RECENT CLIMATIC CHANGE AND URBAN GROWTH IN TOKYO AND ITS ENVIRONS

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I. INTRODUCTION

Tokyo has grown as a modern city since the beginning of the Meiji era. Especially, after the Second World War an incessant increase of population and built-up area has occurred in the suburban area, which resulted in a rapid expansion of DID, densely inhabited district in Population Census of Japan, of Tokyo.

Climate modifications due to the urban growth have been reported by many meteorologists and climatologists (*e.g.* Sasakura, 1965, Arakawa, 1970, Kayane, 1960). The urban climate of Tokyo is characterized by an increase of temperature, and decreases of humidity and insolation.

In this paper we would like to describe the climatic change due to urban controls from both temporal and spatial points of view.

II. DATA AND METHOD

Meteorological data at twelve stations in and around Tokyo were used to analyse temporal and spatial structure of changing urban climate of Tokyo. In the first part, especially in order to clarify secular climatic variation covering more than fifty years, three key stations were adopted: the Meteorological Observatory of Tokyo as designated simply Tokyo here, the Climatological Station of Seikei School at Kichijoji in Musashino-*shi* and the Aerological Observatory of Tateno. The Meteorological Observatory of Tokyo is located in Chiyoda Ward of central Tokyo which is one of the most urbanized wards with tall buildings. The second station at Kichijoji is situated 17 km to the west of the Meteorological Observatory of Tokyo. Its location approximately coincides with the western fringe of DID in Tokyo in and around 1960. The third station at Tateno which is located about 50 km to the north-northeast of Tokyo, is surrounded by cultivated lands and grasslands. We may say, therefore, that the station has not suffered from urban effects up to the present (Table 1).

By using the data of these stations, both the absolute values for each station and the climate differences between each other, we may exclude the influence of large scale climatic change and extract the urban effects on the climate of Tokyo.

In the second part temporal and spatial variations of air temperature in the urban area of

Table 1. Population of Tateno, Yatabe-*cho*, Ibaragi-*ken*.

Year	1950	1955	1960	1965	1970	1975
Population	22,455	22,048	20,570	20,093	20,134	22,225

Tokyo were also investigated by using the data at the following nine stations: Shinjuku, Nishigahara, Setagaya, Nakaarai, Matsudo, Fuchu, Tachikawa, Urawa and Koshigaya (Fig. 1).

III. OUTLINE OF THE URBAN GROWTH OF TOKYO

The built-up area of Tokyo was heavily destroyed twice by the Great Kanto Earthquake of 1923 and the air-raids during the Second World War. Especially, during the war the better part of the area was burnt down. The Korean War caused the rapid economic growth to Japan. As a result, the population of Tokyo has increased and the built-up area has expanded.

Though Tokyo reached a population of 7.36 million in 1940, it decreased to 3.49 million at the end of the war in 1945. However, the population increased again to 7.38 million at

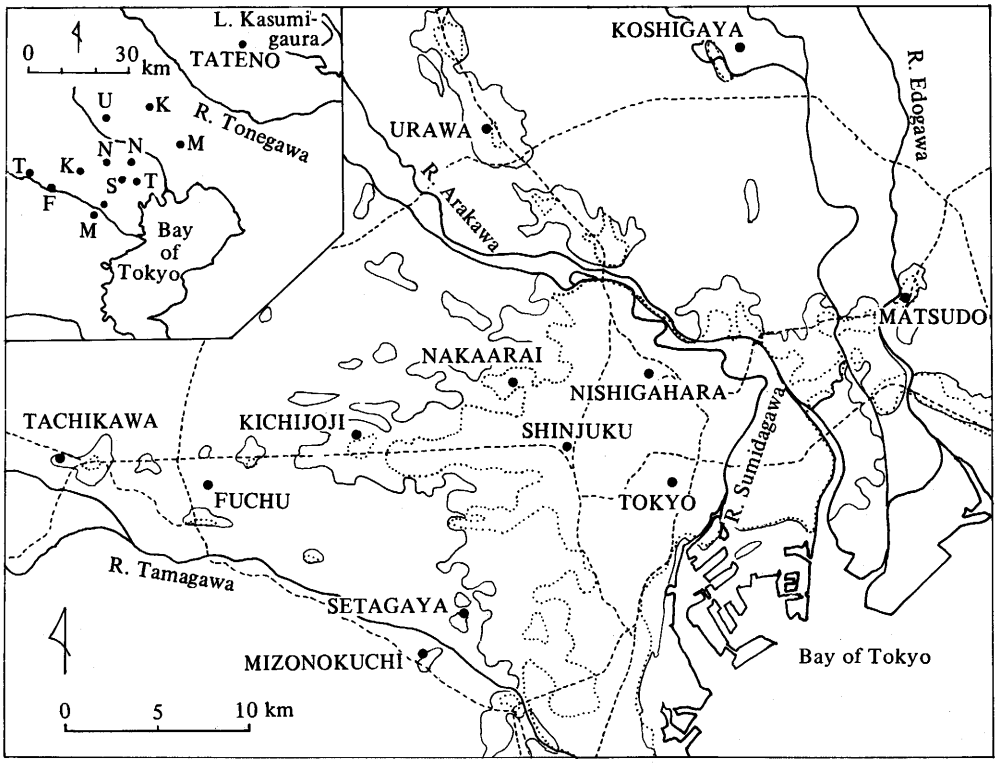


Fig. 1 The location of stations and the built-up area of Tokyo in the years of 1946 (dot line) and 1975 (solid line).

Table 2. Growth of actual capacity ratio (total floor space-to-housing land ratio) in each district. (unit:%) (Nakabayashi)

District	1953	1958	1965	1975
Chiyoda-*ku*	86	112	187	320
Shinjuku-*ku*	28	42	64	108
Musashino-*shi*	–	–	37	56

the end of the Korean War in 1953, and amounted to 11.67 million in 1975. In spite of the increase of the population of Tokyo as a whole, the central wards of Tokyo have depleted a population since the years from 1955 to 1960 up to the present. In addition, the total population of twenty-three wards has also decreased since 1965 with the maximum of 8.89 million.

Similarly, the number and the floor space of buildings has increased rapidly since 1965, reaching their maxima in 1972 and 1973. In 1965 a pronounced increase of building was found especially in the central portion of the ward-area, such as Chiyoda, Chuo and Taito Wards, the rate of increase getting smaller toward the periphery of the area. After that, a progressive increase of buildings has occurred: in 1975 the actual capacity ratio (total floor space-to-housing land ratio) reached upward of 300% in Chiyoda and Chuo Wards and 100% in the surrounding wards such as Taito, Minato, Bunkyo, Shinjuku and Shibuya (Table 2).

The increase of the actual capacity ratio in the ward-area corresponds to the decrease of population of 200,000 from 1970 to 1975 in the ward-area, whereas the population increase of 440,000 and an expansion of built-up area are noticed in the suburban area in the same time (Nakabayashi, 1978). The expansion of the built-up area of Tokyo from 1946 to 1975 is shown in Figure 1.

IV. SECULAR CHANGES OF CITY CLIMATE

For the purpose of elucidating the development of the city climate of Tokyo, secular changes of several meteorological elements at each of three stations of Tokyo, Kichijoji and Tateno, and those of the differences of the elements between both of them were analysed. As mentioned above, Kichijoji is located on the western fringe of DID of Tokyo, and Tateno is free from urban controls.

Meteorological elements treated here are monthly means of maximum and minimum temperatures and water vapor pressures for January and August, and numbers of tropical hot days (daily maximum temperature more than 30°C), frost days (daily minimum temperature less than 0°C) and drizzly days (daily precipitation 0.1–1.0 mm).

Mainly based on the differences of the meteorological elements between the both among three stations described above effects of urban growth were detected. In the secular changes of the elements we may notice, with few exceptions, remarkable features due to urban controls. Especially, noticeable secular changes with regional diversity in the built-up area were recognized concerning the elements, such as temperatures, tropical hot and drizzly days.

Secular changes of the elements at each station and of the differences between both of the stations are as follows.

1. Minimum Temperature for January

At every station a sharp rise of temperature occurred in the 1940s (Fig. 2). It may be chiefly attributed not to urban growth, but to a large-scale climatic change.

The effects of urban growth on the city temperature may be measured by the differences of temperature between both stations. In other words, an increase of temperature differences between Tokyo or Kichijoji and Tateno may imply the development of city temperature in Tokyo area. The rising tendency of city temperatures for Tokyo and Kichijoji can be clearly observed since around 1960 and around 1950, respectively. These facts may coincide with the marked increase of the actual capacity ratio in the central part of Tokyo since the middle of the 1960s, and of the built-up area in the suburban area since the 1950s, respectively. A sharp rise of the temperature in the central part of Tokyo since the middle of the 1960s is causing to increase a temperature gradient toward the outskirts.

2. Minimum Temperature for August

Compared with the minimum temperature for January, the temperature differences between Tokyo or Kichijoji and Tateno are smaller, and vary with smaller amplitude from year to year (Fig. 3). The temperatures at Tokyo and Kichijoji are always higher than that for Tateno throughout the period. The temperature differences between Tokyo or Kichijoji and Tateno increase slightly, and rather sharply rise during the 1960s.

The temperature difference between Tokyo and Kichijoji has undergone little change, being equal to about 1°C throughout the period.

3. Maximum Temperature for January

The temperature differences between Tokyo or Kichijoji and Tateno are smaller than those of minimum temperature for January, being equal to only 1°C at their maxima (Fig. 4). It is noticed that the temperature for Kichijoji is lower than that for Tateno until the middle of 1950s and thereafter the situation is reversed. This fact may indicate an increase of the built-up area on the western fringe of Tokyo during the 1950s and the 1960s.

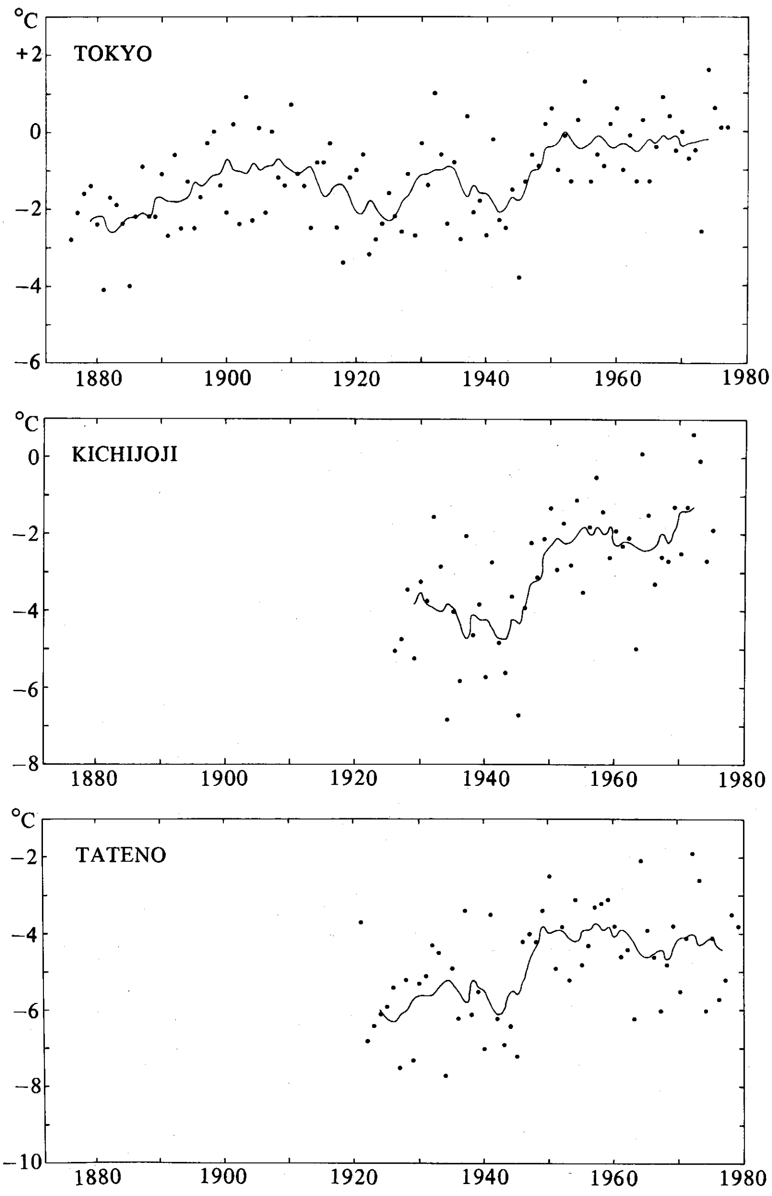
Because of a pronounced rise of maximum temperature at Kichijoji since around 1960, the temperature in the central part of Tokyo has become lower than in the western fringe since the end of the 1960s.

4. Maximum Temperature for August

The temperature differences between Tokyo or Kichijoji and Tateno fluctuate with an amplitude of ±1°C throughout the period (Fig. 5). The temperature at Tokyo has been higher than at Kichijoji and Tateno. On the other hand, at Kichijoji lower temperatures were recorded than those of Tateno from the end of the 1940s to around 1960. Because of a rapid rise of temperature at Kichijoji since 1960, there is little difference in maximum temperature for August in recent years between Tokyo and Kichijoji.

5. Number of Frost Days

At Tokyo and Kichijoji the number of frost days has decreased markedly since around



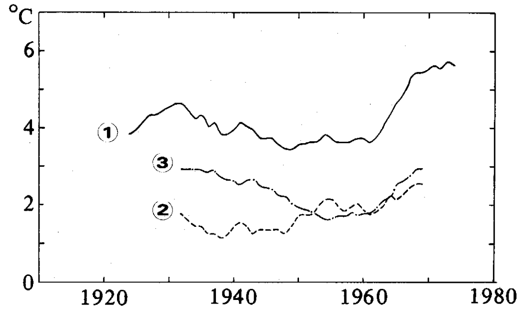
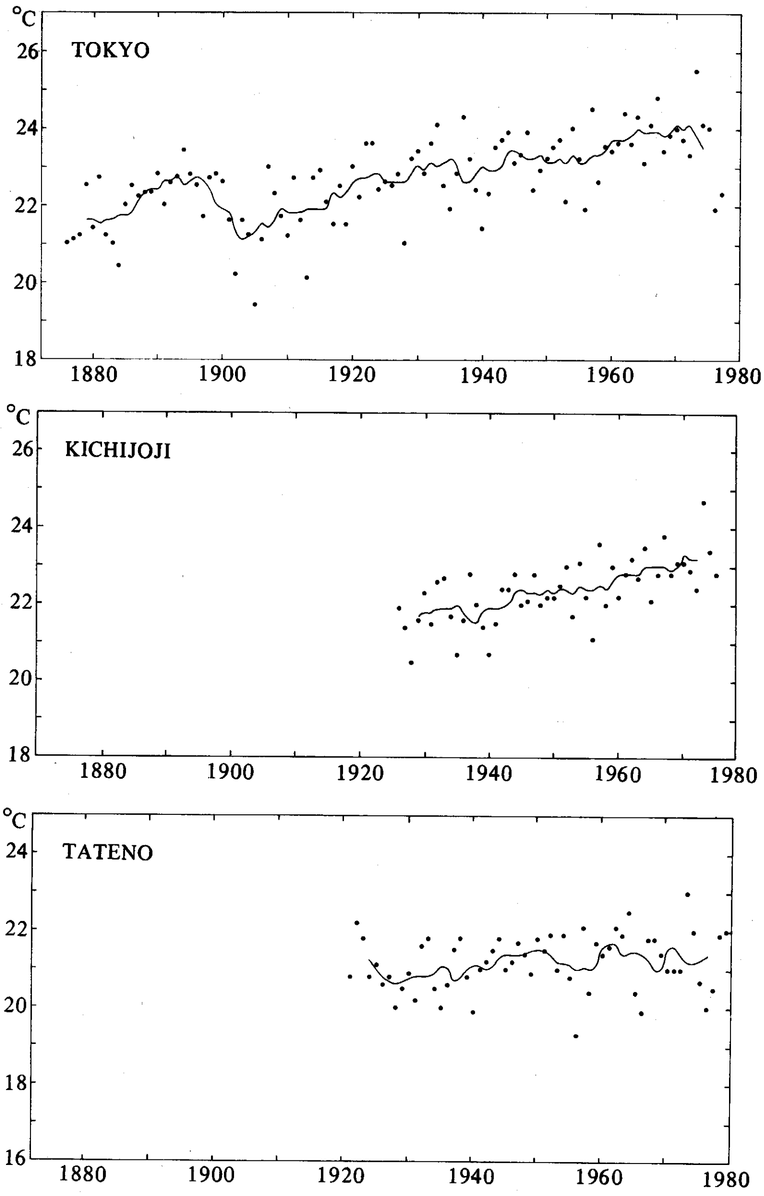


Fig. 2 Monthly mean minimum temperature for January at (1) Tokyo (2) Kichijoji and (3) Tateno and (4) its differences between respective stations, 1 Tokyo–Tateno, 2 Kichijoji–Tateno and 3 Tokyo–Kichijoji. Dots indicate the values of each year and the other lines 11-year running means.



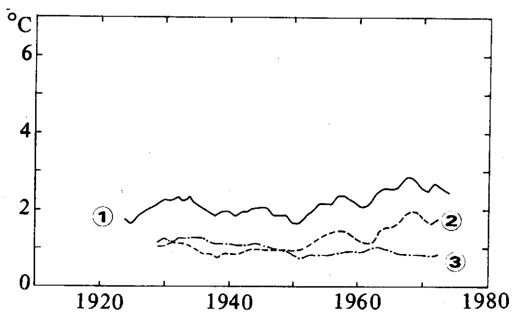
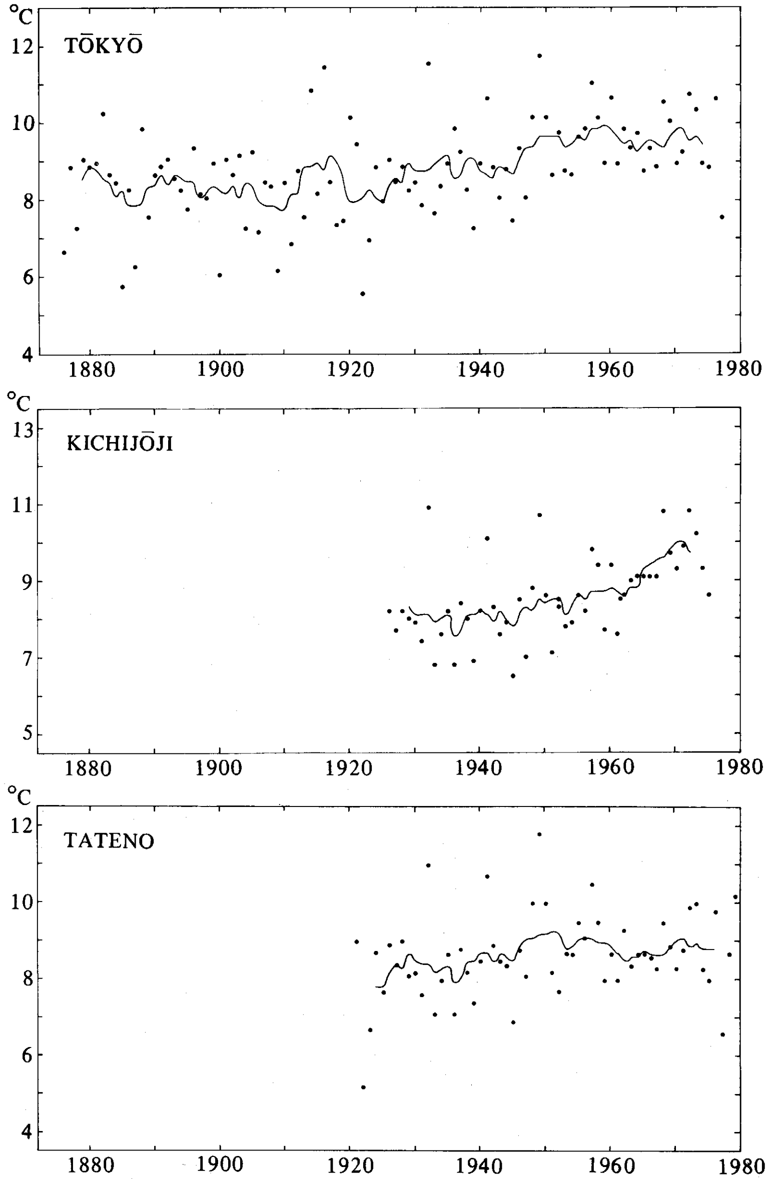


Fig. 3 Same as Fig. 2 but for August.



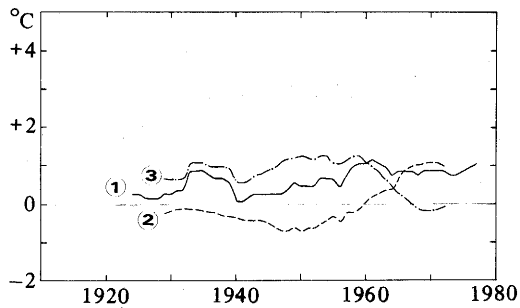
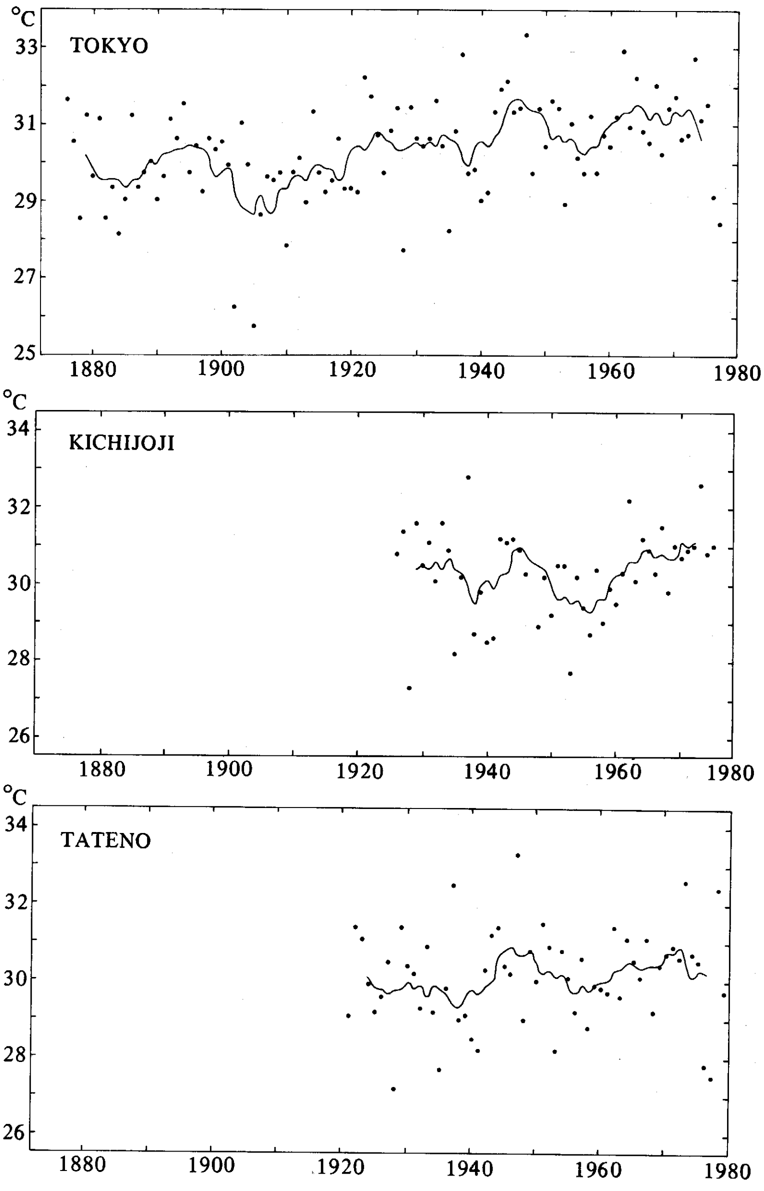


Fig. 4 Same as Fig. 2 but for monthly mean maximum temperature for January.



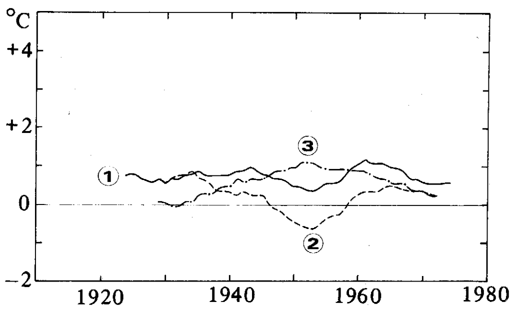
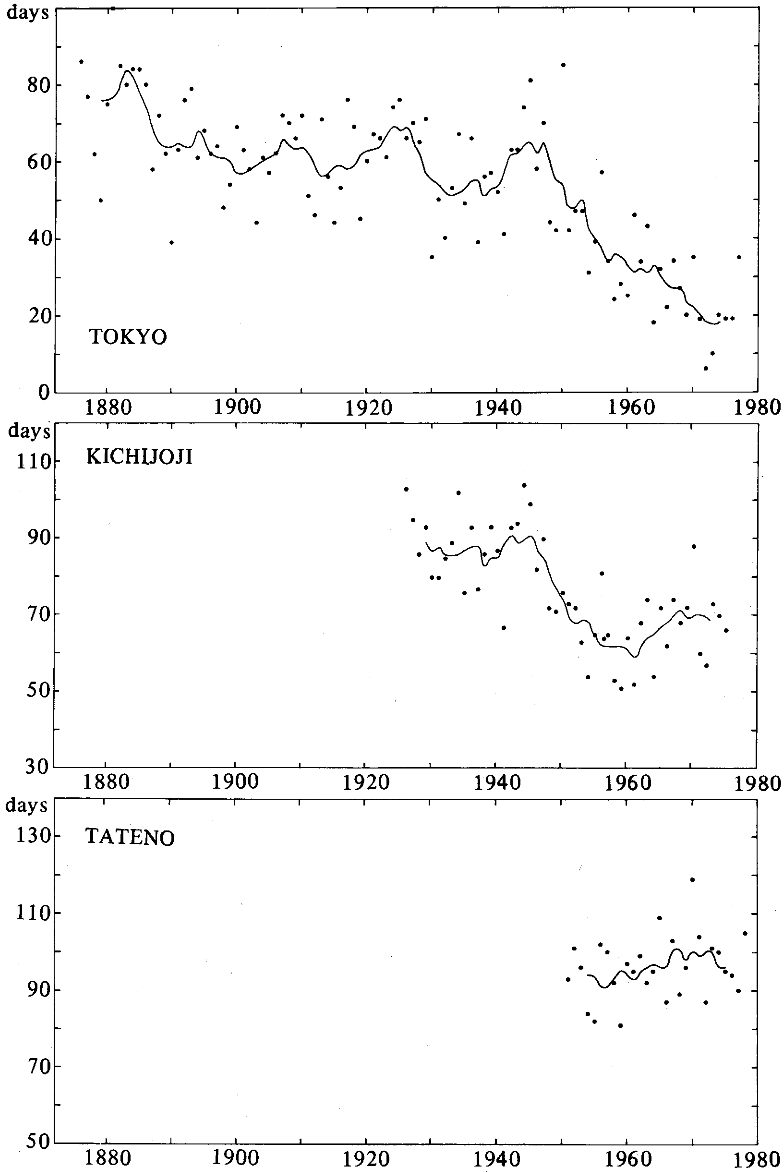


Fig. 5 Same as Fig. 2 but for monthly mean maximum temperature for August.



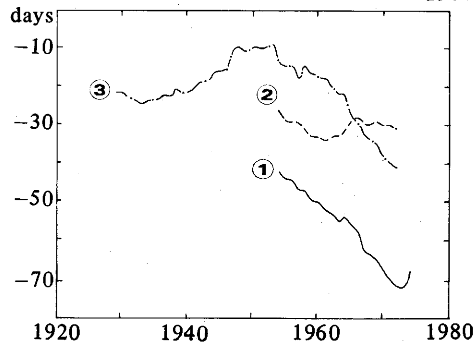


Fig. 6 Same as Fig. 2 but for number of days with daily minimum temperature below 0°C.

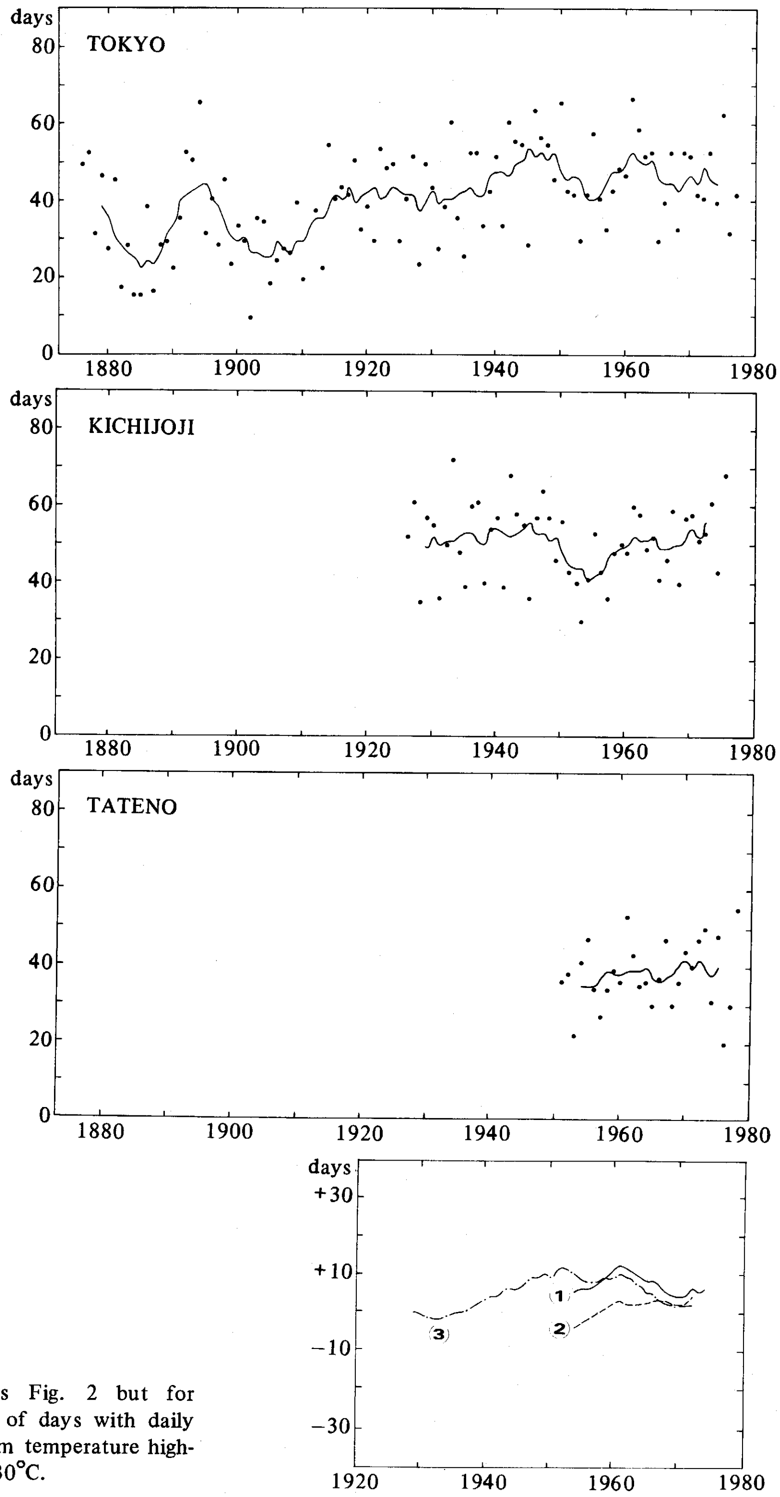
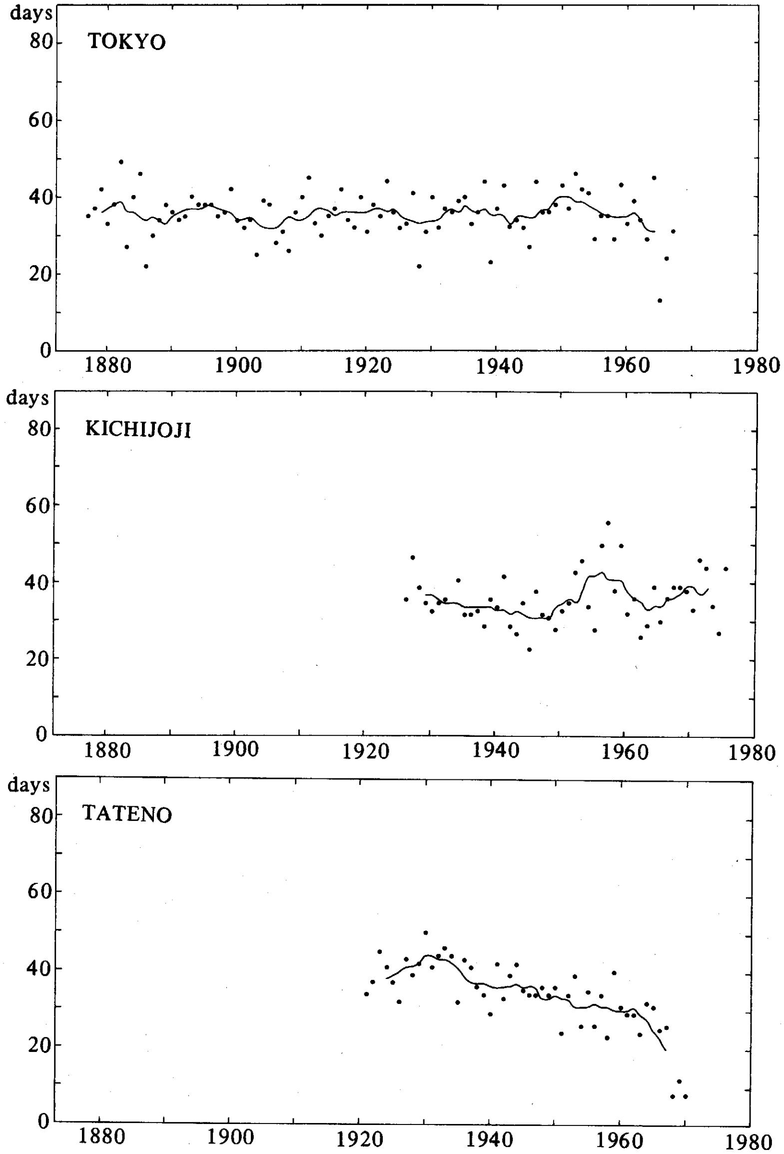


Fig. 7 Same as Fig. 2 but for number of days with daily maximum temperature higher than 30°C.



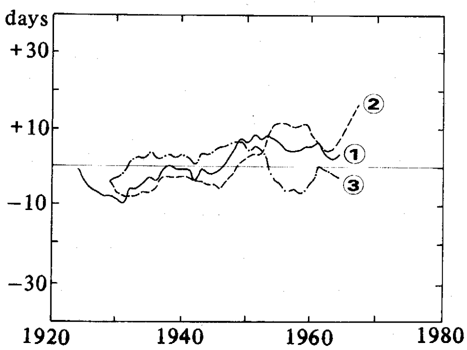


Fig. 8 Same as Fig. 2 but for number of drizzly days.

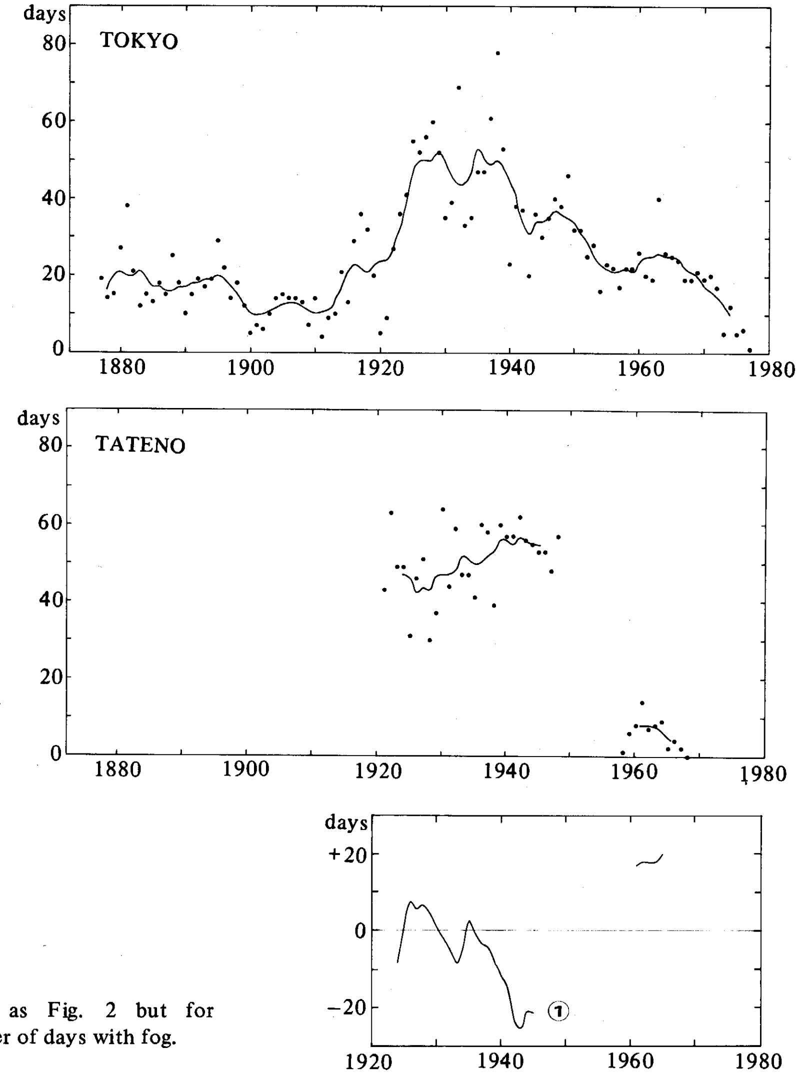


Fig. 9 Same as Fig. 2 but for number of days with fog.

1945 (Fig. 6). This falling tendency coincides well to a rising one for January minimum temperature. The difference in number of frost days between Tokyo and Kichijoji decreases until around 1950 and then increases up to the present. This characteristic variation may be well explained by the minimum temperature features for January during the same period at Tokyo and Kichijoji: a pronounced increase of the difference in number of frost days may be attributed to a sudden rise in minimum temperature at Tokyo since around 1950.

6. Number of Tropical Hot days

In the secular variation in number of tropical hot days at each station we can hardly recognize a certain effect of urban growth (Fig. 7). However, the difference in number of

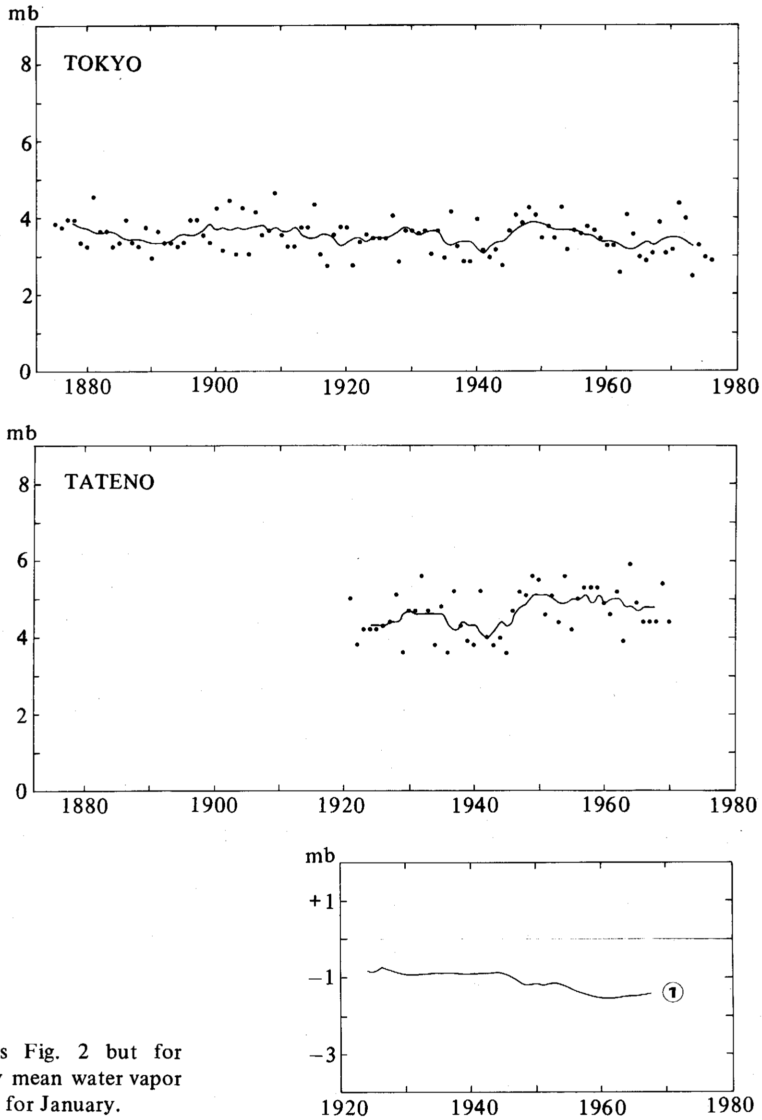


Fig. 10 Same as Fig. 2 but for monthly mean water vapor pressure for January.

days between Tokyo and Kichijoji varies with its maximum around 1950, in a similar manner to that in number of frost days as stated before.

7. Number of Drizzly Days

As shown in the difference between Tokyo and Tateno, an increase in number of drizzly days has occurred since the beginning of the 1930s, showing its maximum around 1950 (Fig. 8). Concerning the difference between Kichijoji and Tateno a similar tendency can be observed, except for a slight time lag of several years. Because of a steady increase in number of days at Kichijoji, drizzly rain occurs more frequently at Kichijoji on the western fringe than at Tokyo in the central portion of Tokyo area.

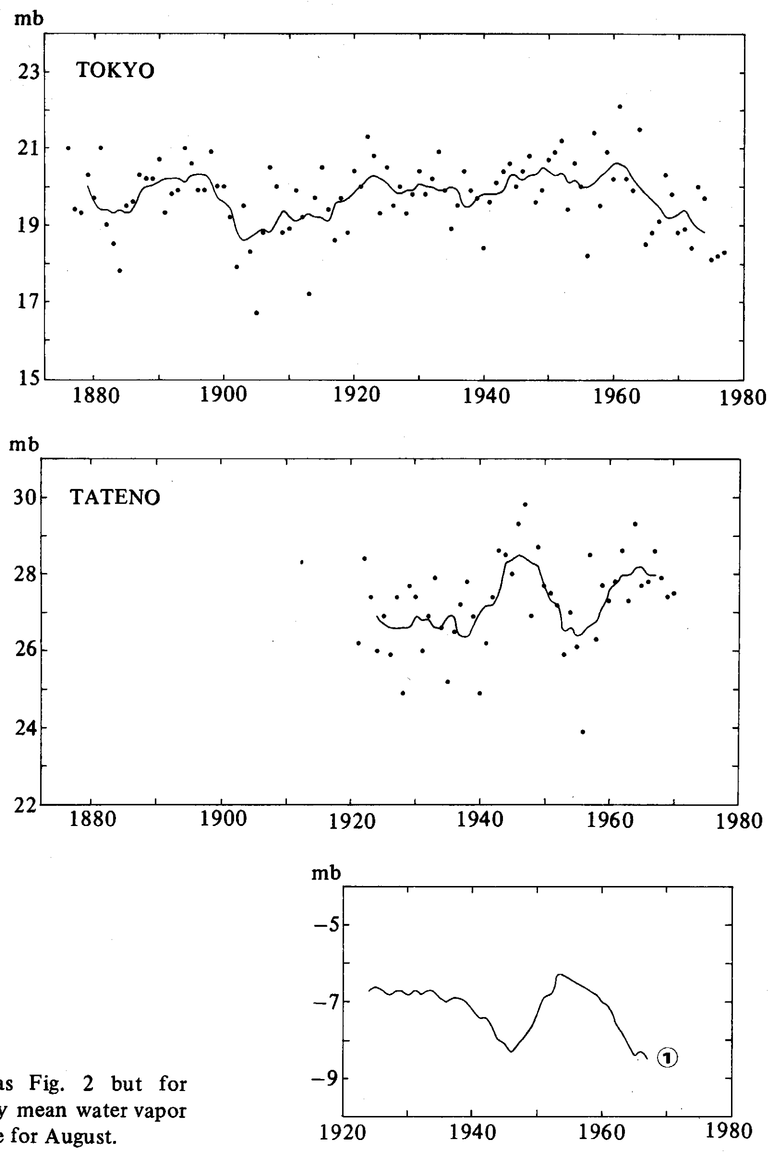


Fig. 11 Same as Fig. 2 but for monthly mean water vapor pressure for August.

8. Number of Days with Fog

At Tokyo annual total of number of days with fog increased rapidly during the period from the beginning of the 1910s to the end of 1930s (Fig. 9). After that it shows a marked decrease up to the present. Especially, it is worthy of notice that the number of days since around 1970 has been less than that in and around the turning point of the century. This sharp decrease to the least value in its time series may be attributed to the change of fuel consumed in the urban area from coal to oil and gas, and also to a legal control of air pollution.

9. Water Vapor Pressure for January

In the secular variation of water vapor pressure for January we can not find out a significant trend. Despite the higher temperatures for January, the value of vapor pressure has been smaller in the central part of Tokyo than in the rural area (Fig. 10).

10. Water Vapor Pressure for August

In the central part of Tokyo vapor pressure has been lower than in the rural area by about 7 mb (Fig. 11). At Tokyo the vapor pressure increased slightly during the period from the 1910s to the 1950s, and has decreased abruptly after that. It is noted that hot and dry weather prevails in midsummer in the built-up area of Tokyo.

As has described above, we may note remarkable features in secular changes of several meteorological elements. Compared with the temperature for August, the temperature features for January are considerably complicated. A pronounced increase in temperature difference between Tokyo and Kichijoji since the middle of the 1950s may be attributed to a standstill of the increase of built-up area in Tokyo and the redevelopment of the central part since the 1960s. The secular variations in maximum temperatures for January and August have similar features. In accordance with the fact that the temperature for August decreased until the first half of the 1950s and increased thereafter on the western fringe of Tokyo, the temperature difference between the central part and the urban fringe of Tokyo increased at first and then decreased. The maximum temperature for January has been lower in the central portion of Tokyo than on the urban fringe of Tokyo since around 1965, because of a rapid rise of temperature on the urban fringe.

The secular change in number of drizzly days arouses interest. The number of drizzly days increased since about 1930 in the central part of Tokyo, and its beginning was delayed by about twenty years on the urban fringe. More frequent occurrence of drizzle in the suburban area is a noticeable fact in recent times.

V. DISTRIBUTION OF TEMPERATURE IN TOKYO AREA

To analyse spatial distribution of city temperature and its temporal change, we prepared temperature profiles in a direction from east to west in Tokyo area by using five-year means (Fig. 12).

As mentioned above, city temperature due to urban control can be noticed in the minimum temperatures for January and August. The differences of maximum temperatures between the central part and the urban fringe are less than those of minimum temperatures.

1. Minimum Temperature for January

The five-year mean temperature at Tokyo was higher by 2.3°C during the period of 1946–1950 and by 1.9°C during the years of 1951–1955 than that of Kichijoji. On the other hand, the temperature at Kichijoji was higher by 0.4°C during the former period and by 0.7°C during the latter period than that of Fuchu (Fig. 13). These facts may be attributed to a rise of city temperature at Kichijoji. The difference of temperature between

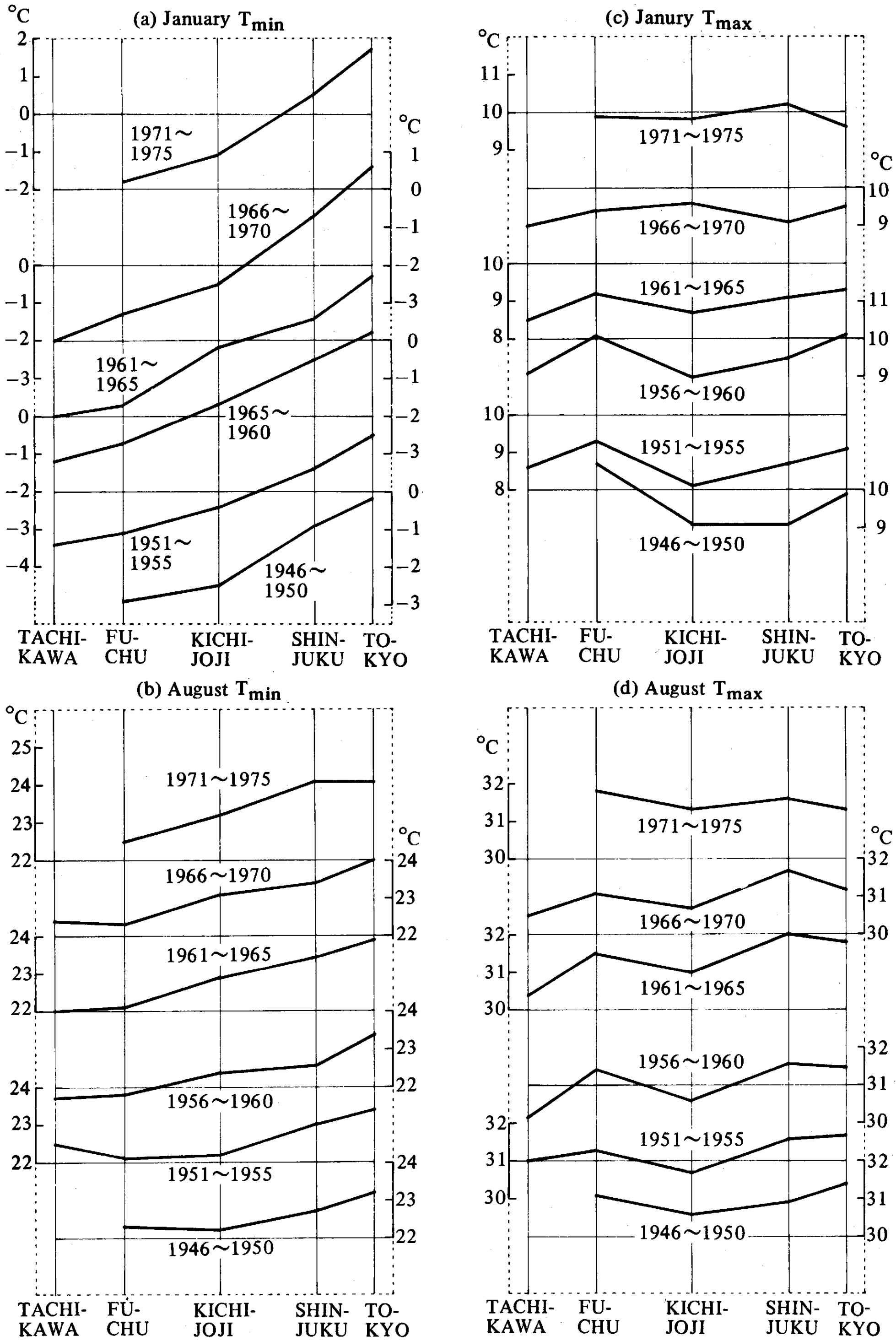


Fig. 12 East-west temperature profile from Tokyo to Tachikawa based on 5-year mean temperature.

Tokyo and Kichijoji remained constant throughout the periods from 1951–1955 to 1961–1965, being equal to 1.9°C. On the other hand, the difference of temperature between Kichijoji and Fuchu was 1.0°C during the years of 1956–1960, and amounted to 1.5°C during the period of 1961–1965. These facts may suggest that the area with climatic features due to urban controls had expanded since 1946. The difference between Fuchu and Tachikawa during 1966–1970 may also suggest the same phenomena. And, the fact that the difference between Tokyo and Kichijoji amounted to 3.1°C during 1966–1970 and 2.8°C during 1971–1975 was caused by a noticeable rise of minimum temperature in the central part of Tokyo.

From these facts, we may distinguish three stages in the postwar development of city temperature, especially concerning minimum temperature for January, in Tokyo and its environs: In the first stage until about 1950 city temperature could be detected in the central portion of Tokyo. In the second stage, from about 1950 to about 1965, city temperature could be observed in wider area including urban fringe. And, in the third stage since about 1966 spatial difference has increased in the area concerned.

2. Minimum Temperature for August

When we define the boundary of the area affected by urban controls by means of a steeper horizontal temperature gradient, it has advanced outward. While the boundary was located between Fuchu and Tachikawa during 1966–1970 with regard to minimum temperature for January, it was situated between Kichijoji and Fuchu in the case of August minimum temperature. This indicates that the area affected by urban controls concerning August minimum temperature was smaller than that in the case of January minimum temperature. During the period of 1971–1975 temperature difference could not be noticed between Tokyo and Shinjuku. This suggests that areal difference of the temperature reached to its minimum in the central part of Tokyo.

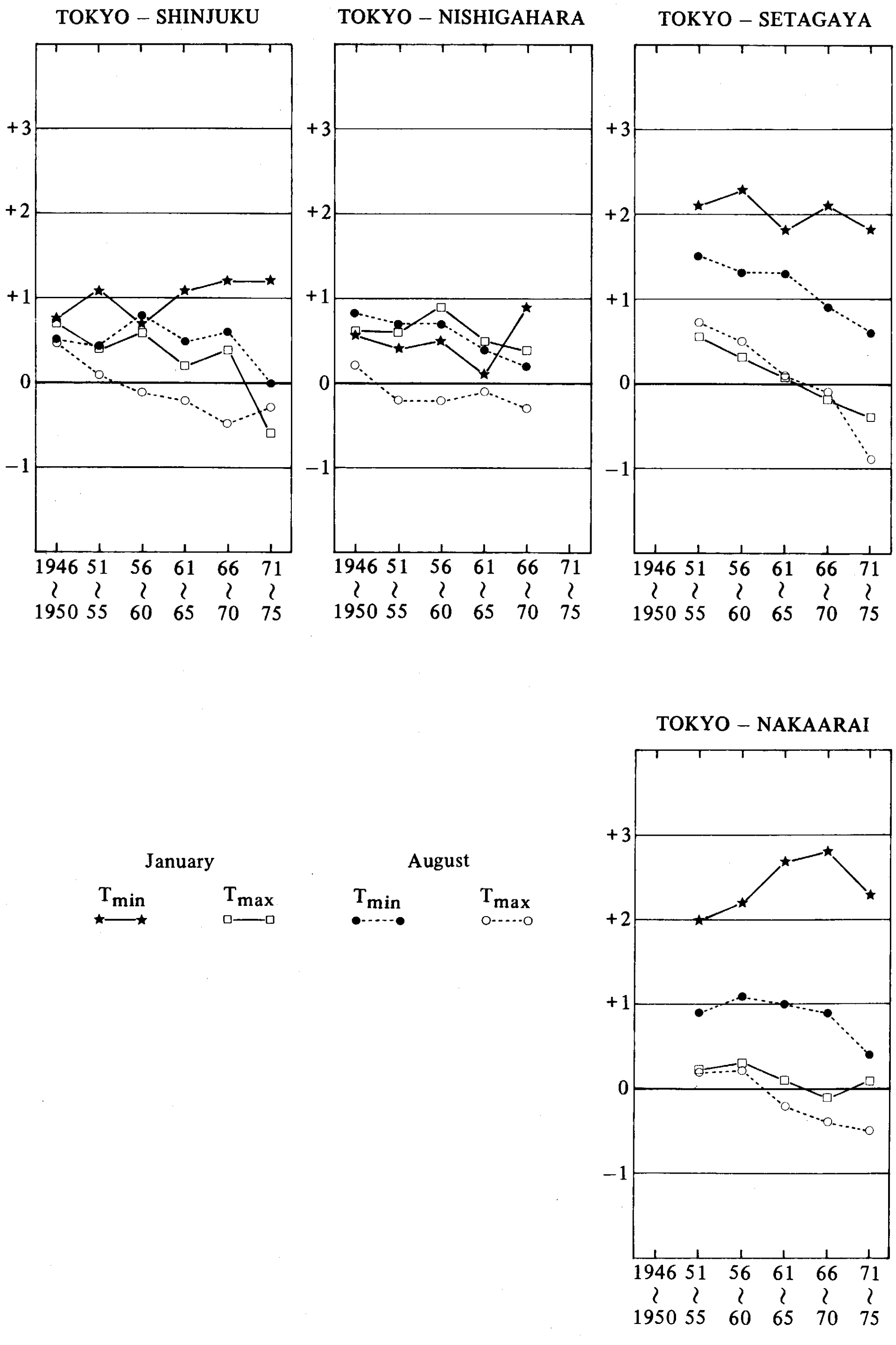
3. Maximum Temperature for January

At Shinjuku city temperature could not be proved clearly during 1946–1950. As a result, the area with city temperature was smaller than that of January minimum temperature. Although January minimum temperature has risen in the central part of Tokyo since 1966, maximum temperature has risen on the urban fringe and has fallen in the central portion.

4. Maximum Temperature for August

Like in the cases of August minimum temperature and January maximum temperature, the boundary of the area affected by urban controls did not advance as far as Kichijoji during 1946–1950. After that the temperature at Shinjuku has risen considerably, which resulted in higher temperature of Shinjuku as early as 1956–1960 than in the core area of Tokyo. The temperature at Kichijoji became higher than that in the core area just only during 1971–1975.

As we have seen, we may distinguish three stages regarding the postwar development of city temperature in the area of Tokyo. In the first stage until 1950 the boundary of the area with city temperature as defined above did not advance as far as Shinjuku or Kichijoji.


TOKYO – SHINJUKU
TOKYO – NISHIGAHARA
TOKYO – SETAGAYA
TOKYO – NAKAARAI
+3
+2
+1
0
−1
1946 51 56 61 66 71
1950 55 60 65 70 75
January
August
T_{min}
T_{max}
T_{min}
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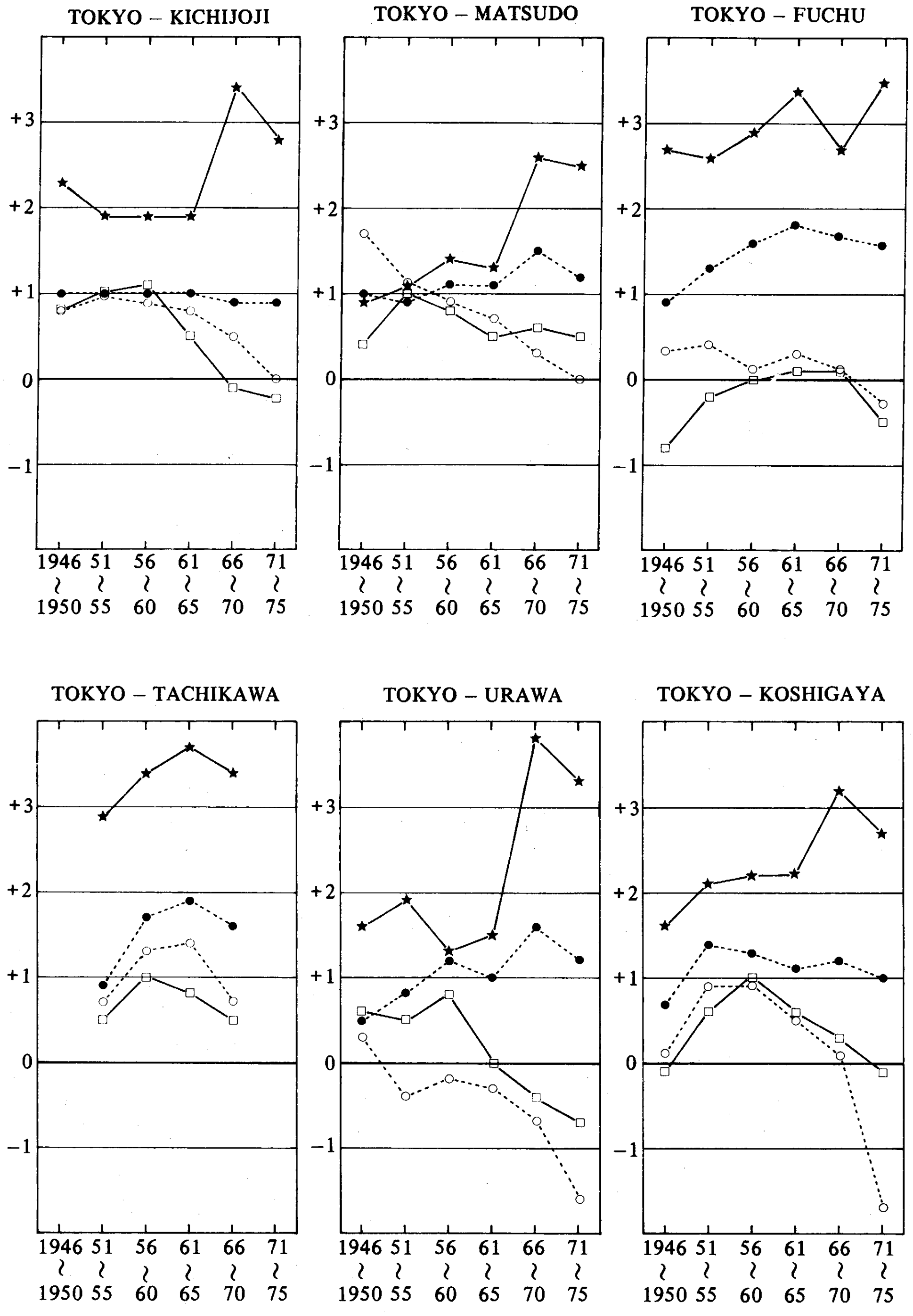

Fig. 13 Changes of 5-year mean temperature differences between Tokyo and respective stations.

In the third stage since about 1966 we can notice a marked rise of January minimum temperature which has resulted in a steepening of horizontal temperature gradient in the central area, and a relative fall of January and August maximum temperatures in the same area to the urban fringe. Between these characteristic stages there is an intermediate stage in which the distribution pattern of temperature within the area underwent little change.

As has been stated before, these facts may be attributed to the increase of tall buildings in the core area and the farther westward expansion of the built-up area in the marginal area since about 1965.

VI. AREAL PATTERN OF THE CHANGE OF CITY TEMPERATURE

From the previous results, we may say that the secular changes of city temperature differ from station to station. So we investigated here areal differences of the secular changes by using the temperature data at several stations.

The stations adopted here may be divided into three categories: the nearest, the intermediate and the distant, which are measured according to the distance from the center of Tokyo. The nearest group contains the stations of Shinjuku, Nishigahara, Setagaya and Nakaarai. The intermediate stations are Kichijoji and Matsudo, and the distant ones are Fuchu, Tachikawa, Urawa and Koshigaya. The location of the stations are shown in Figure 1. The secular changes of the differences of five-year mean temperature between the Meteorological Observatory of Tokyo and the stations stated above are represented in Figure 13.

1. Shinjuku, Nishigahara, Setagaya and Nakaarai

Regarding January and August minimum temperatures, pronounced changes of the differences can not be detected. However, the differences of August minimum temperature tend to decrease recently. Referring to the previous results, these tendencies may indicate that horizontal gradient of temperature has become weak in recent times.

Regarding the maximum temperatures, it is found that a relative fall of the temperatures to the surroundings occurs only in a small limited area of central Tokyo. In the other area we can recognize a relative rise of temperature in general. However, the August maximum temperature at Shinjuku fell relatively to that of central Tokyo during 1971–1975. This may suggest that the area of relative fall in temperature has expanded as far as Shinjuku where many tall buildings have been constructed recently.

2. Kichijoji and Matsudo

Regarding August minimum temperatures we can not recognize remarkable changes of temperature differences between the two stations and Tokyo. But concerning January minimum temperature, an increase of difference, that is, a relative fall of temperature to central Tokyo has occurred since 1966–1970. This indicates that the area with higher city temperature did not reach so far as Kichijoji and Matsudo.

3. Fuchu, Tachikawa, Urawa and Koshigaya

The differences of January minimum temperature between Urawa or Koshigaya and Tokyo abruptly fell during 1966–1970. These chnges are similar to those in the cases of Kichijoji and Matsudo. On the contrary, we can not observe such tendency in the changes at Tachikawa and Fuchu. Regarding August minimum temperature, the differences for respective stations and Tokyo have changed in a similar way. The differences had increased until the period of 1956–1960, and remains constant nearly thenceforth.

The differences in maximum temperatures underwent similar secular change. The temperatures for the respective stations recorded the lowest values to those of Tokyo during the period of 1956–1960 or 1961–1965, and have risen considerably after that. Similar secular change is observed in Kichijoji, where the changing phase is earlier by about five years than at Fuchu, Tachikawa, Urawa and Koshigaya which are situated farther from the urban center than Kichijoji.

VII. CONCLUDING REMARKS

Comparing the data at the rural station with those at the urban stations, we obtained the following results regarding the process of development of the urban climate in Tokyo area.

We can detect the effects of urban growth on the elements such as January and August monthly mean maximum and minimum temperatures, water vapor pressure, and numbers of tropical hot days, frost days, drizzly days and days with fog. And it is also found that the effects of urban growth have changed in accordance with the stages of urbanization. The water vapor pressures at the urban stations have been lower than at the rural station, but their secular changes do not correspond to the stages of urbanization.

In the case of January minimum temperature, the large area with city temperature has appeared, and the temperature in the central area has risen remarkably since about 1965. In the case of August minimum temperature, its relative rise in the marginal area of the central part has occurred to central Tokyo since 1970's, and its horizontal gradient in the central area has become weak.

Secular changes of the maximum temperatures are similar one another. The temperatures on the fringe had fallen until 1950s, relatively to those at the center, and the area where the temperatures were high relatively to the surroundings had clearly appeared in the central area of Tokyo. Thenceforth the temperatures on the fringe have risen, relatively to those at the center, and the area where the temperatures were lower relatively to the surroundings has appeared in the central area. The beginning time of the relative rise of the temperatures corresponds to the distance of places from the urban center. That is, the farther the place is from the center, the later the beginning time of the rise is.

The number of drizzly days has also changed with noticeable features. The numbers have increased in the urban area. The number at the central part has increased earlier by about five years than surroundings, and reached its maximum in and around 1950. As a result, the number at central Tokyo had been larger than on the urban fringe until about 1950, and since about 1955 this situation has reversed.

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