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CLASSIFICATION OF JAPAN'S CLIMATE IN VIEW OF GLOBAL WARMING

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In 2007 the Intergovernmental Panel on Climate Change reported that global warming in the 20th century was induced by human activity and forecasted that mean temperatures around the world would rise another 1.8°C to 4.0°C by the end of the 21st century. When reviewing climatic change in Japan in light of this warming, we found that Takeshi Sekiguchi, a professor at the now-defunct Tokyo University of Education, first classified Japan's climate in 1950. Climate can be classified in two basic ways, by origin or by results. Sekiguchi employed the latter method, focusing on climate factors derived from the results of meteorological observations. Using correlation coefficients of interrelate climate factors, he conducted comparative studies of interannual changes in the diurnal range of temperature, the number of days of rainfall, the percentage of possible sunshine, and the amount of water surplus. Using this data, he classified Japan's climate into 27 categories. In this study, we used the same method as Sekiguchi to compare interannual changes using meteorological data collected from 127 observatories from all parts of Japan except Okinawa and the Ogasawara Islands. We then computed a climate classification for the year 2000, and compared our classification with that determined in 1950. Although we found no notable overall changes in the climate classification of the Japanese archipelago, the number of climate divisions increased in high-latitude areas such as Hokkaido. In Honshu the number of transition regions that cannot be clearly classified also grew. Significant increase in temperature was observed in cities and high-latitude areas, and minimum temperature has also risen.

Key Words: *global warming, Classification of Japan's Climate, diurnal range of temperature, amount of surplus water, Hokkaido district*

1. INTRODUCTION

The latest report by the Intergovernmental Panel on Climate Change (IPCC) on climate changes occurring in recent years[1] makes it scientifically clear that temperatures have increased on a global scale and that human activities are the probable cause. It predicts a rise in the mean global temperature for the 21st century of 1.8°C to 4.0°C. The report clarifies that changes in CO_2, which causes global warming, can only be explained by combining anthropogenic and natural factors, and predicts that there will be substantial increases in temperature and more frequent heavy rain and drought in the northern hemisphere. Europe, North America, Japan, and Southeast Asia are also suffering from frequent flood disasters and draughts as a result of extreme weather. Localized torrential rainfall hit various places during the summer of 2008[2], causing serious damage. Considering the revelations of likely global-scale warming and climate change, the current classification of Japan's climate, which is about 50 years old, needs to be reassessed due to classify the climate in recent years.

Past researches relating to climate classification employed either static or dynamic climatological classification methods. Sekiguchi (1952) and Fukui (1979) proposed a practical method for static classification[3]. They divided climate into factors, which were each classified by area, and then superimposed them. Suzuki (1962a, 1962b) employed dynamic classification involving the use of seasonal movements and distributions of weather fronts and air masses, which show the origin of climate, as indicators of climatic division[3]. This method is useful for macroclimate classification, but has a weakness that it is difficult to make subdivisions at the mesoclimate or smaller scales. Köppen (1923) and Thornthwaite (1931, 1948) developed empirical methods of climate classification[3]. They use vegetation distribution as the climate indicator, and have been employed in climate classification of continents such as Europe and America.

Sekiguchi (1952) 60 years ago employed a static climatological classification[4] to classify climate in Japan. It can be further subdivided into two methods by origin and by results. Classification by origin is based on the assumption that if the causes that characterize the climate are the same, the resulting climates will be similar, and focuses on the causes that shape the climate. Classification by results focuses on climate factors derived from the results of meteorological observations[5]. This was the method used in Sekiguchi's climate classification. Sekiguchi determined his climate classification by using correlation coefficients to compare the interannual changes in four weather factors : the diurnal temperature range, the number of days of rainfall, the percentage of possible sunshine, and the amount of water surplus. Like Sekiguchi's research, this study compiles 50 years of meteorological information from various cities and compares interannual changes in the diurnal temperature range, the number of days of rainfall, the percentage of possible sunshine, and the amount of water surplus to determine a present-day climate classification. The objective are to compare Sekiguchi's climate classification and climate type in each climate zone with current data and to reassess the classification. This study also aims to consider the relationship between climate and social change in urban areas resulting from large increases in city populations over the last 50 years, and the influence of global warming on Japan as a whole.

2. RESEARCH SUBJECTS AND CLIMATE OBSERVATION SITES

The subjects of this research are distributed in the entire country of Japan excluding Okinawa and the Ogasawara Islands. A total of 127 local meteorological observatories and weather stations from Wakkanai in Hokkaido to Yakushima in Kagoshima Prefecture were used. The positions of these observation sites are shown in Fig. 1. In the previous research[6], 120 to 130 observation sites were used, but it was difficult to identify the positions precisely. For this reason, based on the period during which the previous research was published, observation sites that existed prior to 1950 were selected for this research. There are currently 155 observation sites nationwide, 127 of which existed prior to 1950.

3. DATA COLLECTION METHOD AND FACTOR DEFINITIONS

The factors used in the analysis are the diurnal temperature range, the number of days of rainfall, the percentage of possible sunshine, and the amount of water surplus. Details about each are given below. The meteorological data used in the research were all obtained from the 2002 Annual Meteorological Report published by the Japan Meteorological Business Support Center, and the website and the electronic reading room of the Japan Meteorological Agency.

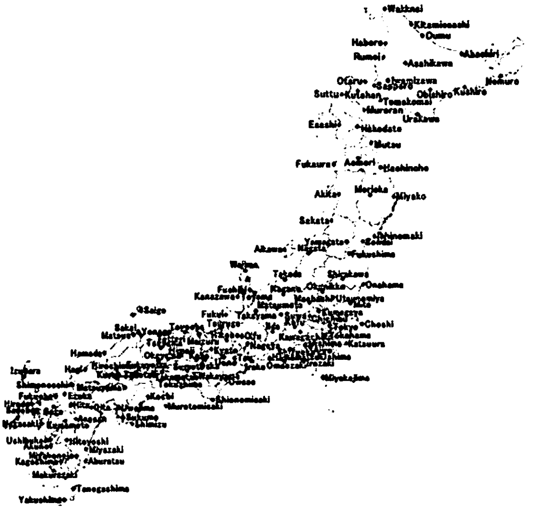

Fig. 1 Weather observation sites (127 locations)

(1) Diurnal Temperature Range

Sekiguchi's research[6] makes it clear that because interannual changes in mean monthly temperatures are almost uniform throughout Japan, it is not possible to use them for climate classification. Therefore, as in the previous research[7], this study makes use of diurnal temperature ranges. Diurnal temperature ranges are calculated from the difference between the monthly mean daily maximum temperatures and the monthly mean daily minimum temperatures. This study also compares annual mean temperatures, as they are very meaningful when comparing temperature characteristics across Japan. Temperatures during fixed periods that are important for vegetation growth , can be easily and uniformly calculated across the country with minimal processing of the figures for annual mean temperatures, since interannual changes in temperature are the same nationwide. This suggests that annual mean temperatures can be used to represent all the temperature data[6].

(2) Number of Days of Rainfall

Moisture contained in the atmosphere appears in its most tangible form as rainfall. Generally, the higher the amount of water vapor in the atmosphere, the higher the amount of rainfall. Also, the amount of rainfall tends to increase as temperature rises. The amount of rainfall is represented in the following equation:

$$R = i \cdot t \qquad (1)$$

Here, R is the amount of rainfall, i is the rain intensity per unit time, and t is the duration of the rainfall. The variable i has the property of sensitively reflecting the effect of temperature, while t characterizes the rainfall itself. In order to examine rainfall characteristics, rainfall duration showed be investigated, however, lacking of rainfall duration statistics for the entire country, we had to use the number of days of rainfall as the closest substitute for rainfall duration. The number of days of rainfall is the total number of days per month in which the amount of rainfall is 0.1 mm or above. It does not take into account whether conditions on that day are clear or cloudy. Even days of fine weather with sudden showers are included. In other words, the number of days of rainfall represents a different weather condition than the number of days of weather classified primarily by degree of cloudiness[7)8)].

(3) Percentage of Possible Sunshine

Various factors that indicate weather condition characteristics are observed, such as the number of clear days, the number of cloudy days, the number of days of rainfall, the degree of cloudiness, and the percentage of possible sunshine. However, the percentage of possible sunshine was adopted in this study as the factor that can be measured most directly. The percentage of possible sunshine is the ratio of the number of hours of actual sunshine at an arbitrary site to the number of hours of possible sunshine if the sun were not obstructed by clouds at all[7)8)].

(4) Water Surplus

In order to consider a climate's humidity, it is insufficient to look only at the amount of rainfall in the area. A part of rainfall is transferred into the atmosphere through evaporation. The rest stays in the area and determines the degree of humidity of the region. In other words, it is necessary to know the amount of rainfall and the amount of evaporation in the entire region[9)]. Therefore, like Sekiguchi's research, this study uses the amount of surplus water to indicate a climate's degree of humidity. The water surplus is calculated from the difference between the amount of rainfall and the amount of evaporation. The Thornthwaite formula[10)] which was monthly mean temperatures, was used to calculate the amount of evaporation. Also, because the amount of evaporation can not be calculated at temperatures below zero with this formula, the Penman equation was used to complement it when necessary[11)].

4. DATA ANALYSIS

(1) Calculation of Correlation Coefficients

In order to compare differences in interannual changes in the four climate factors in each region, this study adopted a method using correlation coefficients, as did Sekiguchi's research. This method involves sequential computation of correlation coefficients of monthly values for climatic conditions in the year 2000 at adjacent observation sites.

As the relationship between two variables becomes more linear, the absolute value of their correlation coefficient approaches 1. Correlation coefficients statistically represent relationships between variables, having nothing to do with causality.

(2) Test of Correlation Coefficients

Because, as mentioned above, correlation coefficients are only indicators of linear relationships between two variables, it is necessary to test their significance. A correlation coefficient can be regarded as a random variable for which t_0, found using Equation (2), follows a t distribution with (n-2) degrees of freedom. Therefore, a t-test was used to assess the significance of the correlation coefficients.

$$t_0 = \frac{r}{\sqrt{1-r^2}}\sqrt{n-2} \qquad (2)$$

The variable r is the correlation coefficient and *n* is the total number of variables.

By comparing t_0 with the critical value $t_{n-2}(\alpha)$, assuming a degree of freedom of n-2 and a significance level of α%, we can state the following:

When $t_0 \geq t_{n-2}(\alpha)$ significant correlation exists.

When $t_0 < t_{n-2}(\alpha)$ the variables are not correlated.

Because this research involved calculation of correlation coefficients for changes in each month over one year, the total number of variables is 12. Therefore, a degree of freedom of 10 was used with significance levels of 5% and 1%. The critical values in this case are shown in Table 1, and correlation was taken to be high if critical values for the significance levels were met and low otherwise. Results were judged using the 1% significance level.

Table 1 T-test critical values

Significance level	5%	1%
Critical value	2.228139	3.169262

(3) Method for Determining Climate Classification

(a) Method for Determining Each Climate Classification Factor

To establish climate classification boundaries, the correlation coefficients for adjacent sites are written in a diagram. If the correlation coefficient is negative or particularly small, it is considered the climatic conditions at the two sites are different and a boundary line dividing climate zones exists. Like line A-B shown in Fig. 2, if a boundary line cannot be continuously drawn, a dotted line is used. The criterion for establishing a boundary[12)] was taken to be a correlation coefficient of less than 0.708, which reflects a 1% significance level. If boundary lines can be drawn, as described above, the mean interannual changes in a climate factor for a region surrounded by the same boundary line are calculated to decide the region's climate type. The correlation coefficients for the mean interannual changes found in that region and each site's interannual changes are calculated, so that the position of the climate classification boundary is confirmed[6]. An example of the determination method is shown in Fig. 2.

(b) Method for Determining Overall Climate Classification

The climate classification lines found in (a) for all the climate factors were superimposed and used to classify the different climate areas of Japan. The procedure was as follows[13]:

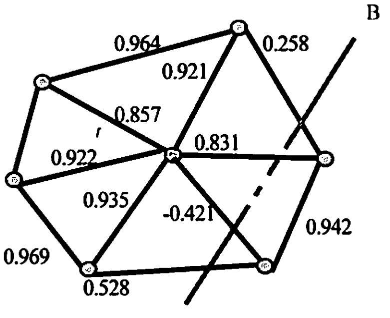

Fig.2 Determination method for climate classification boundaries (example)

Step 1: Climate classification boundary lines for the four factors were traced onto a sheet of tracing paper.

Step 2: For each factor, observation sites were grouped according to their climate type. Climate type alone is not a sufficient basis for determination, so additional indicators of climatic characteristics were considered. This new data included annual mean temperature to the augment diurnal temperature range, annual rainfall for the number of days of rainfall, annual hours of sunshine for the percentage of possible sunshine, and annual water surplus for the amount of water surplus. Also, as in Sekiguchi's research[12], class divisions were employed for each of these factors. These are shown in Table 2. Furthermore, the climate type shown by each factor and additional decision-making indicators were tabulated for each of the 127 sites, and climate types were established by grouping those with a high degree of similarity.

Step 3: Based on the climate types found in Step 2, the four climate classification boundaries determined in Step 1 were brought together as one climate classification boundary line on a separate sheet of tracing paper. This was traced onto a blank map using carbon paper, and the climate classification of Japan was finalized. Regions for which boundary lines could not be drawn using the above determination method and small regions showing unique interannual changes were taken as transitional climate zones[12].

Table 2 Summary of additional decision-making data

Additional decision-making data / Class division	Diurnal range/ Annual mean temperature	No. of days of rainfall/ Annual rainfall	Amount of water surplus/ Annual water surplus
A	≥ 13.5℃	≥2000 mm	≥1250 mm
B	11.1℃ – 13.5℃	1500 – 2000 mm	750 – 1250 mm
C	6.1℃ – 11.1℃	< 1500 mm	< 750 mm
D	< 6.1℃		

(Note) We did not employ a class division for annual hours of sunshine, following Sekiguchi's research.

(4) Test Using Standard Deviations

The year 2000 was chosen for comparison with the climate classification done in the 1950s. In order to test whether this was an unusual year, standard deviations at each observation site for the fifty-year period from 1950 to 2000 were calculated. The results of this test are shown with the results of the next section. As it is difficult to show the results at all of the 127 sites, those at four representative sites, Sapporo, Tokyo, Osaka, and Fukuoka, were selected.

(5) Calculation of Coefficients of Variation

The magnitude of standard deviation, the measure employed in the preceding section, corresponds to the size of variation of the data. A simple size comparison of standard deviations is valid if the mean values of each group's data are similar, but if the mean values are different, even with the similar standard deviations, the practical significance differs[14]. Therefore, coefficients of variation were calculated as practical indices for evaluating the size of variation of the data.

Standard deviations and coefficients of variation at 127 sites were calculated, and overall, the variation in each climate factor's standard deviation was notable. However, with regard to coefficients of variation, as can be observed from the diagrams below that cover the fifty-year time span, there is little variability, and there were few sites for which the year 2000 was unusual. Also, like the year 2000, it is difficult to conclude that the earlier basis of comparison, the year of 1950, is an unusual year. Therefore, both years are suitable as bases for comparison. The key results are shown in Figs. 3, 4, 5, and 6.

Here, factors for Sapporo, Tokyo, Osaka, and Fukuoka are

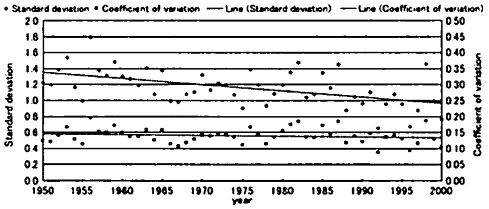

Fig.3 Standard deviation and coefficient of variation of diurnal range in Sapporo

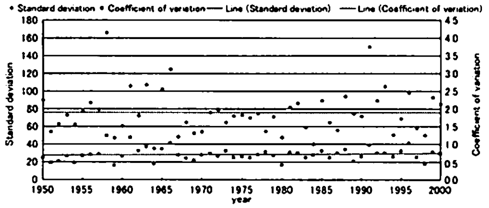

Fig.4 Standard deviation and coefficient of variation of amount of water surplus in Tokyo

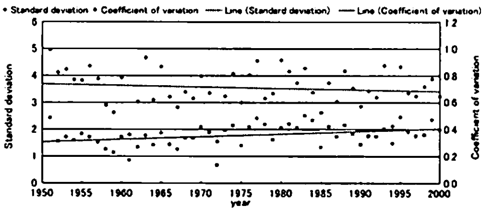

Fig.5 Standard deviation and coefficient of variation of number of days of rainfall in Osaka

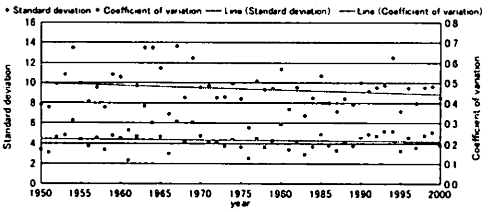

Fig. 6 Standard deviation and coefficient of variation of percentage of possible sunshine in Fukuoka

given as examples. Sapporo is in the high-latitude Japan Sea climate zone and variation in temperature increase and diurnal range over the past 50 years has decreased. Tokyo is in the Pacific Ocean climate zone and the amount of its water surplus is shown to represent temperature increase and the amount of rainfall in large cities. The data for Osaka, representative of the Seto Inland climate zone, show the number of days of rainfall, and the data for Fukuoka represent the Kyushu climate zone, where variation in percentage of possible sunshine has decreased.

Table 3 Comparison of Japan's climate classifications for 1950 and 2000

(1950)	(2000)
I Japan Sea Climate Zone	I Japan Sea Climate Zone
1. Okhotsk Coastal Region	1. Tohoku Japan Sea-type
2. Western Hokkaido Region	2. Hokuriku Japan Sea-type
3. Dewa Region	3. Chugoku Japan Sea-type
4. Hokuriku Region	II Kyushu Climate Zone
5. San'in Region	1. Kyushu-type
II Kyushu Climate Zone	2. North – Kyushu-type
1. Northern Kyushu Region	3. Northwest – Kyushu-type
2. Southern Kyushu Region	4. South – Kyushu-type
III, IV Pacific Ocean Climate Zone	III, IV Pacific Ocean Climate Zone
1. Eastern Hokkaido Region	1. Tohoku Pacific Ocean-type
2. Sanriku Region	2. Kanto Pacific Ocean-type
3. Eastern Kanto Region	3. Chubu Pacific Ocean-type
4. Western Kanto Region	4. South Pacific Ocean-type
5. Boso Region	5. Central Highlands-type
6. Tokai Region	V Seto Inland Sea Climate Zone
7. Nankai Region	VI Hokkaido Climate Zone
8. Zunan Region	1. North – Hokkaido-type
V Seto Inland Sea Climate Zone	2. North-northeast - Hokkaido-type
1. Eastern Seto Inland Sea Region	3. Northeast - Hokkaido-type
2. Western Seto Inland Sea Region	4. East - Hokkaido-type
	5. South - Hokkaido-type
VI Tsushima/South Korea Climate Zone	6. West - Hokkaido-type
	VII Transitional Climate Zones
VII Transitional Climate Zones	1. Asahikawa – Iwamizawa Region
1. Hidaka Region	2. Muroran – Hakodate Region
2. Kitakami Region	3. Hachinohe – Morioka Region
3. Fukushima Region	4. Yamagata Region
4. Central Highlands	5. Nagano Region
5. Iga Region	6. Owase Region
6. Tokushima Region	7. Tsuyama Region
7. Uwajima Region	
8. Oita Region	

5. CALCULATION OF EACH FACTOR AND CLIMATE-TYPE

A climate classification of the whole of Japan for the year 2000 was calculated by putting together the four climate factors. The result is shown in Table 3 and Fig. 7. The climate classification calculated by Sekiguchi for 1950 is shown in Table 3 and Fig. 8. A comparison of the year 2000 climate classification and its representative climate types with the 1950 classification is given below.

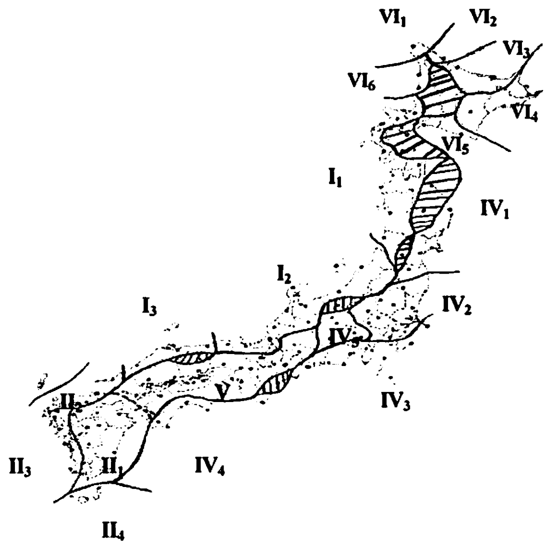

Fig. 7 Climate classification of Japan in 2000

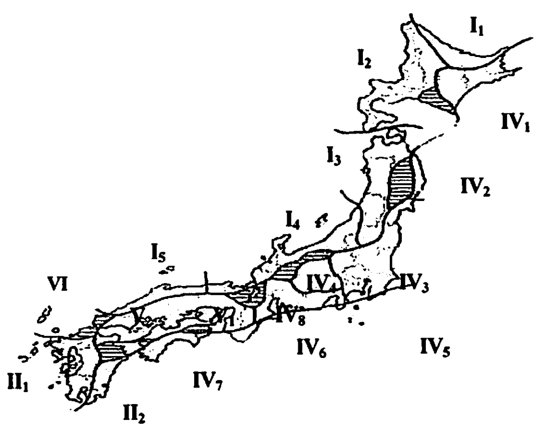

Fig.8 Climate classification of Japan in the 1950s (Sekiguchi)

(1) Comparison of Climate Classifications

It is clear that the climate classifications in Hokkaido has changed significantly. The transitional zone that existed around Urakawa has disappeared, while new ones have formed around Asahikawa, Iwamizawa, Muroran, and Hakodate. Also, in Honshu, although there was little change in the positions of the classification lines, changes in the transitional zones were observed. The transitional zone around Morioka has expanded to Hachinohe, new transitional zones have formed in Yamagata, Tsuyama, and Owase, and the Takayama transitional zone has disappeared.

(2) Comparison of Climate Types

Fifty years ago, Japan was broadly divided into three climate types: the Pacific Ocean climate, the Japan Sea climate, and situated between the two, the Seto Inland climate. A similar result was obtained in 2000. Fifty years ago, Hokkaido was broadly divided into two climate types, the Japan Sea-type and thee Pacific Ocean-type, but in the year 2000, all of the regions except southwestern Hokkaido are unique climate types that do not fit in either of the two main types. In particular, the transitional zone has expanded, and Hokkaido has been subdivided into six climate classifications. meanwhile, the range of the Seto Inland climate type has expanded. The Kyushu climate type, although similar to the Seto Inland climate type, has been classified as such because of poor correlation between the two climate types and differences in climate factors such as annual rainfall. Therefore a dotted line marks the boundary because it is difficult to establish a distinct boundary line.

(3) Change in Surplus Water

Surplus water is an indicator of the climate's humidity, and there are places and periods when the difference between the amount of rainfall and the amount of evaporation is zero or negative. This is common to all regions excluding Kyushu and Hokkaido. In some regions it occurs in December or February, but mainly in August. It is believed to be induced by a decrease in the amount of rainfall in summer. Interannual changes in the number of days of rainfall show the number of rainy days for the Pacific Ocean-type is the lowest in midsummer. The Japan Sea-type and Seto Inland-type also have a minimum number of rainy days in August. Therefore, we can speculate that rainfall in summer has decreased. This result can also be speculated from interannual changes in percentage of possible sunshine, which show an obvious maximum in August for the Japan Sea-type, a secondary maximum in August for the Pacific Ocean-type, and a maximum in August for the Seto Inland-type, all with around 60% of possible sunshine. Interannual changes in the number of days of rainfall and the percentage of possible sunshine for the Japan Sea-type and the Seto Inland-type are shown in Figures 9 and 10.

6. CLIMATE CLASSIFICATION CHANGES AND GLOBAL WARMING

The changes in the climate classifications of each factor and the overall climate classification in Hokkaido are striking. Its interannual changes unique, belonging to neither the Japan Sea-type nor the Pacific Ocean-type climate. The reason for this is believed to be the influence of global warming. We can also infer that global warming is another reason for changes in the amount of water surplus. As shown in the Extreme Weather

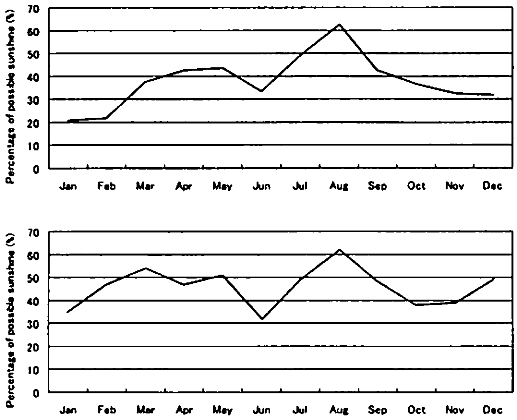

Fig.9 Interannual changes in percentage of possible sunshine (Japan Sea-type (top) and Seto Inland-type (below))

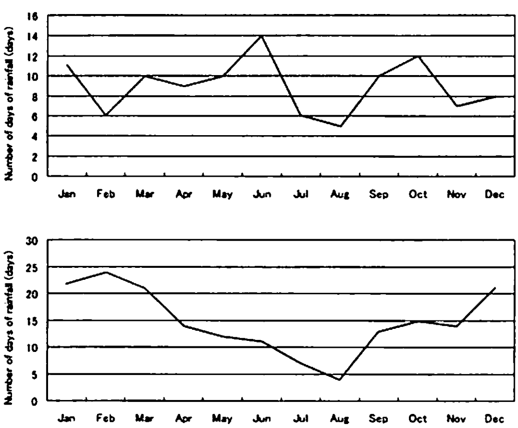

Fig. 10 Interannual changes in number of days of rainfall (Japan Sea-type (top) and Seto Inland-type (below))

Report 2005[15], the annual mean rainfall in Japan has been on a downward trend since the 1950s. This coincides with the fact that annual mean surface air temperatures, which influence the amount of water surplus, have risen over the past 50 years. On the other hand, in order to examine the influence of global warming, it is necessary to focus on changes in minimum temperatures. This study compared annual mean temperatures at each observation site in Hokkaido in 2000 with those measured in 1950. As shown in Figure 11, annual minimum temperatures have increased at 13 out of the 20 sites. Particularly, minimum temperatures increased significantly the Sapporo(1.8°C), Kutchan(1.5°C) and Iwamizawa(1.0°C). Also, the annual minimum temperature has increased by 0.6°C in Asahikawa, which belongs to the same transitional zone as Iwamizawa. Its neighboring towns also showed large increases. The regions with the decreased minimum temperature were Omu and Abashiri, which are categorized as Northeast/North Hokkaido-type, and Muroran, which is in a transitional zone.

These facts lead us to believe that climate changes in Hokkaido are an effect of global warming.

However, large cities such as Sapporo are also subject to a heat island effect, and examination excluding such effect showed be conducted for the future.

Because we confirmed increased annual mean minimum temperatures in Hokkaido, minimum temperatures, which are considered to be influenced by global warming, were examined across the whole of Japan.

The distribution of annual mean minimum temperatures at each observation site is shown in Figure 12. The distribution shows that, like in Hokkaido, annual mean minimum temperatures are increasing in Honshu and Kyushu. The annual mean minimum temperature nationwide has increased by 0.82°C, and temperature dropped at only 6 out of 127 sites.

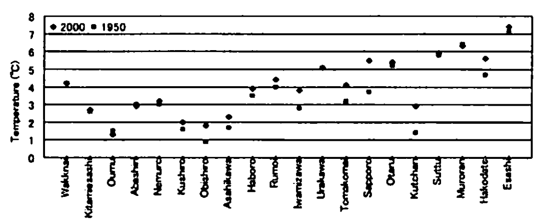

Fig.11 Distribution of annual mean minimum temperatures at each observation site in Hokkaido

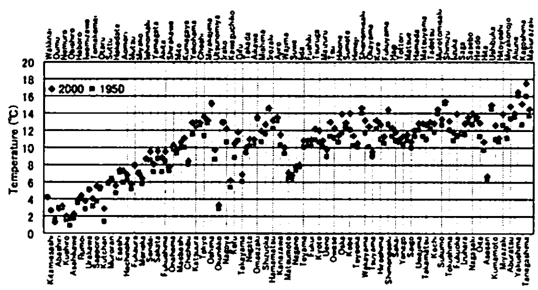

Fig.12 Distribution of annual mean minimum temperatures at each observation site

Large increases in temperature were found at many sites in western Japan, and the mean increase in the Kinki Region and westward was approximately 1°C. We speculate that it is becoming difficult to clearly distinguish between the Japan Sea-type and the Pacific Ocean-type climates due to the effects of this warming and that is why there are more dotted sections of climate classification boundary lines than solid sections in each climate factor's classifications in western Japan. Indeed, even from judging analyses of the factors' interannual changes, the Seto Inland-type and the Kyushu-type can be said to belong to both the Japan Sea-type and the Pacific Ocean-type climates. Sites with large temperature increases in order of magnitude are: Fukuoka(2.6℃); Kagoshima and Okayama(2.4℃); Tokyo and Osaka(2.2℃); Kobe(1.9℃); and Sapporo(1.8℃). Concerning annual mean temperatures, Kagoshima and Okayama had the largest increase. Other high-ranking sites are all ordinance-designated cities with populations of over one million, and their temperatures may well have been affected by huge social changes that have occurred in these cities over the past 50 years.

Global warming caused by CO_2 and other gases, increases in anthropogenic heat waste known as the heat island phenomenon, and changes of the structures in cities have all been identified as factors[16] which cause temperature increases in large cities. Therefore, further research that excluding these effects is needed.

7. CONCLUSION

(1) Climate Classification

In Sekiguchi's climate classification, all the factors were analogous, whereas in the 2000 climate classification, each factor took a different form. Changes in Hokkaido were particularly striking. Overall, transitional zones increased, and the transitional zones in Honshu changed greatly. However, no large changes were found about the position of the climate classification lines in Honshu.

(2) Climate Type

Fifty years ago, Japan was divided into five climate types: Japan Sea, Pacific Ocean, Seto Inland Sea, Kyushu and Hokkaido. Likewise, in 2000, Japan was broadly divided into five types. However, in this study, the Hokkaido Climate Zone, which excludes some parts of Hokkaido, was newly identified as a unique climate type that fits neither the Japan Sea-type nor the Pacific Ocean-type. Also, the Kyushu-type is similar to the Seto Inland-type and both can be said to be intermediate between the Japan Sea-type and the Pacific Ocean-type climates, but it is difficult to clearly distinguish between the two.

(3) Climate Change

Compared to fifty years ago, the amount of rainfall in the region from Honshu to Kyushu has decreased. The decrease in rainfall in February is particularly striking, and a decrease in the amount of rainfall during the summer was also confirmed. This agrees with report by Kimoto which described citing the Extreme Weather Report 2005, that the mean amount of rainfall in Japan had shown a slight downward trend since the 1950s[17]. Also, from our comparison of minimum temperatures, we surmise that the effect global warming is expanding throughout Japan. There has been a large increase in minimum temperatures in large cities with populations of over one million, and annual rainfall is decreasing. We were able to confirm climate change due to urbanization in large cities that have experienced great social change. Further research into temperature increases in large cities is required, isolating the effects of global warming due to CO_2 emissions and those due to the heat island phenomenon.

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