Climatic Change in March Temperature Deduced from Phenological Record for Flowering of Cherry Tree in Tokyo since the Late 18th Century

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Climatic Change in March Temperature Deduced from Phenological Record for Flowering of Cherry Tree in Tokyo since the Late 18th Century

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Abstract

The change in spring temperature in Tokyo since the late 18th century was reconstructed using the phenological data of flowering for cherry trees (*Prunus jamasakura*) from old records. Full flowering dates of cherry trees were closely related to the monthly mean temperatures of March using the DTS method. This method offered accurate estimations of the full flowering dates for *P. jamasakura* from old documents in the late 19th century, then it was introduced with a reversed procedure, namely monthly temperatures for March were estimated from full flowering dates. The root mean square error of 5-year mean value of March temperature fell within 0.5℃ in the late 19th century.

The result showed that there was a cold time from 1810's to 30's with the estimations less than 5℃. This pattern of change in temperature almost synchronizes that in Kyoto. In western and central Japan, it seems that about 2℃ of the large scale climatic warming in spring initiated in the early 19th century, which was the last cold time in the Little Ice Age, and continued to the present.

1. Introduction

The long records of phenological events for plants provide useful information regarding outline for climatic change. The phenological data such as flowering and leafing dates are often applied to the reconstruction of climatic change before the starting of meteorological observation. In Europe, CONRAD[1] and LAUSCHER and LAUSCHER[2] investigated the secular changes in flowering and leafing dates for some plants and suggested the presences of cold winter and spring in the Little Ice Age (from early 15th to mid 19th centuries).

In Japan, TAGUCHI,[3] ARAKAWA[4] and SEKIGUCHI[5] researched the phenological records for full flowering dates of cherry trees from some old documents written in Kyoto, and discussed the climatic change, comparing mean value of full flowering date for each century. AONO and OMOTO[6] supplied the phenological records for full flowering dates from many old documents and deduced the change in March mean temperature in Kyoto since the 11th century. It was cleared by that study that Kyoto experienced a warm time around 1200 AD in the Middle Age Warm Epoch and three cold times of 1500-40's, 1690-1710's and 1810-30's in the Little Ice Age. The estimated March temperatures in three cold times were around 5℃. Those are 3℃ lower than the present value.

However, the reconstruction of old climate using phenological data was seldom done, except for Kyoto in Japan. It is expected that some old documents in Tokyo written after the 17th century remain even in the present and the full flowering dates can be collected sufficiently to estimate spring temperature, since central government or the Tokugawa shogunate had been settled at Tokyo in the top of 17th century.

In this study, an attempt was made to estimate the change in March mean temperature in Tokyo, using the phenological data for flowering of cherry trees in historical time since the late 18th century. The first objective of this study is to obtain the quantitative estimations of the climatic warming in spring at Tokyo since the 1770's, which was still in the Little Ice Age. The estimations for Tokyo are compared with those estimated by previous studies for other cities in Japan. In the 20th century, the urban warming, a local climatic modification, occurred in large cities and influenced on the secular change in temperature as an "urban bias." The second objective is to evaluate the large scale warming over central and western Japan in spring since the Little Ice Age, for eliminating local effect of the climatic modification attributed to urbanization at each city.

2. Research on historical data

In this study, the old diaries written in Tokyo were investigated in order to obtain the phenological data in historical time. The dates, on which cherry festivals (cherry blossom viewing parties) had been held or full flowering had been observed, were collected from old documents, and converted into the Gregorian calendar. It was suggested by many descriptions in old documents that most cherry festivals were held under full flowering. It seems that a native species, *Prunus jamasakura*, was the most common of cherry tree in ancient Japan until the 19th century. Thus, all historical flowering data found by researches were regarded as the full flowering dates of *P. jamasakura*. In order to compare the pattern of yearly variation in full flowering date in Tokyo with those in other cities, phenological data were researched on some other cities with the same method for Tokyo (Fig. 1).

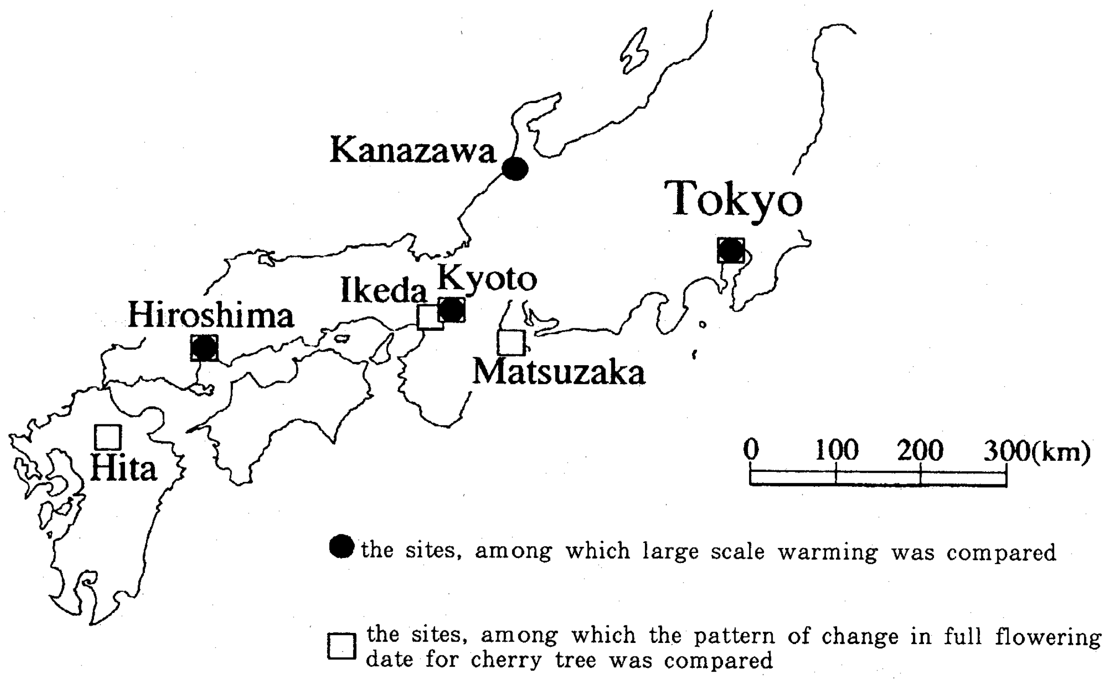

Fig. 1. Map of the location of cities used for analysis in this study.

In order to reconstruct the old climate in historical time, it is necessary to relate the spring temperature to full flowering date. In Tokyo, the meteorological measurements were started by the Central Meteorological Observatory in 1876. The full flowering dates of cherry trees have been observed by some weather stations in Japan since the early 20th century. Because most of these full flowering dates are not for *P. jamasakura* but for *P. yedoensis* —the most common cherry tree species in present Japan, these phenological data may not be used to relate the full flowering dates in old records to spring temperatures in historical time.

By the way, full flowering data were also obtained from the diaries written after the starting of meteorological observation at Tokyo in 1876. The tree species planted in Tokyo City area was gradually changed from *P. jamasakura* to *P. yedoensis* since the late 1880's,[7] and this change seemed to be completed at the occurrence of the Kanto Earthquake in 1923. In this study, it was assumed that the full flowering dates which were obtained from old diaries in the first 30-year period after starting of meteorological observation (1876-1905) can be regarded as those for *P. jamasakura*, considering the period required for *P. yedoensis* to dominate in city area and to grow as to offer sufficient flowers.

For Tokyo, the full flowering dates for 98 years were obtained from various records written in the period of 1770-1905. For the period after starting of meteorological measurements, the data for 24 years were available. Fig. 2 shows the yearly variation of full flowering date at Tokyo over 1770-1905. In the late 18th century, the full flowering date fluctuated in the range between 95th (Apr. 5) and 110th (Apr. 20) day of year. In the period from 1800's to 30's, full flowering date delayed gradually. The mean full flowering date in 1830's was 5 days later than that in 1800's. Since 1840's, full flowering date became earlier again.

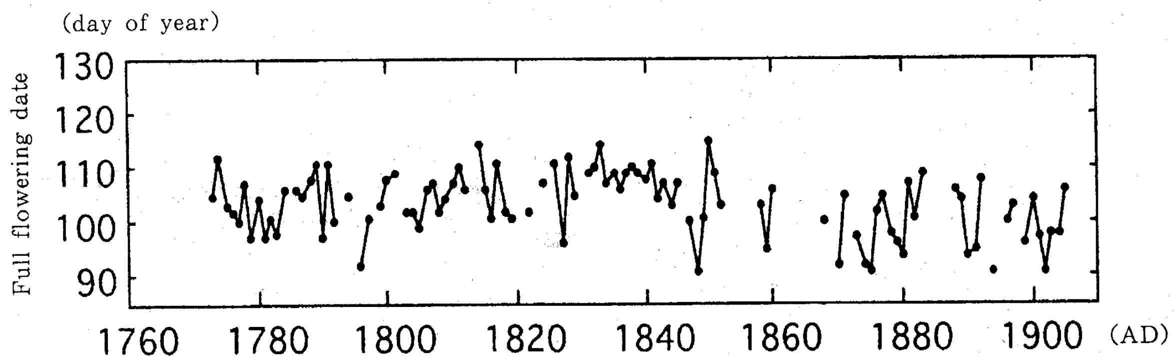

Fig. 2. Secular change of full flowering dates for *Prunus jamasakura* at Tokyo.

The pattern of yearly variation in full flowering date at Tokyo was compared with those at other cities in Japan (Fig. 3). In Kyoto, the change until 1800's is not clear because of the blank of full flowering data. The full flowering dates in 1810's and 1830's were later than those in 1840-50's. In Hiroshima, the trend of delay for full flowering over the period of 1800-30 is more noticeable than that in Tokyo. In Ikeda (Osaka Prefecture) and Hita (Oita Prefecture), the patterns of changes in full flowering dates show dips around 1840 as those in Tokyo and Kyoto. The flowering time of cherry tree fluctuates according to March temperature, except for Tohoku and Hokkaido districts in Japan.[8] Thus, the yearly variation of full flowering date reflects the outline of climatic change in March mean temperature. Fig. 3 qualitatively suggests

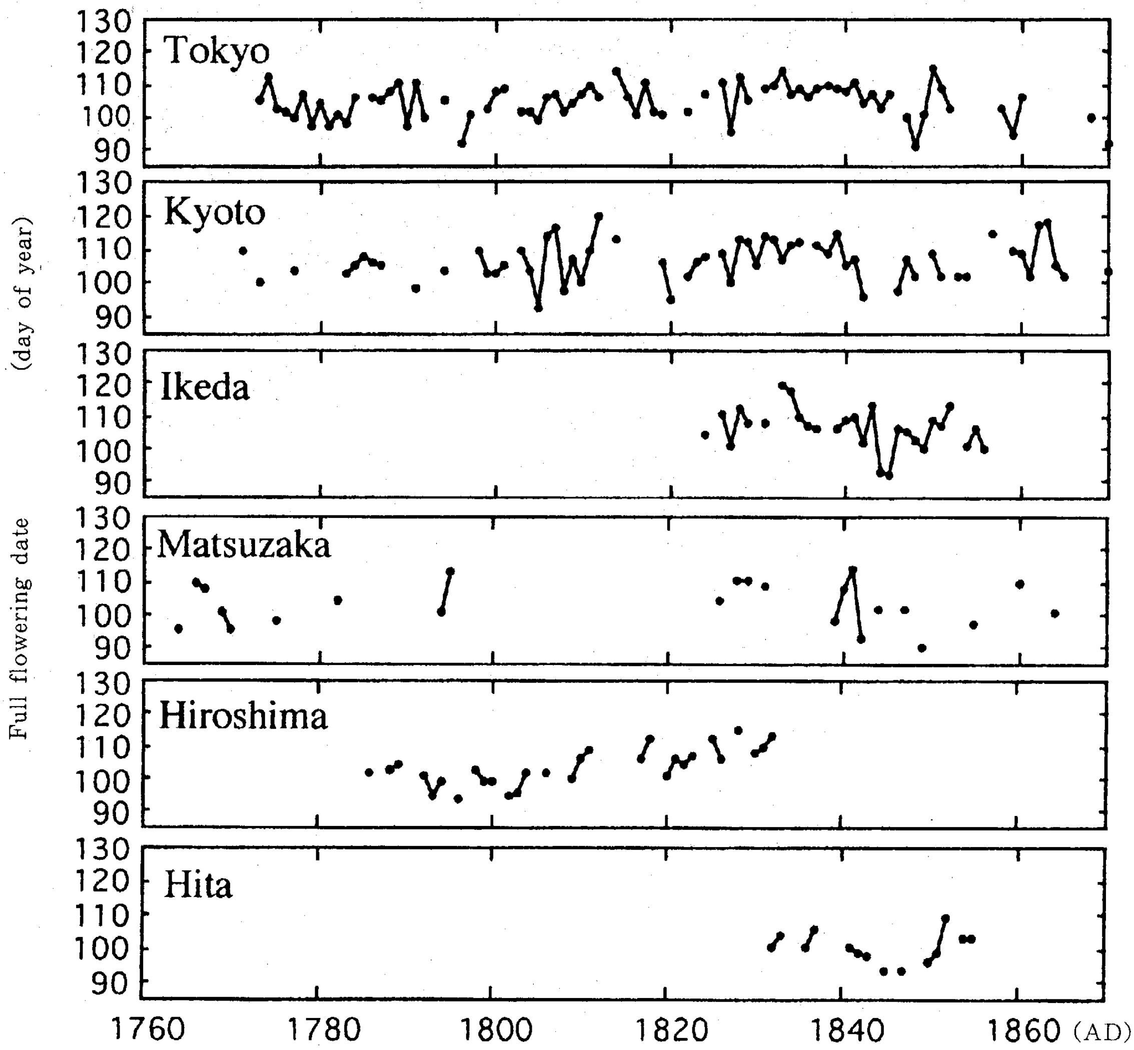

Fig. 3. Secular changes of full flowering dates for *Prunus jamasakura* in the period of 1760-1870 at six cities in central and western Japan.

the presences of 1) the warm period around 1800 with earlier flowering time, 2) the cooling trend over 1800-30's with the delaying of yearly flowering time and 3) the warm period in 1840-50's with earlier flowering, in the climatic change for March over the central and western Japan.

3. Relating full flowering to spring temperature at Tokyo

In order to relate quantitatively the change in the full flowering date to that in spring temperature, the full flowering dates in Tokyo in the period of 1876-1905 were estimated using DTS method. The daily mean temperatures observed at the Central Meteorological Observatory were used for this calibration.

DTS (the number of days transformed to standard temperature; proposed by KONNO and SUGIHARA[9]) is converted from daily mean temperature. DTS value for the *i*-th day $(t_s)_i$ can be calculated as follows:

$$(t_s)_i=\exp\ \{E_a(T_i-T_s)/R\ T_i\ T_s\} \quad (1)$$

where, T_i is the daily mean temperature for i-th day (K), T_s the standard temperature (288K is used in this study), R the molar gas constant (8.314 J K^{-1} mol^{-1}) and E_a the temperature characteristic (J mol^{-1}) which is a parameter expressing the responsivity of development of flower bud to temperature. The estimated full flowering date is the day when the accumulated value of DTS reaches the predetermined mean value. It is necessary for accurate estimation to determine suitable values of the day on which accumulation starts (starting date D_s), and the parameter of temperature characteristic E_a. In this study, the most suitable basis of estimation including both parameters of D_s and E_a was determined by the error analysis for 30-year period starting in 1876.

As the most suitable basis for estimation, the combination of Feb. 15 of D_s and 68kJ mol^{-1} of E_a was determined from the error analysis. Fig. 4 shows the full flowering dates estimated on the most suitable basis, comparing with the actual dates obtained from old diaries in Tokyo. Full flowering dates of *P. jamasakura* could be estimated with the accuracy of 2.49 days of root mean square error (RMSE) for the period from 1876 to 1905. AONO and OMOTO[6] showed that the application of DTS method to the estimation of temperature in Kyoto offered good accuracy even in the period which was not considered to determine the suitable basis of estimation. Thus, in this study, the basis of estimation mentioned above will be also used to estimate the temperature in historical time.

4. Estimation of March mean temperatures at Tokyo

March mean temperatures were estimated by applying the DTS method with a reversed procedure. For estimation of temperature, the normal accumulations of DTS (DTS_N) were calculated using daily temperature normals and mean full flowering dates. DTS_N was calculated as follows:

$$DTS_N=\sum_{i=D_s}^{B_N}\exp\{E_a(T_{Ni}-T_s)/R\ T_{Ni}\ T_s\} \quad (2)$$

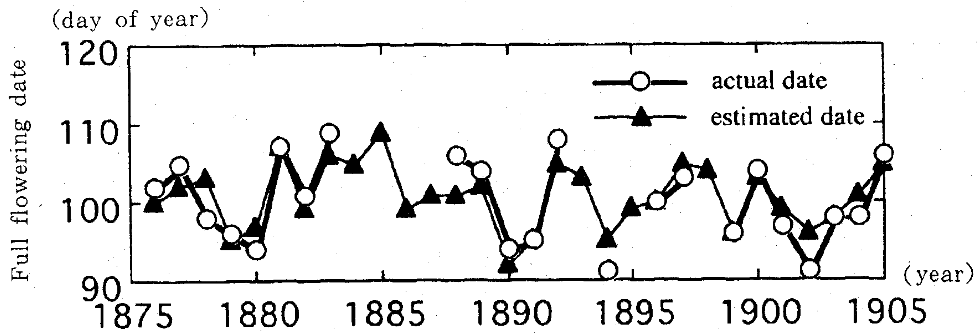

Fig. 4. Secular changes of actual and estimated full flowering dates for *Prunus jamasakura* at Tokyo.

where, B_N is the mean full flowering date over the period of 1876-1905 and T_{N_i} the daily mean temperature on i-th day, averaged over the period of 1876-1905. In this study, T_{N_i} was dealt as the normal value of daily temperature which was used to relate temperature to full flowering data.

A constant temperature anomaly was considered to add to the normal values of daily temperatures. This anomaly was adjusted so as the DTS value accumulated until the actual full flowering date in each year to coincide with DTS_N. For the j-th year, in which full flowering was observed on B_j, the estimated temperature anomaly, ΔT_j, was adjusted as follows:

$$\sum_{i=D_s}^{B_j} \exp\{E_a\,(T_{N_i}+\Delta T_j-T_s)/\,R\;T_s\,(T_{N_i}+\Delta T_j)\}=DTS_N \tag{3}$$

For the calculations in eqs.(2) and (3), Feb. 15 for starting date D_s and 68 kJ mol^{-1} for temperature characteristic E_a were used as the suitable basis for estimation. The value of sum of the March mean temperature averaged over the period of 1876-1905 (6.8℃) and adjusted temperature anomaly, ΔT_j, was regarded as the estimated March mean temperature for the j-th year.

Estimated March mean temperatures in the period of 1876-1905 were compared with actual values to test the accuracy. Fig. 5 shows the relationship between actual and estimated March mean temperatures for each year. Estimated temperatures (small open circles) have large error such as 1.04℃ in root mean square. However, the errors appear both on upper and lower sides from the normal line in Fig. 5, even if actual temperatures take higher or lower values. In order to cancel the errors in estimations each other, the estimated temperatures were averaged over each 5-year period (closed circles in Fig. 5). Eventually, the errors for 5-year mean estimations fell within 0.50℃ of RMSE.

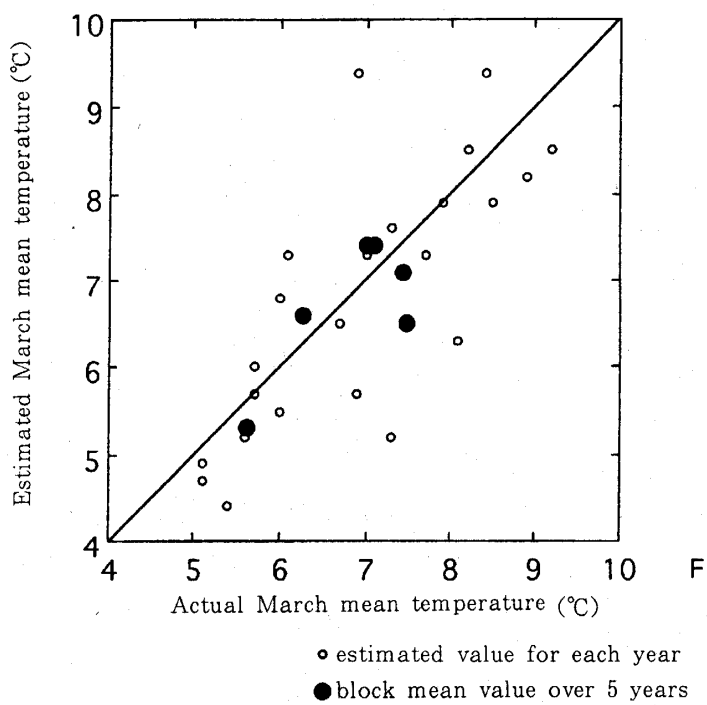

Fig. 5. Comparison of actural and estimated March mean temperatures at Tokyo in the period of 1876-1905.

This procedure was applied to the estimation of 5-year mean temperature of March in historical time. Fig. 6 shows the change of 5-year mean value of the March temperature deduced from full flowering dates. AONO and OMOTO[6] showed that the accuracy of estimated mean temperature depended on the number of data for flowering in each period (block) for averaging, and that the mean temperature, which was deduced from data for half or more years in each block for averaging, would offer high accuracy. In Fig. 6, closed mark means the estimation deduced from 3 or more years of phenological records in each block, and open mark means that deduced from 1 or 2 years of records. For comparison, the change in 5-year mean estimations deduced for Kyoto using almost same procedure is also shown in Fig. 6.

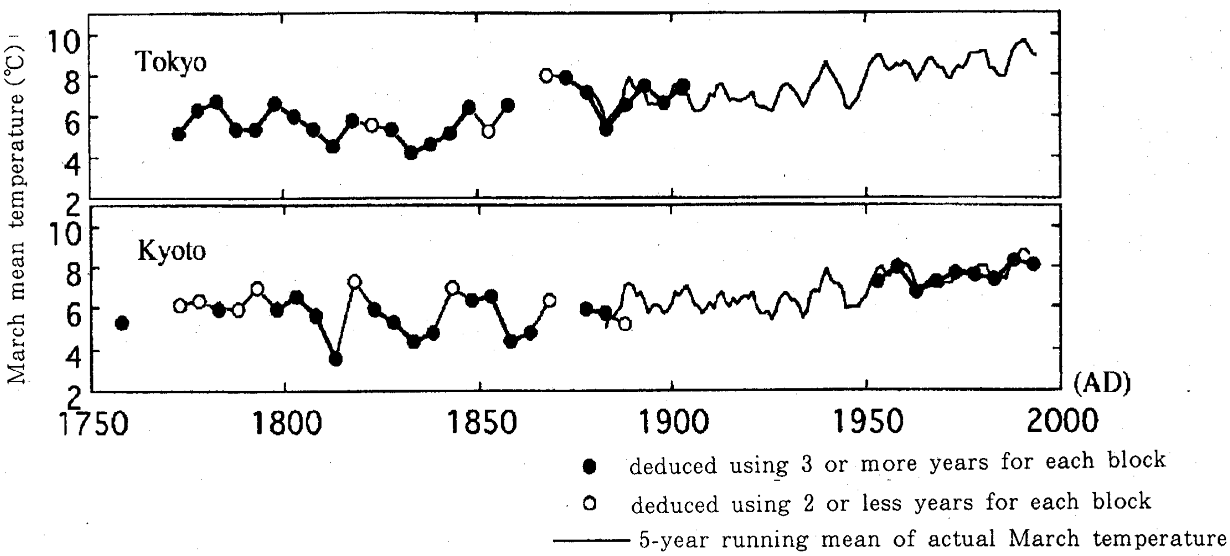

Fig. 6. Estimated mean temperatures for March in Tokyo and Kyoto Cities.

Since the 1770's, it seems that the change in spring temperature in Tokyo would be estimated with high accuracy, because most of 5-year blocks have the data for 3 or more years. From 1770 to 1800's, the estimations both for Tokyo and Kyoto were around 6℃, and they became lower values than 5℃ in 1810 and 30's. During the period of 1830-60's, the estimated temperature in Tokyo shows rising of about 3℃. In the estimated temperature series in Kyoto, such clear warming is not recognized. In Kyoto, the dips of March temperatures in 1810's, 1830's and 1850's are noticeable, while the dip around 1850's is not appeared clearly in Tokyo.

5. Evaluation of large scale warming since the Little Ice Age

The period of 1810-30's is especially known as the last cold time in the Little Ice Age. The estimated March temperature in this cold time was 3-4℃ lower than that in the present in Tokyo. From the early 19th century, climate has become warmer on large scale. Since the urban warming has occurred on local scale such as the Tokyo Metropolitan Area in this century, such temperature rising would be caused by the both of urban warming and large scale warming. In this study, an attempt was made to eliminate the urban warming components from the temperature changes estimated for Tokyo and some other cities, to evaluate the large scale warming since the last cold time over central and western Japan.

Table 1 shows the March temperature estimation averaged over 1826-35 of the last cold time, and the actual value averaged over 1981-90. In this table, the difference between both values is shown as ΔT_A. This difference includes both components of large scale warming and urban (local) warming. The March temperature at Tokyo in early 19th century was evaluated as 4.7℃, which was 4.0℃ lower than that in the last decade. In Kyoto, the March mean temperature over 1826-35 was estimated by previous study[6] as 4.9℃, which was 3.0℃ lower than the current value. In Tokyo and Kyoto, the delay of one day in full flowering date corresponds to approximately 0.26℃ of lapse in March temperature. In Hiroshima City, the full flowering date for *P. jamasakura* averaged over 1826-35 is 5 days later than that over 1923-37. The difference among March temperatures in both periods was approximately estimated in 1.3℃, under the assumption of same effectiveness of temperature on development of flower bud in Hiroshima as those in Tokyo and Kyoto. Then, ΔT_A value at Hiroshima was roughly estimated as 2.6℃, considering the change in March temperature since 1937. KAWAMURA[10] estimated the March mean temperature at Kanazawa City in the period of 1826-37 as 3.5℃. Then, ΔT_A corresponds to 2.8℃. Hiroshima and Kanazawa Cities show less ΔT_A values than that in Tokyo.

The urban bias ΔT_U, which was the mean local warming component for each city in the last decade, was evaluated by the method proposed by OMOTO and HAMOTANI[11]. The urban bias for each city was evaluated using the difference between temperature observations from weather station in urban and rural areas, considering the natural difference among temperatures at both sites. The results are also shown in Table 1. ΔT_U was evaluated as 1.9℃ for Tokyo and 1.4℃ for Kyoto, while only 0.5℃ for Hiroshima and Kanazawa Cities. The value of $\Delta T_A - \Delta T_U$ is regarded as the large scale climatic warming, ΔT_L, deduced by eliminating of urban warming effect. The values of ΔT_L at four cities fell within the range of 1.6-2.3℃. It would suggest that there was almost uniform climatic warming of about 2℃ in spring over central and western Japan. A previous study[12] suggested that the winter temperature in Kinki district in the early 19th century was approximately 2℃ lower than that in the present. It seems that the large scale warming of climate in March since the end of the Little Ice Age is almost the same degree as that in winter.

Table 1. Comparison of the March temperature averaged over 1826-35(estimations) and 1981-90(observations). Difference between both temperatures ΔT_A, mean urban bias ΔT_U and large scale warming ΔT_L are also shown.

Cities	March temperature (℃)		ΔT_A	ΔT_U	ΔT_L
	1826-35	1981-90	(℃)	(℃)	(℃)
Tokyo	4.7	8.7	4.0	1.9	2.1
Kyoto	4.9*	7.9	3.0	1.4	1.6
Kanazawa	3.5†	6.3	2.8	0.5	2.3
Hiroshima	~5.8‡	8.4	~2.6	0.5	~2.1

*: calculated using the results of previous study[6]

†: estimated as the mean value over the period of 1826-37(KAWAMURA[10]).

‡: rough estimations using mean value of full flowering date of *Prunus jamasakura*.

Concluding remarks

The change in March mean temperature in Tokyo since 1770's was reconstructed using old data for flowering phenology of cherry tree. Estimated temperature for Tokyo suggested the presences of warm period over 1770-1800's and cold period in 1810-30's in climatic change in spring. The mean value of estimated March temperature in the period of 1826-35 was 4.7℃, 4.0℃ lower than actual value in the last decade. Since the early 19th century in the end of Little Ice Age, the rising trend of spring temperature was continued to the present. In the large city such as Tokyo, the urban climate modification emphasized the temperature rising in spring. An attempt to eliminate the effect of urban warming bias from whole warming trend showed that the large scale warming of 1.6-2.3℃ has occurred over central and western Japan since the early 19th century.

References

1) CONRAD, C. (1959). Über Schbankungen der Vegetationsperiode und über Variationen ausgewänlter phänologischer Phasen von Kulturpflanzen. *Augewande Meteorol.*, **3**, 193-205. (*in German*)
2) LAUSCHER, A. und LAUSCHER F. (1981). Vom Einfluß der Temperature auf die Belaubung der Roßkastanie nach den Beobachtungen in Genf seit 1808. *Wetter Leben*, **33**, 103-112. (*in German*)
3) TAGUCHI, T. (1939). Climate in historical time of Japan (2). *Umi to Sora*, **19**, 217-227. (*in Japanese*)
4) ARAKAWA, H. (1956). Climatic changes as revealed by the blooming dates of the cherry blossoms at Kyoto. *J. Meteorol.*, **13**, 599-600.
5) SEKIGUCHI, T. (1969). The historical dates of Japanese cherry festival since the 8th century and her climatic changes. *Tokyo Geography Papers*, **13**, 175-190. (*in Japanese*)
6) AONO, Y. and OMOTO Y. (1994). Estimation of temperature at Kyoto since 11th century using flowering data of cherry trees in old documents. *J. Agric. Meteorol.*, **49**, 263-272. (*in Japanese*)
7) TOKYO CITY GOVERNMENT (1932). *Historical documents in Tokyo City.* (*in Japanese*)
8) AONO, Y. (1993). Climatological studies on blooming of cherry tree (*Prunus yedoensis*) by means of DTS method. *Bull. Univ. Osaka Pref., Ser. B*, **45**, 155-192. (*in Japanese*)
9) KONNO, T. and SUGIHARA, S. (1986). Temperature index for characterizing biological activity in soil and its application to decomposition of soil organic matter. *Bull. Nat. Inst. Agro-environ. Sci.*, **1**, 51-68. (*in Japanese*)
10) KAWAMURA, T. (1992). Estimation of climate in the Little Ice Age using phenological data in Japan. *Proc. International Symposium on the Little Ice Age Climate*, 52-57.
11) OMOTO, Y. and HAMOTANI K. (1979). A proposed method of eliminating urban effects from climatological data obtained at stations in big cities. *J. Agric. Meteorol.*, **35**, 93-96. (*in Japanese*)
12) YAMAMOTO, T. (1967). Outline of the climatic change in Japan. *Meteorol. Res. Note*, **91**, 2-9. (*in Japanese*)