Extraction of Diurnal Variation Patterns of the Heat Island Intensity by the Fixed Point Observation and Multivariate Analysis in August, 2013 in Kumagaya, Japan

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1. Introduction

Heat island phenomenon is the thermal pollution of air becoming higher temperature in the urban area than in the suburbs. To evaluate frequency and strength of this heat island quantitatively, heat island intensity (HII) is used well. For example, Kawamura (1977) showed that HII was larger in the winter season than the summer in Tokyo. On the other hand, as a result of the observation in Obuse, a town in central Japan, Sakakibara(1999) reported that HII was very large in May. In addition, Sekiguchi (1970) stated that HII became maximum right after the sunrise in many cities. However, there is the report that the time to show the maximum was different with season (Shigeta and Ohashi, 2009). In this way, the characteristics of HII are greatly different in each city, and the same conclusion is not provided.

Therefore, in this study, the fixed point observation of surface air temperature was carried out during the summer in Kumagaya. Kumagaya is famous as the area where the highest temperature of summer is recorded in Japan. Existence of the heat island phenomenon is recognized in Kumagaya for approximately 50 years (Kawamura, 1965), some studies were conducted afterwards (e.g., Matsumoto et al., 2002). It is expected by these reports that heat island phenomenon promotes a high temperature in the daytime. Therefore, it is important to understand a daily fluctuation pattern of HII in discussing the damage of health such as heat stroke or sleep disorder that are brought by the high temperature.

In this study, the fixed point observation of surface air temperature and the multivariate analysis was carried out and extracted a daily fluctuation pattern of HII on August, 2013 in Kumagaya.

2. Methods of the study

2.1 Object area

Kumagaya is located in the northwestern part of Kanto plains in Japan and is a middle scale city having area of about 160 km^2, and population of about 200,000. Along the southern edge of Kumagaya urban area, Arakawa river rums from west to east. In around the Kumagaya station, a lot of buildings such as city hall exist and are commerce or an office block. In addition, the land cover is mainly a paddy field in the northern part of Kumagaya.

2.2 Observation summary

The observation of surface air temperature at 46 fixed points in the area of 16km in the east-west direction and 16km in the north-south direction around Kumagaya was performed. All observation points are shown in Fig. 1. The observation was carried out from August 1, 2013. Diurnal variations of temperature in August when the

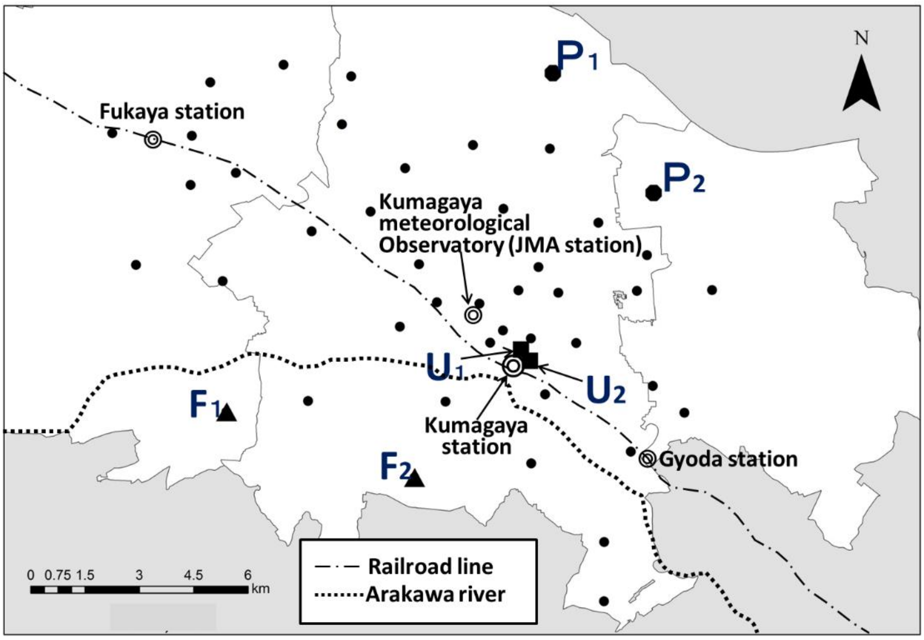

Fig.1 Observation points. Representative points of urban, paddy field and forest are $U_{1,2}$, $P_{1,2}$ and $F_{1,2}$ respectively

extremely hot day of the year the target of this study. We incorporate a temperature sensor (RTR-502 : T&D company) in a natural ventilation shelter, and the measurement of the temperature is used. The measurement was taken by an interval of two minutes, and the 20-minute average calculated every ten minutes was used for the analysis.

Urban park was used when air temperature was observed in this study. But the appearance of "the cool island" that the park is lower temperature than the neighborhood is reported in several large-scale parks in urban (e.g., Narita et al., 2004, Shigeta et al., 2013). Thus, it is great risk that the temperature observed in a park is not proper for the representative value in urban area. For an above-mentioned problem, Chang et al. (2007) pointed out that a meaningful difference was not recognized to the temperature inside and outside the park in the small park of less than 3ha.Therefore, pocket-size parks less than approximately 1ha were chosen in this study to perform the temperature observation. The observation equipment was installed in an altitude of approximately 2.5m with a streetlight or a pole located in a park.

3. Result and discussion

3.1 Horizontal distribution of the temperature above the ground

The horizontal distribution of the surface air temperature anomaly from 14:00 on August 19 to 5:00 on August 20 is shown in Fig. 2 with a characteristic of the typical summer. The temperature anomaly of each observation point was defined by the difference from the mean temperature of all observation points at a same time. In daytime, a low temperature anomaly spreads out in the northeastern part of observation domain, and it is approximately 2 degrees Celsius lower temperature than the outskirts (Fig. 2a). This low temperature anomaly becomes clear for 11:00-1400 when sunlight is the strongest in the day. Because a lot of paddy fields exist around the area, it is thought that evapotranspiration was lively performed on the water surface and green leaves of rice in the daytime. Therefore, since most of the heat from sunlight are converted into latent heat in the surface, it was supposed that it controls a rise in neighboring temperature. The phenomenon that paddy field area becomes the low temperature at the daytime in an affusion period is reported in Sakakibara (1994).

On the other hand, the temperature of the urban area is higher more than 1.5 degrees Celsius than the outskirts at about 22:00. A concentric circle-formed clear high temperature anomaly, so-called "heat island", are shown around the Kumagaya station (Fig. 2b). The diameter of the heat island is approximately 3km. The observation point showing the highest temperature in the heat island is located in approximately 100m northeast from the Kumagaya station. Temperature of this point was always a positive anomaly and, in the night, showed +1.3 degree Celsius on the average. Buildings crowd in the outskirts of this point in comparison with other observation points (sky view factor is 35%).Therefore, upward long wave radiation is inhibited on the surface during the night, and it is supposed that a temperature drop by the radiative cooling was suppressed. On the other hand, a clear low temperature anomaly appears in the southern part of the observed area at just before the sunrise. About the heat balance of the paddy field in the night of the affusion period, Sakakibara (1994) reported that the surface is hard to get cold to mix it even if the water surface gets cold by emission. Therefore, the southern side of the observed area is almost covered by forests and farms, and it is supposed that radiative cooling in the southern suburbs was more active than in the northeastern suburbs.

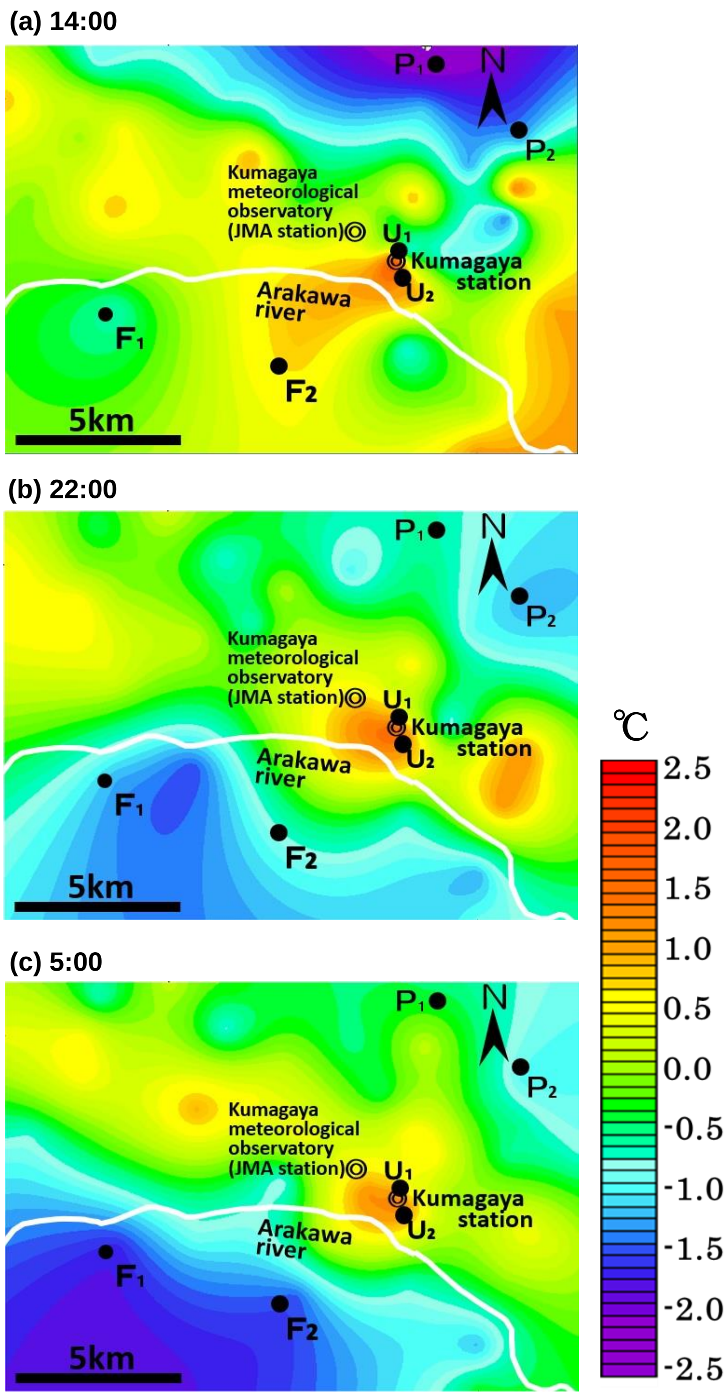

Fig.2 Space deviation distribution of the surface air temperature at August 19-20, 2013 (a) 14:00, (b) 22:00, (c) 5:00

3.2 HII

1) Calculation method of HII

HII has been used in many studies to evaluate the frequency and the strength of heat island quantitatively (e.g., Oke, 1973, Sugawara et al., 2005). In this study, we also calculate HII to evaluate the heat island phenomenon quantitatively. We decided to use the temperature on the average of plural points to avoid the local influence of the observation point in calculation. The representative points of the urban area are U1 and U2 around the Kumagaya station (Fig. 1). In addition, in the northeastern and the southern suburbs part of observation domain, a low temperature anomaly appeared at the different time. Therefore, we chose northeastern paddy field area (P1 and P2) and the southern forest area (F_1 and F_2) as the different suburbs, and two kinds of HII were calculated between U and P, and between U and F.

2) Time series of HII

Fig.3 shows time series of temperature and HII in August 19 (fine and calm day). The diurnal range (differences between the maximum and the minimum temperature of the day) of the forest area is 11.8 degrees Celsius (Fig. 3a). On the other hand, the diurnal range of the urban area is 10.3 degrees Celsius that is 1.5 degrees Celsius smaller than the forest area. In addition, HII using the forest data takes the maximum in the night (the maximum of 2.9 degrees Celsius at 21:00) and becomes small abruptly at the sunrise. Fig. 3b shows time series of temperature in the urban area and the paddy field area, and HII using the paddy field data. The diurnal range of the temperature of the paddy field area is 9.9 degrees Celsius, and it is smaller than other areas. It is thought that the specific heat of water made the thermal capacity of the affused surface larger and the effect of evapotranspiration mentioned above produced it. In addition, HII using paddy field data is large in daytime and the maximum is 3.7 degrees Celsius at 13:00.

HII using the paddy field data is larger than another HII and +1.1 degree Celsius on the daytime average, and the difference of up to 2.5 degrees Celsius (at 11:10) is produced in the daytime. HII using the forest data is relatively big at night and +0.3 degree Celsius on the nighttime average, and the difference between two HIIs in the nighttime is smaller than in the daytime. Furthermore, HII using the paddy field data in the nighttime is smaller than a value in the daytime (1.2 degree Celsius). It is revealed that the maxima and diurnal variations of HII are greatly different by the way how to choose the representative point of suburbs. There are reported cases in other cities about this point (e.g., Grimmond et al., 1993, Sakakibara, 1999), and the inhomogeneity of the suburbs cannot ignored in the evaluation of HII.

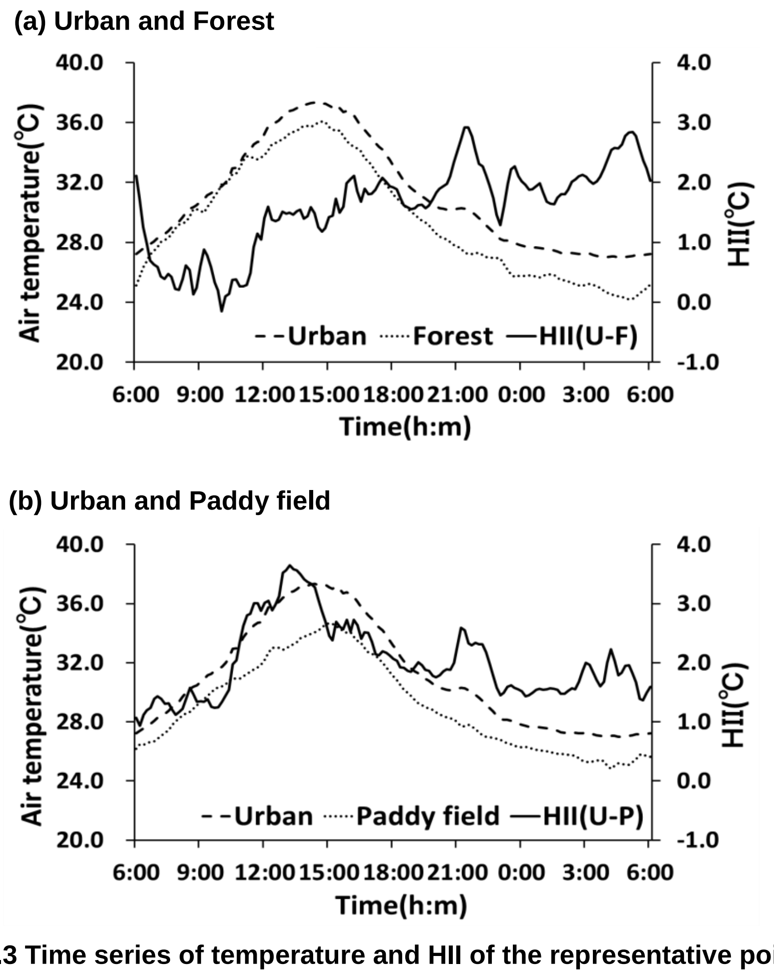

Fig.3 Time series of temperature and HII of the representative point (a) Urban and Forest, (b) Urban and Paddy field

3.3 Analysis by statistical technique

1) Analysis summary

A study by various techniques has been performed until now for the purpose of understanding of the heat island phenomenon. For example, as statistical technique, Kim and Baik (2005) performed the principal component analysis for temperature data in Seoul, clarified the heat island phenomenon, and examined connection with the land use and the artificial exhaust heat. Their result shows that the principal component analysis is effective in clarifying a daily fluctuation pattern of HII. Therefore, this study performs principal component analysis that was a kind of the multivariate analysis, to clarify patterns of time and space of heat island phenomenon generated in Kumagaya. The analysis was carried out for the fine and calm days that heat island should occur conspicuously. The value that was performed ensemble average temperature on the hour of each observation spot was used in this analysis. The number of the data is 44 (points) × 24 (time steps). In addition, we showed characteristic vector about "the time" and decided to calculate a principal component score for "a spot" and "a day", and used a coefficient of correlation matrix for a starting matrix.

2) Contribution

As a result of the principal component analysis, contributions of the first and second principal component is 76.0% and 14.7%, respectively. These components were able to explain approximately 90% of daily fluctuation patterns of the temperature. Because the third principal component became less than 5.0% in a contribution ratio, it was judged not to be a meaningful result. Therefore, we decided to use the first and second principal component for analysis.

3) The first principal component

The eigenvector of the first principal component shows the maximum value of -0.14 in the daytime, but a change is small through a day (Fig. 4). Here, the spatial distribution of the first principal component score is shown in Fig. 5a. Around the Kumagaya station in Fig.5a, the value is extremely small in comparison with the suburbs. It is supposed that the first principal component shows that temperature of urban area is higher than it of suburbs through a day.

4) The second principal component

The eigenvector of the second principal component shows a positive value in the daytime, and a negative value in the nighttime. In addition, the rise in value just after the sunrise is remarkable, and the rising rate of +0.17 degree Celsius /hour is shown from 6:00 to 9:00. But, such an abrupt change is not shown in the night. The second principal component score has a small value in the northeastern paddy field area and a value is larger in the southern forest area (Fig. 5b). Therefore, it is supposed that the second principal component shows a rate of change of the temperature by the different land cover in the suburbs, and it accords with an argument about the difference in HII.

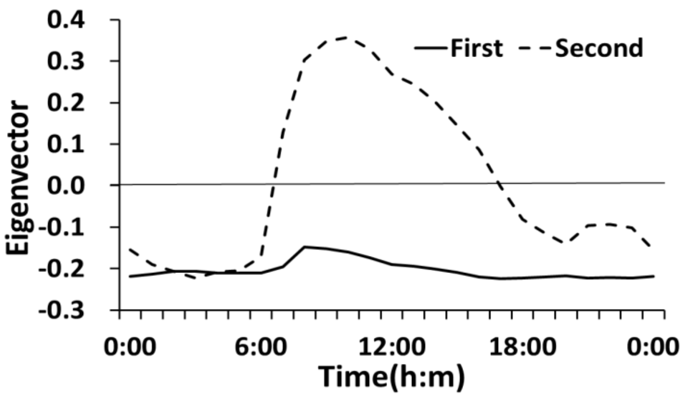

Fig.4 Time series of eigenvector by principal component analysis

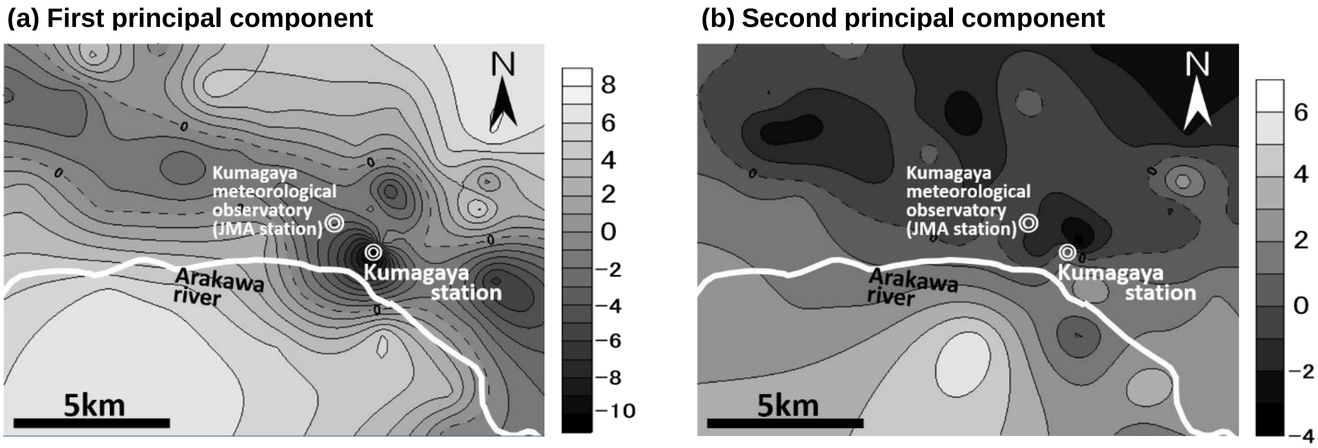

Fig.5 Spatial distribution of the principal component score at fine and calm day August, 2013 (a) First principal component, (b) Second principal component

4 Conclusion

In this study, the fixed point observation of surface air temperature was carried out in Kumagaya and the multivariate analysis extracted daily fluctuation patterns of HII in August 2013. HII using the paddy field data showed the maximum in the daytime (+4 degrees Celsius at 13:00), and HII using the forest data showed the maximum in the night (+3 degrees Celsius at 21:00). Therefore, it is suggested that the selection of suburb stations can have a strong influence on the interpretation of heat island intensity.

Furthermore, as a result of principal component analysis using the observation data, the first principal component showed that the urban area had a high temperature than the suburbs through a day. On the other hand, the second principal component extracted a rate of change of the temperature by the land cover, and the difference of the thermal capacity was shown plainly.

From these results, it was revealed that a daily fluctuation pattern of HII in Kumagaya greatly depended on the land cover in summer.

Reference

Chang, C,R., M.H. Li and S.D. Chang, 2007: A preliminary study on the local cool-island intensity of Taipei city parks. *Urban Plan*., **80**, 386-395.

Grimmond C.S.B., T.R. Oke and H.A. Cleugh, 1993: The role of "rural" in comparisons of observed suburban-rural flux differences, *IAHS Publ*. **212**, 165-174.

Kawamura, T., 1965: ANALYSIS OF THE TEMPERATURE DISTRIBUTION IN THE KUMAGAYA CITY -A TYPICAL EXAMPLE OF THE URBAN CLIMATE OF A SMALL CITY. *Geographical Review of Japan*,**37**,387-392. [in Japanese]

Kawamura, T., 1977: The actual situation of the urban climate distribution. *The recent prospects about the city climate, Meteorological study notebook*, **133**, 26-47.

Kim, Y.-H. and J.-J. Baik, 2005: Spatial and temporal structure of the urban heat island in Seoul. J. Appl.Meteor., **44**, 591-605.

Matsumoto, F., Fukuoka Y., Goto S., 2002: Change in Heat Island Pattern due to Change of Urban Form and Structure in Kumagaya City. *Papers on Environmental Information Science*, **16**, 387-392. [in Japanese]

Narita, K., Mikami T., Sugawara H., Honjo T., Kimura K., Kuwata N. (2004) Cool-island and Cold Air-seeping Phenomena in an Urban Park, Shinjuku Gyoen, Tokyo. *Geographical Review of Japan*, **77** (**6**), 403-420. [in Japanese]

Oke, T.R., 1973: City size and the urban heat island. Atoms.Environ., **7**, 769-779.

Sakakibara, Y., 1994: Heat island intensity in Koshigaya: A case study of the rural with the paddy field. *TENKI*, **41** (**9**), 515-523. [in Japanese]

Sakakibara, Y., 1999: The Relationship between Heat Island Intensity and Rural Land Coverage in Obuse, Nagano. *TENKI*, **46** (**9**), 567-575. [in Japanese]

Sekiguchi, T., 1970: Urban climatology. *TENKI*, **17** (**3**), 89～96. [in Japanese]

Shigeta, Y. and Ohashi Y., 2009: Analysis of Heat Island Intensity from Meteorological Observation Network in Okayama City. *TENKI*, **56** (**9**), 443-454. [in Japanese]

Shigeta, Y., Takaoka T., Ohashi Y., Kikegawa Y., Hirano Y., 2013: Effects of large green park on urban atmospheric cooling during nighttime − Meteorological observations around the Osaka Castle Park— . *JAPANESE JOURNAL OF BIOMETEOROLOGY*, **50** (**1**), 23-36. [in Japanese]

Sugawara, H., JI Done Wook, Tomine K., 2005: Re-examination of City Air Temperature for Heat Island Intensity Evaluation: Case Study in Seoul, Korea. *TENKI*, **52** (**2**), 119-128. [in Japanese]