Original Paper

Distribution and Variation of the Air Temperature from 1990 through 2003 in Urban Areas of Hyogo Prefecture from the aspect of Heat Island Phenomenon

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The distribution and variation of the air temperature from 1990 through 2003 in urban areas in Japan were studied in terms of urban heat islands. The mean air temperature showed a spatial distribution reflecting the elevation above sea level. Some discriminative features were observed in diurnal variation depending on the distance from the sea. Increasing trends were observed for the daily mean, daily maximum, and daily minimum air temperature; in addition, a larger and clearer increasing trend was observed for the daily minimum air temperature than for the daily mean and daily maximum air temperature. Furthermore, the rate of the increases in the air temperature was much greater than those recorded in other studies. Although the diurnal range showed a decreasing trend, few significant trends were observed on hot day, summer day, and frost day.

Ⅰ INTRODUCTION

Rising air temperatures in urban areas are a serious problem as they relate to climate change and urban heat islands. The distribution of the air temperature and its correlation with population and urbanization have been studied[1-3]. Some reports have demonstrated that urban air temperatures increase more on their own than they do as a result of climate change and that the rapid development of urban areas influences the magnitude and patterns of heat islands[4-7]. In addition, air temperature trends have recently been studied by using air temperature data recorded at meteorological observatories and by combining techniques, such as remote sensing[8-13]. On the other hand, the phenomenon of urban heat islands is location-specific and has been attributed to population, geography, and energy consumption. Urban heat islands have been reported in the metropolitan areas of Tokyo[14,15] and in much smaller cities as well[16,17]. Some researchers, such as Mikami *et al.*[18-23] have thoroughly studied urban heat islands in the Tokyo metropolitan area. In the present study, a monitoring data set of air temperatures was analyzed to investigate the current conditions and identify some trend or variation in the air temperatures in Hansin area, which is a 15 x 15 km area between the cities of Osaka and Kobe, two of the largest cities in Japan. The findings are reported below.

Ⅱ MATERIALS AND METHODS

2.1 Survey sites and period

Air temperatures were measured at six ambient air pollution monitoring stations in Hansin area at three cities: Amagasaki (1 station), Nishinomiya (4 stations), and Takarazuka (1 station). The six

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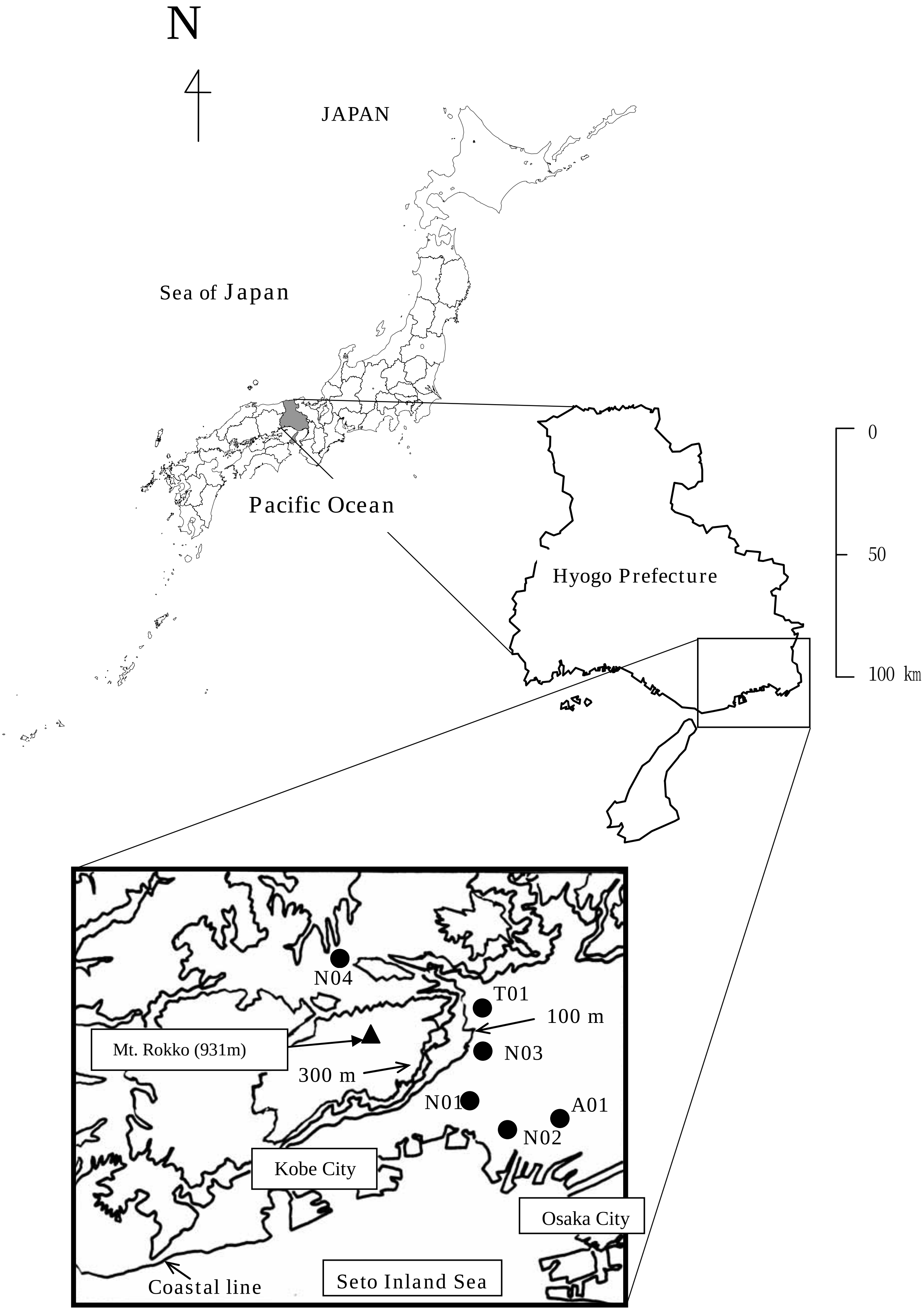


Figure 1 Location of the stations. A01 is located in Amagasaki City, N01, N02, N03, and N04 are located in Nishinomiya City, and T01 is located in Takarazuka City.

stations are in a 15 x 15 km area. The location of the stations is shown in Fig.1. Five of the stations, with the exception of N04, are located less than 50m above sea level (a.s.l.). Hansin area is between Osaka City (population 2,634,000/222 km^2) and Kobe City (population 1,520,000/ 551 km^2). The Hansin area is characterized by intensive industrial development and dense populations. On the other hand, Mt. Rokko (altitude 931 m), which runs east and west, is located in Kobe City. Station N04 is located north of Mt. Rokko, and stations N03 and T01 are at the east end of the mountain range. The characteristics of the six stations are shown in Table 1 and summarized as follows:

Table 1 Characteristics of the six stations

	Longitude	Latitude	Elevation above sea level m
A01	135°24'58"	34°43'19"	0
N01	135°20'38"	34°44'02"	3
N02	135°22'24"	34°42'53"	1
N03	135°21'18"	34°45'54"	50
N04	135°14'21"	34°49'25"	235
T01	135°21'28"	34°47'35"	40

A01: The air temperature was measured on the roof of 5-story building (about 19 m above the ground), where a thermometer shelter was installed. The roof was covered with grass.

N01: The air temperature was measured on the roof of 3-story building (about 10 m above the ground) of a City Hall. The roof is made of slate. The City Hall is surrounded by other buildings that block eastern winds.

N02: The air temperature was measured on the roof of a 4-story building (about 17 m above the ground). The roof is made of concrete.

N03: The air temperature was measured on the roof of a 2-story building (about 8 m above the ground). The roof is made of concrete.

N04: The air temperature was measured on the roof of a 2-story building (about 8 m above the ground). The roof is made of concrete.

T01: The air temperature was measured on the roof of a 2-story building (about 8 m above the ground). The roof is made of concrete. A thermometer box was installed on the concrete roof about 1.5 m above the roof level.

The air temperatures measured from January 1990 to December 2003 were used for analyses.

2.2 Data acquisition and analysis

2.2.1 Data acquisition

The air temperatures were measured hourly. The daily mean, maximum, and minimum air temperatures were used in the evaluations. The hourly air temperatures were measured using a thermometer with Japan Meteorological Agency Certificate.

2.2.2 Statistical analysis

The Kolmogorov-Smirnov test (K-S test) and the least-significant difference test were used to analyze the normality and the seasonal variation, respectively.

Ⅲ RESULTS AND DISCUSSION

3.1 Data distribution

The data distributions of the daily mean, maximum, and minimum air temperatures during the survey were tested by the K-S test, showing that none of them followed a normal distribution (p<0.01) at each station; therefore, it should be appropriate to use a median value rather than a mean value for comparison. The mean and median values for the daily mean, maximum, and minimum air temperatures are summarized in Table 2. The difference between the mean and median values was, however, not significantly large. In addition, the air temperature is usually shown and evaluated by the mean value. Therefore, air temperatures shown by mean values will be used for the following results and discussion.

Table 2 Mean and median values for daily mean, maximum, and minimum air temperatures

	Air temperature /°C					
	Daily mean		Daily maximum		Daily minimum	
	Mean	Median	Mean	Median	Mean	Median
A01	16.7	17.1	20.3	20.9	13.4	13.6
N01	16.0	16.0	19.5	19.7	12.7	12.6
N02	16.4	16.7	19.7	20.3	13.3	13.4
N03	16.0	16.4	19.8	20.3	12.4	12.4
N04	14.3	14.7	18.6	19.2	10.2	10.2
T01	15.9	16.2	19.8	20.4	12.3	12.4

3.2 Mean air temperature

The mean air temperatures of the daily mean, maximum and minimum from each station during the survey are summarized in Fig.2(a). The mean air temperatures from station N04 were lower than those from other stations. One reason that the mean air temperature at station N04 was lower than those from other stations is presumably the difference in elevation. Station N04 is located at an elevation of 235 m a.s.l. and would, therefore, be expected to have lower air temperatures because of its high elevation. Therefore, the mean air temperature at station N04 should be corrected to consider the effect of the elevation of the location. A temperature lapse of 0.6 ℃/100 m was considered. The result of the correction is shown in Fig.2(b). The corrected mean air temperature for the daily maximum at station N04 was the same as that recorded at other stations. However, despite being corrected, the mean air temperature of the daily mean and the daily minimum air temperature were still lower than those from other stations.

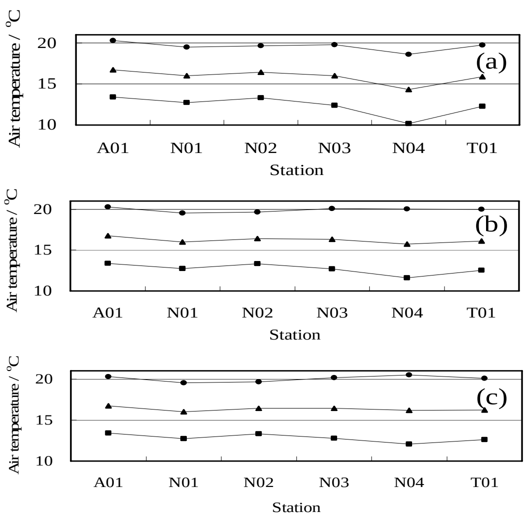


Figure 2 Mean air temperatures of daily mean, maximum and minimum from each station during the survey (a), corrected mean air temperatures of daily mean, maximum, and minimum using temperature lapse rate of 0.6 ℃ /100 m (b), and corrected mean air temperatures using temperature lapse rate of 1.0 ℃ /100 m in winter and spring and temperature lapse rate of 0.6 ℃ /100 m in summer and autumn (c). Filled triangle (▲), filled circle (●), and filled square (■) shows Daily mean, Daily maximum, and Daily minimum, respectively.

As mentioned in 2.1, station N04 is located north of Mt. Rokko. Fog frequently occurs in the vicinity of Mt. Rokko[24-27]; therefore, it is generally appropriate to apply a temperature- lapse rate of 0.6 ℃/100 m for the correction. On the other hand, summer (June, July, and August) fog is common in the vicinity of Mt. Rokko and is uncommon in winter (December, January, and February). In addition, the relative humidity in summer and autumn (September, October, and November) (78.4 and 79.8% during the survey period, respectively) was significantly (p<0.001) higher than in winter and spring (March, April, and May) (75.6 and 70.8%, respectively). Taking these conditions into consideration, it is better to correct the air temperature using a temperature-lapse rate of 1.0 ℃/100 m in winter and spring. The result is shown in Fig.2(c). Little difference was observed between station N04 and other stations in daily mean air temperatures; however, the daily maximum was a little higher, and the daily minimum was a little lower than those recorded at the other stations. The differences in the daily maximum and minimum air temperatures are discussed in more detail in 3.4. However, it can be concluded that the difference in the elevation of the stations is the main reason for the lower air temperature at station N04.

3.3 Diurnal variation

Figure 3 shows the diurnal variation in the air temperature in 2001 calculated by the hourly air temperature at each station. The air temperature at station N04 was low throughout the day, as a result of the elevation of the station.

Figures 3(a), 3(b), and 3(c) are drawn to compare clearly the individual stations. In Fig.3(a), stations N01, N02, and A01 had similar diurnal variations, although the daytime air temperatures at station N02 were slightly lower than those at stations N01 and A01. In Fig.3(b), the daytime (7:00 – 18:00) air temperature at station T01 was higher than that at station N02 and the night (19:00 – 6:00) air temperature at station T01 was lower than that at station N02. In Fig.3(c), air temperature at station N03 was the same as that at

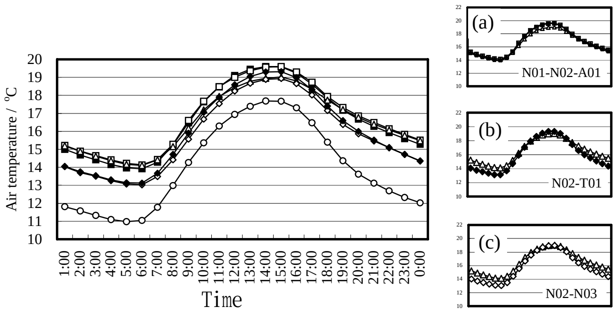


Figure 3 Diurnal variation in the air temperature in 2001 calculated by the hourly air temperature at each station. Figures 3(a), 3(b), and 3(c) compare the individual stations. Filled square (■), open square (□), open triangle (△), open rhombus (◇), open circle (○), and filled rhombus (◆) shows A01, N01, N02, N03, N04, and T01, respectively.

station N02 during the daytime (7:00 – 18:00) while air temperature at station N03 was lower at night (19:00 – 6:00). Stations N01, N02, and A01 are along the coast (approximately 2 km from the sea), which results in similar diurnal variations, i.e., relatively cool daytime and warm nighttime temperatures. In contrast, the nighttime air temperatures at stations T01 and N03 were lower than that from station N02, and the differences were presumably attributed to the fact that these stations are located inland (approximate 6 km and 9 km, respectively). Furthermore, station T01 is located 3 km further inland than station N03, which is probably responsible for the fact that the daytime air temperature at station T01 was slightly higher than those at stations N02 and N03.

The diurnal ranges, which is defined as the difference between the daily maximum and daily minimum air temperatures in the diurnal variation, were 5.7 ℃ (A01), 5.5 (N01), 4.9 (N02), 5.9 (N03), 6.7 (N04), and 6.2 (T01) at each station. The largest difference was observed at station N04. This is attributed to the distance from the sea. At station N04, the air temperature was the lowest, while the diurnal range was the largest, depending on the distance from the sea.

3.4 Trend of air temperature

The air temperature trends are shown in Fig.4, which demonstrates increasing trends at each station. Increasing temperatures during the survey

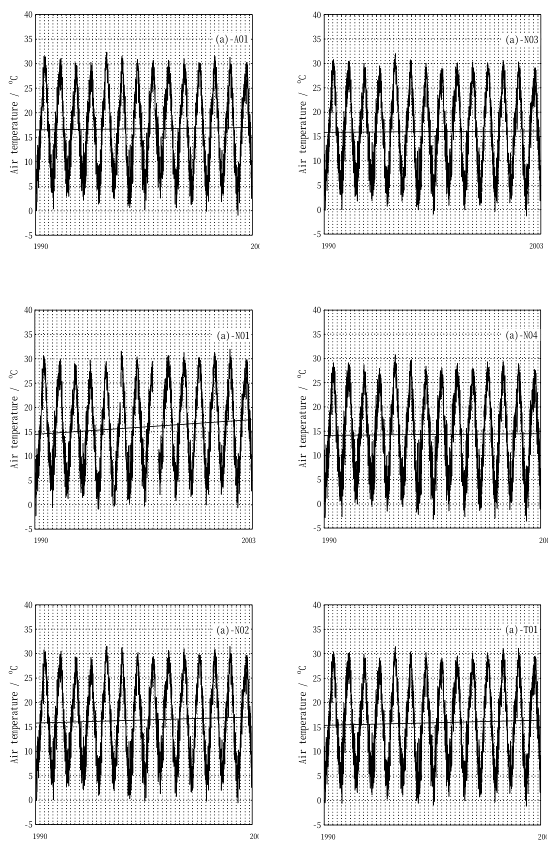
Table 3 Increasing temperatures and trends in diurnal range during the survey

℃・decade^{-1}

	Increasing air temperature			Trends in diurnal range
	Daily mean	Daily maximum	Daily minimum	
A01	0.34	0.35	0.36	0.02
N01	2.17	2.21	2.19	-0.33
N02	0.89	0.70	1.04	-0.41
N03	0.19	0.08	0.38	-0.02
N04	0.24	0.02	0.43	-0.12
T01	0.75	0.70	0.85	-0.15

are summarized in Table 3 together with the trends in diurnal range. The increasing trend was larger and clearer for the daily minimum air temperature than for the daily mean and daily maximum air temperatures for most stations. Larger increasing trends for the daily minimum air temperature were reported as relating to the phenomenon of urban heat islands[5,17,28,29], suggesting the existence of an urban heat island in this area. In addition, the diurnal range showed a decreasing trend in most of stations, also supporting the idea that the urban heat island has grown in this area[5].

The increasing rates for the daily mean, which are shown in Table 3, are much larger than those obtained in other studies[5, 11, 30-34]. This is



presumably due to two reasons; i.e., one is the shorter coverage for the acquisition of air temperature data, and the other is that the 1990s was the warmest decade in the last century[28].

3.5 Hot day, summer day, and frost day

Figure 5 shows trends of the proportion of hot, summer, and frost days in a year. Hot day is defined as that in which the daily maximum air temperature is 30 ℃ and above; summer day, 25 ℃ and above; and frost day is defined as that in which the daily minimum air temperature is 0 ℃ and below. Few significant increasing or decreasing trends were observed. When the numbers of hot, summer, and

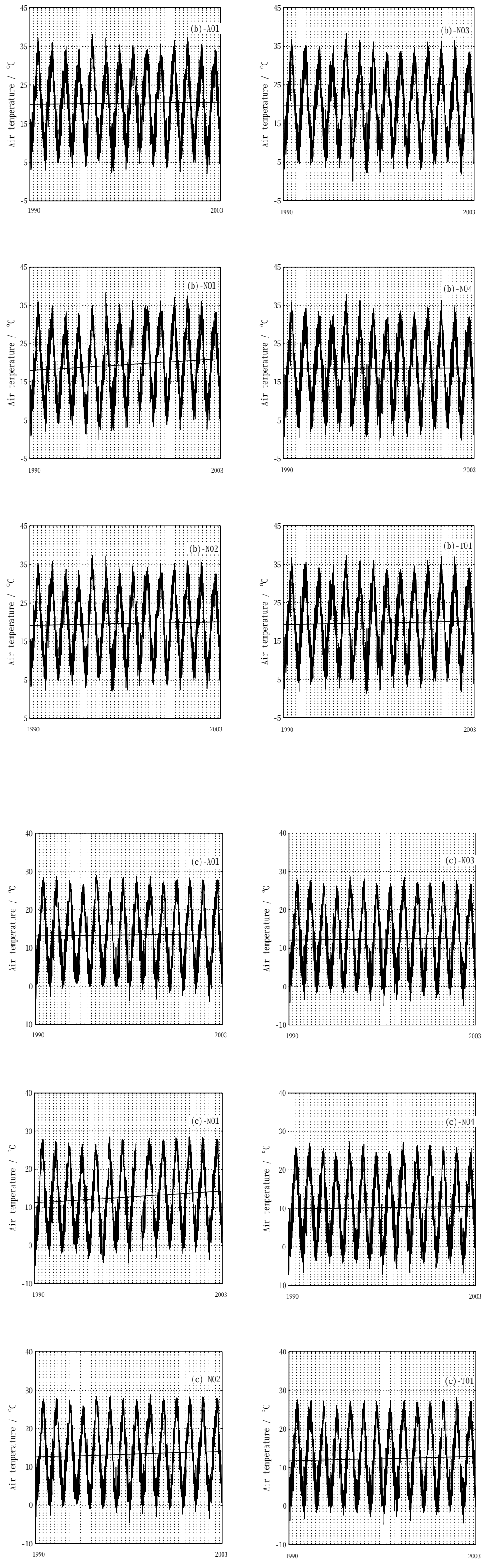


Figure 4 Air temperature trends for daily mean (a), maximum (b), and minimum (c).

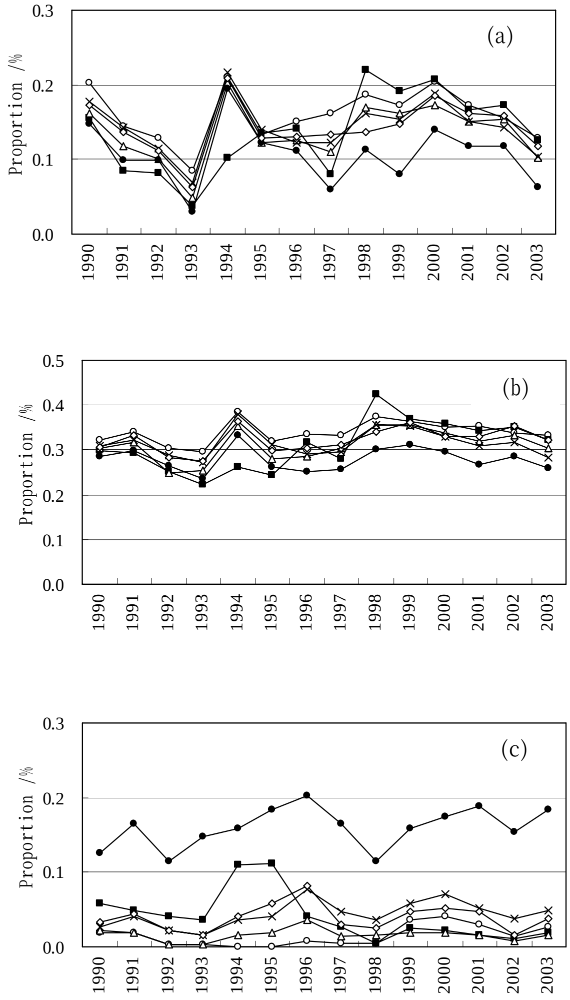


Figure 5 Trends of proportion of hot day (a), summer day (b), and frost day (c) in a year. Open circle (○), filled square (■), open triangle (△), cross mark (×), filled circle (●), and open rhombus (◇) shows A01, N01, N02, N03, N04, and T01, respectively.

frost days are considered, few characteristics of urban heat islands were detected in the study area.

Ⅳ CONCLUSION

Air temperatures measured within a 15 x 15 km urban area in Hyogo Prefecture from 1990 through 2003 were studied. A homogeneous spatial variation of air temperatures was observed within the urban area by considering the elevation at which the monitoring station was located. A more significant increasing trend was observed in the daily minimum air temperature than in the daily mean and daily maximum air temperatures, and the decreasing trend was observed in the diurnal range, suggesting that the urban heat island has grown in this area.

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「原著」

ヒートアイランド現象の観点から見た兵庫県の都市域における気温の分布及び経年変化について

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要　約

一般環境大気測定局で測定されてきた気温データを,

ヒートアイランド現象の現況把握という観点から解析した．データは阪神地域（尼崎市，西宮市，宝塚市）において1990年から2003年に測定された気温データを用いた．

平均気温は観測地点の標高を反映した分布を示し，標高が高い地点で気温が低くなるという分布を示すものであった．

平均気温の日変化は，海岸からの距離を反映し，距離が遠くなるほど日較差（一日における最高気温と最低気温の差）が大きくなる傾向を示した．

対象期間中の経年変化は，日平均気温，日最高気温，日最低気温のいずれについても上昇傾向が観測されたが，日最低気温における気温上昇が最も顕著であった．

また，日較差は対象期間中減少する傾向が観測され，日最低気温における気温上昇が最も顕著であったことと合わせて考えると，阪神地域においてもヒートアイランド現象が進行していることが示唆された．

一方，真夏日，夏日，冬日，真冬日の増加・減少傾向は観測されなかった．