CLIMATIC CHANGE DURING HISTORICAL TIMES IN JAPAN —RECONSTRUCTION FROM CLIMATIC HAZARD RECORDS—

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Abstract A synoptic analysis of climatic hazard records in historical times of Japan is presented. The cool age (7-9c.), the warm age (10-14c.) and the cold age (15-19c.) are indicated. The relationship between summer and winter conditions in the climatic change is also shown. Thus, the knowledge of the climatic change in Japan from the 7th to the 19th century was systematically summarized.

1. Introduction

The climate had changed or fluctuated through historical times. The knowledge of past climate is accumulated by analyzing documentary or field data, particularly, in Europe. Thus, the climatic amelioration or deterioration is well correlated to natural and social phenomena. The medieval warm epoch and the Little Ice Age are approved universally. In Japan there are many documentary proxy data to reconstruct the climate in historical times. Using several kinds of them, it was roughly estimated that the climate was mild in the Middle Ages and cold in the Little Ice Age in Japan (Yamamoto, 1976; Arakawa, 1954a, 1954b; Yazawa, 1976).

However, the detailed picture of Japan's historical climate is not yet obtained, which makes difficult to compare it with the European results. The documentary proxy data which were used in Japan, such as the dates of cherry-viewing and lake freezing, have the following defects: (1) they reflect only local climate, (2) they do not indicate air stream or circulation conditions in most cases, but hygro-thermal conditions, and (3) they are fragmental in space and time. As a result, the long-term change for centuries is not reconstructed in detail by using the century-long homogeneous data. In addition, the spatial coincidence of climate change was not always indicated.

In Japan the previous studies on climatic change were conducted mostly by statistical methods, because the data at a single point or in a restricted area were used. As a

result, the dynamic image of past climate was hardly obtained. In other words, the pressure field pattern could not be reconstructed on a regional scale. The climatic change is a manifestation of temporal march in average circulation pattern on a regional or global scale. Therefore, the reconstruction of past climate has to be conducted from synoptic-climatological point of view.

The attempts at reconstructing the climate in historical times from the synoptic point of view were recently made in Japan (Maejima and Koike, 1976; Yaji and Misawa, 1981; Mikami, 1983). They are based on the reconstructed pressure field patterns in the recent historical times. However, the period of reconstruction is shorter, because the weather data are not enough to analyze the weather pattern in whole Japan from the synoptic point of view, and the work needs much time and labor.

On the other hand, climatic hazards have been usually recorded throughout historical times. In Japan, many historical documents contain the description about unusual weather which caused disaster, especially crop failure. By using these records, the climate in the historical past was reconstructed (Yoshino and Kurosaka, 1983).

In this study the authors make an attempt to reconstruct the historical climate in the Japanese Island by using the climatic hazard records since the 7th century.

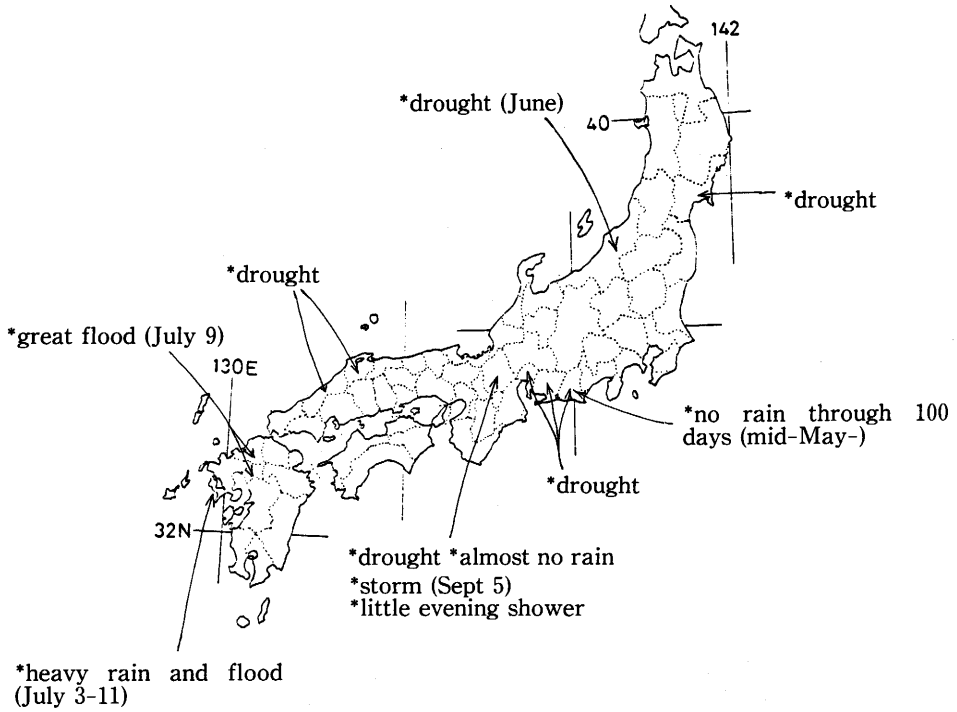

Fig. 1-a Climatic hazard distribution of hot summer type (June, July and August in 1717).

2. Climatic Hazards and Climatic Conditions

Climatic hazards in Japan

Unusual march of seasons have brought disasters in a large area in Japan. Especially, cool summer weather and drought have caused famine, which are usually described in historical documents. The records go back to the 7th century (*Asuka Era*), and the descriptions increase since the 17th century (*Edo Era*).

The contents of climatic hazard descriptions have altered through historical times in Japan. The percentage of drought is decreasing from ancient times to recent times. While the percentage of long rain, cool summer, heavy snow are increasing (Kusakabe, 1959-1981). The change of weather disaster type has been explained by the change of social regime, way of production and so on. On the other hand, its relation to the climatic change has not been satisfactorily examined yet.

Data

There are many lists in Japan that collect weather hazard records from official

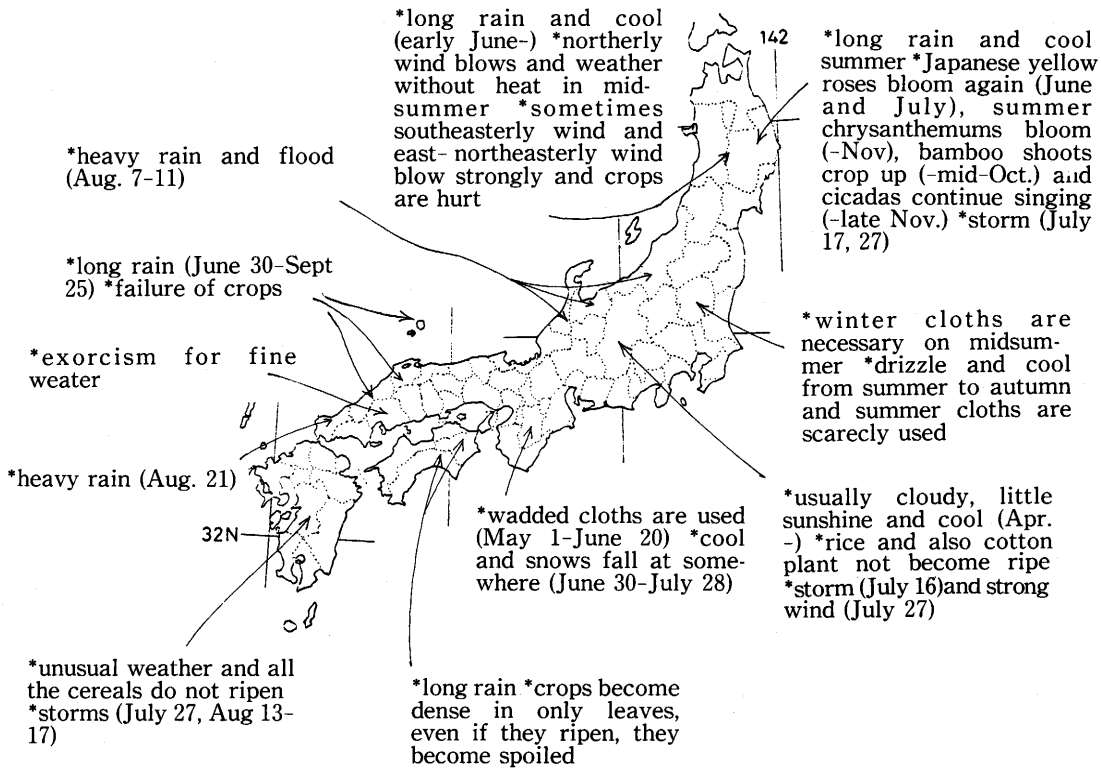

Fig. 1-b Climatic hazard distribution of cool summer type (June, July and August in 1783).

document of governor, personal diary, anthology, biography and so on. "Meteorological Data of Japan" collect climatic disasters from the 7th century to the 19th century all over Japan (Chuo-kishodai and Kaiyo-kishodai, 1939, 1940, 1941). Climatic hazards are classified into storm, flood, thunder, whirlwind, drought, long rain, snow, hail, frost, unusual cloud, rainbow and halo, fog and yellow sand, red sky (aurora), phenomena of season, strange rain.

The hazards which brought severe damage over wide area, covering more than two old Japanese districts, were collected by districts (Kusakabe, 1959-1981). Types of the hazard are as follows: strong wind (with rain) in typhoon season, strong wind (with rain or snow) in extra-typhoon season, heavy rain, heavy snow, long rain, drought, mild winter, unusual cold, cool summer, tornado, thunderstorm, hail, earthquake and tidal wave, eruption, strange rain and ash (sand) fall, unusual blooming. The number of natural hazards are 347 in Hokkaido, 812 in Tohoku, 545 in Kanto, 1042 in Chubu, 992 in Kinki, 593 in Chugoku, 273 in Shikoku and 566 in Kyushu.

"Meteorological Data of Japan" and the collections of natural hazard by Kusakabe are sufficient to examine the climatic change for long time in this study. In particular, the authors examine the records about drought, long rain, heavy snow and mild winter which reflect climatic change.

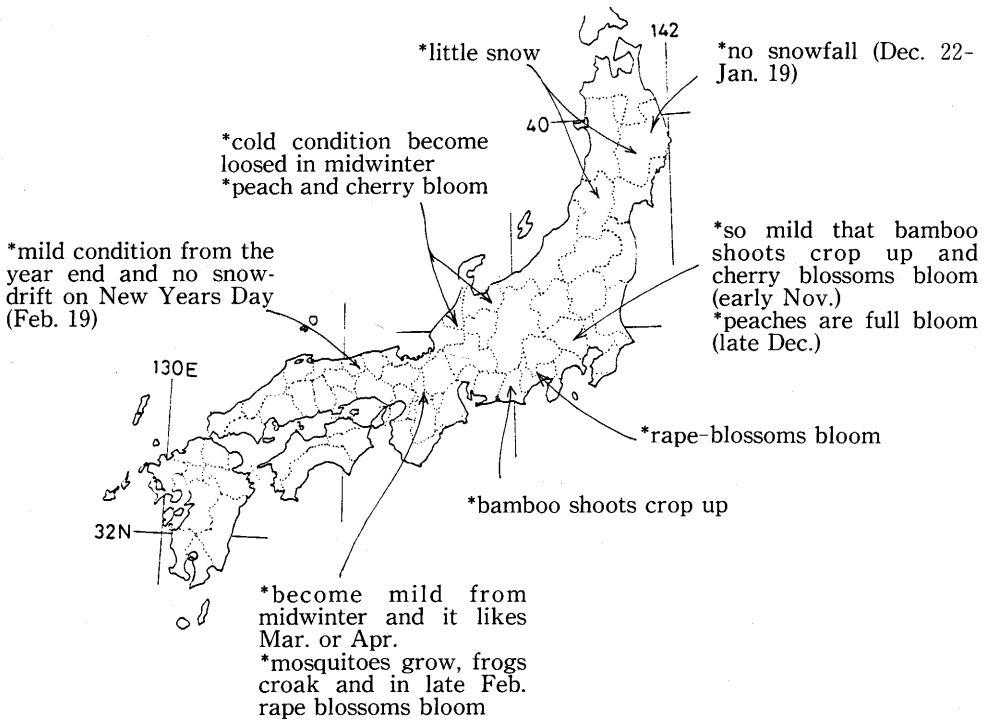

Fig. 1-c Climatic hazard distribution of mild winter type (December in 1737, January and February in 1738).

Method

At the beginning the climatic hazards are plotted on the chart by seasons. Based on these charts, the climatic change from 601 to 1900 is examined in this study. On the chart, the area is divided by old districts which had been used until the mid-19th century. In the previous studies, the changes of weather hazard frequency were surveyed by districts (Maejima and Tagami, 1982, 1983b). Here the spatial characteristics of occurrence of climatic hazard are shown. Thus, the synoptic pattern of pressure field on average may be estimated. Furthermore, the accuracy of the hazard description can be cross-checked at the same time.

Typical examples of weather hazard distribution in summer and winter are as follows: (a) In summer of 1717 drought appeared all over Japan except Kyushu. In ordinary years long rain occurs on the Pacific coast of Tohoku District, whereas there took place a drought in this summer. (Fig. 1-a). (b) In 1783 rainy and cool summer occurs all over Japan. In those years around this year, "*Tenmei* Great Famines" occur (Fig. 1-b). (c) In winter of 1737/1738, there was no snow cover on the Japan Sea coast, and unusual flowering of spring blooms on the Pacific coast (Fig. 1-c). (d) In winter of 1809/1810 heavy snowfall occrred on the Japan Sea coast and there was also heavy snow and cold on the Pacific coast (Fig. 1-d).

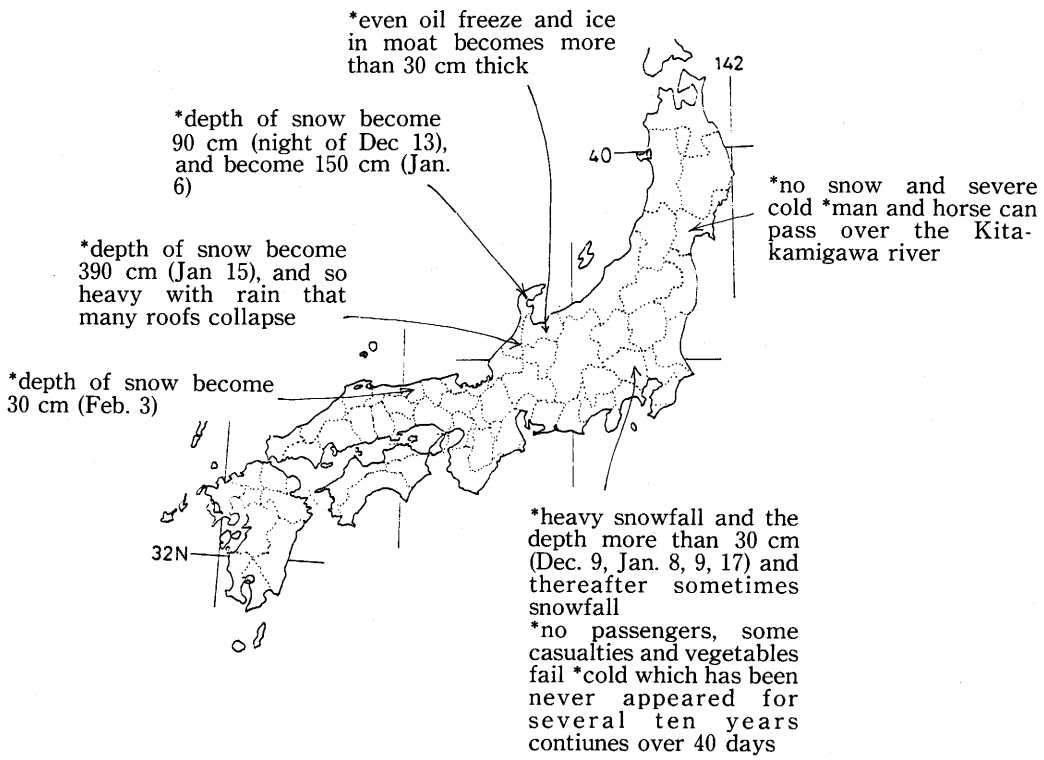

Fig. 1-d Climatic hazard distribution of cold winter type (December in 1809, January and February in 1810).

Table 1 Frequency of weather type for each century
Types are follows : (1) hot summer, (2) west cool-north hot summer, (3) north cool-west hot summer, (4) cool summer, (5) mild winter, (6) cold winter

Century	Type of summer					Type of winter		
	(1)	(2)	(3)	(4)	Sum	(5)	(6)	Sum
7	11	0	0	3	14	1	0	1
8	24	0	1	6	31	0	6	6
9	23	2	2	19	46	2	19	21
10	31	0	0	5	36	0	7	7
11	18	0	0	6	24	1	4	5
12	10	0	0	7	17	2	6	8
13	17	0	0	9	26	0	10	10
14	15	0	0	6	21	0	3	3
15	20	1	0	9	30	1	19	20
16	16	0	2	6	24	10	14	24
17	29	0	5	26	60	16	31	47
18	37	2	21	26	86	18	48	66
19	40	0	11	33	84	9	62	71
Sum	291	5	42	161	499	60	229	289

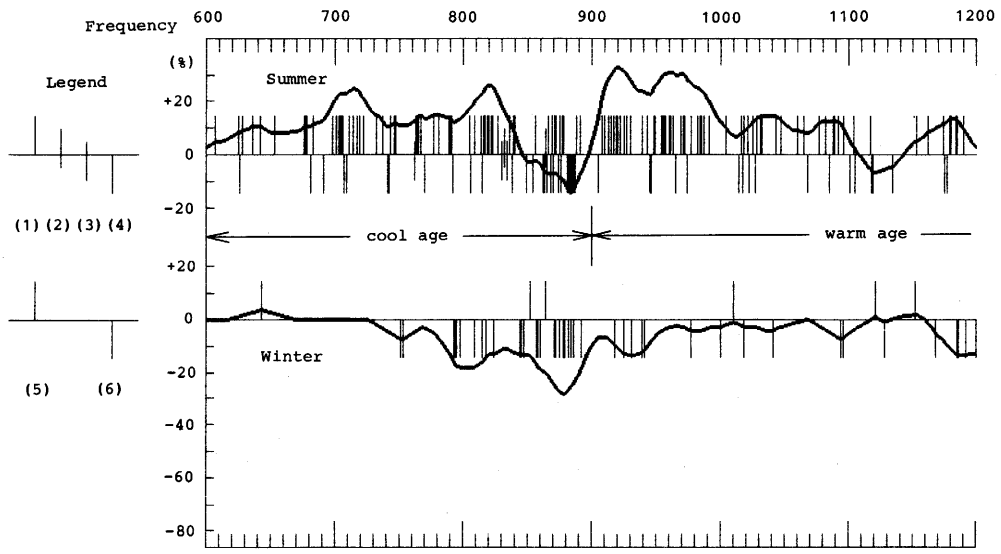

Fig. 2-a Weather type of each year and change of its frequency through histrical times in Japan (601-1900).
Vertical line shows appearance of following type : (1)hot summer (2) west cool-north hot summer (3) north cool-west hot summer (4) cool summer (5) mild winter (6) cold winter.

Next, weather distribution type is set up. As mentioned above, weather conditions in each season are shown in the climatic hazard distribution. They correspond to the synoptic pressure pattern. As both seasons of summer and winter are significant from the view point of climatic change, climatic hazard distribution type for summer and winter are set up.

According to the principal component analysis of temperature, summer weather types in Japan are as follows: (a) hot all over Japan, (b) cool all over Japan, (c) cool in northern Japan, hot in western Japan, (d) cool in western Japan, hot in northern Japan (Mikami, 1975). According to the macro-scale airflow pattern, summer weather patterns are as follows: (a) hot and little rain all over Japan, (b) cool and much rain all over Japan (Tagami, 1985). These results correspond well with each other. Based on these studies, summer weather types may be determined:

(1) Hot summer: Droughts occur all over Japan (Fig. 1-a).
(2) West cool - north hot summer: Long rains appear in southwest Japan, while there are drought in northwest Japan.
(3) North cool - west hot summer: It is cool only on the Pacific coast of Tohoku District, while drought occurs in southwest Japan.
(4) Cool summer: Long rain and low temperature appear all over Japan (Fig. 1-b).

According to macro-scale airflow patterns, winter weather patterns are as follows: (a) cold and much rain (or snow) on the Japan Sea coast, and (b) cold and much rain (snow) on the Pacific coast (Tagami, 1985). Based on these patterns, winter weather type

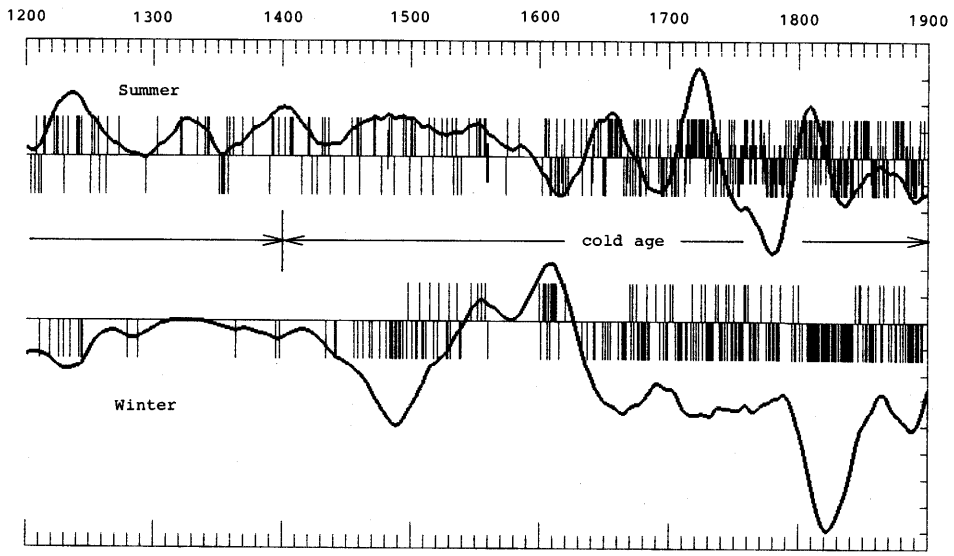

Fig. 2-b Continued

Curved line shows change of weather type frequency (weighted runing mean for 51 years).

They are obtained by following coefficients: type (1) and (2) are +1, type (3) and (4) are −1 in summer while type (5) is +1, type (6) is −1 in winter.

may be determined as follows:

(5) Mild winter: Little rain (or snow) on Japan Sea coast. Warm, unusual flowering in large area (Fig. 1-c).

(6) Cold winter: Heavy snow on the Japan Sea coast. Severe cold, freezing on both the Japan Sea coast and the Pacific coast (Fig. 1-d).

Then, summer and winter weather patterns are discriminated by the types above. If data are so few or show abnormal distribution, weather pattern is not decided. It is not certain, whether the year without climatic hazard means lack of description or ordinal weather conditions.

Results

Severe weather patterns were discriminated by centuries (Table 1). The number of patterns frequency increases toward recent times. Hot summer appears more frequently than cool summer. Cold winter appears more frequently than mild winter. Frequency of each type for several ten years shows clearly the climatic change (Fig. 2). In many studies of climatic change of Japan, because of the limitation of data, it has been usually analysed only for summer or for winter. It is said that the climates for summer and winter change in the opposite direction (Yamamoto, 1967a, 1967b, 1970b, 1971a). Hot summer appears with cold winter and cool summer appears with mild winter in most periods in this result. From this it is said that the summers were relatively cool from the 7th to the 9th century, hot from the 10th to the 14th century and cool from the 15th to the 19th century, and the winters were relatively cold from the 7th to the 9th century, mild from the 10th to the 14th century and cold again since the 15th century.

3. Discussions of Climatic Change in Japan

Cool Age (7c - 9c)

In summer, relatively hot conditions had continued in the 7th and the 8th centuries. Cool conditions appeared for a while in the late 9th century. On the other hand, in winter the climate is uncertain in the 7th century, because the records of weather hazard are few. The climate became cold gradually since the 8th century, reached the coldest climax in the late 9th century (Fig. 2).

Past temperature for 7600 years was estimated by pollen analysis in Ozegahara in the northern Kanto District (Sakaguchi, 1982, 1983). From this, the climatic period in

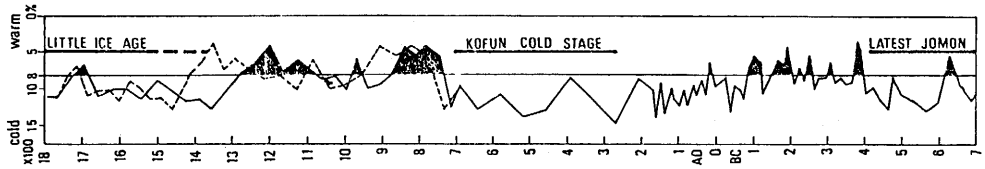

Fig. 3 Paleo-temperature curve of Ozegahara (after Sakaguchi, 1983)
Broken line: curve based on the opinion that the age of Asama B is AD 1281.

historical times can be extracted as follows (Fig. 3).

AD 240 - AD 732 —— cold —— Kofun cold stage
AD 732 - AD 1296 —— warm —— Nara-Heian-Kamakura warm stage
AD 1296 - AD 1900 —— cold —— Little Ice Age

It is shown that climatic conditions turned from cold to warm around 732 A.D.(Fig. 3). However, winter conditions have been cold until the 9th century (Fig. 2). The stage begin 250 years earlier than this study. Nevertheless, it is clear that the climate switched off around the 8th or the 9th century.

Around the early 8th century, historical materials were analyzed by another interesting method. Many poems which express cherry blossoms are in "*Manyoshu*" (first anthology of Japanese short poem). If the poem is added to the letter, the date of cherry blooming and the area are known. Five examples were obtained (Table 2). The date of blooming was compared with that of present in each area. The average date of the five cases was 2.4 days later than present. As a result, it was estimated that climatic conditions in the early 8th century is the same or somewhat cooler than present (Yamamoto, 1976). This result coincides with the winter conditions obtained in this study, as the cherry blooming is affected by temperature conditions of preceding winter.

Table 2 Condition of cherry-blooming in Manyo Era (after Yamamoto, 1976)

year	progress of full bloom date	
706	late	(+8 days)
747	relatively late	(+2 days)
748	late	(+5 days)
750	relatively late	(+1 day)
755	early	(−4 days)

Warm Age (10c - 14c)

In this age warm conditions had continued in summer. At the beginning of this period, climatic conditions turned quickly from cold to warm. It was warm in the 11th century, but, warm conditions were interrupted four times between the 12th century and the 14th century, with the pronounced interruption in the early 12th century. In winter, cold conditions of the preceding age had continued until the early 10th century. Cold winter hardly occurred from the late 10th century to the early 12th century, while it frequently appeared from the late 12th century to 13th century. Then it did not appear again in the 14th century (Fig. 2).

Using Yakusugi cedar of Yakushima Island to the south of Kyushu, temperature change was estimated during this age, too. The date was determined by annual ring and temperature was determined by ratio of oxygen and deuterium isotope ($^{18}O/^{16}O$) (Libby, 1983). The results show that it was cold in the 10th century and the temperature reached to its maximum in the 11th century, and relatively warm period had continued from the 12th century to the 14th century. The climate, however, became cold quickly in the 15th century. Furthermore, cold conditions had continued except the early 17th century. These

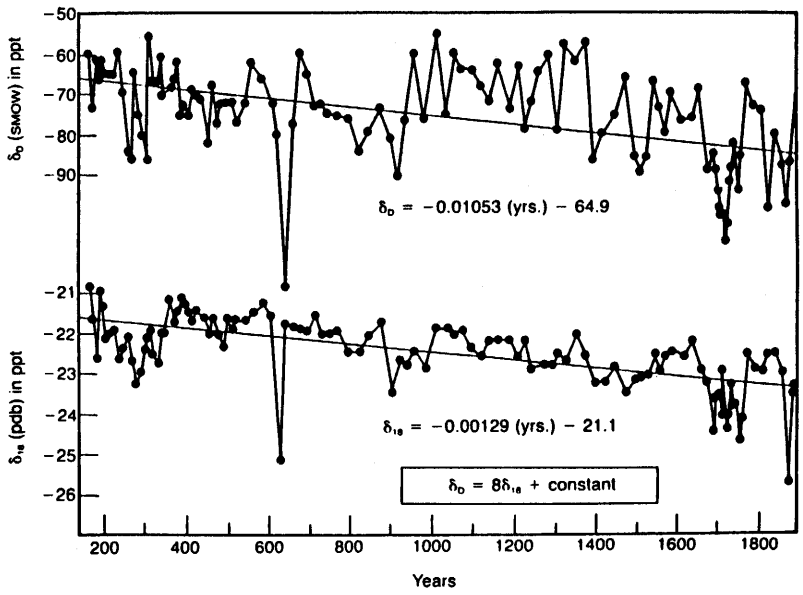

Fig. 4 Deuterium and oxygen isotope ratios in a *Cryptomeria japonica* from Yaku Island, Japan, 160 to 1900. The drawn fits are phenomenological. The slopes are determined by computerized least squares fits to the measured points. (after Libby, 1983).

results coincide with those obtained in this study, especially those for winter (Fig. 4).

By using old diaries, the reconstruction of climate in this age was attempted. Many old diaries describes daily weather and date of cherry blooming. From this, snow ratio, ratio of snowy days and days with precipitation were examined. Averaging the snow ratio of six diaries for Kyoto, it is 23.1% in the period from 982 to 1200 (Table 3). This value is lesser than that of the 15th and 16th centuries (32.8%). It shows that this age was relatively warm condition (Yamamoto, 1967b, 1976, 1978). This result coincides with the winter conditions in this study. In particular, it supports that mild winter had continued for 200 years from the late 10th to the early 12th century.

Among climatic hazards, ratio of drought was high in Ancient Ages and Middle Ages,

Table 3 Snow ratio from diaries in Heian Era (after Yamamoto, 1976)

diary	snow ratio	year
Shoyuki	0.211	982-1024
Midokanpakuki	0.219	999-1021
Gonijomoromichiki	0.301	1083-1096
Chuyuki	0.241	1087-1138
Tenreki	0.201	1097-1117
Gyokuyo	0.214	1167-1200
average	0.231	(982-1200)

while it became low in recent ages. The decrease of ratio has been explained from the development of irrigation system and northward advance of rice cultivation area since the 13th century. But, the transition from cold age to warm age in the 10th century can not be explained from these social regime. It rather shows that there was a climatic change.

Cold Age (15c - 19c)

In summer it was relatively warm in the 15th and 16th centuries. After that, it became cool, five considerably cool periods appeared toward the 19th century. These periods are centered around 1610, 1690, 1780, 1830, 1890. Among these periods, there were relatively hot periods, one of which is marked around 1720. On the other hand, in winter it became cold since the early 15th century. The first cold bottom appeared around 1490. For a while, it was mild from the late 16th century to the early 17th century, with a warm climax around 1610. It had been cold continuously since the late 17th century. In this period, extreme cold appeared four times. Especially, it reached the cold culmination around 1820 (Fig. 2).

In the diary of Sanetaka Sanjonishi who was a court noble lived in Kyoto early in this age, daily weather was described from 1474 to 1533. Frequency of snowy day, the earliest and the latest date of snowfall and so on was examined based on this diary. The results indicate that from the late 15th century to the early 16th century, it was cold and humid in Japan like in Europe (Maejima, 1966). Also from old diary, snow ratio is obtained (Yamamoto, 1970a, 1971b, 1976). Average snow ratio of seven diaries of Kyoto from 1416 to 1600 amounts to 32.8% (Table 4). This value is greater than that from the 10th century to the 12th century (Table 3). It shows that this period was relatively cold. These results corresponds to those for winter in this study (Fig. 2). That is, in winter, temperature began to decrease in the 15th century and it reached to the cold culmination in the early 16th century, with an interruption in the late 16th century.

The Little Ice Age is the coldest period not only in historical times but also through the post-glacial age, which fully developed in the 17th century. There is a long-continued diary records from 1661 to 1866 at Hirosaki, northern Honshu. Based on the description of this diary, the climate was reconstructed precisely (Maejima, 1984; Maejima,

Table 4 Snow ratio from diaries in Muromachi Era (after Yamamoto, 1978)

diary	Snow ratio	year
Kanmongyoki	0.432	1416-1444
Yasutomiki	0.360	1442-1446
Shinchokyoki	0.305	1470-1498
Gohokoinki	0.335	1466-1405
Sanetakakoki	0.305	1474-1533
Nobutsugukyoki	0.313	1544-1571
Nobutsunekyoki	0.276	1584-1600
average	0.328	(1416-1600)

Nogami, Oka and Tagami, 1983; Maejima and Tagami, 1983a, 1983b) In those studies, the frequency of precipitation was set up, eleven year running mean curve of them were drawn, and climatic regime in the Little Ice Age was clarified (Fig. 5). Furthermore, temperature was estimated based on the frequency of precipitation. The Little Ice Age was divided into five periods statistically, and the climatic conditions were clarified (Table 5). There were three extremely cold periods and two interruptions. Among them, the third period was the coldest. These characteristics correspond to the results in this study, especially for winter. However, there are some differences between the reconstructed summer conditions in Japan and those of Hirosaki. Its causes may be attributed to the location of Hirosaki situated in northern most Honshu. In Japan

Table 5 Pattern of the Little Ice Age in Japan (after Maejima and Tagami, 1983b)

period	climatic condition	
1611-1650	very cold	Little Ice Age, Phase I
1651-1690	mild	Interglacial I
1691-1720	very cold	Little Ice Age, Phase II
1721-1740	cold	
1741-1780	mild	Interglacial II
1781-1820	cold	Little Ice Age, Phase III
1821-1850	very cold	
1851-1880	cold	

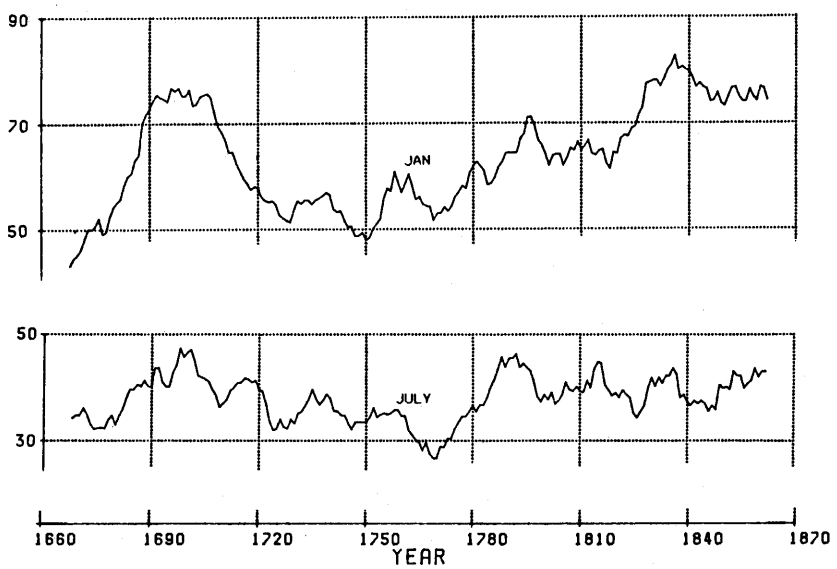

Fig. 5 Year-to-year fluctuation of monthly precipitation frequency at Hirosaki for July to December (eleven year running mean) (Maejima and Tagami, 1983b).

occurred three "Great Famines" in the Little Ice Age: "*Genroku* Famines"(1695-1696), "*Tenmei* Famines"(1782-1787) and "*Tempo* Famines"(1833-1839) (Nakajima, 1981). Thus, the summer weather conditions and the crop failures are closely related in this age.

Above-mentioned past temperature derived from pollen analysis of Ozegahara shows the warm epoch at AD 1700±30 (Fig. 3). The marked interruption of cold conditions in Little Ice Age is called "*Genroku* warm epoch" (Sakaguchi, 1983). Considering the measurement error, this warm epoch may correspond to the hot summer climax around 1720 in this study. This interruption of summer cool conditions in the early 18th century is an exceptionally warm epoch in the Little Ice Age.

4. Concluding Remarks

In this study, climatic change in historical times in Japan was clarified. The charts of climatic hazard distribution were drawn for each season from the 7th to the 19th century. Then, summer and winter weather conditions were classified into the following types: hot summer, west hot - north cool summer, west cool - north hot summer, cool summer, mild winter, cold winter. The weather pattern for individual summer and winter is discriminated by means of these types. And, according to the occurrence frequency of each type during historical times, the historical climatic change was indicated. Main results are as follows.

(1) Concerning the climatic change, the historical times in Japan are divided into the cool age from the 7th century to the 9th century, warm age from the 10th century to the 14th century and the cold age from the 15th century to the 19th century.

(2) In each age, there are some typical periods. Especially, remarkable periods are as follows: cold winter in the 9th century, hot summer in the 10th century, hot summer in the early 18th century and the cold winter in the early 19th century.

(3) In the Little Ice Age the climate for summer varied reversedly to that for winter.

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(* in Japanese, ** in Japanese with English abstract)