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Academic Article

Urban Environmental Climate Maps for Urban Planning Considering Urban Heat Island Mitigation in Hiroshima

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ABSTRACT

In recent years, urban heat island phenomena caused by land cover change and increase of anthropogenic heat release occur in many cities throughout Japan. Temperature rises in urban areas because of this urban heat island phenomenon and global climate change. In Hiroshima, the severe urban heat island phenomenon reportedly engenders high temperatures. Therefore, urban planning incorporating mitigation of the urban heat island phenomenon is also necessary in Hiroshima. Urban Environmental Climate Maps (UECMs) are made for urban planning, architectural design, and environmental policy-making in considation of urban heat island mitigation. For producing UECMs, first, it is necessary to elucidate the summer temperature distribution patterns and their contributing factors in urban area. Therefore, this study aims at analyzing the temperature distribution according to patterns by observed data in Hiroshima, and classifying all observation points based on the daily temperature distribution.

Key Words : Urban environment climate maps, Climate zoning, Urban heat island phenomenon, Coastal city

1. Background and objective

In recent years, urban heat island phenomena caused by land cover change and increased anthropogenic heat release are occuring in many cities throughout Japan. Temperatures rise in urban areas because of this urban heat island phenomenon and global warming. Accordingly, various problems have occurred such as uncomfortable outdoor environments in summer, increased energy consumption, effects on urban ecosystems, and damage to human health. In Hiroshima, the severe urban heat island phenomenon reportedly engenders high temperatures. Therefore, urban planning incorporating mitigation of the urban heat island phenomenon is needed for Hiroshima. The authors intend to produce Urban Environmental Climate Maps (UECMs) for Hiroshima as the final goal of this study.

Few reports in the relevant literature describe studies in which planners (or stakeholders) examine urban heat island phenomenon mitigation based on scientific knowledge in their planning processes. That is true apparently because the urban climate phenomenon is difficult for stakeholders (e.g., residents, local government officials, designers, and planners) to understand. UECMs are therefore proposed as a tool supporting urban planning decision. Although trial UECMs incorporating urban heat island mitigation have been produced in Japan, their definitions differ slightly. Therefore, the authors supply a definition for UECMs from a reference in the literature(1) as follows. UECMs are made for urban planning, architectural design, and environmental policy-making in consideration of urban heat island mitigation. The role of this map is to provide some information from the view of urban climate to the place of decision making (including public involvement). Therefore, the purpose of creating these maps is to support design. The essence of climate research results and recommendations by experts are described on UECMs. When stakeholders (e.g., regidents, planner, architects, specialists) make decisions about urban planning, architecture design, and environmental policy-making, they and experts can use these maps as communication tools. Actually, UECMs consist of a Climate Analysis Map (CAM) and a Hint Map for Urban Planning and Design (HM). The role of CAM is representing actual climate conditions. That of HM is representing recommendations for urban planning and design.

In Japan, CAMs have been produced for Tokyo(2) and Osaka(3). Some HMs have also been made(4)(5). Some HMs presenting recommendations have been produced at the district level, presenting some proposals from a climatic environment perspective. However, such maps showing recommendations for entire city areas are also needed. Outside Japan, HMs have been produced at the city level[6] in Hong Kong, but Hiroshima and Hong Kong differ in their urban structures and factors of underlying the temperature distribution, wind distribution, and so on. Given that background, HM must be made at the city level based on analyses of the urban heat island phenomenon in Hiroshima. In addition, as for HM at the whole city area, indicating issues to be considered in planning processes and climatic resources in each place is expected to be effective. For production of UECMs, first, it is necessary to understand the summer temperature distribution patterns and their contributing factors in urban area. Therefore, this study aims at analyzing temperature distribution according to patterns using observed data in Hiroshima, and classifying all observation points based on the daily temperature distribution.

2. Research outline

2.1 Outline of study area

For this study, Hiroshima is selected as a targeted area (Fig. 1). In Hiroshima, a plain is formed around the Ootagawa Delta. Hilly areas spread to the surrounding plain. Additionally, sea and land breeze circulation are observed in the south area facing the sea. Especially in this area located between the Shikoku Mountains and Chugoku Mountains, sea and land breeze often blow because seasonal winds blow only slightly[7]. Basic information related to Hiroshima is presented below.

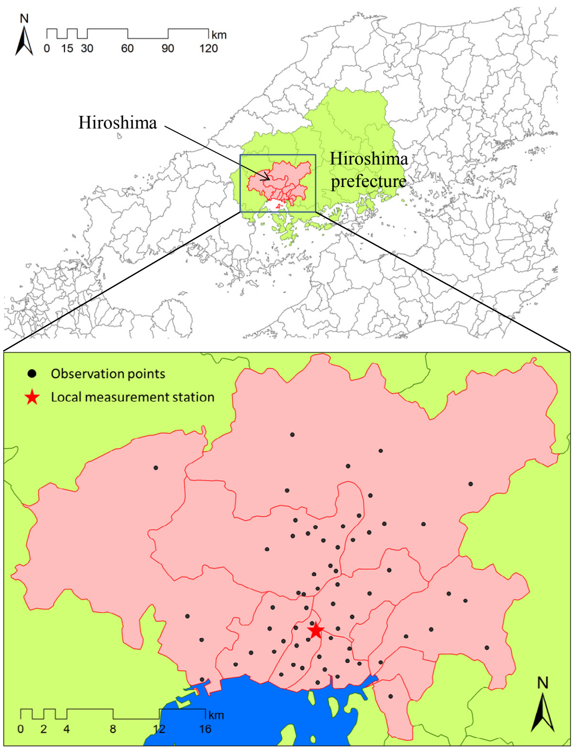

Fig. 1 Location of Hiroshima and observation points

- Area: 905.41 [km^2]
- Total population: 1,174.209 (2012)
- Population density: 1,310 [persons/km^2]
- Number of households: 535,241 [household]

2.2 Method

This study progressed according to the following steps.

1) Observing temperatures in Hiroshima (64 points).
2) Extracting fine weather days.
3) Daily wind pattern classification.
4) Analysis of temperature distributions.
5) Classifying all observation points based on the daily temperature change patterns.
6) Considering local characteristic of the temperature distribution in Hiroshima.

3. Temperature distribution analysis according to the pattern

3.1 Outline of meteorological observations

First, 64 temperature sensors in instrument screens were set in Hiroshima. Basic information related to observation points is given below.

- Period: From July 20, 2013 to September 23, 2013.
- Observation interval: 10 min
- Instrumental error: corrected

In this study, the temperature distribution was analyzed using these observed data and local meteorological station data (temperature and wind). Observation points and meteorological stations are presented in Fig. 1.

3.2 Wind pattern classification of fine weather days

First, typical summer fine weather days (35 days) were extracted from all data (66 days) of the observation period using the following criteria.

- Daily precipitation is within 1 [mm].
- Daylight hours are 40% or more of the possible duration of sunshine.
- Daily maximum temperature is 30 °C or higher.
- The weather is not rainy.

By the following classification, the data of these typical summer fine weather days (35 days) are used. That is true because the target day of this study is typical summer fine weather days.

Second, wind blowing pattern classification was performed using only the wind direction and speed data of the local meteorological station. Some measurement data (wind speed and wind direction) are presented in Fig. 2, a wind rose is depicted in Fig. 3. It is apparent that several different types of the daily wind direction change patterns exist. Wind blowing pattern classification was performed using a method proposed in a report of an early study[7]. In the classification, a "sea breeze" is

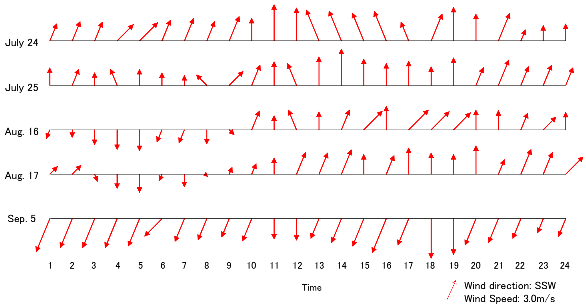

Fig. 2 Part of local meteorological station data

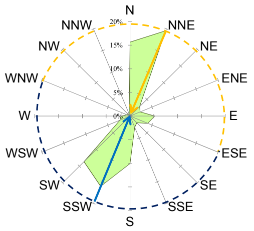

Fig. 3 Wind rose

Table 1 Criteria of classification and results

	Criteria	Classification result
Pattern A Sea breeze doesn't blow	1) Not match the Pattern B or C.	Sep. 5, Sep. 17
Pattern B Sea breeze blows, but land breeze doesn't blow	1) Sea breeze blows the majority of daytime (from 1 p.m. to 4 p.m.). 2) Land breeze doesn't blow the majority of nighttime (from 3 a.m. to 6 a.m. and from 0 a.m. to 3 a.m. in the next day).	July 24, July 25, July 31, Aug. 9
Pattern C Land and sea breeze blow	1) Sea breeze blows the majority of daytime (from 1 p.m. to 4 p.m.). 2) Land breeze blows the majority of nighttime (from 3 a.m. to 6 a.m. and from 0 a.m. to next day 3 a.m. in the next day).	July 20, July 21, July 22, July 26, Aug. 6, Aug. 7, Aug. 8, Aug. 10, Aug. 11, Aug. 12, Aug. 13, Aug.14, Aug. 15, Aug.16, Aug. 17, Aug. 18, Aug. 19, Aug. 20, Aug. 21, Aug. 27, Aug.28, Sep. 10, Sep. 13, Sep. 14, Sep.19, Sep. 20, Sep.21, Sep. 22, Sep. 23

Table 2 Variables of PCA

Variables
1) Average temperature (degree C.)
2) Average of daily maximum temperatures (degree C.)
3) Average of daily minimum temperatures (degree C.)
4) Average daily range of temperatures (degree C.)
5) Integration of degree-hour in the daytime (degree C.*h)
6) Integration of degree-hour in the nighttime (degree C.*h)

Table 3 Result of PCA

Principal component	1st PC	2nd PC
Average temperature	0.772	0.630
Maximum temperature	-0.416	0.896
Minimum temperature	0.973	0.198
Daily range	-0.919	0.391
Degree-hour in the daytime	-0.234	0.961
Degree-hour in the nighttime	0.946	0.293
Eigenvalue	3.51	2.40
Contribution ratio (%)	58.51	40.03
Cumulative contribution ratio (%)	58.51	98.54

defined as "wind blowing from the direction, SE, SSE, S, SSW, SW, WSW, and W" because the major sea breeze direction is SSW. Additionally, a "land breeze" is defined as "wind blowing from the direction, NW, NNW, N, NNE, NE, ENE and E". They do not include wind from the ESE or WNW. As a consequence of classification, the typical summer fine weather days (35 days) are classifiable into three patterns, "pattern A (sea breeze doesn't blow)", "pattern B (sea breeze blows, but land breeze doesn't blow)" and "pattern C (land and sea breeze blow)" (Table 1). In addition, in the following analysis, the data of Pattern C (29 days) are used because the majority of the typical summer fine weather days are of "pattern C".

4. Classifying all observation points based on daily temperature change patterns

Two steps are used for classifying all observation points based on the daily temperature change patterns. In step 1, principal component analysis is performed. In step 2, cluster analysis is conducted using principal component scores (PC scores).

4.1 Principal component analysis (PCA)

PCA was conducted using six variables showing patterns of daily temperature change[8]. Table 2 presents variables. Table 3 presents PCA results. Because the PC loadings of "average temperature," "minimum temperature," "daily range," and "degree-hour in the nighttime" are high, the first PC is apparently the "nighttime temperature characteristic." The PC loadings of "maximum temperature" and "degree-hour in the daytime" are high scores. Therefore the second PC is apparently the "daytime temperature characteristic".

4.2 Cluster analysis

For step 2, cluster analysis was performed using PC scores with Wards method. Fig. 4 shows results of cluster analysis. Furthermore, all observation points were classified into four clusters (C1-C4). Regarding the first PC (nighttime temperature characteristic), C1 and C3 are located on the positive side, and C2 and C4 on the negative side. The temperature of C1 and C3 tend to be high. Those of C2 and C4 tend to be low during temperature characteristic), C1 and C2 are located on the positive side, and C3 and C4 on the negative side. The temperatures of C1 and C2 tend to be high. Those of C3 and C4 tend to be low during the daytime.

5. Considering the local characteristic of temperature distribution

Fig. 5 shows the four clusters on the map. In addition, Fig. 6 shows the average temperature of four clusters. C3 is located in

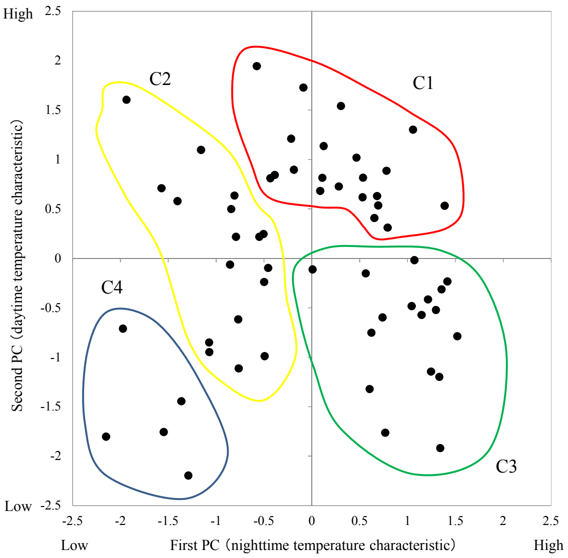

Fig. 4 Results of cluster analysis

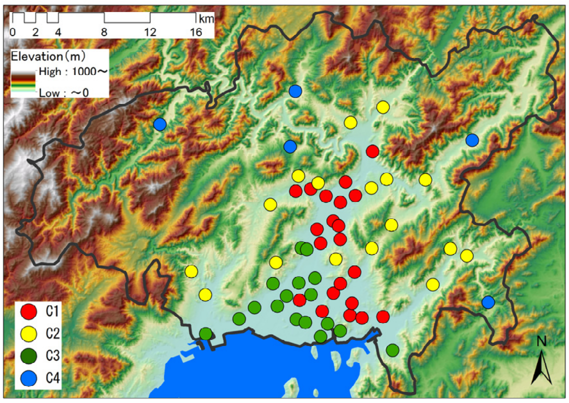

Fig. 5 4 clusters on the map

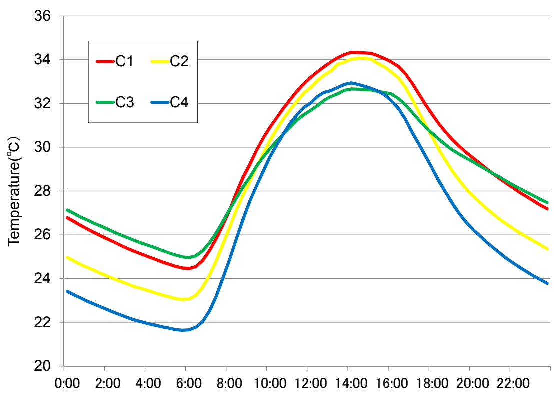

Fig. 6 Hourly average temperature of 4 clusters

the southwest area; C1 is located in the northeast area of the plain. In addition, C2 is in areas surrounding the plain, C4 is in high elevation areas. Then, local characteristic of temperature are found for daytime and nighttime in Figs. 5 and 6. These considerations are presented below.

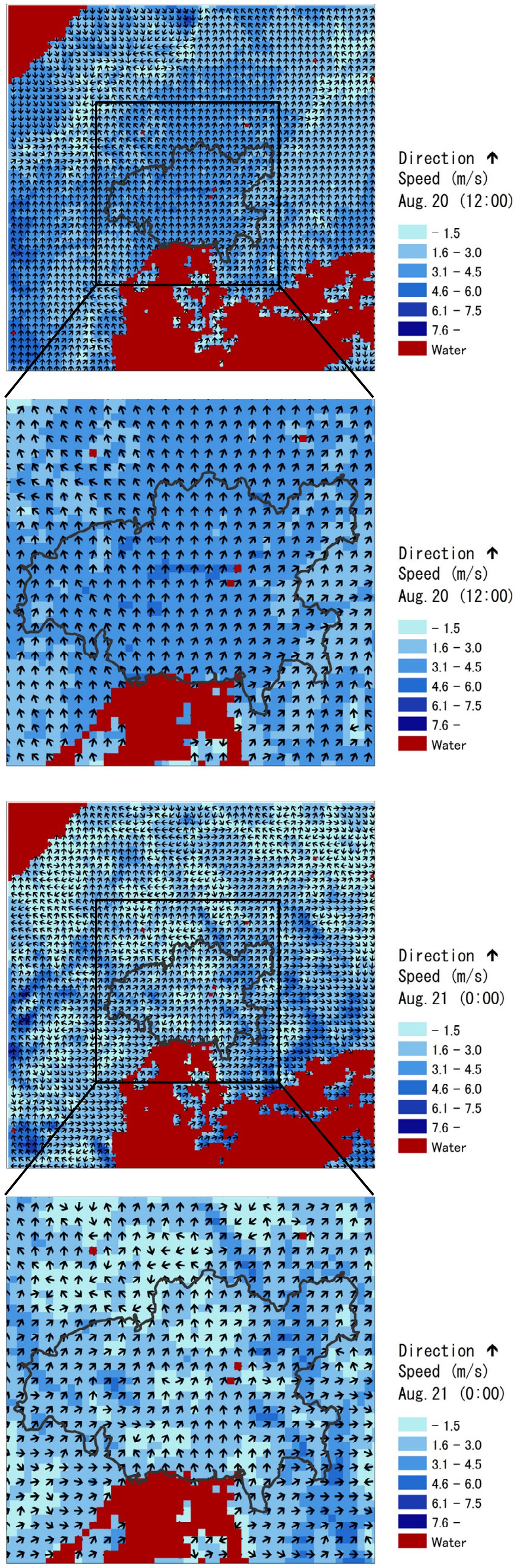

Fig. 7 The numerical simulation results of WRF
(Direction and speed)

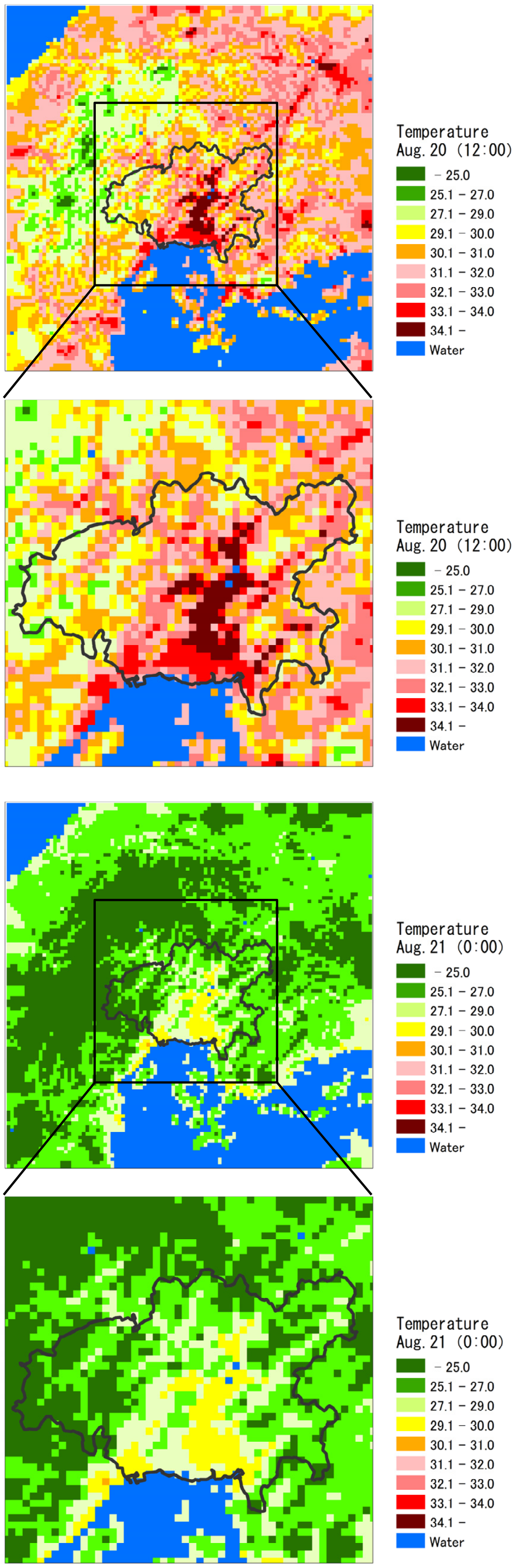

Fig. 7 The numerical simulation results of WRF (Temperature)

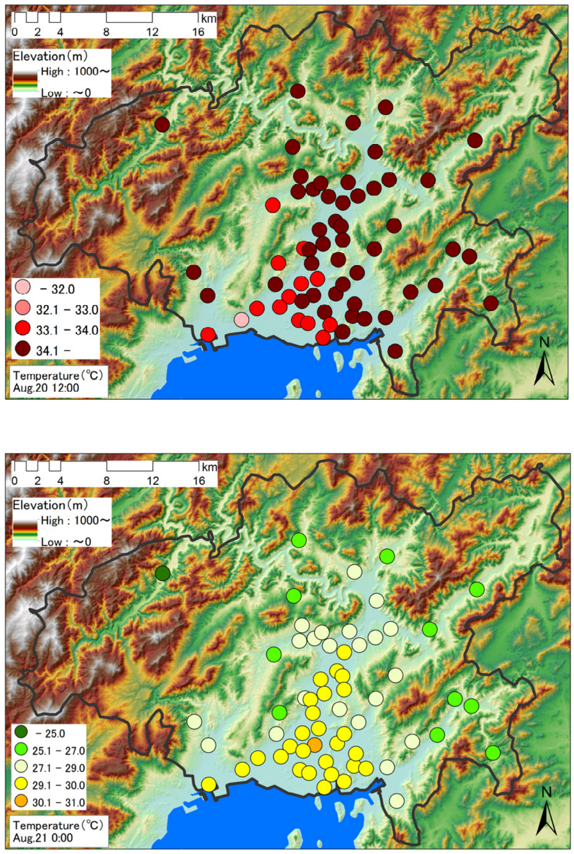

Fig. 8 Temperature distribution

Table 4 Characteristic of daily temperature change patterns and geographical

Cluster	Characteristic of daily temperature change patterns	Geographical characteristic	Points
C1	The temperature is relatively high at daytime and nighttime.	Northeast area of the plain	21
C2	The temperature is relatively high at daytime, the temperature is relatively low at nighttime.	Areas along the plain	17
C3	The temperature is relatively low at nighttime, the temperature is relatively high at nighttime.	Southwest area of the plain	17
C4	The temperature is relatively low at daytime and nighttime.	High elevation area	5

(1) Daytime

The C3 and C4 temperature tend to be lower. Those of C1 and C2 area tend to be higher. Temperature characteristics of C3 are considered to differ from C1 and C2 in the same plain because the distribution is affected by sea breezes. In addition, the difference of temperatures between C3 and C1/C2 is about 2.0 °C during the daytime because the temperature rise is apparently mitigated by sea breezes in coastal areas. In other words, the C3 temperature is mitigated by sea breezes but those of C1, C2 can not be mitigated by sea breezes. Moreover, the distribution of C3, C1 and C2 apparently show that sea breezes blow from the southwest to the northeast.

(2) Nighttime

The C2 and C4 tempperatures tend to be lower. Those of C1 and C3 tend to be higher. In addition, the C1 and C2 temperatures become lower than that of C3 after 6 p.m., which differs from the temperature distribution in the daytime because the temperature of C1 and C2 is apparently lower as a result of the effects of green or cold air drainage, but the C3 is apparently not affected by them.

In addition, Fig. 7 shows numerical simulation results by the meso-scale meteorological model WRF. One might infer from these figures that results of the numerical simulation show similar patterns of temperature distribution (Fig. 8) and cluster analysis. For example, they have the same tendency by which the temperatures in coastal areas tended to be lower and those in the northeast area of the plain tended to be higher during daytime. As subjects for future works, simulation results must be confirmed through comparison with meteorological observation data and by analyses of the results of the numerical simulation to elucidate the wind distribution patterns.

6. Summary

In this study, classification of all observation points was done based on the daily temperature change patterns and local characteristics of the temperature distribution using observation data. Table 4 presents characteristic of daily temperature change patterns and geographical characteristics for each cluster.

Finally, the future works will be undertaken as described below.

(1) Climate zoning based on the classification of all observations.

(2) Analyzing the factors of the temperature distribution using a meso-scale meteorological model (for sea breezes), and satellite remote sensing data (green), and so on.

(3) Examining the urban planning method incorporating mitigation of the urban heat island based on the results of (1) and (2); and finally producing UECMs.

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