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 ⅣV5

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

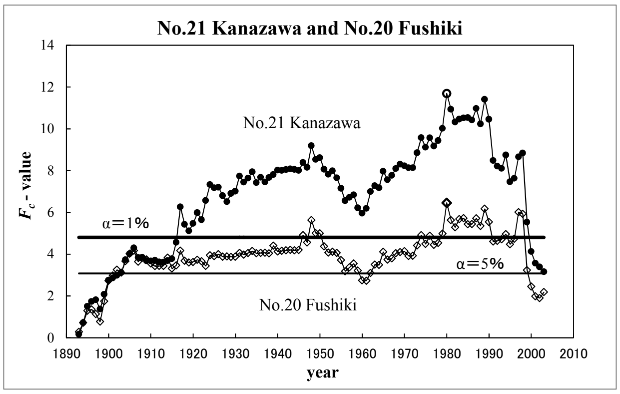

Fig.25 Transition of *F*-value for Kanazawa and Fushiki

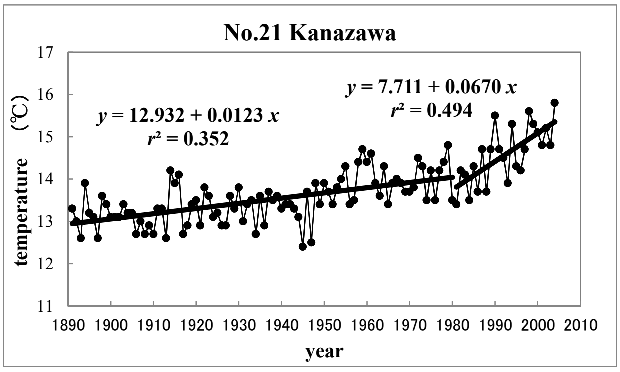

Fig.26 Temperature and two regression lines for Kanazawa

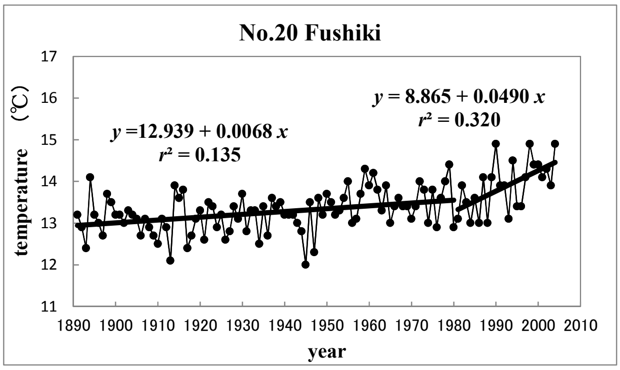

Fig.27 Temperature and two regression lines for Fushiki

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.

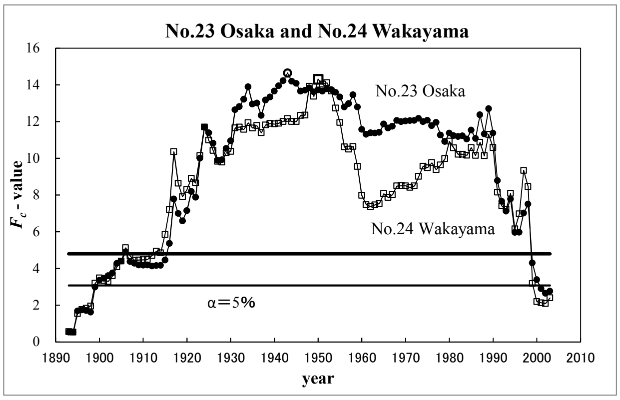

Fig.28 Transition of *F*-value for Osaka and Wakayama

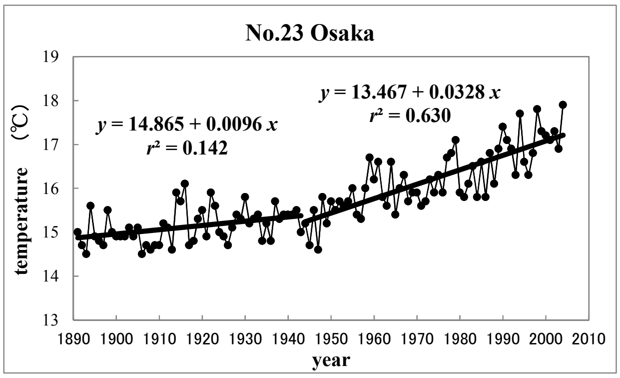

Fig.29 Temperature and two regression lines for Osaka

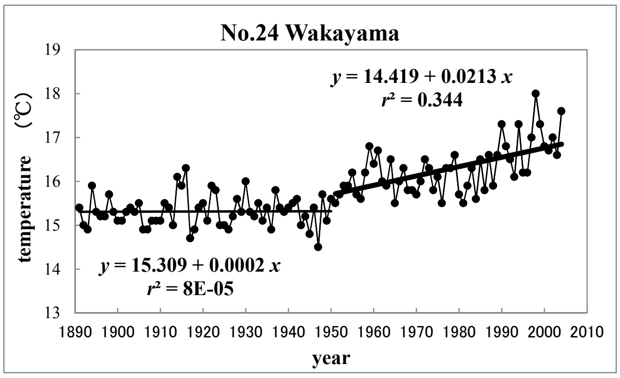

Fig.30 Two regression lines for Wakayama

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.

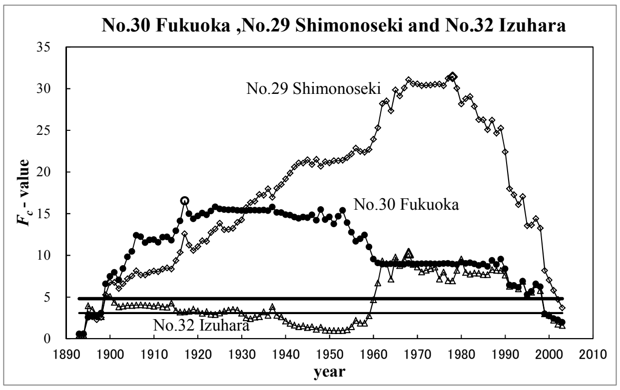

Fig.31 Transition of *F*-value for Fukuoka, Shimonoseki and Izuhara

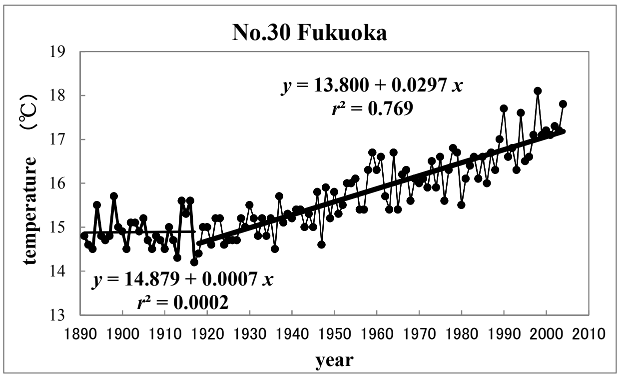

Fig.32 Temperature and two regression lines for Fukuoka

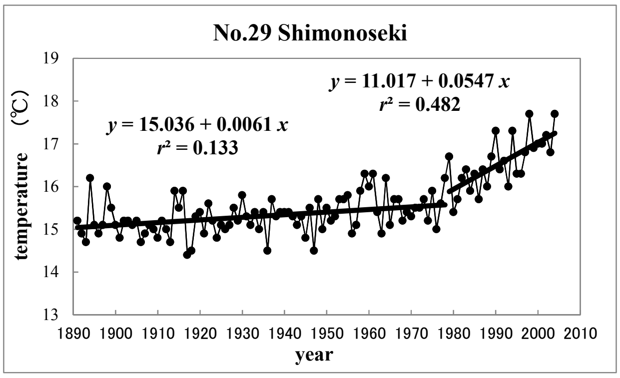

Fig.33 Two regression lines for Shimonoseki

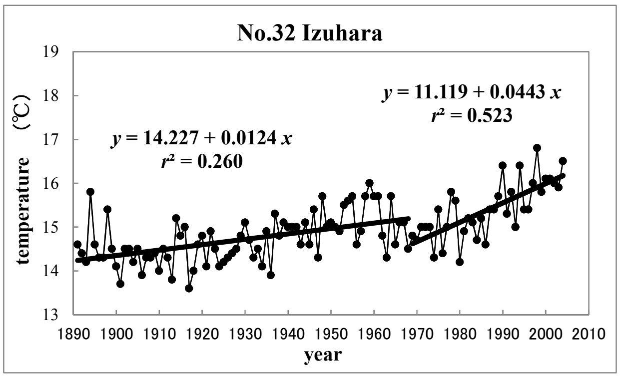

Fig.34 Temperature and two regression lines for Izuhara

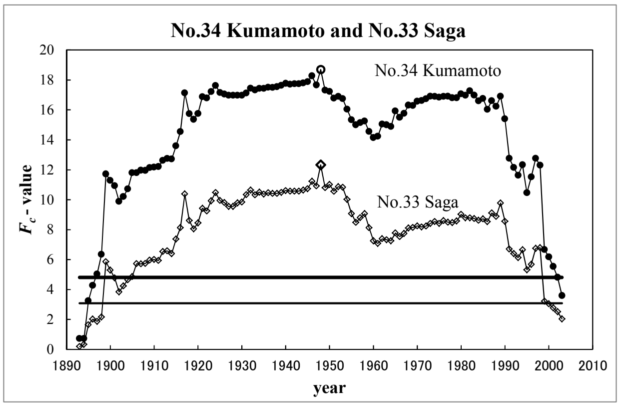

Fig.35 Transition of *F*-value for Kumamoto and Saga

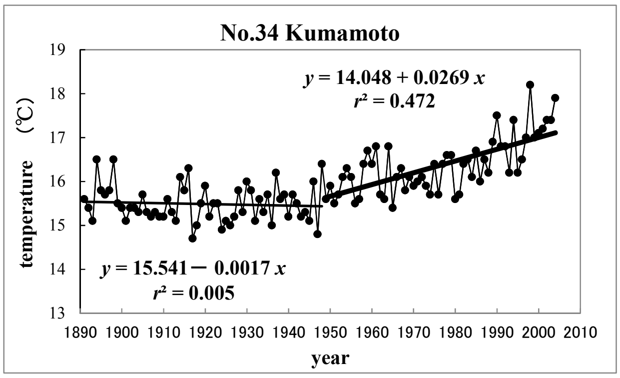

Fig.36 Two regression lines for Kumamoto

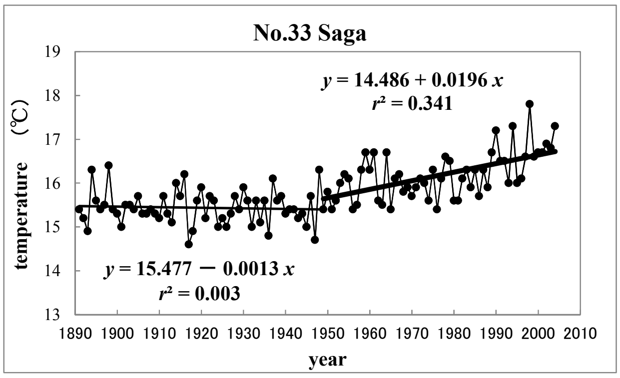

Fig.37 Temperature and two regression lines for Saga

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
	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
B	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
	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
C	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
	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
E	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

This work was supported by JSPS, KAKENHI 24560672.

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

$y = 0.06826 + 3.5 \times 10^{-6} x_1 - 00067 x_2$

[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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