Secular Changes in Occurrence of Two Cool Summer Types over Northern Japan

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1 Introduction

The cool summer phenomena in northern Japan has been investigated for many years because it has an important effect upon rice farming in Japan. With the accumulation of the upper-air data, the investigation regarding cool summers has proceeded from the viewpoint of the general circulation. As a result, it has become evident that cool summers in northern Japan are classified into two types (Wada and Asakura 1967): The first type is called "cool summer of the first class", accompanied by a blocking phenomena under a meridional circulation pattern. This type is identified and influenced by the Okhotsk High and the resulting northeast winds. This type has already been studied since the 1930's as a typical cool summer pattern. In the middle of the 1960's, northern Japan was often affected by cool summers of a new type under a zonal circulation pattern. This type, "cool summer of the second class", is clearly different from the first type in that there exists a Low in the Sea of Okhotsk, accompanied by the prevalence of northwest winds and a hot summer in southwestern Japan.

In this paper, the author intends to clarify the following two aspects of the cool summer phenomena: One is the regional difference of low temperature occurrence. In previous reports, the distribution of temperature anomalies was discussed from a macro scale viewpoint. It is interesting to note the pattern of distribution of temperature anomalies that is presented under the two kinds of circulation pattern through location and altitude.

The other is a comparative long-term tendency of their occurrences. The two cool summer types studied in previous reports have been limited since 1950, because identification is dependent upon the upper-air circulation types. In this paper, the studied term is extended for ninety years by means of estimating the cool summer types from the distribution of temperature anomalies.

2 Two types of cool summer

The following typical years are extracted from the Japan Meteorological Agency (1971) and Matsukura (1972): cool summer of the first class July 1954, cool summer of the second class for July 1965.

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Fig. 1 shows the anomalies of monthly mean temperature, and clearly expresses the temperature anomaly distributions of the two cool summer types. In July 1954, the region with severe below normal temperatures is located on the eastern side of the Ou Range, especially on the Pacific coast of northern Iwate Prefecture. In other words, the strength of the low temperature gradually diminishes from the Pacific coast to the Japan Sea coast. This pattern is exactly similar to the temperature anomaly pattern during the period when *yamase* winds blow (Asai 1950). *Yamase* is a northeast wind from the Okhotsk High, characterized by a cool maritime subpolar air mass near the sea surface. Therefore, the pattern in Fig. 1 (left) is considered to be its result and the cool airflow is screened by the longitudinal ranges, and gradually becomes warmer.

The other hand, the anomaly chart in July 1965 indicates that the region with severe below normal temperatures does not appear on the Pacific coast of Iwate Prefecture, but in the inland or the Japan Sea side. This represents that the cool

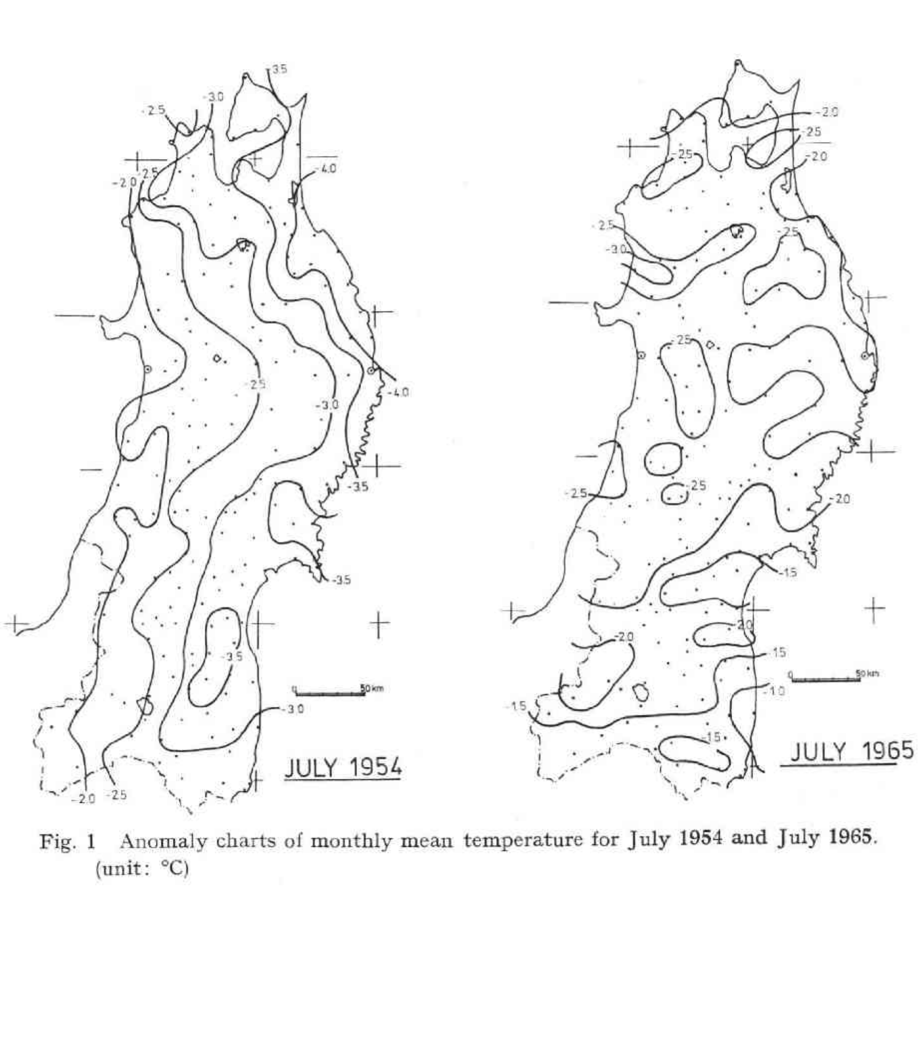

Fig. 1 Anomaly charts of monthly mean temperature for July 1954 and July 1965. (unit: °C)

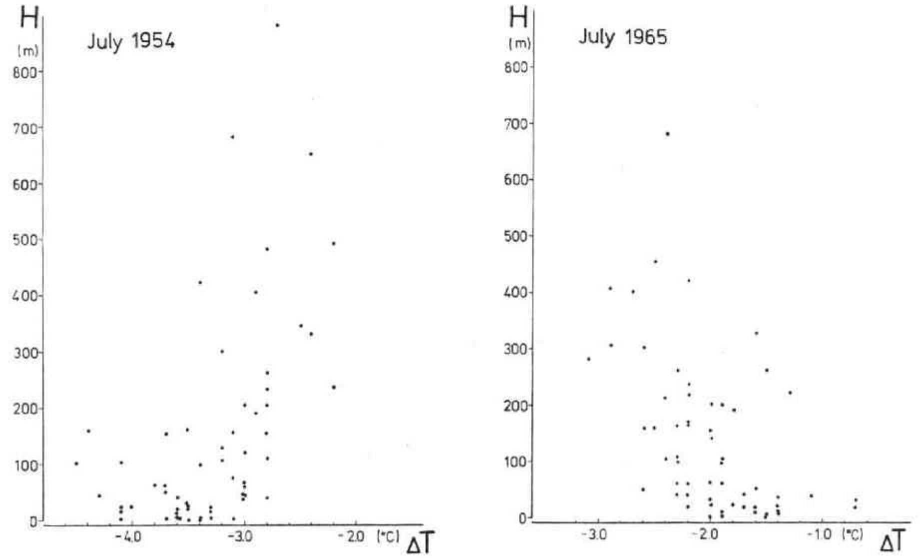

Fig. 2 Relationships between temperature anomalies (ΔT) and elevations (H) for July 1954 and July 1965.

summer of the second class prevails throughout the Tohoku district, with regard to the fact that the normal temperature on the Pacific coast of Iwate Prefecture is the lowest in the Tohoku district.

Fig. 2 shows the relationships between the temperature anomalies (ΔT) and the elevations (H) for the stations of the Pacific side in the two typical months. In the case of the cool summer of the first class (July 1954), the lower altitudes are inclined to be affected by low temperatures, while the summer of the second class (July 1965) have a reverse tendency.

Fig. 1 and Fig. 2 exhibit clearly the characteristics of the two types of the cool summers. That is, it can be considered that in the cool summer of the first class there is a significant effect of the cooling on the sea surface, while the cool summer of the second class is caused by an upper, cold air mass.

3 Seasonal and secular changes

The surface temperature data are available since 1891 in the Tohoku district. Therefore, the secular changes in the occurrence of the two cool summer types can be examined for ninety years by means of the results obtained in the previous section.

3.1. Data and method

There are only six stations in the Tohoku district that supply continuously reliable data of surface temperatures for ninety years. Among those, Miyako (39°39′N, 141°58′E) is a station that observed remarkably low temperature in the case of the cool summer of the first type. Therefore, the temperature anomaly of Miyako is applied to the index of the first type. As the index of the cool summer of the second type, the temperature anomaly of Akita (39°43′N, 140°06′E) is selected. Akita is free from the severe low temperatures in the case of the first type, and has recorded comparatively low temperature in the case of the second type though low temperatures prevailed in the entire district of Tohoku on that occasion.

The pentad (five-day) mean temperature data is applied in place of the monthly mean temperature. The duration of the first type is ten to fifteen days, the second type is seven to ten days (Kashiwabara and Ookawa 1967). When both types appear during the same month, the monthly mean temperature data does not represent any characteristics of the cool summer types.

Therefore, the anomalies of the pentad mean temperature for Miyako and Akita are applied. The object of this study is a period of ninety years from 1891 to 1980, for June, July and August, *i.e.* from the 31st pentad to the 48th pentad.

Fig. 3 shows a standard delineation of the cool summer types. The pentad

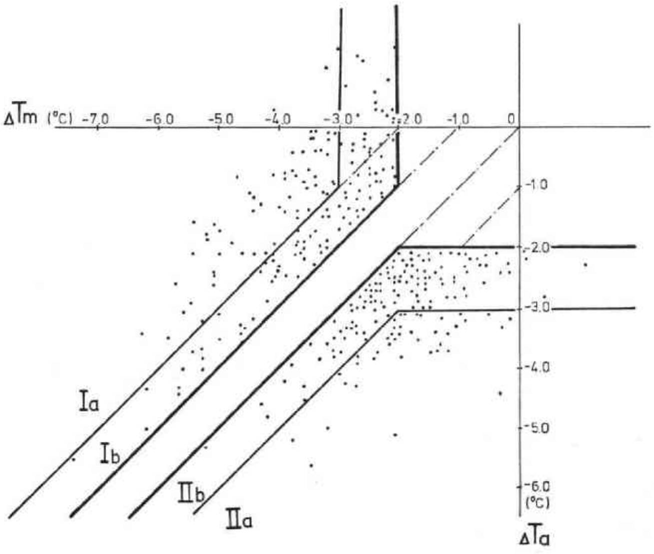

Fig. 3 Standard judgement of the cool summer types.
ΔTm: Anomaly of five day mean temperature in Miyako
Δ Ta: Anomaly of five day mean temperature in Akita

when the temperature anomaly below 2°C was recorded either in Miyako or in Akita is illustrated in Fig. 3. Among these, the pentad when the temperature anomaly for Miyako is greater than 1°C lower than that for Akita is defined as the first type. The pentad when the anomaly for Akita is lower than Miyako is defined as the second type. Moreover, more rigid standards are established in types, Ia, Ib, IIa and IIb. Among 1,440 pentads, the first type amounted to 208 pentads, and the second type 151 pentads.

3.2. Seasonal and secular changes

Fig. 4 shows the seasonal and secular changes of the pentads defined as the first and the second types. In each type, the number of pentads is summed every ten days and for every ten years, and their frequencies are represented. For a example, there occurred seven pentads of the first type in the middle of July in the 1950's.

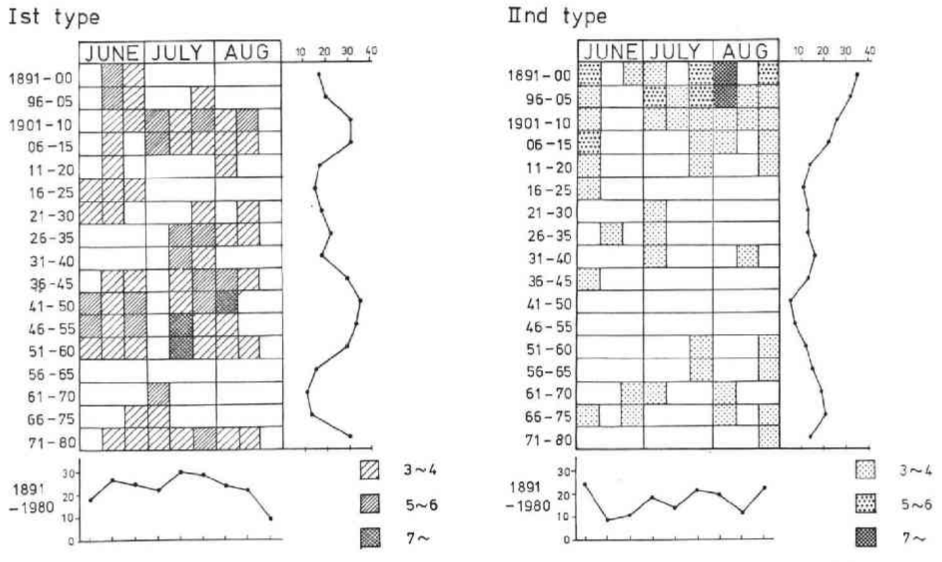

Fig. 4 Occurrence tendencies of the two cool summer types (unit: pentads).

As for the seasonal changes, the first type has a tendency to occur from the second decade of June to July, and by contrast, the second type has no tendencies in seasonality.

As for the secular changes, the first type has a ca. forty years periodicity, with two maxima in the 1900's and 1940's. It should be noted that the first type has been increasing since the latter 1970's. The other hand, the second type has occurred most frequently in the 1890's, and had decreased markedly until the 1940's. In the 1960's, it is found that the first type was reaching a minimum while the second type was increasing. The cool summer of the second type has attracted attention in the latter part of the 1960's is mainly due to its increase during this period.

4 Occurrence tendency of the Okhotsk High

The cool summer of the first class is characterized by the occurrence of the Okhotsk High. Accordingly, the secular change of the Okhotsk High occurrence is examined in relation to that of the first type.

4.1. Data and method

The synoptic charts used are mainly Daily Series Synoptic Weather Maps at the surface, which have been published since 1899. However, those published before 1920 are too vague because they have few stations in and around the Sea of Okhotsk. Therefore, weather maps after 1921 are employed. Maps for the period after 1971 are not available. For this reason, Daily Weather Maps by the

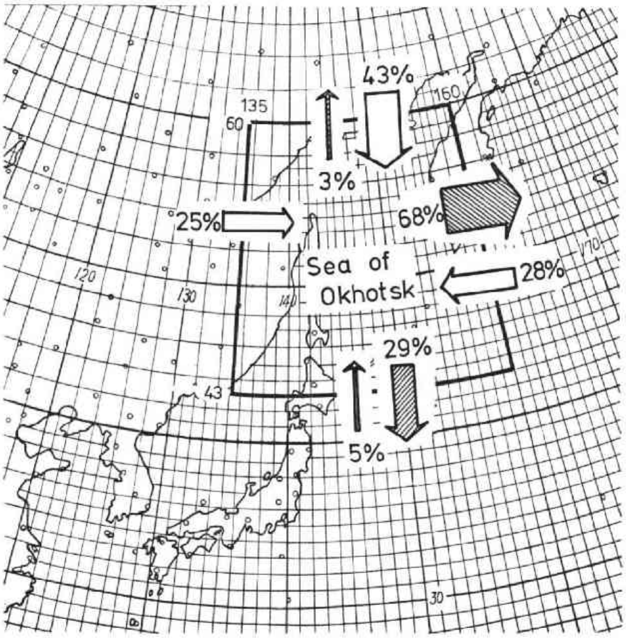

Fig. 5 Definition area and direction of movement ratio of the Okhotsk High from June to August during the period 1921–1980.

Japan Meteorological Agency are employed. The object is the months of June, July and August from 1921 to 1980.

On referring to Suginaka (1965) and Kurashima (1969), the Okhotsk High is defined as follows: The high, whose center exists in and around the Sea of Okhotsk, in an area from 43–60°N, 135–160°E, and occupies most of the Sea of Okhotsk.

Fig. 5 shows the area in which the Okhotsk Highs are defined, and the directions in which they enter and leave. Most of the Okhotsk Highs enter from the north, west and east, and exit to the east and south. Generally the Okhotsk Highs observed in June have a tendency to enter from the east, and those in August from the west.

4.2. Secular changes of the Okhotsk High occurrence

The total number of days with the occurrence of the Okhotsk High is 1,029 for the fifty year period. Fig. 6 shows the secular changes of the pentads defined as the first type, and the number of days with the Okhotsk High occurrence in June, July and August. The former change has three maxima; 1902–13, 1941–54, 1976–80. The latter change satisfactorily corresponds with the former and has maxima in the 1940's and in recent years. Judging from their correspondence, 1941, 1945, 1954 and 1980 are typical years of the first type.

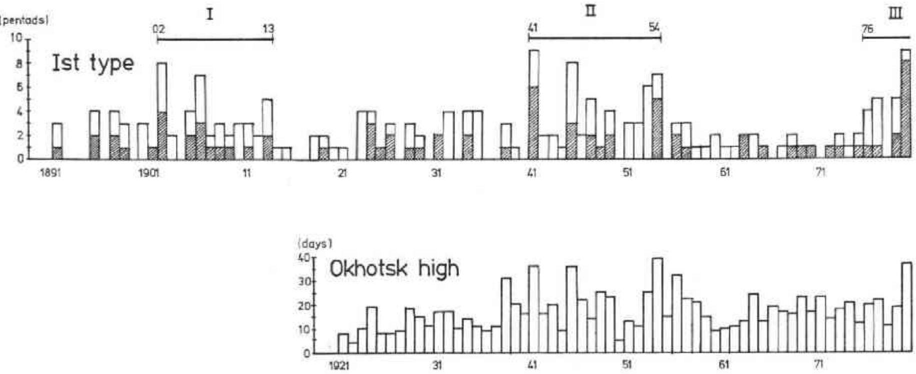

Fig. 6 Secular changes of the cool summer of the first type (upper) and the Okhotsk High occurrence (lower). Hatched columns indicate Ia type defined in Fig. 3.

The change shown in Fig. 6 is the change of the total number of days with the occurrence of the Okhotsk High, from June to August. In order to consider the substance of the Okhotsk Highs, they are classified by their intensity and duration.

Fig. 7 shows their secular changes. The central pressure values are used to determine the index of intensity. The central pressures of the Okhotsk High are classified into six classes by five milibars. The stronger highs, those with pressures

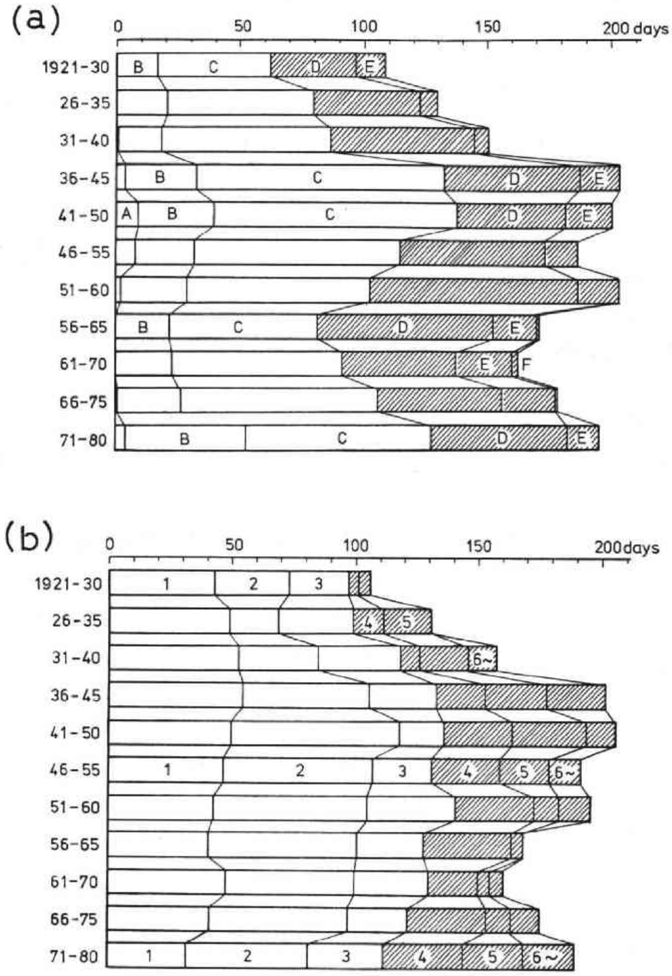

Fig. 7 Occurrence tendencies of the Okhotsk Highs in each ten year period from June to August.

(a) Classification by their central pressure values.

A: less than 1010 mb B: 1011–1015 mb C: 1016–1020 mb

D: 1021–1025 mb E: 1026–1030 mb F: more than 1031 mb

(b) Classification by their durations (unit: days).

of more than 1,021 mb are hatched (Fig. 7-a). Though the total number of days has two maxima about the 1940's and the recent years, the weaker highs, those with pressures of less than 1,020 mb change in accordance with the total. The stronger highs, however, occur constantly through the period 1921–1980. The weaker highs were observed frequently in the 1940's and in the 1970's, when the first type reached the second and third maxima. This confirms that there is no correlation between the intensity of the Okhotsk High and the occurrence of the first type from the viewpoint of secular changes.

Next, the duration of the Okhotsk High is examined. Fig. 7-b shows the secular change of the days with the Okhotsk High occurrence classified by their duration. It is observed that the number of the Okhotsk Highs having a short life span of less than three days is roughly constant, while those with more than four days correspond to the total number of days. In the 1940's and 1970's, highs were inclined to be stagnant around the Sea of Okhotsk, the correlation between the duration of the Okhotsk High and the occurrence of the first type is apparently recognized.

5 Relation with hemispheric temperature change

The secular changes of the two cool summer types and the Okhotsk High occurrence should be considered in relation to the hemispheric temperature field. Fig. 8 shows the secular changes of the two cool summer types (a), the difference

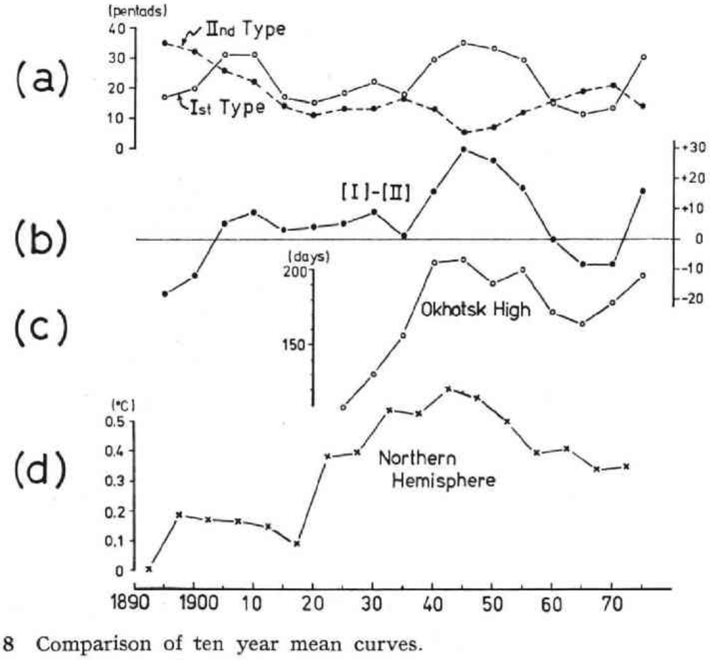

Fig. 8 Comparison of ten year mean curves.
(a) Two types of cool summer
(b) Difference between the first type and the second type
(c) Occurrence of the Okhotsk High
(d) Northern hemisphere mean surface air temperature (after Brinkmann).

between the first type and second type (b), the total number of days with the occurrence of the Okhotsk High (c), and the northern hemisphere mean surface air temperature (d).

Various reports have recently been given on the global mean air temperature (Brinkmann 1976; Yamamoto and Hoshiai 1980; Hansen et al. 1981). The reports satisfactorily coincide with the northern hemisphere mean temperature, indicating a cold period before 1920, with a maximum around 1940. The secular change of the difference between the two cool summer types (b) correlates remarkably with that of the northern hemisphere mean temperature (d). That is, the cool summer of the first type is prevalent during the warmer period around 1940. The second type emerges in the colder period before 1920 and in the 1960's. This tendency supports the opinion that the emergence of the cool summer of the second class results from cooling in high-latitudes (Japan Meteorological Agency 1971).

6 Conclusion

Two cool summer types over northern Japan were investigated. The cool summer of the first type was characterized by an anomaly pattern in which the region with severe below normal temperature is located on the Pacific coast and in lower altitudes. The other hand, the second type influences the entire Tohoku district, and in such a case, the higher areas are inclined to be affected by low temperature.

Secular changes of the two cool summer types were examined for the period 1891–1980, using anomaly data of pentad mean temperature for the months of June, July and August. The first type has a ca. forty year periodicity, and the second type frequently occurred in the 1890's and the 1960's. The secular change of the difference between the first and the second types shows a close correlation with that of the northern hemisphere mean temperature. During the hemispheric warmer period around 1940, the first type is relatively prevalent. It is a very interesting fact that the difference between the first and second types, which are defined by a micro or meso scale temperature contrast, has changed in close connection with the hemispheric temperature field.

The Okhotsk High is one of the most important intermediaries between the cool summer type and the hemispheric temperature field. The secular change of the Okhotsk High occurrence correlates with the occurrence of the first type and the hemispheric temperature field. It is recognized that the Okhotsk High with a duration of more than four days increased in the warmer period around 1940 and in recent years.

It can be considered that the lower sea surface temperature in the Sea of Okhotsk is one of the reasons that the highs were inclined to be stagnant around the 1940's.

Relationships between the Okhotsk High and the hemispheric temperature field should be analyzed by the medium of sea surface temperatures. This may explain the frequent cool summer occurrence in the warmer period.

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