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Evaluation of a Diagnostic Equation for the Daily Maximum Urban Heat Island Effect

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Abstract

A diagnostic equation for the urban heat island (UHI) effectwas evaluated by field observations in Nanjing, China. It is the first time for the equation to be evaluated in a city outside of Europe. The field observation was carried out based on the Local Climate Zone (LCZ) scheme, which aims to provide an objective and standardized classification protocol for urban temperature studies in any city. The diagnostic equation was tested for 7LCZ types under different weather conditions during the period from July to November 2016. The results show that the equation is capable of diagnosing the daily maximum UHI with an acceptable level of accuracy (r^2=0.46, *RMSE*=1.08 K, *MEAE*=0.76 K).

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Keywords: Urban heat island; diagnostic equation; local climate zone; field observation

1. Introduction

Urbanization and climate change aggravate the phenomenon of urban heat island (UHI). The UHI can be modelled with numerical models such as the Weather Research and Forecasting (WRF) modeland the Town Energy Balance (TEB) model.But these models are usually time-consuming and over-complicated. Alternatively, there have

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been several attempts to diagnose the UHI using simple equations. Hidalgo et al.[1] provided a set of equations through numerical experiments. It is dependent upon the difference in the sensible heat flux between the rural and urban surface and the boundary-layer height.Lee et al. [2] found that the UHI intensity can be scaled with the urban length scale, wind speed, and sensible heat flux. However, the application of these equations is still difficult because some of the parameters used in these equations are not routinely measured, such as sensible heat flux.

In the latest study by Theeuwes et al.[3], a new diagnostic equation for the UHI just based on routine meteorological parameters is proposed. Unlikemost of theUHIdiagnosticequations derived from regression analysis, this diagnostic equation is physically based using dimensional analysis. It is based on routine weather observations and basic urban characteristics. The required meteorological variables include screen-level temperature, solar radiation, and 10-m wind speed in the rural area. For urban morphology parameters, sky view factor and vegetation fraction are needed.The evaluation of the equation for 14 cities across northwestern Europe shows a satisfactory estimation of the daily maximum UHI under different weather conditions [3]. However, further evaluations in other climate zonesarenecessary. In the present study, the field observations in Nanjing, China, based on the Local Climate Zone (LCZ) scheme were used to test the diagnostic equation.

The LCZ scheme, developed by Stewart and Oke[4], aims to providean objective and standardized classification system for UHI studies. A Local Climate Zone is defined as an area with a minimum radius of 200–500 m which has uniform features in terms of surface cover, structure, material, and anthropogenic heat flux. Each LCZ has a characteristic screen-height temperature regime that is most obvious on calm, clear nights. The evaluation and application of the LCZ scheme have been increasingly reported from various cities around the world [5-8]. In these literatures, the LCZ scheme shows a good climatological relevance of the thermal climates of LCZs with their local surface structural and land cover properties.

The present study is the first attempt to evaluate the performance of the diagnostic equation for the daily maximum UHI, using the field observations from different LCZ sites in metropolitan Nanjing, China.

2. Methods

2.1. UHI observation based on the LCZ scheme

Nanjing, which covers an area of 860 km^2 with a population of more than 8 million, is located in the Yangtze River Delta (32°49′ N, 118°48′ E). Nanjing endures a hot summer and cold winter climate, with a daily average temperature between 28.6 ℃ (Jul.) and 2.2 ℃ (Jan.). The city's varied topography comprises mountains, low hills, plains, rivers, and lakes. According to the indicators and illustrations of the LCZ scheme [4], 12 LCZ sites were selected by viewing satellite images, field visits, and urban indicators calculations. Since the diagnostic equation is valid for $0 < f_{veg} < 0.4$ and $0.2 < SVF < 0.9$ (where f_{veg} is the vegetation fraction in a radius of 500 m, SVF is mean sky view factor), 7 LCZ sites of 12 met the criterion and were analyzed for this study. The classifications, satellite images, photos, and properties for the 7 LCZ sites are listed in Table 1.

Temperature data were collected from the three fixed observation points located within the core area of each LCZ site (within a radius of 100 m). Each observation point housed a HOBO Temp/RH data logger (type U23-001, precision ±0.2K) in a louvred radiation shield. All data loggers were mounted onlamp posts at 2.3–2.7 m height above groundfor the sake of safety. Data were recorded in theinternal memory at 1-hour intervals and were downloaded in situ every couple of months. The average temperature of the threeobservation points of each LCZ site was used to obtain a better spatial representativeness of the local thermal climate. In thestudy, the first batch of data from 21 July to 18 November 2016 was analyzed.

The weather condition of light winds, clear skies is suitable for the development of heat island effect. The weather factor proposed by Oke[9] was used to identify relatively calm, clear nights. In total, 29 days met the selection criterion for the studied period (5 days in Jul., 8 days in Aug., 10 days in Sept., 6 days in Nov.). For more detailed description about the selections of the LCZ sites and the typical meteorological days, please refer to the article "*Analysis of local heat islands in Nanjing, China, based on the local climate zone scheme* (Yang et al.)"[10]in the same conference.