Proc. NIPR Symp. Polar Meteorol. Glaciol., 1, 91–102, 1987

CLIMATIC JUMP IN THE POLAR REGION (I)

Ryozaburo YAMAMOTO[1], Tatsuya IWASHIMA[1]
and Makoto HOSHIAI[2]

[1]*Laboratory for Climatic Change Research, Kyoto University, 17–1, Ohmine-cho, Kitakazan, Yamashina-ku, Kyoto 606*
[2]*Physics Laboratory, Aichigakuin University, 12, Araike, Iwasaki, Nisshin-cho, Aichi-gun, Aichi 470–01*

Abstract: From the analysis of the climatic elements over Japan, we can detect the "climatic jumps" around the years 1920 and 1950, which is a new concept in the climatic diagnosis proposed by the present authors (R. YAMAMOTO *et al.*: J. Meteorol. Soc. Jpn., **63**, 1157, 1985, **64**, 273, 1986). Taking account of several results which show the simultaneous occurrence of the climatic jumps of the surface air temperature, precipitation, etc., in the other regions by the other investigators, we may infer the "climatic jump" of the atmospheric general circulation.

In the present paper we attempt to detect a climatic jump of sea-level pressure distribution in the Northern Hemisphere. We can clearly detect an abrupt change of the phase angle of the ultra-long waves with the wavenumber one in winter associated with the "climatic jumps" of the atmospheric general circulation.

Taking into consideration the time-series of several external forcings associated with the climatic jump, we may give a tentative conclusion that the climatic jumps may be caused by the almost intransitivity.

1. Introduction

The climate of our planet is produced by a highly non-linear physical system. In his non-deterministic theory of climatic change, LORENZ (1976) proposed an important concept of the almost-intransitivity, and suggested that there appear some abrupt changes of time-mean quantities of climatic elements for a long but finite duration, even if there are no changes of external or boundary forcings for the climatic system. By using a low-order time-space spectral model of the general circulation with seasonal forcing, IWASHIMA and YAMAMOTO (1986) showed that some abrupt changes of multi-year average of the general circulation may occur.

On the other hand, we have detected "abrupt changes" in several climatic elements averaged over a few decades, and proposed a new concept of the "climatic jump" in the climatic diagnosis (YAMAMOTO *et al.*, 1985, 1986). Independently of the present authors, FLOHN (1986) has also noticed abrupt changes of climatic element over a regional area. In our analysis of climatic elements over Japan, we have detected the climatic jumps around the year 1950. In several papers by the other authors, we can also find that the jump occurred almost simultaneously in the other areas. These facts suggest that some abrupt changes, *i.e.* the "jumps" of the general circulation occurred, although the quantitative check should be needed. In the present work we will detect the climatic jumps of the sea-level pressure distribution in the Arctic region, and will examine the cause of the jumps.

2. Climatic Jumps in the Regional Climate

In the preceding papers (YAMAMOTO *et al.*, 1985, 1986), we analyzed the data of climatic elements over Japan, and found their abrupt changes around the year 1950 as shown in Fig. 1. In the papers published up to date we can find several examples which suggest occurrence of the "climatic jumps", although the quantitative check still remains. For example, in Fig. 2 of the monthly mean surface air temperature for the 4 grid-points along the meridian 60°W by YAMAMOTO and HOSHIAI (1980), we

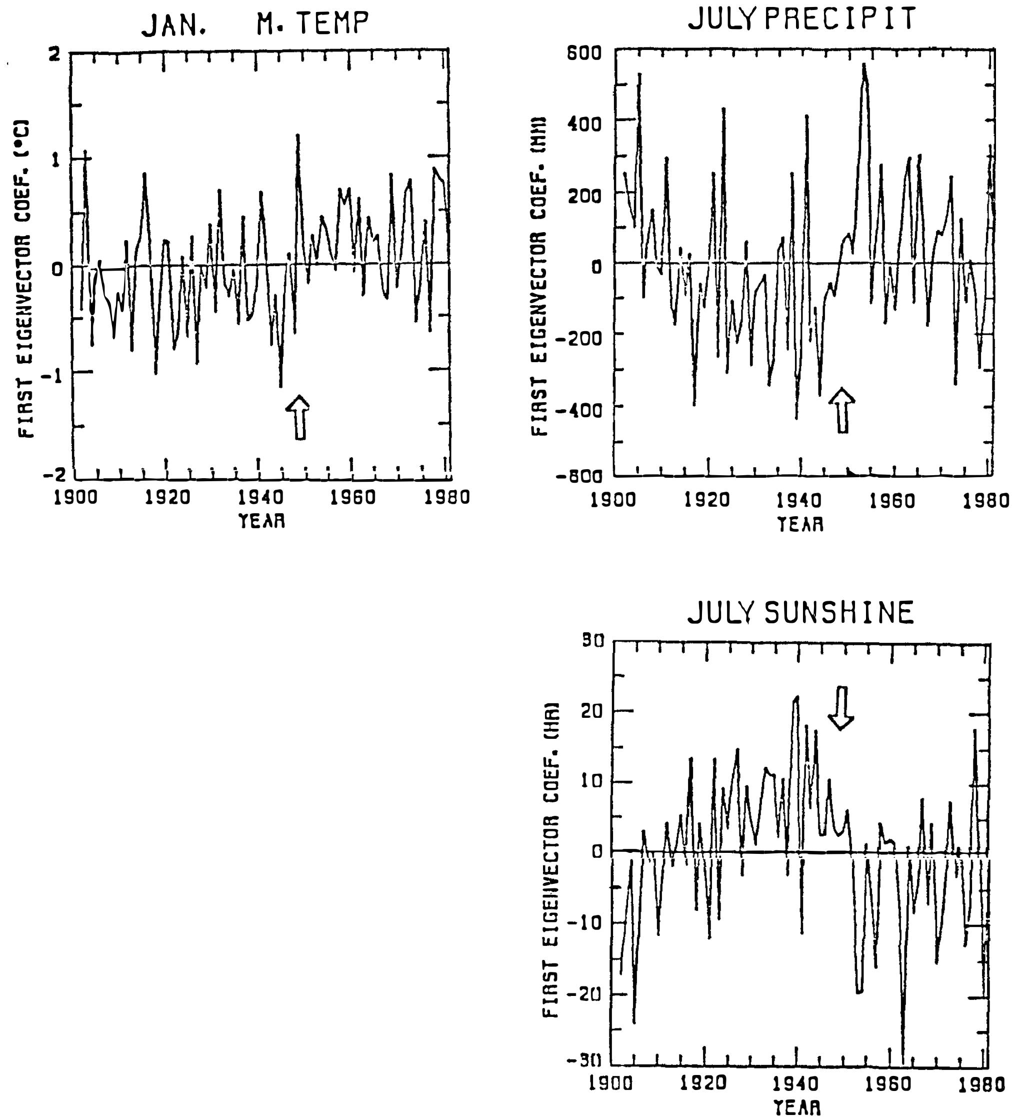

Fig. 1. Coefficients of the first eigenvectors of monthly mean surface air temperature in January, monthly precipitation and sunshine-duration in July over Japan. These are estimated by the use of the data at 48, 48 and 38 stations in Hokkaido, Honshu, Shikoku and Kyushu Island, respectively. The arrows indicate the detected jump around the year 1950.

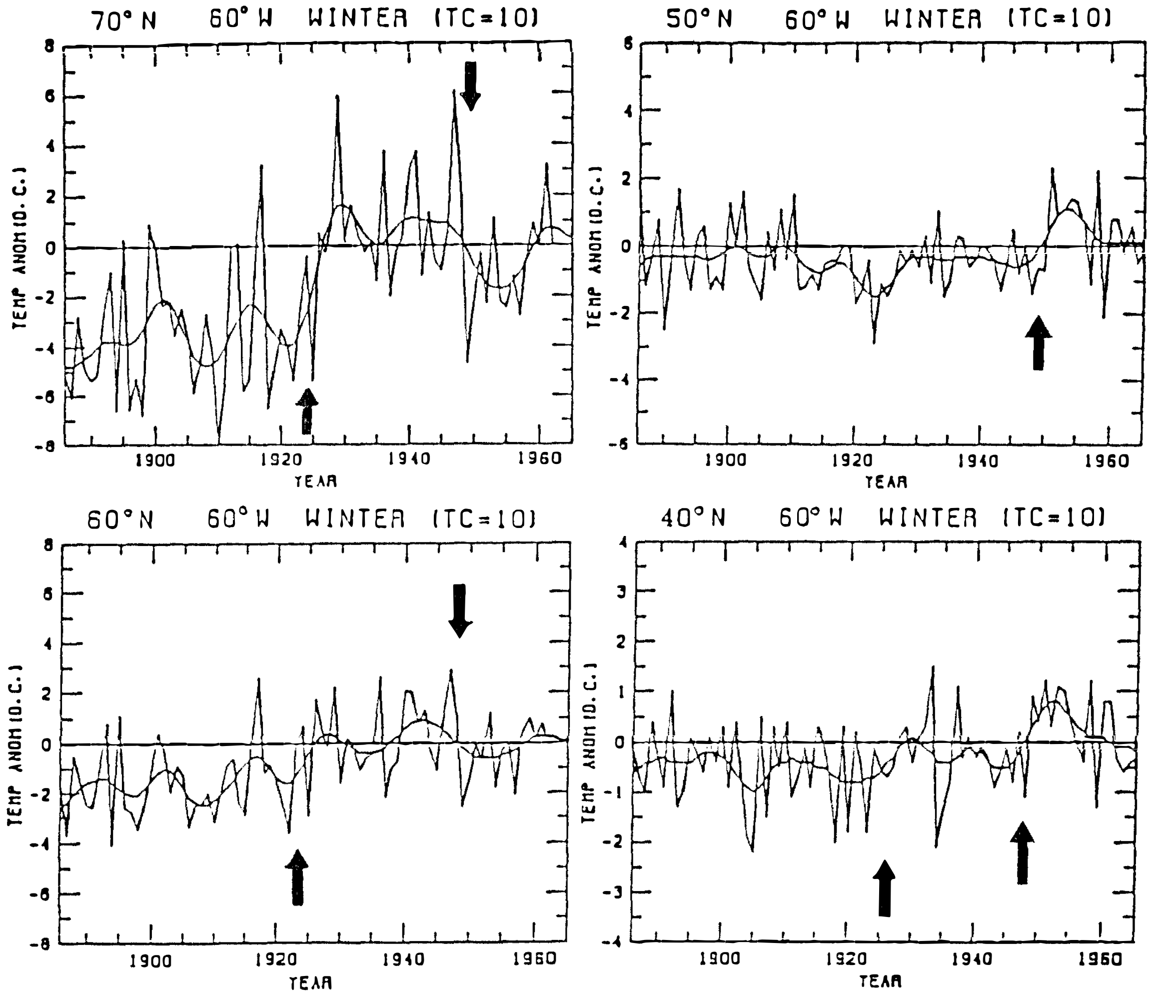

Fig. 2. 3-month mean temperature anomaly from 30-year average (1931–1960) at 4 grid points along the meridian 60°W. These are obtained by the optimum interpolation of the observational data at the adjacent stations (YAMAMOTO and HOSHIAI, 1980). Smooth curves show the anomalies applied with a low-pass filter of 10-year cutoff period. The arrows indicate the detected jump around the year 1950.

can find the "climatic jumps" around the years 1925 and 1950 except around the year 1925 of 50°N. The sense of the abrupt changes at 70 and 60°N is opposite to those of 50 and 40°N.

In the other example we can find the jumps around the years 1920 and 1950 as in Fig. 3 of the surface air temperature in the Arctic area by KELLY *et al.* (1982) and in Fig. 4 of eigenvector coefficients of precipitation along the Pacific coast of North America by MCGUIRK (1982). These results suggest that the abrupt changes occurred in the global scale, *i.e.* the climatic jump of the general circulation, although they should be quantitatively ascertained, based on our proposed criterion.

In the following section we will examine the climatic jumps in the higher latitudes by using the sea-level pressure data.

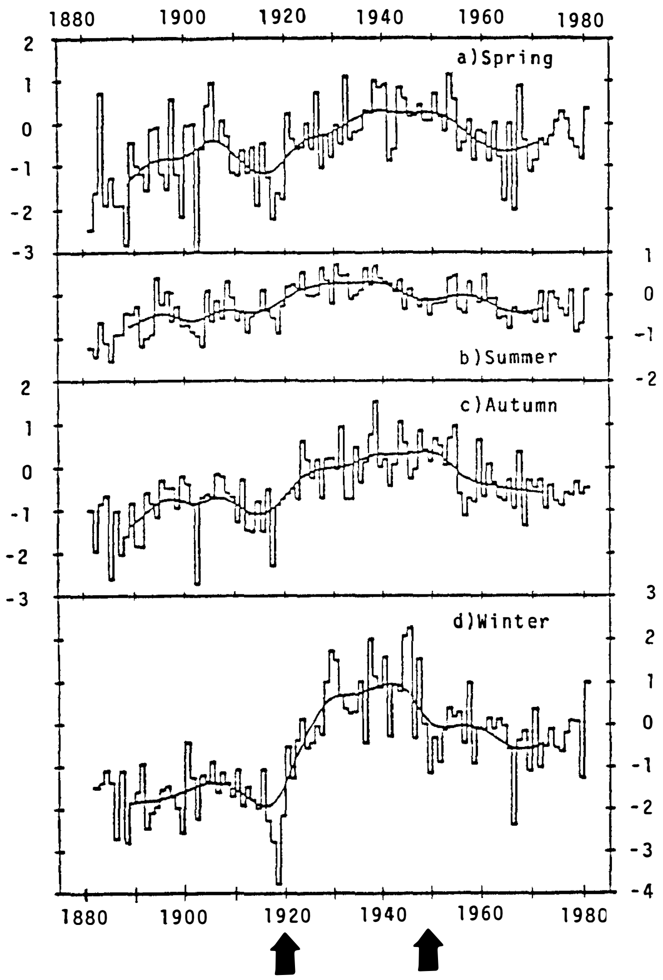

Fig. 3. Seasonal temperature (°C) as departures form the reference period 1946–1960 averaged over the Arctic (65–85°N), reproduced from KELLY *et al. (1982). The arrow drawn by the present authors indicates the abrupt change of the multi-year means to be noted.*

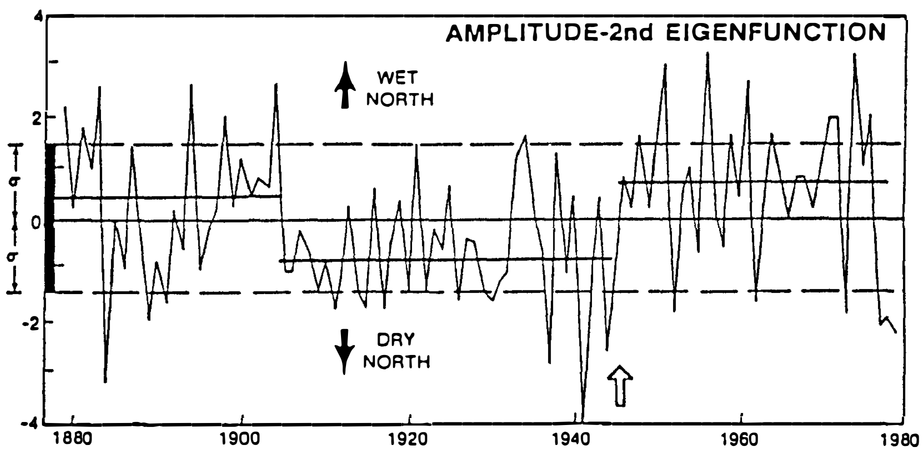

Fig. 4. Time series of the amplitude of the second eigenfunction of the seasonal precipitation (October–April) along the Pacific coast of North America, reproduced from MCGUIRK *(1982). The open arrow, drawn by the present authors, indicates the abrupt change of the multi-year mean to be noted.*

3. Detection of Climatic Jumps of Sea-level Pressure in the Northern Hemisphere

By using the NCAR data set of sea-level pressure in the Northern Hemisphere, we will re-examine KUTZBACH (1970)'s results, because he overlooked the effects of natural variability or climatic noise on the monthly mean values.

Here, we use a spatial low-pass filter with cut-off wavelength above 8000 km and a low-pass time filter with cut-off period of 6 months, and suppress contamination of the natural variability from the raw data.

Firstly, in order to detect the time (year) of the climatic jumps of the sea-level

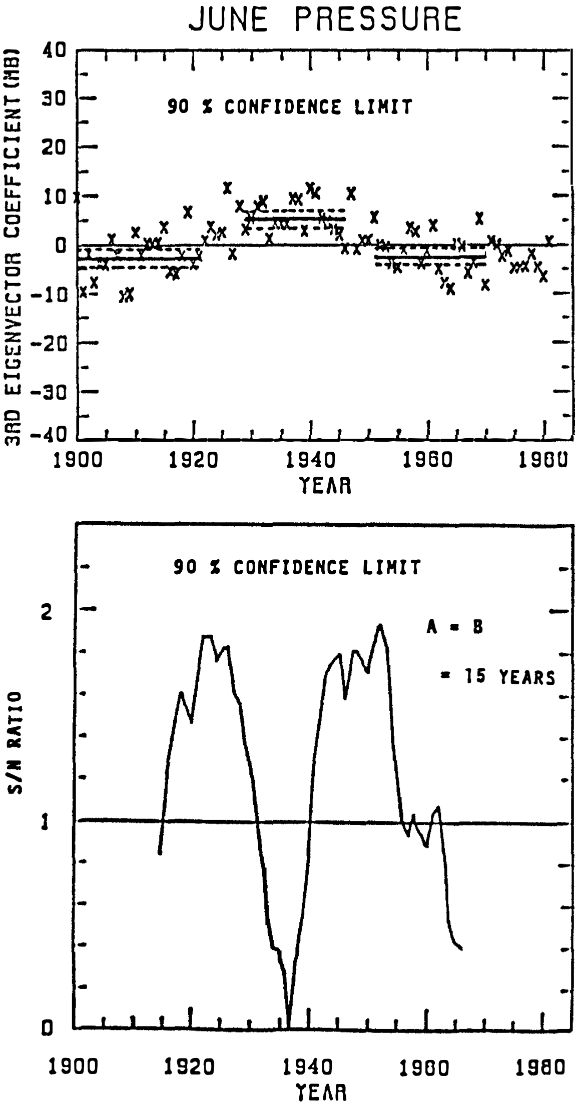

Fig. 5. Time series of the coefficients of the third eigenvector (crosses) and their averages (full line) and 90% confidence limits (broken lines) over the 3 periods 1900–21, 1929–46 and 1952–70 in the top panel; and time-series of the SN ratio $(S/N)_{90}$ of the third eigenvector coefficients of the Northern Hemisphere sea-level pressure in June for averaging period $A=B=15$ years in the bottom panel.

pressure distribution all over the Northern Hemisphere, we made an empirical orthogonal functional analysis of the filtered data of monthly averaged sea-level pressure during the years 1901–1982 from 20 to 70°N for each month after KUTZBACH (1970). The percent of the first, second and third eigenvalues to the total variances is 16–23, 12–15 and 9–12%, respectively.

In the second step, we calculated the signal-to-noise ratio as was done by YAMAMOTO *et al.* (1986) in the following way: We define the signal-to-noise ratio $(S/N)_p$ of the jump with $p\%$ confidence limit;

$$(S/N)_p = |M_A - M_B| / (\sigma_{A_p} + \sigma_{B_p}) ,$$

where M_A and M_B, and σ_{A_p} and σ_{B_p} are the averages and $p\%$ confidence limits over years A and B before and after a reference year, respectively (see a good example of Fig. 5 for the 3rd eigenvalues of June). If a jump occurs in the time series of a climatic element, the maximum value might appear in a reference year of the time series, and the value of the SN ratio $(S/N)_p$ may exceed the unity 1.

In order to detect any climatic jumps, we apply the above-mentioned method assuming that the averaging periods before and after a reference year are the same, *i.e.* $A=B$. Here we tentatively choose three values, 10, 15 and 20 years, for A and B, not to take any monotonic or oscillatory changes as a jump.

Applying the above method to the coefficients of the first to third eigenvectors of the sea-level pressure, we found two jumps within the 95% confidence limit: 1922–23 and 1947–48 for the first eigenvector; and 1927–28 and 1941–1951 for the third eigenvector. Here, from all the reference years we picked up only such a year when maximum SN ratios for the three averaging durations 10, 15 and 20 years exceed the unity 1 within a difference of two years from the reference year. In the rigorous condition for the jump occurrence we cannot find jumps of the second eigenvector coefficients. Taking account of the ambiguity of the identification of jump occurrence time due to large year-to-year fluctuations, we conclude that the jumps occurred around 1922–28 (referred to 20's climatic jump, hereafter), and 1947–51 (50's climatic jump) during 42 years from 1920 to 1961.

4. Detected Climatic Jumps in the Arctic Region

Although we detected two jumps in the time-series of the sea-level pressure eigenvectors in the preceding section, it is not necessarily appropriate to use the eigenvectors and their coefficients for further examinations of the jumps of the hemispherical distribution of the sea-level pressure, because each principal component of eigenvectors has only a small contribution to the total variance and we must, therefore, take a large number of eigenvectors. Therefore, we use the values at the grid points, and get two maps of hemispherical distribution of the differences between term-averaged sea-level pressures before and after the 20 and 50's climatic jumps. In the maps the shaded area indicates that the difference of the sea-level pressure before and after the jump is above 90% confidence limit. Here the positive and negative signs denote increase and decrease of the sea-level pressure at the jumps, respectively.

Figures 6 and 7 show the distribution of the pressure difference and significant

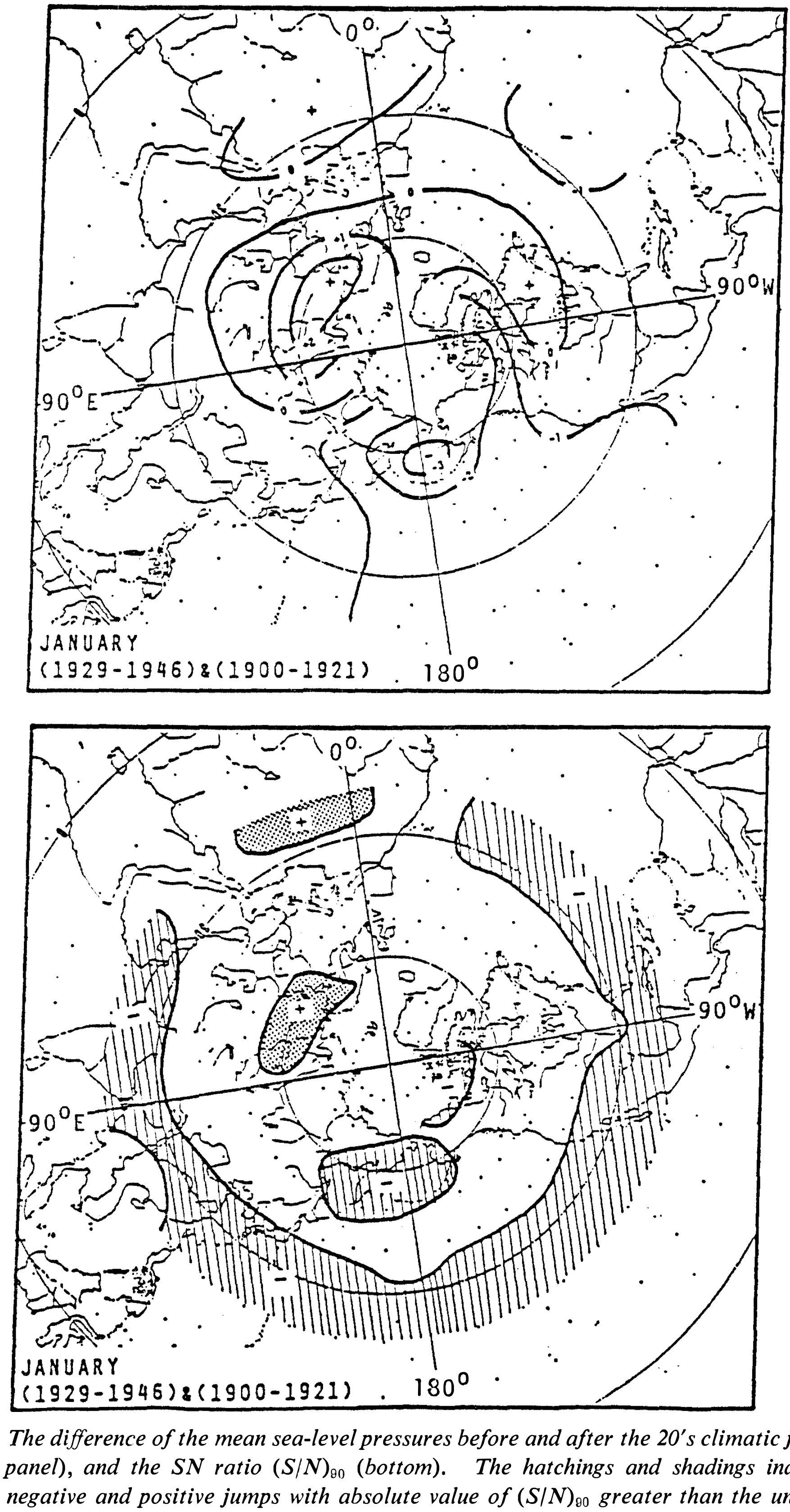

Fig. 6. The difference of the mean sea-level pressures before and after the 20's climatic jump (top panel), and the SN ratio $(S/N)_{90}$ *(bottom). The hatchings and shadings indicate the negative and positive jumps with absolute value of* $(S/N)_{90}$ *greater than the unity 1, respectively.*

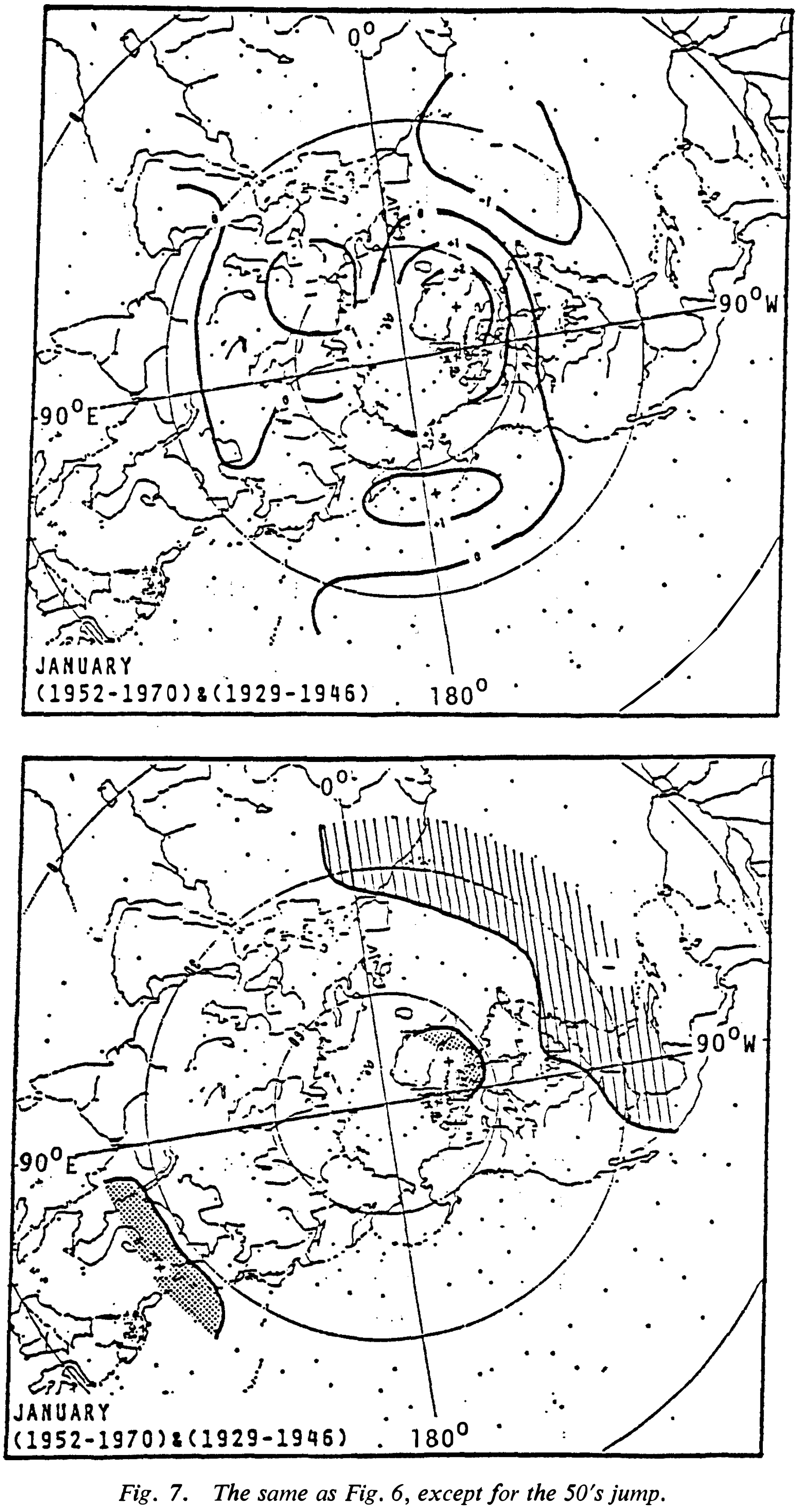

Fig. 7. The same as Fig. 6, except for the 50's jump.

area for the 20 and 50's jumps in January, respectively. In the 20's jump we can find two extremes: increasing with the Siberian high; and maximum decreasing with the Aleutian low. Both maximum increasing and decreasing of the sea-level pressure are significant within 90% confidence limit region. While, in the case of 50's jump, we can find almost similar distribution patterns of the difference of sea-level pressure but with opposite signs: they may be due to weakening of the Siberian high and the Aleutian low. The low in northern Canada also weakened and shifted southward. Only the pressure jump of the low in northern Canada is significant, and that of the Siberian high and of the Aleutian low are not within 90% confidence limit. Although

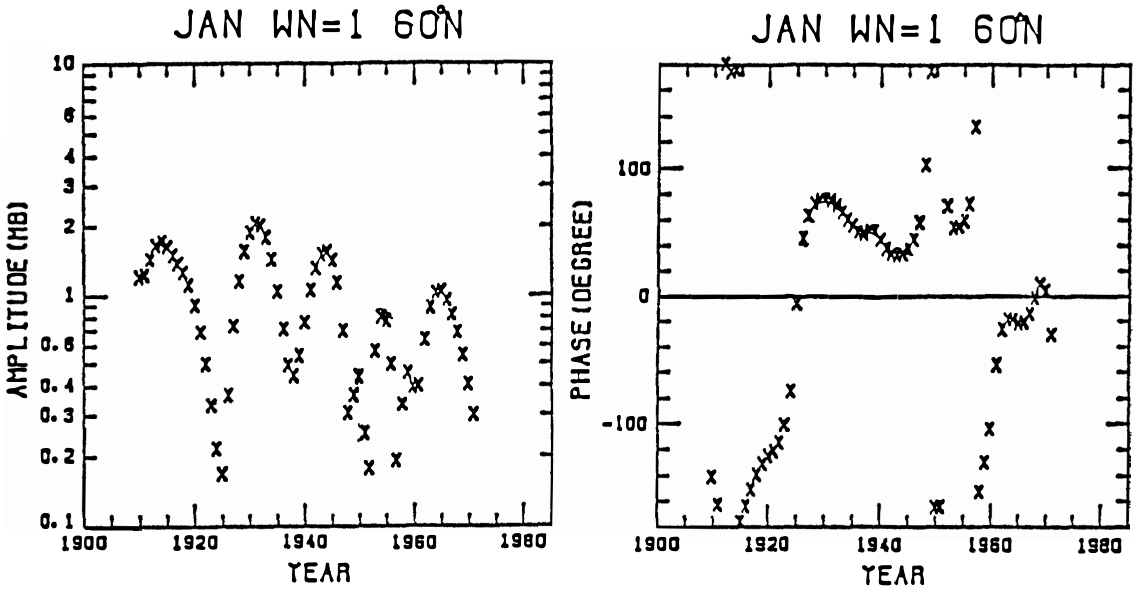

Fig. 8. Time series of the amplitudes and phase angles of zonal wavenumber one of sea-level pressure anomaly from the mean values all over the period (1900–1982) along 60°N.

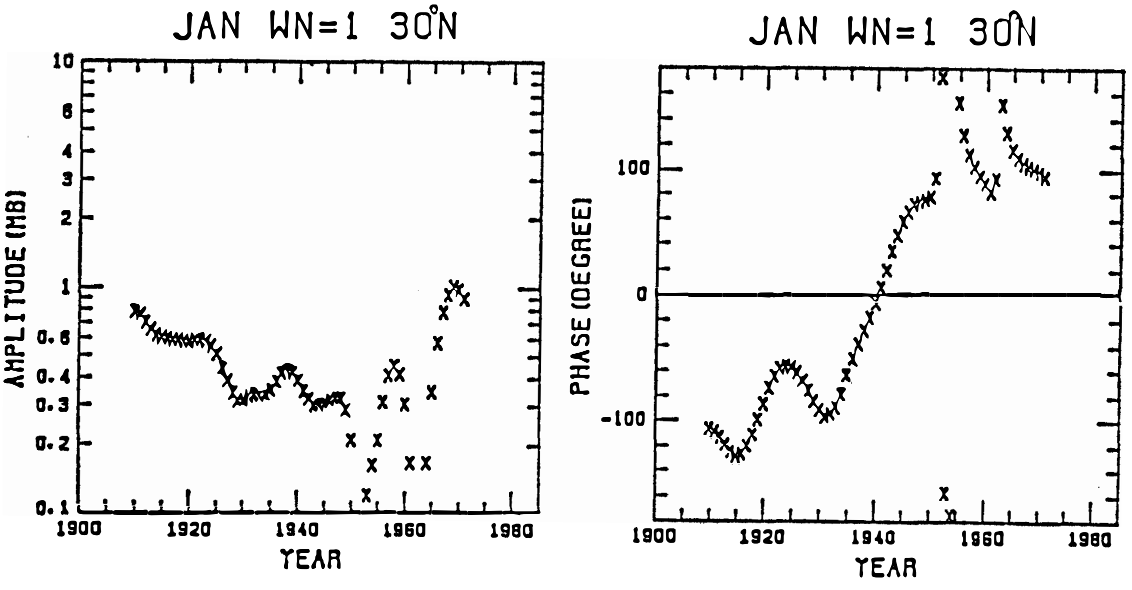

Fig. 9. The same as Fig. 8, except for 30°N.

we must keep in mind the above fact that the jump in the higher latitudes did not exceed the 90% confidence limit in their larger part, we may infer from their systematic distribution of the sea-level pressure difference that the 50's jump is nearly opposite to the 20's jump in their senses. These systematically distributed spatial patterns of the sea-level pressure difference indicate that the jumps are associated with an abrupt change of the large-scale field, corresponding to the zonal wavenumbers one and/or two. For a clearer illustration of these changes of the large-scale field, we will show the time-series of amplitudes and phase angles of wavenumber one of the sea-level pressure anomaly field at 30 and 60°N latitudinal circles in Figs. 8 and 9.

In the amplitudes of wavenumber one along the latitude 60°N we can find a little difference before and after the 50's jump, but no differences for the 20's jump. While, the 20 and 50's jumps of phase angles along 60°N are clearly seen in the figures: the phase angles before and after the 20's jump are about −160 and 40–50°, respectively; and the phase after the 50's jump is about −20–0°.

In Fig. 9 of the 30°N we can find rather large differences in the phase angles and rather small differences in the amplitudes before and after the respective jumps. In the case of wavenumber two (not shown here) we can also find rather clear differences in the phase angles and small differences in the amplitudes.

5. Discussions and Concluding Remarks

It is a very interesting but difficult question whether the jumps detected above would result from the regime transition due to the almost-intransitivity.

If no abrupt changes of the external and boundary forcings governing the climate could be found around the jumps, we could convincingly conclude that the jumps might be due to the internal cause, *i.e.* the nonlinearity of the climate system. As far as the available data of the solar activity and of the carbon dioxide concentration

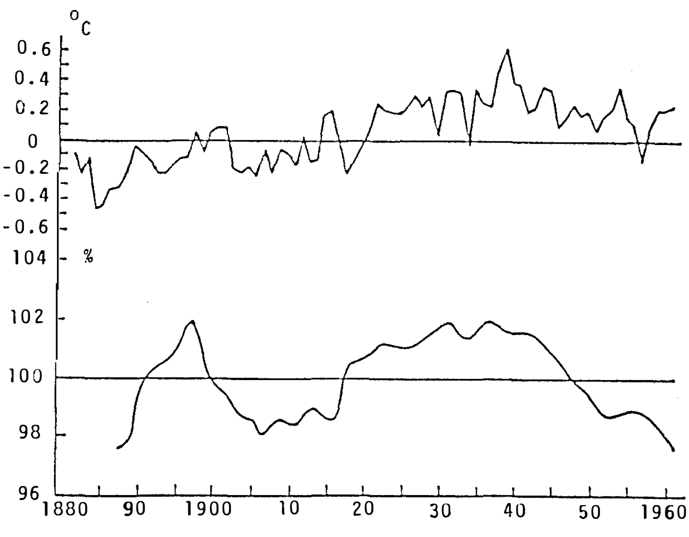

Fig. 10. Secular variations of the surface air temperature (top) and the direct solar radiation with cloudless sky which was estimated from the data at the stations in Europe and North America (adapted from BUDYKO, 1969).

in the atmosphere are concerned, no evidences of the abrupt change, simultaneous with the jumps, can be found. In Fig. 10 of the time-series data of the direct insolation given by BUDYKO (1969), which are the observational data averaged over Europe and North America, we can find rather larger increase and decrease: rather sudden increasing around the years 1917–19; and less sudden decrease around the years 1943–52. These changes may represent the hemispherical situation of the direct insolation, and may be caused mainly by change of volcanic aerosol concentration in the stratosphere, because of the good relation between the direct insolation and volcanic activity (MITCHELL, 1975).

The changes of the direct insolation occurred nearly simultaneously with the above-mentioned two climatic jumps. However, if taking into consideration that the decrease of insolation around the year 1950 is rather gradual compared with the sudden decrease of the surface air temperature, and that the surface air temperature in Japan (YAMAMOTO *et al.*, 1986), contrary to the hemispherical mean temperature, increased in the 50's jump, we cannot conclude that the jump in question is caused by the direct global effect of decrease of insolation as in the transitive system. Although there still remains a possibility that the decrease and increase of direct solar radiation due to volcanic aerosol loading play a role of a trigger for the climatic jumps, we may state, as a tentative conclusion, that the climatic jump may have resulted from the almost-intransitivity, or a manifestation of nonlinearity of the climate system. We have no further basis of argument for any quantitative conclusion at present, and this is one of our research subjects in the near future.

Acknowledgments

The climatic data over Japan used in the present work are furnished to us by the Japan Meteorological Agency. The present work is partially supported by the Scientific Fund from the Ministry of Education, Science and Culture of Japan; General Research (C) No. 61111.

References

BUDYKO, M. I. (1969): The effect of solar radiation variations on the climate of the Earth. Tellus, **21**, 611–619.

FLOHN, H. (1986): Singular events and catastrophes now and in climatic history. Naturwissenschaften, **73**, 136–149.

IWASHIMA, T. and YAMAMOTO, R. (1986): Time-space spectral general circulation model (I). J. Meteorol. Soc. Jpn., **64**, 183–196.

KELLY, P. M., JONES, P. D., SEAR, C. B., CHERRY, B. S. G. and TAVAKOL, R. K. (1982): Variations in surface air temperature; Part 2. Arctic regions, 1881–1980. Mon. Weather Rev., **110**, 71–83.

KUTZBACH, J. E. (1970): Large-scale features of monthly mean northern hemisphere anomaly maps of sea-level pressure. Mon. Weather Rev., **98**, 708–716.

LORENZ, E. N. (1976): Nondeterministic theories of climatic changes. Quat. Res., **6**, 495–506.

MCGUIRK, J. P. (1982): A century of precipitation variability along the Pacific coast of North America and its impact. Clim. Change, **4**, 41–56.

MITCHELL, J. M., Jr. (1975): A reassessment of atmospheric pollution as a cause of long-term changes of global temperature. The Changing Global Environment, ed. by S. F. SINGER. Dordrecht,

D. Reidel, 149–173.

YAMAMOTO, R. and HOSHIAI, M. (1980): Fluctuations of the northern hemisphere mean surface air temperature during recent 100 years, estimated by optimum interpolation. J. Meteorol. Soc. Jpn., **58**, 187–193.

YAMAMOTO, R., IWASHIMA, T., SANGA-NGOIE, K. and HOSHIAI, M. (1985): Climatic jump; A hypothesis in climatic diagnosis. J. Meteorol. Soc. Jpn., **63**, 1157–1160.

YAMAMOTO, R., IWASHIMA, T., SANGA, N. K. and HOSHIAI, M. (1986); An analysis of climatic jump. J. Meteorol. Soc. Jpn., **64**, 273–281.

(Received January 30, 1987; Revised manuscript received May 19, 1987)