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Local Climate Zone Study for Sustainable Megacities Development by Using Improved WUDAPT Methodology – A Case Study in Guangzhou

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Abstract

High density urban development in the past has not only changed natural landscape into artificial constructions and pavements, but also brought along many environmental problems like air pollution, urban heat island (UHI) and dust haze, which can affect the public health condition. There are limited applied urban climatic studies in urban planning and development. One of key reasons is there is a missing link between urban development and its corresponding impact on local climatic conditions. The concept of Local Climate Zone scheme has been developed to fit into this gap¹. It introduces a standardized scientific way to describe the land cover and its thermal performance on the UHI. Since 2012, The World Urban Database and Access Portal Tools (WUDAPT) have been developed to call for international efforts and collaborations on world-wide LCZ studies. Its level 0 method can quickly collect urban morphology information and create LCZ maps². However, it's time consuming to use WUDAPT to classify cities globally as WUDAPT is designed at city scale. This paper aims to improve the current methodology to classify more cities in a shorter time and also achieve a more accurate result. In this paper, Guangzhou is selected as case study since it has complex urban morphology and can represent as typical megacity in China. The study firstly reviews the concept of LCZ and WUDAPT. Secondly, the level 0 method of WUDAPT is used to initially classify LCZs of Guangzhou. For enhancing the efficiency of the existing WUDAPT, an improved methodology is developed to use WUDAPT to classify a region and extract the cities inside the region. Thirdly, the relevant quality checking work of the two methodologies is also conducted to detect the accuracy of the two methodologies. The improved outputs can be applied to numerical modellings and local planning implementation³. Because the future trend of urbanization in China is towards megacity development, the lessons learnt from the study can be applied to other megacities and regions for better climatic-spatial planning in future.

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1. Introduction

The rapid urbanization in China has led to a serial of environmental problems, especially the urban heat island (UHI) phenomenon. Excessive heat in cities has impact on the sensation of thermal comfort, health and performance of inhabitants and affects their daily or leisure activities. Because of this, it is important and necessary to understand the urban development and its corresponding impact on local climatic conditions. For this purpose, the concept of Local Climate Zone has been developed to quantify the correlation between urban morphology and UHI¹. The World Urban Database and Portal Tool (WUDAPT) is a newly developed approach to recognize the LCZ classification. WUDAPT has been created to collect requisite urban morphology and activity data globally, and provided the information in a form suitable for climate science by using a straightforward methodology as well as open and free software and data².

However, the existing WUDAPT method is developed for urban climate study at city scale. It will take an excess of time to classify numerous cities one by one by the method^{4, 5, 6}. Thus it is significant to improve the existing WUDAPT methodology to generate the LCZ maps in a more effective and quicker way. If WUDAPT can classify a large region then extract cities inside separately, the efficiency will be much improved. Whether WUDAPT is still suitable to classify several cities at one time has not been studied yet. This paper aims to check the feasibility of WUDAPT for regional study and provide a more efficient WUDAPT methodology for individual city. The LCZ map of either the whole region or the cities in the region can be generated based on the results. Thus the efficiency of LCZ classification can be greatly improved, which is significant for urban climate study.

2. Review

2.1 Local Climate Zone (LCZ)

Steward and Oke developed LCZ to redefine and quantify the UHI effect¹. Each LCZ aims to have homogenous air temperature and is defined by both qualitative and quantitative properties. One of the major advantages of LCZ is the new perspective of urban heat island, looking into the temperature differentiation among LCZ classes rather than the traditional “urban” and “rural” classes. It emphasized the importance of intra-urban temperature comparison among different urban classes, to analyze the influence of heterogeneous urban morphology on local climate formation. LCZ has 17 standard types including two subsets: 10 built types and 7 land cover types.

2.2 The World Urban Database and Access Portal Tools (WUDAPT)

This method is designed to be universal, simple and objective which targets to be part of a global protocol to derive information about form and function of cities. With free satellite images and free software of Google Earth (GE) and SAGA-GIS. It applies globally available Landsat satellite images as an input data.

2.3 The problems in existing WUDAPT methodology

WUDAPT aims to classify cities globally and generate a world urban morphology database. Worldwide urban climate researchers have applied WUDAPT for LCZ studies. Currently 31 Chinese cities have been classified while there are 333 prefecture-level cities in China that are still needed to be classified⁷. It is a time-consuming process filled with image preprocessing and selecting training samples for each city. It is even a bulky workload to analyze cities globally. The existing methodology, therefore, has to be improved.

3. Methodologies

3.1 Study area

The GPRD (Greater Pearl River Delta) includes the HKSAR, the Macao Special Administrative Region, and the PRD Economic Zone portion of Guangdong Province. The PRD Economic Zone, as specified by Guangdong Province, includes nine municipalities, namely Guangzhou, Shenzhen, Dongguan, Foshan, Jiangmen, Zhongshan, Zhuhai, and the urban areas of Huizhou and Zhaoqing⁸. It is one of the most densely urbanized regions in the world. With China's remarkable economic growth since the beginning of the country's reform period in 1978, the urbanized areas increase by 8.47% annually, rising from 1,068.7 km² in 1979 to 4,617.16 km² in 2008⁹. The rapid expanding urban areas have emerged into one large region and formed a megaregion and urban agglomeration. Given these dramatic land use changes, it is not surprising that the GPRD has experienced noticeable regional climate changes. The Guangdong Meteorological Administration reported that the GPRD witnessed great temperature change of averaging +0.3 °C every 10 years¹⁰.

Guangzhou of the GPRD is located in the South of China with total area of 7434 km². It is one of the most urbanized cities in GPRD and megacities in China. During its rapid urban expansion, the previously dispersed built-up areas have been integrated to a large extent and spread into the adjacent cities like Foshan and Dongguan¹¹. In addition, Guangzhou has high population of about 8.5 million population, greatly increasing the anthropogenic heat emissions¹². Therefore, the UHI phenomenon is a significant, moreover immediate, problem of Guangzhou and GPRD that has to be investigated.

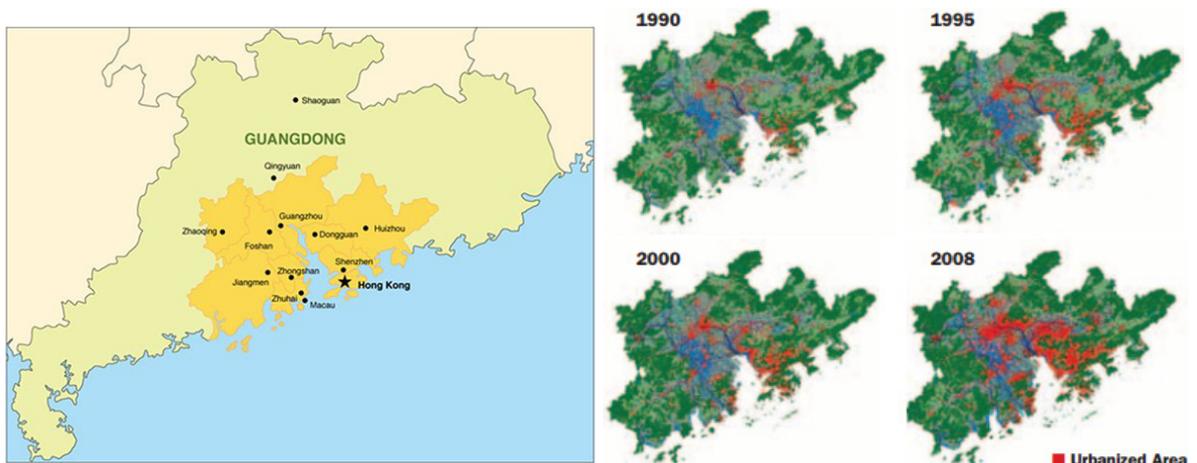


Fig. 1. (a) The Pearl River Delta; (b) Urban Expansion in the GPRD⁹.

3.2 data

Landsat 8 level 1 images of the PRD with resolution of 30m were downloaded from the USGS (U.S. Geological Survey). Urban morphology Information including the building and land cover was derived from GE.

Table 1 Landsat images information.

Landsat Entity ID	Date
LC81210442013278LGN00	October 5, 2013
LC81220452013365LGN00	December 31, 2013
LC81210452015220LGN00	August 8, 2015
LC81220442015291LGN00	October 18, 2015

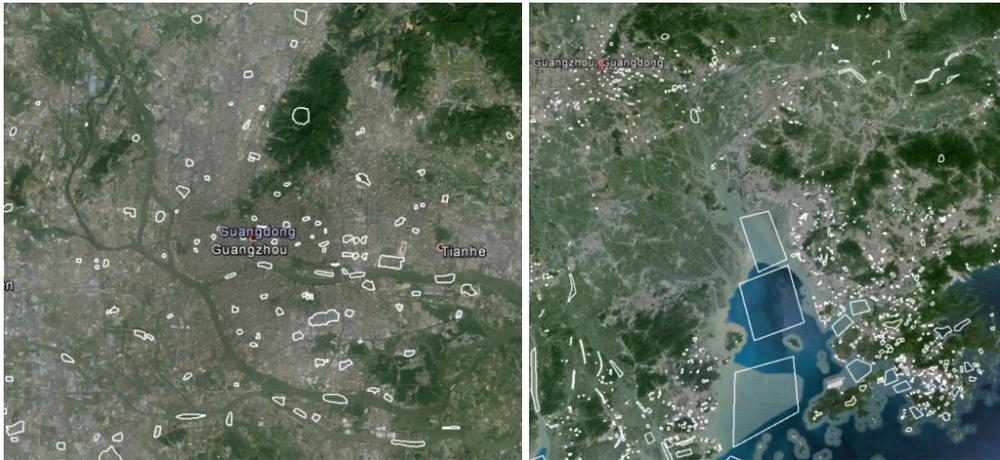


Fig. 2. (a) Screenshots of Training samples of Guangzhou from GE; (b) Screenshots of Training samples of GPRD from GE.

3.3 Improved WUDAPT methodology

The existing WUDAPT generates the LCZ map at city scale. Only satellite image and training samples of Guangzhou were involved in the workflow (Fig.3. (a)). In order to apply WUDAPT to a region, the 4 Landsat images of the whole GPRD (Table 1) were used for the classification. The GPRD is regarded as one part in this method due to the similar geographic characteristic and urban morphology of the GPRD cities. The training samples of Shenzhen, Huizhou were added to the Training samples of Guangzhou. As the urban morphology of Hong Kong is different from the other GPRD cities, the training samples of Hong Kong were also used (Fig.3. (b)).

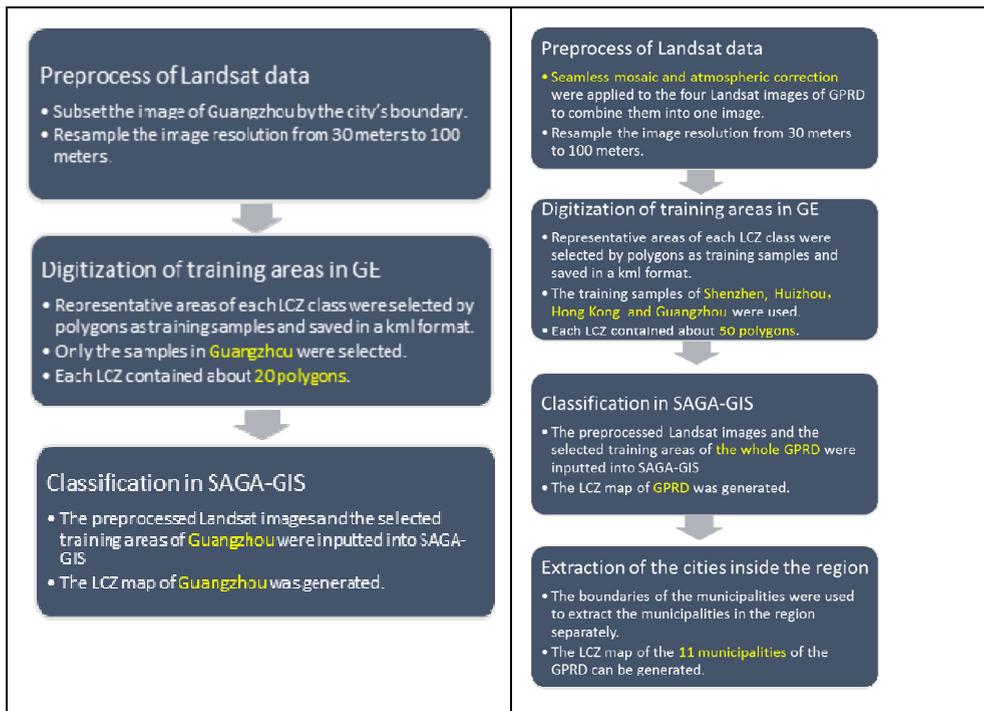


Fig. 3. (a) Workflow of WUDAPT²; (b) workflow of improved WUDAPT.

4. Results and analysis

4.1 LCZ map of GPRD

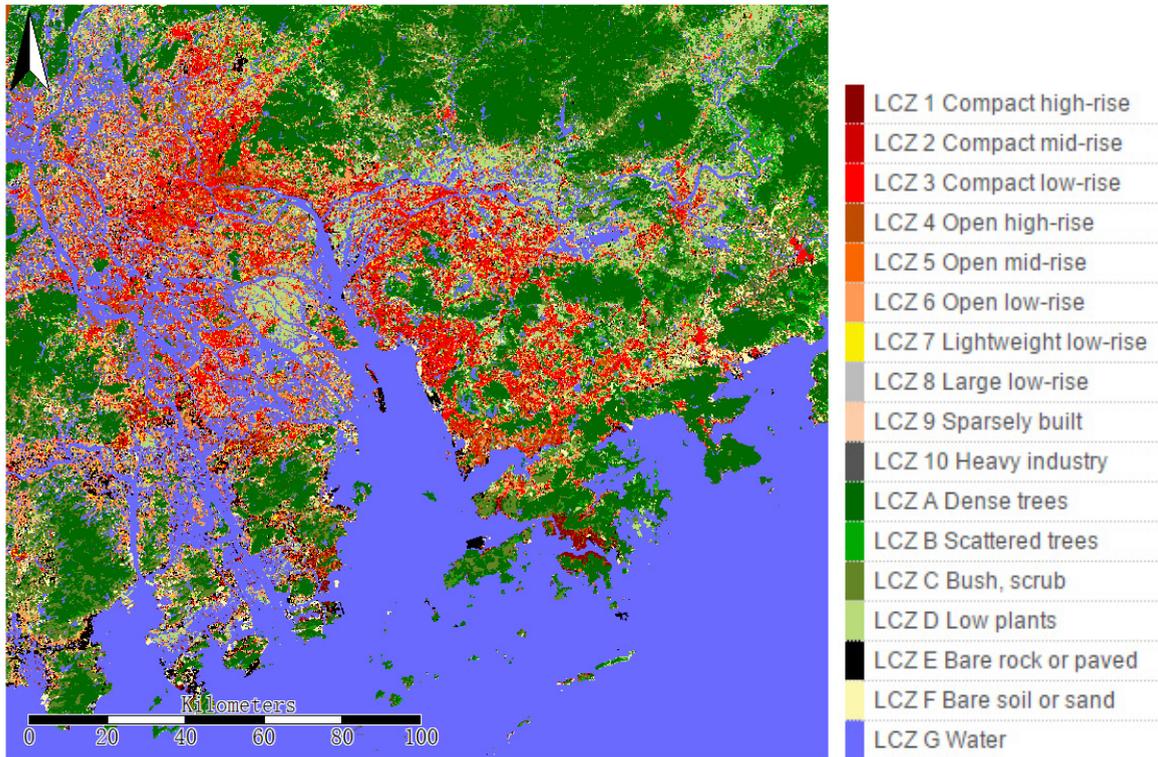


Fig. 4. LCZ map of GPRD

The classification result of the PRD is more reliable and accurate due to the atmosphere correction of the satellite images that eliminated the solar and atmosphere influence in comparison to the existing WUDAPT. The LCZ map of PRD indicated the high degree of urbanization with widely-spread and densely-located built-up areas of LCZ 1-6. In addition, the GPRD region is a megalopolis with several municipalities combining into one large area. In particular, the urban morphology in Hong Kong and Macau is extremely dense with LCZ 1 accounting for most of the urban area. The large urban areas of GPDR imply the potentially high UHI intensity and poor thermal environment.

4.2 comparison of Guangzhou LCZ maps by the two methodologies

In order to make comparison of the accuracy between the two methods, the LCZ map of Guangzhou is extracted from the LCZ map of GPRD (Fig.5. (b)).

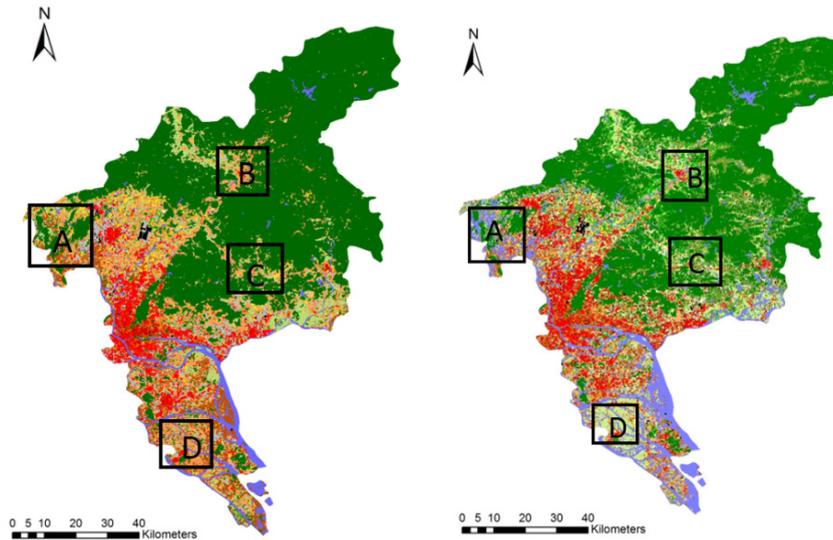


Fig. 5. (a) Guangzhou LCZ map by existing methodology¹; (b) Guangzhou LCZ map by improved methodology.

In the two LCZ maps of Guangzhou appear to be similar in general while there is some obvious difference in the rectangular areas (Fig. 5).

Area A is supposed to be a region with the fish ponds and wetlands according to GE image. The improved methodology has a more correct result as there is no LCZ for this land covering. What's more, area B, C, D were classified as LCZ6 by existing methodology while it was classified as LCZ D by the improved methodology. Area B and C are suburbs and have mostly low rise buildings thus the first result is better. Area D is comprised of villages and farmlands, hence the improved methodology performs better for this area.

In order to get quantified accuracy comparison between the two results, accuracy assessment is conducted to the two LCZ maps separately. The GE image is regarded as the reference data in this paper which is believed to be accurate enough to reflect the true land-cover to validate the classification result. For more objective evaluation of the classifiers' performance, an independent subset of about 0.5% of each class was randomly chosen which was not selected as training sites. The accuracy assessment of the two methodologies used the same set of validation samples from GE to make an objective comparison.

The results of an accuracy assessment are usually summarized in a confusion matrix. The degree of confusion between the classification result and the ground truth can be calculated in the matrix.

Table 2. Confusion matrix of Guangzhou by existing WUDAPT methodology.

LCZ	1	2	3	4	5	6	7	8	9	10	A	B	C	D	E	F	G	No. Classified pixels	user accuracy
1	11	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	25	0.44
2	2	31	0	10	10	0	0	0	0	33	0	0	0	0	0	0	1	87	0.36
3	0	0	84	2	0	0	1	7	0	3	0	0	0	0	0	0	154	251	0.33
4	23	1	1	122	7	29	2	2	0	75	0	0	0	6	0	0	0	268	0.46
5	0	0	0	1	11	0	2	0	0	2	0	0	0	0	0	0	0	16	0.69
6	0	0	0	1	3	37	12	0	18	32	0	3	0	4	5	1	0	116	0.32
7	0	0	0	0	0	0	69	0	0	24	0	0	0	1	0	0	0	94	0.73
8	0	0	0	0	0	0	7	64	0	6	0	0	0	0	1	0	0	78	0.82
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	25	1.00
A	0	0	0	0	0	0	0	0	175	0	1833	0	0	0	0	0	15	2023	0.91
B	0	0	0	0	0	3	0	0	0	0	0	6	0	0	0	0	0	9	0.67
C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	0	0	0	0	0	3	7	0	31	0	11	0	160	0	0	0	0	212	0.75
E	0	0	0	0	0	0	0	8	0	3	0	0	0	0	7	0	0	18	0.39
F	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	14	0	17	0.82
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	706	706	1.00
No. ground truth pixels	36	32	85	150	31	72	103	81	224	203	1833	20	0	171	15	15	876	3945	
producer Accuracy	0.31	0.97	0.99	0.81	0.35	0.51	0.67	0.79	0.00	0.12	1.00	0.30	0	0.94	0.47	0.93	0.81		
overall accuracy	80.61 %																		
Kappa	72.82 %																		

Table 3. Confusion matrix of Guangzhou by improved WUDAPT methodology.

LCZ	1	2	3	4	5	6	7	8	9	10	A	B	C	D	E	F	G	No. Classified pixels	user accuracy
1	12	0	0	13	0	0	0	0	0	11	0	0	0	0	0	0	0	36	0.33
2	3	32	0	10	9	0	0	1	1	31	0	0	0	0	0	0	0	87	0.37
3	1	0	87	3	0	0	0	11	0	44	0	0	0	2	3	0	0	151	0.58
4	25	0	0	112	5	0	1	3	0	19	0	0	0	12	0	0	0	177	0.63
5	0	0	0	8	10	2	2	0	2	12	0	0	0	0	0	0	0	36	0.28
6	0	0	0	0	0	67	15	1	43	34	0	0	0	10	0	1	0	171	0.39
7	0	0	0	0	0	0	73	1	1	5	0	0	0	11	0	0	0	91	0.80
8	0	0	0	0	0	0	8	57	0	0	0	0	0	0	0	0	0	65	0.88
9	0	0	0	0	0	1	0	0	2	0	0	0	0	10	0	0	0	13	0
10	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	25	1.00
A	0	0	0	0	0	0	0	0	119	0	1830	0	0	0	0	0	15	1964	0.93
B	0	0	0	0	0	0	0	0	10	0	9	10	0	0	0	0	0	29	0.34
C	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	30	0
D	0	0	0	1	0	0	4	0	18	3	0	11	0	114	0	0	0	151	0.75
E	0	0	0	2	0	0	0	3	2	14	0	0	0	6	6	0	0	33	0.18
F	0	0	0	0	0	0	5	0	2	0	0	0	0	0	0	14	0	21	0.67
G	0	0	0	0	0	0	0	0	0	1	0	0	0	3	0	0	854	858	1.00
No. ground truth pixels	41	32	87	149	24	70	108	77	230	199	1839	21	0	168	9	15	869	3938	
producer Accuracy	0.29	1.00	1.00	0.75	0.42	0.96	0.68	0.74	0.01	0.13	1.00	0.48	0	0.68	0.67	0.93	0.98		
overall accuracy	83.93%																		
Kappa	0.7743																		

According to the two confusion matrix, improved WUDAPT methodology has higher overall accuracy and kappa coefficient of the Guangzhou LCZ map. Also, the result regarding the classes LCZs 2, 3, 5, 6, B, E, G have been improved. The reason can be the increase of extra training samples of these classes. To be specific, the urban

morphology of GPRD except Hong Kong and Macau is very similar and homogeneous. The improved methodology adds samples from Shenzhen and Huizhou, improving the classification of Guangzhou in return.

5. Conclusion

In this paper we presented the classification results of Guangzhou with different WUDAPT methodologies. The overall accuracy has been improved from 80% to 84% for the Guangzhou LCZ classification by using the new method. It is not necessary for researchers to classify each city individually. Instead, a large region can be classified once at a time in the first place and each city in the region can be extracted correspondingly. The improvement will be helpful for enhancing the classification efficiency. What's more, this study demonstrates the future potential for regional study of WUDAPT. The Chinese Government recently announced as part of its Thirteen Five Year Plan for national economic and social development that urban agglomerations are one of the main focus for the future urban development¹³. There is growing need to improve the urban system and ensure the healthy development of the urban agglomerations. Other Chinese urban agglomerations similar with the GPRD such as the Yangtze River Delta region can also use the new WUDAPT method to conduct urban climate research in the future. The result can work as the database and information platform for the sustainable urban development implementation in China. Finally, the extensive results can be used as input data for urban climate model simulation and climatic-spatial planning at both regional and city scales.

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