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［Original］

Influence of the increase in the number of survey sites on the analysis of the air temperature distribution

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阪神地域における気温分布評価における測定局数の影響

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Data sets of the air temperature measured at 18 and 22 sites were examined from the viewpoint of the influence of the difference in the number of sites on the evaluation of the air temperature distribution. The findings are summarized as follows:

The seasonal variation due to the difference of the number of sites was smaller in December than in August. The smaller variation was more notable in the air temperature distribution estimated by the air temperature corrected by the altitude of the site. Accordingly, the most accurate estimation of the air temperature distribution can be achieved with a data set corrected by the altitude in December. In conclusion, the air temperature distribution could be estimated and evaluated using fewer survey sites with less variation in the winter by correcting the air temperature by the altitude, while it is necessary to establish more survey sites for more precise estimation and evaluation of the air temperature distribution in the summer.

I　INTRODUCTION

The thermal environment in urban areas has become severe for humans due to the urban heat island phenomenon. The urban heat island phenomenon has been studied worldwide with the objective of limiting thermal pollution in urban areas [1-6]. The Hyogo Prefectural Government of Japan established an action plan for the heat island phenomenon and constructed a new monitoring network in July 2005 to measure the air temperature for the verification of the effects of the action plan. The action plan aims to mitigate the heat island phenomenon by decreasing artificial waste heat, improving the urban earth’s surface, reshaping the urban form, and changing people’s lifestyle. Aikawa *et al.* [7] thoroughly analyzed the data sets obtained in the new monitoring network and clearly defined the growing heat island phenomenon in the area. Furthermore, Aikawa *et al.* [8-10] studied the air temperature distribution and clarified the severe thermal conditions in the inland area. The monitoring network was constructed in 2005, as described above. Based on the evaluation/review of the monitoring results, the monitoring network was reconstructed to understand the air temperature distribution more clearly and with less bias and/or error. In the reconstruction, some new survey sites were established on the originally planned network. In the present study, the effect of the newly established sites on the evaluation of the air temperature distribution was examined. The findings are reported below.

II METHODS

1 Air temperature measurement

The air temperature was first measured at 18 sites located within the 10 x 15-km region in Hyogo Prefecture from July 2005. Four sites were then added within the same area; as a result, the air temperature was measured at 22 sites from May 2007 (Fig. 1). The area is between Osaka City (population density: 2,634,000/ 222 km^2) and Kobe City (population density: 1,520,000/ 551 km^2). The southern area is characterized by intensive industrial development and dense population, which categorize it as an urban area. In contrast, urbanization has been progressing rapidly in the northern areas, which include satellite cities of Osaka and Kobe Cities [11]. The air temperature was measured using a thermometer (Thermo Recorder TR-52, TandD Corporation, Nagano, Japan) calibrated with a thermostat bath at two temperatures, 5 and 35°C. The measurement resolution was 0.1°C. The measurement accuracy was ± 0.3°C. The thermometer was installed in a naturally ventilated thermometer shelter (about 1.5 m above the ground in principle). The air temperature was measured at the survey site every 15 minutes, and hourly data measured on the hour were used for the evaluation. The air temperature measured in August and December 2007 was analyzed in the study.

2 Survey site characteristics

The present survey area can be classified into three categories: (1) the highly urbanized area along the coast, (2) the suburban area, primarily in the southern part of the study areas, and (3) the residential area being developed as satellite cities, primarily in the northern part of the study areas. This categorization is reported in detail elsewhere [10, 11].

3 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.

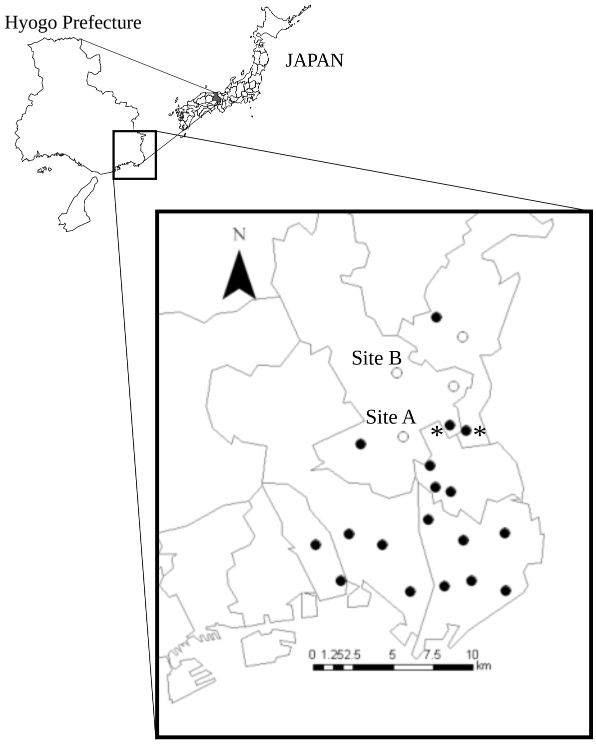

Fig.1 Location map of the survey site. The site marked by solid circle is from July 2005, and the site by open circle is from May 2007. The data in August 2007 at the site marked with * was missing.

4 Correction by the altitude

In the analysis of the air temperature distribution, the air temperature was corrected by the altitude of the sites and a temperature-lapse rate of 0.6°C/100 m. The temperature-lapse rate varied depending on the season and the period of time (daytime and nighttime). Therefore, it was difficult to reflect the variation of the temperature-lapse rate precisely. On the other hand, fog is frequently present at Mt. Rokko (summit: 931 m a.s.l), located next to the present study area [12-15]. The fog is frequently observed in the summer season and occasionally in the winter season [12-15]. Therefore, we employed 0.6°C/ 100 m because some sites are located at 200 m a.s.l or more.

5 Seasonal classification

There are typically four seasons in Japan: spring (March-May), summer (June-August), autumn (September-November), and winter (December-February); therefore, the air temperatures measured in August and December were analyzed as representative of the summer and the winter, respectively, in the present study.

III　RESULTS AND DISCUSSION

1　Air temperature distribution in August

1.1　Air temperature distribution without correction by altitude

Figure 2(a) and (b) shows the air temperature distribution based on the air temperature data without the correction by the altitude. Figure 2(a) is drawn for the data set of the 18 sites first established, and Fig. 2(b) is for that of the 22 sites presently operating. It should be noted that, in Fig. 2, the data at the two sites among the 18 sites first established were missing in August 2007; therefore, the data sets obtained at 16 and 20 sites are used in Fig. 2(a) and (b), respectively.

The distributions in the southern area were similar to each other; however, those in the northern area were different. This would be mainly due to the insufficient number of survey sites in the northern area.

1.2　Air temperature distribution after correction by altitude

Figure 3(a) and (b) shows the air temperature distribution on the basis of the air temperature data after the correction by the altitude. Figure 3(a) is drawn for the data set prepared for the 18 sites first established, and Fig. 3(b) is for that of the 22 sites presently operating. For the same reason as in Section 3.1.1, the data sets obtained at 16 and 20 sites are used in Fig. 3(a) and (b), respectively. The air temperature distributions in the northern area were different from each other in Fig. 3(a) and (b), while those in the southern area were similar to each other, as shown in Fig. 2(a) and (b). A notable difference was observed between the air temperatures at Sites A and B. The air temperature at Site B was relatively high in Fig. 3(b) but moderate in Fig. 2(b). The altitude of Site B was higher than those of other sites, which suggests that the altitude of the site may be an important factor to control the air temperature at Site B. On the other hand, the air temperature at Site A was considerably low in Fig. 3(b) but moderate in Fig. 2(b). The reason for the air temperature at Site B would mainly be the altitude of the site; however, the reason for the low air temperature at Site A remains unidentified.

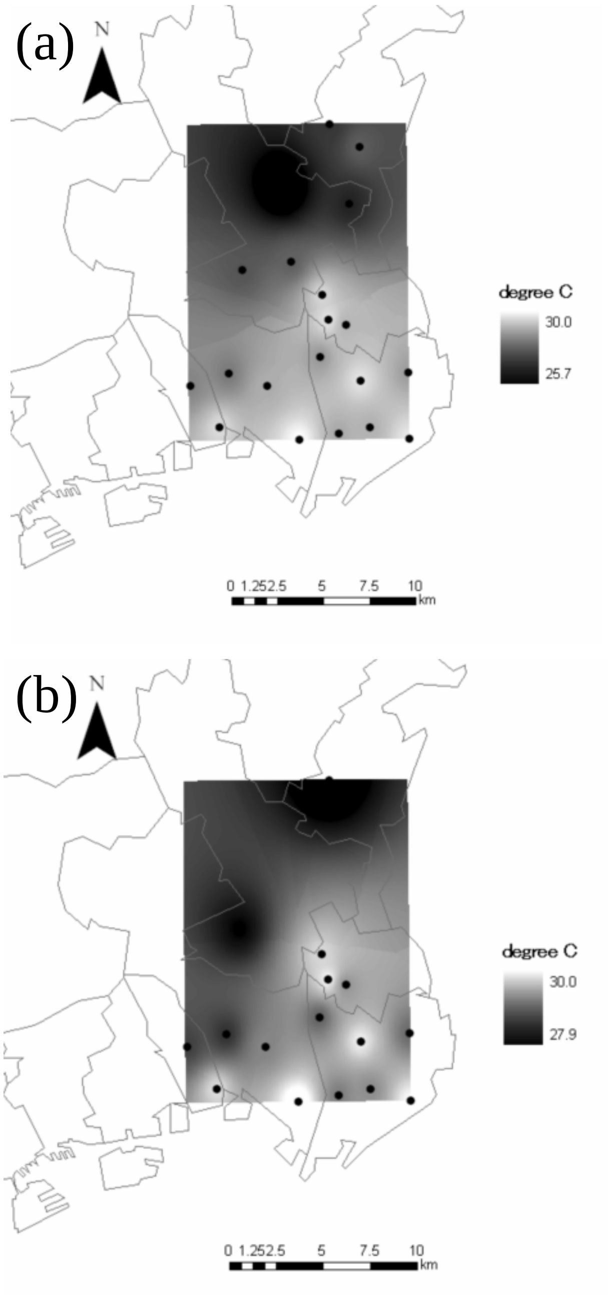

Fig.2　Air temperature distribution of August 2007 calculated by the monthly mean air temperature based on the dataset before adding the new sites (a) and after adding the new sites (b).

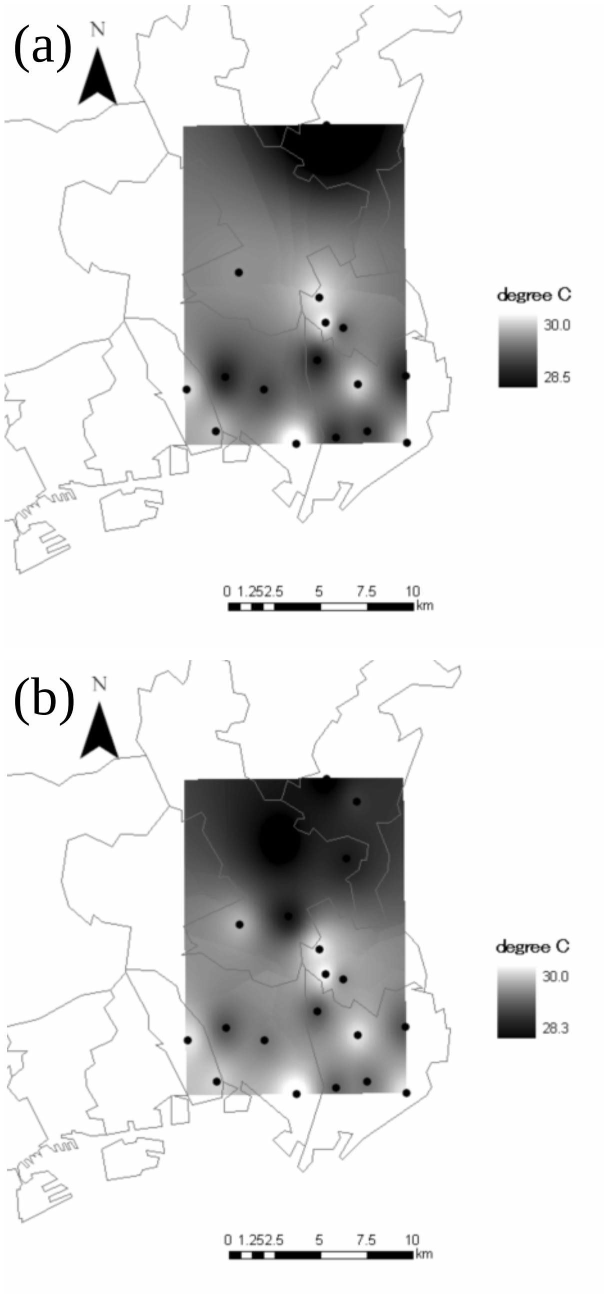

Fig.3 Air temperature distribution of August 2007 calculated by the monthly mean air temperature corrected by the altitude based on the dataset before adding the new sites (a) and after adding the new sites (b).

2 Air temperature distribution in December

2.1 Air temperature distribution without correction by altitude

Figure 4(a) and (b) shows the air temperature distribution based on the air temperature data without the correction by the altitude. Figure 4(a) is drawn for the data set of the 18 sites first established, and Fig. 4(b) is for that of the 22 sites presently operating. The variation in the air temperature distribution between Fig. 4(a) and (b) was small compared with the case of Figs. 2 and 3. This smaller variation was pronounced in the northern area.

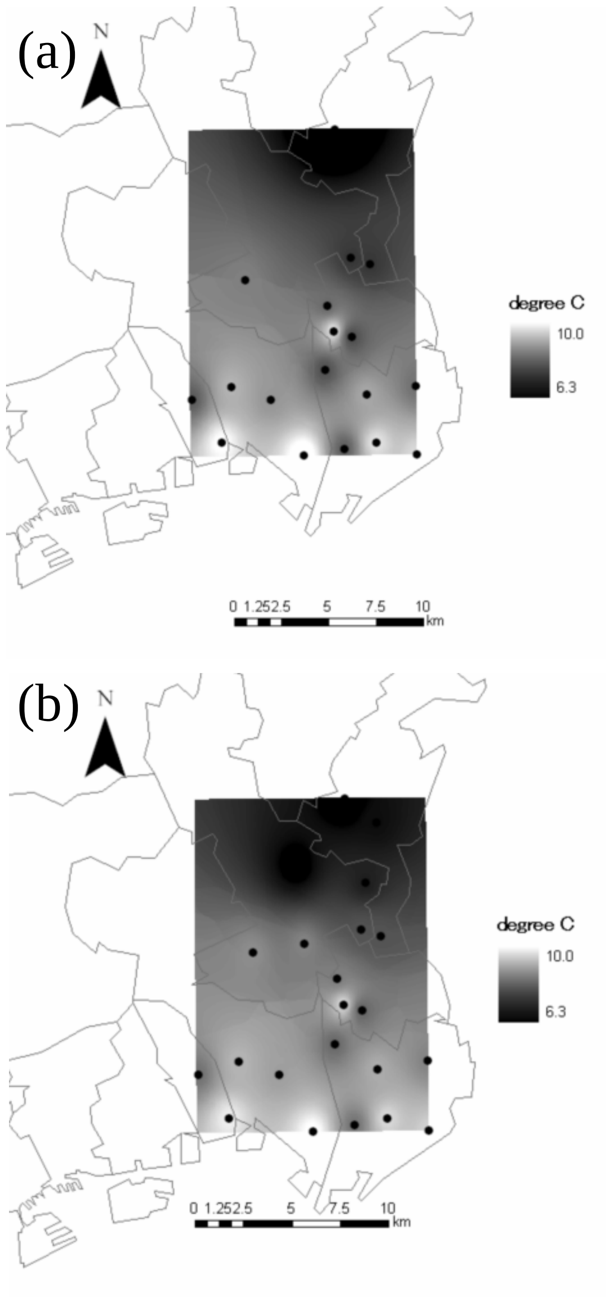

Fig.4 Air temperature distribution of December 2007 calculated by the monthly mean air temperature based on the dataset before adding the new sites (a) and after adding the new sites (b).

2.2　Air temperature distribution after correction by altitude

Figure 5(a) and (b) shows the air temperature distribution based on the air temperature data after the correction by the altitude. Figure 5(a) is drawn for the data set of the 18 sites first established, and Fig. 5(b) is for that of the 22 sites presently operating. The variation between Fig. 5(a) and (b) was smaller than those shown in Figs. 2, 3, and 4. Aikawa *et al.* [16] studied the evaluation methodology of the monthly highest and lowest air temperatures in a heat island phenomenon survey and clarified that the monthly highest air temperature in August reflected particular meteorological conditions relatively easily; on the other hand, the outlier hardly appeared in the monthly lowest air temperature in January. The smallest variation of the air temperature distribution in December coincides with the findings by Aikawa *et al.* [16]. Accordingly, the air temperature distribution in December can be estimated with less variation even though the number of sites is limited when the air temperature is corrected by the altitude.

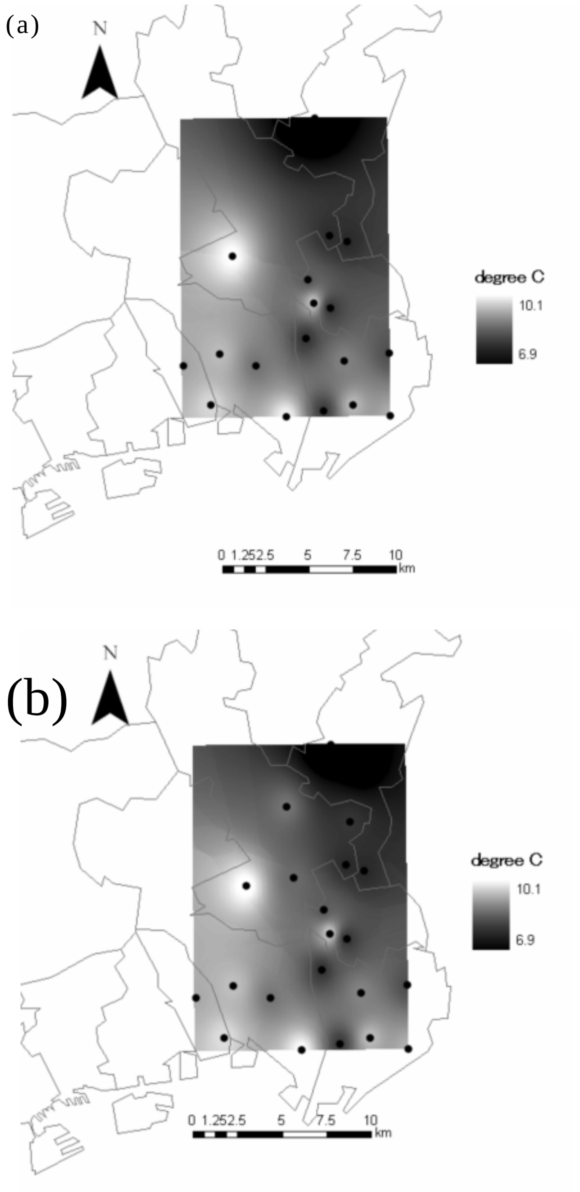

Fig.5　Air temperature distribution of December 2007 calculated by the monthly mean air temperature corrected by the altitude based on the dataset before adding the new sites (a) and after adding the new sites (b).

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要　約

気温分布を評価する際に重要となる測定局数の違いが気温分布解析に及ぼす影響について考察した。その結果、測定局数 18 局に基づく気温分布と 22 局に基づく気温分布を比較すると、その差は夏季においてよりも冬季において小さく、その差は気温を測定地点の標高で補正すると小さくなった。従って、より精度の高い気温分布は夏季よりも冬季に、さらには気温を測定地点の標高で補正することにより得られる。このことから､気温分布は、冬季の気温を測定地点の標高で補正した場合に少ない誤差で評価できる一方、夏季においては、より正確な気温分布を見積もるにはより多くの測定地点を設ける必要があることが明らかとなった。