Variation in the March Mean Temperature Deduced from Cherry Blossom
in Kyoto since the 14th Century

Y. Aono and Y. Omoto
(University of Osaka Prefecture, Sakai 593, Japan)

Abstract

Changes in spring temperatures in Kyoto since the 14th century are estimated using flowering phenological data of cherry trees (*Prunus jamasakura*, a native species) from old records. It is shown that flowering dates of cherry trees in Kyoto are closely related to the monthly mean temperature of March. This result is obtained using the so called DTS method, which has been used to estimate the first flowering date of *P. yedoensis* (a horticultural species). However, in this case it is applied to estimate the full flowering date of *P. jamasakura*. It is shown that accuracy for both is almost the same. In this study, using this method with a reversed procedure, namely monthly temperatures for March are estimated from full flowering dates. It is shown that for decadal means, calculated averaged March temperatures fell within 0.5°C from the actual value in the 20th century.

The result shows that there were relatively cold periods around the mid-14th, early 16th and late 17th through the early 19th centuries. There were warm springs during the early 17th century. A steady warming trend starting the early 19th century continuing to the present is noteworthy. It is attributable to both urban warming and large scale warming.

Key words: Cherry trees, Climatic change, Full flowering date, Old record, Spring temperature

1. Introduction

Long records of plant phenological events provide useful information regarding outlines for climatic change. Variations in flowering dates of deciduous trees or shrubs, such as cherry, azalea and wisteria are related to spring temperatures. Especially, the first flowering date of *Prunus yedoensis* (the most common species of cherry tree in present Japan) can be estimated with high accuracy by using the DTS method, which is a kind of accumulation model of the temperature index (Omoto and Aono, 1989; Aono and Omoto, 1990, 1992). This suggests that the application of the DTS method to flowering phenological data of cherry trees gives quantitative information on spring temperatures even in historical time.

The phenological observations made at weather stations in Japan started at the end of 19th century. However, in Kyoto, which had been the capital of Japan from 794 to 1868 A.D., the old data for full flowering dates of cherry trees since the 8th century have been found by Taguchi (1939), Arakawa (1956) and Sekiguchi (1969). Such data enable us to estimate the changes in spring temperatures at Kyoto in historical times, applying the DTS method.

In this study, an attempt is made to estimate quantitatively the changes of the March mean temperature at Kyoto from phenological data in historical times since the 14th century. To estimate temperatures as accurately as possible, the blanks of flowering data, which were already found are supplied with the flowering data found during our research on old records.

2. Research on historical data and results

In this study, the chronicles and old diaries written by Emperors, aristocrats, governors and monks in Kyoto were investigated in order to fill in the blanks of historical data already found. The dates, on which cherry blossom viewing parties had been held or full flowerings had been observed, were collected from old documents, and converted into the Gregorian calendar. It seems that *P. jamasakura* was the most common native species of cherry tree in western Japan in the past. It is also suggested by many descriptions in old documents that most cherry blossom viewing parties were held under full flowering. Thus, all historical flowering data found by earlier and later our researches were regarded as the full flowering dates of *P. jamasakura*.

As of now, the flowering dates of 136 years were obtained from fourteen diaries and five chronicles. The total number of full flowering data was 233, including the data found by earlier studies (Fig. 1). For the 15th and the 16th centuries, the full flowering dates were available for more than half the years of each century. However, for the 19th century, the data for only several years were available. In order to obtain them, full flowering dates of *P. jamasakura* recorded in an old diary written at Ikeda, Osaka, about 40km from Kyoto, were employed to estimate temperatures at Kyoto for the period from 1820's to 1850's.

Fig. 1. The number of phenological data in historical time, counted for each quarter of the century.

by earlier research, by our research,
by the diary written at Ikeda, Osaka

3. Relating full flowering to spring temperature

To relate quantitatively the yearly variations in the full flowering dates to those in spring temperatures, full flowering dates in Kyoto in recent years were estimated by the DTS method. Daily mean temperatures observed at the Kyoto meteorological observatory and full flowering dates at several places in Kyoto City were used for this analysis. Full flowering dates of *P. yedoensis* (a horticultural species) were provided by the phenological report published by the Japan Meteorological Agency (1988), and those of *P. jamasakura* (a native species) at Arashiyama and at Daigo-temple, places noted for cherry blossoms in Kyoto City, were obtained from information in daily newspapers.

DTS (the number of days transformed to standard temperature; proposed by Konno and Sugihara, 1986) is converted from daily mean temperature. The estimated full flowering dates are 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 from which accumulation starts (starting date) and that of a parameter, which is used to convert temperatures in DTS (temperature characteristic). Both most appropriate values of the starting date and temperature characteristic at each place are determined by using a sort of trial and error approach, by varying both parameters. Such a most suitable basis of estimation including both parameters was determined by the error analysis for the 25 year period starting in 1966.

Most appropriate starting

Fig. 2. Actual and estimated full flowering dates of cherry trees.
●: actual dates, △: estimated dates.

dates for three places fell within a narrow range, i.e., 17–20, February. In Kyoto City, full flowerings of cherry trees occur in early and mid-April. This suggests that temperature of March significantly influences yearly variations in flowering dates in Kyoto.

Fig. 2 shows full flowering dates estimated on a most suitable basis for each place, compared with actual value. Accuracy of about 2 days of root mean square error (RMSE) was obtained for *P. yedoensis* at the Kyoto meteorological observatory. Full flowering dates of *P. jamasakura* at Arashiyama and at Daigo-temple could be estimated with accuracies within 2 days of RMSE for the period from 1966 to 1990. Even errors in estimations for the period 1952–1965 were not so great. This suggests that the DTS method is applicable to relate flowering to spring or March temperatures even in historical times.

4. Estimation of March mean temperatures

Mean March temperatures were estimated by applying the DTS method with inverse procedures. The normals of daily mean temperatures were used here. The normal values of DTS, converted from temperature normals were accumulated until the mean full flowering date at each place. A constant temperature anomaly was considered to add to the daily temperature normals. This temperature anomaly was adjusted, so as the DTS value accumulated until the full flowering date in each year to coincide with the normal value of DTS accumulations described above. The value including the normal of March mean temperature and adjusted temperature anomaly was regarded as the estimated March mean temperature for the year under consideration. Conversion of temperature into DTS was made on a most suitable basis of estimation at each place.

Estimated March mean temperatures in recent years were compared with actual values to test the accuracy. It is shown that yearly variations in estimated temperatures were somewhat larger than those of actual temperatures, and caused large errors (RMSE ranged from 0.7 to 1.0°C). For smoothing, temperatures were averaged over each decade. Eventually, the error for decadal averages of March mean temperatures, estimated from *P. yedoensis*, fell within 0.5°C except for the 1910's when the observed cherry trees had still been young plants, and that, estimated from *P. jamasakura* at Arashiyama, fell within 0.1°C (Fig. 3).

These procedures were applied to estimate the decadal

average of March mean temperatures in historical times. As the basis in estimation, those for *P. jamasakura* at Arashiyama or at Daigo-temple were used. Fig. 4 shows the results of estimation. March mean temperatures fell within the range of 4–6°C in the mid-14th century, and fluctuated between 5.5 and 7.5°C in the 15th century. This fluctuation may have been caused by the mixture of flowering data from many old records written at different places in Kyoto City.

From the 1500's to 1540's, March mean temperatures were around 5°C. This dip of estimated temperature in the early 16th century was deeper than that of change in winter and spring season temperature deduced by Yamamoto (1971). March mean temperatures had small peaks around the 1550's and 1600's, coinciding with changes in temperature for winter half year revealed from dendroclimatological analysis of coniferous trees in central Japan (Sweda, 1992).

From the 1680's to 1690's, March mean temperatures fell below 6°C again. For

Fig. 3. Estimated decadal average value of March mean temperature.
—○—: actual value.
---△---: estimated from flowering for *P. yedoensis*.
···×···: estimated from flowering for *P. jamasakura* at Arashiyama.

Fig. 4. Variation of March temperatures since 1301 deduced from flowering phenological data for *P. jamasakura* in Kyoto

●: 10-year averaged deduced temperatures with 5 or more years of records of flowering in Kyoto.

○: 10-year averaged deduced temperatures with less than 4 years of records of flowering in Kyoto.

■: 10-year averaged deduced temperatures estimated by using flowering data outside of Kyoto.

△: 10-year averaged observed temperatures at Kyoto meteorological observatory plotted 5 year intervals.

most of the 18th century, changes of temperature were not able correctly estimated in this study, because of many blanks in historical flowering data during this century. During the early part of the 19th century, it seems that March mean temperatures were lower than the present by about 3°C. From the early 19th century, March mean temperature showed a steady warming trend which continues to the present. It seems that urban warming partly contributed to this trend. The small fluctuation of estimated temperature in the 20th century was attributed by using uniform criteria in phenological observation.

5. Conclusion

The variation of March mean temperatures in Kyoto since the 14th century were estimated from old data of the full flowering of cherry trees. It seems that there were relatively cold periods around the mid-14th, early 16th and late 17th through the early 19th centuries. Estimated temperatures also have small peaks around the 1550's and 1600's.

Relatively large fluctuations of estimated temperature were caused by the unequal quality of full flowering data in historical times. To eliminate large fluctuations due to blank spaces in the time series, it is necessary to obtain more flowering phenological records.

References

- Aono, Y. and Omoto, Y., 1990: Estimation of blooming date for *Prunus yedoensis* using DTS combined with chill-unit accumulations. *J. Agr. Met.*, 45, 243-239.
- Aono, Y. and Omoto, Y., 1992: Estimation of blooming dates of *Rhododendron kaempferi*, *Wisteria floribunda* and *Hydrangea macrophylla*. *J. Agr. Met.*, 47, 233-240.
- Arakawa, H., 1956: Climatic change as revealed by the blooming dates of the cherry blossoms at Kyoto. *J. Meteor.*, 13, 599-600.
- Japan Meteorological Agency, 1988: Phenological observation in Japan. *Technical Report of the Japan Meteorological Agency*, No. 110, 233pp.
- 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.
- Omoto, Y. and Aono, Y., 1989: Estimation of blooming date for *Prunus yedoensis* by means of kinetic method. *J. Agr. Met.*, 45, 25-31.
- Sekiguchi, T., 1969: The historical dates of Japanese cherry festivals since the 8th century and her climatic changes. *Tokyo Geography Papers*, 13, 175-190.
- Taguchi, T., 1939: Climate in historical time of Japan(2). *Umi to Sora*, 19, 217-227.
- Yamamoto, T., 1971: On the climatic change in XV and XVI centuries in Japan. *Geophys. Mag.*, 35, 187-206.