS LST dataset, Wang et al. (2011) evaluated the representativeness of 142 weather stations and investigated the relationship between the representativeness of a station and its surrounding conditions. Ren et al. (2010) and Ren and Ren (2011) proposed to combine remote sensing images from Google Earth and MODIS LST data to evaluate the representativeness of observational stations and investigate the effect of urban heat islands. Using Landsat remote sensing data, Li et al. (2015) calculated the normalized LST and the heat effect contribution index (HECI) of different land use/land cover (LULC) type to classify the stations' observational environment into three types (urban, sub-urban and rural), and these two indexes could be used conveniently, effectively and quantitatively to choose a reference station when analyzing observational data in weather and climate research. However, thermal environment and representativeness around many Chinese meteorological stations are still not clear, especially the ones located in the southeastern China where has undergone rapid urbanization. Therefore, it is essential to use satellite-derived LST to monitor spatial-temporal variations of thermal environment and representativeness of these meteorological stations.

In this study, taking five typical meteorological stations as samples in Anhui province, a southeastern province in China, where the tremendous growth of urban sprawl, population, vehicles and economy have occurred since the 1990s (Shi et al., 2008; Li et al., 2012; Yang et al., 2011, 2013), spatio-temporal variations of LULC and thermal environment (LST) around meteorological stations are systematically explored by using Landsat remote sensing data. Moreover, the effects of urbanization on the thermal environment of meteorological stations are quantitatively evaluated by using LULC change around these meteorological stations. Finally, the relationship between LST and normalized difference vegetation index (NDVI) are quantitatively investigated.

2. Data and method

2.1. Data

The Landsat-5 remote sensing data used in this study are obtained from the Open Spatial Data Sharing Project, which was launched by the Institute of Remote Sensing and Digital Earth of the Chinese Academy of Sciences (http://ids.ceode.ac.cn/en/). The TM (ETM) sensor which is on board of the Landsat-5 satellite has seven bands, and the sixth band (TM6, with the band wavelength 10.40−12.50 μm) is selected here for LST retrieval (Li et al., 2015). In addition, the fourth band (TM4, with the near infrared band wavelength 0.62−0.69 μm) and the third band (TM3, with the red band wavelength 0.76−0.96 μm) are also selected here for NDVI retrieval (Shi et al., 2011b). In order to better capture the local vegetation information in a similar season, only data during the vegetation growth periods (i.e., May to September in China) in 1990, 2000 and 2010 are selected.

To investigate the temporal-spatial variability of the meteorological stations' surrounding environment, the LULC types in the buffer zone of the station are categorized into three types, vegetation (including farmland, forest and grass land), water (including lakes, rivers and pools), and construction (including buildings and roads), which are derived exactly through supervised classification together with visual interpretation (Li et al., 2015).

Five stations under rapid urbanization are selected as typical cases (Fig. 1), i.e., Suzhou (SZ), Hefei (HF), Chuzhou (CZ), Anqing (AQ) and Wuhu (WH); and five reference stations in rural areas are also selected corresponding to the five urban stations, i.e., Lingbi (LB), Feixi (FX), Quanjiao (QJ), Huaining (HN) and Nanling (NL). In addition, the underlying surfaces around the five reference stations experienced little changes during 1990−2010. The annual mean air temperatures for the period 1980−2010 were recorded at the above mentioned 10 meteorological stations in Anhui province.

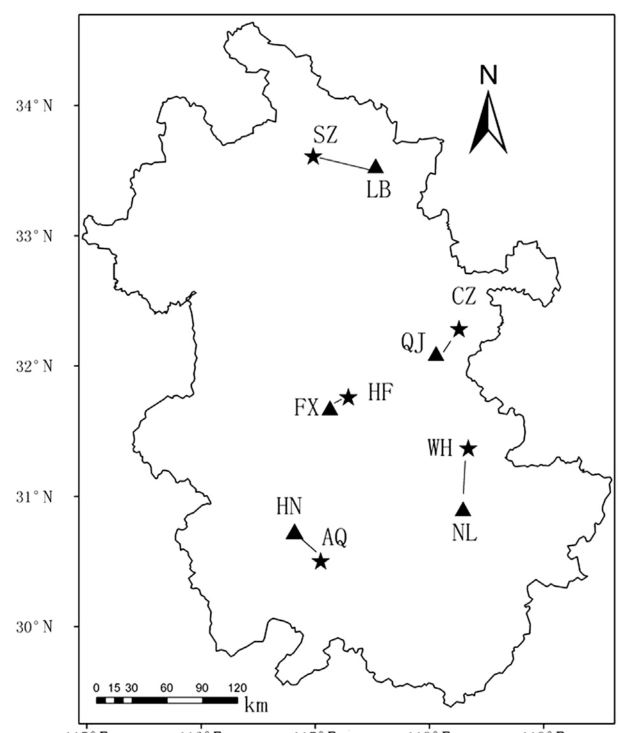

Fig. 1. The locations of five urban meteorological stations (indicated by stars), i.e., Suzhou (SZ), Hefei (HF), Chuzhou (CZ), Anqing (AQ) and Wuhu (WH), and five reference stations (indicated by triangle), i.e., Lingbi (LB), Feixi (FX), Quanjiao (QJ), Huaining (HN) and Nanling (NL) in Anhui province, China.