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Using land use change trajectories to quantify the effects of urbanization on urban heat island

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Abstract

This paper proposed a quantitative method of land use change trajectory, which means the succession among different land use types across time, to examine the effects of urbanization on an urban heat island (UHI). To accomplish this, multi-temporal images from Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) of Xiamen City in China from 1987 to 2007 were selected. First, the land use change trajectories were extracted based on the classified images from different years. Then the land surface temperatures (LST) were retrieved and the magnitudes of the UHI were evaluated using the UHI intensity (UHII) indicator. Finally, the indices of the contribution to UHI intensity (CUHII) were constructed and calculated to quantify the effects of each land use change trajectory on the UHI during urbanization. The results demonstrated that the land use change trajectories and CUHII are effective and useful in quantifying the effects of urbanization on UHI. In Xiamen City, a total of 2218 land use change trajectories were identified and 530 of them were the existing urban or urbanization trajectories. The UHII presents a trend of continuous increase from 0.83 °C in 1987 to 2.14 °C in 2007. With respect to the effects of urban growth on UHI, the contribution of existing urban area to UHI decreased during urbanization. Prior to 2007, the existing urban area of trajectory NO. 44444 had the most significant effect on UHI with the greatest CUHII, while the value has decreased from 55.00% in 1987 to 13.03% in 2007 because of the addition of new urbanized area. In 2007, the greatest CUHII was replaced by a trajectory from farmland to built-up area (NO. 22224) with the CUHII of 21.98%, followed by the existing urban area of trajectory NO. 44444 with the CUHII of 13.03%. These results provide not only a new methodology to assess the environmental effects of urbanization, but also decision-supports for the planning and management of cities.

Keywords: Urbanization; Land use change trajectory; Urban heat island; Contribution to UHI intensity (CUHII); Xiamen

1. Introduction

Urbanization profoundly influences the ecosystem of an urban area. One of the best-documented examples of this, is the urban heat island (UHI) effect, which refers to the higher temperatures found in urban areas compared with the surrounding rural area (Grimm et al., 2008). UHI not only influences the living environment (Konopacki and Akbari, 2002), but also increases energy consumption (Kolokotroni et al., 2012), and even harms human health (Changnon et al., 1996). Recently, a great deal of research has been carried out on the causes and impacts of UHIs, and their qualitative and quantitative characteristics have been documented (Rosenfeld et al., 1998; Rizwan et al., 2008; Imhoff et al., 2010).

UHI was observed through air temperature at the early stage. For example, Howard (1818) firstly proposed the

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phenomenon of UHI when he observed a higher the air temperature of urban area than the surrounding rural area of London. Jusuf et al. (2007) used the qualitative and quantitative methods to evaluate the influence of land use on the UHI from air temperature in Singapore. In recent decades, since assessment of land surface temperature (LST) from satellite data was first proposed by Rao (1972), this remote sensing method has been widely used to analyze UHI characteristics on a regional and global spatial scale (Gallo et al., 1993; Weng, 2001; Sobrino and Romaguera, 2004; Zhao et al., 2010b; Schwarz et al., 2011; Weng et al., 2011). LST is strongly related to the surface properties and much previous research focused on the relationship between the LST and land use in mono-temporal (Weng et al., 2004), across different seasons (Gallo et al., 1993; Li et al., 2011) or different years (Chen et al., 2006; Yuan and Bauer, 2007; Zhang et al., 2009). The results of this research effort indicated a positive correlation between the LST and impervious land use, and a negative correlation with the vegetation fraction. Furthermore, the effects of urbanization on the UHI were also analyzed. For example, Gallo et al. (1996) concluded that the transformation from rural to urban land use can impact the trend in temperature in a similar manner to that which would be expected under an enhanced greenhouse warming scenario. Amiri et al. (2009) examined the relationship between the temporal dynamics of LST and land use through the method of temperature vegetation index (TVX) space. They found that the LST trajectory in TVX space was reflected by the shift from the high vegetation – low LST fraction, to the low vegetation – high LST areas during the process of urbanization. Zhou et al. (2011) showed that the impact of urbanization on the UHI can be mitigated by balancing land use composition through optimizing land use configuration. However, the quantitative relationship between urbanization and its effects on the UHI is still ambiguous. The environmental response due to urbanization associated with different land use changes (e.g., from farmland to built-up areas and from forest to built-up areas.), is highly variable because of the different properties of each land use type (Houghton and Goodale, 2004; Pauleit et al., 2005). Therefore, it is essential to quantify the effects of different land use change during urbanization on the UHI, to understand fully the characteristics of the UHI.

This study used land use change trajectory as a method to quantify the effects of different land use change types on the UHI during urbanization. A trajectory was defined as the succession areas of land use types, through this method, the urban areas could be divided into several parts according to the transformation of other land use types to built-up area (Lambin, 1997; Mertens and Lambin, 2000; Petit and Lambin, 2001). For example, Liu and Zhou (2005) simulated the process of urban growth through the land use change trajectory in Beijing. Zhou et al. (2008) analyzed the spatial pattern analysis of land cover change trajectories in Tarm Basin, northwest China. Wang et al. (2012, 2013) illustrated the spatial patterns and the driving forces of the land cover change trajectories in the Xihe watershed of the Loess Plateau, China. The results of researches could support the methodology of this research. After the retrieval of LST and the calculation of the UHII, land use change trajectories were extracted and their CUHII calculated. In this way, the quantitative relationship between urbanization and its effects on the UHI was analyzed in the context of urbanization in Xiamen City. The results not only provide a useful tool for quantifying the effects of urbanization, but also support the planning and management of cities.

2. Study area and data pre-processing

2.1. Study area

The city of Xiamen, which has experienced rapid urbanization in the past three decades, is selected as the study area for this research. It locates at 24°25'–24°55' N and 117°53'–117°28' E, and is situated on the southeast coast of Fujian Province and at the estuary of Jiulong River. It comprises Xiamen Island, Gulang Island, and the coastal part to the north of the Jiulong River (Fig. 1). It has an area of more than 1565 km^2, a sea area of 390 km^2, and in 2007, a population of 2.43 million with nearly 70% of which in urban areas (Xiamen Bureau of Statistics, 2008). In 1980, Xiamen Special Economic Zone was established. Since then, Xiamen has experienced rapid urbanization, which has led to significant environmental and ecological effects (Zhao et al., 2010a). Meanwhile, UHI in Xiamen has become more and more obvious (Xu and Chen, 2004; Zhao et al., 2010a,b; Huang and Huang, 2011).

2.2. Data resources and pre-processing

Images acquired from the Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) sensors (Jan 17, 1987; Jan 15, 1992; Jan 12, 1997; Jan 2, 2002, and Jan 8, 2007) were used in this research. The multi-images were co-registered to the same coordinate system of UTM/WGS84 based on the image of 1987. Moreover, the images were then re-sampled using the nearest neighbor algorithm with a spatial resolution of 30 m for all bands. To remove the atmospheric influence, the MODTRAN4-based FLAASH module in the software of ENVI4.7 was adopted to correct atmospheric errors. Its parameters included the information about the sensor and scene, atmosphere and aerosol model, and the atmosphere correction model. For the study area of this paper, the scene center location, sensor altitude, sensor type, flight date and time were obtained from the Landsat TM/ETM+ header book, the average elevation was 0.05 km, the atmospheric model and aerosol model were Mid-Latitude Summer (MLS) and urban, and the aerosol retrieval was adopted the K-T method. Finally, to analyze the land use change, all the individual images were classified