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Influence of a large urban park on the local urban thermal environment

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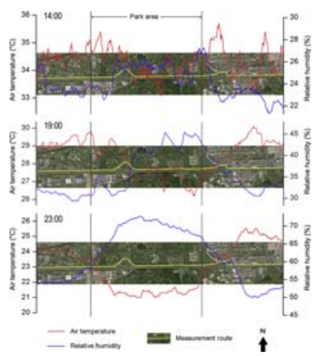
HIGHLIGHTS

- We study the cooling effects of a large park and observed significant cooling effects.
- The park was 0.6 to 2.8 °C cooler than the surrounding urban environment.
- The park cooling was variable but could extend almost 1.4 km beyond the park's border.
- Large differences in temperature exist both within the park and surrounding urban areas.
- The air temperature differences depended strongly on land cover features of each site.

GRAPHICAL ABSTRACT



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ABSTRACT

Green areas in the city can greatly improve the outdoor thermal environment, as well as mitigate the urban heat island effect by reducing summer air temperature. In a context of climate change, with the expected increase in temperature and intensity of heat waves, cooling by green areas is set to become increasingly important. In this study, field observations were carried out to investigate the thermal performance of a large urban vegetated park and its influence on thermal environment of the surrounding urban areas in Beijing, China. Measurements were conducted along a selected path during three summer days with clear skies and light winds by mobile traverses. The results showed that the park was cooler than the surrounding urban areas both during the daytime and at night. The mean air temperature differences between the park and the surrounding areas were in the range of 0.6–2.8 °C at different times, with a maximum of 4.8 °C observed at midnight. The results also found that as the distance from the park border increased, the ambient air temperature exhibited a gradually increasing trend. This indicated the park has a cooling effect on the urban environments adjacent to the park, and this cooling effect extended approximately 1.4 km from the park boundary. The air temperature variations also depended strongly on the land cover characterizing the immediate environment of the measurement sites. Increasing the percent vegetation cover could significantly decrease air temperature, while the increase of percent impervious surface area would significantly increase it.

1. Introduction

In the last decades, a great concentration of people around urban areas took place worldwide, especially in developing countries. Presently, more than half of the world's population lives in urban areas and this value is set to increase to 66% by 2050 (United Nations, Department of

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Economic and Social Affairs, Population Division, 2014). The urbanization process, with its fast population increase and urban expansion, results in significant modifications in the urban climate (Kalnay and Cai, 2003). The most obvious feature of urban climate is the urban heat island (UHI), which refers to the phenomenon of higher air and surface temperatures occurring in urban areas than in the surrounding rural areas (Oke, 1982; Voogt and Oke, 2003). Increased temperatures due to UHI may affect the inhabitability of cities, worsen air pollution and increase cooling energy consumption (Sarrat et al., 2006; Tan et al., 2010; Kolokotroni et al., 2006; Chen et al., 2016). In addition, the increased energy consumption under warm conditions not only violates the principles of urban sustainability, but also contributes to the global warming. With rapid urbanization, the urban heat island will affect a larger number of urban residents (Grimmond, 2007). Therefore, there is a pressing need for urban researchers to evaluate strategies that may mitigate against further increases in temperatures in urban areas.

There are several strategies to provide cooling in cities, such as increasing urban vegetation, using cool roofs and cool pavements (Rosenfeld et al., 1995). Among all the cooling measures, urban greening has been always recommended as an important adaptation strategy and significant approach to regulate urban air temperatures and reduce the health related consequences of increased air temperatures (Givoni, 1991; Gill et al., 2007; Brown et al., 2015; Jamei et al., 2016). Urban green areas such as parks can ameliorate UHI effect by the combined impact of shading and evapotranspiration (Oke et al., 1989; Jonsson, 2004). Extensive field based measurements have demonstrated that urban parks are usually 0.5–4 °C (Jauregui, 1991; Ca et al., 1998; Chang et al., 2007; Jansson et al., 2007; Lee et al., 2009; Cohen et al., 2012; Skoulika et al., 2014; Doick et al., 2014; Sugawara et al., 2016), and sometimes even 5–7 °C (Spronken-Smith and Oke, 1998; Upmanis et al., 1998; Oliveira et al., 2011), cooler than their surrounding urban built-up areas. This phenomenon of patchy, cooler green areas within the urban environment is often called "park cool island" (PCI) (Barradas, 1991). Previous studies in relation to the PCI effects usually focus on investigating the temperature difference inside an urban park compared to an urban area either in the park surroundings or elsewhere in the city, with much fewer studies examining the spatial form of PCI or the cooling effect of urban parks on the surrounding urban environment (Bowler et al., 2010).

The cooling effect of urban park not only creates a relatively comfortable thermal environment in the park for the rest and recreation of city residents but also, more importantly, influences the surrounding urban area through convection and diffusion. In addition to significantly improving the urban thermal environment and reducing energy consumption by buildings, the cooling effect is also a manifestation of macro-scale ecological benefits exerted by green spaces. Several studies have revealed that the cooling effect of parks could extend into the surrounding urban areas. In Mexico City, Jauregui (1991) found that the cooling effect of a large park (~500 ha) reaches a distance of up to 2 km, about the same as its width. Ca et al. (1998) did some field measurements to determine the cooling effect of a park on the surrounding area in the Tama New Town, a city in the west of Tokyo. The results indicated that with a size of about 0.6 km^2, the park can reduce by up to 1.5 °C the air temperature in a busy commercial area 1 km downwind. Other relevant studies also indicated that urban park have a cooling effect on the surrounding environment (Upmanis et al., 1998; Spronken-Smith and Oke, 1998; Shashua-Bar and Hoffman, 2000; Chen and Wong, 2006; Hamada and Ohta, 2010; Doick et al., 2014).

However, the thermal performance of a park and its influence on the surrounding urban areas is not only affected by the characteristics of park itself, but is also affected by the surrounding urban features, such as local urban morphology around the park, sky view factor (SVF), spatial location, and land cover features (Chang et al., 2007; Lee et al., 2009; Lau et al., 2012). Because these characteristics and factors can all be adjusted and controlled through reasonable planning and design, an investigation into the intensity and range of the cooling effect for urban parks and their primary influencing factors is required to formulate a theoretical basis to scientifically and reasonably plan and design urban parks, thus maximizing the degree to which the "cool island effect" of urban green areas is achieved. However, there are too few studies that explicitly examined this, for example by analyzing and presenting data at increasing distance from the park boundary, to be able to speculate on the strength and shape of this relationship (Bowler et al., 2010). Therefore, further empirical research is required in order to better understand all the different factors that explain the influence of the green areas on the surrounding environment, providing the necessary feedback to planners to improve the characteristics and spatial arrangements of parks in urban areas, taking into consideration the specific features of each city.

The present paper analyses the field measurements performed in and around a large urban vegetated park in northern Beijing, China, during hot summer weather conditions. The aim of this research is to investigate the thermal performance of the large park and its influence on the thermal environment of the surrounding urban areas. The specific objectives of this research were:

(1) to present data illustrating the air temperature differences between the park and its urban surrounding, as well as variations within the respective environment;
(2) to investigate the intensity and range of the cool island effect from the park into its immediate surrounding urban areas;
(3) to analyse if the urban environment characteristics, such as spatial location and land cover feature have an influence on the air temperature of each measurement sites.

2. Methodology

2.1. Study area and site description

Beijing (39°56′ N, 116°20′ E), the capital of China, is located in the northern part of the North China Plain. It is the second largest city in China with a total population of 21.7 million by the end of 2016. It has a monsoon influenced humid continental climate characterized by hot and humid summers and generally cold, windy and dry winters. According to the climatological normals (1971–2000), January is the coldest month with an average temperature of −3.7 °C, while July is the hottest month with an average temperature of 26.2 °C. The main wind direction is from southeast to northeast in summer and in reverse during winter. Since 1978, Beijing's urban population and the extent of the urban built-up area have been gradually increasing. This urbanization process, with its increasing built-up areas and anthropogenic activities, results in significant modifications in the underlying surface properties and the quick increase in the intensification of the UHI effect.

This study was conducted in and around Beijing Olympic Forest Park (BOFP), which is located in the northern end of Central Axis of Beijing city. With a total occupation of 680 ha, the park is the largest public green area ever built in Beijing. The Park with hills, forest, lakes, wetland and other natural landscapes as its main part has become the green park and called the green lung of the Beijing city. The 5th Ring Road divides the park into a southern part (380 ha) and a northern part (300 ha). Measurements were conducted along a side road passing through the BOFP and its surroundings urban areas. The side road is oriented in an east-west direction and has virtually no anthropogenic heat sources. The vehicle traffic is not intense and its impact on the air temperature would be negligible.

The whole measurement route was divided into two routes with respect to their different greenery and building distribution conditions. To make the data spatially comparable, 31 equidistant measurement sites were chosen with the intention to investigate the quantitative relationship between air temperature and environment characteristics of each location (Fig. 1). These measurement sites located sufficiently close to one another to be affected by uniform meso-scale climate conditions,