ACTA ECOLOGICA SINICA
Volume 28, Issue 11, November 2008
Online English edition of the Chinese language journal

Cite this article as: Acta Ecologica Sinica, 2008, 28(11), 5209−5217.

RESEARCH PAPER

Change in flowering dates of Japanese Cherry Blossoms (*P. yedoensis* Mats.) on campus of Wuhan University and its relationship with variability of winter temperature

Chen Zhenghong[1,2,*], Xiao Mei[3], Chen Xuan[2]

1 *Wuhan Institute of Heavy Rain*, *CMA*, *Wuhan 430074*, *China*
2 *Wuhan Climate Center*, *Wuhan 430074*, *China*
3 *College of Resource and Environmental Science*, *Wuhan University*, *Wuhan 430072*, *China*

Abstract: Change in first-flowering dates and its correlation with climatic factors was mainly analyzed, and several predicting models for the first-flowering dates were established based on the flowering dates of Japanese Cherry Blossoms (*P. yedoensis* Mats.) during 1947–2008 on campus of Wuhan University and the climatic data in the same period. The results show that: 1) in 1947–2000, the first-flowering dates advanced with 2.17 d per decade, with an overall trend of 11.72 d in the 54 years, the fading dates were postponed for only 1.83 d in the same period, and the florescence duration increased by 13.55 d; 2) the first-flowering dates have negative correlation with monthly average temperature from December to March. The increasing winter (from December to February) temperature is the main reason for the advancement of the first-flowering dates. Per 1°C increase in average temperature of February and wintertime makes the first-flowering dates advance by 1.66 d and 2.86 d, respectively; 3) some statistical models of the first-flowering dates were built up with average temperature of February and wintertime based on the data during 1947–2000, and they are detected independently during 2001–2008.

Key Words: Japanese Cherry Blossoms (*P. yedoensis* Mats.); first-flowering date; fading date; florescence duration; climate change; flowering date prediction

The global average temperature increased significantly in the last century, especially in the recent more than 20 years. All observed evidences indicate that climate warming has impact on many natural systems[1–4]. According to the phenological theory, the flowering time is influenced greatly by previous climate conditions such as sunlight, temperature and precipitation[5], among which temperature is the most important factor affecting the phenophases of woody plants in China[6,7]. The longitude, latitude, height above sea level[8] and local topography[9] are also considered as main factors due to their influence on temperature. Plants on the earth surface, the important components of the natural ecosystem, are influenced by climate warming, and one of the most sensitive and easily observed consequences is the change of phenophases[10].

A great deal of observations and researches show that in the last several decades, especially in the most recent more than 20 years, almost all phenophases (such as squaring, flowering, branch shooting, sprouting and foliating) of the forests and crops advanced in spring, and were postponed in autumn obviously. So the whole growing seasons are extended. Whether in Europe[11–17], America and Canada[18–20] or in China[4,6,7,21–23], all phenophases have already advanced 3–28 d in spring. In Japan, the advance of flowering dates of Japanese Cherry Blossoms caused by urban heat island effect can be found[24].

Cherry Blossoms is a kind of important ornamental plants in spring. Xiao *et al*. have kept on observing the flowering dates including the first-flowering dates and the fading dates of Japanese Cherry Blossoms for 62 years (1947–2008). A very valuable long-time dataset of the flowering dates has been built up for climate change research. Based on the data until 1997, he found that the first-flowering dates of Japanese Cherry Blossoms tend to flower earlier since late 1980s. By comparing with the limited meteorological data, he found that this phenomena may have certain relationship with the global

Received date: April 9, 2008; Accepted date: July 21, 2008
*Corresponding author. E-mail: hbhjqx@vip.sina.com; chenzh64@126.com

warming, especially in the continuous warm winters①. Same conclusion was made by Yang from Shaanxi Province, that is, the first-flowering dates of Japanese Cherry Blossoms come 10 d earlier in recent 10 years in Japan and some parts of the world[23,24]. This research analyzed the effect of climate change on the flowering properties of Japanese Cherry Blossoms on campus of Wuhan University, and provided an important proof of climate change in local area and the world. Some other researches by the authors show that the warming of Wuhan City becomes stronger[25], and the urban heat island effect is very obvious[26], especially during the recent years[27]. The global warming together with the strengthened urban heat island effect has definitely brought considerably earlier first-flowering dates of Japanese Cherry Blossoms on campus of Wuhan University.

Flowering date forecasting is very valuable in the field of orchard, bee-keeping, gardening, tourism and so on. Based on the relationship between flowering dates and climate factors (mainly temperature), it is possible to forecast the flowering dates. Currently in China, the flowering dates of peony[28], sweet-scented osmanthus[29], pear tree②, peach blossom[30,31], winter jasmine[32] and some other plants can already be predicted. Firstly, the characteristics of the Japanese Cherry Blossoms was analyzed, then the key climate factors and the critical periods which might influence the flowering dates were found, and lastly the equations between flowering dates and climate factors were established. Forecasting of the flowering dates can be carried out to guide the appreciation of flowers and the management of tourism.

1 Data and methods

1.1 Data

Observation samples: there are 6 kinds of cherry trees on campus of Wuhan University such as Early Cherry, Drooping Rosebud Cherry and Japanese Late Cherry. The observations were mainly focused on 28 Japanese Cherry Blossoms trees (*P. yedoensis* Mats.), cultured in 1939 at Laozhaishe (now the Cherry Park) on campus of Wuhan University. In 1957 and 1985, some Japanese cherry trees were planted and replaced, and more cherry trees are added gradually after 1990s.

Observation periods: 62 years from 1947 to 2008, without breaking, from March to April.

Observation items: first-flowering dates and fading dates. Bursting of 3–5 buds into blossoms indicates the first-flowering date, while fading of 70%–80% of the flowers indicates the fading date.

Observers: Professor Xiao Yihua, biologist, his wife Liu Wenfang, daughter Xiao Mei and Mr. Chen Quanlong, who are all teachers of Wuhan University.

Meteorological data: monthly average temperature from 1947 to 2008 at Wuhan Weather Station.

1.2 Methods

Turn the first-flowering dates and fading dates into the days from the first day every year (January 1st as 1, January 2nd as 2 and so on), and calculate the duration from the first-flowering date to the fading date (florescence duration). 3 series of phenophases for 62 years were built up.

The data from 1947 to 2000 were used to analyze properties of flowering dates and their variation, and to establish some models between flowering dates and climate factors. The data from 2001 to 2008 were used to verify the forecasting results of independent samples.

The average results, earliest/latest days and longest/shortest days, mean square deviation, trend of 3 phenophases, and the correlation coefficients between the series of the first-flowering dates and the monthly average temperature in minter (from last April to this March) and the average temperature in winter (from last December to this February), were calculated for 54 years or every 10 years. The sensitive periods to the temperature changes were found out. The linear and nonlinear regressive equations between the days from the first day every year and the average temperature of the key periods were established.

The dates can be predicted by putting the temperature of the key period of 2001–2008 into the equations, and can also be verified by comparing with the observation dates.

2 Analysis results

2.1 Analysis on the basic properties and the tendency of first-flowering dates

78.5 d is the average day for the first-flowering dates of Japanese Cherry Blossoms from the first day every year during 1947–2000, that is, March 19th or 20th in non-leap year, or March 18th or 19th in leap year.

The earliest date was March 6th (1987 and 1997). Besides, there were 4 years whose earliest dates were before March 10th (March 9th in 1977 and 1995, March 10th in 1992 and 1993). Among these 6 years, 5 years were after 1986, the starting year for persistent warm winters.

Meanwhile, the latest date was April 4th (1969). Then, other latest dates were March 31st (1980), March 28th (1985), and March 25th 1949 and 1984. All these 5 years were before 1986.

Fig. 1 shows how the days of the first-flowering dates from the first day every year changed from 1947 to 2000 and the linear fitting. There are 2 obvious features in the figure: one is that the days tend to decrease with a bias of 2.17d/10a, and the other one is that the total deduction is 11.72 d during the 54

① Xiao Yihua, Liu Wenfang, Xiao Mei. The relationship between the flowering dates of Japanese cherry blossoms at Loujia hill and the variation of temperature in last 51 years. Research Papers Presented at the 11th conference for the Hubei Province Society of Plant Physiology, Wuhan University, Loujia hill,Wuchang,1997.

② Wu Xiuzhi, Li Ruilin. The meteorological conditions of full blossoms of pear flower and its services. Anhui Meteorology,1998,(2):46-47 years, which means that the first-flowering dates come 12 d earlier nowadays than the earliest years. The variability of the days tends to become larger apparently since mid-1960s, and the earliest and latest flowering dates all appeared after that time.

Table 1 shows the features of first-flowering dates for every decade. It can be seen that the first-flowering dates have come earlier gradually. The earliest first-flowering dates in the last 4 years are 15 d earlier than the one in the first decade. The latest first-flowering dates are stable in the first 2 decades, the latest in the 2 middle decades, and earlier gradually since mid-1980s. Compared with the last 4 years, the first-flowering dates have advanced 14 d. Average first-flowering dates of every decade show that the days from the first day every year of the first 30 years remain from 80 d to 82 d, which means that the average first-flowering dates are from March 20th to March 22nd. The days started decreasing obviously since mid-1970s, and are 10 d less in the last 4 years than that in the first decade, which means that the average first-flowering date is March 12th, 8–10 d earlier.

The mean squaredeviation of the days shows the stability of the first-flowering date. In the first 2 decades, the first-flowering dates were very stable with one or two days earlier or later than the average (there were only 4 d differences between the earliest and the latest). But ever since mid-1960s, the deviation has increased obviously. In most years, the first-flowering dates can be earlier or later than the average by 5 d to 8 d (10 d to 16 d differences between the earliest and the latest).

2.2 Analysis on the basic properties and the tendency of the fading dates

The average was 92.5 d for the fading dates of Japanese Cherry Blossoms from the first day every year during 1947–2000, that is, April 2nd or 3rd in non-leap year, or April 1st or 2nd in leap year.

The earliest date was March 20th in 1997. Besides, there were 5 years whose earliest dates were before March 29th, that is, March 25th in 1993, March 26th in 1996, March 27th in 1979, March 27th in 1986 and March 29th 1978, among which 4 years were before 1986.

The latest date was April 16th in 1969, followed by April 15th in 1980 and 1996, April 10th in 1998 and 1999, April 9th in 1985, and April 7th in 1976 and 2000, among which 4 years were before 1986 and 4 years after 1986.

Fig. 2 shows the annual variation and linear fitting results of the days of the fading dates from the first day every year in the

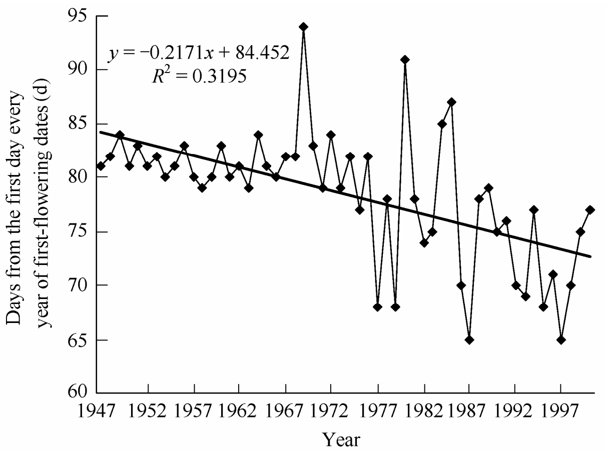

Fig. 1 Yearly change in days from the first day every year of first-flowering date for Japanese Cherry Blossoms (*P. yedoensis* Mats.) in Wuhan University and its linear fitting (1947–2000)
x: ordinal number of the year, x = 1 for 1947, x = 2 for 1948, …;
R: correlation coefficient between y and x

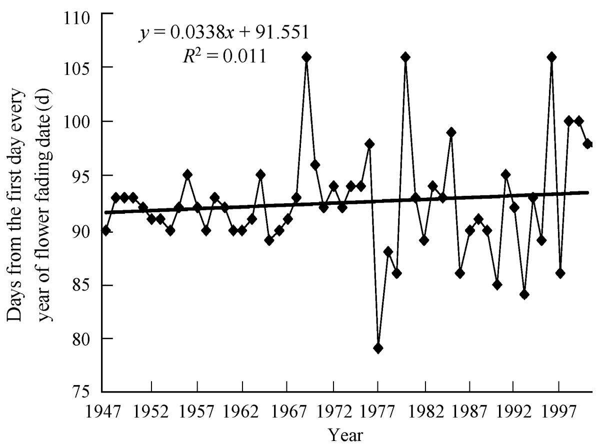

Fig. 2 Yearly change in days from the first day every year of flower fading dates for Japanese Cherry Blossoms (*P. yedoensis* Mats.) in Wuhan University and its linear fitting (1947–2000)
x and R: the same as in Fig. 1.

Table 1 Yearly difference and change in basic properties of first-flowering dates of Japanese Cherry Blossoms (*P. yedoensis* Mats.) in Wuhan University (1947–2000)

Period	Earliest date (m/d)	Latest date (m/d)	Average date (m/d)	Average days from the first day every year (d)	Mean square deviation of days from the first day every year (d)
1947–1956	3/21	3/25	3/(21±1)	81.8	1.3
1957–1966	3/20	3/24	3/(20±1)	80.7	1.6
1967–1976	3/18	4/04	3/(22±1)	82.4	4.6
1977–1986	3/09	3/31	3/(18±1)	77.4	8.1
1987–1996	3/06	3/02	3/(13±1)	72.8	4.8
1997–2000	3/06	3/17	3/(12±1)	71.8	5.4

period of 1947–2000. During the 54 years, the mean square deviation of the days was getting larger obviously since the late 1960s, and the earliest and latest dates were all after that, which is consistent with the first-flowering dates. But the bias of the days is not obvious, with only increase of 0.338d/10a and a total increase of 1.83 d, which means 2 d delay of the fading dates nowadays than the earliest years.

Table 2 represents the basic characteristics of the flower fading dates in each decade. The earliest fading dates advance with years. It is 3–12 d earlier for recent 3 periods than that for the first 3 periods, and the latest fading dates in the first 2 decades were stable, all on April 4th. In the most recent years, there is an obvious delay of 4–12 d. But the average fading dates in each decade change a little, no more than 1–5 d.

The mean square deviation of the days of flower fading dates from the first day every year tends to increase gradually. In the first 2 decades, there was little difference every year, only 1–2 d (only 4 d gap between the earliest and the latest). However, since mid- 1960s, the deviation has increased greatly, with 3–7 d gap on average and 6–14 d gap between the earliest and the latest.

2.3 Analysis on the basic properties and the tendency of florescence duration

The average florescence duration was 15.0 d for Japanese Cherry Blossoms from 1947 to 2000 on the campus of Wuhan University. The shortest was 9 d in 1965 and 1984, followed by 10 d in 1947, 1949, 1951, 1953, 1960, 1962 and 1967. All these years were before 1986. The longest was 36 d in 1996, and there were other 9 years whose florescence duration was longer than 20 d(1983, 1987, 1991, 1992, 1995, 1997, 1998, 1999, 2000). Except 1983, the other 9 years were all after 1986.

The variation of the florescence duration and the linear fitting can be seen in Fig. 3. There are 2 obvious features: the duration tends to increase significantly, with a bias of 2.5d/10a and 13.5 d in total, that is to say, the florescence duration prolongs by 13.5 d in recent years than the earliest years. The variability of florescence duration has become notably larger since 1980s and the longest one also happened after that time. As more varieties of cherry trees are cultured on the campus, people can enjoy the flowers longer.

Table 3 shows the basic features of the florescence duration. We can see that the shortest florescence duration varied a little, and increased suddenly in the late 1990s, while the longest one began to increase since 1960s, and increased significantly in the middle and late 1980s, and the longest one was 36 d, which was 1.4–1.7 times more than the one in the first decade. The florescence duration increased slowly with a bias of 1d/

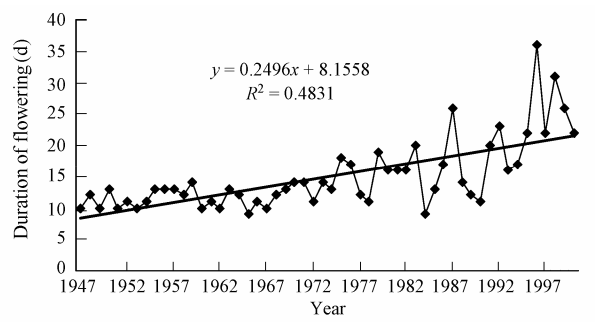

Fig. 3 Yearly change in duration of flowering for Japanese Cherry Blossoms (*P. yedoensis* Mats.) in Wuhan University and its linear fitting (1947–2000)

x and R: the same as in Fig. 1.

Table 2 Yearly difference and change in basic properties of flower fading dates for Japanese Cherry Blossoms (*P. yedoensis* Mats.) in Wuhan University (1947–2000)

Period	Earliest date (m/d)	Latest date (m/d)	Average date (d)	Average days from the first day every year (m/d)	Mean square deviation of days from the first day every year (d)
1947–1956	3/31	4/04	92.0	4/(2±1)	1.3
1957–1966	3/30	4/04	91.2	4/(1±1)	1.6
1967–1976	4/01	4/16	95.0	4/(5±1)	2.3
1977–1986	3/20	4/15	91.3	4/(1±1)	3.5
1987–1996	3/25	4/15	91.5	4/(1±1)	7.3
1997–2000	3/27	4/10	96.0	4/(6±1)	4.8

Table 3 Yearly difference and change in basic properties of duration of flowering for Japanese Cherry Blossoms (*P. yedoensis* Mats.) in Wuhan University (1947–2000)

Period	Shortest duration of flowering (d)	Longest duration of flowering (d)	Average duration of flowering (d)	Mean square deviation of duration of flowering (d)
1947–1956	10	13	11.3±1	1.3
1957–1966	9	14	11.5±1	1.6
1967–1976	10	17	13.6±1	2.5
1977–1986	9	20	14.9±1	3.5
1987–1996	11	36	19.7±1	7.5
1997–2000	20	31	25.3±1	4.3

10a before 1986 and increased rapidly with a bias of 5d/10a since 1986. Compared with the first decade, the florescence duration in the last decade was 13.7 d longer. The extended flowering period was mainly due to the advancing of the first-flowering dates, while the fading dates were postponed only a little.

Mean square deviation can indicate the stability. The same as the yearly florescence duration, the decadal florescence duration also increased slowly at first, and then rapidly at the turning point, the middle and late 1980s. In the first 3 periods, the florescence duration in most years was 1–2 d earlier or later than the average with only 3–4 d difference between the earliest and latest years. However, since the middle and late 1970s, the mean square deviation has been enlarged significantly so that the florescence duration in most years can be earlier or later than the average by 4 d to 7 d. The largest difference between the earliest and latest was 8 d to 15 d.

To make tourism and management convenient, it is quite necessary to forecast first-flowering dates and predict the florescence duration for the larger variation of first-flowering dates and the florescence duration.

2.4 Relationship between first-flowering dates and the previous temperature change

The days of the first-flowering dates from the first day every year are negatively correlated with the monthly average temperature from last December to this March, and were not correlated with the monthly temperature before last November. In the 4 months from December to March, the correlation was weak in last December, and is stronger since then, especially strong in February. The average temperature in winter is strongly correlated with the first-flowering dates (see Table 4).

From 1947 to 2000, the average temperature in winter increased obviously, especially in February since 1990. The bias of the average temperature in wintertime and February was 0.27°C/10a and 0.33°C/10a (Fig. 4). But the trend of the average temperature in winter is more notable.

Figs. 5 and 6 show the correlation and curve-fitting results of days from the first day every year of first-flowering dates with the average temperature of wintertime and February from 1947 to 2000. It is clear that higher temperature corresponds with less days and earlier flowering dates; meanwhile, lower temperature corresponds with more days and later flowering dates. The linear fitting results indicate that per 1°C increase in the average temperature of wintertime and January will lead to 2.86 d and 1.66 d decrease in days from the first day every year, respectively, that is, 2.86 d and 1.66 d earlier for flowering dates. If the average temperature in February is over 7.2°C (or below 2°C), the days will decrease (or increase) rapidly. In order to get better fitting effects, the cubic equation is also used for February. The equations are as followings:

The days from the first day every year of first-flowering dates (y) with the average temperature of wintertime (x_1):

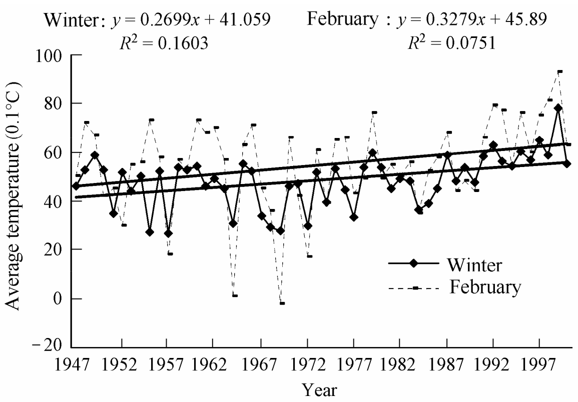

Fig. 4 Yearly change in average temperature for winter and February in Wuhan and its linear fitting (1947–2000)

y and R: the same as in Fig. 1.

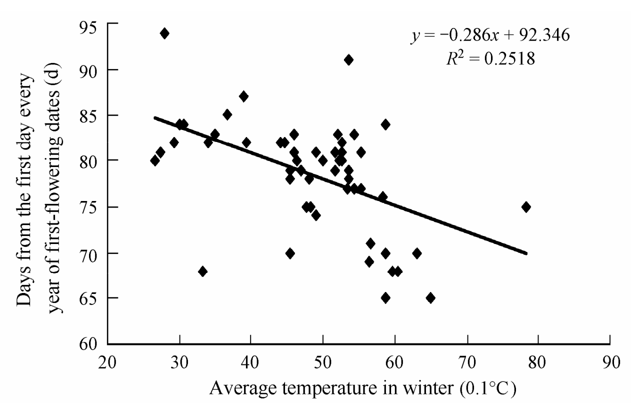

Fig. 5 Yearly change in days from the first day every year of first-flowering dates of Japanese Cherry Blossoms (*P. yedoensis* Mats.) in Wuhan University and its correlation and linear fitting with average temperature in winter (1947–2000)

R: correlation coefficient between y and x

Table 4 Correlation coefficient between first-flowering dates of Japanese Cherry Blossoms (*P. yedoensis* Mats.) in Wuhan University and the temperature in the previous period (1947–2000)

Period	Last year						This year			Winter
	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	
Correlation coefficient	–0.02	–0.02	0.00	–0.11	0.05	–0.17	–0.27*	–0.52***	–0.27*	–0.50***

* and *** mean reliability of 95% and 99.9%, respectively.

$$y = -0.286x_1+92.346 \quad (r = 0.50,\ a = 0.001) \quad (1)$$

The days from the first day every year of first-flowering dates (y) with the average temperature of February (x_2):

$$y = -0.166x_2+87.595 \quad (r = 0.52,\ a = 0.001) \quad (2)$$

$$y = -0.00005x_2^3+0.0067x_2^2-0.388x_2+88.466 \quad (r = 0.53,\ a = 0.001) \quad (3)$$

2.5 Testing of the predicted result by previous temperature

The above equations and the average temperature of February or wintertime were used to calculate first-flowering dates from 2001 to 2008 (Table 5). The average difference was only 3 d between the calculating and observing results. Especially in 2004 and 2007, the abnormal first-flowering dates were successfully predicted with the nonlinear equation.

3 Conclusions and discussion

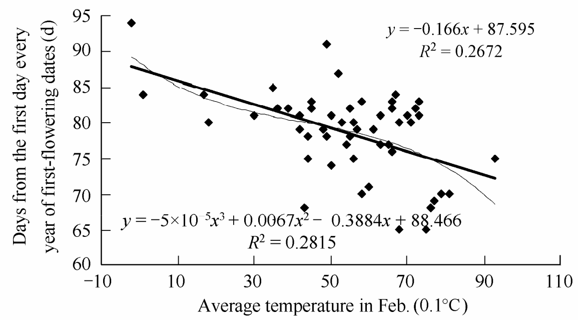

Fig. 6 Yearly change in days from the first day every year of first-flowering dates of Japanese Cherry Blossoms (*P. yedoensis* Mats.) in Wuhan University and its correlation and linear fitting with average temperature in February (1947–2000)

R: correlation coefficient between y and x

Based on a dataset of flowering dates of Japanese Cherry Blossoms (*P. yedoensis* Mats.) recorded continuously in the last 54 years (1947–2000) on campus of Wuhan University and climatic data in the same period, some conclusions were drawn:

1) The average first-flowering dates of Japanese Cherry Blossoms on campus of Wuhan University were from March 18th to 20th, and the average fading dates were from April 1st to 3rd, with an average duration of 15 d. The earliest first-flowering date and the longest duration both occurred after 1987, while the latest first-flowering date and the shortest duration occurred before 1984.

2) The average first-flowering dates advanced significantly for about 12 d, the fading dates were delayed for about 2 d, and therefore the duration increased prominently for up to 2 weeks. In the early 20 or 30 years, first-flowering dates, fading dates and duration were stable, but all changed dramatically in the late periods.

3) The first-flowering dates are negatively correlated with the monthly average temperature from last December to this March, and are not correlated with the monthly average temperature before last November. The closer to first-flowering dates, the more significant the correlation is. The strongest correlations are recorded with the average temperatures of February and wintertime. Per 1°C increase in the average temperature of February and wintertime will lead to 1.66 d and 2.86 d advances, respectively, for the first-flowering dates. In the early 54 years, the average temperatures of February and wintertime in Wuhan increased notably, with a bias of 0.43°C/10a and 0.31°C/10a, respectively, which can account for the advance of the first-flowering dates of Japanese Cherry Blossoms. So the flowering dates of cherry blossom can clearly

Table 5 Calculating and testing first-flowering dates and duration of flowering for Japanese Cherry Blossoms (*P. yedoensis* Mats.) in Wuhan University (1947–2000)

Year	Average temperature x_1 in winter and its difference (°C)	Average temperature x_2 in February and its difference (°C)	Days from the first day of the year and date of first-flowering (m/d) calculated from formula (1)	Days from the first day of the year and date of first-flowering (m/d) calculated from formula (2)	Days from the first day of the year and date of first-flowering (m/d) calculated from formula (3)	Days from the first day of the year and date of first-flowering (m/d) recorded	Difference between the calculated by formula (3) and the recorded (d)
2001	6.4 (1.2)	6.9 (1.8)	74.0 (3/14–15)	76.1 (3/16–17)	77.1 (3/17–18)	70 (3/11)	6
2002	7.2 (2.0)	10.0 (4.2)	71.8 (3/12–13)	71.0 (3/11–12)	66.6 (3/7–8)	69 (3/10)	–2
2003	5.9 (0.7)	7.1 (1.3)	75.5 (3/15–16)	75.8 (3/15–16)	76.8 (3/17–18)	79 (3/20)	–2
2004	7.2 (2.0)	11.2 (5.4)	71.8 (3/11–12)	69.0 (3/9–10)	58.8 (2/27–28)	57 (2/26)	1
2005	4.9 (–0.3)	3.6 (–2.2)	78.3 (3/19–20)	81.6 (3/22–23)	80.8 (3/21–22)	86 (3/27)	–5
2006	5.3 (0.1)	5.8 (0)	77.2 (3/18–19)	78.0 (3/18–19)	78.7 (3/19–20)	77 (3/18)	1
2007	7.3 (2.1)	10.7 (4.9)	71.5 (3/12–13)	69.8 (3/10–11)	62.4 (3/3–4)	61 (3/2)	1
2008	4.7 (–0.5)	5.0 (–0.8)	78.9 (3/18–19)	79.5 (3/19–20)	79.6 (3/19–20)	71 (3/12)	7

Temperature difference is the real value minus average value in 1971–2000 (30a) reflect the fact that the temperature in winter and early spring in Wuhan has increased.

4) Linear and nonlinear fitting equations were established and tested based on the average temperatures of February and wintertime to predict the first-flowering dates from 2001–2008, with an average error of 3 d or so. Especially the non-linear model was capable of predicting the early first-flowering dates in 2004 and 2007. The error will be reduced if the abnormality of the temperature from March 1st to the first-flowering dates could be taken into consideration.

Since the 21st century, the first-flowering dates from 2001 to 2008 fluctuated dramatically as a result of the fluctuation of wintertime temperature. The earliest one occurred even in winter, i.e., February 26th, 2004. The first-flowering dates of Japanese Cherry Blossoms on campus of Wuhan University had advanced 2.22d/10a and 13.79 d (about 2 weeks) in total during the 62 years from 1947 to 2008 (including the latest 8 years), which was 2 d earlier than that before 2000. All the results above can substantially testify that the phenophases of the Japanese Cherry Blossoms in Wuhan has advanced remarkably by the dual impacts of global climate change and urban heat island effect. If the temperature continues to increase in future, the Japanese Cherry Blossoms will flower frequently in winter rather than in spring in Wuhan. The benefits or harms of this kind of seasonal advance in the fields of climatic ecological environments, social economy development and resident health is still to be studied.

Acknowledgements

This paper is especially dedicated to Prof. Xiao Yihua (including his family), a famous biologist, of Wuhan University who has supplied all data of flowering dates of Japanese Cherry Blossoms observed on campus of Wuhan University from 1947 to 2008.

References

[1] IPCC (Intergovernmental Panel on Climate Change). Summary for policymakers of climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, USA: Cambridge University Press, 2007.

[2] IPCC (Intergovernmental Panel on Climate Change). Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, USA: Cambridge University Press, 2007.

[3] Ding Y H, Ren G Y, Shi G Y, *et al*. National assessment report of climate change (I): climate change in China and its future trend. Advances in Climate Change Research, 2006, 2(1): 3–8.

[4] Lin E D, Xu Y L, Jiang J H, *et al*. National assessment report of climate change (II): climate change impacts and adaptation. Advances in Climate Change Research, 2006, 2(2): 51–56.

[5] Zhu K Z, Wan H M. Phenology. Beijing: Scientific Press, 1984.

[6] Zhang F C. Effects of global warming on plant phonological events in China. Acta Geographica Sinica, 1995, 50(5): 402–410.

[7] Xu Y Q, Lu P L, Yu Q. Impacts of climate change on first-flowering dates of *Robinica pseudoacacia* L. and *Syringa amurensis* Rupr. in China. Journal of Beijing Forestry University, 2004, 26(6): 94–97.

[8] Chen Z H. Phenological characteristics of Tong oil trees in the eastern subtropical hills and mountains of China. Scientia Geographica Sinica, 1991, 11(3): 287–294.

[9] Chen Z H, Yang H Q, Ni G Y. The cold and hot damage to the citrus in the Three Gorges area of the Changjiang River. Chinese Geographic Science, 1994, 4(1): 66–78.

[10] Lu P L, Yu Q, He Q. Responses of plant phenology to climatic change. Acta Ecologica Sinica, 2006, 26(3): 923–929.

[11] Menzel A, Fabian P. Growing season extended in Europe. Nature, 1999, 397: 659.

[12] Menzel A, Estrella N, Fabian P. Spatial and temporal variability of the phenological seasons in Germany from 1951–1996. Globe Change Biology, 2001, 7: 657–666.

[13] Ahas R, Aasa A, Menzel A, *et al*. Changes in European spring phenology. International Journal of Climatology, 2002, 22: 1727–1738.

[14] Chmielewski F M, Muller A, Bruns E. Climate changes and trends in phenology of fruit trees and field crops in Germany, 1961–2000. Agricultural and Forest Meteorology, 2004, 121(1): 69–78.

[15] Ahas R, Jaagus J, Aasa A. The phonological calendar of Estonia and its correlation with mean air temperature. International Journal of Biometeorology, 2000, 4(4): 159–161.

[16] Peñuelas J, Filella I. Phenology: responses to a warming world. Science, 2001, 294: 793–795.

[17] Walkowszky A. Changes in phenology of the locust tree (*Robinia pseudoaeacia*) in Hungary. International Journal of Biometeorology, 1998, 41: 155–160.

[18] Bradley N L, Leopold A C, Ross J, *et al*. Phenological changes reflect climate change in Wisconsin. Proceedings of the National Academy of Sciences of USA, 1999, 96: 9701– 9704.

[19] Abu-Asab M S, Peterson P M, Shetler S G, *et al*. Earlier plant flowering in spring as a response to global warming in the Washington DC area. Biodiversity and Conservation, 2001, 10(4): 597–612.

[20] Beaubien E G, Freeland H J. Spring phenology trends in Alberta, Canada: links to ocean temperature. International Journal of Biometeorology, 2000, 44: 53–59.

[21] Liu J, Zheng Y F, Zhao G Q. Responses of phenology to climate change in Zhengzhou area. Acta Ecologica Sinica, 2007, 27(4): 1471–1479.

[22] Chen S Q, Zhang F C. Spring phonological change in Beijing in the last 50 years and its response to the climatic changes. Chinese Journal of Agrometeorology, 2001, 22(1): 1–5.

[23] Luo J. Evolution of the florescence of Japanese flowering cherry and its indication meanings in the last 30 years in Yangling, Shaanxi. Journal of Northwest A&F University (Natural Science Edition), 2007, 35(11): 165–170.

[24] Omoto Y, Aono Y. Estimation of change in blooming dates of flower by urban warming. Journal of Agricultural Meteorology, 1990, 46(3): 123–129.

[25] Chen Z H. The diagnosis and analysis of abrupt changes in mean the temperature during 20th century in Wuhan and Yichang. Resources and Environment in the Yangtze Basin, 2000, 9(1): 56–62.

[26] Ren G Y, Chu Z Y, Chen Z H, *et al*. Implications of temporal change in urban heat island intensity observed at Beijing and Wuhan stations. Geographic Research Letters, 2007, 34: L05711; doi: 10.1029/2006GL027927.

[27] Chen Z H, Wang H J, Ren G Y. Asymmetrical change of urban heat island intensity in Wuhan, China. Advances in Climate Change Research, 2007, 3(5): 282–286.

[28] Wei X L, Kong F Z, Zhang Z J, *et al*. Long-range forecasting of peony's anthesis at Heze. Meteorological Monthly, 2001, 27(6): 55–57.

[29] Jiang J M, Zhu M, Lou M Y. The relationship between the flowering date of osmanthus flower (*Osmanthus fragrans*) and the previous meteorological condition. Journal of Zhejiang Agricultural Sciences, 2002, (5): 225–227.

[30] Zhang X Y, Hu D Y. Prediction of peach-blossom flowering phase. Journal of Beijing Forestry University, 1995, 17(4): 88–93.

[31] Li J. Long-term forecasting model of the beginning date of peach flowering. Acta Botanica Boreali-Occidentalia Sinica, 2005, 25(9): 1876–1878.

[32] Che S J, Zhao S L, Zhi L H. Forecast of beginning of flowering period of winter jasmine (*Jasminum nudiflorum* L.). Chinese Journal of Agrometeorology, 2004, 25(3): 70–73.