Volcanic Eruptions, Cool Summers, and Famines in the Northeastern Part of Japan

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ABSTRACT

During the last 300 years, most of the poor rice harvests caused by unusual cool summers and leading to famine conditions in the Tohoku district (the northeastern part of Japan), took place just after the great volcanic eruptions.

An analysis of instrumental observations in the past century on the Kinkasan Island indicates that, though the standard deviation in the summer air temperature is 1.1°C for 1882–1985, the summer air temperature averages 1.3 ± 0.5°C lower than normal during the summer following the great volcanic eruptions; the mid-latitude mean surface air temperature in the northern hemisphere decreased only about 0.2°C. This result indicates that the summer air temperature in Tohoku district tends to be particularly sensitive to such eruptions. In all the cool summers, a blocking high persisted over the ocean northeast of Japan, and impeded the northward movement of the “Baiu” front (the stagnating polar front during the early summer).

Exceptionally cool summers occurred frequently without great volcanic eruptions during 1931–45. During this period, the sea water temperatures at Tohoku’s coastal stations on the Pacific were lower by 1.5°C, on the average, than those of the subsequent period of 1946–79.

1. Introduction

Poor rice harvests in Japan, leading to famine conditions, have taken place from various causes: droughts, floods, cool summers, and damage from insects. Before the year 1600 in Tohoku district (the northeastern part of Japan), drought was the major cause of damage to rice (Kondo 1985c). During the period after the unification of Japan by the Tokugawa Shogunate in 1600, with long-lasting national peace and no severe domestic war, the effects of droughts and floods were gradually diminished by the river conservation and irrigation projects (Fig. 1).

Figure 1 shows a change of causes of poor harvests in the Tohoku district. Each cause is presented by a ratio to the total occurrence of poor harvest years during each time period. This is obtained from the large number of historical records which are compiled in “Climate of Tohoku” published by Sendai Meteorological Observatory (1951) in which the “poor” harvest year and the “cause” are listed. The number of poor harvests during each time period is 33 (1300–1599), 21 (1600–99), 48 (1700–99), 32 (1800–99), and 12 (1900–80), respectively (Kondo 1985c). These numerals do not show absolute number of “poor” harvests because the sources of historical records are not uniform in each time period.

The last 300 years in the Tohoku district include seven periods with frequent famine/lean years caused by cool summers, at intervals of about 50 years (Kondo 1985b). These periods are 1692–1703, 1747–57, 1783–86, 1833–38, 1902–13, 1931–45 and 1980–83. One of the reasons for frequent famine/lean years is that once a famine has happened it tends to recur due to a labor shortage caused by the death and illness resulting from the previous famine. Another reason is a tendency for cool summers to occur for several years consecutively.

The Tohoku district occupies 18% of the land area of Japan, has 8% of the population, and produces 27% of the rice harvest. The rice harvest is closely related to the summer mean air temperature (Kondo 1985c). A temperature deviation of 1.5°C below normal results in a rice harvest about 30% below normal. In such lean years there is an especially poor harvest in the cooler mountain areas and the coastal region on the Pacific. The term “lean year” is defined in this paper as a year when the total amount of rice harvest in the Tohoku District is smaller than about 80% of the normal year.

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Famine conditions had often happened until the early years of this century. Most of the famines, caused by a widespread damage to the crops due to cool summers in Tohoku, took place after the great volcanic eruptions (Kondo 1985a). The worst two famines in Japanese history, “Tenmei famines” and “Tempoh famines,” brought about the death of 20% of the people in Tohoku. “Tenmei famines” (1783–86) followed a great volcanic eruption on 9 May 1783 of Mt. Asama in central Japan. Ashes fell in Tokyo, 150 km away, lying about 3 cm deep, and they even reached the Tohoku district. In the same year, there was another eruption at Lakagigar, Iceland, in July, which caused the worst famine in Iceland’s history (Wood 1984).

“Tempoh famines” (1835–38) followed a great volcanic eruption on 20 January 1835 at Coseguina, Nicaragua. The famine of 1836 was the worst around the Sendai area during the Tokugawa feudal era. Because instrumental observations in Japan only began late in the nineteenth century, the detailed weather in connection with the “Tempoh famine” was not studied until quite recently. A diary was found a few years ago in the town of Wakuwa near Sendai. This diary contains a full description of the daily weather during the period of Tempoh famines. By analyzing this description I estimated that the summer mean air temperature deviation was 2.8°C below normal. This figure breaks the coolest record in instrumental observations since 1882 (Kondo 1985b). The summer of 1836 in Tohoku was remarkably similar to the famous “year without a summer” in the northeastern part of the United States in 1816 following Tambora’s eruption (Stommel and Stommel 1983). Note that there was no famine in the Tohoku district following Tambora’s eruption.

After instrumental observations started, cool summers, causing widespread rice crop failure, followed the eruptions of Krakatau, Indonesia in 1883; St. Vincent, West Indies, and Santa Maria, Guatemala both in 1902; Novarupta-Katmai, Alaska in 1912; St. Helens, Washington in 1980; and El Chichón, Mexico in 1982.

Instrumental observations over the last 100 years show that, in the Tohoku district, the summer air temperature averaged 1°C–2°C below normal for 1–2 yr following great volcanic eruptions (Kondo 1985d).

Five exceptionally cool summers during 1931–45 occurred without great volcanic eruptions. During this period the sea water temperatures of Tohoku’s coastal stations on the Pacific averaged 1.5°C lower than those of the subsequent period of 1946–79 (Kondo 1987). In all the cool summers, a blocking high persisted over the ocean to the northeast of the Tohoku district, and a “Baiu” front remained around the southern coast of Japan. (“Baiu” front is a stagnating polar front.) In Japan, between spring and summer there is a season of prolonged rainfall, i.e., Baiu season. Baiu is caused by the stagnation of the polar front while it is moving from south to north. After the northward progression
of the Baiu front Japan has its hottest part of the summer, when a rice crop grows quickly.

Much of this article presents a brief overview of papers on this subject [Kondo 1985a,b,c,d; Kondo 1987 (written in Japanese)].

2. A weather diary written by Anretsu Hanai

A weather diary written by Anretsu Hanai was found in the town of Wakuya. (He may have been a high-class vassal of a feudal lord ruling the area around Wakuya.) In the upper part of Fig. 2, a map of Japan is shown; the lower part shows Wakuya; Ishinomaki, where a main weather station is situated; Enoshima Island, where sea water temperatures have been recorded from May 1910; and Kinkasan Island where instrumental weather observations have been conducted since June 1882 at a lighthouse. This is the earliest weather station in the Tohoku district.

Hanai’s diary describes the daily weather: wind strength and direction, degree of heat and cold, intensity of rainfall, snowfall, disasters, and rice crop conditions from November 1833 through 1847. His description is qualitative: for example, describing the wind as “windy,” “strong wind,” “stormy,” “strong storm”; the rain as “light shower,” “light rain,” “the ground is damp with rain,” “strong rain,” etc. Accordingly, we can infer the general weather situation around the Tohoku district each day from his diary, e.g., the day of an approaching typhoon.

Figure 3 shows the daily weather transition for the summer of 1836 (famine year) obtained from Hanai’s diary. The period of 3 months indicated in this figure includes the rice-planting season to the harvest. For comparison, a rich harvest year (1834) and a normal year (1839) are also shown. The closed circle indicates a rainy day excluding light showers. The mean number of rainy days in a normal summer is about 30. In the year of 1836, it was 52! The solid rectangle means a “cool day,” and the horizontal stripes mean a “very hot day.”

We assume a cool day when the sentence “it was cool” or the words “cool air” are found in the diary; and a very hot day when the words “very hot,” “extremely hot,” or the sentences “unable to bear the heat,” or “the hottest temperature in recent years.” The year of 1836 has many “cool days” in June and July and only two “very hot days” in August.

3. A deduction of the air temperatures during Tempoh famine years

Air temperatures during Tempoh famine years were deduced as follows. Using the recent instrument-recorded meteorological data of daily weather concerning wind direction and speed, amount of rainfall, and the air temperature at Ishinomaki Weather Station, we could find a certain relationship between the air temperature and the daily meteorological condition. Applying this relation to Hanai’s diary we are able to assume that, for summer, a “cool day” means a day with the mean air temperature below 18°C, and a “very hot day” means a day with the maximum air temperature above 28°C.

Summers similar to a rich harvest year (1834) and a normal year (1839) are found in 1977–79. For each of these summers, the meteorological data of daily weather, wind speed and direction, amount of rainfall, the highest and the lowest air temperatures, and daily mean air temperature are plotted in a graph. Viewing
year

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1836
(Historical greatest famine)

1834
(Rich rice crop)

1839
(Normal rice crop)

- rainy day (except light shower)
- cool day
- very hot day

FIG. 3. Daily weather transitions obtained from Hanai’s diary for the summers of 1836 (the greatest famine year), 1834 (rich harvest year), and 1839 (normal year).

![Graph showing mean air temperature versus the number of "very hot days" minus that of "cool days".](image)

FIG. 4. The summer (16 June to 15 September) mean air temperature versus the number of “very hot days” minus that of “cool days” based on the instrument observations at Ishinomaki Weather Station. The solid circles are the poor rice crop years in the Tohoku district.

This, we can find an air temperature value for specific weather. For example, for calm winds and fine weather, the daily maximum temperatures are 30°C, 28°C, 33°C, 30°C, etc. (above 28°C). A similar arrangement of figures was made for 2 years in the Tempoh era (1834 and 1839), which consists of daily weather, wind strength and direction, strength of rainfall, degree of heat and cold, and from this we can estimate the probable temperatures for specific weather. For example, for calm winds and fine weather, the terms are “very hot,” “extremely hot,” “unable to bear the heat,” etc. From careful viewing over a long period of these figures, we are able to infer the temperature limits.

These temperature limits, 18°C and 28°C, are supported by another weather diary kept in 1890–1908 by Goro Sengoku in the same town of Wakuya (Mori

![Graph showing temperature deviation versus number of rainy days.](image)

FIG. 5. The summer (16 June to 15 September) mean air temperature deviation versus the number of rainy days. Small circle: instrumentally observed period after 1902; square: period from 1834-41.
1985). Mori compared Sengoku’s diary with the instrument data at the meteorological observatory, and came to the same conclusion as I did.

Applying 18°C and 28°C limits to the instrument data after 1902, a relationship between the observed summer mean-air-temperature and the number of “very hot days” or “cool days” can be obtained. When the number of “very hot days” is larger, or “cool days” is smaller, the summer mean-air-temperature is higher.

In Fig. 4 the ordinate is the observed summer mean-

![Diagram](image-url)

**Fig. 6.** The chronological mean rice production per hectare over Tohoku district after 1835. The large circle is the lean year caused by cool summer, the dashed line is the boundary the year below which is designated to be a famine/lean year.

**Table 1.** List of volcanic eruptions during the last 150 yr. An asterisk in the lowest line indicates the year which was excluded because it coincides with the year of the Bezymianny, Kamchatka, eruption. The VEI is the Volcanic Eruption Index of Simkin et al. (1984), and dvi is the dust veil index of Lamb (1970).

(a) **The Great Volcanic Eruption Occurring North of 10°S**

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<th>VEI</th>
<th>dvi (world)</th>
<th>Date</th>
<th>Summer</th>
<th>Winter</th>
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<td>5</td>
<td>4000</td>
<td>20 Jan 1835</td>
<td>1835</td>
<td>1836</td>
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<td>Hekla, Iceland</td>
<td>4</td>
<td>250</td>
<td>2 Sep 1845</td>
<td>1846</td>
<td>1846</td>
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<tr>
<td>Sheveluch, Kamchatka</td>
<td>5</td>
<td>—</td>
<td>18 Feb 1854</td>
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<td>1855</td>
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<td>Askja, Iceland</td>
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<td>29 Mar 1875</td>
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<td>300</td>
<td>6 May 1902</td>
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<td>Santa Maria, Guatemala</td>
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<td>24 Oct 1902</td>
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(b) **The Volcanic Eruptions Occurring South of 30°S**

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<th>Volcano</th>
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<th>Summer</th>
<th>Winter</th>
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<td>5</td>
<td>400</td>
<td>10 Jun 1886</td>
<td>1886</td>
<td>1887</td>
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<td>100</td>
<td>13 Dec 1921</td>
<td>1922</td>
<td>1923</td>
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<td>Azul Cerro, Chile</td>
<td>6</td>
<td>35</td>
<td>10 Apr 1932</td>
<td>1932</td>
<td>1933</td>
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<tr>
<td>Ranco &amp; Puyehue, Chile</td>
<td>4</td>
<td>20</td>
<td>Jun 1955</td>
<td>1955</td>
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air-temperature (from 16 June to 15 September) at Ishinomaki Weather Station, and the abscissa is the difference between the number of “very hot days” and that of “cool days.” Using this figure, the summer air temperature deviations during the 8-yr period 1834–41 were deduced. The summer air temperature deviation for 1836 was estimated to be 2.8°C below normal. This extremely cool summer led to a rice harvest of only 10% of the normal year, resulting in subsequent famine and economic depression.

A convincing check of the deduced temperatures for 1834–41 is shown in Fig. 5, where a relationship between the summer mean-air-temperature-deviation and the number of rainy days is plotted. The small circles are temperatures measured by instruments and the squares are the deduced temperatures for 1834–41.

4. Cool summers with poor rice harvest

Figure 6 displays the change with time of the mean rice production (per hectare) in the Tohoku district. The 1880s was the period of Japanese industrial and political revolution, and 1955–63 was the economic growth period. During both periods, the rice production rates increased. A year with a rice production rate lower than 80% of the normal was designated as a lean year. The large square and circle indicate those designated lean years. The dashed line is a boundary; the year below it is designated to be a famine/lean year.

Frequent occurrences of famines in 1835–38, 1902–13, and 1931–45 brought about economic and social crises in Japan. Again, the primary cause of famine/lean years is seen to be cool summers (circles). Most of the lean years, including the period 1980–83, followed volcanic eruptions except for those during the period 1931–1945.

5. Air temperature at Kinkasan Island and the mean surface air temperature in the Northern Hemisphere after volcanic eruptions

The following terms are used in this paper: Great volcanic eruption. Volcanic eruptions of VEI ≥ 5, and those of VEI = 4 with dvi > 200 are defined as great volcanic eruptions. Here VEI is the volcanic eruption index of Simkin et al. (1981) and dvi is the dust veil index of Lamb (1970). The great volcanic eruption ejects massive amounts of ashes and gases

![Graph showing air temperature deviations](image)
into the stratosphere. Fourteen great eruptions occurred north of 10°S during the last 150 years, as listed in Table 1a.

Moderate volcanic eruption. Volcanic eruptions of VEI = 4 with dvi \(\leq 200\) are defined as moderate volcanic eruption. It will be shown later that there is no correlation between this class of eruption and the surface air temperature (Fig. 8).

Southern midlatitudinal eruption. Two great and two moderate volcanic eruptions occurred south of 30°S, and are defined as southern midlatitudinal eruptions (Table 1b).

Summer just after eruption. The “summer just after eruption” is the summer of the same year when a volcanic eruption occurred between January and June, or the following summer when a volcanic eruption occurred between July and December. The “next summer” is the summer following “the summer just after eruption.”

No eruption. Several tens of small eruptions of VEI \(= 0\) to \(3\) occur every year. In this paper we call such an ordinary year a year of no eruption.

Air temperature. Instrumental observations were begun at Kinkasan Island in 1882, the first in the whole

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Fig. 8. The summer air temperature deviation at Kinkasan Island vs the summer northern midlatitudinal average air temperature deviation. Upper left: summer just after the great eruption and the next summer; upper right: summer with the southern eruption; bottom left: summer with the moderate eruption; and bottom right: summer with no eruption.
Fig. 9. As in Fig. 7 except for the high-latitude average value (60°-90°N) and the low-latitude average value (0°-30°N).

Fig. 10. A surface weather map for 0000 UTC (0900 JST) 18 July 1980, typical of a cool summer with bad harvest.
Tohoku district. No appreciable change in the natural environment of Kinkasan Island has occurred. The air temperature data at Kinkasan Island will be analyzed. Mean air temperatures of the Northern Hemisphere have been reported by Yamamoto and Hoshiai (1980) (with additional data by Hoshiai 1986, personal communication) in which the 68% confidence limits of the errors are estimated. These estimate error will be shown later in Figs. 7–9.

Climate mean. The climate mean is the mean air temperature for the 74 years from May 1910 to April 1984. May 1910 was the beginning of observations by instrument of the sea water temperature at Enoshima Island. (Enoshima Island has a diameter of 600 m and lies just to the north of Kinkasan Island.) The temperature deviation is the difference from the climate mean.

The summer air temperature deviations at Kinkasan Island and the midlatitudinal summer surface air temperature deviation are shown in Fig. 7. In the lower figure, the deduced values from Hanai’s diary during the Tempoh famine years (1834–41) are also given. Note that each symbol for 1834–41 is the average over the period from 16 June through 15 September.

The large solid circle indicates the value for the summer just after a great volcanic eruption, and the small solid circle the value for the next summer. Clear evidence of cooling which followed volcanic eruptions is seen at Kinkasan Island. Though the standard deviation in the summer air temperature is 1.1°C for 1882–1985, the temperature averages 1.3 ± 0.5°C lower than the normal for the summer just after great volcanic eruptions.

Figure 8 shows the summer air temperature deviation at Kinkasan Island versus the summer northern midlatitudinal average air temperature deviation. A clear correlation is seen for both the summer just after a great eruption and for the next summer (upper left figure); i.e., the summer northern midlatitudinal average air-temperature is indicated to have decreased by about 0.2°C, while the summer air temperature deviation of Kinkasan Island by about 2°C. (Note that the abscissa scale is magnified.)

For southern midlatitudinal eruptions, however, a
clear correlation is not seen (upper right figure), but rather, slight evidence of warming at Kinkasan Island. Since the number of southern midlatitudinal eruptions is small, this requires a further study. If a conjugate station of Kinkasan Island were known in the Southern Hemisphere, interesting information concerning the global influence of volcanic eruptions might be found, because of the large number of northern eruptions.

Figure 9 shows the long-term variation of the summer air temperature deviations averaged in the high latitudes (60°–90°N) and in the low latitudes (0°–30°N). At the high latitudes, the temperature is indicated to have decreased following great volcanic eruptions, but there is little evidence of a decrease in the low latitudes. As for the winter temperature (not shown in this paper), no evidence of cooling following volcanic eruptions is found at Kinkasan Island or in the latitudinal average air temperature (Kondo 1985d).

6. The meteorological consequences of volcanic eruptions

In a normal summer, a southerly monsoon blows over the Tohoku District. But in an abnormal summer, a northeasterly wind from a blocking high situated over the ocean to the east of northern Japan, brings frequent rainy days with insufficient sunshine, and a low air temperature, thus leading to a widespread poor rice harvest.

The year of 1980 was the coolest summer and the worst harvest year to the Tohoku district in the last 35 years (Fig. 6). In the same year, there was an extremely poor harvest in Korea too. Figure 10 is a typical example of a weather map for the summer of 1980. The shading designates the region with an air temperature below 20°C. An anticyclone situated to the east of northern Japan impedes the northward progression of

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**Fig. 12.** Monthly mean surface air temperature deviations in the Northern Hemisphere in July 1980 (after Fujita 1984). Negative deviations are shaded.
middle and high latitudes, large positive deviations are seen over the southern United States and eastern Siberia, and large negative deviations over and around Japan and Western Europe. According to Fujita (1984), a similar (but not the same) distribution of temperature deviations is found in the summer following volcanic eruptions. When the large-scale H-bomb experiments were carried out in 1954, similar distributions were also found on record (Arakawa et al. 1955).

Angell and Korshover (1985) made studies on the effect of the volcanic eruptions on regional surface temperature in Europe and North America between 1780 and 1980, and reported that, although volcanic eruptions certainly did not cause a warming of the earth’s surface, there is not convincing evidence either that they cause cooling. On the other hand, the present paper shows that almost all great volcanic eruptions (except the Tambora eruption in 1815) resulted in the regional cooling in summer in the Tohoku District of Japan (Kondo 1985a,b,d).

Some conjecture on this subject is given. The great volcanic eruption ejects massive amount of ashes and gases into the stratosphere, which must change the general air circulation pattern, forming a strong blocking high over the ocean to the east of northern Japan. Some regions tend to have frequent northerly cooler winds, and others southerly warmer winds in comparison with normal years. The summer air temperature in the Tohoku District may be most sensitive to such abnormal pattern.

7. Exceptional cool summers

Five abnormally cool summers (1931, 1934, 1935, 1941, and 1945) occurred without great volcanic eruptions. In the period of 1923–45, the sea water temperatures at Tohoku’s coastal stations on the Pacific were 1.3–1.5°C lower, on the average, than those in the subsequent period of 1946–79 (Figs. 13 and 14).

At Enoshima Island, the average annual mean sea water temperature in the period 1923–45 is 12.49°C (with a standard deviation of 0.69°C), and in the period 1946–79 is 13.87°C (with a standard deviation of 0.74°C). An abrupt change (climatic jump) is seen around 1946. The magnitude of this climatic jump is estimated at 1.38°C. This is twice as large as the standard deviations in the periods before and after the climatic jump. As for winter and summer (not shown), the magnitudes of the climatic jump are 1.42°C and 1.51°C, respectively.

The largest jumps are seen at Enoshima Island and Shioyasaki Cape where the warm Kuroshio and the cool Oyashio currents meet, and the jump gradually decreases in magnitude with the increase of distance from this region. This suggests that frequent cool sum-
Fig. 14. Long-term variations of the annual mean sea-surface water-temperatures on the east coast of Japan. The range with a shading indicates ±1°C from the long-term mean (horizontal bar).

Mers and poor rice harvests during 1931–45 were associated with an abnormal oceanic general circulation, resulting in an unusual southward penetration of the cool Oyashio current.

Figure 15 shows the long-term variations of the 5-yr averages of annual mean values of air temperature at Kinkasan Island (open circle), of the seawater temperature at Enoshima Island (dotted line), and of the
air temperature at Tokyo (solid circle). A noticeable depression is seen in the seawater temperatures during 1926–45. On the other hand, a trend of the air temperature going up at Tokyo in this century is evident. The difference of the mean temperature between the end of the nineteenth century and the recent period reaches 2°C. This temperature increase is probably mostly due to the urbanization.

8. Summary

The present analyses can be summarized as follows:

1) Most of the widespread poor rice harvests due to cool summers in the northeastern part of Japan took place after great volcanic eruptions.

2) Observations by instrument in the last 100 years at Kinkasan Island indicate that the summer air temperature averages 1°–2°C lower than the normal for 1–2 yr after great volcanic eruptions, while the northern midlatitudinal mean surface air temperatures decrease about 0.2°C.

3) During the period between 1931 and 1945 the seawater temperature at the east coast of Japan averaged 1.5°C lower than that of the subsequent period of 1946–79. Exceptional cool summers, with no volcanic eruption, took place during this period.

REFERENCES


—, 1985d: Correlation between the seasonal mean air temperature at Kinkasan Island and the middle latitudinal average air tem-


