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River effects on the heat island of a small urban area

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ABSTRACT

This study examined the urban heat island (UHI) of a small urban area divided by a river in central Pennsylvania. As more of the population resides in urban areas, the study of UHIs is imperative due to increased mortality during heat waves, elevated energy costs, and increased air pollution. Hourly temperatures were collected from 19 urban stations and one rural reference station. All stations were compared to one another to assess UHI intensity and intra-urban variability and were also assessed based on their distance to the bisecting river. Results indicate an average yearly UHI of 2.25 °C that is strongest at night, in summer, in the most urbanized areas, and closer to the river. For every 1000 m increase in distance from the river, the UHI decreased by 0.6 °C to 0.3 °C depending on season. In the summer, the distance to the river is more important that the urban score at a station for predicting the UHI. The river enhances the UHI due to its warmer temperatures during the nighttime and by increasing the local humidity levels. Assessment of the heat island of this area can assist in determining the best locations for mitigation efforts to reduce the heat island effect.

1. Introduction

Within urban areas, construction of roads, buildings, and other structures replace the natural vegetated landscape, leading to changes in the local climate and the development of an urban heat island (UHI) (Maria et al., 2013). These structures will absorb, store, and radiate more heat than natural areas, as well as maintain less moisture for evaporative cooling (Wong et al., 2013). Additionally, developed urban areas increase the roughness length of the surface, decreasing wind speeds and promoting air stagnation and warming within the urban area (Ambrosini et al., 2014).

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UHIs come in all magnitudes ranging from as small as 0.6 °C in Atlanta, GA (Memon et al., 2008) to as high as 12.9 °C in Phoenix, AZ (Hawkins et al., 2004). Substantial diurnal fluctuations also exist in UHI intensities. Urban areas retain more heat from the day (Acero et al., 2013) and release heat more slowly than rural areas, which contributes to a stronger UHI intensity at night (Doyle and Hawkins, 2008).

UHI intensity may differ seasonally based on the local climate and land cover. Yang et al. (2013) concluded the Beijing UHI intensity was strongest in autumn and winter and Souch and Grimmond (2006) report from a review of UHI literature that UHIs are weakest in the summer. Conversely, Giannaros and Melas (2012) and Tan and Li (2015) report that UHI intensity is strongest in the summertime in Thessaloniki, Greece and the Beijing region respectively. Doyle and Hawkins (2008) suggest that UHIs are strongest during the season that is the driest and least windy at the specific urban area of interest.

Intra-urban variability is an important consideration as cities are a heterogeneous mixture of development types. Building height and density, population size and distribution, and percentage of land as green spaces are a few of the factors that can affect the magnitude of UHIs (Souch and Grimmond, 2006). Parks within urban areas provide cooler regions within a UHI, while industrial areas, which lack vegetation and may have constant anthropogenic heat emissions, tend to have more elevated temperatures (Hart and Sailor, 2009). Huang and Lu (2015) found that long-term warming rates in the Yangtze River Delta varied from 37.1%–73.8% due to differences in local urbanization at their 41 meteorological stations. Meanwhile, Du et al. (2016) found no correlation between population density and UHI intensity in the Yangtze River Delta.

The UHI phenomenon has also been shown to occur in small sized cities. In Poland, the small town of Wasilków (population 9000) was found to have elevated temperatures indicative of a UHI while the medium sized town of Bialystok (295,000) had a mean UHI of 2.3 °C and a maximum UHI of 8.2 °C (Czubaszek and Wysocka-Czubaszek, 2016). A study conducted in Hungary, looked at the UHI intensity of four settlements ranging in population size from approximately 1000–30,000, and found that even the smallest settlement developed a UHI (Szeged et al., 2013). In Iporá, Brazil, (population 31,274) a UHI intensity > 1 °C was found in 90% of the urban area, with approximately 27% of the urban area reaching a UHI intensity > 3 °C (Alves and Lopes, 2017).

It is well established that large water bodies, such as oceans and large lakes, have the ability to affect land temperatures. However, research is on-going regarding how smaller water bodies, especially rivers, can affect the microclimate of the surrounding urban areas (Hathway and Sharples, 2012). In Japan, cooling from the Ota River was noted to occur close to 300 m away from the 270 m wide river (Murakawa et al., 1991). On a smaller scale, cooling from a 22 m wide river in Sheffield, UK was recorded up to 30 m from the river banks (Hathway and Sharples, 2012). Hongyu et al. (2016), found the cooling of water bodies can vary depending on their geometry, with lakes demonstrating larger cooling effects than rivers. Further research on water bodies shows that they provide increased cooling in downwind areas (Syafii et al., 2016).

The goal of this study was to assess the magnitude of the urban heat island (UHI) for a relatively small urban area as well as to assess the impact that a fairly large river flowing through the urban area has on the UHI. There is extensive literature on UHIs of large global cities such as New York (Gaffin et al., 2008), London (Giridharan and Kolokotroni, 2009), Buenos Aires (Camilloni and Barrucand, 2012), and Singapore (Chow and Roth, 2006) and mid-sized cities such as Atlanta, GA (Memon et al., 2008) and Portland, OR (Hart and Sailor, 2009). However, UHIs and small cities have been studied to a lesser degree, with especially limited research involving the effects of rivers on the UHI intensity of a small city. Therefore, this study examines the UHI of a small urban area in central Pennsylvania that straddles the Susquehanna River.

2. Data and methodology

2.1. Study area

This study was conducted in central Pennsylvania, U.S.A. (Fig. 1) along the Susquehanna River. The urban area is the city of Harrisburg (40° 16′ 11″, 76° 52′ 32″) plus the surrounding townships and boroughs. This urban area has a total population of 96,345 and covers a total area of 76.93 km^2 (U.S. Census, 2010). The elevation of the study area ranges from 91–152 m above mean sea level (USGS, 2012). The mean yearly temperature of Harrisburg is 11.6 °C (PSC, 2004) and the climate is classified as Cfa (warm temperate, fully humid, hot summer) according to the Koppen-Geiger climate classification system. The area consists of low, medium, and high

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