Evaluation of Local Climate Zones in Large Japanese Cities and Its Application to Modelling of Mesoscale Climate over Sendai

	シュウ キ リン
氏名	周 希 霖
授与学位	博士（工学）
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指導教員	東北大学教授　持田　灯
論文審査委員	主査　東北大学教授　持田　灯　東北大学教授　石田　壽一 東北大学准教授　小林　光　東北大学准教授　後藤　伴延

論文内容要旨

1.Introduction

The Local Climate Zone (LCZ) scheme which is originally designed for urban heat islands (UHIs) study is a climate-related classification of homogenous urban structures and land cover types introduced by Stewart and Oke (2012), that has been adopted world-wide as an international standard for climate-related studies. World Database and Access Portal Tools (WUDAPT) Level 0 method announced a workflow of mapping LCZs using a supervised method based on satellite images. For collecting the urban data from worldwide, the expedience and universality is the primary characteristics in this approach. The conventional studies related with LCZ generally focused on the three stages in the "life cycle" of LCZ: accuracy, UHI analysis and model application.

However, the low accuracy of LCZ classifications in Level 0 especially for the built-up areas caused by recognition of classes and operator bias is becoming an obstacle for further study in WUDAPT Level 1 and 2 which required more detailed datasets. Since urban morphology in major cities of Japan is complicated, the recognition of classes and operator bias may also exist for delineating training areas. What's more, as large Japanese cities are coastal cities, the air temperature distribution is influenced by the sea-land breeze. Few studies have been done to examine the UHI magnitude using the LCZ scheme. Furthermore, the properties in the lookup table for the WUDAPT L0 only provided ranges of values that makes the operators hard to select the appropriate values for their target city. For solving the problems mentioned above, this study focused on three aspects:

1) To develop an improved WUDAPT L0 method for mapping LCZ so as to control the subjective problems on the recognition of names, sizes and number of LCZ types.

2) To evaluate the distributions of land surface temperature (LST) and air temperature of LCZs in large Japanese cities under the influences of local winds, such as sea-land breeze.

3) To propose a meso-scale climate modelling method for quantitative scenario analyses on air temperature, energy consumption and heat strokes using LCZ. The accuracy of the new method should be evaluated by comparing with the observed data.

2. A new combined method based on WUDAPT L0 method and GIS method

This new combined method using both GIS and WUDAPT L0 methods is shown in Fig.1. An extended workflow using the calculated the BH, BSF, PSF for re-checking the recognition of standard LCZ types and their subclasses was added in the original WUDAPT level 0. In order to assess the classification accuracy, a set of independent validation samples was randomly selected in Google earth, based on an objective data source (digital land use map of Sendai) to compare with the LCZ map classifications using a confusion matrix. The geometric and land cover properties of building coverage ratio (BCR), building height (BH), pervious surface fraction (PSF) were intersected with LCZ map for analysis and expound of the pre-set recognition of LCZ classes. (Table 1)

The standard training areas and subclass mixed training areas selected in Sendai with different names, number and sizes of LCZ types were taken as examples to present the effectiveness of the improved WUDAPT L0 method to control the recognitions on LCZs and the ability to provide accurate data for WUDAPT L1 and L2. As a result, both of the two sets of training areas can result satisfied accuracies of more than 90% which implies that the number and sizes of LCZ types don't significantly affect the accuracy at the pre-set recognition. Furthermore, the LCZ map generated by standard training areas was generally consistent with the Land Use map of Sendai. (Fig.2) Yet, as the ranges of geometric and land cover properties defined in the WUDAPT lookup table for the standard and subclass LCZs, the names of LCZs should be finally defined according to the comparison between the calculated properties ranges in Sendai and the default ranges in the WUDAPT lookup table.

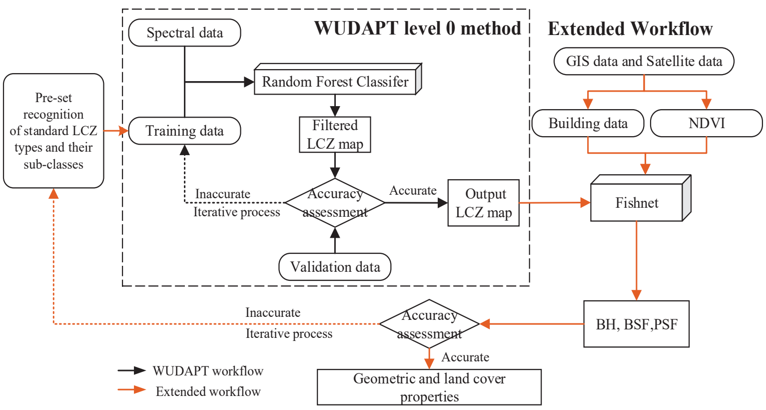

***Fig. 1** A new combined method for mapping LCZs based on WUDAPT L0 method 0*

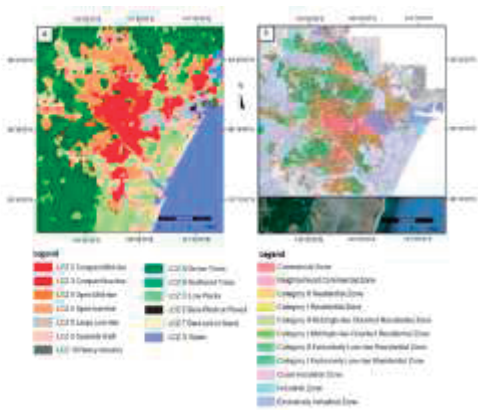

***Fig. 2** (a) LCZ map on 100 m resolution;(b) land use map of Sendai.*

Table 1 Geometric, surface cover, and radiative properties of the LCZ built types in Sendai and the ranges in the lookup table

LCZ	BH (m)			BSF			SVF			PSF			ALB		
	Mean	SD	Stewart & Oke	Mean	SD	Stewart & Oke	Mean	SD	Stewart & Oke	Mean	SD	Stewart & Oke	Mean	SD	Stewart & Oke
LCZ 2 (compact mid-rise)	19.61	9.98	10 - 25	0.29	0.13	0.4 - 0.7	0.67	0.14	0.3 - 0.6	0.04	0.04	<0.2	0.13	0.01	0.10 - 0.20
LCZ 3 (compact low-rise)	7.21	2.41	3 - 10	0.26	0.08	0.4 - 0.7	0.79	0.07	0.2 - 0.6	0.08	0.04	<0.3	0.14	0.01	0.10 - 0.20
LCZ 5 (open mid-rise)	9.15	5.15	10 - 25	0.14	0.11	0.2 - 0.4	0.88	0.08	0.5 - 0.8	0.17	0.11	0.2 - 0.4	0.15	0.02	0.12 - 0.25
LCZ 6 (open low-rise)	6.52	2.01	3 - 10	0.21	0.09	0.2 - 0.5	0.82	0.08	0.6 - 0.9	0.16	0.09	0.3 - 0.6	0.14	0.02	0.12 - 0.25
LCZ 8 (large low-rise)	7.53	3.66	3 - 10	0.22	0.16	0.3 - 0.5	0.90	0.07	>0.7	0.05	0.04	<0.2	0.16	0.02	0.15 - 0.25
LCZ 9 (sparsely built)	6.31	1.55	3 - 10	0.06	0.07	0.1 - 0.2	0.94	0.07	>0.8	0.34	0.17	0.6 - 0.8	0.17	0.02	0.12 - 0.25
LCZ 10 (heavy industry)	7.00	2.65	5 - 15	0.12	0.13	0.2 - 0.4	0.95	0.06	0.6 - 0.9	0.07	0.05	0.4 - 0.5	0.18	0.03	0.12 - 0.20

3. Evaluation of LCZ classifications via the distributions of air Temperature and LST under the influences of sea-land breeze

To assess the influence of mountain-sea breeze on UHIs, thirteen of twenty-two fixed loggers were selected and separated into two groups, named Line P and Line Q, based on the diurnal (6:00-18:00, JST) and nocturnal (21:00-5:00, JST) prevailing wind directions obtained from the one-hour averaged wind data of the Automated Meteorological Data Acquisition System (AMeDAS). The surface kinetic temperature product (AST_08) of ASTER is widely used for LST data. Two AST_08 images – acquired during the night (10:30 pm) on July 29th (Fig. 3.3a) and during the day (10:30 am) on September 26th (Fig. 3.3b)– were used for the hot, summer LST analysis (Identity IDs: AST_08.003:2179595158; AST_08.003: 2127457027). The images were chosen based on availability and cloud cover (less than 10%). Moreover, the regression analysis of corrections of diurnal and nocturnal LST with the PSF, SVF, ALB and of each LCZ built types had been done to invest the mechanism of LCZs thermal distribution.

By dividing Sendai into two regions along its urban center, the mitigating effects of sea-land breeze on the magnitudes of UHIs in each urban-rural area were demonstrated. LCZ map was found to be generally consistent with LST distribution but not match well with air temperature distribution. LCZ scheme should be used cautiously for UHI analysis in Japanese coastal cities, for example under a principle to set the loggers parallel or perpendicular prevailing to wind directions. This part confirmed that the LCZ scheme can be used by urban planners to assess both surface UHI (SUHI) and UHI effects and proposed a feasible process for developing targeted UHI mitigation strategies using LCZ and observing data of LST and air temperature.

4. A meso-scale climate modelling method using LCZ for quantitative scenario analyses on air temperature, energy consumption and heat strokes

WRF/Noah/BEP+BEM scheme was selected for modelling of mesoscale climate over Sendai. While Domain 1 covered the lands of Japan, Domain 2 covered the northeast region of Japan. The horizontal resolution of the smallest domain, namely Domain 3 which covered Sendai Major Metropolitan Area (MMA), was set to 1 km. U.S. Geological Survey (USGS) land-use data was employed for Domain 1 and 2. In the domain 3, land use data from National Land Numerical Information for Japan. For integrating urban LCZ classifications into BEP+BEM, the areas of land use data in region of interest (ROI) of Domain 3 was overlaid by LCZ built types in Sendai. (Fig.3) The heat release of vehicles was first added as the additional sensitive heat release from the air condition. At last, four cases were set up for the accuracy evaluation by comparing with the observed air temperature. (Table 2)

It shows that the appropriate settings of urban fraction makes that errors of Mean Bias (MB) in case i decreased 0.27°C compared with the case ii. Furthermore, compared with the case i, the results of cases ii using WUDAPT L0 data only over underestimate the MB 0.08°C which implies that the WUDAPT L0 data can be used for mesoscale modelling over the cities which didn't have GIS data. In addition, the MB of case iv without the heat release of vehicles has slightly lower MB at 0.011°C which implies that the limited effects of the anthropogenic heat release on the model accuracy. Yet, the new model integrated with the unit of heat release of vehicles provided a feasible way for quantitative analysis on the scenarios related with heat release of vehicles.

Overall, the new meso-scale climate modelling method using LCZ was built up by integrating LCZs with real geometric, land cover properties and heat release of vehicles. It can be used for the analysis on quantitative mitigation effects of countermeasures on the air temperature, skin temperature, energy consumption, and heat risk by setting or changing the geometric, land cover properties and heat release of vehicles of each LCZ type.

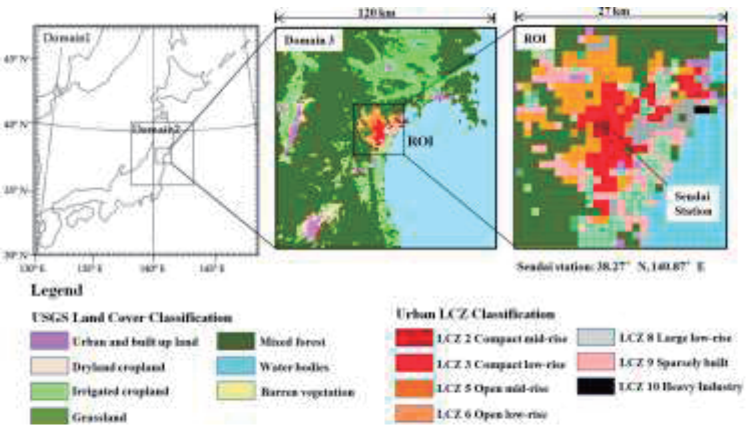

Fig. 3 *Calculations domains for WRF and the domain of ROI*

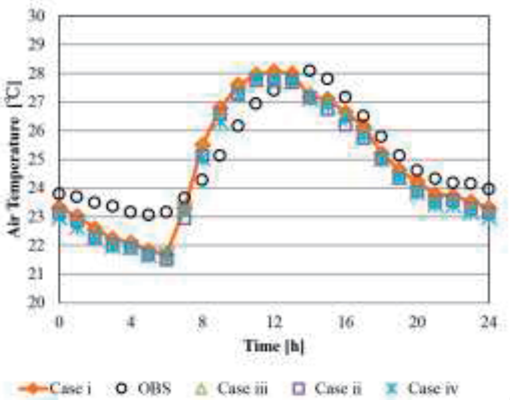

Fig. 4 *The average air temperature comparison in 24 hours during the period*

Table. 2 *The setting of the cases and the results of RMSE and MB by comparing the cases to the observed data*

Items	Urban morphology	Urban Fraction	Heat Release of Vehicles	RMSE	MB	Max	Min
OBS	-	-	-	0	0	28.080	23.050
Case i	GIS Sendai	GIS Sendai	Yes	0.888	-0.271	28.066	21.699
Case ii	GIS Sendai	WUDAPT_1	Yes	0.981	-0.540	27.740	21.491
Case iii	WUDAPT_2	WUDAPT_2	Yes	0.915	-0.359	27.956	21.581
Case iv	GIS Sendai	GIS Sendai	NO	0.889	-0.282	28.082	21.749

論文審査結果の要旨

本論文は、近年、都市気候の研究分野で注目されているLocal Climate Zone (LCZ) に基づく市街地の分類手法を我が国の都市に適用したものである。LCZに基づく市街地分類は、都市のヒートアイランドと土地利用、市街地形状等の関係を分析する目的でStewartとOkeにより2012年に提案され、その後、機械学習により衛星画像等から都市内のLCZの分布 (LCZ map) を求める手順 (WUDAPT (World Database and Access Portal Tools) Level 0 method) が公表された、欧米や中国、香港の都市のLCZ mapの作成が進められつつある。しかし、日本の都市を対象にした研究は非常に少なく、本研究は先駆的な取り組みとして評価される。

LCZ mapの作成の際には、都市内を凡そ1km四方の区画ごとに分割し、各区画毎の市街地形状を高層・高密、低層・低密等の様に分類するが、1km四方の区画内では土地利用、建物形状が余り変化しない欧米の都市を前提に開発された手法を、低層の戸建て住宅の並ぶ市街地に高層マンションが隣接するような我が国の都市に適用する際には、二つの大きな問題があった。一つ目の問題は、従来のWUDAPT Level 0 methodでは、高層・中層・低層、或いは、高密・低密等の市街地形状に係る分類の際の基準が明確ではなく、作業者の主観に委ねられているため、作業者が異なると異なるLCZ mapとなってしまっていたという点である。これに対して、本論文ではGISデータを用いてWUDAPT Level 0 methodより得られたLCZの精度を確認するという手順を付加して、この問題を解決している。二つ目の問題は、我が国の都市では、一つの1km四方の評価領域内に様々な土地利用が混在する場合が多いということである。これに対して、本論文では、1km四方の評価領域内の土地利用を更に細かく調べて、LCZのclass分けにsubclassを付加した市街地類型を、従来の市街地類型に加えることにより解決している。

さらに、本論文では、仙台のLCZ分布と地表面温度分布、気温分布を比較し、地表面温度の分布や比較的風速の弱い夜間の気温の分布はLCZの差からよく説明できること、一方、海風の影響下の日中の気温はLCZだけでは説明が難しいことを指摘している。これらは、大都市の多くが沿岸部に位置する我が国において、今後、LCZを用いた分析を行う上で重要な指摘である。

最後に、本論文では、LCZ分類に基づく土地利用分類から領域気象モデルWRF (Weather Research and Forecasting) のための入力データを生成し、これを用いた仙台の都市気候の解析を試みている。LCZとBuilding Energy Model (BEM) を組み合わせることにより、建物からの空調排熱や自動車排熱の影響を含む詳細な解析が可能となっており、今後の研究のための有効な解析技術が整備されたものと評価される。

以上のように、本研究は、欧米の都市の状況を前提に開発されてきたLCZによる土地利用分類法を我が国の都市に適用する際の課題を抽出し、解決策を提案するとともに、これを用いて我が国の沿岸都市の気候形成メカニズムを分析する際の留意点を明らかにしたものであり、今後の我が国の都市気候の研究の発展に大きく寄与し得るものである。また、本論文における手法の改良の過程において、我が国の都市空間の構成要素や都市気候の形成要因の特徴に関する様々な知見が得られている点も評価される。

よって、本論文は博士（工学）の学位論文として合格と認める。