Academic Article

A Study on Structural Changes of Urban Air Temperature in Japan
- Data for 114 years of 1891-2004 at 36 observatories -

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Abstract

The temperature data in Japan over 100 years is accumulated. The purpose of this study is to express the urban warming phenomena in Japan through statistical analysis of such long-term data. The object data is the annual data of the daily mean air temperature for 114 years from 1891 to 2004. There are 36 object observatory points. The main conclusions are as follows. First, the air temperature fluctuations of all the observatories are judged with very high accuracy that it is expressed more appropriately by two regression lines rather than one. Second, it turns out that the larger the city scale (administrative district population) in which observatory is located, the steeper the urban warming. Third, it becomes clear that in most large cities or the middle-scale cities, in the second period, the air temperature rose rapidly. Therefore, it is supposed that urbanization factor as well as geographical climate factor has influence on the urban warming in Japan.

Keywords: urban warming, long period air temperature data, statistical analysis, Chow test, regression analysis

1. Introduction

In Japan, there are many observatories from large cities to rural areas where the weather observation data is accumulated over more than 100 years. Air temperature data is one of the main weather observation data. In order to elucidate urban warming phenomenon, it is necessary to grasp the phenomenon itself at various standpoints .The examination of a long-term air temperature data can be one of these measurements.

Incidentally, it seems that moving average method and regression analysis are usually used as for analysis of the long-term time series data about the weather. It seems that regression analysis is effective in the point that air temperature rise is expressed numerically. In a great deal of research, however, it seems that one regression line is used to express air temperature fluctuation.

The purpose of this study is to express the aspect of the urban warming phenomenon in Japan by analyzing the long-term air temperature data of many observatories with the following statistical methods. From an expost viewpoint in order to represent air temperature fluctuation, using the Chow Test, it is investigated statistically whether one regression line is appropriate or whether two regression lines are appropriate. If it is judged that two regression lines are proper, it is said that there is a 'structural change' of the air temperature data of the observatory. To the second, when a 'structural change' exists, the two regression lines are examined. As stated object data is annual data of the daily mean air temperature for 114 years from 1891 to 2004, and there were 36 object observatories from large cities to rural areas.

2. Analytic procedure

Analysis of this study is executed with four steps of following procedures.

The 1st step: **Original Chow test of a single year**

The Chow test, which was developed in econometrics, judges statistically whether there was any structural change for a certain year. That is, the Chow test decides whether one regression line is appropriate or not from an ex post viewpoint. The 'structural change', which is the technical term of econometrics, means that the parameter of a regression line changes.

The numerical formulas necessary for this test are listed in Table 1. The regression line of all data for the target period is assumed as the formula (1). On the other hand, if the structural change year is assumed t_{0+1}, two regression lines as formula (2) and (3) are assumed for the data divided in before and after the structural change year. The following null hypothesis H_0 and the alternative hypothesis H_1 are tested by these.

H_0 : b_0=c_0 b_1=c_1 H_1 : not H_0

The null hypothesis H_0 means ' two regression lines divided before and behind t_{0+1} are equal, that is, regression lines are one line'. The Chow's F-value of the formula (4) is distributed under F-distribution of the degree-of-freedom (k, T-2k). If in a given the Chow's F-value is over the numerical value corresponding to significance level α, H_0 is rejected and H_1 is adopted. Hereinafter, the Chow's F-value of the formula (4) is described as Fc-value [1].

Table 1 Formulas for the Chow test

One regression line	$y_t = a_0 + a_1 x_t + \varepsilon_t$	(1)
Two regression lines	$y_t = b_0 + b_1 x_t + u_t \quad (t \le t_0)$	(2)
	$y_t = c_0 + c_1 x_t + v_t \quad (t > t_0)$	(3)
Chow's test statistics	$F = \dfrac{\{S_1 - (S_2 + S_3)\}/k}{(S_2 + S_3)/(T - 2k)}$	(4)

where, x_t : calendar year t
y_t : annual mean temperature of daily mean temperature of year t
t_0+1: assumed structural change year
a_0, b_0, c_0 : constant terms a_1, b_1, c_1 : air temperature terms
ε_t, u_t, v_t : error terms F : Chow's F-value
T : number of target period k : number of parameters,
S_1 : residual square sum of the formula (1)
S_2 : residual square sum of the formula (2)
S_3 : residual square sum of the formula (3)

The 2nd step: **transition of *Fc*-values**

As the Fc-values are calculated while moving t_{0+1} year by year, a transition diagram of Fc-values are made up. Then under any significance level α, it will be judged whether the structural changes exist.

The 3rd step: **Division year of the object period**

Under standard significance levels of α＝5% and 1%, the year in which Fc-value exceed the significance levels may become a large number. In that case, although a period may be divided for applicable arbitrary years, in order to dare to choose one point here, target period are formally divided by the year of a maximum Fc-value. Such year is defined here a 'maximum Fc-value year' described as Fc_{MAX} year, and the following year is a 'structural change year'. Then, the target period from 1891 to 2004 is divided into two periods. The first period during the former half is from 1891 to the Fc_{MAX} year, and the second period during the later half is from structural change year to 2004.

The Fc_{MAX} year and structural change year here, of course, are judged by all the data from an expost standpoint, so that such years never signified that something decisive occurred. In order to avoid confusion, a structural change year is not used but Fc_{MAX} year is mentioned mainly.

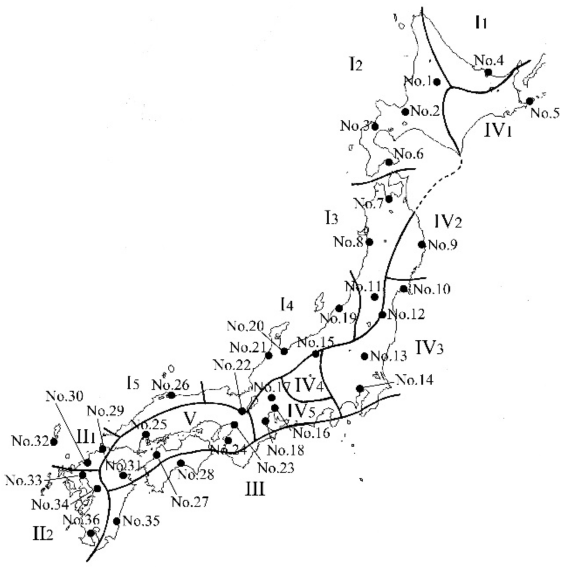
The 4th step: **Examination of two regression lines**

If all the data is divided in this way, regression analysis is applied to these two periods and two regression lines will be obtained. The coefficient of each regression line is statistically tested by a significance level α= 5%. The coefficient of year variable x_t such as a_1, b_1 and c_1 means each air temperature gradient.

3. Data for specifications

The data used is annual data of the daily mean air temperature of the Meteorological Agency homepage publication, and the unit of the temperature is displayed in degrees Centigrade (°C) (1). In consideration of obtaining as much long-term observational data as possible, and of obtaining the data sets from large cities to local small size cities in order to compare between cities, the time span of the data is from 1891 to 2004 (this study was started in 2005). The observatories which gathered the data of the target period are placed in 36 locations including metropolises, medium-sized cities, and rural areas as shown in Fig.1.

Although this study does not deal with global warming directly, it is because the observatories in rural areas are expected that the influence of global warming appeared easily, because the observatories in rural areas are expected to show less influence of global warming, the features of urban warming phenomenon are conspicuous in contrast [2]. However, the aim of using 36 points is to survey the global warming situation and urban warming situation of the whole of Japan, without examining individually either each observatory points or its specific location. In addition, the data were examined simply, and this analysis is only based on the information released by the Meteorological Agency [3].



Number and name of observatory			
No.1 Asahikawa	No.10 Ishinomaki	No.19 Niigata	No.28 Kochi
No.2 Sapporo	No.11 Yamagata	No.20 Fushiki	No.29 Shimonoseki
No.3 Suttsu	No.12 Fukushima	No.21 Kanazawa	No.30 Fukuoka
No.4 Abashiri	No.13 Utsunomiya	No.22 Kyoto	No.31 Oita
No.5 Nemuro	No.14 Tokyo	No.23 Osaka	No.32 Izuhara
No.6 Hakodate	No.15 Nagano	No.24 Wakayama	No.33 Saga
No.7 Aomori	No.16 Nagoya	No.25 Hiroshima	No.34 Kumamoto
No.8 Akita	No.17 Gifu	No.26 Sakai	No.35 Miyazaki
No.9 Miyako	No.18 Tsu	No.27 Matsuyama	No.36 Kagoshima

Fig.1 The object observatories

The climatic division is also shown in Fig.1 [4]. Even when only limited to Japan, the climate of each area is complicated and various. Thus, the results of this study are also fundamentally specific to the climate of each area and the influences of urbanization are assumed as being artificial turbulence factor. The climatic divisions are displayed via two numbers: the first, Roman numerals, display five kinds of large classification, and the second Arabic numerals are internal classifications. Classification names are regional names in Japanese. An explanation of the climate features of each classification is omitted here.

4. Result of analysis

Analysis results are described in order of the following. In 4.1, in order to represent the area from the northern part of Japan to the southern part among large cities (with a population of one million or higher) in 2000, the structural change situation of the air temperature of Tokyo, Sapporo, Kyoto, Osaka, and Fukuoka are shown illustratively. In 4.2, the comparative examinations of the observatories are explained where the different city scales within the same climatic division. A survey of all 36 observatories is shown in 4.3.

In addition, Tokyo, Kyoto and Osaka were relatively large cities from old times, but they became large metropolitan areas after the mid-1950s. Moreover, the rapid urbanization of other large cities and the medium-sized cities followed. Below, the population of administrative district in 2000 in which an observatory is located shown as a reference index (2) [5].

4.1 Examples of large cities

(1) No.14 Tokyo

The analysis procedure is expressed concretely with the case of Tokyo as an example.

STEP1 and 2: When the Fc-value of each year is obtained, the transition diagram of the Fc-value is as in Fig.2. The Fc-values gradually show a reductive tendency to after having risen in the early 1900s. As the horizontal line of significance level α = 5% and α = 1% are shown in the diagram, if the year when the Fc-value is larger than these levels, the null hypothesis H_0 would be rejected, and representation by two regression lines would become appropriate.

STEP3: Most years are able to become dividing points with a significance level α = 5% and α = 1% as shown in Fig.2. For the purpose of this study, the Fc_{MAX}-value year has been conveniently chosen in order to divide the data into two periods, and the next year is determined as 'structural change year'. In other words, the period from 1891 to the Fc_{MAX}-value year becomes the first period, and from the structural change year to 2004 becomes the second period. In Fig.2, the year of the Fc_{MAX}-value is in 1909, the structural change year is 1910. The Fc_{MAX}-value is 12.879, and the P-value, that is, $P_{rob}.(Fc_{\mathrm{MAX}} < Fc) = 9.4\times10^{-6}$. The structural change is identified with high accuracy.

STEP4: When regression lines are applied to the first period data and the latter period data, they appear as in Fig.3. The regression coefficients are examined by testing statistical hypothesis with a significance level α = 5%. As is shown by the 114 years data, in Tokyo the air temperature dropped from 1891 to 1909 and rose from 1910. As comparison, one regression line is shown in Fig.4. When the temperature gradient terms are compared, it turn out that the temperature gradient coefficient of one regression is a_1=0.0271 while the temperature gradient coefficient c_1=0.0303 in the second period regression line show a rapid temperature rise [6] .

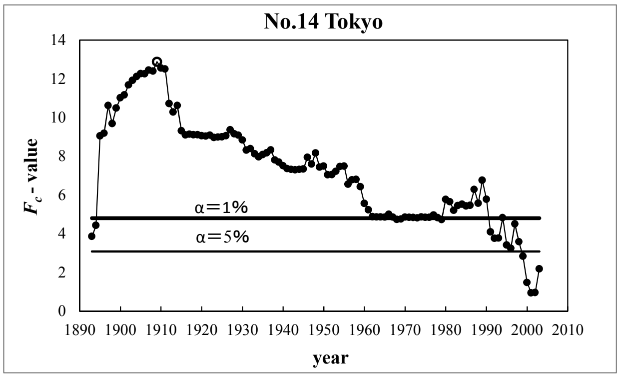


Fig.2 Transition of Chow's *F*-value for Tokyo

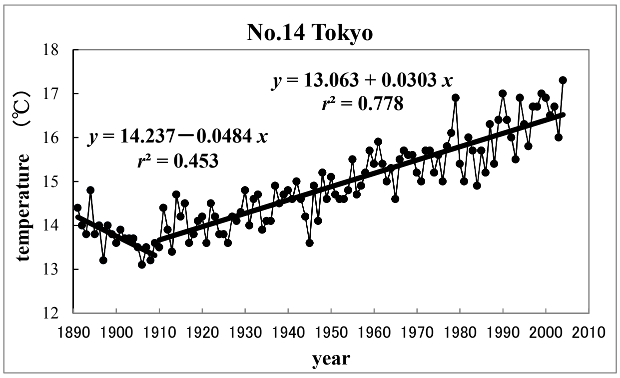


Fig.3 Temperature and two regression lines for Tokyo

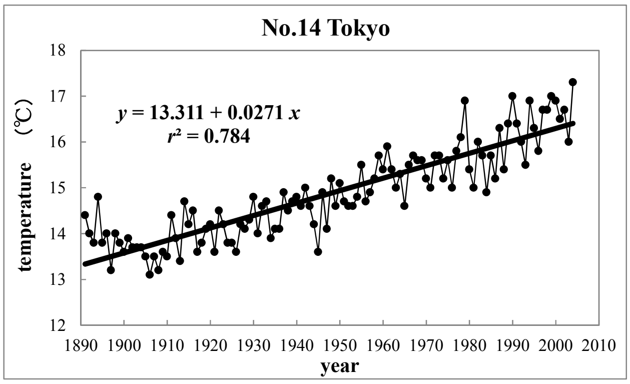


Fig.4 One regression line for Tokyo

If a comparatively long temperature change in the second period is expressed by regression lines still more finely, what is necessary is just to repeat the analysis by making the second period into a new target period. Although this analytic procedure is slightly mechanical, it is because it uses a technique that avoids choosing the dividing point of the data arbitrarily but choosing it statistically. Moreover, in order to divide the period, it is desirable to consider historical events which brought about serious changes in the land use of Tokyo, such as the Great Kanto Earthquake (1923) and war disasters (1944-1945) at the end of World War II which brought about serious damage to Tokyo.

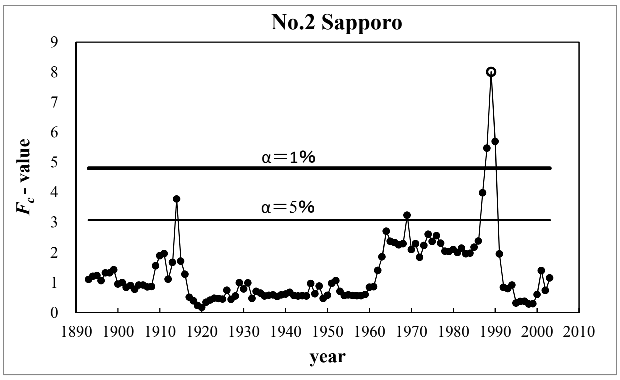


Fig.5 Transition of Chow's *F*-value for Sapporo

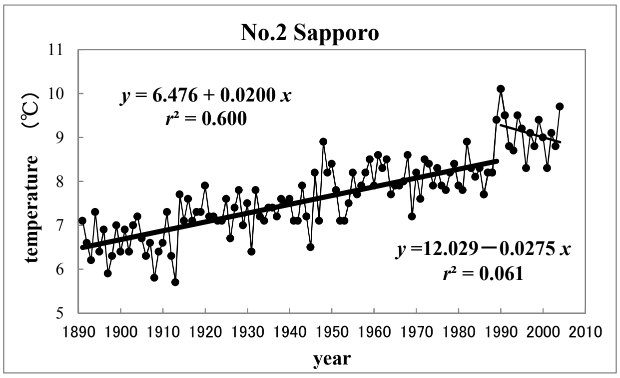


Fig.6 Temperature and two regression lines for Sapporo

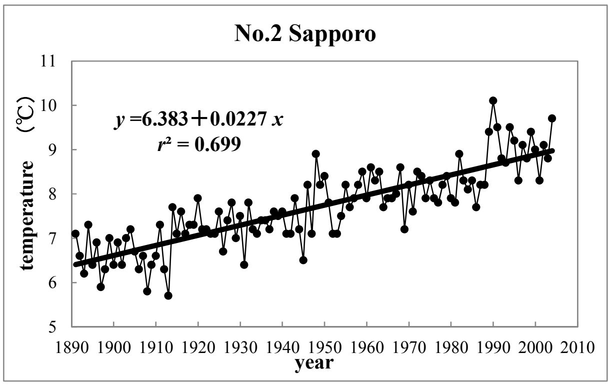


Fig.7 One regression line for Sapporo

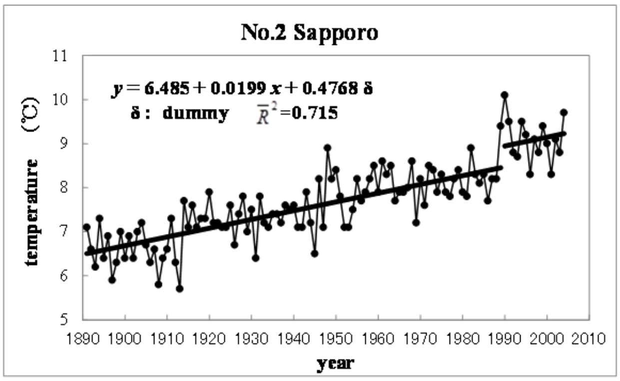


Fig.8 Regression line with dummy variable for Sapporo

(2) No.2 Sapporo

Similarly, the transition diagram of *Fc*-value of Sapporo is shown in Fig.5. The *Fc*-value generally changed with the low value, but two peaks are recognized in 1913 and in 1989. The data is divided automatically in 1989 when the *Fc*-value is at a maximum. The fluctuation of air temperature and two regression lines are shown as Fig.6. One regression line is shown in Fig.7. The temperature gradient of one regression is a_1=0.0227, whereas the temperature gradient of two regressions becomes b_1=0.0200 in the first period and c_1=−0.0275 in the second period. However, the air temperature term of the regression coefficient after 1990 was not significant under a significance level α = 5%. It means that the regression line of the second period might be horizontal.

There is a difficult aspect to evaluating this type of urban warming. If the air temperature jump of the end of the 1980s is disregarded, the urban warming would be represented by a_1=0.0227, which is the coefficient of one regression line. If the jump in air temperature, that is, the structural change is considered important, the urban warming would be represented by b_1=0.0200, which is the coefficient of the long regression line of the first period. Although a structural change is accepted when is a temperature jump, if it is assumed that a warming tendency is constant, the regression lines which introduce the dummy variable would also be considered. The situation of regression lines which introduced the dummy variable is shown in Fig.8. The coefficient of the dummy variable as 0.4767 indicates the height of the temperature jump, and is significant under α= 1%. It is shown like and the temperature gradient obtained using the whole data is 0.0199. In the end, from the viewpoint of this study, it would be natural to adopt Fig.6. That is, urban warming advanced by b_1=0.0200 untill 1989, air temperature jumped after that, and kept conditions at high levels[7].

(3) No.22 Kyoto

The transition diagram of the *Fc*-value of Kyoto is shown in Fig.9. This diagram resembles that of Sapporo, but shows two peaks in 1911 and in 1980. When the data is divided at 1980 the Fc_{MAX}-value, air temperature fluctuation and two regression lines are shown as Fig.10. A representation with one regression line is shown in Fig.11. The air temperature terms of two regression lines are significant at significance level α = 5%, respectively. Whereas temperature gradient term of one regression is a_1=0.0248, temperature gradient term of two regressions becomes b_1=0.0240 in the first period and c_1=0.0610 in the second period.

(4) No.23 Osaka

The transition diagram of the *Fc*-value of Osaka is shown in Fig.12. In this case, the *Fc*-value rose until the 1930s, remained at a very high level until the late 1980s, and then decreased afterwards. When the data are divided at 1943 of Fc_{MAX}-value, the air temperature variations and two regression lines are shown as Fig.13. One regression line is shown in Fig.14. The air temperature terms of two regression lines are both significant under significance level α = 5%. The temperature gradient of one regression is a_1=0.0204, temperature gradient of two regressions becomes b_1=0.0096 in the first half and c_1=0.0328 in the second half.

(5) No.30 Fukuoka

In case of Fukuoka, the transition diagram of the *Fc*-value, temperature fluctuation and two regression lines, and one regression line are shown in Fig.15, Fig.16 and Fig.17. Though

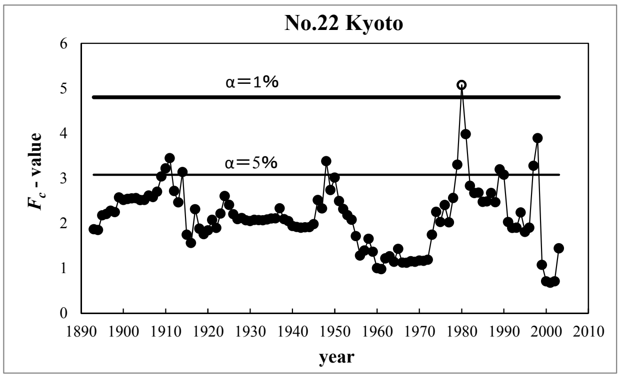


Fig.9 Transition of Chow's *F*-value for Kyoto

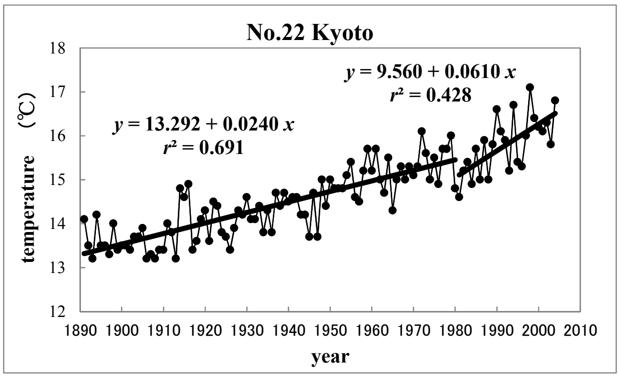


Fig.10 Temperature and two regression lines for Kyoto

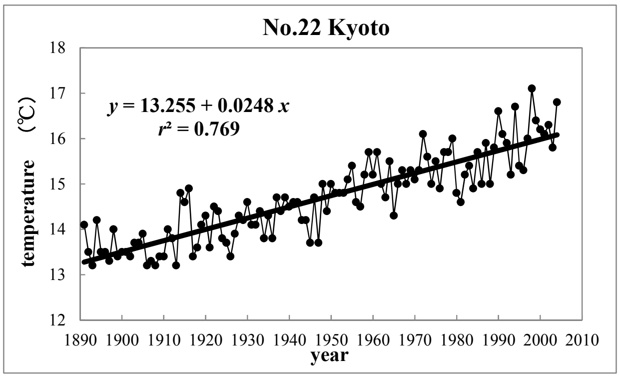


Fig.11 One regression line for Kyoto

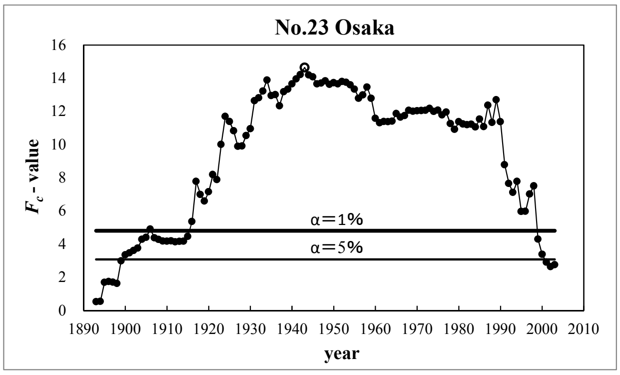


Fig.12 Transition of Chow's *F*-value for Osaka

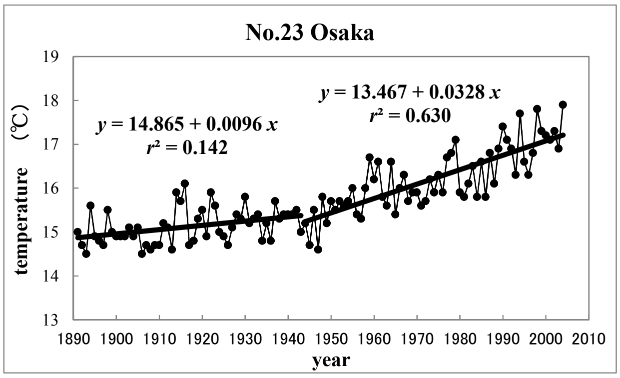


Fig.13 Temperature and two regression lines for Osaka

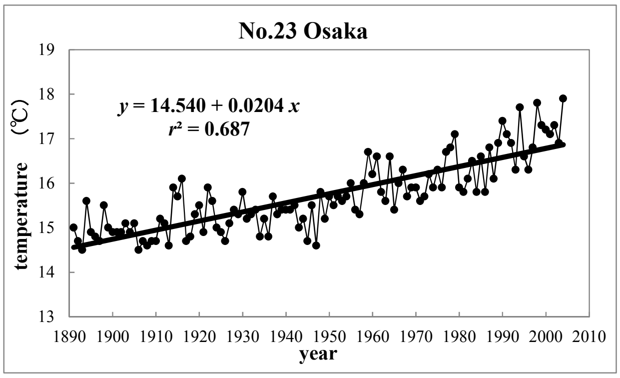


Fig.14 One regression line for Osaka

Fig.15 is somewhat similar to Fig.12 of Osaka, the *Fc*-value rose until the 1910s, remained at a high level until the 1950s, and dropped afterwards while maintaining a high level. In Fig.15, the data are divided at 1917, the Fc_{MAX}-value, and two regression lines are shown.

Temperature gradient of one regression is a_1=0.0229, the temperature gradient of two regressions becomes b_1=0.0007 in the first period and c_1=0.0297 in the second period. However, the air temperature term of the regression coefficient before 1917 is not significant under significance level α = 5% in case of Fukuoka.

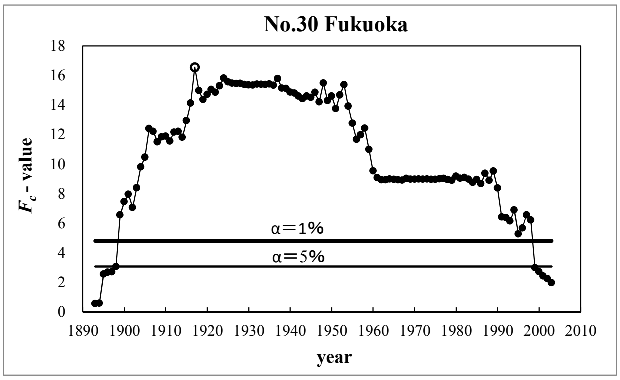


Fig.15 Transition of Chow's *F*-value for Fukuoka

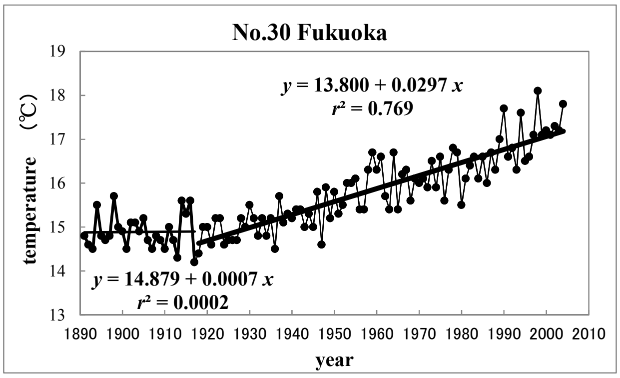


Fig.16 Temperature and two regression lines for Fukuoka

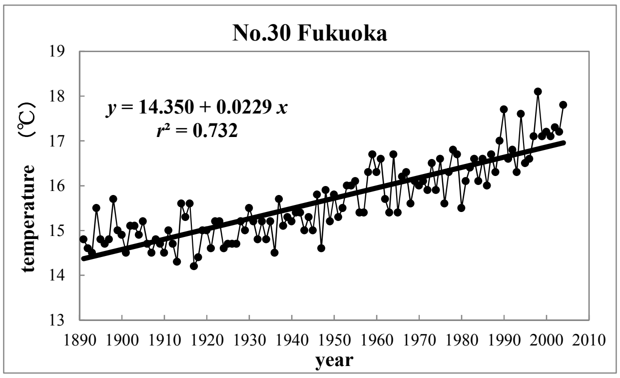


Fig.17 One regression line for Fukuoka

4.2 Comparison of observatory in the same climatic division

In this section, at observatories within a comparatively close distance in the same climate division, it is examined whether the difference of city scales in which the observatories are located has an influence on the warming phenomenon. For convenience, the city scale is represented by population of administrative district. Like the former, the transition diagram F_C-value, air temperature fluctuation and the regression line of each observatory are shown. Since most coefficients of temperature gradients become significant with a high level, it is noted only when not significant under α= 5%.

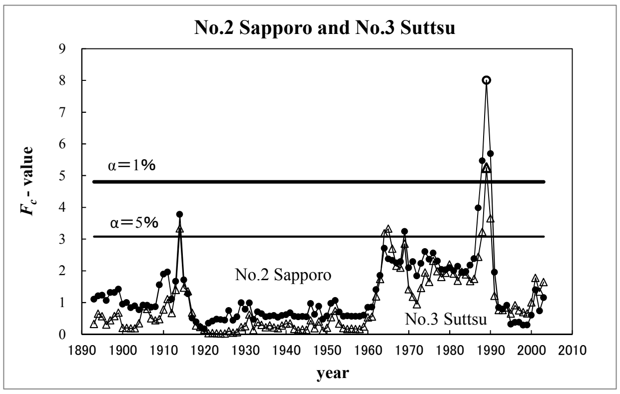


Fig.18 Transition of *F*-value for Sapporo and Suttu

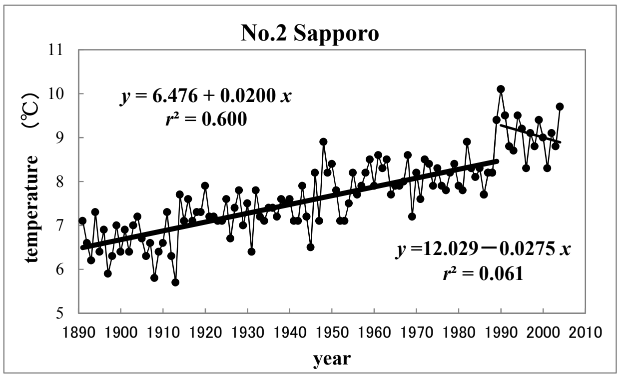


Fig.19 Temperature and two regression lines for Sapporo

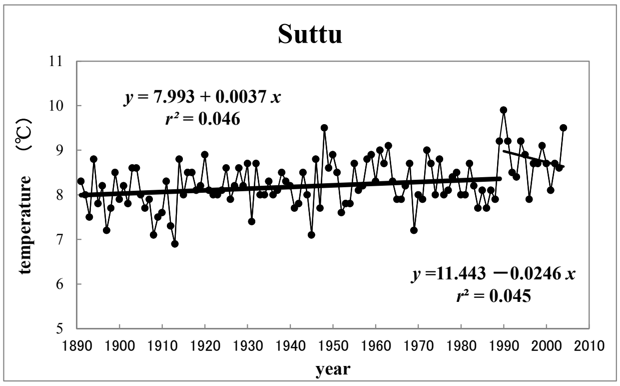


Fig.20 Temperature and two regression lines for Suttu

(1) No.2 Sapporo and No.3 Suttsu in the climatic division I2

Whereas Sapporo (1,822 thousand people) is a large city exceeding one million people, Suttsu (4 thousand people) is a small town. In Fig.18, both observatories are in transition with low level of *Fc*-value. The *Fc*-value of Sapporo is slightly higher than that of Suttsu generally. Each *Fc*-values transition pattern is similar. Both Fc_{MAX}-value years are in 1989, and are significant under significance level α=1%. However, *Fc*-value exceeding α=1% in Suttsu only occurs this year.

Air temperature fluctuation and the regression lines of Sapporo, Suttsus are shown in Fig.19 and in Fig.20. Neither temperature gradient of the second period is significant at α=

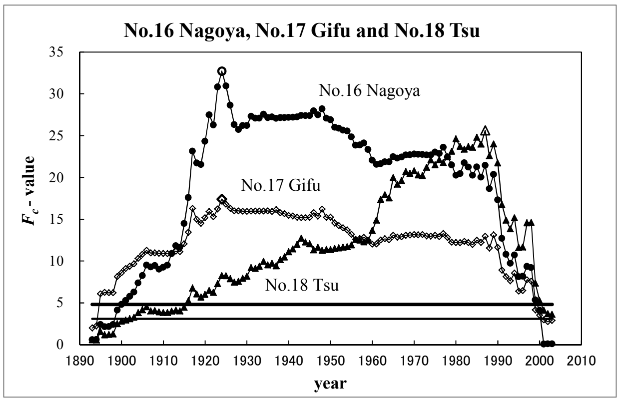


Fig.21 Transition of *F*-value for Nagoya, Gifu and Tsu

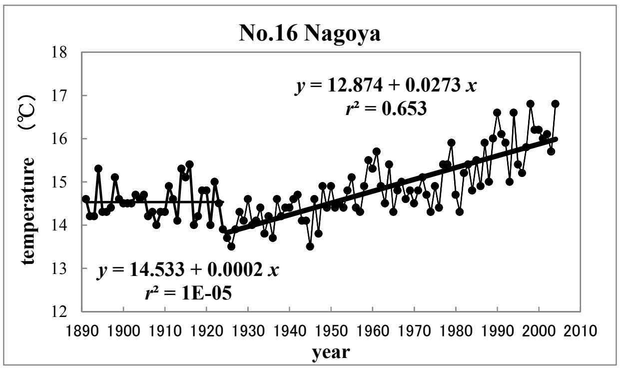


Fig.22 Temperature and two regression lines for Nagoya

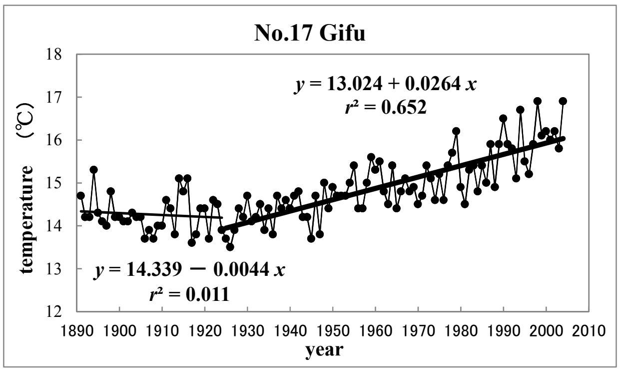


Fig.23 Temperature and two regression lines for Gifu

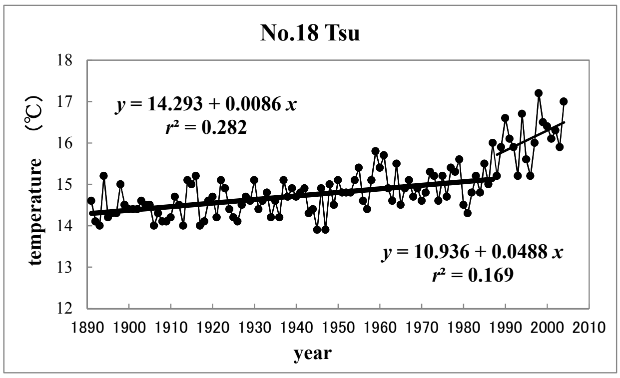


Fig.24 Temperature and two regression lines for Tsu

5%. Since the length of the first period is the same, it is possible to compare the temperature gradient of each regression line in the first period. Air temperature gradient of Sapporo is much steeper than that of Suttsu.

(2) No.16 Nagoya, No.17 Gifu and No.18 Tsu in the climatic division Ⅳ5

Nagoya (2,172 thousand people) is a large city, Gifu (403 thousand people) is a mid-scale city, and Tsu (163 thousand people) is a small city. Transitions of *Fc*-value of these observatories are shown in Fig.21. The *Fc*-value levels of Nagoya and Gifu are high through the 20th century. Nagoya especially is changing with the very large *Fc*-value. Whereas transition pattern of *Fc*-value of Nagoya and Gifu is similar, Tsu is slightly different and increased to high *Fc*-value level in the latter half of the 20th century.

As for temperature fluctuation and regression lines, Nagoya, Gifu and Tsu are shown in Fig.22, Fig.23 and Fig.24 respectively. Temperature gradients of Nagoya and Gifu are not significant in the first period, and the temperature gradient of Tsu in the second period is not significant. Since Fc_{MAX}-value year of Nagoya and Gifu is the same year at 1924, the temperature gradient of the second period can be compared with each other. The temperature gradient c_1=0.0273 of Nagoya is slightly larger than c_1=0.0264 of Gifu, although one regression line gradient a_1 =0.0135 of Nagoya is slightly smaller than a_1 = 0.0170 of Gifu (shown later in Table2).

On the other hand, the temperature gradient in the first period of Tsu is b_1 =0.0088, and the temperature gradient of one regression line with a_1 =0.0147 (shown later in Table2) are all also smaller than the temperature gradient in the second period of Nagoya and Gifu.

(3) No.21 Kanazawa and No.20 Fushiki in the climatic division Ⅰ4

Kanazawa (456 thousand people) is a mid-scale city, and Fushiki is an observatory of a rural area region, although it is located in Takaoka city (172 thousand people). Transitions of *Fc*-value are shown in Fig.25. Although *Fc*-value of Kanazawa is larger, Transition patterns between Kanazawa and Fushiki are much alike. From the end of the 1970s, it was fundamental that Fushiki's *Fc*-value exceeded a line α= 1%.

Temperature fluctuation and the regression line of Kanazawa, Fushiki are shown in Fig.26, in Fig.27. Although both Fc_{MAX}-value years are in 1980 and each air temperature rise is seen from the first period, in second period it is steeper. As for each temperature gradient of the same period, Kanazawa exceeds Fushiki.

(4) No.23 Osaka and No.24 Wakayama in the climatic division Ⅴ

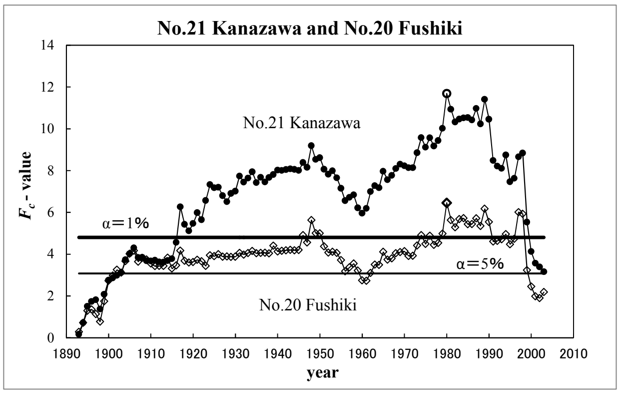


Fig.25 Transition of *F*-value for Kanazawa and Fushiki

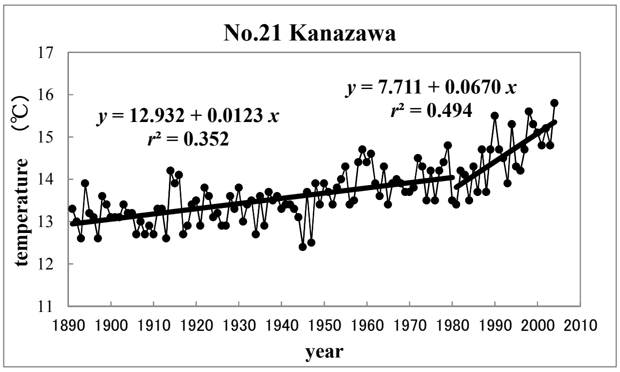


Fig.26 Temperature and two regression lines for Kanazawa

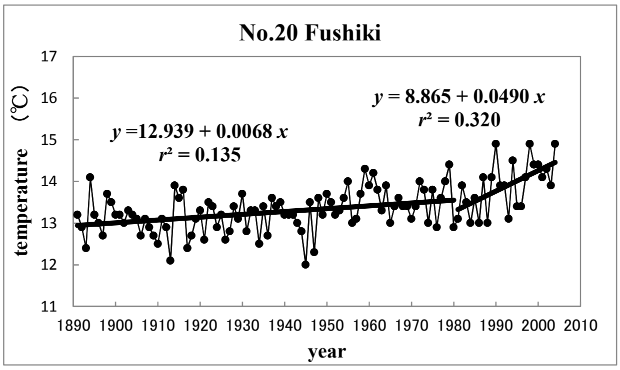


Fig.27 Temperature and two regression lines for Fushiki

Osaka city (2,599 thousand people) forms the megalopolis with Kobe city and other cities. On the other hand, Wakayama (387 thousand people) is a mid-scale city. Transition of *Fc*-value of each observatory is shown in Fig.28. Both forms are comparatively similar, although *Fc*-values of Osaka exceed those of Wakayama from the 1930s to 1990s. The Fc_{MAX}-value year of Osaka is at 1943, and Wakayama is at 1950.

Temperature fluctuation and regression lines are shown for Osaka and Wakayama in Fig.29 and Fig.30. Although the regression line of the first period of Osaka shows the temperature rose gently, the sudden rise is shown in the second period.

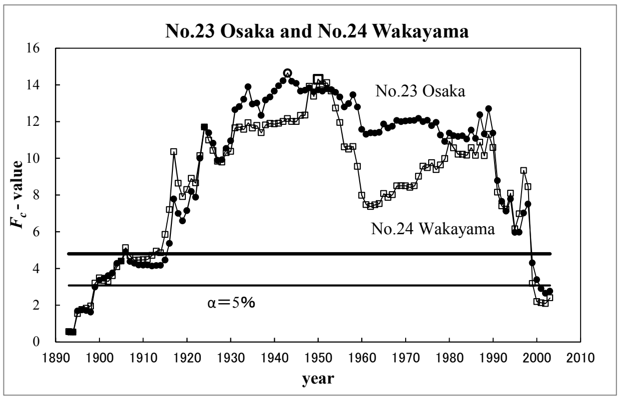


Fig.28 Transition of *F*-value for Osaka and Wakayama

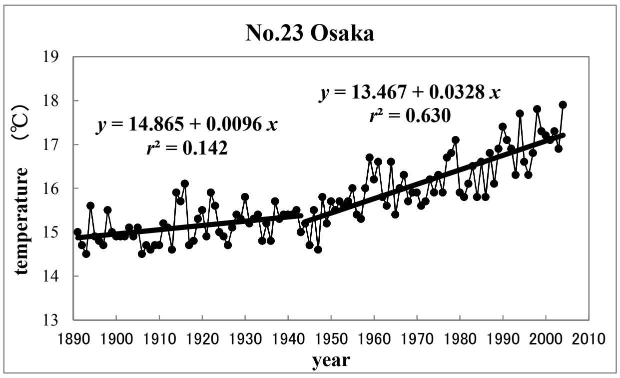


Fig.29 Temperature and two regression lines for Osaka

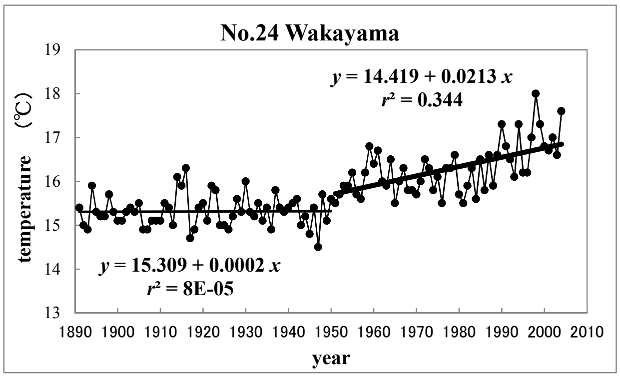


Fig.30 Two regression lines for Wakayama

On the other hand, the coefficient of the temperature gradient in the first period of Wakayama is not significant under significance level α= 5%. The temperature rise is shown at the second period.

(5) No.30 Fukuoka, No.29 Shimonoseki and No.32 Izuhara in the climatic division II1

Fukuoka (1,341 thousand people) is a large city, whereas Shimonoseki (252 thousand people) is a minor city, and Izuhara town (15 thousand people) is a central town in Tsushima islands.

In Fig.31, each transition of the *Fc*-value of 3 observatories is shown. Each form and *Fc*-value level differs considerably.

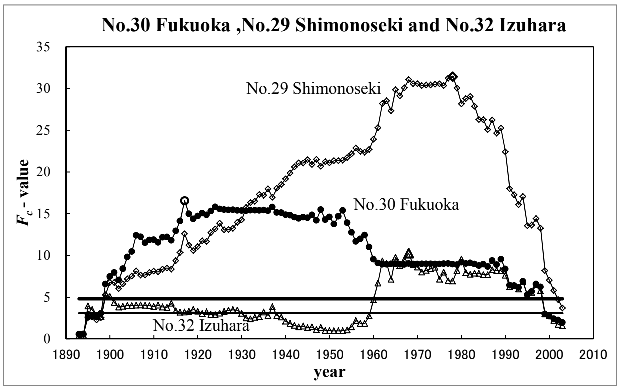


Fig.31 Transition of *F*-value for Fukuoka, Shimonoseki and Izuhara

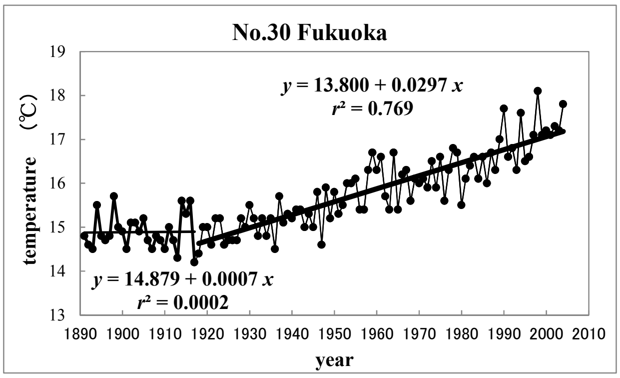


Fig.32 Temperature and two regression lines for Fukuoka

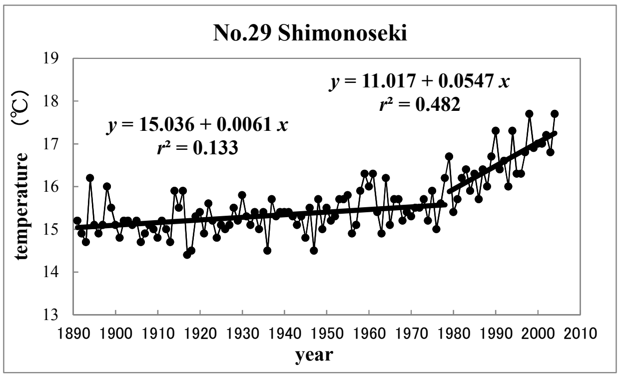


Fig.33 Two regression lines for Shimonoseki

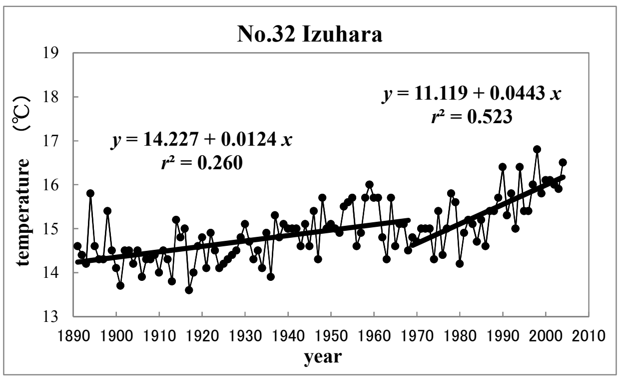


Fig.34 Temperature and two regression lines for Izuhara

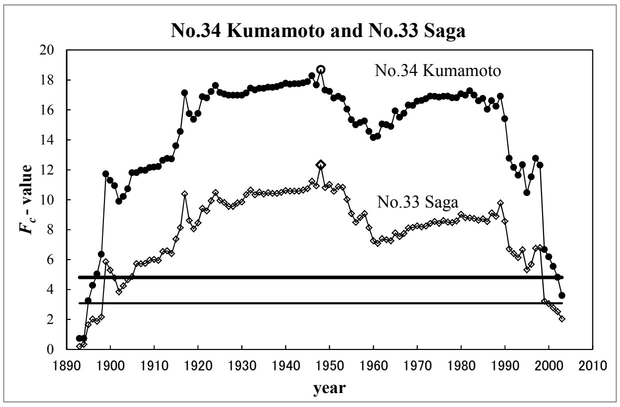


Fig.35 Transition of F-value for Kumamoto and Saga

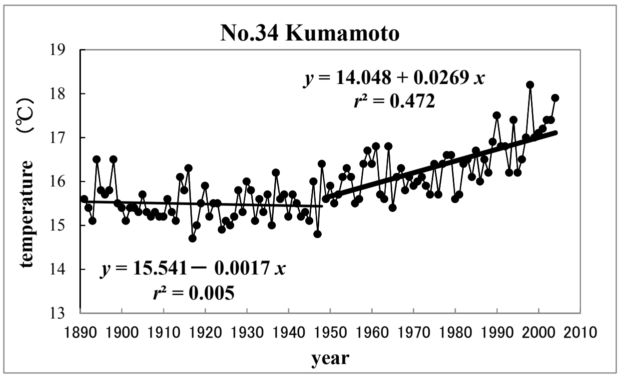


Fig.36 Two regression lines for Kumamoto

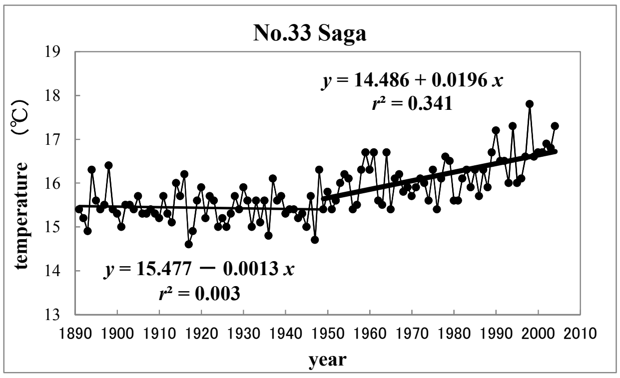


Fig.37 Temperature and two regression lines for Saga

Shimonoseki shows the very large Fc-value from the end of the 1960s to the end of the 1970s. The Fc_{MAX}-value year, Fukuoka is at 1917, Shimonoseki is at 1978 and Izuhara is at 1978.

As for air temperature fluctuation and regression lines, Fukuoka, Shimonoseki, Izuhara are shown in Fig.32, in Fig.33 and in Fig.34. The temperature gradient at the second period is larger than at the first period in each case.

(6) No.34 Kumamoto and No.33 Saga in the climatic division II2

Kumamoto (662 thousand people) is a large middle-scale city, and Saga (168 thousand people) is a small city. Transition shape of the Fc-value of both observatories is similar, and the value level of Kumamoto is higher than that of Saga (in Fig.35). Both Fc_{MAX}-value years are the same in 1948.

As for temperature fluctuation and a regression line, Kumamoto and Saga are shown in Fig.36 and Fig.37. Neither of the coefficient of the temperature gradient in the first period is significant under significance level $\alpha = 5\%$. At Comparison of the temperature gradient in the second period, Kumamoto shows the temperature rise which exceeds Saga.

As mentioned above, in order to diminish the influence of climate factors, by comparing the observatory in the close distance within the same climatic division, the changes of the air temperature structure of observatories were compared [8]. As a result, it is supposed that the relative large scale city (population of administrative district) in which an observatory is located has an effect on higher air temperature.

4.3 General view of all the object observatories

A summary of the calculation results of all object observatories are indicated in Table 2. The items of table 2 are the Fc_{MAX}-value year, its P- value calculated mechanically, air temperature gradient b_1, c_1 that are coefficient of x_t of two regression lines in the first period and the second period. In addition, as a reference, climatic division, air temperature gradient a_1 of one regression line, mean temperature for 114 years and administrative district population are shown.

Although most P-values are unrealistic and extremely small values, it is concluded that the structural change of air temperature arose in remarkable accuracy. That is, in order to represent air temperature fluctuation of all the observatories, it is judged that two regression lines are more appropriate.

In table 2, each observatory is classified into five types according to the form of two regression lines in the first period and the second period. Each coefficient of regressions is tested under a significance level $\alpha = 5\%$. Five types are the same as large cities types of 4.1. It is as follows when the account of the feature of each type is carried out.

Type A (Tokyo type): Both regression coefficients are significant. The air temperature gradient in the first period descends and in the second period rises.

- It is only No.31 Oita except Tokyo.
- Naturally the temperature gradient of the second period becomes larger than the first period.
- The temperature gradient of the second period became larger than that of one regression line.

Type B (Sapporo type): Temperature gradient in the first period is significant and in the second period is not significant. The air temperature gradient in the first period rose.

Table 2 Summary of all the object observatories

Type	Observatory	Climatic division	Structural change: Maximum Fc-value year	Structural change: P-value	Two regression lines: The first period temperature coefficient b_1	Two regression lines: The second period temperature coefficient c_1	One regression line temperature coefficient a_1	Mean temperature for 114 years (℃)	Population of administrative area in 2000 (in thousands)
A	No.14 Tokyo	Ⅳ3	1909	9.4×10^{-6}	**−0.0484**	**0.0303**	**0.0271**	14.9	8135
	No.31 Oita	Ⅴ or Ⅲ8	1948	6.4×10^{-10}	-0.0065	**0.0276**	**0.0133**	15.4	436
B	No.2 Sapporo	Ⅰ2	1989	0.00057	**0.0200**	-0.0275	**0.0227**	7.7	1822
	No.12 Fukushima	Ⅳ3	1989	0.00180	**0.0180**	0.0046	**0.0138**	12.3	291
	No.8 Akita	Ⅰ3	1989	0.00004	**0.0106**	0.0150	**0.0145**	10.8	318
	No.13 Utsunomiya	Ⅳ3	1989	6.1×10^{-8}	**0.0097**	0.0304	**0.0152**	12.8	444
	No.19 Niigata	Ⅰ4	1989	0.00001	**0.0089**	0.0186	**0.0132**	13.0	501
	No.11 Yamagata *	Ⅰ3	1989	0.00001	**0.0076**	0.0054	**0.0119**	11.0	255
	No.15 Nagano *	Ⅰ4 or Ⅳ4	1989	0.00111	**0.0075**	0.0107	**0.0110**	11.3	360
	No.7 Aomori	Ⅰ3	1989	1.4×10^{-7}	**0.0063**	-0.0243	**0.0118**	9.5	298
	No.4 Abashiri *	Ⅰ1	1989	0.00288	**0.0058**	-0.0221	**0.0092**	5.9	43
	No.25 Hiroshima	Ⅴ	1989	8.1×10^{-16}	**0.0052**	0.1000	**0.0138**	15.0	1126
	No.10 Ishinomaki *	Ⅳ3	1989	0.00521	0.0044	-0.0096	**0.0075**	11.1	120
	No.3 Suttsu *	Ⅰ2	1989	0.00664	0.0037	-0.0246	**0.0061**	8.3	4
	No.18 Tsu	Ⅳ5	1987	7.3×10^{-10}	**0.0086**	0.0488	**0.0147**	14.9	163
	No.35 Miyazaki *	Ⅲ8	1987	7.2×10^{-9}	**0.0048**	0.0422	**0.0103**	16.9	306
C	No.22 Kyoto	Ⅰ4 or Ⅴ	1980	0.00778	**0.0240**	**0.0610**	**0.0248**	14.7	1468
	No.21 Kanazawa	Ⅰ4	1980	0.00002	**0.0123**	**0.0670**	**0.0162**	13.7	456
	No.27 Matsuyama	Ⅴ	1980	0.00001	**0.0125**	**0.0577**	**0.0171**	15.4	473
	No.20 Fushiki *	Ⅰ4	1980	0.00224	**0.0068**	**0.0490**	**0.0094**	13.4	172
	No.26 Sakai *	Ⅰ5	1980	0.00002	**0.0070**	**0.0618**	**0.0097**	14.5	37
	No.32 Izuhara	Ⅱ1	1968	0.00008	**0.0124**	**0.0443**	**0.0131**	14.9	15
	No.29 Shimonoseki	Ⅱ1	1978	1.6×10^{-11}	**0.0061**	**0.0547**	**0.0151**	15.6	252
D	No.23 Osaka	Ⅴ	1943	2.3×10^{-6}	**0.0096**	**0.0328**	**0.0204**	15.7	2599
	No.6 Hakodate	Ⅰ2	1941	1.6×10^{-8}	0.0107	**0.0230**	**0.0048**	8.5	288
E	No.30 Fukuoka	Ⅱ1	1917	5.2×10^{-7}	0.0007	**0.0297**	**0.0229**	15.7	1341
	No.1 Asahikawa	Ⅰ2	1914	0.00732	0.0121	**0.0154**	**0.0189**	6.0	360
	No.5 Nemuro *	Ⅳ1	1914	0.00253	-0.0391	**0.0065**	**0.0079**	5.8	33
	No.9 Miyako	Ⅳ2	1914	0.02318	-0.0137	**0.0053**	**0.0065**	10.3	55
	No.16 Nagoya	Ⅳ5	1924	7.1×10^{-12}	0.0002	**0.0273**	**0.0135**	14.8	2172
	No.17 Gifu	Ⅳ5	1924	2.7×10^{-7}	-0.0044	**0.0264**	**0.0170**	14.8	403
	No.36 Kagoshima	Ⅱ2	1948	2.8×10^{-13}	-0.0047	**0.0366**	**0.0179**	17.2	552
	No.34 Kumamoto	Ⅱ2	1948	1.0×10^{-7}	-0.0017	**0.0269**	**0.0146**	15.9	662
	No.28 Kochi	Ⅲ8	1948	1.2×10^{-6}	-0.0020	**0.0201**	**0.0145**	16.0	331
	No.33 Saga	Ⅱ2	1948	0.00001	-0.0013	**0.0196**	**0.0119**	15.8	168
	No.24 Wakayama	Ⅴ	1950	3.0×10^{-6}	0.0002	**0.0213**	**0.0150**	15.8	387

Notes 1) Asterisk : Relatively suitable observatories for observing global warming by the Meteorological Agency

2) Temperature coefficient ・Gotyic type number : significant under α = 1%

・Under line number : signuficant under α=5%

・Except above : not significant under α=5%

- There are 14 observatories of this type. When it is Fc_{MAX}-value in the same year, in Table 2, observatories are arranged in order with a large temperature gradient of the first period.
- Fc_{MAX}-value years are many as 12 the same in 1989, the others are two in 1987. An air temperature jump of the end of 1980s in whole Japan might be related to this.
- Most of the observatories are located in northern part region, and Sea of Japan sides. The climatic divisions except No.25 Hiroshima and No.56 Miyazaki are I or IV.
- Nine observatories in 1989 could be compared, there is a tendency that the larger city scale (administrative district population) except No.25 Hiroshima, the larger temperature gradient of the first period is [9].
- Since the temperature jump of the end of the 1980s is not considered, the temperature gradient in the first period is smaller than that of one regression line.

Type C (Kyoto type): Both regression coefficients are significant. Both air temperature gradients have risen. The Fc_{MAX}-value year is around 1980.

- The Fc_{MAX}-value years are 7 in 1980, the others are in 1968 and in 1978.
- There are locations of 6 observatories beside the Sea of Japan. No.27 Matsuyama is exceptional.
- The temperature gradient in the second period is larger than the first period. In this sense, the warming phenomenon has accelerated.
- The temperature gradient in the second period is larger than one regression line.

Type D (Osaka type): Both regression coefficients are significant. Both air temperature gradients have risen. The Fc_{MAX}-value year is around 1940.

- The difference from Type C is only the times of Fc_{MAX}-value year, and this Type is earlier than Type C.
- It is only No.6 Hakodate except Osaka.
- The character of a temperature gradient is the same as Type C.

Type E (Fukuoka type): The temperature gradient of the first term is not significant and the second period is significant.

- The regression line in the first period might be horizontal. And after that, the temperature gradient in the second period expresses subsequently warming phenomena. This type of air temperature variation might change from the stationary process in the first period to the non-stationary process in the second period.
- The areas where the observatory belongs are divided roughly into two. One is in the northern region where observatories of Fc_{MAX}-value year in 1914 are located, and the other is the Pacific Ocean side of the central area and a southern area.
- The temperature gradients in the second period of the former type show a small and moderate temperature rise, whereas those of the latter type show a rapid and steep temperature rise. And observatories of the former are located in small cities, whereas the latter are located in relative large cities.
- The temperature gradient of the second period of the latter type is larger than that of one regression line. That is, the rapid urban warming occurred rather than having thought conventionally.

In general, it is certain that global warming or urban warming advanced for these 114 years. If Type B is excluded especially, the temperature gradient of the second period is large altogether (although Type B is temperature jump). Moreover, if Type B and Type E of the Fc_{MAX}-value years in 1914 are excluded, it turns out that the temperature gradient of the second period is larger than that of one regression line at 19 observatories. Furthermore, if the length of the second period is shorter and the city scale (population of administrative district) in which an observatory is located is larger, the tendency for the temperature gradient of the second period to become large can be guessed [10].

That is, although the urban warming in Japan is fundamentally subject to geographical and climate influence, it is supposed that the urban warming increases and the air temperature rises rapidly in the latter half mainly [11].

Incidentally, this study does not explore the cause of urban warming directly. However, it is very interesting to investigate the cause of urban warming, and taking measures is, of course, very important. Here, except climate factors, the following matters are pointed out from the result of this study. That is, first, many cities more than middle-size in Japan were in ashes as a result of the destruction caused by World War II (in 1945). After that, from the 1950s, it is supposed that rapid urbanization invited the rapid urban warming. Second, it is guessed that though an increase in population is a comprehensive index, physical changes of urbanization such as change of land use, increase of energy consumption and so on, have a greater essential influence on urban warming. It is because of this that in recent years, in mainly rural regions, quite a few not only urban substantial population but the urban administrative district population decrease, while urban air temperature rise continues in the middle-scale city.

5. Conclusion

Main results of this study are as follows.

First, in order to represent air temperature fluctuation, by the Chow test, it was judged with high accuracy that there were structural changes of air temperature all over object observatories, that is, two regression lines are more appropriate than one regression line.

Second, by the comparative examinations of the observatories where the different city scales within the same climatic division, it turned out that more remarkable warming phenomenon is, the larger city scales in which observatories are located.

Third, in the large city or the mid-scale city, it becomes clear that the urban air temperature rose rapidly in the second period of the target period.

By these facts, although the urban warming in Japan received regulation of geographical and a climate factor, it is clear that urbanization factor has influence on urban warming.

There are many future examination subjects.

First, the period covered and object observatories need to be expanded. If the covered period is different, transition figure, the Fc_{MAX}-value year and the structural change year might be different. It is necessary to adopt various period covered. Moreover, if time has decreased, the data of the observatory in various areas from other large cities to rural areas will be able to be used.

Second, another method of presuming a structural change year is required. The Chow's *F*-values were too large and long period in order to specify the structural change year in some large cities such as Tokyo, Nagoya, Osaka and Fukuoka. In such a case, probably, it will be more desirable to use this method together with another method, in order to presume a structural change year.

Third, the transition figures of Chow's *F*-value need further inquiry. There are various patterns of them, and it is guessed that they have a useful piece of information on the difference in urban warming concerning climates and city scales.

Thereby, it will be expected that the further knowledge concerning urban warming is acquired.

Acknowledgment

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Notes

[1] Strictly, the Chow test is performed in two steps. First, in the test of the dispersibility such as error terms u_t, v_t. *F*-test of the normal equal dispersibility is used for this. If homogeneity of variance is adopted by this test, the F_C-value will be tested. In addition, homogeneity of variance was adopted under the significance level α= 5% in almost all the object observatories and in almost all covered periods, and dishomogeneity of variance data were excepted from the annual judgment of the Chow test, hereinafter, only the F_C-values are described.

[2] With observational data of global warming, the Meteorological Agency notes the air temperature change of 17 observatories as being 'comparatively little although the influence of urbanization has won general influence'. The targeted observatories of this study are located at 9 points, No.3 Suttsu, No.4 Abashiri, No.5 Nemuro, No.10 Ishinomaki, No.11 Yamagata, No.15 Nagano, No.20 Fushiki, No.26 Sakai and No.35 Miyazaki.

[3] Examination of the temperature data across 114 years is difficult. The discontinuous year points caused by relocation of observatories, changes in apparatus used, etc. are apparent in the annual data of the Meteorological Agency homepage.

In this study, the data used was checked with a simple method. First, there are no points that the Fc_{MAX}-value year or a structural change year coincides with the discontinuous data years. And it is three places, No.6 Hakodate, No.16 Nagoya, and No.25 Hiroshima, that a discontinuous year corresponded to one year before the Fc_{MAX}-value year.

Next, under the assumption of a constant error, multiple regression analysis with the dummy variable and the coefficient test were carried out. Those are adapted about the data before or after the discontinuous year of some observatories. Although at the three above-mentioned observatories, it was difficult to distinguish between the influence of relocation of an observatory and the influence of temperature change, at almost all other observatories with the discontinuous data points, the null hypothesis (the coefficient of a dummy variable is Zero) was not rejected under a significance level α = 5%. Even if there is influence of data discontinuity, it is surmised that it is a grade which is not detected statistically. Such statistical tests need to be carried out about all the discontinuous points of all the observatories, and there is room for improvement of the test.

However, a more serious problem is that the necessity of revision concerning the past data was been noted. It is said that the past data was influenced by not only changes in location but also in charges of used but the situation of the observation methods, such as the number of observations per day, the circumference of observation equipment, etc(3). Probably, it will be impossible at least for the main observatories to investigate such details over a long period of time, if the Meteorological Agency does not carry out its data gathering systematically. Archives that contain more comprehensive data, however, might no longer exist.

[4] Japanese archipelagoes are surrounded by sea, and are a gentle bow-formed from the northeastern part to the southwestern part, and mountain ranges run along the central part of the islands. Because of them, the climatic divisions of regions in Japan are complicated and varied. For this reason, various climatic division figures are proposed. Fig.1 is made based on Takeshi Sekiguchi's climatic division figure which is most often used (4). Although the original drawing had the transitional zones where Kyoto, Nagano and Oita were established in, those are simplified in Fig. 1.

[5] For convenience, as a single index which guesses a city's scale, administrative district population is adopted as a reference. It is because the present administrative district population is not necessarily expressing a city scale. The current large cities and medium-sized cities had population influx from outside of the city and repeated municipal mergers after the 1950s. Consequently, the spatial domain expanded and administrative district population increased. The merger of municipalities, which were government led, included 'a large municipal merger of Showa era' (1953 to 1956), and 'a large municipal merger of Heisei era' (1999-2010). Thus, since the large city has repeated the municipal mergers, it is not so easy to pursue the population

change of a city concerning the present district (Every five years from 1920, there are Population Census which is made for every cities, towns and villages before mergers). On the other hand, according to a map or aerial photograph, cities where observatories are located and their land use patterns are various. When examining the urban warming of each city over a long period, it is necessary to examine the actual conditions of the city where observatories have been located from its historical context.

[6] Here, x is the natural number which set 1891 to x= 1 and set 2004 to x= 104. The coefficient of the regression line is taken of more decimal places below the decimal point than the usual o.oo or o,ooo so that it might be easier to carry out comparison between observatories. Rather than an actual conditional numerical value, a small number is an expedient numerical value.

[7] Although Fig.8 is also interesting, there is no guarantee that a warming tendency is constant. And if the coefficient of a dummy variable is not significant, Fig.6 will be adopted after all.

[8] The transition form of *Fc*-value has various patterns by observatories. However, it may have common case under certain circumstances. It is observed that there is a tendency which shows the similar form with the low value level in the northern part region of Japan, and that there is another tendency which shows the similar form with the high value level in a southern part region etc. It is given impression generally that *Fc*-value is large in the southern part region or relative large city where mean of air temperature is high and its fluctuation is large, in contrast, and that *Fc*-value is small in the northern part region or relative small city where mean of air temperature is low and its fluctuation is small (Since there are many large scale or medium-sized cities in which an object observatory is located in the southern part region, it is not easy to distinguish the influence of a city scale and the influence of a climatic factor clearly). However, this is not always certain statistically. Therefore, in this study, the interpretation of *Fc*-value considers only the formal meaning of the numerical formula (4) in Table 1.

[9] If No.25 Hiroshima is included, the coefficient-of-determination between city scale and the temperature gradient in the first period is r^2=0.335 (correlation coefficient r = 0.579). And if Hiroshima is excluded, r^2 = 0.571 (r = 0.775).

[10] The next multiple linear regression analysis is carried out about Type A, Type C, Type D and Type E. An explaining variables fulfill sign conditions and are significant under α = 1%.

y: the temperature gradient in the second period

x_1 : the urban scale (administrative district population. unit: in thousand)

x_2 : the length of the second period

Multiple correlation coefficient R = 0.898

Multiple correlation coefficient adjusted for degrees of freedom $\overline{R}$ = 0.887

$$y = 0.06826 + 3.5\times10^{-6}x_1 - 00067x_2$$

[11] It is not easy to distinguish global warming and urban warming only by local air temperature data. In this study also, warming phenomenon of a relative large scale city is only called 'urban warming'.

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