Landscape and Urban Planning 96 (2010) 224–231

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Quantifying the cool island intensity of urban parks using ASTER and IKONOS data

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ARTICLE INFO

Article history:
Received 18 April 2009
Received in revised form 18 March 2010
Accepted 21 March 2010
Available online 14 April 2010

Keywords:
Park cool island
Land surface temperature
Land use
Shape
ASTER
IKONOS

ABSTRACT

Urban parks can help mitigate urban heat island (UHI) effects and decrease cooling energy consumption in summer. However, it is unclear how park characteristics affect the formation of a park cool island (PCI). In this study, PCI intensity values for 92 parks in Nagoya, Japan were obtained from ASTER land surface temperature (LST) products and then correlated to detailed and use information derived from high-spatial-resolution IKONOS satellite data. The results indicate that (1) the cooling effect depends on the park size and seasonal radiation condition, and park size is non-linearly correlated to PCI intensity; (2) PCI intensity is mainly determined by the area of tree and shrub inside the park as well as the park shape, and grass has negative impact on PCI formation. The park vegetation and shape index (PVSI) proposed here well predicted PCI intensity of selected parks. These findings can help urban planners to understand PCI formation and design cool parks to counteract UHI effects.

1. Introduction

The urban heat island (UHI) can lead to urban temperatures being 2–5 °C higher than those in rural surroundings (Oke, 1973; Ackerman, 1985; Taha, 1997). Higher temperatures in urban areas not only accelerate urban smog formation and affect the inhabitability of cities (Mihalakakou et al., 2004), they also greatly increase cooling energy consumption in summer, contributing to global warming (Kolokotroni et al., 2007). Estimates for major US cities have shown that once temperatures exceed 15–20 °C, a 1 °C increment will increase peak electricity demand by 2–4%. Thus the additional cooling energy consumption caused by a UHI is responsible for 5–10% of electricity demand (Akbari et al., 1992). With rapid urbanization and accelerating global warming, UHI is of increasing public concern and strategies to mitigate UHI effects are needed both for energy-savings and urban-planning applications (Chang et al., 2007).

Many field-based measurements have found that urban parks are 1–2 °C, and sometimes even 5–7 °C, cooler than their urban surroundings, forming a "park cool island" (PCI) (Jauregui, 1990; Spronken-Smith and Oke, 1998; Upmanis et al., 1998; Chang et al., 2007; Jusuf et al., 2007). Through advection caused by differences in surface and air temperatures between the cooler park and its warmer built-up surroundings, the park cooling effect can extend beyond the park by the park's width or even farther. A stronger PCI affects a more extensive area, resulting in lower cooling energy consumption in buildings around the park (Jauregui, 1990; Spronken-Smith and Oke, 1998; Ca et al., 1998; Eliasson and Upmanis, 2000). Considerable research efforts have been made to reveal which park characteristics are crucial to PCI formation. Previous studies have found that larger parks have stronger PCI effects (Spronken-Smith and Oke, 1998; Upmanis et al., 1998), but the relationship between PCI effect and park size might be non-linear (Chang et al., 2007). Shashua-Bar and Hoffman (2000) reported that the tree-shaded area was a significant factor for the cooling effect, while Saaroni and Ziv (2003) found that water ponds in the park contributed to park cooling. Different park types or vegetation combinations have also been discussed, but quantifiable effects and statistical relationships have not been established (Spronken-Smith and Oke, 1998; Chang et al., 2007), only with confirmation that vegetation lowers neighborhood temperatures by shading and by absorbing and converting ambient heat to latent heat through evapotranspiration.

The above park characteristics are essential for urban planning and global change studies. However, the relationship between PCI intensity and park characteristics, especially in regard to detailed land cover/land use in a park, is not yet fully understood and thus limits the design of optimal parks for significant UHI mitigation (Chang et al., 2007). Compared with in situ air temperature measurement, remote sensing provides not only the detailed land cover/land-use information, but also the land surface temperature (LST) observation with a more complete and uniform sampling. Considering the strong relationship between LST and air temper-

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0169-2046/$ – see front matter
doi:10.1016/j.landurbplan.2010.03.008

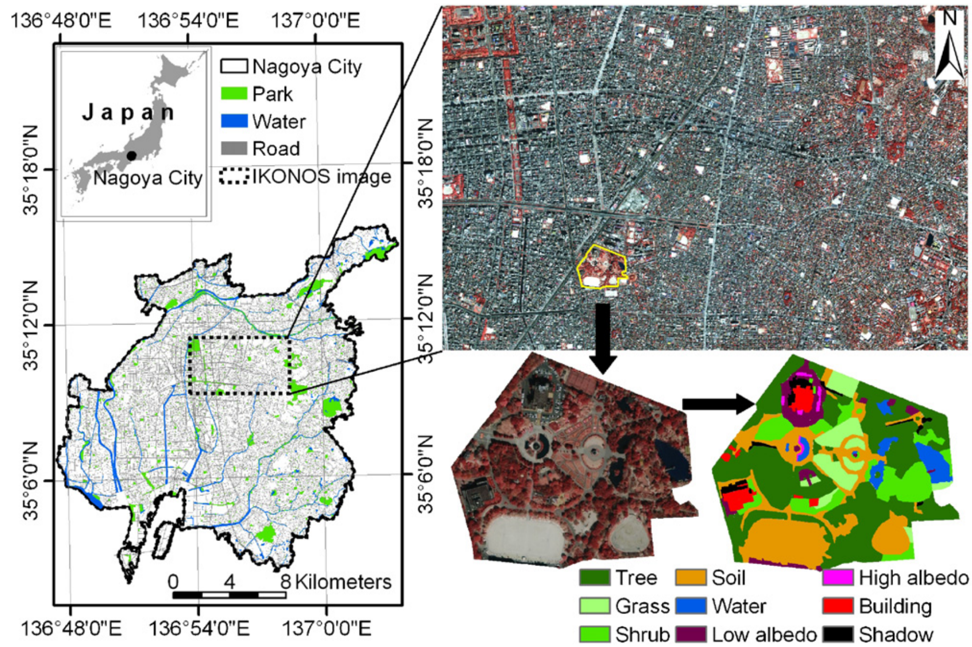

Fig. 1. Location of Nagoya in Japan and the IKONOS image. The IKONOS image is displayed by false color with RGB composition of band 4 (near infrared), band 3 (red) and band 2 (green). The parks areas were extracted and then manually classified into 9 land-use types of tree, grass, shrub, soil, water, low albedo surface, high albedo surface and shadow. Here shows an example of Tsurumai Park with park size of 22.7 ha. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

ature (Cristóbal et al., 2008), various satellite data sources have been used to model UHI, such as NOAA Advanced Very High Resolution Radiometer (AVHRR) (Streutker, 2002), Moderate Resolution Imaging Spectroradiometer (MODIS) (Wang et al., 2007), Landsat Enhanced Thematic Mapper Plus (ETM+) (Weng et al., 2004) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) (Kato and Yamaguchi, 2005; Lu and Weng, 2006; Liu and Weng, 2008). Within these efforts, remotely sensed LST observations have confirmed the cooling effect of vegetation, showing a negative correlation between LST and vegetation abundance (Weng et al., 2004; Lu and Weng, 2006) or the normalized difference vegetation index (NDVI) (Dousset and Gourmelon, 2003). Despite the achievement of modeling UHI by remotely sensed data, few attempts have been made to relate PCI intensity to the park characteristics (e.g. park size, the land cover/land-use inside parks) derived from remotely sensed data for exploring the factors affecting cooling effect of parks. As one of important park characteristics, park shape may influence the scale of cooling effect and has been ignored by most of existing studies. The landscape shape index (LSI) designed by Patton (1975) describes the compactness degree of the patch shape and it maybe is a potential factor to explain the PCI.

With these issues in mind, we addressed the following questions in this study: (1) How does park size affect the PCI intensity? (2) What is the relationship between the PCI intensity and park characteristics including land-use types inside a park and park shape, and can the PCI intensity be predicted by the park characteristics? The study objective was to identify the role of park parameters (e.g., park size, land-use types, and shape) in the PCI phenomenon, and then to develop a PCI estimation model to help urban planners design cooler parks. To achieve the above purposes, we used remotely sensed ASTER LST data (90-m spatial resolution) to represent the PCI intensity of parks in Nagoya, Japan, in spring, summer and autumn. We also extracted detailed data on the land-use distribution inside parks from high-resolution IKONOS data (4-m spatial resolution) to analyze the relationship between PCI intensity and land use.

2. Materials and methods

2.1. Study site and data

Nagoya is the fourth largest city in Japan and is densely populated (Fig. 1), with an area of 326.45 km^2 and a population of 2.24 million. The climate in Nagoya is temperate maritime with high humidity and marked seasonal changes. According to meteorological records of 1971–2000, the annual precipitation of Nagoya is 1550 mm with seasonal average precipitations of 400 mm, 560 mm, 445 mm and 145 mm in spring, summer, autumn and winter, and the annual average temperature is 15.4 °C with a hot summer (25.2 °C), temperate spring (13.6 °C) and autumn (17.6 °C) and a relatively cold winter (5.2 °C). In recent years, temperatures have increased in Nagoya with annual average air temperatures increasing 1.25 °C from 1970s to 2000s, particularly in the hot, humid summer season, resulting from the UHI phenomena and global warming. Land use in Nagoya is heterogeneous, with a complex assemblage of business districts, densely and less densely populated residential areas, vegetated open spaces, industrial areas, and many mixed residential–commercial areas. As a study site, we selected an area that was close to the city center, covered by IKONOS imagery, and included almost all land-use types.

ASTER is an advanced multispectral images onboard the NASA's EOS-Terra satellite. It collects data with a wide spectral region of visible to near infrared (VNIR, channels 1, 2 and 3), shortwave infrared (SWIR, channels 4, 5, 6, 7, 8 and 9) and thermal infrared (TIR, channels 10, 11, 12, 13 and 14) with a 16-day recurrent cycle (Yamaguchi et al., 1998). The spatial resolution varies with wavelength: 15-m in the VNIR, 30-m in the SWIR and 90-m in the TIR. The Earth Remote Sensing Data Analysis Center (ERSDAC) produces the ASTER LST products from five thermal infrared channels between 8 and 12 μm using the temperature and emissivity separation (TES) algorithm with an accuracy of less than 1.5 K (Gillespie et al., 1998). We acquired these ASTER LST products with good quality for the following dates: 25 May 2004 (spring), 10 July 2000 (summer), and 30 October 2003 (autumn). The preliminary examination of winter