On the Nature of the Climatic Change in Japan Since the "Little Ice Age" Around 1800 A.D.

By Takeo Yamamoto

*Dept. of Education, Yamaguchi University
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Abstract

Through an investigation of various historical records on climate written from the beginning of the XVII to the end of the XIX century, it is tried to connect the climatic change in the recent instrumental observation age to that of the historical times in Japan. It is concluded that the Japanese climate passed through a "little ice age" around 1750 to 1850. The mean January air temperature in the first half of the XIX century and the mean July air temperature from 1751 to 1850 are estimated as 1° – 2° C lower than the present normal and the summer climate is concluded to have been pluvial, judging from the frequency of flood occurrences and their unprecedented scale. On the basis of the data of recent meteorological observations, it is concluded that the "little ice age" was caused by the weakening of the subtropical high and the southward retreat of the climatic zone.

1. Introduction

The climate of Japan is chiefly influenced by the Far East monsoon in winter and summer. The cold air current originating in the Siberian High causes the winter air temperature to fall in the middle and the south-western parts of Japan and brings much snow in the districts along the Japan Sea. The summer air temperature in the north-eastern part of Japan, on the other hand, rises due to the invasion of the summer monsoon from lower latitudes revolving along the rim of the North Pacific High.

The decade means of December, January and February air temperatures averaged at Kagoshima ($31^{\circ}34'N$ $130^{\circ}33'E$), Sakai ($35^{\circ}33'N$ $133^{\circ}14'E$) and Wakayama ($34^{\circ}14'N$ $135^{\circ}10'E$) change in parallel, though the sign is opposite as seen in Fig. 1, with those of June, July and August temperatures averaged at Niigata ($37^{\circ}55'N$ $139^{\circ}03'E$), Miyako ($39^{\circ}39'N$ $141^{\circ}58'E$) and Hakodate ($41^{\circ}49'N$ $140^{\circ}45'E$) during the period since the countrywide instrumental observations started in Japan.

Through the rhythmic change of the decade means mentioned above, a rising trend of air temperature with longer periods is observed in winter and in summer, that is, at the rate

of $0.41^{\circ}C/century$ for the eight decade means in winter* and $0.95^{\circ}C/century$ in summer.

As seen in Fig. 1, the rising trend of summer air temperature in Japan seems to have attained its summit in the neighborhood of 1918–1927 or 1938–47, consistent with the world-wide temperature patterns in recent years. In the case of winter in Fig. 1, however, the rising trend does not seem to have come to an end, which suggests a phase lag of twenty years or so between winter and summer situations. It must be noticed that the longer-period trend of air temperature shows the same rising direction in winter and summer, whereas their decade means change in opposite directions.

The same relation can be observed in the case of January precipitation in the districts along the Japan Sea and that on the Pacific side. As will be shown later in Fig. 6, the total of the amounts of January precipitation at Kanazawa ($36^{\circ}33'N$ $136^{\circ}39'E$), Fushiki ($36^{\circ}47'N$ $137^{\circ}03'E$) and Fukui ($36^{\circ}03'N$ $136^{\circ}14'E$), and that of Hachijo-jima ($33^{\circ}06'N$ $139^{\circ}47'E$) indicate the same increasing secular

*Note: The rate of Dec., Jan. & Feb. air temperature rise at Wakayama is $+1.2^{\circ}C/century$ for the nine decade means from 1880–89 to 1960–69.

Fig. 1. Change of decadal means of winter (D.J.F.) air temperatures in south-western part of Japan and of summer (J.J.A.) air temperatures in north-eastern part of Japan. upper...Dec., Jan., Feb. air temperatures averaged at Kagoshima, Sakai and Wakayama. lower...June, July, Aug. air temperatures averaged at Niigata, Miyako and Hakodate.

trend, though the two curves of ten-year running means of January precipitation on the Japan Sea side and on the Pacific side change in parallel with opposite signs.

These facts lead to the conclusion that the causes of the change in the general circulation which produces the longer-period change in the Japanese climate through centuries must be sought for outside of the Far East monsoon, which is considered to be responsible for the regulation of the rhythm found in the decade means of various climatic factors in Japan, such as winter and summer temperature, and winter precipitations on the Japan Sea side and the Pacific side. (Fig. 1 and Fig. 6)

The Japanese historical documents used in this paper are

"Inpu-Nenpyo" (The chronicle of Inaba

feudal clan)

"Setsu-Yo-Kikan" (The wonders of Settsu-Province)

"Buko-Nenpyo" (The chronicle of Edo)

"Ishikawa-Ken-Saiishi" (The records of natural calamities and unusual weather in Ishikawa-Pref.)

"Shiga-Ken-Saiishi" (The records of natural calamities and unusual weather in Shiga-Pref.)

"Iwate-Ken-Saii-Nenpyo" (The chronicle of natural calamities and unusual weather in Iwate-Pref.)

2. The climate in winters around 1800

Ishikawa Prefecture and its vicinity faces the Japan Sea on the west and north with a background of high mountains and is one of the most snowy districts in Japan. The climatic data for Kanazawa, a city at the center of this district, are as follows.

Table 1. Snow at Kanazawa in the period from 1889 to 1960.

	Dec.	Jan.	Feb.	Mar.
Number of snowy days	8.8	19.5	14.0	8.6
Depth of snow cover(cm)	9.3	22.0	21.4	9.6
The record of max. depth of snow cover(cm)	143 (1917)	180 (1940)	167 (1927)	115 (1893)

This district was governed by a feudal lord, the Maeda family, from 1583 to the beginning of the Meiji Era and abundant historical documents on the weather and climate have been well preserved. "Ishikawa-Ken-Saiishi", compiled by the Ishikawa Prefectural Office and the Kanazawa Local Meteorology Office, utilizing the above-mentioned documents, and published in 1961, gives a series of trustworthy records on heavy-snow years and light-snow years. The curve (A) in Fig. 2, which is based upon "Ishikawa-Ken-Saiishi", represents the difference between the number of heavy-snow years and that of light-snow years. The last part of this curve shows a relatively nice agreement with the change of winter temperatures which was shown in Fig. 1. The curve (B) represents the change of the number of decadal totals of heavy-snow years in "Shiga-Ken-Saiishi". The curve (C) was constructed to represent the change of winter severity, based upon the records in "Inpu

Fig. 2. Various curves of decade-by-decade difference between the number of severe winters and that of mild winters.

- [A] (heavy - snow years — light - snow years) at Kanazawa.
 [B] decade totals of heavy-snow years in Shiga Pref.
 [C] (heavy-snow years + severe cold winters) — (light-snow years + extraordinarily warm winters) at Tottori.
 [D] 5-year mean curve of the sea level observed at Amsterdam Tide Gauge (Veen).

↑.....successive occurrences of extraordinary cold winters.

Nenpyo", in which the difference of [the number of (heavy-snow years and severe cold winter) minus the number of (light-snow years and extraordinarily warm winters)] is taken as a measure of the winter severity.

On comparing the curve (A) with curve (B) and (C), it is concluded that the period of worst winter climate occurred in the first half of the XIX century. Furthermore, as seen

in the curve (D) in Fig. 2, the extraordinarily cold winters, as listed in Table 2, occurred successively in Japan at the beginning of the XIX century, corresponding to the trough part of the five-year mean curve of the sea level at Amsterdam Tide Gauge presented by Van Veen.

Table 2. Records of freezing of the rivers and lakes in the Kanto, Kinki and Sanin districts in the XVIII and XIX centuries.

1775	Freezing of the River Ryogoku ("Ushiromi-Gusa")
1813	Freezing of the River Yodo ("Setsuyo-Kikan")
	Freezing of the River Ryogoku ("Buko-Nenpyo")
	Freezing of Lake Koyama and the sea-shore neighbouring Yonago (35°26'N 133°21'E) ("Inpu-Nenpyo")
1820	Lake Koyama was packed with ice about 30 cm thick ("Inpu-Nenpyo")
1822	Freezing of the River Yodo ("Setsuyo-Kikan")
1824	Freezing of the River Yodo ("Setsuyo-Kikan")
	Severest cold and snow cover of about 1 meter at Tottori (35°31'N 130°11'E) ("Inpu-Nenpyo")
1881	The sand banks in the River Sumida were fringed by about 3 cm thick ice ("Meiji-Chronicle")

The River Yodo rises from Lake Biwa, the largest lake in Japan, and flows through Osaka-City (34°39'N 135°32'E) into Osaka Bay. The freezing of rivers on the level land in the Osaka district is unthinkable at the present day.

However, Lake Biwa, though rarely, freezes partially along the shore over a large area, for instance on Feb. 3 (1936), Jan. 24 (1963) and Jan. 17 (1967).

The normal January air temperature at Hikone (35°10'N 136°15'E 88.5 m), which is situated on the coast of Lake Biwa, is

$\bar{\theta}=2.9^{\circ}\text{C}$ (1894–1966, $n=73$), being 1.3°C lower than that of Osaka, for which

$\bar{\theta}=4.2^{\circ}\text{C}$ (1883–1966, $n=84$)

It is not so unreasonable to deduce that the climate of Osaka in the first half of the XIX century, which was cold enough to freeze the River Yodo, was similar to the present climate of Hikone, that is to say, the normal January

air temperature at Osaka at that time was at least 1.3°C or so lower than that at present. On examining the actual cases, it is known that a succession of over twenty uncommonly cold days before freezing, which is long enough to lower the monthly mean temperature, is necessary for Lake Biwa to freeze. The monthly mean of January air temperature of 1936 and 1963, when Lake Biwa froze respectively on Feb. 3 and on Jan. 24, was 1.0°C and 0.6°C.

The probability equations which give the frequency of the monthly mean air temperatures in January are

$$f_1(x) = \frac{1}{1.46\sqrt{\pi}} e^{-(x-4.2)^2/2.14} \quad \text{at Osaka}$$

$$f_2(x) = \frac{1}{1.59\sqrt{\pi}} e^{-(x-2.9)^2/2.52} \quad \text{at Hikone}$$

Following the above equations, the probabilities of the monthly mean air temperatures in January being lower than 1°C are calculated:

$$P_1 = \frac{1}{1053} \quad \text{at Osaka}$$

$$P_2 = \frac{1}{22} \quad \text{at Hikone}$$

Now, P_1 is too small to explain the possibility of three freezings of the River Yodo in the half century.

Therefore, in order to raise P_1 from 1/1053 to 3/50, the normal of monthly mean air temperature in January at Osaka is assumed be lower than present one by $\Delta x = 1.6^\circ\text{C}$ which is computed as follows:

$$\frac{1}{2} \left\{ 1 - \frac{2}{\sqrt{\pi}} \int_0^{1.7} e^{-t^2} dt \right\} = \frac{3}{50}$$

$$\frac{2}{\sqrt{\pi}} \int_0^{1.7} e^{-t^2} dt = \frac{44}{50} = 0.88$$

$$\tau = \frac{(4.2 - \Delta x) - 1.0}{1.46} = 1.124$$

$$3.2 - \Delta x = 1.6$$

$$\therefore \Delta x = 1.6^\circ\text{C}$$

The value of 1.6°C, though it is a rough estimation, is comparable with the difference of mean January air temperatures in Central England between the cold epoch of 80 years from 1776 to 1849 and the more recent 80

years from 1870 to 1949, which is obtained in reference to the investigation of G. Manley as shown in the following.

$$1770-1849 \quad \bar{\theta} = 2.5^\circ\text{C}$$

$$1870-1949 \quad \bar{\theta} = 3.8^\circ\text{C}$$

$$\text{diff. } -1.3^\circ\text{C}$$

3. The climate of summers during the period from the latter half of the XVII century to the first half of the XIX century

Iwate Prefecture is situated in the north-eastern part of the Main Island of Japan, and was governed, with adjoining regions, continuously by a feudal lord, the Nanbu family, from the year 1599.

The number of years of famines, of floods, and of long-continued rains in Iwate Prefecture, which are counted up in historical chronicles, are illustrated for every 50 years during the 300 years from 1601 to 1900 in Fig. 3(A), in which it is seen that maximums of the three curves coincide in the 1751-1850 period, being in accord with the twenty-year mean curve of freezing time (weeks/year) in the coast of Iceland, which was published by H. H. Lamb. (Fig. 3(B)) Among the disastrous famines of 1695, 1755, 1783 and 1838, which are called the biggest four of the many bad harvests in the history of the Nanbu Clan, the latter three occurred in the period from 1751 to 1850, being simultaneous with the period of the famous country-wide famine groups of Tenmei (1782-1787) and of Tenpo (1833-1839). "The Structure of Population in the Recent Times of Japan"* compiled by Prof. Naotaro Sekiyama, as seen in Fig. 3(A)(d), also shows that the population in the Tohoku district** touched bottom in the 1751-1850 period.

The curves based upon the data of historical records are apt to be deceptive from lack of evenness of the records in the chronicles. However, it may be said that the agreement of the climatic curve with the population curve in Fig. 3 proves the reality of the changing pattern. The chronicle of Iwata Prefecture says that the summer of 1775 was so cool that the

*Written in Japanese and published by Yoshikawa-Kobun Kan (Tokyo) in 1958.

**Totals of populations of Iwaki, Iwashiro, Rikuzen, Rikuchu, and Mutsu provinces.

Fig. 3. Secular Change of Summer Climate in Japan and Europe.

(A) Secular change of summer climate in Tohoku District.

(a) number of years (in every 50 years) of great famines, lesser famines and poor harvests.

(b) number of floods.

(c) number of long-continued rains.

[(a, b, c, in Iwate Pref.]

(d) populations of Iwaki, Iwashiro, Rikuzen, Rikuchu and Mutsu provinces.

(B) Duration of Iceland Ice (H.H. Lamb).

Polar Ice at the coast of Iceland. weeks/year.

snow cover on Mt. Kurakake (897 M.S.L.) remained throughout the year and the first snow fell over the remaining snow on the 2nd or 3rd of October in the same year. Mt. Kurakake belongs to the mountain system of Mt. Iwate (2041 M.S.L.) and we have a meteorological observatory at present on a branch of the mountain system, at a height of 1771 m.

The date of disappearance of snow and the summer monthly mean air temperature observed at the Iwate-Yama meteorological observatory are as follows:

Table 3. Snow disappearance date and monthly mean air temperature in summer season at the Iwate-Yama Weather Station.

	Snow disappearance date	Monthly mean temperature			
		July	June	July	August
1936	11	9.3	11.7	13.2	
1937	20	7.6	14.3	14.8	
1938	18	7.9	13.7	15.0	
1939	15	8.6	14.6	14.0	
1940	15	8.1	13.4	12.9	

Average July 16 8.3°C 13.5°C 14.0°C

The relation of the date of disappearance of remaining snow with the air temperature is not so simple, for the date is also influenced by the amount of snow accumulated during the preceding winter and other climatic factors. However, with reference to the above table, it is possible to infer that the summer monthly mean air temperature of the year when the snows remained on Mt. Kurakake throughout the year did not exceed 14°C. The monthly mean air temperatures of July and August at Mt. Kurakake for the period from 1936 to 1940 are estimated, respectively, to be 18.2°C and 18.6°C, by utilizing the data* of the Iwate-Yama observatory (1771 m) and the Morioka Weather Station (39°42'N 141°10' 155 m).

If the summer air temperature of the year

*Mean temperature at Iwate-Yama and Morioka for the period of 1936-40:

place/month	July	August
Iwate-Yama	13.5°C	14.0°C
Morioka	22.1°C	22.6°C

when the snows on Mt. Kurakake remain over is estimated to be below 14°C , the monthly mean temperature of July and August in 1755 are estimated to have been respectively at least 4.2°C and 4.6°C lower than the average of 1936–1940.

Another estimate of the summer air temperature in 1755 can be derived from the loss in percentage of the rice crop in that year, for, as is well known, the rice harvest in the north-eastern part of Japan is much affected by summer air temperature. By using the data of the six years 1889, 1894, 1897, 1901, 1902 and 1904 in the early period of Meiji, when the agricultural technique is not supposed to have been at a high level, the regression equation of the percentage of the deviation of rice harvest in Iwate Prefecture (P) with the average of monthly mean air temperature of July and August at Miyako ($39^{\circ}39'\text{N } 141^{\circ}58'\text{E}$) (θ) is obtained,

$$P = 19.2(\theta - 20.5).$$

The loss-ratio of the rice harvest in 1755 is computed to be 80.5%, referring to the description** in the above-mentioned historical chronicle. And we have the estimate that the summer air temperature in 1755 at Miyako must have been 4.2°C lower than the average of the six years, by putting $P = -80.5\%$ into the above equation.

The probability equation which gives the frequency of the average of monthly mean air temperatures in July and August at Miyako is

$$f(x) = \frac{1}{1.84\sqrt{\pi}} e^{-(x-20.3)^2/3.39} \quad (1883-1966 \text{ } n=84)$$

In order to raise the probability of the occurrence of the deviation $\leq -4.2^{\circ}\text{C}$ to 3/100 (three occurrences in the 100 years from 1751 to 1850), the normal of summer air temperature at that time must be lower than that of the present day, as seen in the following computation:

$$P = \frac{1}{2} \left\{ 1 - \frac{2}{\sqrt{\pi}} \int_0^{|t|} e^{-t^2} dt \right\} = \frac{1}{2} (1 - \Phi(t)) = \frac{3}{100}$$

$$\Phi(\tau) = 0.94$$

**The damage in 1755 was recorded as 199700 "koku", one "koku" being 4.96 bushels, while the normal value of the fief yield of Lord Nanbu was estimated at 248000 "koku". The loss-ratio of the rice harvest in 1755 is, therefore, $199700/248000 = 0.805$.

$$\therefore \tau = 1.33$$

$$|\tau| = \frac{4.2 - \Delta x}{1.84} = 1.33$$

$$\Delta x = 1.7^{\circ}\text{C}$$

If this is accepted, the rate of the summer air temperature rising from the cool summer period around 1800 up to the present time from 1883 to 1966 is

$$\frac{\Delta\theta}{\Delta t} = \frac{1.7}{1925-1800} = \frac{1.7}{125} = 1.4^{\circ}\text{C/Century}$$

This result approximately agrees with the rising rate of the average of monthly mean air temperatures in July and August instrumentally observed at Miyako through the period from 1883 to 1966, $\Delta\theta/\Delta t = 1.2^{\circ}\text{C/Century}$. (see Fig. 4) In Fig. 3, we see that the total

Fig. 4. The rising rate of mean July & Aug. air temperature at Miyako during the present meteorological age from 1883 to 1966.

number of floods for every fifty years reached its maximum around 1800 in Iwata Prefecture. The numbers of great floods given for the whole country in "Nihon-Saii-Shi" (The Chronicles of Natural Calamities in Japan), compiled by K. Okajima and published in 1884, are shown in the following table, in which the maximums are also found in the 1751–1800 period.

"Ushiromigusa" (Memoirs on the Events of the World) written by Sugita Genpaku (1733–1817), one of the greatest scholars on Dutch medicine at that time, describes in detail the disastrous flood at Edo (now Tokyo) accompanied by a long spell of heavy rain in 1786.

Table 4. Numbers of floods for every fifty years given in "Nihon-Saii-Shi".

Period	Number of floods
1601-1650	31
1651-1700	34
1701-1750	36
1751-1800	49
1801-1850	30
1851-1900	20*

Note: * Number for 1851-1883.

He said that the flood was far greater than that of 1742 and also the greatest since the first Shogun Tokugawa Ieyasu moved his head-quarter from Mikawa province (now Aichi Pref.) to Edo in 1590.

According to the historical record of Takashima province in Shiga Prefecture, in 1836, it was so cool and rainy in the midsummer and the water level of Lake Biwa was about 10 cm higher than in 1807. Snow fell on October 22* and remained unmelted for long, and the farmers harvested their rice from under the snow. In the same year, 1836, according to the historical chronicle of the Mori clan, which governed the present Yamaguchi Prefecture, the city of Hagi (34°24'N 131°24'E) suffered from a record-breaking flood unknown since 1604, when the Mori clan was ordered by the Shogunate to settle there.

As already reported (Yamamoto, 1962), the summer air temperature at higher levels or at mountain observatories in the central regions of Japan, for instance at Karuizawa (36°20'N 138°36'E 934 m) has a relatively good correlation negatively with the amount of summer precipitations in the district around the Seto Inland Sea in the south-western part of Japan and positively with that of Hokkaido. The following correlation coefficients and regression ratios are given between the average of June and July air temperature at Karuizawa, and the total amount of June and July precipitation around the Seto Inland Sea and in Hokkaido for the 30 years from 1939 to 1968.

The relation indicates that when the North

Table 5. Correlation coefficients and regression ratios of the total amount of June-July precipitation around the Seto Inland Sea and in Hokkaido with the average of June-July air temperature at Karuizawa.

	Correlation coefficient	Regression ratio
precip. around* the Seto Inland Sea	$R = -0.44$	$k = -16.8\%/^{\circ}\text{C}$
precip. in ** Hokkaido	$R = +0.49$	$k = +15.1\%/^{\circ}\text{C}$

* Oita (33°14'N 131°37'E), Hiroshima (34°22'N 132°26'E), Matsuyama (33°50'N 132°37'E), Okayama (34°41'N 133°55'E), Tadotsu 34°16'N 133°45'E).

** Sutttsu (42°47'N 140°14'E), Sapporo (43°03'N 141°20'E), Asahikawa (43°46'N 142°22'E), Haboro (44°22'N 141°42'E).

Pacific High is weak during June and July and the Okhotsk air mass bulges out towards the Main Island of Japan, precipitation is generally scanty in Hokkaido under stable strata of air, and the activity of the front along the Japan Islands, which is formed between the subtropical air mass and the Okhotsk air mass, will be stimulated and bring about much precipitation over the whole of Japan except Hokkaido. The pluvial climate associated with cool summer in the historical times is probably explained in this way.

4. Meteorological considerations

The contemporary correlation coefficients of average air temperatures in the central regions of Japan in December, January and February with the strength of the Far East monsoons, taking the pressure difference

$$\text{Irkutsk} \left(\begin{smallmatrix} 52^{\circ}16'N \\ 104^{\circ}19'E \end{smallmatrix} \right) - \text{Nemuro} \left(\begin{smallmatrix} 43^{\circ}20'N \\ 145^{\circ}35'E \end{smallmatrix} \right)$$

$$\left(\frac{\Delta}{\sigma} - \frac{\Delta'}{\sigma'} \right), *$$

as an index of monsoon intensity, are considerably large and the correlation has been stable during the past 84 years.

Next, as seen in the following table, the sign of the deviations of decadal means of monsoon strength is mostly opposite to that of the deviations of the air temperatures.

It must be emphasized that, as seen in Fig. 5, the seven points of the decadal means of mon-

*The earliest date of snowfall is November 6 at Hikone during our meteorological observation time (1894-1969).

Table 6. Contemporary correlation coefficients of D.J.F. air temperatures with the pressure differences**.

$$\left[\text{Irkutsk-Nemuro} \left(\frac{\Delta}{\sigma} - \frac{\Delta'}{\sigma'} \right) \right]$$

Wakayama	R = -0.76 (1886-'7 ~ 1949-'50 n = 64)	R = -0.70 (1950-'1 ~ 1969-'70 n = 20)
Sakai	R = -0.82 (1886-'7 ~ 1949-'50 n = 64)	R = -0.76 (1950-'1 ~ 1969-'70 n = 20)
Gifu	R = -0.81 (1886-'7 ~ 1949-'50 n = 64)	R = -0.65 (1950-'1 ~ 1996-'70 n = 20)

Table 7. Decadal means of monsoon strength and and D.J.F. air temperatures in the central part of Japan.

D.J.F. Irkutsk Press. (at station level) (mmHg)			D.J.F. Nemuro Press. (at M.S.L.) (mmHg)	D.J.F. press. Diff. between Irkutsk & Nemuro (mmHg)
	Δ	(1.04 Δ)	Δ'	1.04 Δ - Δ' ****
1888-1897	727.35 (-0.33)	-0.34	758.66 (-0.20)	-0.14
1898-1907	727.28 (-0.40)	-0.42	759.38 (+0.52)	-0.94
1908-1917	727.07 (-0.61)	+0.63	759.25 (+0.39)	-1.02
1918-1927	727.86 (+0.18)	+0.19	758.47 (-0.39)	+0.58
1929-1937	728.24 (+0.56)	+0.58	759.45 (+0.59)	-0.01
1938-1947	728.14 (+0.46)	+0.48	757.80 (-1.06)	+1.54
1948-1957	727.81 (+0.13)***	+0.14	759.03 (+0.17)	-0.03
Means	727.68 mmHg		758.86 mmHg	

* $\frac{\Delta}{\sigma}$ = yearly deviation / standard deviation

** Before 1950, the Irkutsk pressure is represented by the station-level pressure. After 1951, the Irkutsk pressure is represented by the mean sea-level pressure.

*** As the station-level pressure at Irkutsk is not available after 1951, the mean sea-level pressure is roughly reduced to the station-level one by the deduction of 46.8 mmHg (Dec.), 47.2 mmHg (Jan.), and 46.7 mmHg (Feb.), the means of the differences of (M.S.L. press. - S.L. press.), averaged for the twenty years of 1921-'30 and 1941-'50.

**** $\sigma = \sqrt{\frac{\sum \Delta^2}{N}} = 1.33$ mmHg at Irkutsk (1886-87-1949-50)

$\sigma' = \sqrt{\frac{\sum \Delta'^2}{N}} = 1.38$ mmHg at Nemuro (1886-87-1949-50)

$\frac{\sigma'}{\sigma} = \frac{1.38}{1.33} = 1.04$

Dec., Jan. & Feb. Air Temperatures in Central Japan

	Wakayama	Sakai	Gifu	Averaged at three places
1888-1897	5.55°C (-0.22)	4.54°C (-0.24)	4.01°C (-0.06)	4.70°C (-0.17)
1898-1907	5.94°C (+0.17)	4.96°C (+0.18)	4.27°C (+0.20)	5.06°C (+0.19)
1908-1917	5.98°C (+0.21)	5.04°C (+0.26)	4.30°C (+0.23)	5.11°C (+0.24)
1918-1927	5.35°C (-0.42)	4.38°C (-0.40)	3.57°C (-0.50)	4.43°C (-0.44)
1928-1937	5.82°C (+0.05)	4.88°C (+0.10)	4.09°C (+0.02)	4.93°C (+0.06)
1938-1947	5.19°C (-0.58)	4.23°C (-0.55)	3.42°C (-0.65)	4.28°C (-0.19)
1948-1957	6.58°C (+0.81)	5.44°C (+0.66)	4.80°C (+0.73)	5.61°C (+0.74)
mean	5.77°C	4.78°C	4.07°C

Fig. 5. Decadal means of monsoon strength and those of winter air temperature in central Japan. upper...Dec. Jan. Meb. press. difference; (1.04 Irkutsk-Nemuro). lower...Dec. Jan. Feb. temp. averaged at Wakayama, Gifu, & Sakai.

soon strength and those of the averaged December, January and February air temperatures in central Japan indicate the same sign of the secular trend of increasing, respectively with the ratio $+2.24 \text{ mmHg/century}$ and $+0.35^\circ\text{C/century}$, notwithstanding that the yearly correlation of monsoon strength with winter temperature in central Japan is significantly negative (Table 6) and the rhythms of the decadal means of monsoon strength and winter temperature change with opposite signs (Fig. 5). This leads us to the conclusion that the secular trend observed in the winter air temperature of Japan must be due to some longer period change in the general circulation other than the change in Far East monsoon strength.

When the winter monsoon is strong, the

north-west winds originating from the cold Siberia prevail over the warm Japan Sea and bring much precipitation to the districts along the Japan Sea, ascending the slopes of the high mountain ranges in the central part of Japan. After passing over the mountains, the air becomes drier while descending and fine weather continues for a long time on the Pacific side. This is the reason why the ten-year running means of totals of January precipitation at

Fig. 6. 10-year running means of Jan. press. at Nemuro, total amount of Jan. precip. at Kanazawa, Fushiki & Fukui, Jan. precip. at Suttsu, Jan. precip. at Hachijo-jima and Jan. precip. at Katsuura. (a)...Jan. press. at Nemuro. (b)...Total amount of Jan. precip. at Kanazawa, Fushiki & Fukui. (c)...Amount of Jan. precip. at Suttsu. (d)...Amount of Jan. precip. at Hachijo-jima. (e)...Amount of Jan. precip. at Katsuura.

Fukui, Kanazawa and Fushiki in the Hokuriku district, and at Suttsu in Hokkaido change opposite to those of the Izu Islands and the Boso Peninsula, both being related, negatively or positively, with the change of January pressure at Nemuro, as seen in Fig. 6. Notwithstanding the opposite relation in the rhythm of the ten-year running means, the curves of January precipitation on the Japan Sea side and on the Pacific side show the same trend of increasing with the ratios shown in the following.

Table 8. Increasing ratios of the amount of precipitation in January on the Japan Sea side and the Pacific side.

The Japan Seaside	
Totals of Fukui, Kanazawa and Fushiki	
...+57.8%/century	
[(1887-1906)-(1960-1969) n=64]	
Suttsu (Hokkaido) ...+31.8%/century	
[(1889-98)-(1960-69) n=72]	
The Pacific side	
Hachijo-jima ...+23.4%/century	
[(1907-16)-(1960-69) n=54]	
Katsuura ...+64.5%/century	
[(1912-21)-(1960-69) n=49]	

The upward trend of January precipitation on the Japan Sea side is explainable by the increasing strength of the monsoon, but this explanation is contradictory with a similar trend of precipitation on the Pacific side. And we face the same problems as in the relation between monsoon strength and winter temperature in the central part of Japan. Thus, another meteorological factor must be introduced to explain the long-period climatic change of January precipitation in Japan.

Mean winter sea-level pressure charts of the northern hemisphere, averaged on the data of December, January and February, have been constructed for the period from 1899-1900 to 1959-1960 with the kind assistance of Mr. T. Tokuda, former chief of the Hagi Weather Station, based on data on the monthly mean M.S.L. pressure charts, the micro-films of which were kindly given to me by the U.S.A. Weather Bureau.

A period of about 60 years, covering all the winters for which the M.S.L. pressure charts are available, is divided into parts, the first half being the period of (1899-1900)~

(1928-29), $n=30$ and the second half being (1929-30)~(1959-60), $n=27$.*

Fig. 7 shows a comparison of the two mean pressure charts averaged for each period, broken lines standing for the first half period and solid lines for the second half. Average pressure gradients increased from the first half to the second half, that is to say, the pressure of the Siberian High increased, while that of the Pacific Low decreased, resulting in intensifying the Far East monsoons, in accord with the result shown in Fig. 5. The decreasing trend of January pressure at Nemuro, illustrated in Fig. 6, can be explained also in connection with the deepening of the Pacific Low as shown in Fig. 7.

Another important fact is that the position of the center of the Siberian High shifted significantly to the northwest (about 3.5° northwards and 5.0° westwards) and that of the Pacific Low appears to have moved to the northwest too, (about 1° northwards and 2° westwards), though it is not as distinct as in the case of the Siberian High. The 1015 mb isobar in the low latitude zone shifted to the north, though it seems to be pushed down southwards in the area from 115°E to 132°E , probably due to the bulge of the intensified Siberian High towards lower latitudes.

It is my opinion that the secular trend of climate, which is observed through the variations in the ten-year means of several climatic factors in winter, for instance, winter temperature and amount of January precipitation in Japan, must be a reflection of the northward shift of the atmospheric climatic zone as seen in Fig. 7. In other words, the meteorological factors which regulate the climatic changes in winter in Japan are mainly two, one being the change of general circulation which causes the long-period (some decades or a hundred years) north-south oscillation of the climatic zone in the Far East and the other being the relatively short-period rhythm in the strength of the Far East monsoon, though the long-period change of the latter is not independent of the former.

The summer air temperature in the middle and northern parts of Japan is influenced by the current of subtropical air revolving around the western edge of the North Pacific High which bulges out towards the Japan Islands. If we take the pressure difference of Choshi and Asahikawa as an index of summer mon-

Fig. 7. Comparison of the two winter (D.J.F.) M.S.L. pressure charts averaged for the period from 1900 to 1929 ($n=30$) and the period from 1930 to 1960 ($n=27$).
 1900-1929 ($n=30$).
 ——— 1930-1960 ($n=27$) (missed: 1940, 1942, 1943, 1944).

soon intensity in July, fairly large correlation coefficients are available between the July pressure differences and July air temperatures in the Kanto District, the Tohoku District and Hokkaido for 80 years period from 1891 to 1970, as seen in the following table.

At the beginning of this paper, I have made a brief mention of the secular change of summer temperatures in the middle and northern Japan in the past about 80 years. The summer climate which had been cool in the early times became hotter, the summer air temperature attained its summit around the period from 1918 to 1947, and the climate has turned cooler for the recent period of about 20 years. (Fig. 1) The whole period of 80 years is divided broadly into three parts, the early period (cooler period), the middle period (hotter period) and the recent period (cooler period), and the correlation coefficients of July air temperature with July monsoon strength are computed for each period. The geographical distributions of the correlation coefficients

Table 9. Correlation coefficients of July air temperature in the Kanto District, the Tohoku District and Hokkaido with July pressure difference of Choshi and Asahikawa.

Station	Correlation Coefficient
Hakodate (Hokkaido)	$R=0.77(1891-1970)$
Aomori (Tohoku District)	$R=0.73(\quad " \quad)$
Miyako (" ")	$R=0.74(\quad " \quad)$
Yamagata (" ")	$R=0.71(\quad " \quad)$
Fukushima (" ")	$R=0.77(\quad " \quad)$
Utsunomiya (Kanto District)	$R=0.71(\quad " \quad)$
Average at 4 stations in the Tohoku District	$R=0.76(\quad " \quad)$
Average at 6 stations	$R=0.74(\quad " \quad)$

change with time, as seen in Table 10(A)(B), in which the pressure difference between Choshi and Asahikawa is used as an index of monsoon strength in Table 10(A) and the pressure difference between Hachijo-jima and

Shikka* (49°13'N 143°06'E) is adopted in Table 10(B). The region of maximum correlation coefficient goes northwards or southwards as the mean air temperatures averaged for each period are hotter or cooler, with exception of the case at Tokyo and Sapporo, where the air temperature may have been

under the strong influence of urban expansion in the recent times.

By using all the northern hemisphere charts on hand, given by the U.S.A. Weather Bureau some years ago, the secular change of July pressure in the central part of the North Pacific High is investigated, though the data

Table 10. Geographical distribution of the correlation coefficients of July air temperature with an index of the summer monsoon strength.

(A) Correlation coefficients of July air temperature with July pressure difference of Choshi and Asahikawa for the periods of (i) 1891-1910 (cooler periods) (ii) 1911-1950 (hotter period) (iii) 1951-1970 (cooler period).

Period & temp. change Station	(i) 1891-1910		(ii) 1911-1950		(iii) 1951-1970		Change of Mean July temp.	
	Correlation coeff.	Mean July temp.	Correlation coeff.	Mean July temp.	Correlation coeff.	Mean July temp.	(ii)-(i)	(iii)-(ii)
Asahikawa (43°46'N 142°22'E)	R=0.33	18.9° C	R=0.58	20.4° C	R=0.45	20.1° C	+1.5° C	-0.3° C
Sapporo (43°03'N 141°20'E)	R=0.38	18.6	R=0.60	19.9	R=0.50	20.1	+1.3	+0.2
Hakodate (41°49'N 140°45'E)	R=0.62	18.4	R=0.70	19.5	R=0.57	19.2	+1.1	-0.3
Aomori (40°49'N 140°47'E)	R=0.66	20.3	R=0.74	21.1	R=0.65	20.8	+0.8	-0.3
Miyako (39°39'N 141°58'E)	R=0.63	19.6	R=0.76	20.7	R=0.70	20.2	+1.1	-0.5
Yamagata (38°15'N 140°10'E)	R=0.65	22.5	R=0.73	23.5	R=0.59	23.1	+1.0	-0.4
Fukushima (37°15'N 140°28'E)	R=0.73	22.5	R=0.78	23.9	R=0.68	23.6	+1.4	-0.3
Utsunomiya (36°33'N 139°52'E)	R=0.74	22.9	R=0.66	23.9	R=0.73	23.6	+1.0	-0.3
Tokyo (35°41'N 139°46'E)	R=0.69	23.7	R=0.64	25.0	R=0.69	25.1	+1.3	+0.1
Hamamatsu (34°42'N 137°43')	R=0.55	24.5	R=0.34	25.0	R=0.64	25.0	+0.5	0.0

(B) Correlation coefficients of July air temperature with July pressure difference of Hachijo-jima and Shikka for the periods of (ii)' 1908-1944 (hotter period) (iii) 1951-1970 (cooler period).

Period & temp. change Station	(ii)' 1908-1944		(iii) 1951-1970		Change of Mean July temp.
	Correlation coeff.	Mean July temp.	Correlation coeff.	Mean July temp.	(iii)-(ii)'
Sapporo	R=0.71	19.6° C	R=0.50	20.1° C	+0.5° C
Suttsu*	R=0.80	18.8	R=0.60	18.6	-0.2
Hakodate	R=0.80	19.4	R=0.62	19.2	-0.2
Aomori	R=0.83	21.0	R=0.66	20.8	-0.2
Miyako	R=0.79	20.6	R=0.73	20.2	-0.4
Yamagata	R=0.69	23.4	R=0.64	23.1	-0.3
Fukushima	R=0.74	23.8	R=0.78	23.6	-0.2
Utsunomiya	R=0.63	23.9	R=0.78	23.6	-0.3
Maebashi	R=0.64	24.5	R=0.79	24.3	-0.2
Tsukubasan*	R=0.62	19.8	R=0.81	19.6	-0.3
Tokyo	R=0.63	24.8	R=0.75	25.1	+0.3
Hamamatsu	R=0.38	25.1	R=0.69	25.0	-0.1

* Suttsu (42°47'N 140°14'E) Tsukubasan (36°13'N 140°06'E)

*The data of Shikka (Poronaysk) in Sakhalin are unavailable for 6 years from 1945 to 1950.

are insufficient to cover the whole period of 80 years. It will be seen in Fig. 8 that the area enclosed by 1026 mb isobar in the central part of the North Pacific High in the mean pressure chart averaged for the period from 1911 to 1950, the hotter period in Japan, is remarkably large compared with those before and after the period, and the center of the North Pacific High is situated moving to the

north-west in comparison to those before and after the period.

The north-south oscillation of the region of maximum correlation in Table 10(A)(B) must be due to the long period north-south movement of the action center of the North Pacific High, and it is concluded that the secular change of the summer climate in Japan is composed of the two parts, as it is in the case of winter climate, one being the rhythmic variation of relatively short period due to the change of the summer monsoon strength and the other being the long period trend (some decades or a hundred years), which is probably caused by the long period north-south oscillations of the center of the North Pacific High.

Fig. 9 illustrates the decadal means of central pressure of the North Pacific High* in July, those of July air temperature in the Tohoku District, averaged at eight stations** as well as at Miyako only, and those of July pressure differences (Hachijo-jima-Shikka)*** and Tokyo-Suttsu.

As seen in Fig. 9, the decadal means of July air temperatures averaged at eight stations in the Tohoku District change in good accordance with those of July pressure differences Hachijo-jima-Shikka and Tokyo-Suttsu. The correspondence of the decadal means of the central pressure of the North Pacific High and those of July air temperature does not seem so good, but a correlation coefficient $R=0.82$ is obtained between them. If we take July air temperature at Miyako, the correlation coefficient is $R=0.77$ and the regression ratio is $\alpha=0.90$ mb/°C.

In the previous section, it was estimated that the normal of the average of monthly mean July and August air temperatures at Miyako during the period from 1751 to 1850 should be about 1.7°C lower than it is at present. If the regression ratio $\alpha=0.90$ mb/°C is used, the mean July central pressure in the North Pacific High in the period from the

Fig. 8. The July pressure distribution in the central part of the North Pacific High.

*Based upon the data in "Secular Variations of the Atmospheric Circulation since 1750" by H. H. Lamb and A. I. Johnson.

**Aomori, Miyako, Akita (39°43'N 140°06'E), Yamagata, Niigata, Ishinomaki (38°26'N 141°18'E), Fukushima, Nagano (36°40'N 138°12'E).

***July pressures at Shikka for the period from 1945 to 1950 are roughly estimated from H. H. Lamb and A. I. Johnson's maps.

Fig. 9. Decadal means of central pressure of the North Pacific High in July, July air temperature averaged at eight points in the Tohoku District and at Miyako, and July press. differences (Hachijo-jima — Shikka) and (Tokyo—Suttsu).

- (a) ... July press. difference (Hachijo-jima—Shikka)
- (b) ... July press. difference (Tokyo—Suttsu)
- (c) ... Central pressure of the North Pacific High in July at Miyako.
- (d) ... July air temp. in the Tohoku district and at Miyako (broken line).

latter half of the XVIII century to the first half of the XIX century should be 1.5 mb lower than it is now. This estimate is comparable with the result obtained by H. H. Lamb that the mean July central pressure of the North Atlantic High in the forty years from 1790 to 1829 is 1 mb lower than the mean in the period from 1900 to 1939, and it is concluded that when the North Atlantic High declines, the North Pacific High weakens as well, and vice versa.

5 Summary

i) In reference to a number of Japanese historical records, it is concluded that the mean air temperature in Japan in the period from the latter half of the XVIII century to the first half of the XIX century was sig-

nificantly lower in winter as well as in summer than it is at present.

ii) The mean January air temperature in the first half of the XIX century and the mean July air temperature in the period from 1751 to 1850 are estimated to have been 1°C–2°C lower than they are at present from considerations of probability based on the fact of the successive occurrences of freezing of the River Yodo, on the records of yearlong snow cover on Mt. Kurakake and of very cool summers which caused heavy famines in the Tohoku District.

iii) The general features of the so-called "Little Ice Age" in Japan may be characterized as follows:

- (1) In winter, sonwy in the districts along the Japan Sea and severely cold over the whole country.
- (2) In summer, cool especially in the northern part of Japan and pluvial over the whole country except Hokkaido.

iv) The meteorological factor which caused the "Little Ice Age" in Japan is concluded to have been the change of the general circulation which causes the southward retreat of the climatic zone in winter and in summer in the Far East and the weakening of the North Pacific High in summer, which seems to have occurred both at the same time and on the same order of magnitude as the weakening of the North Atlantic High.

v) The meteorological observation period in Japan, which started about 80 years ago on a country-wide scale is considered to coincide with the recovery stage from the "Little Ice Age". The climatic change in Japan may be analyzed into two component parts, one being a change with a period of some decades or a hundred years caused by the long-period north-south oscillations of the climatic zone in the Far East and the other being the relatively short-period rhythm due to the change of the intensity of the Far East monsoons in winter and summer.

vi) It seems that the little optimum of the long-period change of the Japanese climate, which is estimated around 1920–9 in summer and 1950–9 in winter, is over and now the climate is probably taking a turn for the worse.

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