近年の8月における北日本の低温化とチベット高気圧の弱化との関係

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Recent cooling trend over northern Japan in August in relation to the weakening of the Tibetan high

Yoshinori NAGANO*, Hisashi KATO**, and Shuji YAMAKAWA**

*Institute of Natural Science, College of Humanities and Sciences, Nihon University, Tokyo, 156–8550, Japan
**College of Humanities and Sciences, Nihon University, Tokyo, 156–8550, Japan

Abstract

This study examines interannual changes in the behavior of the August 100 hPa Tibetan high in East Asia. In addition, this study statistically analyzes the influence of interannual changes of the Tibetan high on the weather in northern Japan. A positive anomaly of geopotential height at the 100 hPa was endured before 1991 over northern Japan, but a negative anomaly has continued since 1992 after discontinuous change. The Tibetan high weakened significantly over northern Japan since 1992. Using pressure patterns to analyze the frequency of the front appearing around Japan shows that the mean frequency has increased about 2.5 times since 1992, which is statistically significant. In addition, the temperature in Hokkaido has shown a negative anomaly since 1992, when discontinuous change also occurred. The strength of the Tibetan high is directly related to the increase in the frequency at which the front appears around Japan and the temperature drop in Hokkaido. This study also analyzes typical years. In both 1982 and 1990, when the Tibetan high was strong, temperatures were high in Hokkaido and a few fronts appeared around Japan. In contrast, in 1993 and 2002, the extent of the Tibetan high was smaller, temperatures were lower in Hokkaido, and the appearance frequency of the front around Japan was higher respectively.

Key words: Cool summer, Interannual change, Northern Japan, Stationary fronts, Tibetan high.

1. Introduction

Low summer temperatures are very harmful to many crop yields, particularly rice. Typical cool summers in 1993 and 2003 caused serious damage to rice production in northern Japan. The summer temperature in northern Japan is variable, and it has been recognized that a hot summer tends to appear after a cool summer (Kurihara, 2003). Kanno (2004) ascertained a five-year cycle in northern Japan's summer temperatures since 1982. Kato (1996) found negative temperature trends in July and August in northern Japan over the past 73 years from 1920 to 1992 after removing the urban effects from the monthly mean temperature. In the analysis of temperature data from 1898 to 2004, the Japan Meteorological Agency (JMA, 2005) reported that significant positive trends exist every season, except summer (June-August), in northern Japan. Yagai (2005) analyzed cool Augusts in northern Japan using an index defined for the "north-cold west-warm" pattern, and found that six of the ten coolest summers since 1898 had occurred during the 1990s. Although the IPCC (2007) predicts global warming in future, cooling trends may also occur in some areas such as northern Japan within relatively short timescales. Frequent cool summer events might have a large impact on society. Thus, examination of cool summers in northern Japan should begin immediately to enable prediction and adaptation.

Despite the fact previous studies showed statistically significant cooling trends or frequent occurrences of low temperatures in summer in northern Japan, they did not investigate its cause from a synoptic climatological perspective. Wakahara and Fujikawa (1997) showed that cool summers are associated with the strong Okhotsk high, the weak north Pacific high, and the weak Tibetan high by analyzing atmospheric conditions for

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the past five low-temperature years. On the other hand, by analyzing the hot summer that follows the cool summer, Nishimori (1999) indicated that two kinds of atmospheric circulation may be responsible for hot summers since the late 1970s. One type of hot summer is connected with the local anticyclones around Japan formed by warm sea surface temperatures (SST) in the western Pacific, and the other is partially connected to the strength of the northwest part of the north Pacific high and the strength of the Tibetan high. Ogasawara and Kawamura (2007) showed that the Tibetan high has an impact on summer temperature in northern Japan, by the barotropic structure of the troposphere from upper to lower. Enomoto (2004), meanwhile, demonstrated the barotropic structure occurs by propagation of the Rossby wave along the Asian jet, and indicated the anticyclonic anomaly in the upper troposphere accompanies a positive temperature anomaly over Japan in the entire troposphere, too. The aforementioned analyses show that various factors control the summertime climate around East Asia, and that the Tibetan high plays an important role in this process. For example, when the Tibetan high expands to East Asia, the Japanese summer becomes hot (Wakahara and Fujikawa, 1997).

The center of the Tibetan high is usually located over Central Asia (Fujinami and Yasunari, 2001) and covers East Asia from the upper troposphere to the lower stratosphere in summer. Enomoto (2004) indicates that an anticyclone in the upper troposphere expands toward the northeast around Japan. He named the ridge as the 'Bonin high', although it was considered part of the Tibetan high by Yasunaka and Hanawa (2006) and Ogasawara and Kawamura (2007). On the other hand, the Rossby wave propagated along the Asian jet (Terao, 1998; Enomoto, 2004). Enomoto *et al.* (2003) known as the Silk Road pattern, and the development of the Bonin high was recorded during a clear Silk Road pattern.

Zhang *et al.* (2002) discussed the behavior of the Tibetan high and found it was particularly significant in determining East Asia's precipitation. Lau (1992) pointed out the fact that the Tibetan high has an important effect on the general circulation, which directly affects the precipitation fluctuations caused by the East Asian summer monsoon, as well as tropospheric phenomena such as the west Pacific subtropical high, Hadley circulation, and Walker circulation. Yatagai and Yasunari (1995) indicated that the eastern part of the Tibetan high covers the East Asia region, so the Tibetan high affects summertime precipitation there. This work intends to investigate the importance of the Tibetan high on the summer climatological system in East Asia. Previous studies concerning the Tibetan high were only case studies and did not examine its interannual variation. With this in mind, this study shows the time variation and spatial extending pattern, especially for the eastern periphery, of the Tibetan high, and assesses how it affects the frequent cool summers that have appeared in northern Japan since the 1990s. Previous studies have not analyzed the relationship between the Tibetan high and the temperature over Japan in summer, especially the difference between July and August, although Nagano *et al.* (2008) did analyze taking the latter into consideration. They showed that the Tibetan high effects the temperature over eastern and western Japan in July, and northern Japan in August respectively. The temperature in northern Japan was high under the extent over Japan or the northward deviation of the Tibetan high over East Asia in August. Moreover, they also confirmed the relationship between the Tibetan high and the temperature over northern Japan by analyzing the case studies of cool and hot summers in northern Japan in August. The purpose of this study is to analyze the relationship between the Tibetan high and the summertime weather in northern Japan in August depending on the comparatively long time scale data.

This paper is organized as follows. Section 2 introduces the analytical methods. Section 3 describes the August changes of geopotential height at 100 hPa in Asia. Section 4 shows the relationships among the 100 hPa geopotential height, the temperature in Hokkaido, and the frequency of the front around Japan, while Section 5 describes case studies of typical hot/cool years.

2. Data and analysis methods

This study analyzed the 100 hPa geopotential height over East Asia to clarify the behavior of the Tibetan high, with emphasis on the period from 1981 to 2002. Yatagai and Yasunari (1995) analyzed the relationship between interannual variations of summertime precipitation over arid and semi-arid regions in China and Mongolia and global circulation, and used geopotential height at 100 hPa to analyze the Tibetan high. Furthermore, Zhang *et al.* (2002) analyzed the Tibetan high also using geopotential height at 100 hPa. They observed that the Tibetan high exists from the upper troposphere to the lower stratosphere and is strongest and steadiest at the 100 hPa level. In addition, a similar examination was conducted at the 500 hPa geopotential height, which is representative of the middle troposphere. These analyses used NCEP/NCAR reanalysis data. The mean geopotential heights at both 100 and 500 hPa were conducted for twenty-eight years from 1979 to 2006, and to ensure confidence in the upper-level data, TOVS satellite data was also used starting in 1979 (Kalnay *et al.*, 1996).

Furthermore, changes in pressure patterns (Yoshino, 1968) were analyzed to understand fluctuations in the frequency of occurrence of fronts on the weather charts. The pressure pattern calendar is based on weather charts published by JMA. Finally, this study analyzed the relationship between August temperatures in Japan and the behavior of the Tibetan high.

3. Changes at 100 hPa geopotential height in Asia

We examine the behavior of the Tibetan high in East Asia from 1981 to 2002, Fig. 1 shows the longitude-time cross section of the 100 hPa geopotential height anomaly from 120°E to 150°E along average from 40°N to 45°N, corresponding to the region from northeastern China to Hokkaido. From 130°E to 140°E around Hokkaido, the 100 hPa anomaly changed from positive to negative after 1991, with a few exceptions. The negative anomaly was the most remarkable in 1992 and 1993.

The Lepage test was used to inspect the discontinuous change at the geopotential height of 100 hPa in 1991. The target area is 40°N-50°N/130°E-150°E, over which the values are averaged. Fig. 2 indicates the results of the Lepage tests, which are taken from 6 to 11 years before and after every observational year, with the difference of the August mean inspected at a geopotential height of 100 hPa before and after the length of the period for the average was taken from 6 to 11 years. The Lepage test statistic (HK) exceeds 5.991 depending on the number of data used, and the level of significance is 5% for the differences between two samples (Yonetani, 1992). HK for the 1991 change exceeds 5.991 for every sample (Fig. 2). To confirm the discontinuity, we divide the time series of 1981-2002 into two parts, and applied the t-test to the difference of the means. It emerged that the difference between the paired means was significant at 1% when the length of the period was 11 years (1981-1991 and 1992-2002), 10 years (1982-1991 and 1992-2001), 9 years (1983-1991 and 1992-2000) and 8 years (1984-1991 and 1992-1999) and also at 5% with 7 years (1985-1991 and 1992-1998) and 6 years (1986-1991 and 1992-1997) by the t test. Therefore, there is evidence of a discontinuous change having occurred in 1992 at 100 hPa.

Fig. 3 indicates the differences of the geopotential height of 100 hPa in August between the eleven-year mean from 1992 to 2002 and that of 1981 to 1991. Negative values mean that the 100 hPa geopotential height anomaly of the second half of the data is lower than that of the first half in this area. Negative anomalies prevail over almost the entire area in Asia, and the center of the negative anomaly at 100 hPa

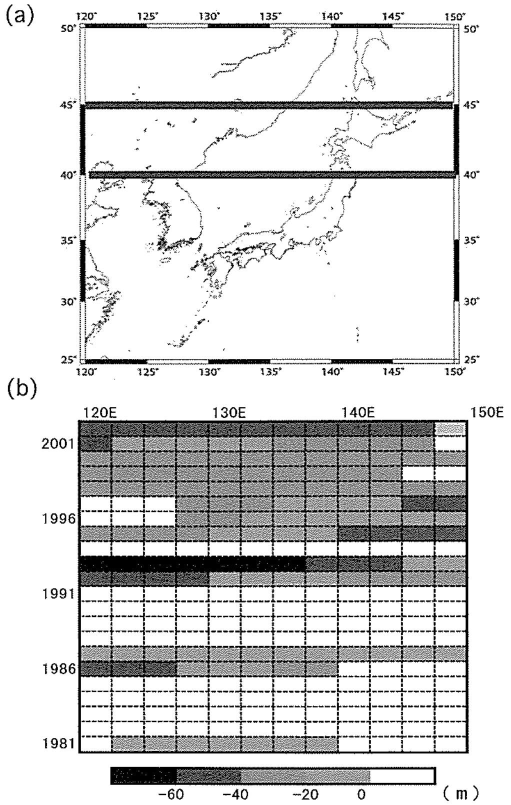


Fig. 1. Isopleths of the 100 hPa geopotential height anomaly in a longitude-time cross section from 40°N to 45°N (August 1981 to 2002).

The thick line in the map (a) indicates a section of the isopleths (b). Contour lines of (b) are drawn every 20 gpm and the hatched areas indicate negative anomalies. The data lines up time series only August from 1981 to 2002.

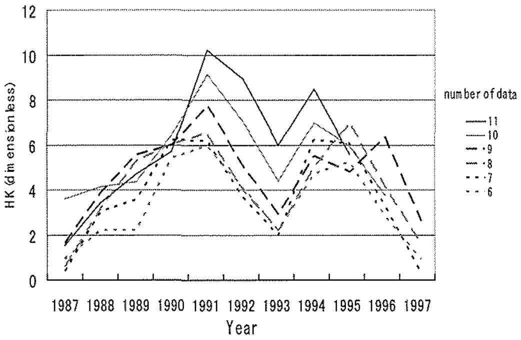


Fig. 2. The results of the Lepage test of difference of the mean from six years to eleven years for 100 hPa geopotential height (the case of separating 1991).

The horizontal axis indicates the divided year, the vertical axis indicates the size of the Lepage test statistic (HK). 6 indicates difference of statistics between from 1986 to 1991 and from 1992 to 1997. The following is the same. The number 6 of the legend in Fig. 2 indicates differences in statistics from 1986 to 1991 and from 1992 to 1997. The following is the same.

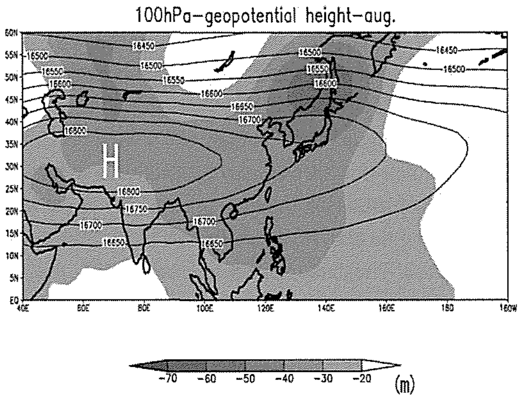


Fig. 3. Distribution chart of 100 hPa geopotential height and around Asia (August 1981 to 2002).

The solid lines indicate the average value from 1979 to 2002. Contour lines are drawn every 50 gpm and the center line is at 16800 gpm. The hatched areas show –20 gpm below the average values, which are differences between the mean from 1992 to 2002 and that from 1981 to 1991.

geopotential height is located over northern Japan. Therefore, the Tibetan high in August was weaker in the second half of the dataset than in the first.

The northward shift of the North Pacific high around

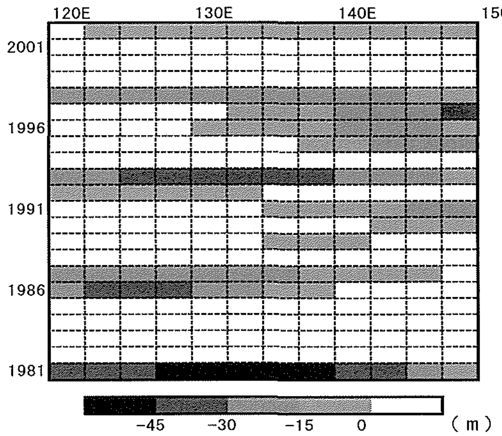


Fig. 4. Isopleths of the 500 hPa geopotential height anomaly in a longitude-time cross section from 40°N to 45°N (August 1981 to 2002).

Contour lines are drawn every 15 gpm and hatched areas indicate negative anomalies. The data lines up time series only August from 1981 to 2002.

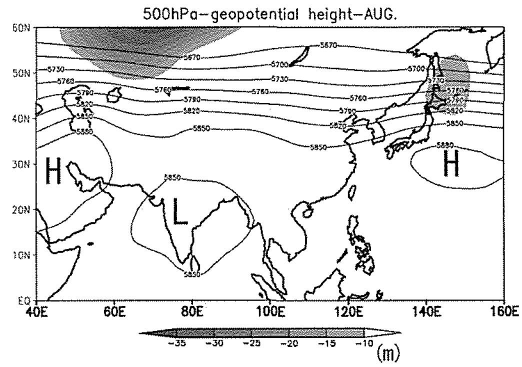


Fig. 5. Distribution chart of the 500 hPa geopotential height in and around Asia (August 1981 to 2002).

Solid lines indicate the average from 1979 to 2002. Contour lines are drawn every 30 gpm and the center line is at 5880 gpm. The hatched areas show –10 gpm below the average, which are differences between the means from 1992 to 2002 and that from 1981 to 1991.

Japan was examined using the longitude-time cross section of the 500 hPa geopotential height anomaly (Fig. 4). In the area from 130°E to 140°E over Hokkaido, a positive anomaly frequently appears in 1980s, but a negative anomaly is frequently observed after 1991. Fig. 5 is similar to Fig. 3 but for the 500 hPa geopotential height. A negative anomaly over northern Japan in August is also seen there, as well as that at 100 hPa.

As mentioned above, this study clarified the fact that both the Tibetan high, which stretches to northern Japan in the upper troposphere, and the north Pacific high, which extends to this area in the middle troposphere, were strong (weak) in the first half (second half) of the dataset before (after) 1991. This result is consistent in Enomoto (2004), in which the anticyclone, when extending over Japan in the upper troposphere, has a barotropic structure. Moreover, it also corresponds to the vertical structure reported by Nikaidou (1986) in northern Japan. With this in mind, our study analyzes how to influence the summertime weather in Japan, especially northern Japan, and divides the data into two halves for analysis.

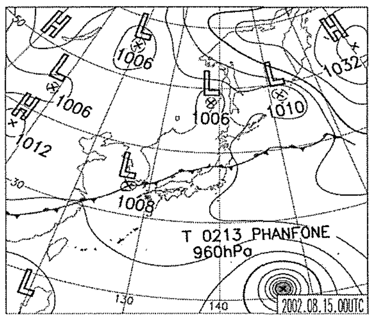
4. Variability of the surface pressure pattern

The frequency of the appearance of pressure patterns (Yoshino and Yamakawa, 1985) is analyzed for every year of both periods 1981 to 1991 (called PA) and 1992 to 2002 (called PB). In particular, the focus here is on Type IV conditions to analyze the front, appearing in summer. Type IV pressure patterns are defined as stationary frontal patterns, and Type IV is further subdivided into Types a and b. Type IVa is mainly a stationary front remaining from east to west over Japan, which was identified by Yamakawa (1988), while Type IVb is mainly a stationary front sitting from east to west along the Pacific coast of Japan or to the south. Fig. 6 shows the typical patterns of Types IVa and IVb. By analyzing data from 1941 to 1980, Yamakawa (1988) pointed out that pattern IVa occurred often in both the early 1940s and late 1960s, during which time there was considerable rainfall. The active period of Type IVb occurred from the late 1960s to the 1970s, which was marked by low temperature and much rainfall (Yoshino and Yamakawa, 1985). Thus, it is useful for this study to examine summer weather to analyze the number of IV periods having occurred.

The total days of conditions of Type IVa and IVb were compared in August to examine the frequency of PA and PB datasets on the difference between 1991 and 1992. For both Types IVa and IVb, each day of the composite- or transition-type is counted as 0.5 day. Fig. 7 indicates the total days of Types IVa and IVb on every year by bar graph. The monthly mean of Type IVa days in the PB is 9.4, about 2.5 times as many Type IVa days as in the PA (3.6 days), with a 95% significance level determined by the Lepage test and a 99% significance level determined by the t test respectively. However, the mean number of IVb days is 0.6 for both PA and PB. The number of Type IVa days in August has increased since 1992, when fronts began to appear more frequently over Japan. The increased frequency of the front has meant a decrease in the amount of sunshine on the Pacific coast of northern Japan from July to August from the mid-1980s onward (Inoue and Matsumoto, 2003). When the tendency toward the eastward expansion of the Tibetan high at 100 hPa surface changed, a notable change also emerged in the frequency of the surface pressure pattern IVa.

As mentioned in Section 3, it is evident that the retreat season of the Tibetan high from northern Japan in August changes in 1991. We analyze the difference in temperature between PA and PB at all JMA's observation stations in the Hokkaido and Tohoku districts. We also use the mean of every JMA station for thirty years from 1971 to 2000, and apply the Lapege test

(a)



(b)

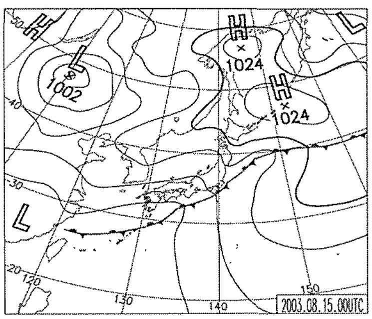


Fig. 6. The typical weather charts of the pressure patterns of Type IVa (a) and Type IVb (b).
(a) on August 15th, 2002, (b) on August 15th, 2003.

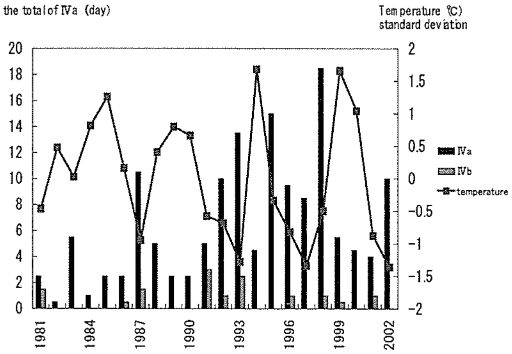


Fig. 7. The total days of surface pressure pattern and fluctuations of the temperature at all the observational stations maintained by JMA in Hokkaido in August.

The horizontal axis indicates year, the left vertical axis indicates the total days of Type IVa and IVb (bar graph), the right vertical axis indicates the temperature in Hokkaido. The standard deviation is 1.49℃.

at every observational station. The three stations of Sapporo (Hokkaido), Sendai and Onahama (Tohoku) were not used because Sapporo and Sendai are greatly influenced by heat islands, and Onahama lacks data for the periods of interest. Even though low temperatures tend to occur everywhere in Hokkaido, eight stations were judged to be significantly different at the 95% confidence interval by the Lapege test. Although the temperature tends to decrease in Tohoku district, its overall trend does not differ by a statistically significant degree at each station. This can be understood when considering the existence of a center of negative 100 hPa anomaly over Hokkaido (Fig. 1). The influence on the Tibetan high of the surface temperature is greater in Hokkaido than in the Tohoku district.

Fig. 7 indicates the temperature fluctuations in Hokkaido in August in a line graph. However the right vertical axis shows standardized temperature. The temperature correlates negatively to the total days of Type IVa conditions with a 5% significance level. All Type IVa conditions occur over six days when the temperature is higher in August than in a normal year. This paper has already clarified the fact that the frequency of IVa was lower in the PA period and its number was less than six days, except 1987. However, in the PB period, there are seven years, including over six IVa pattern days. In particular, five years have ten days and the maximum frequency in 18.5 occurred in 1998.

The temperature during the period PA was higher than normal for many years; conversely, during the PB, it was often lower than normal.

5. The case study

The case study was carried out for two typical years when the Tibetan high was strong (1982, 1990) and two when it was weak (1993, 2002). Both 1982 and 1990 belong to the period PA, while both 1993 and 2002 belong to the period PB. This case study also investigated how the temperature in Hokkaido was influenced by the Tibetan high at 100 hPa over northern Japan. To analyze details of these four years in August, Fig. 8 indicates isopleths of a geopotential height of 100 hPa in a longitude-time cross section (left panel) and fluctuations of the daily normal temperature in Hokkaido in August (right panel). The hatched area shows levels above 16700 gpm at 100 hPa; the 16680 gpm contour line at 100 hPa was determined as the eastern edge of the Tibetan high overhanging northern Japan following examination of the hot 1994 summer (Wakahara and Fujikawa, 1997). The daily time-series temperature is shown. It is averaged by observational data in Hokkaido except Sapporo. On both the left and right panels, the vertical axis indicates progress from the bottom to the top.

1982 saw the least number of Type IVa conditions occurring, and the monthly temperature exceeded normal levels by half the standard deviation (Fig. 7). Analysis of the daily temperature change for August 1982 showed that it remained above normal until about the 20th, except on the 12th. Based on geopotential over 16700 gpm height at 100 hPa from 120E to 150E until the 20th, the Tibetan high expanded over East Asia. In late August, however, it was relatively higher on the east side of 130E, there was the ridge over Japan. This corresponded to the Bonin high defined by Enomoto *et al.*, (2003). At these times, the temperature in Hokkaido was higher than in a normal year. The case study reported that surface temperature increased when the Bonin high occurred in mid-July in 2004 (Enomoto, 2005). In 1982, this study revealed high temperature in late August, with a similar height pattern also recurring in the upper troposphere. However, the temperature was lower than normal from the 23rd to the 27th, while after the 28th, it was higher than normal again. The daily change at the geopotential height of 100 hPa (Fig. 8a) corresponded to the surface temperature; at

140°–150°E over Hokkaido, the 16700 gpm 100 hPa contour line moved westward on about the 12th and from the 20th to the 25th, indicating the weakness of the overhanging Tibetan high. In 1990, the number of Type IVa days was 2.5 and the monthly temperature exceeded the normal level by 0.7 times the standard deviation (Fig. 7). The center area with the highest value of more than 16800 gpm at 100 hPa appeared from 130E to 140E over Japan around the 20th. This ridge was alike in late August in 1982. In addition, there were areas over 16700 gpm in East Asia at the beginning and around 25th. The height distribution was zonal in the former case, and higher on the west side in the latter, with the Tibetan high expanding eastward from its center. At the same time, the higher temperature remained higher than normal in Hokkaido. However, both before and after the 15th and before and after the 25th, it was lower than at other times, and the anomaly of the temperature became around 0℃ at that time. The temperature changed relatively little in 1990 when it remained 1℃ above the daily normal (Fig. 8b).

In 1993, various evidence shows it was a typical cool summer in Japan; the monthly August temperature in Hokkaido was lower than the normal by 1.3 times the standard deviation (Fig. 7) and the number of type IVa days was 13.5, the third greatest number for any period. The variation of daily normal temperature and

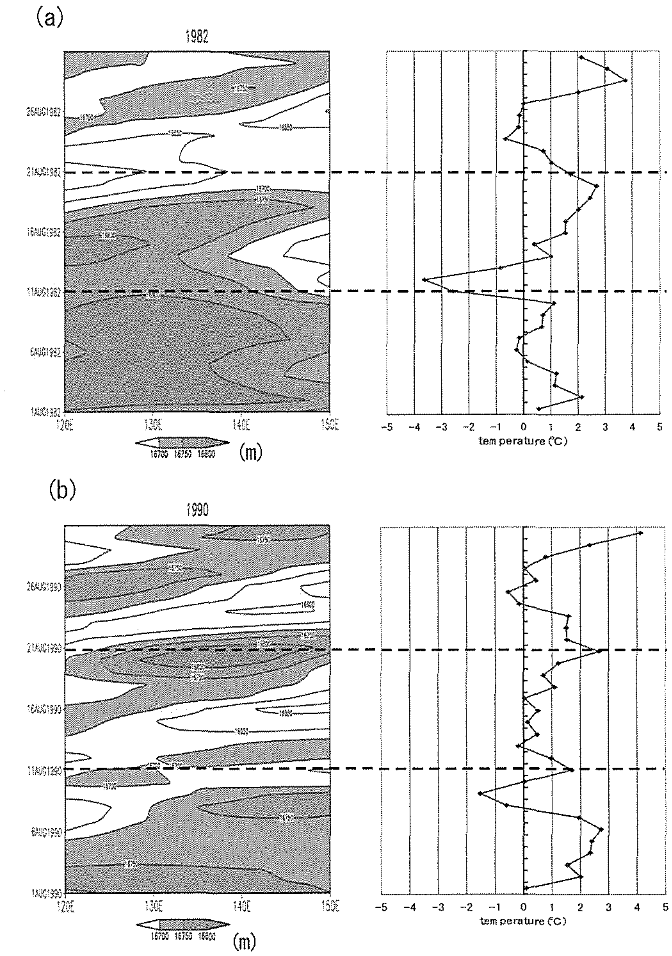


Fig. 8. Isopleths of 100 hPa geopotential height in a longitude-time cross section from 40°N to 45°N and fluctuations of daily mean temperature for all JMA's observational stations in Hokkaido in August.
(a) 1982 (b) 1990 (c) 1993 (d) 2002
Hatched areas show the higher-level over 16700 gpm. Contour lines are drawn every 50 gpm. Daily fluctuations of temperature illustrate the anomalies in 1982, 1990, 1993, and 2002.

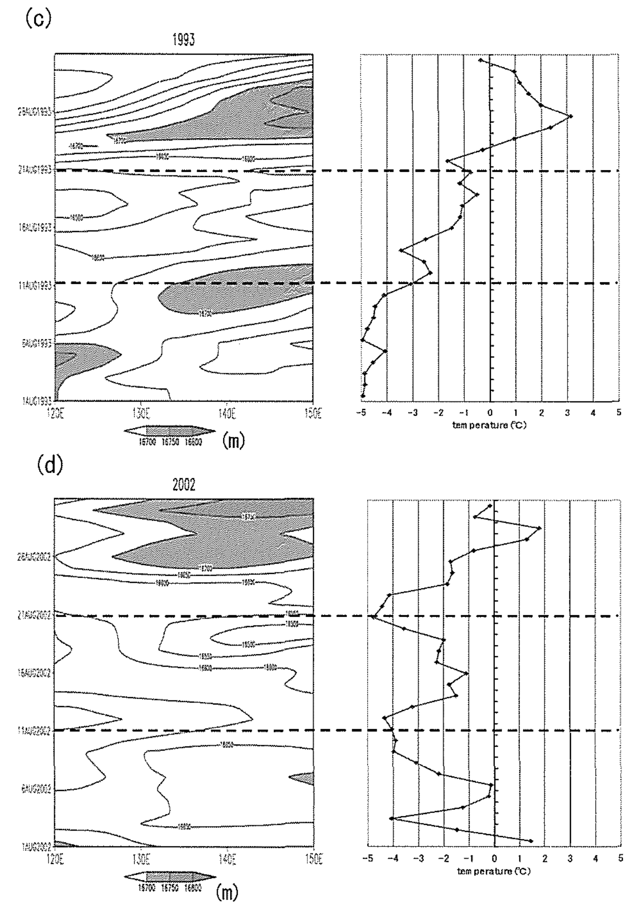


Fig. 8. continued.

low temperatures changed in early and mid-August. However, the geopotential height at 100 hPa was low during both these periods, though later in August, when the surface temperature increased, the 16700 gpm contour line at 100 hPa appeared over Hokkaido (Fig. 8c). As for around 25th, the ridge at 100 hPa on the east side of 150E moved over the east so the propagation of Rossby wave differed from the Silk Road pattern along the Asian jet (Enomoto *et al.*, 2003). The temperature was lower than normal in 2002 by 1.4 times the standard deviation (Fig. 7), and the coolest summer of the period was recorded, with only three days above the normal temperature: the 1st, the 28th, and the 29th. The Tibetan high continued weakly until late August from 120E to 150E, and the temperature was lower than a normal year. The 16700 gpm contour line at 100 hPa appeared over Hokkaido after the 26th, this area was higher than the west side of 130E, the ridge of the pressure, which corresponded to the time surface temperature increase (Fig. 8d). Therefore, the temperature in Hokkaido rises in proportion to the Tibetan high at 100 hPa above the area.

6. Discussion and Conclusions

Through analysis of the 100 hPa geopotential height in August, this study showed that the effect of the Tibetan high was weak for northern Japan after 1991. The discontinuous change that occurred in 1991 was identified by the t-test or the Lepage test, and a statistically significant decrease was also observed over northern Japan. These facts indicate that the behavior of the Tibetan high weakened after 1991. The weakness of the Tibetan high corresponds to the negative anomaly trend at the geopotential height of 500 hPa, we found the barotropic structure in the troposphere. Nikaidou (1986) analyzed the potential vorticity off Sanriku and showed that a negative anomaly acts around Japan in developing the midsummer subtropical high, and that this negative anomaly was the barotropic structure leading to the stratosphere. Consequently, there was a barotropic structure in the troposphere around Japan, which is consistent with Nikaidou (1986), Enomoto (2004), Enomoto (2005) and Ogasawara and Kawamura (2007). This study shows the development of the barotropic high from the upper to lower troposphere during the PA results in high temperatures, because the barotropic high around Japan is higher than the other areas of the troposphere from its upper to lower levels (Enomoto, 2004). Moreover, the front tended to stay around Japan and the surface temperature in Hokkaido decreased during period PB. A poorly developed high during PB conversely results in low temperatures and lingering of the front. The fronts tend to appear about 500 km south of the jet stream in the upper troposphere (Akiyama, 1990) and when the Tibetan high weakens, the jet stream goes southward. The fronts are also likely to linger around Japan. By analyzing the change in temperature in Northeast Japan focusing on Miyako in Iwate, Hanawa (1997) pointed out the fact that temperatures in the 1980s, which peaked in the past eighty years, equaled those of the 1940s. Our study corresponds to the period studied by Hanawa (1997), when the temperature was high in the 1980s. According to the results of this study, the strength of the Tibetan high influenced the high temperature in the 1980s. We investigated typical cases, both in 1982 and 1990, during the period of the PA, and discovered that the Tibetan high was strong, the temperature was high in Hokkaido, and the front appeared infrequently. However, in both 1993 and 2002 in the PB, the Tibetan high was weak, the temperature was low, and the front was dominant. However, every year, the temperature was lower than normal when the Tibetan high was relatively weak over northern Japan. The link between the expansion of the Tibetan high and the temperature in northern Japan corresponds to Ogasawara and Kawamura (2007).

One possible factor affecting the weak overhang of the Tibetan high during PB could be the eruption of Mt. Pinatubo. Pollack *et al.* (1976) showed that volcanic aerosols trigger the cooling of the earth's surface and warming of the stratosphere due to thermal radiation. The eruption of Mt. Pinatubo significantly affected the upper levels of the atmosphere (Maruyama and Kodera, 1993; Yagi, 1994). Its 1991 eruption was the second largest volcanic eruption in the 20th century and resulted in the cool summer of 1993 (Yamakawa, 1997). Ozone destruction induced by heterogeneous chemical reactions involving Mt. Pinatubo aerosols were expected to persist until at least mid-1993 (Gobbi *et al.*, 1996). The remarkable drop at 100 hPa geopotential height in both 1992 and 1993 suggests the possible effects of Mt. Pinatubo's eruption in 1991.

The JMA report on global warming (2005) states that the increase in Central Asia's surface temperature, where the center of the Tibetan high exists in summer, is the most remarkable in the world. The behavior of the Tibetan high affecting East Asia influences the Tibetan high's center location along with its strength (Zhang *et al.*, 2002). This suggests that global warming may have partially contributed to the weakening of the Tibetan high in recent years.

This study indicates that the extent of the Tibetan high was smaller and the temperature lower after 1991. Hanawa (1997) pointed out that periodic changes in summer weather comparatively balance over time and the significant change of the temperature since the late 1970s is recognized in the past eighty years. Therefore, the trend toward cool summers in northern Japan should not always continue in future as Yagai (2005) found. However, cool and rainy summers may cause agricultural failures as we have already experienced in 1993. The factors considered in this study, namely the eruption of Mt. Pinatubo, and global warming, may all have weakened the Tibetan high, and detailed studies are warranted. Furthermore, it is particularly necessary to study trends in the Tibetan high caused by global warming after accumulating more data. Although there is a statistically significant correlation between the number of Type IVa and annual temperature, the relations seem to weaken for some years. This indicates the need for additional investigation into the influence of other factors apart from the Tibetan high. This possibility must be analyzed in future and it is important to connect the predictions of cool summers in northern Japan with trends in the Okhotsk high and the condition of the subtropical high-related SST in the western tropical Pacific.

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近年の8月における北日本の低温化とチベット高気圧の弱化との関係

永野良紀＊・加藤央之＊＊・山川修治＊＊

（＊日本大学文理学部自然科学研究所
＊＊日本大学文理学部）

要　約

8月のチベット高気圧の東アジアへの張り出しの年々変動を解析した．また，チベット高気圧の変動が北日本への天候の影響を統計的に解析した．北日本上空における100 hPa高度場は，1991年以前は正偏差であったが，1992年以降では負偏差が続いており，1991年を境に有意な不連続が認められた．8月のチベット高気圧は，1991年を境に北日本への張り出しが弱まっていることが統計的に確認された．気圧分類型を用いて日本付近における前線の出現日数を調べた結果，1992年以降の平均出現日数が1991年以前の平均出現日数の2.5倍になり，統計的にも有意な差が認められた．また，北海道における気温も1992年以降は負偏差が続いており，有意な不連続が認められた．日本付近における前線出現日数の増加や北海道の気温の低下はチベット高気圧の盛衰と連動していた．代表的な事例の解析も試みたが，チベット高気圧の張り出しが強かった1982年，1990年は北海道でも気温が高く前線出現は少なかった．対照的にチベット高気圧の張り出しが弱かった1993年や2002は北海道では気温が低く，前線も平年より多く出現していた．

キーワード：北日本，チベット高気圧，停滞前線，年々変動，冷夏