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Mapping the local climate zones of urban areas by GIS-based and WUDAPT methods: A case study of Hong Kong

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ABSTRACT

Local Climate Zone (LCZ) developed by Stewart and Oke has become an international standard to analyse urban morphology and the corresponding urban heat island phenomenon. Primary methods for LCZ mapping include in-situ measurements, geographic information system (GIS)-based and remote-sensing-image-based calculations. However, there are few studies discussing their accuracy and suitability. This study focuses on examining and discussing the GIS-based method and the World Urban Database and Access Portal Tools (WUDAPT) Level 0 method. Hong Kong is selected as the study area due to its complex urban morphology and high-density context. The results show, at a city level, both methods can detect LCZ classifications that match with the actual spatial distribution of land use in Hong Kong. Thus WUDAPT level 0 data can be used as input data for mesoscale weather and climate modelling, when lacking precise urban morphology data. Meanwhile, at a district level, the GIS-based method detects more details than the WUDAPT method. However, WUDAPT method classifies land cover types more accurately. These findings provide an in-depth understanding of different LCZ mapping methods and their advantages and limitations. It can also help climatologists, modellers and planners select an appropriate LCZ mapping method for their studies of urban climatic applications.

1. Introduction

Urbanization in the past half-century has not only changed the physical environment in cities, but also formed local climate characteristics and features unique to urban areas (Esser, 1989; He et al., 2007; Lam, 2006; Lambin et al., 1999; Oke, 1987; Zhou et al., 2004). The Urban heat island (UHI) effect is regarded as one of the most significant consequences of urbanization and industrialization in the 21st century (Wang and Bai, 2008). It is also a popular topic investigated internationally by various approaches and techniques. LCZs are the first attempt to standardize urban climatic studies across the world. Since then, many studies in this field have adopted this concept and method. The concept of LCZ also makes cross-comparisons between different UHI studies world-wide possible because of a standardized LCZ definition and classification hierarchy. More importantly, the output data and the understanding of LCZ classification can be potentially used for weather and climate modelling and other applications since urban information is much needed for climate change research (Pachauri et al., 2015) and climatic-responsive design (Bechtel, 2011; Cleugh et al., 2009; Grimmond et al., 2010; Ng and Ren, 2015).

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1.1. Local Climate Zone studies

1.1.1. Local Climate Zone (LCZ)

The merit of the LCZ scheme lies in its detailed classification of urban land-use type. LCZ scheme serves as a standardized and quantitative method to describe the physical properties of urban morphology and explain their corresponding urban climatic properties (Stewart and Oke, 2009, 2010). There are 17 types of LCZ, including ten built types (LCZ 1–10), and seven land cover types (LCZ A-G) (Stewart and Oke, 2009, 2010). The properties of each LCZ class can be differentiated by metadata, including sky view factor (SVF), aspect ratio, building surface fraction, impervious surface fraction, pervious surface fraction, height of roughness elements, and terrain roughness class (Stewart and Oke, 2012). According to the LCZ scheme, different cities can classify and develop their own LCZs after analysing land use types, morphology features and functions (Stewart and Oke, 2009). LCZs generated following the same scheme help examine UHI phenomenon in different cities.

1.1.2. Primary methods of LCZ classification

The primary methods include in-situ measurement, GIS-based and remote sensing image-based analysing methods. These methods have their own advantages and limitations. In-situ measurement is the most basic method used in LCZ classification. It makes use of an electronic distance meter and the global positioning system to conduct field measurements (Thomas et al., 2014). The measurements record corresponding LCZ's parameters, which are the grounds for subsequent LCZ class identification. An obvious advantage of in-situ measurement is its ease of operation, but the high time and labour costs involved limit its popularity.

GIS-based methods are common techniques for mapping out LCZs. It relies on precise GIS data of urban morphology, planning and even building information to calculate each contributing factor for classifying LCZs. Several researchers use this method to develop LCZ classification maps of their target regions (Perera et al., 2012; Lelovics et al., 2014; Gál et al., 2015). Since the metadata of GIS-based methods are derived from real urban morphologies, GIS-based methods can usually achieve high accuracies. However, not every city's GIS data are complete or accessible to the public, especially in developing countries and regions.

The remote-sensing-image-based method is another widely used way to classify LCZ classes. Different kinds of remote sensing image classification methods are applied to extract LCZ classes by analysing their spatial and spectral information, including object-based image analysis, supervised classification, hierarchical classification with different Normalized Difference Vegetation Indices, and multi-source satellite images (Bechtel et al., 2016; Lin and Xu, 2016). Several kinds of remote sensing images (such as Landsat images, panchromatic VHR, short for "Very High Resolution" data, synthetic aperture radar images, etc.) are used as input data for LCZ classification (Bechtel et al., 2015; Bechtel and Daneke, 2012; Gamba et al., 2012; Lin and Xu, 2016; Mitraka et al., 2015). Among these satellite image-based LCZ classification methods, World Urban Database and Access Portal Tools (WUDAPT) is a global initiative and a community-based volunteer program. It aims to develop an easily achievable LCZ classification scheme that makes use of free data sources, such as Landsat images and training samples from Google Earth (Bechtel et al., 2015; Bechtel et al., 2016; Mills et al., 2015). Thus, many world-wide researchers have adopted and applied the WUDAPT method in their UHI studies (Brousse et al., 2016; Cai et al., 2016; Kaloustian and Bechtel, 2016; Verdonck et al., 2016). It aims to provide products of three levels: Level 0 contains mainly 2-dimensional urban morphological information and rough urban function based on their effect on the local air temperature (Mills et al., 2015; Stewart and Oke, 2012); both Level 1 and 2 provide more detailed 3-dimensional urban morphological information, material composition data and anthropogenic functions at building level, so they are suitable for various weather and climate models (Ching et al., 2017). There are four main advantages of the WUDAPT method:

(1) WUDAPT level 0 method follows a specific standard and procedure for data collection and data processing;
(2) required data, software and generated results of WUDAPT are free and can be publicly accessed;
(3) anyone can refer to, share and process these results further;
(4) the data generated from this process can be applied to other studies, such as weather and climate modelling, urban planning, and public health (Feddema et al., 2015).

1.2. Research gap and objectives

Although various classification methods have been developed since the LCZ scheme was proposed, there are limited cross-comparison studies carried out to examine the classification accuracy of different LCZ mapping methods, as well as their suitability for applications (Gál et al., 2015). Thus, this study focuses on both GIS-based and WUDAPT level 0 methods to analyse their advantages and limitations, and explore their suitability for potential applications at both city and district levels. Hong Kong is selected as the case study city due to its complex urban morphology and the availability of data. Performance evaluation is also conducted to determine both methods' applicability. The results of the study can help researchers select an appropriate LCZ mapping method, and further develop and improve their accuracy.

2. Methodology

2.1. Site and location

Hong Kong is located at the south coast of China. It has a humid subtropical climate. According to the historical records of Hong Kong Observatory (HKO), urban wind speed has continued to decrease and urban air temperature has increased over half a century of