LONG TERM VARIATIONS OF SUMMER TEMPERATURES IN TOKYO SINCE 1721

Takehiko MIKAMI

Abstract In Japan, summer temperatures are highly correlated with precipitation frequencies. Based on this assumption, we made an attempt to reconstruct summer (July) temperatures in Tokyo for 1721-1995 by using weather records in old diaries in the western suburbs of Tokyo. The results indicate that summer temperatures of Tokyo during the 18th and 19th centuries were estimated to have been 1 to 1.5 degrees lower than today. However, it was rather warm in the early 19th century, and rather cool in the 18th and early 20th centuries. A result of power spectrum analysis reveales several periodicities related to the solar cycle (21 and 10.5 year), ENSO cycle (6.3, 5.0 and 3.2 year) and QBO (2.18 year). Cool episodes in the 1780s, 1830s and 1900s are in accordance with poor rice harvests and severe famines. A comparison with the reconstructed July temperatures in Beijing, China shows opposite trends in the 18th century and similar trends since the late 19th century.

Key words: summer temperature, weather record, climate reconstruction, Little Ice Age, Tokyo

1. Introduction

It has been suggested by many historical documents that the climate and weather of Japan in the 18th and 19th centuries, which were corresponding to the latter half of the Little Ice Age, might have been rather cool and wet as compared to the present climatic conditions, especially in summer. For example, severe famines occurred recurrently in the 18th and 19th centuries from northeastern Japan to central and southwestern Japan. In Japan, great famines were mostly caused by poor rice harvests under the influence of extremely cool and rainy summer weather conditions. Therefore it would be significant to evaluate climate variations and variabilities during the Little Ice Age quantitatively for the purpose of predicting future climate variabilities.

In order to clarify long term variations in temperature and precipitation from decadal to century time scale, some statistical analyses should be taken into account to combine both meteorological data and proxy climatic record. For instance, the length of available meteorological data in Tokyo is only 120 years since the establishmment of the Tokyo Meteorological Observatory in 1875. Before this year, we have very few continu-

ous instrumental and meteorological data in Japan to discuss interannual and interdecadal climate variations and variabilities. Thus it would be required to reconstruct long term temperature series in objective and quantitative methods based on proxy climatic records in historical period.

A number of studies have attempted to reconstruct climate variations in Japan during the Little Ice Age on the basis of proxy climatic records in historical documents, among which continuous weather records in old diaries would be most effective (*e.g.*, Maejima and Tagami, 1983, 1986; Mikami, 1987, 1988, 1992, 1994; Mikami and Tsukamura, 1992; Murata, 1992, 1993). These studies proved that weather records in old diaries were usuful and powerful tool for reconstructing past climate variations in Japan. Both private and official diaries have been found in various regions, most of which are kept in local libraries and museums. Some of the private diaries, which have been kept for more than 200 years from generation to generation, give us valuable information on long term climate variations.

The purpose of this paper is to clarify interdecadal variations in summer temperatures in Tokyo for 1721—1995 based on both instrumental data and weather records in old diaries, and to describe long term trends and periodicities revealed in the temperature time series.

2. Summer Temperature Variations in Tokyo Based on Meteorological Data

Before describing the long term reconstructed summer temperature time-series, we will examine variations in observed (meteorological) temperatures in Tokyo for summer months; June, July and August during 1876-1995. Figure 1 shows year-to-year variations in monthly mean temperatures (solid line) and 11-year running means (broken line) for each summer month.

The most prominent features of these temperature series might be the coolest decade which appeared just after the turn of the century and the following warming trend till around the 1940s. Since the 1940s, June and August temperatures show slight increasing trends, whereas July temperatures seems to have been stationary with large year-to-year variabilities. In 1994 and 1995, we experienced extremely hot summers, in which temperatures of July 1994 and August 1995 recorded their highest values since 1876. On the other hand, we had very cool summers in 1980 and 1993, which were comparable to the coolest decade of the 1900s. Interannual temperature variabilities apparently become larger for the last 20 years as compared to those in the 1950s and 1960s.

The reason why three summer month temperature time-series show slightly different trends could be explained by the distinct mechanisms of temperature and atmospheric circulation relationships in each month. From synoptic climatological point of view, the main atmospheric circulations and the center of action in summer months would be the strength of Okhotsk Anticyclone (Blocking High) in June and July, the displacement and activity of polar (Baiu) fronts in July, and the northwestward expansion of North Pacific Anticyclone (Subtropical High) in July and August.

In considering the temperature trend of Tokyo since around the 1940s, attention

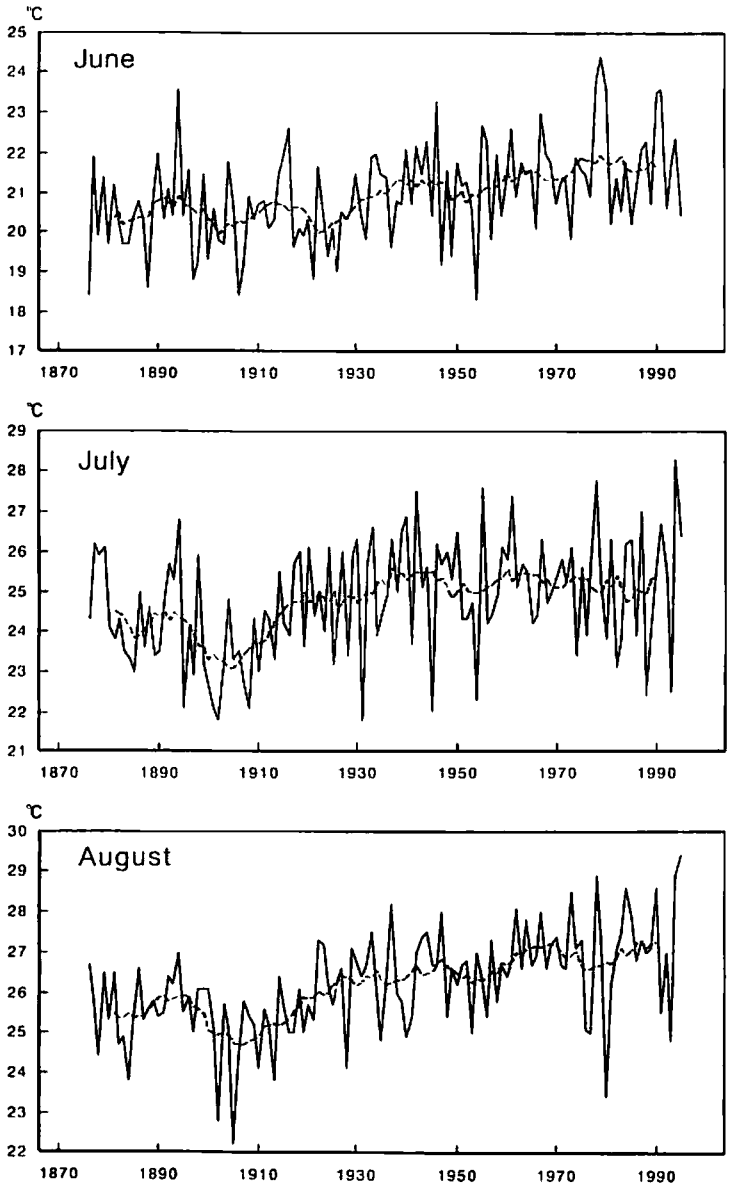

Fig. 1 Monthly mean temperature variations of Tokyo in June. July and August for 1876-1995 Broken line indicates 11-year running means.

should also be paid to the recent global warming due to anthropogenic greenhouse effects and the effect of urban heat island phenomena.

3. Temperature Reconstructions Using Weather Records

In order to discuss the decadal to century scale variations in summer temperatures of Tokyo, above-mentioned meteorological data for the last 120 years would be insufficient. Thus we made an attempt to reconstruct summer temperatures in Tokyo based on weather records in old diaries. The data used in this study are daily weather records in the continuous diaries of Ishikawa's Family (Ishikawa diaries) in the western suburbs of Tokyo kept from generation to generation since 1721. All the weather data were extracted from these diaries and compiled as a form of weather calendars by Yoshida(1987) for the period 1721-1940.

In general, we have hot summers in Japan under the influence of strong subtropical high which bring us dry and sunny weather conditions, whereas we have cool summers under the influence of stagnant polar fronts and passing extratropical cyclones which bring us cloudy and rainy weather situations. This suggests that there may be high correlations between the number of rainy days and the mean temperature in summer month. Fortunately, both historical weather records in Ishikawa diaries and meteorological observed data in Tokyo (JMA data) overlapped for 65 years from 1876 to 1940, during which we could check and verify both data each other.

So, we first compared the number of rainy days in Ishikawa diaries and JMA data. Concerning JMA data, the rainy day was defined as a day when daily rainfall exceeds 1 mm. During the overlapped period (1876-1940), the average number of rainy days in Ishikawa diaries for June, July and August were 9.2, 8.4 and 7.7, respectively, while those in JMA data for June, July and August were 10.8, 8.7 and 7.1, respectively. Although June rainy days were underestimated in Ishikawa diaries, July and August rainy days demonstrated good agreement between Ishikawa diaries and JMA data.

In order to confirm the temperature and rainy day relationships, correlation coefficients were calculated using JMA data between the number of rainy days and the mean temperatures in summer months for the overlapped period (1876-1940). Correlation coefficients for June, July and August are -0.41, -0.70 and -0.45, respectively. Because July mean temperatures are most highly correlated with the number of rainy days in a month, it would be possible to reconstruct July temperatures in Tokyo for the period 1721-1940 based on the weather records in Ishikawa diaries. As for June and August, other weather information such as the number of fine days or cloudy days might be effective to estimate mean temperatures in historical period. In this study, we will focus on the July temperature reconstructions, since July temperature variations could roughly represent the summer temperature variations for century time scale as indicated in Fig. 1.

We applied a simple Least-square regression method to the July mean temperatures and the number of rainy days in Tokyo (JMA data) for 1876-1940 (Fig. 2). We obtained the linear regression equation $Y = 26.46\text{-}0.235X$, where X (predictor) is the number of

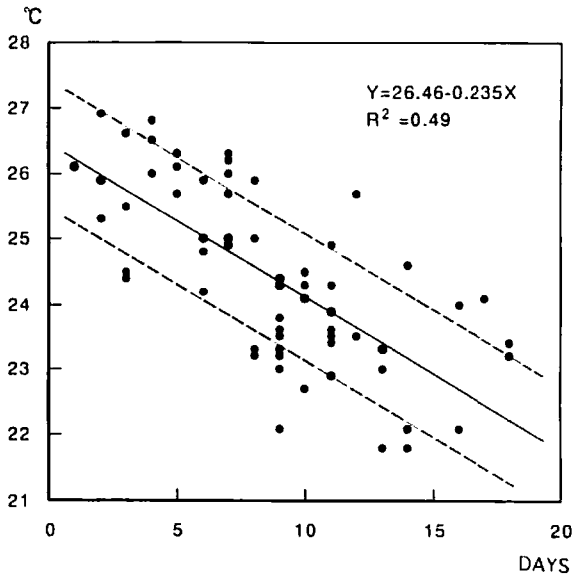

Fig. 2 Scatter diagram which shows relationships between the number of rainy days and monthly mean temperatures of Tokyo in July for 1876-1940

rainy days and Y (predictant) is the monthly mean temperature in July. The coefficient of determination R^2 equals 0.49 and the standard errors of Y is 0.98. Based on this regression equation, we estimated July temperatures in Tokyo for each year from 1721 to 1940, in which both proxy (historical) and observed (meteorological) data were available from 1876 to 1940.

4. July Temperature Variations in Tokyo for 1721-1995

Characteristics of variations and trend

By combining the reconstructed temperature time series for 1721-1940 with the observed temperatures of JMA data for 1876-1995, long term variations in July temperatures for the period 1721-1995 have been revealed. Figure 3(a) shows year-to-year variations, where both reconstructed (broken line) and observed (solid line) temperatures are separated. Figure 3(b) displays smoothed temperature curves with 11-year running means. Shaded area indicates that temperatures were below the average of 1961-1990.

Estimated temperature series shows several cooler and warmer periods. From 1721 to 1790, temperatures are estimated to have been around 1 to 1.5 degrees lower than present. During this period, July temperatures show large year-to-year variabilities with the lower values below 22 degrees in 1728, 1736, 1738, 1755, 1758, 1783, 1784 and 1786. It should be noted that the temperatures in the 1780s were often extremely low with large interannual variations. In the summer of 1783, they experienced an extremely poor rice harvest under the influence of exceedingly cool and wet climate conditions, and this unusual weather brought a historic severe famine in Japan (Mikami, 1987,1992).

On the other hand, it was rather warm in the 19th century, especially in the 1810s and

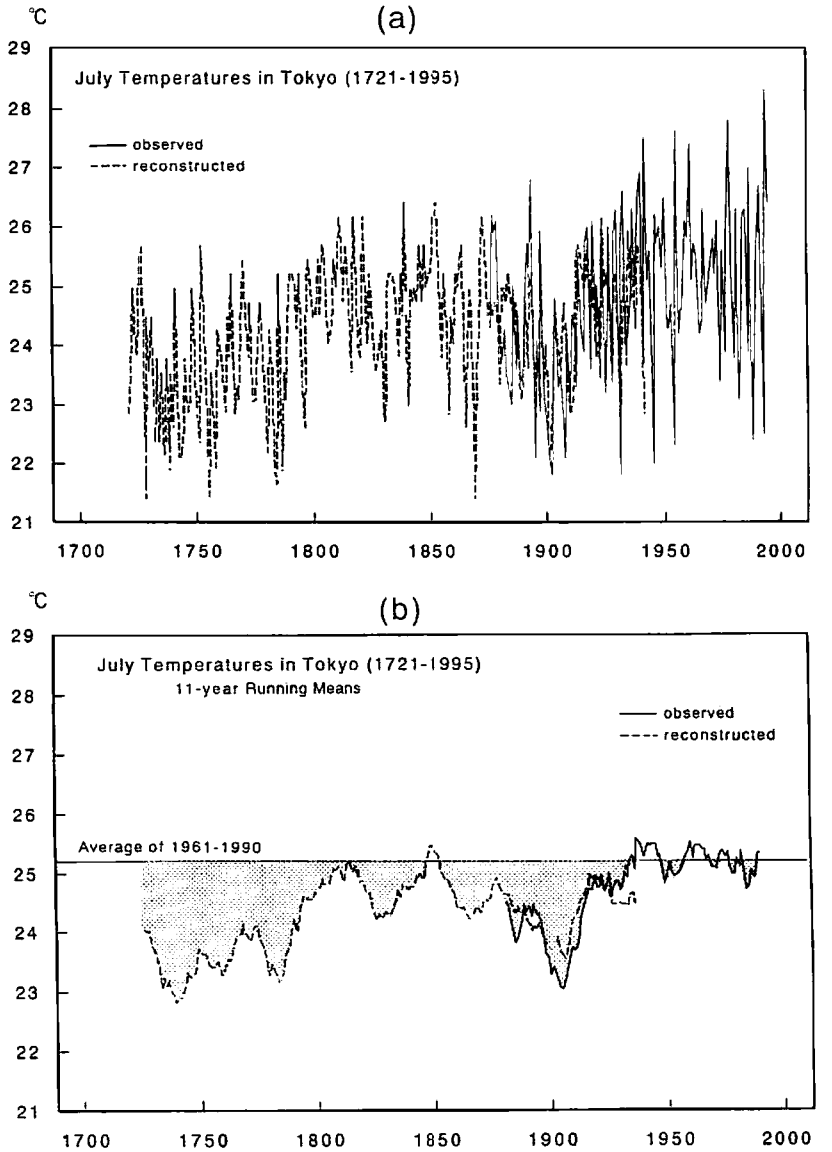

Fig. 3 Combined time series of reconstructed (broken line) and observed (solid line) July temperatures in Tokyo for 1721-1995
(a) year to year variations; (b) smoothed curve by 11-year running means

early 1850s with the higher values above 26 degrees in 1811, 1817, 1821, 1851, 1852 and 1853. Among these warmer periods, the 1830s, late 1860s and late 1890s were relatively cool decades, and great famines occurred recurrently in the 1830s as appeared in the 1780s. July temperatures reached their lowest level around 1900, when 11-year mean temperatures were as same as those around 1740. It is interesting to note that there may be 160 year periodicities in summer temperature variations, which should be examined more in detail and careful.

Since both reconstructed temperatures based on weather records and observed temperatures overlapped in the period 1876-1940, we can verify the reliability of reconstructed temperature time series. As indicated in Fig. 3, both time series are well correlated during the overlapped period. Observed temperatures show remarkably the lowest level around 1900, which also appeared clearly in the reconstructed temperature series.

Periodicities

In the long term July temperature series, there might exist some periodicities which are climatologically significant. Therefore, we applied power spectrum analysis by Maximum Entropy Method to the July temperature time series from 1721 to 1995, in which reconstructed series for 1721-1875 and observed series for 1876-1995 were combined into a single 275 years time series.

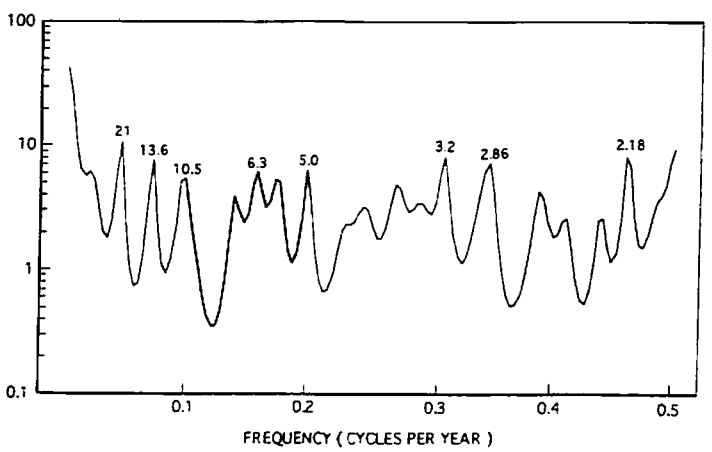

Fig. 4 Power spectrum of July temperature series in Tokyo for 1721-1995 by MEM

As shown in Fig. 4, several spectral peaks can be detected, such as 21, 13.6, 10.5, 6.3, 5.0, 3.2, 2.86 and 2.18 years, though we have no efficient method to check the confidence level of each spectral peak. These peridicities might be related to some causes of global climate variations. Periodicities of 21 and 10.5 years are sunspot cycles, which may related to variations in solar activities. Whereas, periodocities of 6.3, 5.0 and 3.2 years will probably be connected with ENSO cycles, which have strong correlations to SST in

the equatorial Pacific Ocean. Peridicities of 2.18 year seems to be related to QBO (Quasi-Biennial Oscillation), which is also detected in the long term variations of the periodicitiy of drought and flood in the Yangtze River region and north of the Yellow River in China by Wang and Zhao (1981).

Comparison with Chinese temperature reconstructions

Wang *et al.*(1992) reconstructed July temperatures in Beijing, China for 1724-1986 based on the rainfall records in historical documents. As pointed out in the previous section, July climates of Tokyo was comparatively cool and wet in the 18th century. By contrast, Wang *et al.* (1992) estimated that it was rather warm in Beijing during this period. On the contrary, it was cool in the 1800s and 1810s in Beijing. Since the 1840s, both Beijing and Tokyo temperature variations show similar trends. However, the temperature bottom of Tokyo around 1900 appeared earlier in Beijing.

Such differences depicted in the long term trend of summer temperature variations in Beijing and Tokyo might have been caused by the changes in atmospheric circulation patterns in East Asia.

5. Conclusions

July temperature variations in Tokyo for 1721-1940 were reconstructed based on the long term weather records in the diary of Ishikawa's Family in the western suburbs of Tokyo. Reconstructed temperature series were linked with observed meteorological data in Tokyo for 1876-1995. Thus we obtained 275 years long continuous time series of July temperatures in Tokyo. The results show that July temperatures in the middle of 18th century were 1 to 1.5 degrees lower than present. Several periodicities related to solar activities, ENSO and QBO were detected. It should be noted that the reconstructed July temperatures in Tokyo show both positive and negative correlations with those temperature series in Beijing by Wang *et al.*(1992). Further studies should be made to clarify the mechanisms of long term variations and variabilities in summer temperatures in Japan, as well as in East Asia.

Acknowledgements

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