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学 位 論 文 題 目	Extraction and Comparison of Urban Climate Characteristics in Tokyo, Shanghai, and Hong Kong Based on Local Climate Zone Scheme (LCZ スキームに基づく東京、上海、香港の都市気候特性の抽出と比較)
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論文内容要約

1. Introduction

Urban heat islands (UHIs) worsen the conditions in the urban thermal environment and negatively affect energy consumption and the health of urban residents. Land surface temperature (LST) and air temperature are the two most important indicators to describe and study UHI, and reducing LST and air temperature is of great significance to mitigate the UHI. To reduce the LST or air temperature, various countermeasures have been proposed. However, effective countermeasure differs in different urban areas according to the local climate, urban morphology, land cover, and so on.

The local climate zone (LCZ) scheme is an urban morphology and land cover-based classification system for studying UHIs, it includes 17 standard types: 10 for built types and 7 for land cover types. Previous studies have demonstrated that LCZ types were generally consistent with LST, and each LCZ type had a characteristic LST. Therefore, using the LCZ scheme to classify different urban areas and analyzing the main factor influencing LST of each LCZ built type can contribute to formulating appropriate countermeasures for different areas to reduce LST, but few studies have investigated this. The heat balance mechanism includes advection, turbulent diffusion, and anthropogenic heat release components, so the heat balance analysis can clarify which component is contributing to the air temperature increase, to formulate appropriate countermeasures for reducing air temperature for different urban areas. LCZ scheme includes 10 built types, so it can better reproduce the urban morphology, land cover, and anthropogenic heat release, improving the accuracy of urban climate simulation, and thereby facilitating the heat balance analysis. Therefore, the LCZ scheme was applied in this study.

Considering that the main factors influencing LST, and the heat balance characteristics may be different in different cities, and the temperature increase in East Asian coastal megacities are much more rapid than the pace of global warming, three East Asian coastal megacities were selected as study areas, including Tokyo, Shanghai, and Hong Kong. This study aimed to extract and compare the urban climate characteristics of Tokyo, Shanghai, and Hong Kong, to propose appropriate countermeasures to reduce LST and air temperature for East Asian coastal megacities, the sub-objectives include as follows:

(1) Clarifying the main factors influencing LST of each LCZ built type in Tokyo, Shanghai, and Hong Kong.

(2) Extracting and comparing heat balance characteristics in Tokyo, Shanghai, and Hong Kong.

2. Thesis structure

This thesis consists of 5 chapters.

Chapter 1: This chapter describes the background and purposes of the current study.

Chapter 2: In this chapter, the LCZ maps of Tokyo, Shanghai, and Hong Kong were generated, and a series of data was calculated using satellite images or geographic information system data, including land cover properties (pervious surface fraction (PSF) and surface albedo (SA)), and urban morphological properties (average building height ($\langle BH \rangle$) and gross building coverage ratio (λp)) of each LCZ built type for each city. The distribution characteristics of LCZ, PSF, SA, $\langle BH \rangle$, and λp of each city were also clarified in this chapter.

Chapter 3: The main purpose of Chapter 3 is to clarify the main factor influencing LST of each LCZ built type in Tokyo, Shanghai, and Hong Kong. In this chapter, the LST of each city was retrieved using satellite images. The LST data was then combined with the data of Chapter 2 to calculate the LST, PSF, SA, $\langle BH \rangle$, and λp of each LCZ in each city. Finally, the linear regression model was used to investigate the relationship between the above properties and LST of each LCZ built type, to clarify the main factors influencing LST of each LCZ built type in each city.

Chapter 4: In this chapter, the weather research and forecasting model (WRF) was used to simulate the urban climate of Tokyo, Shanghai, and Hong Kong in the standard August of the 2000s. In WRF, LCZ was used as land use data, and the data in Chapter 2 was also used to calculate the urban parameter values of each LCZ built type required in WRF to better reproduce the characteristics of each LCZ built type. The WRF results were then used to analyze the heat balance mechanism in different areas of the three cities, to clarify the influence of advection, turbulent diffusion, and anthropogenic heat release components on the air temperature in different areas of the three cities.

Chapter 5: In this chapter, the conclusions of the thesis were highlighted, and future works were discussed.

3. Highlights

3.1 LCZ distribution characteristics in Tokyo, Shanghai, and Hong Kong (in Chapter 2)

The LCZ distributions for Tokyo, Shanghai, and Hong Kong were illustrated in Fig 1 (a), (b), and (c), respectively. In Tokyo, the LCZ built type zones in LCZs in the urban area were distributed as three approximately concentric circles. The open high-rise type zones were concentrated in the central ring (Tokyo Station), the compact mid-rise type zones were in the middle ring, and the compact low-rise type zones were in the outer ring, extending into the suburban area; in Hong Kong, there were some compact high-rise type zones, and they were mainly distributed in the Kowloon Peninsula and Hong Kong Island near Victoria Harbour. The open high-rise type zones were also concentrated in the Kowloon Peninsula and Hong Kong Island. The compact mid-rise type zones were mainly distributed in the north of Hong Kong near Shenzhen; In Shanghai, the urban area was dominated by open built type zones (open high-rise, open mid-rise, and open low-rise type zones). Compact built type zones (compact mid-rise and compact low-rise type zones) were concentrated in a small region on the west side of the Huangpu River near the Shanghai Railway Station, and there were more built type zones on the west side of the Huangpu River than on the east side.

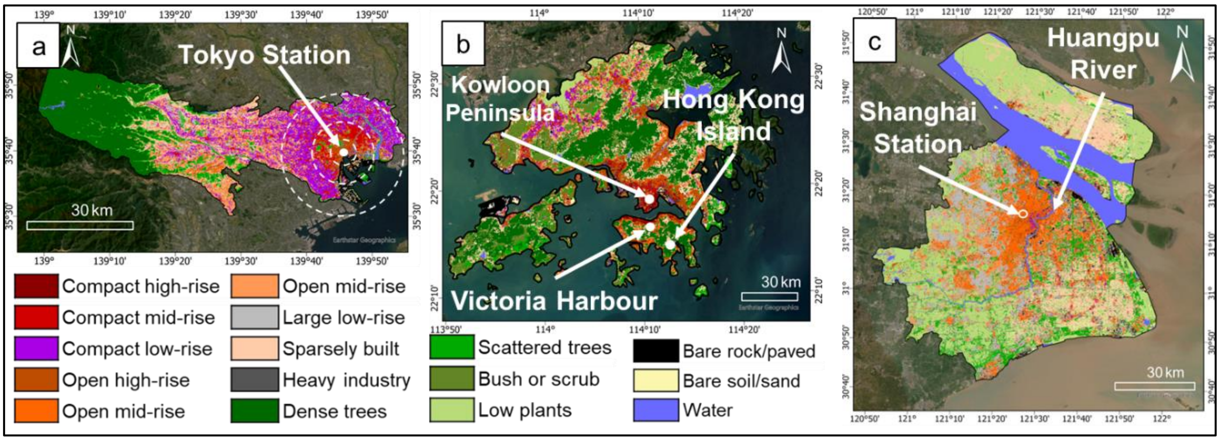


Fig. 1 *LCZ maps of Tokyo, Hong Kong, and Shanghai : (a) Tokyo; (b) Hong Kong; (c) Shanghai*

3.2 Main factor influencing LST of each LCZ built type in Tokyo, Shanghai, and Hong Kong (in Chapter 3)

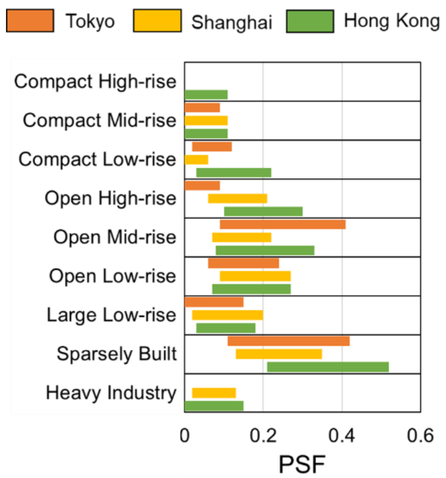
To understand the relationship between PSF, SA, $\langle BH \rangle$, λp and LST of each LCZ built type in each city, linear regression analyses were performed. The correlations between LST and properties were measured by the coefficient of determination (R^2). The main factor influencing LST of each LCZ built type was clarified by comparing the value of R^2.

Table 1 *Correlations between properties and LST of each LCZ built type in Tokyo, Shanghai, and Hong Kong*

no correlation | negative correlation | positive correlation

LCZ built type	R^2 between properties and LST					
	Tokyo		Shanghai		Hong Kong	
	PSF	$\langle BH \rangle$	PSF	$\langle BH \rangle$	PSF	$\langle BH \rangle$
Compact high-rise	-	-	-	-	0.010	0.127
Compact mid-rise	0.014	0.154	0.012	0.112	0.062	0.131
Compact low-rise	0.122	0.095	0.162	0.003	0.416	0.023
Open high-rise	0.022	0.227	0.292	0.029	0.341	0.004
Open mid-rise	0.336	0.003	0.336	0.050	0.380	0.023
Open low-rise	0.364	0.014	0.342	0.001	0.371	0.028
Large low-rise	0.102	0.077	0.282	0.001	0.212	0.001
Sparsely built	0.502	0.000	0.257	0.015	0.523	0.034
Heavy industry	-	-	0.115	0.000	0.186	0.037

Table 2 *PSF ranges of each LCZ built type in Tokyo, Shanghai, and Hong Kong*



The results in Table 1 illustrated that the main factors influencing LST of different LCZ built types differed in Tokyo, Shanghai, and Hong Kong. For compact mid-rise type in three cities, $\langle BH \rangle$ was the main factor influencing LST. For open mid-rise, open low-rise, large low-rise, sparsely built, and heavy industry types, PSF was the main factor influencing LST. For open high-rise type, there are differences between Shanghai, Hong Kong, and Tokyo. The main factor influencing LST of open high-rise type in Tokyo was $\langle BH \rangle$, while that in Shanghai and Hong Kong was PSF. The reason is that the buildings in open high-rise type zones in Tokyo are mainly commercial buildings, and the land cover between buildings is mainly artificial cover, with very little vegetation, which leads to the low PSF. In contrast, the buildings in open high-rise type zones in Shanghai and Hong Kong are mainly residential buildings, the areas between buildings are covered with many vegetations, which leads to the relatively high PSF. Table 2 showed the PSF ranges of each LCZ built type in three cities. In Tokyo, the PSF of open high-rise type is very low, and in a narrow range, so PSF showed no correlation with LST. In Shanghai and Hong Kong, the PSF of open high-rise type is relatively high and in a relatively wide range, so PSF showed a correlation with LST.

3.3 Heat balance characteristics in Tokyo, Shanghai, and Hong Kong (in Chapter 4)

The daytime wind speed and wind direction distributions of Tokyo, Hong Kong, and Shanghai in standard August of the 2000s were illustrated in Fig 2 (a), (b), and (c), respectively. In the daytime, the wind in Tokyo is mainly the sea breeze from Sagami Wan, and the wind in Hong Kong is mainly the sea breeze from the southeast. The wind in Shanghai not only comes from the sea but also from the lake on the west side, so Shanghai may be influenced by both sea breeze and lake breeze. To evaluate the influence of sea breeze or lake breeze, a series of control volumes (C.V.s) were selected in each city along the direction of the sea breeze or lake breeze, and then the advection, turbulent diffusion, and anthropogenic heat release components of each C.V. were compared. The location of each C.V. was shown in Fig.2. The land use of C.V.1 and C.V.2 in Hong Kong are compact high-rise type, and the land use of the rest of C.V. are open LCZ built types.

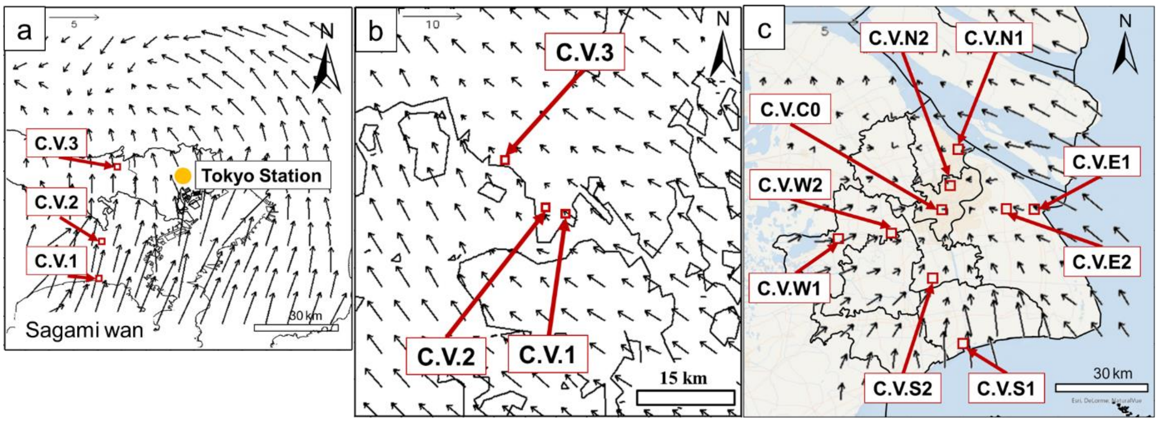


Fig. 2 *Wind speed and wind direction of daytime in Tokyo, Hong Kong, and Shanghai :*

(a) Tokyo; (b) Hong Kong; (c) Shanghai

The comparison results illustrated that the advection component of all C.V.s during the daytime are negative, and the closer to the coastal area, the greater the absolute value of the advection, indicating that for Tokyo, Hong Kong, and Shanghai, the sea breeze is the most import way to reduce the air temperature. On the west side of Shanghai, the closer to the lakeside, the greater the absolute value of the advection, which indicated that the lake breeze is also an important way to reduce the air temperature in Shanghai. The comparison of anthropogenic heat release showed that the anthropogenic heat release of C.V.1 and C.V.2 in Hong Kong is much higher than other C.V.s in these three cities. This is because the land use of C.V.1 and C.V.2 in Hong Kong are compact high-rise type. Among these three cities, only Hong Kong has compact high-rise type, and the total building floor area of compact high-rise type is much higher than other LCZ built types, resulting in its high anthropogenic heat release. Therefore, the anthropogenic heat release of the compact high-rise type in Hong Kong has a great effect on increasing the air temperature.