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Characterization of the urban heat island at Toronto: Revisiting the choice of rural sites using a measure of day-to-day variation

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A R T I C L E I N F O

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A B S T R A C T

The quantification of the Urban Heat Island (UHI) relies on the establishment of urban–rural station pairs for comparison. We revisited the selection of three rural stations (Albion Field Centre, Millgrove, and King Smoke Tree) and two urban stations (Toronto and Toronto Pearson International Airport) that have previously been used to perform UHI analysis in Toronto, Ontario, Canada. We explored the seasonal patterns of day-to-day temperature variation. We employed a derived measure of day-to-day temperature variability, the novel ΔDTD metric—the difference between the variation in daytime maximum temperatures and nighttime minimum temperatures—to determine whether our stations exhibited the ΔDTD values that are characteristic of rural (negative or less positive ΔDTD) and urban (positive or less negative ΔDTD) sites. Our results indicate that both of our urban stations do, indeed, exhibit day-to-day variation that is characteristic of urban stations. Of our three rural sites, Albion Field Centre was found to be the most rural. King Smoke Tree, an agricultural station, showed the highest ΔDTD values of the three rural sites, indicating that ΔDTD is, therefore, a useful tool for the detection of anthropogenic disturbance and the evaluation of urban and rural members of urban–rural station pairs.

1. Introduction

The term ‘urban heat island’ describes the anthropogenic phenomenon whereby temperatures in urban centres are relatively higher than the temperatures of surrounding rural areas (Oke, 1976). Oke identifies factors such as the reduction of evaporation in cities due to the elimination of vegetation and the paving of surfaces, reduced albedo due to snow removal and the use of dark surfaces such as shingles and asphalt, and the production of heat from commercial, industrial, and residential processes as being key contributors to the presence of an urban heat island. Indeed, Jin et al. (2005) found that the albedo and emissivity of urban areas was between 2 and 5% and 1 to 2% lower than that of adjacent cropland, respectively. In the most extreme cases, the urban heat island effect can lead to urban–rural temperature differences of up to 10°C, but the magnitude of a heat island varies widely depending on the particular physical, geographical, and climatological characteristics of a city (Tam et al., 2015).

Studies quantifying UHI effects in cities rely in the comparison of urban–rural station pairs. In their 2012 study, Mohsin & Gough examined three rural stations and two urban stations to quantify the Urban Heat Island at Toronto, Ontario, Canada. Those authors found that the choice of urban–rural station pairs can have significant impacts on the outcomes of the analysis. The authors caution that the proper selection of urban–rural station pairs is one of the most difficult tasks in UHI analysis.

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One of the least studied areas of UHI is its effect on the day-to-day (DTD) temperature variability in cities. In a recent study, Tam et al. (2015) examined how the Urban Heat Island influences day-to-day temperature variation. They detected increasing day-to-day variation in the daytime maximum temperature (T_{max}) at a given station as urbanization around the site intensifies. Tam et al. (2015) used the ΔDTD metric—the difference between the day-to-day variation of daytime maximum temperatures (DTD T_{max}) and night-time minimum temperatures (DTD T_{min})—as the basis of their analysis, and showed that the rural station members of urban–rural pairs exhibited negative, or less positive ΔDTD values, while the urban member showed positive, or less negative ΔDTD values. This result was confirmed in another study of four urban–rural (or less urban) pairings in China. Gough and Hu (2016) found a negative average ΔDTD value in only one of their station pairs, but in all cases the rural (or less urban) station was less positive than the urban counterpart.

It is interesting to note that a derived meteorological metric such as DTD variability can detect the UHI signal in temperature data. The physical reasoning behind this observation can be explained using the differences in energy partitioning in urban and rural areas. In an urban environment where built surfaces dominate, more energy goes into surface heating and less into evaporation, thus increasing heat storage and surface temperature. On the contrary, in rural areas heat storage and surface heating are mitigated by the cooling effect from green spaces and abundance of moisture-rich surfaces. As such, in general, for a given input of solar energy, ambient temperature at an urban site will be warmer than the rural site. Daytime temperatures are also influenced by convective processes. Daytime surface warming can lead to convection, which mixes air and removes heat from the surface, limiting surface warming and, therefore mitigating T_{max} extrema. When surfaces cool at night, the air above them cools, thus producing a stable density structure, limiting convective mixing. Thus, there is no convective mechanism to mitigate T_{min} extrema. However, urban centres exhibit slower overnight convective heat loss due to the trapping of radiative energy by the constructed canyon geometry (Oke, 1981) and the general higher heat capacity of urban surfaces (Oke, 1982). This leads to the mitigation of heat loss from urban centres, and can lead to lower overall nocturnal temperature variability (Tam et al., 2015).

Given this framework, the present study revisits the station pairs used in Mohsin and Gough (2012), and examines them using the ΔDTD framework to detect a suitable urban-rural pair. The urban-rural pairs used in Mohsin and Gough (2012) were selected based on the criteria provided in the Thermal Climate Zone Classification System (Stewart and Oke, 2009) in addition to changes in minimum temperature (T_{min}). The purpose of the current study is to use a statistically-sound metric to describe the degree to which a site can be described as urban and rural based solely on the DTD of both maximum and minimum temperatures. It is critically important for urban planners to link DTD variability with the UHI effect to assess the health burden of heat, issue local heat-related weather alerts and closures, or target UHI mitigation strategies.

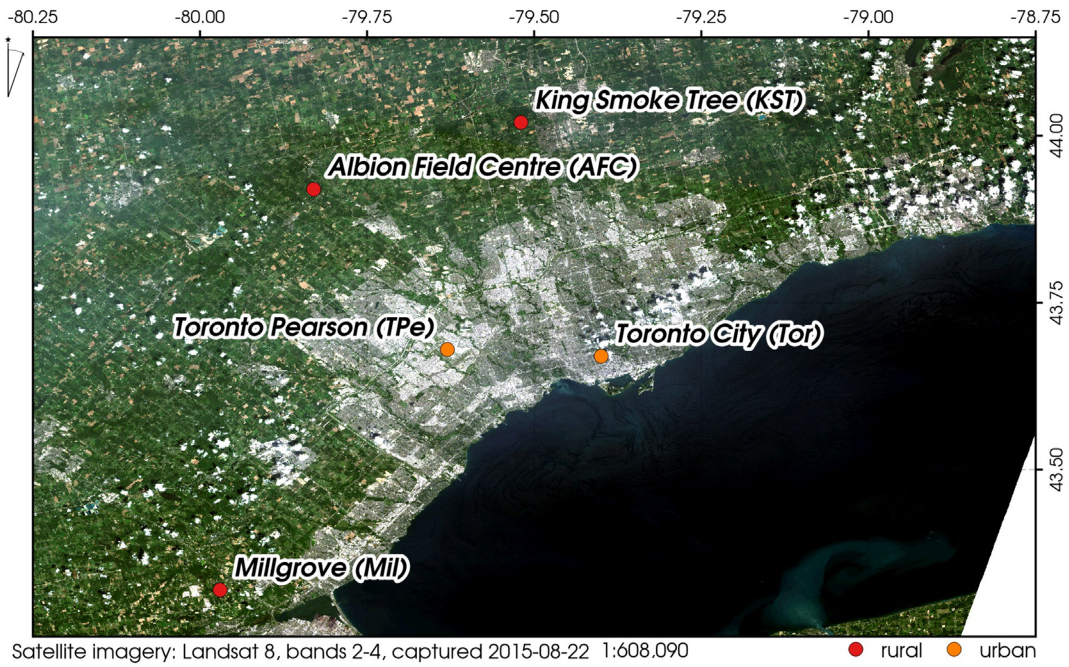

Fig. 1. Map of study stations, urban sites have orange markers; rural sites have red markers. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)