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Evaluation of output of abnormal weather and heat island phenomenon

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2006 年度の暖冬とヒートアイランド現象の解析

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As part of a heat island survey campaign, we have been continuously monitoring the air temperature in an urban area of approximately 10 x 15 km in Hyogo Prefecture, Japan. We analyzed the data sets of the air temperature obtained in the above campaign from the viewpoint of the spatial distribution of the air temperature and the influence of abnormal weather. The air temperature in December 2006 was 2.8 °C higher than that in December 2005. The winter from December 2006 through February 2007 was unusually warm. The temperature difference (2.8 °C) between December 2005 and 2006 was attributed to the abnormal winter of 2006, since the 2.8 °C deviation was too large to be attributed to the progression of the heat island phenomenon in one year; further its deviation was within the range of the variation observed in the survey results by the Meteorological Agency of Japan around the study area. The abnormal winter of 2006 produced higher air temperatures in the early morning, which was the most significant difference with the winter of 2005. This study newly indicates that the abnormal weather or the unusually warm winter of 2006 in Japan appeared in the daily-lowest air temperature, a phenomenon that generally occurs as a result of a heat island phenomenon.

Keywords: Urban heat island, Air temperature, Spatial distribution, Annual variation, Daily-lowest air temperature, Abnormal weather

I　INTRODUCTION

With the objective of limiting thermal pollution in urban areas, scientists worldwide have studied the urban heat island phenomenon[1-7]. Because urban heat islands are a local environmental pollution issue and not a global one, local governments must counteract them. The government of Hyogo Prefecture implemented measures against heat islands in August 2005. The air temperature must be measured to verify the effects of action plans and to establish effective measures in the future. Aikawa et al.[8] studied the accumulated air temperature data in a 15 x 15-km urban area in 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 using the data sets obtained from a monitoring network newly constructed by the government of Hyogo Prefecture. To precisely verify the effect of the action plans and to propose effective and appropriate measures in the future, detailed data sets on the air temperature must be continuously collected and properly analyzed. The data sets obtained in 2005 were previously studied in detail[7], and the annual variation in the summer season was also studied (unpublished). In the present study, accumulated winter data sets from 2005 to 2007 were analyzed, and the findings are reported in this paper.

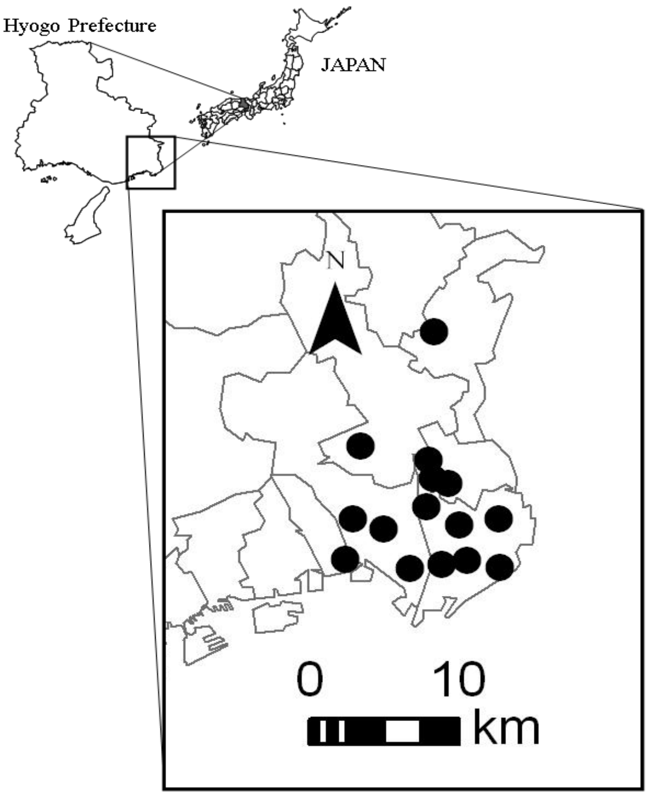


Fig. 1　Location map of the survey site.

II　METHODS

1.　Air temperature measurement

The air temperature was measured at elementary and junior high schools located within a 10 x 15-km area in Hyogo Prefecture, Japan. The geographic characteristics and the land use of the study area are described in detail elsewhere[7]. The locations of the sites are shown in Fig. 1. The air temperature was measured by a thermometer calibrated with a thermostat bath and installed in a naturally ventilated thermometer shelter positioned about 1.5 m above the ground. The data measured on the hour, i.e., hourly data, was used for the evaluation.

2.　Analyzed period

In general, December, January, and February are considered to be the winter season in Japan. Aikawa et al.[7] studied in detail the characteristic air temperature distributions observed in summer and winter in urban areas of Japan; in the study, they used the data sets of August and December as the representative periods of the summer and winter seasons, respectively. Therefore, in the present study, the air temperatures obtained in December of 2005 and 2006 were analyzed as the representative periods of the 2005 and 2006 winter seasons.

3.　Number of survey sites

The air temperature was measured at 18 survey sites. However, the data was missing from one survey site in December 2005 and from two sites in December 2006, as a result of which 17 datasets for December 2006 and 16 for December 2005 were available. To compare the monthly air temperature distributions in December of 2005 and 2006, the data sets obtained at 15 survey sites, excluding the above 3 (1+2) survey sites, were used.

4.　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. The temperature-lapse rate should vary depending on the season and the time (daytime and nighttime). Therefore, it is difficult to reflect the variation of the temperature-lapse rate precisely. On the other hand, fog is frequently observed at Mt. Rokko (summit: 931 m a.s.l), which is located next to the present study area [9-12]. Aikawa et al. [7,13] applied 0.6 °C /100 m for the correction of the air temperature in the previous study. Therefore, we employed 0.6 °C / 100 m in the present study, although the fog is frequently observed in the summer.

III RESULTS AND DISCUSSION

1. Peculiarities of the 2006 winter

Figs. 2 shows the trends of the monthly mean air temperatures in December, January, and February, observed at the Kobe Marine Observatory. The 2006 winter (December 2006 through February 2007) proved to be unusually warm. This peculiarity of the 2006 winter was most typically observed in January and February 2007.

2. Comparison of the monthly mean air temperatures

The monthly mean air temperature, not being corrected by the altitude, is summarized in Table 1. The monthly mean air temperature in December 2006 was 2.8 °C higher than that in December 2005. The median values of the air temperature among the survey sites in December of 2005 and 2006 were 6.0 and 8.5 °C, respectively, showing that the air temperature in December 2006 was higher than that in December 2005.

Table 1 Monthly mean air temperatures in Decembers 2005 and 2006

Unit: °C

	2005	2006
Monthly mean air temperature	5.7	8.5

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

3. Distribution of the deviation in the monthly air temperatures

The distribution of the deviation for the monthly mean air temperature, monthly mean of the daily highest air temperatures, and monthly mean of the daily lowest air temperatures in December of 2005 and 2006 are shown in Figs. 3(a) and (b), respectively, where the deviation is defined as Tip – 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), Tip is the air temperature at site i and for p, and T'p is the average of Tip for each p.

The distribution patterns in December 2005 and 2006 were similar, i.e., the air temperature in the north was lower than that in the south, although the pattern of 2006 was slightly different from that of 2005 in the detailed distribution of the south. The 2005 and 2006 distribution patterns of the deviation in the monthly mean air temperature (Figs. 3 (a)-1 and (b)-1), monthly mean of the daily highest air temperatures (Figs. 3 (a)-2 and (b)-2), and monthly mean of the daily lowest air temperatures (Figs. 3 (a)-3 and (b)-3) were similar in each year. Therefore, the following analysis and discussion are based on the data sets of the monthly mean air temperatures.

4. Difference in air temperature between December of 2005 and 2006

Fig. 4 shows the distribution of the difference in the air temperature between December 2005 and 2006, where the difference is defined as Δ = air temperature in December 2006 – air temperature in December 2005. In Fig. 4, the difference in the air temperature seems to be large at survey sites located in the north. In the present survey area, the altitude is higher in the north than in the south[7], showing that the higher altitude likely resulted in the larger difference in the air temperature. On the other hand, in the present survey area, the survey site with the higher altitude is generally located in an area far from the coast, indicating that distance from the nearest coast might also be responsible for the variation in the air temperature between December 2005 and 2006.

Fig. 5(a) and (b) shows the relationship between the altitude of the survey site (a), the distance from the nearest coast to the survey site (b), and the difference in the air temperature between December 2005 and 2006. In the relationship between the altitude and the difference (Fig. 5(a)), when the altitude of the survey site was higher than 20 m, the difference in the air temperature had a clearly linear relationship with the altitude, and the higher altitude provided a larger difference in the air temperature between December

2005 and 2006. In contrast, there was no relationship between the distance from the nearest coast to the survey site and the difference in the air temperature between December 2005 and 2006 (Fig. 5(b)). Aikawa et al. [7] demonstrated that the current 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 area, and (3) the residential area being developed as satellite cities, primarily in the northern part of the study area. According to the classification by Aikawa et al. [7], there would be no or little change of the land use pattern in the southern part, while the residential development possibly progressed in the northern part. When quantitatively considering the surface condition around the survey area, Britter and Hanna[14] studied the surface roughness length of the urban area by introducing “lambda parameter”; and further, Klysik and Fortuniak[15] studied the degree of the obstruction of the horizon around the survey site. However, we can not calculate the change of the land use pattern between 2005 and 2006 because the land use data prepared in 1997 by the National Land Agency of Japan is the latest. On the other hand, the change of the land use pattern would not be so drastic because the passage of time is just one year.

5. Temporal dependence of the difference in air temperature between December 2005 and 2006

The temporal dependence of the difference in the air temperature between December 2005 and 2006 is shown in Fig. 6(a). Fig. 6(a) indicates that the air temperatures in December 2006 were higher at any given time than those in December 2005. On the other hand, the difference seems to show a temporal dependence in that the difference was larger in the early morning (4:00 – 8:00) than at any other time. Fig. 6(b) also shows the difference in the air temperature between December 2005 and 2006, where the following value is plotted along the vertical axis:

The value of the vertical axis = $\Delta it - \bar{\Delta}i$ (i = site, t = 0:00 to 23:00), where Δit is the difference in the air temperature between December 2005 and 2006 at site i and at time t, and $\bar{\Delta}i$ is the average of Δit at site i.

Fig. 6(b) indicates that the air temperatures in the early morning (4:00 – 8:00) and during the daytime (8:00 – 18:00) made a larger contribution to the difference in the air temperature between December 2005 and 2006. In particular, the contribution in the early morning was large at most sites.

6. Evaluation of the influence of an unusually warm winter

In general, the daily lowest air temperature was observed in the early morning in the diurnal variation, and, in fact, the daily lowest air temperature was noted at 8:00 at all sites in the present study. As shown in Fig. 6(b), the largest contribution to the difference in the air temperature between December 2005 and 2006 was observed in the early morning, or, in other words, the influence of the warm winter of 2006 was the clearest in the difference in the early morning. On the other hand, larger increasing trends for the daily lowest air temperature were reported as related to the phenomenon of urban heat islands[16-19]. In the present study, the air temperature in December 2006 was 2.8 °C higher than that in December 2006, as described in 3.2. The mean difference in the air temperature between December 2005 and 2006 observed in the survey by the Meteorological Agency of Japan around the present survey area was 3.5 °C (the number of the site: 20); maximum and minimum was 4.2 °C and 2.6 °C, respectively. The variation of 2.8 °C was within the range of the variation observed in the results by the Meteorological Agency of Japan. The survey sites of the Meteorological Agency of Japan were distributed in the rural and remote areas as well as in the urban area. Therefore, the variation of 2.8 °C in our present study should be mainly attributed to the deviation due to global phenomena, such as abnormal weather, rather than local causes, such as the progression of the heat island phenomenon. The influence of the heat island phenomenon is clearly observed in the daily lowest air temperature[16-19]. Accordingly, the present study newly indicates that global phenomena, such as abnormal weather, may influence changes in the daily lowest air temperature along with heat island phenomena.

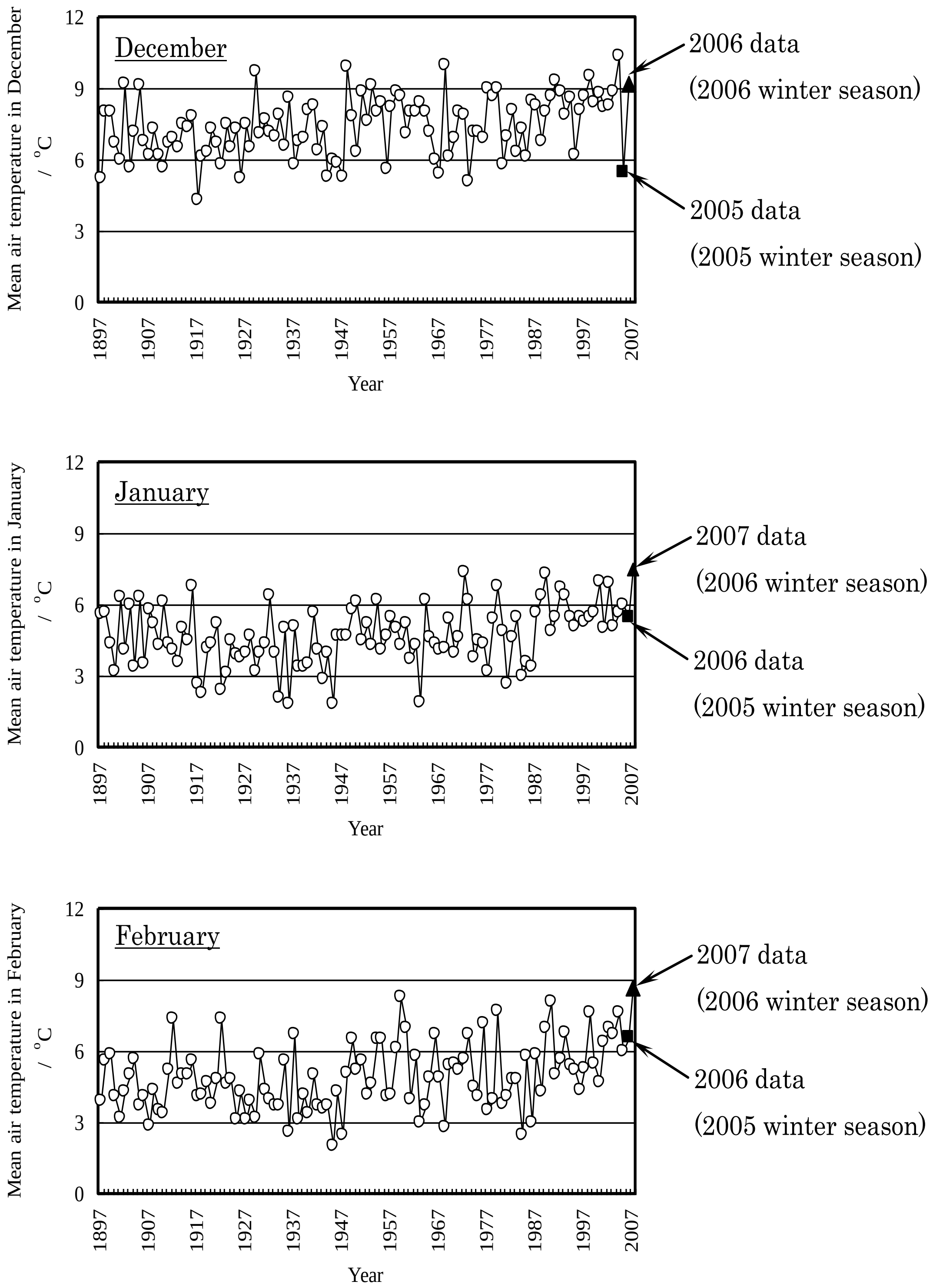
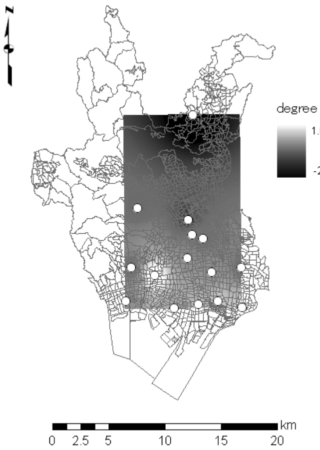
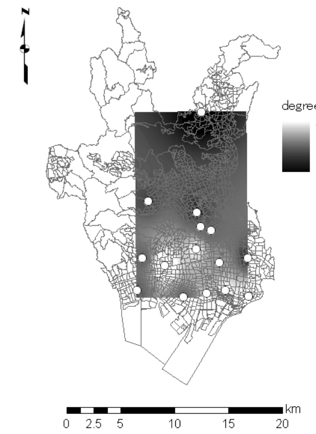


Fig. 2　Trend of the monthly mean air temperature in December, January and February.
The data was observed in the Kobe Marine Observatory.

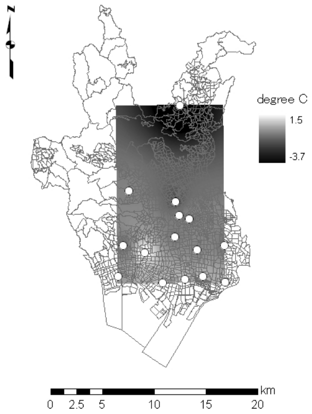
(a)-1



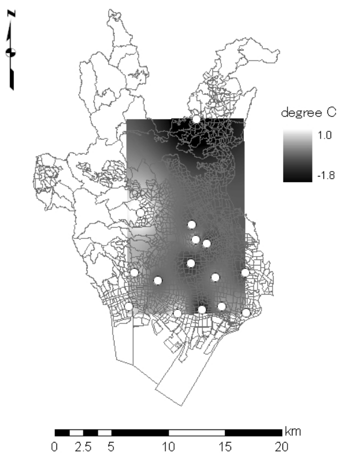
(a)-2



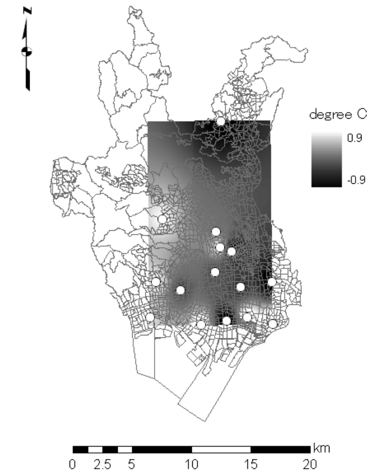
(a)-3



(b)-1



(b)-2



(b)-3

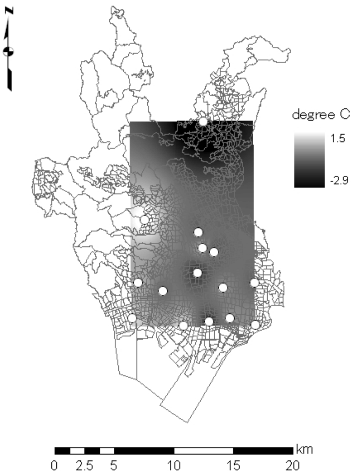


Fig. 3 (a)-1: Distribution of the deviation in the monthly mean air temperatures in December 2005.
(a)-2: Distribution of the deviation in the monthly mean of the daily-highest air temperatures in December 2005.
(a)-3: Distribution of the deviation in the monthly mean of the daily-lowest air temperatures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

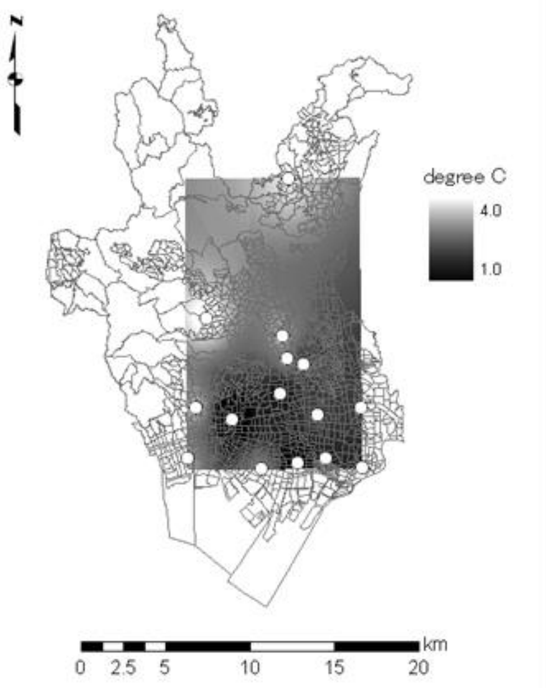


Fig. 4 Distribution of the difference of the air temperature between Decembers 2005 and 2006

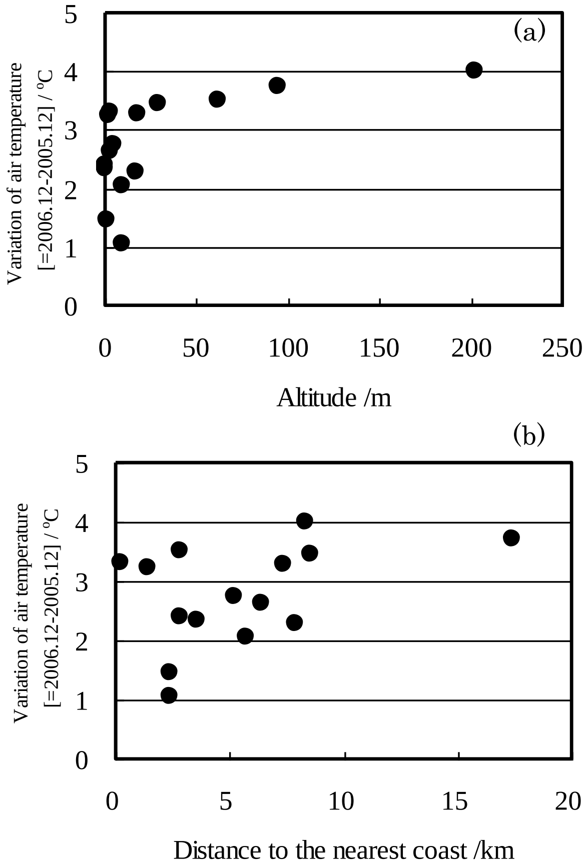


Fig. 5 Relationship between the altitude of the survey site (a), the distance from the nearest coast to the survey site (b) and the difference of the air temperature between Decembers 2005 and 2006

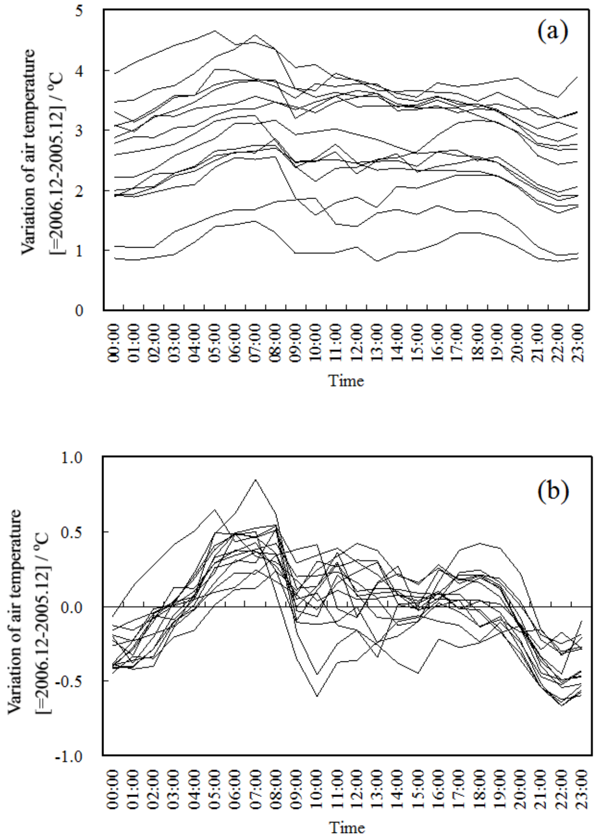


Fig. 6 Temporal dependence of the difference of the air temperature between Decembers 2005 and 2006

(a): Vertical axis: Difference itself in air temperature between December 2005 and 2006

(b): Vertical axis: Value = Δ_{it} - $\bar{\Delta}_i$ (i = site, t = 0:00 to 23:00)

Δ_{it} ; Difference in air temperature between December 2005 and 2006 at site i and at time t,

$\bar{\Delta}_i$; Average of Δ_{it} at site i

IV CONCLUSIONS

The data sets for the air temperature in December 2005 and 2006 obtained from a survey network that covered a 10 x 15-km urban area in Hyogo Prefecture, Japan were studied from the viewpoint of comparing the spatial distributions and influences of an unusual warm winter. The findings are summarized as follows.

(1)The monthly mean air temperature in December 2006 was 2.8 °C higher than that in December 2005 in our survey network.
(2)The higher air temperature was presumably attributed to the deviation due to abnormal weather rather than to the progression of the heat island phenomenon in just one year.
(3)The spatial distribution of the deviation in the monthly mean air temperature, monthly mean of the daily highest air temperatures, and monthly mean of the daily lowest air temperatures showed similar patterns in each year.
(4)The influence of the warm winter was clearly observed at survey sites at higher altitudes.
(5)The influence of global phenomena, such as abnormal weather, was observed in the daily lowest air temperature; in other words, the influence of both the heat island phenomenon and the abnormal weather was observed in the daily lowest air temperature.

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REFERENCES

1) Oke TR, 1973. City size and the urban heat island. Atmospheric Environment, 7: 769-779.
2) Oke TR, Maxwell GB, 1975. Urban heat island dynamics in Montreal and Vancouver. Atmospheric Environment, 9: 191-200.
3) Gotoh T, 1993. Relation between heat islands and NO2 pollution in some Japanese cities. Atmospheric Environment, 27B: 121-128.
4) Saitoh TS, Shimada T, Hoshi H, 1996. Modeling and simulation of the Tokyo urban heat island. Atmospheric Environment, 30: 3431-3442.
5) Yamashita S, 1996. Detailed structure of heat island phenomena from moving observations from electric tram-cars in metropolitan Tokyo. Atmospheric Environment, 30: 429-435.
6) Oke TR, Spronken-Smith RA, Jauregui E, Grimmond CSB, 1999. The energy balance of central Mexico City during the dry season. Atmospheric Environment, 33: 3919-3930.
7) Aikawa M, Hiraki T, Eiho J, Miyazaki H, 2007a. Characteristic air temperature distributions observed in summer and winter in urban area in Japan. Environmental Monitoring and Asseessment, 131: 255-265.
8) Aikawa M, Hiraki T, Sumitomo S, Eiho J, 2006. Distribution and Variation of the Air Temperature from 1990 through 2003 in Urban Areas of Hyogo Prefecture from the aspect of Heat Island Phenomenon. Bulletin of the Hyogo Prefectural Institute of Public Health and Environmental Sciences, 2: 1-9.
9) Aikawa M, Hiraki T, Shoga M, Tamaki M, 2001. Fog and precipitation chemistry at Mt. Rokko in Kobe, April 1997-March 1998. Water, Air and Soil Pollution, 130: 1517-1522.
10) Aikawa M, Hiraki T, Shoga M, Tamaki M, 2005a. Chemistry of fog water collected in the Mt. Rokko area (Kobe city, Japan) between April 1997 and March 2001. Water, Air and Soil Pollution, 160: 373-393.
11) Aikawa M, Hiraki T, Shoga M, Tamaki M, 2005b. Six-year trend and frequency distribution of the pH value of fog water collected on Mt. Rokko (Kobe City, Japan). Bulletin of the Hyogo Prefectural Institute of Public Health and Environmental Sciences, 1: 1-5.
12) Aikawa M, Hiraki T, Shoga M, Tamaki M, Sumitomo S, 2007b. Seven-year trend of the time and seasonal dependence of fog water collected near an industrialized area in Japan. Atmospheric Research, 83: 1-9. DOI:10.1016/j.atmosres.2006.01.011
13) Aikawa M, Hiraki T, Eiho J, 2008. Summer air

temperature distribution and thermal environment in urban areas of Japan. Atmospheric Science Letters, 9: 209-213.
14) Britter RR, Hanna SR, 2003. Flow and dispersion in urban areas. Annual review of fluid mechanics, 35: 469-496.
15) Klysik K, Fortuniak K, 1999. Temporal and spatial characteristics of the urban heat island of Lodz, Poland. Atmospheric Environment, 33: 3885-3895.
16) Kameyama J, Ohkura K, Ishizaka J, Hino T, 1996. Relationship between urbanization and warming in a medium size city. Case study on Miyazaki City. Memoirs of the Faculty of Engineering, Miyazaki University, 25: 35-46. (in Japanese with English abstract)
17) IPCC (Intergovernmental Panel on Climate Change), 2001. The Scientific Basis, eds. Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K., Johnson, C.A., Cambridge Univ. Press, Cambridge, U.K.
18) Arnfield AJ, 2003. Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island. International Journal of Climatology, 23: 1-26.
19) Zhou L, Dickinson RE, Tian Y, Fang J, Li Q, Kaufmann RK, Tucker CJ, Myneni RB, 2004. Evidence for a significant urbanization effect on climate in China. Proceedings of the National Academy of Sciences of the United States of America, 101: 9540-9544.

要　約

2005 年度と 2006 年度の冬期（12 月から 2 月）の気温を比較すると，2006 年度の冬期は 2005 年度の冬期と比べて 2.8℃高かった．これはヒートアイランド現象が 1 年間でより顕著になったとして解釈できる気温差ではなく，この 2.8℃の気温差は 2006 年度の冬期が暖冬（異常気象）であったためであると考えられる．2005 年度と 2006 年度の冬期を比べると，最も顕著な気温差は早朝の気温差に観測された．一般にヒートアイランド現象の影響は早朝気温（日最低気温）に，より顕著に現れるとの研究報告があるが，暖冬等の異常気象の影響もヒートアイランド現象による影響と同様に早朝気温（日最低気温）に観測されることが明らかとなった．