[Original Paper]

Annual variation of air temperature distributions observed in Augusts 2005 and 2006 in urban area of Japan

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The air temperature distributions in August (summer season) were measured for two years (2005 and 2006) in an approximately 10 x 15-km urban area in Hyogo Prefecture, Japan, in order to evaluate the annual variation of the spatial air temperature distribution. The ultimate aim of the study is to propose effective measures against the heat island phenomenon in the future. The air temperature was measured by using naturally ventilated thermometer shelters installed in elementary schools and junior high schools. Some similar characteristics were observed in the distributions of the monthly mean air temperature, monthly mean of the daily-highest air temperatures, and monthly mean of the daily-lowest air temperatures in 2005 and 2006. On the other hand, some annual variations were also observed in each air temperature distribution. The characteristic air temperature distributions described in the previous paper (Aikawa et al., 2007) were observed more clearly in 2006. The higher monthly mean air temperature appeared 5 to 10 km inland from the coast, and the severe thermal condition represented by the daily-highest air temperature was found in inland areas. The air temperature distributions showed an annual variation, suggesting that continuous monitoring is necessary in order to propose effective measures in the future.

Ⅰ　INTRODUCTION

With the objective of limiting thermal pollution in urban areas, scientists around the world have studied the urban heat island phenomenon [1-7]. Because the urban heat island phenomenon is not a global but a local environmental pollution issue, it is necessary for local governments to take measures against individual phenomena. Mikami et al. [8-13] have thoroughly studied urban heat islands in the Tokyo metropolitan area, and the Tokyo metropolitan government has established measures against the urban heat island phenomenon in that area. The Hyogo prefectural government instituted measures against heat islands in August 2005. It is necessary to measure the air temperature to verify the effect of the action plan and to propose effective measures in the future. Aikawa et al. [14] studied the accumulated air temperature data in a 15 x 15-km area in an urban area of Hyogo Prefecture, Japan, and characterized the growing heat island phenomenon in the area. In addition, Aikawa et al.[7] clarified the characteristic air temperature distributions by season in the relevant area, by using a data set obtained from the monitoring network newly constructed by the Hyogo prefectural government. In order to verify the effect of the action plan precisely and to propose effective measures in an appropriate manner in the future, we have to continuously collect detailed data sets on the air temperature, and properly analyze the accumulated data sets. The data sets obtained in 2005 were studied previously in detail by Aikawa et al. [7]. The newly

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accumulated data sets in the summer season (August, 2006) were analyzed, and the findings will be reported and discussed in this paper.

II MATERIALS AND METHODS

1 Air temperature measurement

The air temperature was measured at elementary schools and junior high schools located within a 10 x 15-km area of Hyogo Prefecture, Japan. The area is located between Osaka City (population 2,634,000/ 222 km^2) and Kobe City (population 1,520,000/ 551 km^2). The southern part of the area is urban, characterized by intensive industrial development and a dense population. In the northern part of the area, which includes the satellite cities of Osaka and Kobe, urbanization has been progressing rapidly [15]. The land use in the area was analyzed in detail in the previous paper [7]. The locations of the sites are shown in Fig. 1. The air temperature was measured by a thermometer calibrated with a thermostat and installed in a naturally ventilated thermometer shelter positioned about 1.5 m above the ground. The air temperature data were stored in a data logger. The air temperature was measured at the survey site every 15 minutes, and data measured on the hour was used for the evaluation. The air temperatures obtained in August (summer season) of 2005 and 2006 were studied.

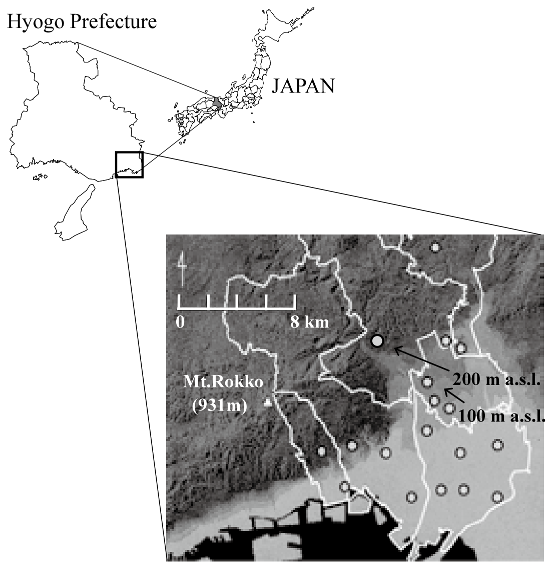

Fig.1 Location map of the survey site.

2 Number of survey sites

The air temperature was measured at 18 survey sites. However the data at one survey site was missing in 2005, resulting in that 17 monthly data sets for August 2005 and 18 for August 2006 are available. To compare the monthly air temperature distributions in 2005 and 2006, the data sets obtained at 17 survey sites, excluding the above one survey site, were used.

3 Altitude correction

The air temperatures were corrected by the altitude of the sites and a temperature-lapse rate of 0.6 °C/100 m, when the air temperatures of the sites were compared.

4 Survey site characteristics

The survey site characteristics were previously studied [7]. A concise summary is as follows: (1) the most urbanized area along the coast; (2) the suburban area, mainly in the southern part of the study area; and (3) the residential development area in satellite cities, located mainly in the northern part of the study area.

5 Geographic information system

A geographic information system (ArcView) was used for the spatial analysis of the air temperature. An inverse distance-weighted method was employed to draw the distribution of the air temperature.

III RESULTS AND DISCUSSION

1 Comparison of monthly mean air temperature

The monthly mean air temperature, not being corrected by the altitude, is summarized in Table 1. The monthly mean air temperature in 2006 was higher than that in 2005 by 0.7 °C. The median values of the air temperature among the survey sites in 2005 and 2006 were 28.9 and 29.5 °C, respectively, showing that the air temperature in 2006 was higher than that in 2005.

Table 1　Monthly mean air temperatures in August 2005 and 2006

Unit: °C

	2005	2006
Monthly mean air temperature	28.8	29.5

Note: The air temperatures are not corrected by the altitude.

2　Distribution of deviation in monthly air temperatures

The distribution of the deviation in the monthly mean air temperatures, monthly mean of the daily-highest air temperatures, and monthly mean of the daily-lowest air temperatures in Augusts 2005 and 2006 are shown in Figs. 2(a) and (b), respectively, wherein the deviation is defined as $T_{ip} - T'_{p}$ (i = site, p = monthly mean air temperature, monthly mean of the daily-highest air temperatures, monthly mean of the daily-lowest air temperatures).

T_{ip} ; Air temperature at site i and for p

T'_{p} ; Average of T_{ip} for each p

Aikawa et al.[7] demonstrated that the corresponding area in a region 5-10 km inland had a higher monthly mean air temperature distribution in August 2005. A similar distribution for the monthly mean air temperature was observed in 2006 (Fig. 2(b)-1) although the area with the higher monthly mean air temperature shifted a few kilometers northward. In addition, the southwestern area showed higher air temperatures in 2006 (Fig. 2(b)-1) although the area with higher air temperature in 2006 was somewhat different from that in 2005 (Fig. 2(a)-1).

Aikawa et al. [7] showed that the higher monthly maximum air temperature was also in the region 5-10 km inland in 2005. As for the distribution of the deviation in the monthly mean of the daily-highest air temperatures, different characteristics were observed in 2006, comparing 2006 (Fig. 2(b)-2) with 2005 (Fig. 2(a)-2). The distribution of the deviation in the monthly mean of the daily-highest air temperatures in 2005 appeared in the region 5-10 km inland like a hot spot (Fig. 2(a)-2), while a higher monthly mean of the daily-highest air temperatures was found inland in the distribution for 2006 (Fig. 2(b)-2).

As for the distribution of the deviation in the monthly mean of the daily-lowest air temperatures, quite similar distributions were observed in 2005 (Fig. 2(a)-3) and 2006 (Fig. 2(b)-3), i.e., the monthly mean of the daily-lowest air temperatures in the southwestern area showed a higher air temperature. This characteristic was similar to the results of Aikawa et al. [7].

3　Classification of distribution by wind speed

3.1　Categorization by wind speed

The wind is one of the most important parameters to determine air temperature. The wind speed and direction were measured at 27 air pollution monitoring stations (16 ambient air pollution monitoring stations (APMSs) and 11 national roadside air pollution monitoring stations (RAPMSs)) in the study area. Aikawa et al. [16] selected 5 APMSs to obtain a representative wind field by studying the characteristics of the wind speed and direction at 27 stations.

The 31 days in August were classified by wind speed at the selected 5 APMSs in order to study the wind speed-dependence of the air temperature distribution. The frequency distributions of the mean of daily-mean wind speeds at the 5 APMSs in August 2005 and 2006 are summarized in Table 2. The days on which the mean of daily-mean wind speeds at the 5 APMSs was less than 2.0 m/s were categorized as a weak wind-speed day, and more than 3.0 m/s were a strong wind-speed day.

Table 2　Frequency distributions of the mean of daily-mean wind speeds at 5 APMSs in August 2005 and 2006

Unit: $m \cdot sec^{-1}$

	2005	2006
0 ≦ ＜0.5	0	0
0.5≦ ＜1.0	0	0
1.0≦ ＜1.5	3	0
1.5≦ ＜2.0	7	10
2.0≦ ＜2.5	12	15
2.5≦ ＜3.0	6	1
3.0≦ ＜3.5	3	2
3.5≦ ＜4.0	0	2
4.0≦	0	1

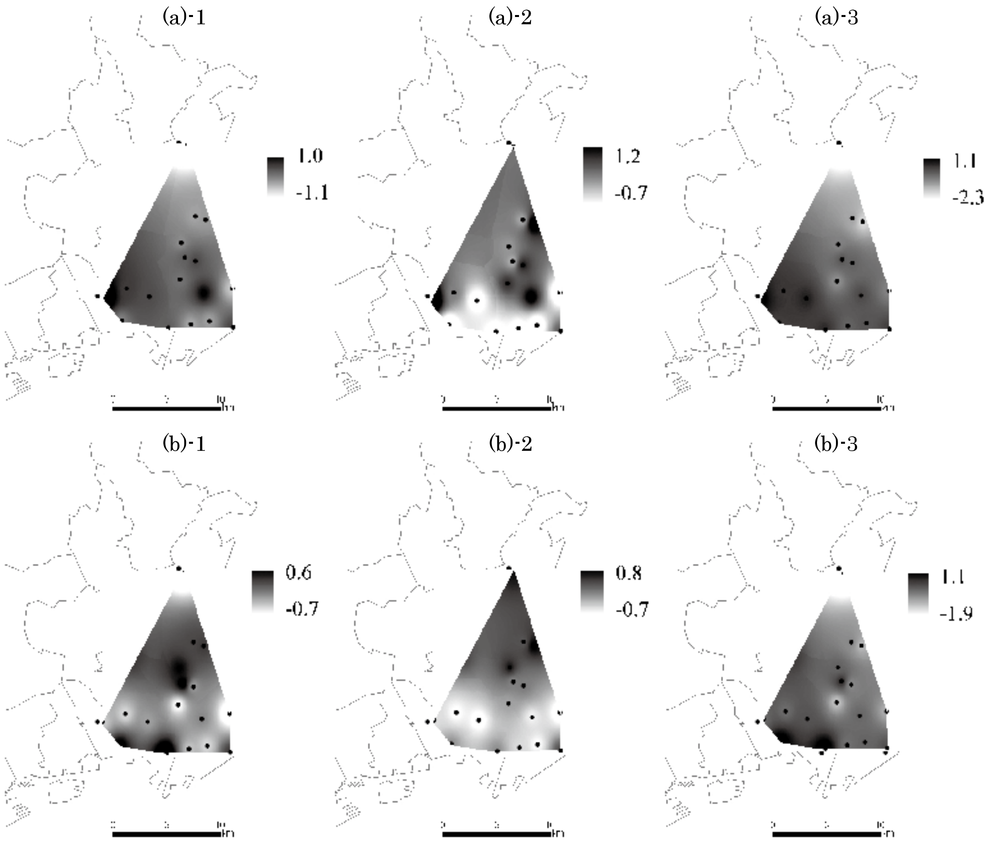

Fig.2 (a)-1: Distribution of the deviation in the monthly mean air temperatures in August 2005
(a)-2: Distribution of the deviation in the monthly mean of the daily-highest air temperatures in August 2005
(a)-3: Distribution of the deviation in the monthly mean of the daily-lowest air temperatures in August 2005
(b)-1: Distribution of the deviation in the monthly mean air temperatures in August 2006
(b)-2: Distribution of the deviation in the monthly mean of the daily-highest air temperatures in August 2006
(b)-3: Distribution of the deviation in the monthly mean of the daily-lowest air temperatures in August 2006

3.2 Distribution of deviation in monthly air temperatures on weak wind-speed days and strong wind-speed days

The distribution of the deviation in the monthly mean air temperatures, monthly mean of the daily-highest air temperatures, and monthly mean of the daily-lowest air temperatures on weak wind-speed days in August of 2005 and 2006 are shown in Figs. 3(a) and (b), respectively. In addition, the distribution of the deviation in the monthly mean air temperatures, monthly mean of the daily-highest air temperatures, and monthly mean of the daily-lowest air temperatures on strong wind-speed days in August of 2005 and 2006 are shown in Figs. 4(a) and (b), respectively.

The distribution patterns on both weak wind-speed days (Figs. 3(a) and (b)) and strong wind-speed days (Figs. 4(a) and (b)) were generally similar to those of the monthly distributions (Figs. 2(a) and (b)), while the contrast between distributions on weak wind-speed days was more pronounced.

IV CONCLUSIONS

The distributions of the monthly mean air temperature, the monthly mean of the daily-highest air temperatures, and the monthly mean of the daily-lowest air temperatures were studied for data sets obtained in Augusts 2005 and 2006. Some annual variations were observed in the distributions while the outline of the distributions in each year was common and similar each other, showing that continuous monitoring is necessary in order to verify the effect of action plans against heat islands and propose effective measures in the future. Furthermore, the dependence of the distributions of the monthly mean air temperature, the monthly mean of the daily-highest air

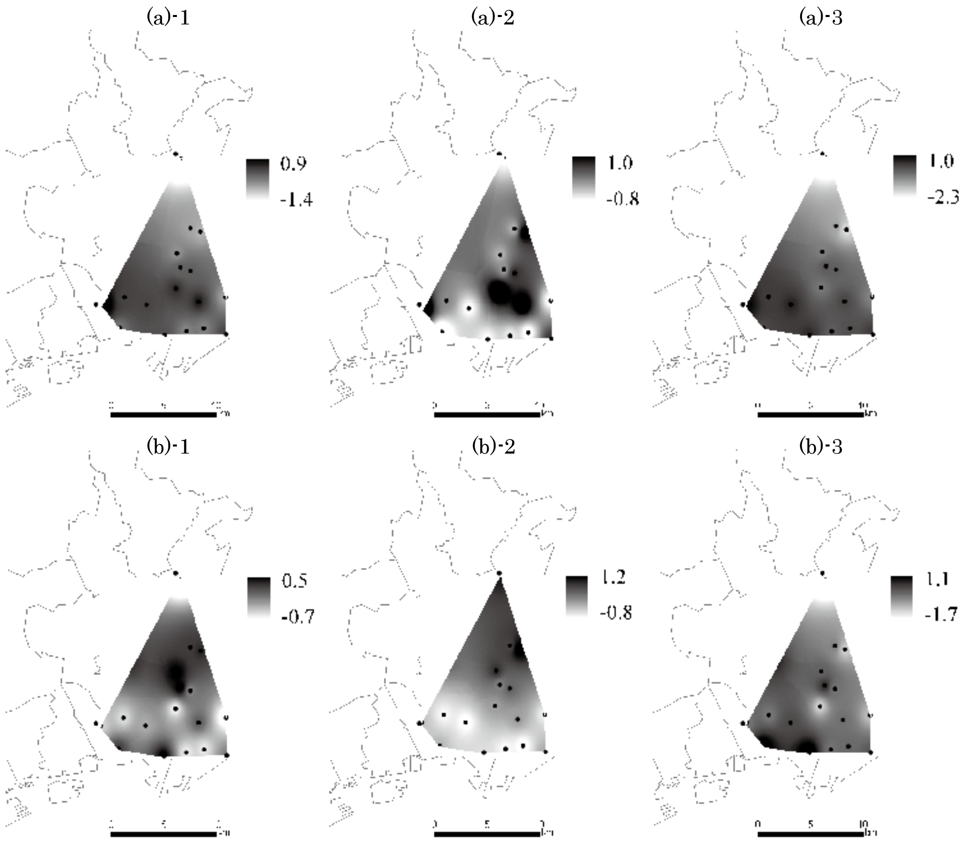

Fig.3　Distribution of the deviation in the monthly mean air temperatures (1), monthly mean of the daily-highest air temperatures (2), and monthly mean of the daily-lowest air temperatures (3) at weak wind-speed day in Augusts 2005 (a) and 2006 (b).

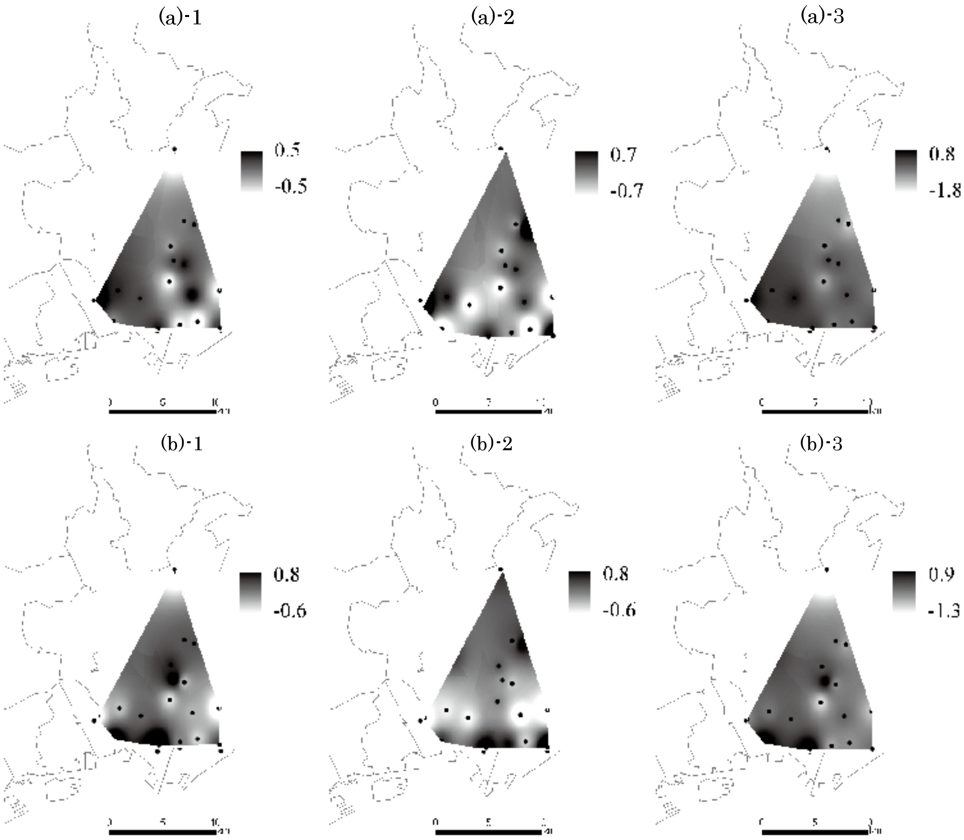

Fig.4　Distribution of the deviation in the monthly mean air temperatures (1), monthly mean of the daily-highest air temperatures (2), and monthly mean of the daily-lowest air temperatures (3) at strong wind-speed day in Augusts 2005 (a) and 2006 (b).

temperatures, and the monthly mean of the daily-lowest air temperatures on the wind speed was studied. The characteristics observed in the monthly distributions appeared on the weak wind-speed days more clearly.

V ACKNOWLEDGEMENT

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［原著］

ヒートアイランド現象観測に係る 2005 年 8 月と 2006 年 8 月の気温分布の年偏差

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要　約

ヒートアイランド現象への効果的な対策を提言することを将来目的として本研究を実施した。兵庫県の都市域において 2005 年度及び 2006 年度の 2 年間気温分布を観測した。気温は小中学校に設置されている百葉箱を利用して行った。2005 年 8 月と 2006 年 8 月の気温分布を比較すると、共通する分布の特徴が観測された。すでに学術論文で公表している 2005 年 8 月に観測された月平均気温の分布の特徴（気温の高い地域が海岸から 5～10 km の地域で観測される）が 2006 年 8 月にはより顕著に観測された。また、月最高気温により代表される厳しい熱環境が内陸の地点ほど観測されやすい傾向も 2006 年 8 月にはより顕著に観測された。この 2 年の調査結果から、夏期の気温分布には共通する特徴が観測される一方、年偏差も観測されることから、将来、効果的な対策を検討するためには引き続き調査を行い、年偏差等も含めた正確な現況把握が必要であると考えられる。