Five-year Cycle of North-South Pressure Difference as an Index of Summer Weather in Northern Japan from 1982 Onwards

Hiromitsu KANNO

National Agricultural Research Center for Tohoku Region, Morioka, Japan

(Manuscript received 5 December 2002, in final form 15 December 2003)

Abstract

Summer weather in northern Japan since 1982 appears to exhibit a distinct five-year cycle, with the pressure difference between Wakkanai and Sendai (PDWS) as an index of this climatic variability. The temporal variation in the June–August mean PDWS in the period 1982 to 2001 progresses through four cycles, each with conspicuous similarities, such as a peak PDWS in the second year of each cycle. The temperature also progresses in similar five-year cycles, varying inversely to the trend in the PDWS. The pattern of mean surface-pressure anomalies in the second year of each cycle is typical of the Yamase, a cold northeasterly wind, and is consistent with the cool summer in northern Japan. The following year of each cycle is characterized by a prevailing subtropical high-pressure cell, consistent with the hot summer. The correlations between the seasonal variations in the PDWS, and sea-surface temperature indicate that in the summer following an El Niño event, the PDWS tends to become positive and a cool summer ensues. An area of strong positive correlation between the PDWS and the 500 hPa geopotential height, can be identified extending from Southeast Asia to east of the Philippines, appearing to be closely related to the convective activity around the western tropical Pacific. The progression of the difference in sea-surface temperature between the South China Sea, and east of the Philippines, exhibits similar temporal variations to the PDWS, and may play an important role in the sudden change from cool summer to hot summer in northern Japan.

1. Introduction

The annual variability of the summer climate in northern Japan has been the focus of much research in recent decades, because of the importance of summer weather to Japanese rice production. Since the late 1970s, the summer temperatures in northern Japan have tended to fluctuate considerably from year to year, led by characteristic circulation patterns (Nishimori 1997, 1999). Hanawa (1997) showed that the magnitude of the year-to-year temperature fluctuation in the Pacific-coast region of northern Japan was enhanced during the mid 1970s, probably associated with the 1970s regime shift, first reported by Nitta and Yamada (1989). Hanawa also suggested that the magnitude of the inter-year variation is related to a regime shift and/or climatic jump. Recently, Kurihara (2003) showed that in northern Japan, extremely hot and cool summers tend to occur alternately, with a cyclic period of about six years. That periodic cycle forms the primary focus of this paper. If the temperature, and/or weather variations, are in fact strongly cyclic, and if the cycles can be adequately defined, the accuracy of long-range weather forecasting may be significantly improved, conferring great benefits to the agricultural and economic activity of northern Japan.

Corresponding author: Hiromitsu Kanno, National Agricultural Research Center for Tohoku Region, 4 Akahira, Shimokuriyagawa, Morioka 020-0198, Japan.
E-mail: kanno@affrc.go.jp
© 2004, Meteorological Society of Japan
marily in terms of the Yamase, a cold north-easterly wind characteristic of northern Japan. This is an important phenomenon in summer northern Japan, and can result in considerable damage to crops by causing large variations in summer temperatures (Ninomiya and Mizuno 1985). The Yamase has a constant wind direction, and brings low temperatures. It can usually be distinguished from local sea breezes based on hourly wind direction and daily temperature deviation data (e.g., Kanno 1993). The Yamase blows under a characteristic synoptic pattern of high pressure over the Sea of Okhotsk, and a cyclone and/or frontal zone around the southern coast of Japan (e.g., Kudoh 1981). As these conditions result in a gradient of high pressure in the north to low pressure in the south, the pressure difference between north and south in this region may prove particularly useful in the examination of climatic variability. As an example of the use of this difference in calculating climatic fluctuations, Sato and Takahashi (2001) revealed year-to-year variations in sunshine duration and pressure distribution anomalies, based on the pressure difference between Toyama (on the Japan Sea side of central Japan) and Wakkanai (in the northern-most area of Japan). Similarly, the monsoon index in winter is calculated from the pressure difference between Irkutsk in Russia and Nemuro in northeastern Japan, and is used for the analysis of winter monsoon strength (Matsumura and Xie 1998).

As the Yamase blows when the pressure gradient varies from high in the north to low in the south, the pressure difference between northern and southern meteorological observation stations in northern Japan can be expected to reflect the strength of the Yamase event. The north-south pressure difference also reflects the rise and fall of the subtropical high-pressure cell, and as such is very useful for analyzing summer weather fluctuations. In this study, the north-south pressure difference is adopted as an index of summer weather in northern Japan, to examine the origin and structure of the periodic cycle of the summer climate in northern Japan.

In this paper, after introducing the data used for analysis, the relationships between the north-south pressure difference and the summer climate of northern Japan are discussed, and the periods of fluctuation in recent years are extracted, paying particular attention to the special features in each cycle stage. The relationships between the pressure difference, sea-surface temperature (SST), and the 500 hPa geopotential height fields are investigated in detail, and finally the origin of the extracted periodic cycle is discussed.

2. Data

The data used in calculations of the pressure difference was selected considering the locations of observation stations. Sato and Takahashi (2001) used pressure data from the Wakkanai and Toyama stations, to analyze the meteorological fluctuations in central Japan. In this study, the atmospheric pressure data (not sea-level pressure) recorded by the Wakkanai (3 m above sea level) and Sendai (39 m above sea level), meteorological observation stations is used. The Wakkanai station provides data for the northern-most area of Japan, while the Sendai station is located on the southern limit of the Yamase, and provides a good southern point of observation. The monthly mean difference in surface pressure difference between Wakkanai and Sendai (denoted PDWS) is then used as the index of climatic variability in northern Japan. The locations of Wakkanai, Sendai and other manned meteorological observation stations are shown in Fig. 1. The two major regions of northern Japan are the island of Hokkaido, and the northern area of the main island of Japan, known as Tohoku.

The relationship between the PDWS and the summer climate is extracted using the three-monthly mean (June–August; JJA) of temperature, sunshine duration and precipitation at all stations in northern Japan, for the period 1950–2002. The periodic cycle of the PDWS and the Yamase, is also investigated using temperature data from the Hachinohe meteorological observation station (shown in Fig. 1), which is located in an area that is strongly affected by the low temperatures brought by the Yamase. Some stations moved during the observation period, but despite the resulting statistical discontinuities, the general climatic trends over northern Japan, which are important to this study, can still be clearly recognized. These general trends are probably affected only to a small degree by the relocation
of these observation stations, and as such the relocation was not taken into account. The pressure data from the Wakkanai and Sendai stations are not affected by missing data or relocation problems.

The relationships between the PDWS, SST and 500 hPa height fields are examined using reanalysis data from the national Center for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR), reported by Kalney et al. (1996). Some figures are provided by the NOAA-CIRES/Climate Diagnostic Center, Boulder Colorado from their Web site at http://www.cdc.noaa.gov/.

3. Results

3.1 PDWS as an index of the summer climate of northern Japan

To investigate the relationships between the north-south pressure difference and the summer climate of northern Japan, the correlations between PDWS and some meteorological elements are calculated. Figure 1 shows the correlation coefficients between the JJA mean PDWS and temperatures in northern Japan in the period 1950–2002. The significance levels are calculated using a t-test with 50 degrees of freedom. All correlation coefficients are negative, and the significance levels are less than 1% with the exception of Onahama (the southeastern-most station), where the coefficient has a significance level of less than 5%. The northeastern parts of both Hokkaido and Tohoku exhibit high negative correlations of less than \(-0.6\), and two stations in these regions exhibit the highest correlation coefficients in this analysis \((r = -0.71)\). This correlation distribution is very similar to the temperature distribution during Yamase events (e.g., Kudoh 1981), indicating that under a high PDWS, the Yamase causes low temperatures over areas facing northeast in Hokkaido and Tohoku. The southeastern-most station (Onahama) has the lowest correlation coefficient of \(-0.28\), consistent with the weaker influence of the Yamase toward more southerly stations.

The correlation coefficients between the JJA mean sunshine duration and PDWS are shown in Fig. 2. Three stations located in the northwestern part of Hokkaido exhibit no significant correlations, with coefficients of less than \(-0.2\), and significance levels of more than 5%. The isolines generally run from north to south, and the east-west contrast in sunshine duration is generally greater than for temperature. During Yamase events, low cloud and/or fog usually encroaches from the Pacific Ocean, resulting in shorter sunshine durations. This cloud and fog is readily blocked by mountains, which run from north to south around the center of Hokkaido and Tohoku, effectively restricting the influence of the Yamase to the Pacific side (e.g., Kudoh 1984). These correlation patterns are therefore regarded as characteristic of a Yamase event.

Figure 3 shows the correlation coefficients between the JJA mean precipitation and PDWS. Many stations exhibit no significant correlation, and those stations with significant correlations are restricted to the Pacific coastal
area. Some stations gave positive coefficients of more than 0.5. When under the influence of the Yamase, the Pacific coastal area is commonly covered by a layer of low cloud and/or fog, and drizzle is common (e.g., Asai 1950). This gives rise to a positive correlation between precipitation and the PDWS. Although the stations with significant correlations are limited to the Pacific coast, it is noteworthy that under a northern-high southern-low pressure pattern, precipitation around the Pacific coast tends to increase.

As mentioned above, the PDWS is closely related to climatic variations, particularly on the Pacific side of northern Japan. Thus, the PDWS can be regarded as a good index of the summer climate in northern Japan.

3.2 Year-to-year variation in PDWS
To examine the temporal variability of PDWS, monthly and seasonal mean PDWSs from 1950 to 2002 are illustrated. Figure 4 shows the year-to-year variations in the monthly mean PDWS in the period 1950–2002. In the cold season (November–April), the PDWS is frequently negative. In winter, cyclones sometimes develop around the Bering Sea, with a strong anticyclone over the Eurasian continent. This eastern-low western-high pressure pattern is typical in winter, and gives rise to a negative PDWS.

In the warm season (May–October), the PDWS was higher during the 1950s than in the 1970s, but no distinct periodic variation can be recognized prior to 1980. The PDWS after 1980 is consistently higher than 2.0 hPa during the warm season, and can be seen to undergo cycli-
The years 1983, 1988 and 1998 produced PDWSs of over 4.0 hPa in the JJA period (and until September in 1983 and 1988). In 1993, the PDWS in August was only 2.8 hPa, increasing to 5.2 and 5.8 hPa in June and July. The averaged JJA value is thus more than 4.0 hPa. From this analysis, four PDWS peaks emerge, 1983, 1988, 1993 and 1998, with a distinct periodicity of just five years.

Temporal variations in the JJA mean surface pressures at Wakkanai and Sendai are correlated with the PDWS in Fig. 5. The pressures at both stations fluctuate from year to year with a subtle long-term variation, while the periodic and long-term variability of the PDWS is much more prominent. The PDWS progresses from higher values in the 1950s to lower values in the 1970s through short-term fluctuations of indistinct periodicity. After 1980, the nine-year running mean becomes stable, but the year-to-year variation reveals regular fluctuations with four significant peaks (1983, 1988, 1993 and 1998), and three smaller peaks (1986, 1991 and 1996). The four large peaks correspond to the four years of high PDWS shown in Figure 4, and the three small peaks occur in intermediate years in a common cycle such that the large peak appears first, and a small peak appears three years later. A large peak then appears two years after the small peak, restarting the cyclic variation.

As this characteristic cycle is not discernable before 1982, the start year for this regular
variation is defined as 1982. In the 20-year period from 1982 to 2001, a total of four complete cycles have occurred, each with a five-year period. Thus, the period since 1982 can be divided into four cycles of 1982–86, 1987–91, 1992–96 and 1997–2001.

### 3.3 Characteristics of five-year cyclic fluctuation in PDWS and temperature

The JJA mean PDWS and temperature at the Hachinohe meteorological observation station in each five-year cycle are shown in Fig. 6, with the stages within each cycle numbered 1 to 5. The temporal variations in the four PDWS cycles exhibit conspicuous similarities, such as a peak PDWS in the second year (stage 2). Three small peaks appear in stage 5. However, from 2001 to 2002, the PDWS increased such that the value in 2001 (stage 5) cannot be identified as a peak. Although the temperature varies inversely to the variation in PDWS, the variations are otherwise very similar, with minimum temperatures occurring in stage 2 of each cycle. In 1983, 1988 and 1993 (all classed as stage-2 years), rice production in northern Japan was significantly reduced, due to severe cooler weather brought by the Yamase. In contrast, summer temperatures were much higher than normal in 1984, 1994 and 1999 (all classed as stage-3 years).

Figure 7 shows the JJA mean PDWS (inverted values) and temperature deviations at the Hachinohe meteorological observation station, along with the mean temperature deviations for all of northern Japan. Although the variations in PDWS and temperature deviation are almost synchronous, the standard deviations (SDs) indicate different situations during each stage. In stage 1 for example, the SD of the PDWS is relatively large, whereas that of the temperature deviation (particularly of the northern Japan mean) is small. On the other
hand, in stage 2, the SD of the PDWS is small, while that of the temperature deviation is relatively large. These observations indicate that in stage 2, patterns of high pressure in the north appear frequently and consistently, while the temperatures vary from year to year. In stage 3, the SDs of both the PDWS and temperature deviation are large. However, it is noteworthy that the mean PDWS values in stages 1 and 3 are nearly the same, whilst the mean temperature deviation in stage 3 is consistently highest over all cycles. The cause of this sudden change in temperature, from lowest in stage 2 to highest in stage 3, will be discussed later. In stages 4 and 5, the SDs are small.

In stage 2, the northern Japan mean temperature deviation is about 0.5°C higher than that at Hachinohe. This is due to the characteristic temperature distribution pattern in Yamase events, during which the Pacific coastal area suffers directly from low temperature, while the western side remains relatively warm. The averaged temperature over northern Japan is higher than at Hachinohe. In stage 3, both areas have almost the same average temperature deviations, and both have relatively large SDs. In hot summers, a subtropical high-pressure cell dominates northern Japan, and the temperatures recorded by all observation stations rise to similar extents with only minor local variations. In stage 1, the SD of the northern Japan mean is very small (±0.15°C). Although the large temperature deviations are under investigation here, the stabilization of the temperature variation in stage 1 is also important.

3.4 Pressure anomaly distribution over East Asia

To analyze the relationship between the PDWS and synoptic pressure patterns, composite patterns of the JJA surface-pressure anomaly in two characteristic stages, cool stage 2 and hot stage 3, are shown in Fig. 8. In stage 2, positive pressures occur over the Sea of Okhotsk, accompanied by negative pressures over the southern part of Japan. Positive pressures extend from the South China Sea to east of the Philippines (Fig. 8a). Three years, 1983, 1988 and 1998, have pressure deviation patterns similar to that shown in this figure. In 1993, the area of positive pressure extends from the Sea of Okhotsk to the Bering Sea, showing that the Okhotsk high-pressure zone is extremely strong (data not shown). Therefore, the pressure anomaly patterns of these four years can be considered typical of the pressure deviation patterns during Yamase events. Consequently, the northern-high southern-low pressure pattern, in which high pressures occur over the Sea of Okhotsk and cyclones and/or fronts occur around the southern coast of Japan, is predominant in these years (stage 2) and the Yamase occurs frequently.

In stage 3, the pressure anomaly pattern is somewhat opposite to that in stage 2, becoming
negative around the Sea of Okhotsk, positive over northern Japan as part of a large positive-pressure anomaly extending from the North Pacific, and negative to the south of Japan (Fig. 8b). The four stage-3 years, 1984, 1989, 1994 and 1999, exhibit similar patterns, and this stage can be characterized by the dominating influence of the subtropical high-pressure cell and its associated hot and humid weather conditions. As the pressure anomaly patterns in stages 1, 4 and 5 are less consistent, composite charts of these stages will not be presented in this paper.

3.5 Relationship between PDWS and SST

To investigate the relationship between PDWS and SST, the correlation coefficients between the JJA mean PDWS and SST were calculated for the period 1950–1981 and the period 1982–2002. Figure 9 shows the correlation coefficients for the preceding boreal winter (December–February; DJF) in the period 1949–1981. Areas with positive correlation coefficients occur in the northern part of the Pacific Ocean and in the Atlantic Ocean, and patterns persist for an entire year, from the preceding JJA to the concurrent JJA. Indeed, areas with statistically significant correlations can be found everywhere, but the correlation coefficients are relatively small. It is notable that over the tropical Pacific Ocean, correlations involving SST before 1981 are virtually non-existent.

The correlation coefficients between the JJA mean PDWS and SST in the period 1982–2002 are shown in Figure 10. In the preceding DJF period, correlation coefficients of more than 0.6 (statistically significant) prevail from the eastern tropical Pacific Ocean to off the coast of Peru (Fig. 10a). This positive area resembles the SST distribution during an El Niño event, and also disappears in the subsequent JJA SST correlation field similar to the end of an El Niño event (Fig. 10b). In 1983, 1993 and 1998, which had summers of high PDWS (stage 2), El Niño events terminated in the summer, whereas in 1988, the El Niño event terminated in the preceding winter. From these seasonal variations in the correlation between PDWS and SST, it appears that in the period from the conclusion of an El Niño event to the subsequent summer, the PDWS tends to become positive and a cool summer ensues. On the other hand, La Niña events concluded in the low-PDWS summers (stage 3) of 1989 and 1999. However, the PDWS in 1989 is not particularly low, and no La Niña event occurred in the lead up to the low-PDWS summers of 1984 and 1994. Thus, the correlation between La Niña events, and low-PDWS summers (stage 3), is not as clear as that between El Niño events and high-PDWS summers (stage 2).

The most important feature of the JJA profiles in the period 1982–2002 is that the PDWS and SST are positively correlated (about 0.6) around the South China Sea, with a strong re-
3.6 Relationship between PDWS and 500 hPa geopotential height

The relationship between the PDWS and the atmospheric circulation pattern, is examined based on the 500 hPa geopotential height data, as shown in Fig. 11, for JJA periods in 1950–1981 and 1982–2002. The PDWS and 500 hPa height in 1950–1981 exhibit a strong positive correlation of more than 0.6 around eastern Siberia, and high negative coefficients of less than −0.6 in a region extending from central Japan to off the east coast (Fig. 11a). These positive-negative distributions are consistent with the geographical distribution of the PDWS, as expected from the close relationship between the surface pressures at the Wakkani and Sendai stations, and the surrounding 500 hPa geopotential height fields. It is noteworthy that a similar positive-negative distribution pattern is apparent around Buffin Island (positive) and Newfoundland Island (negative). It can be interpreted that the meandering of an upper westerly wave produces simultaneous height variations around Japan, and to the northeast of North America. Although there are other areas exhibiting negative correlations around the tropical oceans, there is no strong correlation in the region extending from Southeast Asia to the tropical Pacific.

The PDWS and 500 hPa height in the period 1982–2002 exhibit a strong positive correlation around eastern Siberia and the Sea of Okhotsk, and negative correlations around central Japan (Fig. 11b). These patterns are the same as observed in the period 1950–1981, except that the areas with strong positive correlations extend from Southeast Asia to east of the Philippines. The areas of positive correlation are also distributed widely over the tropical Pacific. These areas exhibited mainly negative correlations prior to 1981 (Fig. 11a), showing that the influences of the tropical SST, and land surface temperatures on atmospheric circulation, changed distinctly in the 1980s.

In comparison with the JJA mean SST correlation distributions (Fig. 10b), high positive correlation coefficients between the SST and 500 hPa geopotential height occurred around the Indochina Peninsula. This area acts as a driving force behind the periodic variability of the PDWS after 1982, as discussed later.

4. Discussion and conclusion

The PDWS after 1982 exhibits distinct periodic variations with a five-year cycle. The PDWS is closely related to the summer climate.
in northern Japan, and the periodic cycle corresponds to cool and hot summers over the last 20 years. For these periodic variations, the SST around the South China Sea is a key factor, as derived from the strong positive correlation between the PDWS, SST and 500 hPa geopotential height around the South China Sea. No strong correlation can be identified before 1981, indicating that the role of the SST changed in 1982.

The tropical Pacific SSTs have become significantly higher since the late 1970s (Nitta and Yamada 1989). The frequency of El Niño events has increased (Trenberth and Hoar 1996), and the characteristics of the onset of the El Niño event have also changed in this period (Wang 1995). Moreover, the SSTs in the North Pacific fluctuate over multiple time scales, and change from hot to cold within a similar period to the change in tropical SSTs (Tanimoto et al. 1993), strengthening the year-to-year variability of zonal wind stress in the central Pacific (Minobe and Mantua 1999). The SSTs in the western tropical Pacific have been shown to be related to the surface air temperatures in Japan (Kurihara 1985). In the case of warm SSTs, Rossby waves are generated by the tropical heat source of high SSTs, resulting in
the formation of a high-pressure anomaly over East Asia and the Northwest Pacific, and leading to a hot summer (Kurihara and Tsuyuki 1987; Nitta 1987). The El Niño is also closely correlated with the Indian monsoon (Krishnamurthy et al. 2000) and North American surface pressures (Gershunov and Barnett 1998). Consequently, the regime shift of the Pacific SSTs has affected many meteorological phenomena since the late 1970s, including the periodic variability of the PDWS.

Kawamura et al. (1998) found that from the beginning of the 1980s the inter-annual variability in the east-west gradient of summertime SST anomalies, between the South China Sea and the tropical western Pacific east of the Philippines, has become large. Using a global model, they demonstrated the emergence of extremely cold and hot summers from the difference in convection around the Philippines, and pointed out that the convective activity is suppressed (or enhanced) by SST east-west gradients formed by a positive (or negative) SST anomaly around the South China Sea, and a negative (or positive) tropical SST anomaly east of the Philippines. From this point of view, east-west SST contrasts are hypothesized to form through a strong positive correlation around the South China Sea and a weak negative correlation to the east of the Philippines (Fig. 10b), such that the convective activity east of the Philippines is theoretically suppressed during seasons of positive PDWS.

To examine this hypothesis, areas in the South China Sea (A) and east of the Philippines (B) were selected for analysis (Fig. 12), and the JJA mean SSTs in each area averaged. The temporal variations in the east-west differences (A–B) are indicated in Fig. 13. The temporal variations of the SST difference (SSTD) are

![Figure 11. Correlation coefficients between JJA mean PDWS and 500 hPa geopotential height for (a) 1950–1981 and (b) 1982–2002.](image)
similar to those of the PDWS, and similar to the surface temperatures in Fig. 6. SSTDs in all stage-2 years, except for 1988, are positive, theoretically suppressing the convective activities to the east of the Philippines. In stage 3, the SSTDs change suddenly to low values, suggesting an enhancement of convective activity. The SSTDs in stage 1 are higher compared to stage 3. Hence, the effect of convective activity in stage 1 is weaker than in stage 3, consistent with the differences in temperatures between these two stages (Fig. 6). The reason why the PDWSs in stages 1 and 3 are nearly the same, despite the differences in temperature and SSTD, is that the surface pressure pattern in stage 3 is characterized by a prevailing subtropical high-pressure cell over Japan (Fig. 8b), so that the meridional pressure gradient in northern Japan becomes weak, as in stage 1. The sudden change from cool summer in stage 2 to hot summer in stage 3 is then deeply related to the temporal variability of the east-west contrast of the SST, from the South China Sea to east of the Philippines.

This variability appears closely related to the El Niño and southern oscillation (ENSO). After Jiang et al. (1995) established the periodicity of the ENSO to be quasi-biennial and quasi-quadrennial, Zhang et al. (1998) identified three modes with distinctive spatio-temporal SST structures over the Pacific Ocean, from 20°S to 58°N. These modes were interdecadal, quasi-quadrennial (51 months), and quasi-biennial (26 months). Tomita (2000) also revealed an interannual tropical SST variability of 51–68 months in the region around 160°W. Thus, the five-year period of the present cycle is similar to the 4–5 year cycles of these previously reported modes, indicating that this newly identified cycle may be closely related to the peculiar cycle of the tropical SST, which includes the ENSO cycle. Furthermore, as demonstrated in this study, years of high PDWS (stages 2) generally correspond well with the termination of an El Niño event.

Kurihara (2003) calculated the variability of summer temperature over northern Japan based on a spectrum analysis of long-term data, and identified a six-year periodicity. As a similar spectrum analysis of the PDWS for the limited period (1982–2002) in this study (data

Fig. 12. Locations of two areas in (A) the South China Sea (10.476°N–18.095°N, 110.625°E–118.125°E) and (B) east of the Philippines (10.476°N–18.095°N, 131.25°E to 138.75°E). JJA mean SSTs are averaged over each area.

Fig. 13. Four cycles of JJA mean SST east-west differences (A–B in Fig. 12).
not shown) was not sufficient to give statistically reliable findings, the recognition of a five-year cycle in this study does not necessarily refute the existence of a six-year period. In fact, five- and six-year fluctuations would be virtually indistinguishable in the consideration of meteorological phenomena. The existence of five- or six-year weather cycles in northern Japan should therefore be considered very likely, and the understanding that such a variation exists, may lead to more accurate long-range meteorological forecasting for this region.

Acknowledgments

The author thanks Dr. Shoshiro Minobe and two anonymous reviewers for their constructive comments. The author also thanks Dr. Jun Matsumoto and Mr. Tomoshige Inoue of Tokyo University for helpful advice. Special thanks are extended to Dr. Masaharu Yajima of the National Agricultural Research Center for Tohoku Region for helpful suggestions.

References


