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Climate of the Past Discussions

How could phenological records from the Chinese poems of the Tang and Song Dynasties (618-1260 AD) be reliable evidence of past climate changes?

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Abstract. Phenological records in historical documents have been proved to be of unique value for reconstructing past climate changes. As a literary genre, poetry reached its peak period in the Tang and Song Dynasties (618-1260 AD) in China, which could provide abundant phenological records in this period when lacking phenological observations. However, the reliability of phenological records from poems as well as their processing methods remains to be comprehensively summarized and discussed. In this paper, after introducing the certainties and uncertainties of phenological information in poems, the key processing steps and methods for deriving phenological records from poems and using them in past climate change studies were discussed: (1) two principles namely the principle of conservative and the principle of personal experience should be followed to reduce the uncertainties; (2) the phenological records in poems need to be filtered according to the types of poems, the background information, the rhetorical devices and the spatial representations; (3) the animals and plants are identified to species level according to their modern distributions and the sequences of different phenophases; (4) the phenophases in poems are identified on the basis of modern observation criterion; (5) the dates and sites for the phenophases in poems are confirmed from background information and related studies. Finally, the temperature anomalies reconstructed by phenological records from poems were compared with those reconstructed by other historical documents in published studies to demonstrate the validity and reliability of phenological records from poems in studies of past climate changes. This paper proved that the phenological records from poems could be useful evidence of past climate changes after being

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

Climate of the Past Discussions

scientifically processed and also provides a reference in both principle and methodology for the extraction and application of phenological records from poems.

Keywords. phenological records, poems, processing method, past climate changes, the Tang and Song Dynasties

1 Introduction

Phenology is the study of recurring biological life cycle stages and the seasonality of non-biological events triggered by environmental changes (Schwartz, 2003;Richardson et al., 2013). Phenological data derived from historical documents have been widely used as proxies to reflect past climatic changes over the world, especially in Europe and Asia. The records of grape harvest dates (Chuine et al., 2004;Meier et al., 2007;Maurer et al., 2009;Daux et al., 2012;Možný et al., 2016;Labbé et al., 2019), grain harvest dates (Nordli, 2001;Kiss et al., 2011;Wetter and Pfister, 2011;Pribyl et al., 2012;Brázdil et al., 2018) and ice break-up dates (Tarand and Nordli, 2001;Nordli et al., 2007;Etien et al., 2008) have been adopted to reconstruct past climate changes in Europe. In Japan, cherry blossom records have been used to reconstruct spring temperatures dating back to the medieval period (800–1400 AD) (Aono and Kazui, 2008;Aono and Saito, 2010;Aono, 2015).

In China, occasional phenological observations began around 2000 years ago and they have been recorded in various documents. These documents can be further divided into the sources produced by institutions and the sources generated by individuals. The former includes Chinese classical documents, local gazettes, the archives of the Qing Dynasty (1644-1911 AD) and the archives of the Republic of China (1912-1949 AD) (Ge et al., 2008). Based on the documents produced by institutions, abundant phenological records have been extracted to reconstruct the past climate change of specific regions and periods in China (Chu, 1973;Ge et al., 2003;Zheng et al., 2005;Hao et al., 2009;Liu et al., 2016). However, the phenophases recorded in these documents are mainly non-organic, such as “ice phenology” (the time of freezing and opening of water-bodies), “snow phenology” (the dates of first and last snows) and “frost phenology” (the dates of first and last frosts). The limited amounts of organic phenophases in these documents are principally “agricultural phenology” (e.g., the beginning dates of spring cultivation, winter wheat harvest in summer and millet harvest in autumn). Therefore, the phenological data from documents produced by institutions can hardly be compared with those

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

from modern observations, which majorly focus on the seasonal changes of ornamental plants. In contrast, the phenological information in personal documents (mostly refers to private diaries) are much more varied, which include quantities of records about both non-organic and organic events, such as flowers blossoming, leaf expansion and discoloration and fruit ripening (Ge et al., 2008;Liu et al., 2014;Zheng et al., 2014). Using phenological evidence from diaries, many studies reconstructed the past climate changes in different regions and periods in China (Fang et al., 2005;Xiao et al., 2008;Ge et al., 2014;Wang et al., 2015;Zheng et al., 2018). In spite of these efforts, the diaries were most abundant within the past 800 years, especially in the Ming Dynasty (1368-1644 AD), the Qing Dynasty and the Republic of China, and the earliest diary found in China so far (The Diary of Genzi-Xinchou by Lv Zuqian) merely dated back to 1180 AD (Ge et al., 2018). Thus, there is a lack of phenological records on natural plants and animals before the 1180s.

As another literary genre, the poetry reached its highest level during the Tang and Song Dynasties (618-1260 AD) in ancient China. People in the Tang and Song Dynasties preferred to record their thoughts and daily lives in poems. Abundant phenological information that described in the poems of the Tang and Song Dynasties is a valuable source for the phenological records in this period. However, it is an extraordinary challenge to extracting phenological records from poems due to the usages of rhetorical devices, the limitations on poetic rules and forms as well as the needs of rhymes and sounds in the poems. In addition, the phenological evidence in the poems did not always follow the modern criterion, which would yield considerable uncertainties if the real phenophases in poems were not properly identified. Chu (1973) laid the foundation for climate reconstructions based on documents and has been highly praised worldwide. In his study, 17 pieces of evidence were from poems and 11 of them were phenological information of the Tang and Song Dynasties. Although a few following studies (Man, 1998;Ge et al., 2010) has adopted phenological evidence from poems to reconstruct climate changes, further systematical and specialized research on deriving phenological records from poems of the Tang and Song Dynasties still needs to be carried out.

In this study, we first introduced the characteristics of phenological information in poems, including its accessibility and inherent uncertainties. Subsequently, we put forward basic principles and key processing steps for extracting phenological records from poems of the Tang and Song Dynasties. We also compared phenological records from poems with other documents in the reconstruction of past climate changes in the Guanzhong Area of central China. Our overall objectives are to demonstrate the

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

validity and reliability of phenological records from poems as a proxy of past climate changes and to provide a reference in both theory and method for the extraction and application of phenological records from poems.

2 The Certainties and Uncertainties of Phenological Information in Poems from the Tang and Song Dynasties

2.1 The certainties of phenological information from poems

Poetry is one of the major genres of Chinese literature. It expresses peoples' social life and spiritual world with concise words and abundant emotions according to the requirements of certain syllables, tones and rhythms. The poetry of the Tang and Song Dynasties represents the highest level of poetry development and has become the treasure of Chinese traditional literature. People in the Tang and Song Dynasties preferred recording and sharing their lives and ideas via poems, which is similar to recording diaries in the later dynasties. Phenology, which could be used to indicate seasons and guide agricultural activities, is one of the favorite contents recorded by poets in their poems. As most of the poems were improvised, they commonly reflect the real-time experiences of the poets. In addition, the great mass of the poems passed down to present were written by well-educated scholars, who were able to describe the phenological phenomena they saw without abusing the words. Thus, poetry is an excellent carrier of phenological information.

Regarding different types of poems of the Tang and Song Dynasties, phenological information is most abundant in natural poems and realistic poems. The natural poems describe the force and beauty of nature, such as mountains, rivers, animals and plants, which contain almost all kinds of phenological records, including organic ones and non-organic ones (Table 1). The realistic poems strive for the typicality in images, the authenticity in details and the objectivity in descriptions. For example, there is a line in a poem by Bai Juyi: "There is a crescent moon on the third night and the cicada sings for the first time"[1], which detailedly recorded the phenology of the first call of cicadas. Generally speaking, the phenological information from poems, especially natural poems and realistic poems, is objective and authentic, which can be an available data source for reconstructing past climatic changes.

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

2.2 The numbers and accessibility of phenological records from poems

By their very nature, poems have many distinctions in the field of keeping phenological information with documents produced by institutions and personal diaries (Table 2). Poems have evident advantages in the quantity and variety of phenological evidence. According to Quan-Tang-Shi (the Poetry of the Tang Dynasty) and Quan-Song-Shi (the Poetry of the Song Dynasty), nearly 50 thousand poems from the Tang Dynasty and more than 270 thousand poems from the Song Dynasty are preserved. Numerous phenological records in the poems not only include non-organic events, but also include a variety of organic phenomena, most of which are phenology of ornamental plants and animals. However, unlike documents produced by institutions in which phenological evidence was recorded by dedicated persons, the phenological evidence in poems was recorded more inadvertently. The information of phenophases in poems may be incomplete or ambiguous. For a specific phenophase, a poet usually only recorded it a few times in poems during his lifetime. Thus, the frequency and continuity of the phenophase in his poems were relatively low. Only by integrating the same phenophase recorded by different poets could improve frequency and continuity. In general, the accessibility of phenological records of poems is relatively lower than that of other documents. Take the word "willow" as an example, it has been mentioned in 9041 poems in the Quan-Tang-Shi and the Quan-Song-Shi, but clear species names, phenophases, dates and sites can be obtained from only 80 (0.88%) poems. The accessibility of phenological records of poems may vary with different features of poets. For example, Li Bai and Du Fu are the most representative romantic poet and realistic poet in the Tang Dynasty, respectively. According to Quan-Tang-Shi, there were 896 poems written by Li Bai and 1158 poems written by Du Fu. Among them, 23 (2.56%) poems by Li Bai and 76 (6.56%) poems by Du Fu are related to phenology. Thus, the accessibility of phenological information from poems by Du Fu is more than two times greater than that of Li Bai.

2.3 Inherent uncertainties of phenological evidence in poems

In addition to the uncertainties arising from data interpretation, calibration, validation and verification, the extraction of phenological evidence from poems could also have inherent uncertainties during the identification of species, the identification of phenophases, and the ascertainment of dates and sites, which should be excluded before using the phenological records to reconstruct past climate changes.

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

2.3.1 Uncertainties in the identification of species

Since the Chinese language has not changed fundamentally during the long history, the people in present day can read ancient poems almost without too much difficulty. Nevertheless, the changes in meanings and expressions of particular words and phrases still exist. Some words or phrases may have several additional meanings in ancient Chinese compared with modern usage. For example, the phrase "jin hua" (mainly refers to golden flower in modern Chinese) has at least four meanings in the Quan-Tang-Shi, but only one of them is a substantial description of phenology (Table 3).

The different names of some specific species in ancient China have also been simplified and unified at present. For example, the Si sheng du juan (*Cuculus micropterus*) have at least three different names during the Tang and Song Dynasties (Table 4). It was also noticed that the names of plants and animals in poems were mostly recorded at the genera level due to the lack of modern taxonomic knowledge. Nevertheless, different species within the same genus may exhibit divergent responses to climate change according to modern phenological studies (Dai et al., 2013). Thus, large uncertainties exist during the identification of species in poems.

2.3.2 Uncertainties in the judgment of phenophases

Phenophases in poems are not recorded in strict accordance with modern systematic criteria, but are described through multiple rhetorical devices such as metaphor, personification, hyperbole, quote, pun and rhyme, so it is difficult to extract clear phenophases from poems. For example, there is a line in a poem by the poet Quan Deyu: "Peonies occupy the spring breeze with their fragrance alone"[12], which describes the phase of peonies flowering. However, the phenophase in this line is equivocal due to the use of personification. In order to compare the phenological records from poems with corresponding modern observational phenophases, the exact phenological stages need to be identified from the first flowering date, the full-flowering date and the end of flowering date. Therefore, uncertainties may be produced during the identification of specific phenophases.

2.3.3 Uncertainties in ascertainment of dates

The exact date is the crucial factor for quantitatively evaluating phenological and climatic changes from past to present. By converting the Chinese lunar calendar into the modern Gregorian calendar, the phenophases in the poems can be compared with modern observational phenophases. Unfortunately,

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

writing time was not consciously kept for most poems. Any lack of information of year, month, or day may lead to failures in phenological and climatic reconstructions. For instance, the poet Bai Juyi recorded in his poem: "People are busy in the fifth lunar month because the wheat is yellow in the field."[13] Here, only the information of the month was directly presented in this poem, which would probably cause uncertainties when deducing the year and the day. To make matters worse, some poems were even not improvised, but were written according to the memories or imaginations of poets. The information from this kind of poems required to be excluded.

2.3.4 Uncertainties in ascertainment of sites

By matching the ancient name of a site with the modern one, the phenophases in the poems can be compared with the corresponding observational phenophases at the same site. However, similar to date, the sites of phenophases in poems are sometimes missing. Even worse, some names of the sites mentioned in the poems are imagined to express the emotions rather than to record real locations. For example, Lu You wrote a verse in his poem: "There are so many willow branches in Ba Qiao, but who would have thought sending one to me?"[14] Ba Qiao is a location in Xi'an (a city in central China), which is more than 700 km away from the place Lu You wrote this poem (Chengdu, China). By describing the willow branches in his hometown in this poem, the poet expressed his homesickness. When ascertaining the sites, these kinds of uncertainties should be carefully dealt with.

3 The Methods of Processing Phenological Records in Poems from the Tang and Song Dynasties for past climate studies

In order to minimize the uncertainty during the extraction of clear species, phenophase, date and site information from poems and to make them comparable with modern observations, several basic principles and processing steps should be put forward.

3.1 The basic principles for data processing

3.1.1 The principle of conservative

The principle of conservative refers to deducing the ambiguous information conservatively, so as to keep the characteristics of phenological information without causing too much deviation. Take the aforementioned poem of Bai Juyi[13] as an example, the poem was written in 807 AD in Xi'an according

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

to background information while the exact date is not recorded. From the poem, we can know that the harvest date of wheat in that year appeared in the fifth lunar month (from June 10 to July 8 in the Gregorian calendar), so that the date of June 10 which is the closest to the modern observations (from May 26 to June 8 with the average of June 2) can be determined as the date of wheat harvest in 807 AD in Xi'an. It should be noted that if the recorded period in the poem is overlapped with the time of the modern phenophase, the principle of conservative is inapplicable, and the record in the poem is invalid.

3.1.2 The principle of personal experience

The principle of personal experience demands that the phenological information described in the poems was being experienced by the poet, thus excluding the records based on imaginations or memories. For example, Yang Wanli recorded a line in his poem: "Begonias in my hometown are flowering on this date and I see them booming in my dream."[15] From the line, we can easily know that he was not in his hometown when he wrote this poem. Thus, the phenophase of Begonia in this poem can not be used. It takes effort to diagnose the information in some poems. For example, Lu You wrote a poem in 1208 AD: "The Begonias in Biji Fang (place name) are the best in the world. Each branch looks dyed with scarlet blood."[16] By looking up into the life experience of Lu You, this poem is found to record his memory in 1172 AD. Therefore, this piece of record also can not be used as the phenological evidence according to the principle of personal experience.

3.2 The key steps of data processing

On the basis of the principles, four steps are required for the processing of phenological records in poems (Figure 1).

3.2.1 Step 1: filtering the records

(1) Filtering the records according to the features of poets and poems

Poems commonly reflect the thoughts and daily lives of the poets. Thus the poems written by people in certain professions who have little contact with phenological events, such as the alchemists mentioned in Table 3, may contain little phenological information. In this way, the poems written by alchemists can be excluded to improve the accessibility of phenological evidence from the poems. Furthermore, the records can be filtered according to the styles of poems and the interests or life experiences of the poets. For example, it is more likely to extract phenological records from pastoral poems than from history-intoned poems.

(2) Filtering the records according to the background information

According to the background information of a poem, we can judge whether the phenophases in the poem actually happened, thus ensuring the effectiveness of phenological evidence. For example, there is a line of Su Shi saying: "A few branches of peach blossom outside the bamboo grove, and the ducks will notice the warming of the river firstly."[17] From this line, it seems to describe the natural phenophases in spring. However, by looking into the background information, we know that this poem is an illustrated poetry in painting. Therefore it describes the scenery within the painting instead of real nature. The record requires to be excluded.

(3) Filtering the records according to the rhetorical devices

Whether the use of rhetorical devices in poems may affect the authenticity of phenophases is required to be distinguished. For instance, despite the rhetorical device of personification used in the aforementioned poem by Quan Deyu[12], it does reflect the blossom of peonies. Thus, this poem can be used in the study of past climate changes. The line of Lu Zhaoling saying: "The water in Laizhou (place name) has become shallower several times and how ripe is the peach fruit?"[18] seems to ask the time of peach phenophase, but actually, it is the quotation of the myths that the peaches mature once every three thousand years in wonderland. The rhetorical device of quotation in this line has affected the authenticity of phenophases. Thus, this piece of record should be eliminated.

(4) Filtering the records according to the spatial representations

For a specific species, phenophases vary with latitude, longitude and elevation. It is necessary to clarify the spatial representation of phenological records in poems and to select records that are not affected by the local microclimate. For example, Bai Juyi recorded in his poem: "All the flowers on the plain have withered in the fourth lunar month, but the peaches in the temple on the mountain just begin to bloom."[19] This piece of record can not be directly compared with modern observational data because the difference in altitude is almost 1000 meters between the mountain in the poem and the modern observation site on the plain. Other factors that contribute to spatial differences such as valley, depression and heat island effect are also used to filter the records.

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

Climate of the Past
Discussions

3.2.2 Step 2: identifying the animals and plants to species level

There are mainly two ways to identify the animals and plants in poems from genera level to species level. The first way is to identify the species according to the modern distribution of different species under the genera. For instance, the poet Liu Xian recorded the following information in his poem: "The flowers of peach are going to fall while the branches of willow are stretching."[20] This poem was written in Xi'an, which is located in the middle reaches of the Yellow River. In history, the species of peach were mainly *Amygdalus davidiana* and *Amygdalus persica*. According to modern species distribution, the former species distributes along the middle and lower reaches of the Yellow River while the latter distributes in the Huai River basin (Gong et al., 1983). Thus, the peach in the poem can be identified as *A. davidiana*. The second way is to identify the species according to the sequences and correlations of different phenophases. For example, Gao Shi wrote a poem in Chengdu: "The green-up of willow leaves and the blossom of plum can't stop me from being sad."[21] The plant plum in ancient Chinese language usually refers to *Chimonanthus praecox* or *Armeniaca mume*. From the text content, we can infer that the blossom of plum was close in time with leaf expansion of willow. According to modern observation data in Chengdu, the average full leaf expansion date of willow (*Salix babylonica*) is on February 23, while the average full flowering date of *Chimonanthus praecox* and *Armeniaca mume* are January 10 and February 10, respectively. The average date of full flowering date for *A. mume* is closer in time with the average date of full leaf expansion for willow. Thus, the plum in the poem can be identified as *A. mume*.

3.2.3 Step 3: identifying the phenophases according to the modern observation criteria

By applying the semantic differential technique, which is commonly used in the studies of past climate changes (Academy of Meteorological Science of China Central Meteorological Administration, 1981;Wang, 1991;Wei et al., 2015;Yin et al., 2016;Su et al., 2018;Fang et al., 2019), the descriptions in poems are classified and graded according to the criteria of the phenological observation methods in China (Wan and Liu, 1979;Gong et al., 1983;Fang et al., 2005). Take the aforementioned poem of Quan Deyu[12] as an example, the line described a scene where many peonies were blooming and filling the spring breeze with strong perfume. By classifying and grading the key words "occupy" and "fragrance" in this poem with other common descriptions of flowering phases in poems such as "tender", "sparse", "flourish", "dense", "wither", "fallen" etc, the description of peony blooming in this

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

poem was most likely to match with the full flowering date under the modern criteria “more than half of the flowers have blossomed in the observed species”. Thus, the phenophase in the poem can be identified as the full flowering date. The classification and grading results for some representative examples of phenological descriptions in poems are shown in Table 5.

3.2.4 Step 4: ascertaining the dates and locations

This step firstly sought the time information, including clear year, month and date of the phenophase, from the titles, prefaces and lines of the poems. Then, for the missing time information, it could be deduced by consulting the background information, related studies or estimated reasonably according to the principle of conservative. Finally, the time information in the Chinese lunar calendar needs to be converted into the modern Gregorian calendar. For example, the poet Cui Riyong recorded in his poem: “The plums in the palace smell fragrant and look delicate with the background of snow.”[28] The title of this poem indicates that this poem records a banquet in the imperial palace on People’s Day (Chinese traditional festival on 7th day of the first lunar month). From the poem, we did not know which year it was. However, this banquet was also recorded by Xin Tang Shu (New Books of Tang, a history book of the Tang Dynasty) in the year 730 AD. Hence, we can know that this poem was written in 730 AD.

Similarly, the exact location of the sites could be confirmed. It should be noted to check whether the place names appearing in the poems are real sites for phenophases. For example, Ba qiao is not the site of phenophase for willow in the aforementioned poem by Lu You[14]. Thus, the record in this poem can not be used as the phenological evidence for past climate studies.

4 Validation of the phenological records from poems for reconstructing the past climate changes

In order to test the reliability of phenological records in poems for past climate change studies, we firstly extracted 86 phenological records from the poems of the Tang Dynasty (618-902 AD) according to the above processing methods. The transfer functions were applied to reconstruct the annual temperature anomalies (with respect to the mean temperature in 1961—1990 AD) in the Guanzhong Area (Figure 2) during 600-902 AD. The modern phenological and meteorological data used and the method of the transfer function were shown in appendix B. Then, we obtained the records from

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

historical documents used by Liu et al (2016) to reconstruct the annual temperature anomalies in Guanzhong Area during 600-902 AD for validation.

Table 6 shows the historical data sources, types and the numbers of phenological evidence in the study of Liu et al. (2016) and in this study. In general, the two studies have similar amounts of evidence, while the data types of the two studies are quite different. In terms of Liu et al. (2016), 71 of 87 (nearly 82%) pieces of phenological data are from documents produced by institutions. Among the 87 pieces of evidence, 67 of them (more than 77%) are non-organic phenophases or agricultural phenophases. On the contrary, the majority (more than 96%) of evidence from poems in this study are phenophases of ornamental plants (Figure 3). These differences prove that the phenological records in poems are effective supplements to historical phenological evidence both in quantities and types for the period of Tang Dynasty.

Figure 3 shows the reconstructed annual temperature anomalies by the two studies. It is worth noting that the numbers of years reconstructed in this study (38) is relatively less than that based on the records in Liu et al. (2016) (76), further demonstrating that the frequency and continuity of phenological records preserved in poems is more sporadic than that of documents produced by institutions (Table 2). The mean annual temperatures reconstructed from poems in this study and from documents in Liu et al. (2016) were respectively 0.43 ℃ and 0.29 ℃ higher during the study period (600-902 AD) than at present (1961-1990). During the whole overlapping period (600s-870s), the difference of temperature anomalies reconstructed by two data sources did not exceed 0.10 ℃. There were approximately simultaneous temperature fluctuations between the two reconstructions, and both of them indicated a clear shift from warm to cold occurring around the 800s. For both reconstructions, the relatively higher temperatures occurred around the 670s and the 780s, while the colder years mainly appeared in the last decades of the period. Furthermore, the amplitude of reconstructed temperature from documents was 3.30 ℃, which was very similar to the amplitude of reconstructed temperature by poems (2.94 ℃) in this study. Generally speaking, the temperature anomalies reconstructed by the two studies are almost consistent.

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

Climate of the Past Discussions

5 Discussions

There are still controversies on how climate changes in the Tang and Song Dynasties (Chu, 1973;Yang et al., 2002;Ge et al., 2003;Tan et al., 2003;Thompson et al., 2006;Zhang and Lu, 2007). One of the reasons lies in the lack of sufficient evidence supporting the climatic reconstructions. Although some studies have reconstructed the temperatures during this period using natural evidence such as tree rings, pollens, and sediments (Xu et al., 2004;Zhang et al., 2014;Zhu et al., 2019), their results either cannot cover the whole period or they have relatively low temporal resolutions. In addition, these natural proxies are mostly collected from uninhabited areas, thus they can hardly be used for further evaluating the interactions between climate change and human activities. In comparison, documentary evidence, which occurs more frequently and is closer to human life, has become an important data source for reconstructing the climate change in this period. As one of the most popular literary forms in the Tang and Song Dynasties, poetry has huge potential to provide abundant and various phenological information, which will undoubtedly contribute to the study of historical climate change.

Despite this, very few studies so far have been reported to use phenological records from poems to reconstruct historical climate change quantitatively due to the lack of effective methodology for data extraction. Unlike climate reconstructions using other proxies that have standard processing methods and clear reference objects, the processing of phenological records from poems is much more complex. For example, dating tree-ring samples requires only counting the number of annual rings from the outside to the inside or comparing them with a standard chronology. However, the temporal information in the poems cannot be obtained directly from a reference chronology. As already mentioned, the temporal information in the poems may be hidden in the poet’s biography, the official history book, or some related studies. It is necessary to search through these materials one by one and make careful comparisons before ascertaining the exact temporal information, even if some information is found to be unrecorded after searching through large amounts of materials. The problem also exists when extracting the information of species, phenophases and sites from poems.

We attempt to introduce a standard procedure for extracting phenological records from poems, which could, on the one hand, minimize the uncertainties of the records, and on the other hand, filter the useless records efficiently. By following the principles and steps, researchers are able to know where to find the information needed and how to deal with the phenological data from poems. The extracted phenological records are comparable with modern observation data and can be used as the proxy for reconstructing the climate changes quantitatively.

In this study, we only used 85 phenological records extracted from poems to reconstruct the temperature anomalies for a small area in the Tang Dynasty. This is a case to prove the reliability of the records in indicating past climate changes. In fact, there are still plenty of phenological records that are not extracted. By rough estimation, the temporal resolution of the phenological records from poems of the Tang and Song Dynasties can reach at least 20 years. In addition, phenological records from poems of the Tang and Song Dynasties are widely distributed, covering almost all the regions of modern China. The rich records around the capitals and developed cities are of great value in comparison with modern phenological observations. Future work will be focused on extracting more records from poems, and developing integration methods for different phenophases at different sites to explore the overall phenological change and climate change over a large region.

6 Conclusions

In this study, we put forward a processing method to extract phenological information from poems of the Tang and Song Dynasties, which includes two principles (the principle of conservative and the principle of personal experience) and four steps: (1) filtering the records based on the features of poets and poems, the background information, the rhetorical devices and the spatial representations; (2) identifying the animals and plants to species level; (3) judging the phenophases according to the modern observation criteria; (4) ascertaining the time and sites. Then, we used this method to extract 85 phenological records from the poems of the Guanzhong Area in central China and reconstructed the annual mean temperature anomalies for the period of 600-902 AD. The reconstructed temperature anomaly series was comparable with that reconstructed by records from documents in the same area and period, demonstrating that our method is effective and reliable. This paper provides a reference in both theory and method for the extraction and application of phenological records from poems in the studies of past climate changes.

Author contributions.

Yachen Liu and Zexing Tao contributed to the idea and design of the structure of paper; Yachen Liu collected and analysed the data; Yachen Liu, Qiuqi Fang, Junhu Dai, Huanjiong Wang and Zexing Tao wrote the paper.

Competing interests.

The authors declare that they have no conflict of interest.

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References

Academy of Meteorological Science of China Central Meteorological Administration: Yearly Charts of Dryness/Wetness in China for the Last 500-Year Period, Cartographic Publishing House, Beijing, China, 1981(in Chinese).

Aono, Y., and Kazui, K.: Phenological data series of cherry tree flowering in Kyoto, Japan, and its application to reconstruction of springtime temperatures since the 9th century, Int J Climatol, 28, 905-914, http://doi.org/10.1002/joc.1594, 2008.

Aono, Y., and Saito, S.: Clarifying springtime temperature reconstructions of the medieval period by gap-filling the cherry blossom phenological data series at Kyoto, Japan, Int J Biometeorol, 54, 211-219, http://doi.org/10.1007/s00484-009-0272-x, 2010.

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

Aono, Y.: Cherry blossom phenological data since the seventeenth century for Edo (Tokyo), Japan, and their application to estimation of March temperatures, Int J Biometeorol, 59, 427-434, http://doi.org/10.1007/s00484-014-0854-0, 2015.

Brázdil, R., Možný, M., Klír, T., Řezníčková, L., Trnka, M., Dobrovolný, P., and KotyzaIch, O.: Climate variability and changes in the agricultural cycle in the Czech Lands from the sixteenth century to the present, Theor Appl Climatol, 136, 553-573, http://doi.org/10.1007/s00704-018-2508-3, 2018.

Chu, K.: A preliminary study on the climatic fluctuations during the last 5,000 years in China, Sci China, 16, 226-256, 1973.

Chuine, I., Yiou, P., Viovy, N., Seguin, B., Daux, V., and Ladurie, E. L. R.: Historical phenology: grape ripening as a past climate indicator, Nature, 432, 289-290, https://doi.org/10.1038/432289a, 2004.

Dai, J., Wang, H., and Ge, Q.: Multiple phenological responses to climate change among 42 plant species in Xi'an, China, Int J Biometeorol, 57, 749-758, http://doi.org/10.1007/s00484-012-0602-2, 2013.

Daux, V., De Cortazar-Atauri, I. G., Yiou, P., Chuine, I., Garnier, E., Ladurie, E. L. R., Mestre, O., and Tardaguila, J.: An open-access database of grape harvest dates for climate research: data description and quality assessment, Clim. Past, 8, 1403-1418, https://doi.org/10.5194/cp-8-1403-2012, 2012.

Etien, N., Daux, V., Masson-Delmotte, V., Stievenard, M., Bernard, V., Durost, S., Guillemin, M. T., Mestre, O., and Pierre, M.: A bi-proxy reconstruction of Fontainebleau (France) growing season temperature from AD 1596 to 2000, Clim. Past, 4, 91-106, http://doi.org/10.5194/cp-4-91-2008, 2008.

Fang, X., Xiao, L., Ge, Q., and Zheng, J.: Changes of plants phenophases and temperature in spring during 1888~1916 around Changsha and Hengyang in Hunan province, Quaternary Sciences, 25, 74-79, http://doi.org/10.3321/j.issn:1001-7410.2005.01.010, 2005(in Chinese).

Fang, X., Su, Y., Wei, Z., and Yin, J.: Social impacts of climate change in historical China, in: Socio-Environmental Dynamics along the Historical Silk Road, edited by: Yang, L. E., Bork, H.-R., Fang, X., and Mischke, S., Springer, Cham, Switzerland, 231-245, 2019.

Ge, Q., Zheng, J., Fang, X., Man, Z., Zhang, X., Zhang, P., and Wang, W.-C.: Winter half-year temperature reconstruction for the middle and lower reaches of the Yellow River and Yangtze River, China, during the past 2000 years, Holocene, 13, 933-940, https://doi.org/10.1191/0959683603hl680rr, 2003.

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

Climate of the Past Discussions

Ge, Q., Zheng, J., Tian, Y., Wu, W., Fang, X., and Wang, W.-C.: Coherence of climatic reconstruction from historical documents in China by different studies, Int J Climatol, 28, 1007-1024, http://doi.org/10.1002/joc.1552, 2008.

Ge, Q., Liu, H., Zheng, J., and Zhang, X.: Reconstructing temperature change in Central East China during 601-920 AD, Chinese Sci Bull, 55, 3944-3949, http://doi.org/10.1007/s11434-010-4179-z, 2010.

Ge, Q., Wang, H., Zheng, J., This, R., and Dai, J.: A 170 year spring phenology index of plants in eastern China, J Geophys Res Biogeosci, 119, 301-311, https://doi.org/10.1002/2013JG002565, 2014.

Ge, Q., Hao, Z., Zheng, J., and Liu, Y.: China: 2000 years of climate reconstruction from historical documents, in: The Palgrave Handbook of Climate History, edited by: White, S., Pfister, C., and Mauelshagen, F., Springer, Basingstoke, UK, 189-201, 2018.

Gong, G., Zhang, P., and Wu, X.: Research Methods of Historical Climate Change, Science Press, Beijing, China, 1983(in Chinese).

Hao, Z., Ge, Q., and Zheng, J.: Temperature variations during the Song and Yuan dynasties (960~1368A.D.) in the eastern part of north west China, Quaternary Sciences, 29, 871-879 http://doi.org/10.3969/j.issn.1001-7410.2009.05.03, 2009(in Chinese).

Kiss, A., Wilson, R., and Bariska, I.: An experimental 392-year documentary-based multi-proxy (vine and grain) reconstruction of May-July temperatures for Koszeg, West-Hungary, Int J Biometeorol, 55, 595-611, https://doi.org/10.1007/s00484-010-0367-4, 2011.

Labbé, T., Pfister, C., Brönnimann, S., Rousseau, D., Franke, J., and Bois, B.: The longest homogeneous series of grape harvest dates, Beaune 1354-2018, and its significance for the understanding of past and present climate, Clim. Past, 15, 1485-1501, https://doi.org/10.5194/cp-2018-179, 2019.

Liu, Y., Wang, H., Dai, J., Li, T., Wang, H., and Tao, Z.: The application of phonological methods in reconstruction of past climate changes, Geogr Res, 33, 2-15 http://doi.org/10.11821/dlyj201404001, 2014(in Chinese).

Liu, Y., Dai, J., Wang, H., Ye, Y., and Liu, H.: Phenological records in Guanzhong Area in central China between 600 and 902 AD as proxy for winter half-year temperature reconstruction, Sci China Earth Sci, 59, 1847-1853, http://doi.org/10.1007/s11430-016-5325-5, 2016.

Man, Z.: Climate in Tang Dynasty of China: discussion for its evidence, Quaternary Sciences, 20-30, 1998(in Chinese).

Maurer, C., Koch, E., Hammerl, C., Hammerl, T., and Pokorny, E.: BACCHUS temperature reconstruction for the period 16th to 18th centuries from Viennese and Klosterneuburg grape harvest dates, J. Geophys. Res., 114, https://doi.org/10.1029/2009JD011730, 2009.

Meier, N., Pfister, C., Wanner, H., and Luterbacher, J.: Grape harvest dates as a proxy for Swiss April to August temperature reconstructions back to AD 1480, Geophys Res Lett, 34, https://doi.org/10.1029/2007GL031381, 2007.

Možný, M., Brázdil, R., Dobrovolný, P., and Trnka, M.: April-August temperatures in the Czech Lands, 1499--2015, reconstructed from grape-harvest dates, Clim. Past, 12, 1421-1434, https://doi.org/10.5194/cp-12-1421-2016, 2016.

Nordli, Ø., Lundstad, E., and Ogilvie, A. E. J.: A late-winter to early-spring temperature reconstruction for southeastern Norway from 1758 to 2006, Ann Glaciol, 46, 404-408, http://doi.org/10.3189/172756407782871657, 2007.

Nordli, P. Ø.: Reconstruction of nineteenth century summer temperatures in Norway by proxy data from farmers' diaries, Climatic Change, 48, 201-218, https://doi.org/10.1007/978-94-017-3352-6_10, 2001.

Pribyl, K., Cornes, R. C., and Pfister, C.: Reconstructing medieval April-July mean temperatures in East Anglia, 1256-1431, Climatic Change, 113, 393-412, http://doi.org/10.1016/j.quaint.2012.08.1205, 2012.

Richardson, A. D., Keenan, T. F., Migliavacca, M., Ryu, Y., Sonnentag, O., and Toomey, M.: Climate change, phenology, and phenological control of vegetation feedbacks to the climate system, Agric For Meteorol, 169, 156-173, https://doi.org/10.1016/j.agrformet.2012.09.012, 2013.

Schwartz, M. D.: Phenology: an integrative environmental science, Springer, Netherlands, 2003.

Su, Y., He, J., Fang, X., and Teng, J.: Transmission pathways of China's historical climate change impacts based on a food security framework, Holocene, 28, 1564-1573, http://doi.org/10.1177/0959683618782600, 2018.

Tan, M., Liu, T. S., Hou, J. Z., Qin, X. G., Zhang, H. C., and Li, T. Y.: Cyclic rapid warming on centennial-scale revealed by a 2650-year stalagmite record of warm season temperature, Geophys Res Lett, 30, 1617, https://doi.org/10.1029/2003GL017352, 2003.

Tarand, A., and Nordli, P. Ø.: The Tallinn temperature series reconstructed back half a millennium by use of proxy data, Climatic Change, 48, 189-199, http://doi.org/10.1023/A:1005673628980, 2001.

Thompson, L. G., Yao, T., Davis, M. E., Mosley-Thompson, E., Mashiotta, T. A., Lin, P.-N., Mikhalenko, V. N., and Zagorodnov, V. S.: Holocene climate variability archived in the Puruogangri ice cap on the central Tibetan Plateau, Ann Glaciol, 43, 61-69, http://doi.org/10.3189/172756406781812357, 2006.

Wan, M., and Liu, X.: Phenological observation methods in China, Science Press, Beijing, China, 1979(in Chinese).

Wang, H., Dai, J., Zheng, J., and Ge, Q.: Temperature sensitivity of plant phenology in temperate and subtropical regions of China from 1850 to 2009, Int J Climatol, 35, 913-922, https://doi.org/10.1002/joc.4026, 2015.

Wang, S.: Reconstruction of tempeature series of North China from 1380s to 1980s, Sci China, 34, 751-759, 1991.

Wei, Z., Rosen, A. M., Fang, X., Su, Y., and Zhang, X.: Macro-economic cycles related to climate change in dynastic China, Quaternary Res, 83, 13-23, http://doi.org/10.1016/j.yqres.2014.11.001, 2015.

Wetter, O., and Pfister, C.: Spring-summer temperatures reconstructed for northern Switzerland and southwestern Germany from winter rye harvest dates, 1454-1970 Clim. Past, 7, 1307-1326, https://doi.org/10.5194/cp-7-1307-2011, 2011.

Xiao, L., Fang, X., and Zhang, X.: Location of rainbelt of Meiyu during second half of 19th century to early 20th century, Scientia Geographica Sinica, 28, 385-389, http://doi.org/10.3969/j.issn.1000-0690.2008.03.015, 2008(in Chinese).

Xu, Q., Xiao, J., Nakamura, T., Yang, X., Yang, Z., Liang, W., and Inouchi, Y.: Climate changes of daihai basin during the past 1500 from a pollen record, Quaternary Sciences, 24, 341-347, http://doi.org/10.3321/j.issn:1001-7410.2004.03.014, 2004(in Chinese).

Yang, B., Braeuning, A., Johnson, K. R., and Yafeng, S.: General characteristics of temperature variation in China during the last two millennia, Geophys Res Lett, 29, 38-31, https://doi.org/10.1029/2001GL014485, 2002.

Yin, J., Fang, X., and Su, Y.: Correlation between climate and grain harvest fluctuations and the dynastic transitions and prosperity in China over the past two millennia, Holocene, 26, 1914-1923, http://doi.org/10.1177/0959683616646186, 2016.

Zhang, D. E., and Lu, L. H.: Anti-correlation of summer/winter monsoons? , Nature, 450, E7-E8, http://doi.org/10.1038/nature06338, 2007.

Zhang, Y., Shao, X. M., Yin, Z.-Y., and Wang, Y.: Millennial minimum temperature variations in the Qilian Mountains, China: evidence from tree rings, Clim. Past, 10, 1763-1778, http://doi.org/10.5194/cp-10-1763-2014, 2014.

Zheng, J., Man, Z., Fang, X., and Ge, Q.: Temperature variation in the eastern China during Wei, Jin and South-North Dynasties (220-580A. D.), Quaternary Sciences, 25, 129-140, http://doi.org/10.3321/j.issn:1001-7410.2005.02.002, 2005(in Chinese).

Zheng, J., Ge, Q., Hao, Z., Liu, H., Man, Z., Hou, Y., and Fang, X.: Paleoclimatology proxy recorded in historical documents and method for reconstruction on climate change, Quaternary Sciences, 34, 1186-1196, http://doi.org/10.3969/j.issn.1001-7410.2014.06.07, 2014(in Chinese).

Zheng, J., Liu, Y., Hao, Z., Zhang, X., Ma, X., Liu, H., and Ge, Q.: Winter temperatures of southern China reconstructed from phenological cold/warm events recorded in historical documents over the past 500 years, Quatern Int, 479, 42-47, http://do.org/10.1016/j.quaint.2017.08.033, 2018.

Zhu, Y., Lei, G., Li, Z., Jiang, X., Jin, J., and Wang, L.-C.: Montane peat bog records of vegetation, climate, and human impacts in Fujian Province, China, over the last 1330 years, Quatern Int, 528, 53-62, http://doi.org/10.1016/j.quaint.2019.04.016, 2019.

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

Climate of the Past
Discussions

Figures and tables

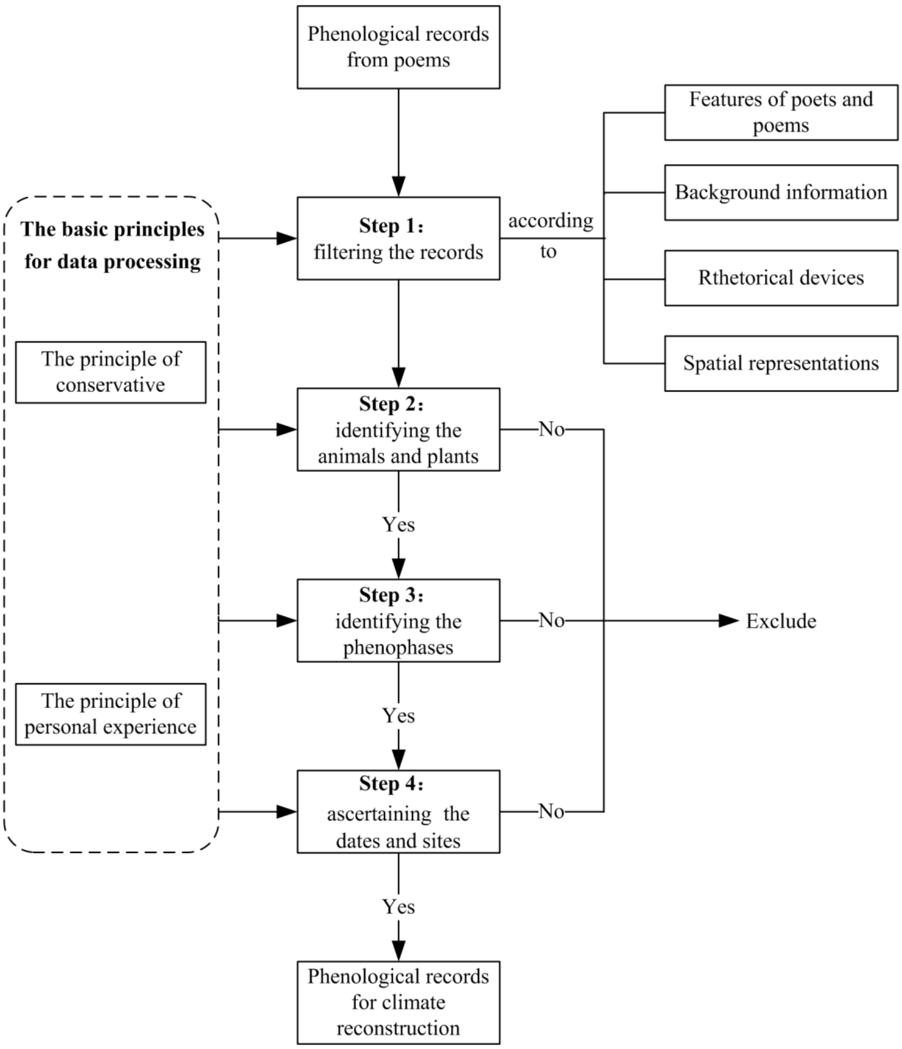

Figure 1 Processing steps of phenological records in poems for climate reconstructions

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

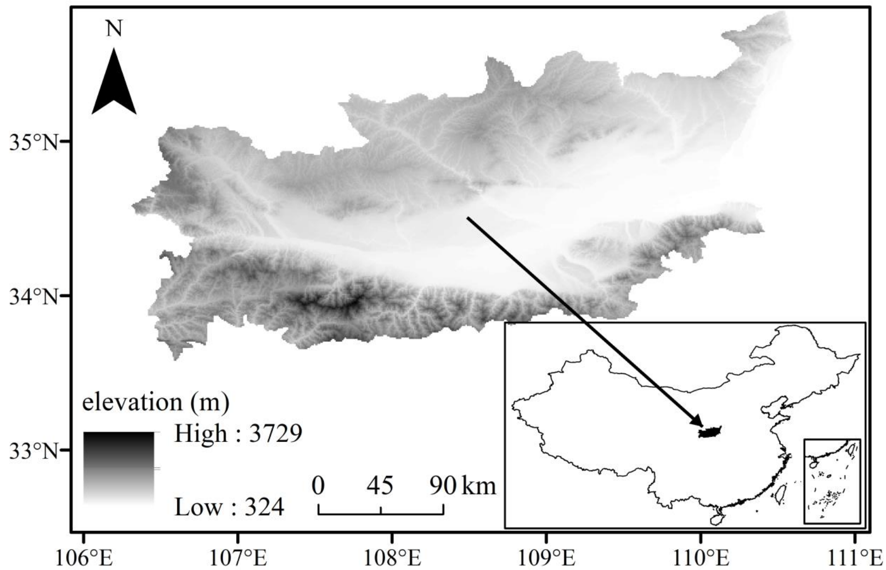

Figure 2 The location of the Guanzhong Area for the climatic reconstructions in this paper

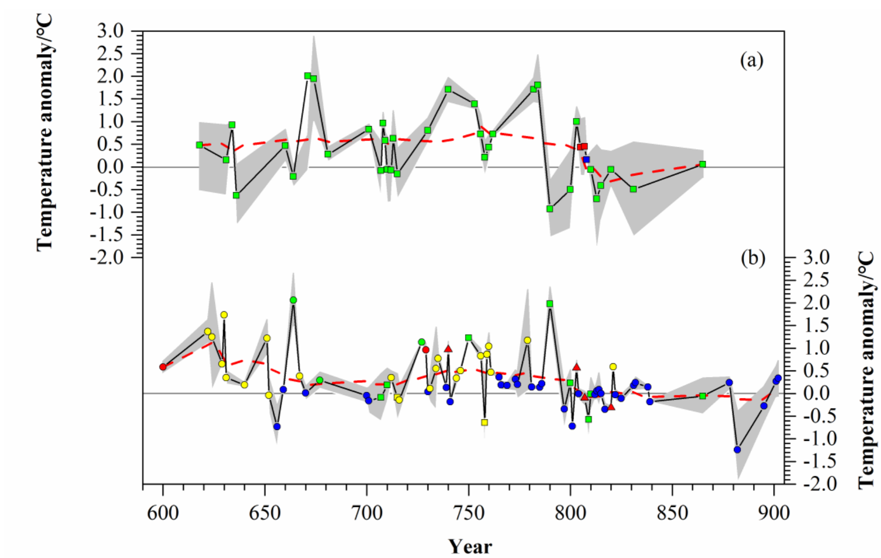

Figure 3 The mean annual temperature anomalies of two reconstructions for Guanzhong Area in the period 600-902 AD (with respect to the mean climatology between 1961 and 1990). (a): The annual mean temperature anomalies reconstructed in this study; (b): The annual mean temperature anomalies reconstructed using the records in Liu et al. (2016); The squares:

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

temperature anomalies reconstructed from poems; The circles: temperature anomalies reconstructed from documents of institutions; The triangles: temperature anomalies reconstructed from both poems and documents of institutions; The color green: temperature anomalies reconstructed by phenophases of plants; The color yellow: temperature anomalies reconstructed by agricultural phenophases; The color blue: temperature anomalies reconstructed by non-organic phenophases; The color red: temperature anomalies reconstructed by at least two types of phenophases; The red dotted line indicates temperature anomalies smoothed by the 10 year moving average. The gray area approximates the 95% confidence interval completed from linear regression error.

Table 1 The different types of phenology in the poetry of the Tang and Song Dynasties

Types of phenology		Examples of poems
Non-organic	phenology of ice	All the springs are frozen and stagnant[2]
	phenology of snows	It snows in the 8th lunar month in frontier regions[3]
	phenology of frosts	Frost falls in the 8th lunar month of every year[4]
Organic	phenology of agriculture	The poople have just finished planting mulberry trees to raise silkworms and they are going to transplant rice seedling again[5]
	phenology of ornamental plants	Plum blossoms begin to bloom in early winter[6]
	phenology of animals	The river reflects the autumn scenery and the geese begin to fly south[7]

Table 2 Comparisons among the phenological evidence from poems, diaries and documents produced by institutions in China

	Poems	Diaries	Documents produced by institutions
Types of	organic (phenology of	organic (phenology of	most

Climate of the Past
Discussions
Open Access

phenological evidence	plants and animals) and non-organic (phenology of ice, snow and frost)	plants and animals) and non-organic (phenology of ice, snow and frost)	non-organic(phenology of ice, snow and frost) and a few organic(agricultural phenology)
Numbers of phenological evidence	more	more	less
Reasons for phenological record-keeping	memory of daily life/expressing feelings	memory of daily life/observing phenology	recording extreme climatic events and agriculture-related activities
Frequency of phenological record-keeping	sporadic	sporadic/phenophase-specific recurrent	phenophase-specific recurrent
Continuity of phenological record-keeping	intermittent	intermittent/less than the lifetime of the observer	up to the occurrence of extreme climatic events
Species clarity	ambiguous/ species-specific clear	ambiguous/species-specific clear	most clear
Phenophases clarity	ambiguous/phenophase-specific clear	ambiguous/phenophase-specific clear	most clear
Spatial clarity	ambiguous/inferable	clear/inferable	most clear
Temporal clarity	ambiguous/inferable	clear/inferable	most clear

Table 3 Different meanings of the Chinese phrase "jin hua" in poems of the Tang Dynasty

Pinyin of the verses	The meanings of "jin hua" in the poems
fan ci huang **jin hua**[8]	chrysanthemum (inferred from context)
sheng li **jin hua** qiao nai han[9]	decorations on ladies' headwear

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

xuan miao mei **jin hua**[10]	an alchemistic term for Taoist priests
cui wei **jin hua** bu ci ru[11]	golden patterns on the tails of peacocks

Table 4 Comparisons among the ancient, modern and Latin names of several common species

Species	Pinyin of ancient names	Pinyin of modern names	Latin names
Animals	Si jiu, Zi gui, Du yu	Si sheng du juan	*Cuculus micropterus*
	Cang geng, Shang geng, Chu que, Huang niao	Hei zhen huang li	*Oriolus chinensis*
	Xuan niao, Yi niao, Luan niao, Tian nv, Wu yi	Jia yan	*Hirundo rustica*
	Tiao, Fu yu, Ni, Qi nv	Cao chan	*Mogannia conica*
Plants	Fu qu, Fu rong, Han dan	Lian	*Nelumbo nucifera*
	Lu, Wei, Jian jia	Lu wei	*Phragmites australis*
	Shan shi liu, Ying shan hong, Shan zhi zhu	Du juan	*Rhododendron simsii*
	Mu li, ming zha, Man zha	Mu gua	*Chaenomeles sinensis*

Table 5 The classification and grading results for representative examples of phenological descriptions in poems

Phenophases	Translations of the original verses	Descriptions in the modern observation criteria
First song	New cicada tweeted two or three times[22]	The date of first call
First appearance	New swallow came ten days before the festival of She[23]	The date of first appearance
First leaf	Willow leaves are tender just like a beauty frown slightly[24]	The date when the first one or two leaves are spread out
Full leaf	The green lotus leaves stretch to the	The date when the leaflets on half of the

expansion	horizon[25]	branches of the observed tree are completely flat
First flowering	The hibiscus is at the beginning of the red and they cover the palace[26]	The date when the petals of one or several flowers begin to open fully
Full flowering	Peonies occupy the spring breeze with their fragrance alone[12]	The date when more than half of the flowers have blossomed in the observed species
End of flowering	The flowers of peach are going to fall while the branches of willow are stretching[20]	The date when there are very few flowers on the observed trees
Fruit drop	The willows and poplars in the street are shrouded in smog[27]	The date when *Salix* spp. and *Populus* spp. begin to have fluffy catkins

Table 6 The comparisons of data sources, types and numbers of records used in Liu et al. (2016) and in this study

	Liu et al. (2016)			This study
	Documents of institutions	Poems	Total	Poems
Non-organic phenophases	42	0	42	1
Agricultural phenophases	24	1	25	1
Phenophases of ornamental plants	5	15	20	82
Phenophases of animals	0	0	0	1
Total	71	16	87	85

Appendix A: The original verses and sources of the poems in Chinese used in this paper

1. “微月初三夜，新蝉第一声”（[唐]白居易《六月三日夜闻蝉》）；
2. “百泉冻皆咽，我吟寒更切”（[唐]刘驾《苦寒吟》）；

https://doi.org/10.5194/cp-2020-122
Preprint. Discussion started: 28 September 2020

Climate of the Past
Discussions

3. “北风卷地白草折，胡天八月即飞雪”（[唐]岑参《白雪歌送武判官归京》）；

4. “仍说秋寒早，年年八月霜”（[宋]司马光《晋阳三月未有春色》）；

5. “乡村四月闲人少，才了蚕桑又插田”（[宋]翁卷《乡村四月》）；

6. “梅信初传冬未深，高门熊梦庆相寻”（[宋]胡寅《吴守生朝》）；

7. “江涵秋影雁初飞，与客携壶上翠微”（[唐]杜牧《九日齐山登高》）；

8. “泛此黄金花，颓然清歌发”([唐]李白《忆崔郎中宗之游南阳遗吾孔子琴抚之潸然感旧》);

9. “尊前柏叶休随酒，胜里金花巧耐寒”（[唐]杜甫《人日两首其二》）；

10. “黄帝术，玄妙美金花”（[唐]吕岩《忆江南》其三）；

11. “赤霄玄圃须往来，翠尾金花不辞辱”（[唐]杜甫《赤霄行》）；

12. “澹荡韶光三月中，牡丹偏自占春风”（[唐]权德舆《和李中丞慈恩寺清上人院牡丹花歌》）；

13. “田家少闲月，五月人倍忙。夜来南风起，小麦覆陇黄”（[唐]白居易《观刈麦》）；

14. “灞桥烟柳知何限，谁念行人寄一支”（[宋]陆游《秋夜怀吴中》）；

15. “故园今日海棠开，梦入江西锦绣堆”（[宋]杨万里《春晴怀故园海棠二首》）；

16. “碧鸡海棠天下绝，枝枝似染猩猩血”（[宋]陆游《海棠歌》）；

17. “竹外桃花两三枝，春江水暖鸭先知”（[宋]苏轼《惠崇春江晚景》）；

18. “莱洲频度浅，桃实几成圆”（[唐]卢照龄《于时春也慨然有江湖之思寄赠柳九陇》）；

19. “人间四月芳菲尽，山寺桃花始盛开”（[唐]白居易《题大林寺》）；

20. “桃花欲落柳条长，沙头水上足风光。”（[唐]刘宪《上巳日祓禊渭滨应制》）；

21. “柳条弄色不忍见，梅花满枝空断肠”（[唐]高适《人日寄杜二拾遗》）；

22. “故人千万里，新蝉三两声”（[唐]白居易《立秋日曲江忆元九》）；

23. “要信今年春事早，社前十日燕新来”（[宋]陆游《新燕》）；

24. “学嚬齐柳嫩，妍笑发春丛”（[唐]许敬宗《奉和登陕州城楼应制》）；

25. “接天莲叶无穷碧，映日荷花别样红”（[宋]杨万里《晓出净慈寺送林子方》）；

26. “向浦回舟萍已绿，分林蔽殿槿初红”（[唐]沈全期《兴庆池侍宴应制》）；

27. “满街杨柳绿丝烟，画出清明二月天”（[唐]韦庄《鄜州寒食城外醉吟》）.

28. “曲池苔色冰前液，上苑梅香雪里娇”（[唐]崔日用《奉和人日重宴大明宫恩赐彩缕人胜应制》）；

Appendix B: The modern data sources and reconstructing method for the two reconstructions

Modern phenological observation data in Xi'an, which located in the center of Guanzhong Area, were derived from the China Phenological Observation Network (CPON). Xi'an has kept observations every year since 1963 except for the period of 1997–2002. The corresponding annual mean temperature data in Xi'an were obtained from the Chinese Meteorological Administration. Owing to a lack of data, some modern phenophases were defined based on the meteorological data. For instance, the modern date of spring cultivation were defined as the first day when the daily mean temperature is consecutively higher than 5 ℃ for five days (Ge et al., 2010). The modern date of millet harvest in autumn is defined as the first day when the daily mean temperature is continuously lower than 10 ℃ for five days (Hao et al., 2009).

After changing the time series of temperature and phenophases to anomalies with respect to the reference period (1961–1990 AD), the transfer functions between the phenological and temperature anomalies were developed by linear regression, which can be expressed as:

$$y=ax_i+b \tag{1}$$

where y is the annual temperature anomalies, and x_i is the phenological anomalies for phenophase i. The constants a and b are estimated using the least square method, which represents the regression slope and intercept, respectively.

Subsequently, the phenophase-specific transfer functions were applied to each historic phenological anomaly to obtain the annual temperature anomalies. If there was more than one record in a single year, temperature in that year was calculated as the arithmetic mean of all of the reconstructed temperatures in that year.

Appendix C: Transfer functions for the two temperature reconstructions in this study

Phenophases	Transfer functions	Number of observations	Correlation coefficients	Standard error at 95% confidence level (°C)
First date of frost	y=0.033x+0.423	53	0.432**	0.742
Last date of frost	y=-0.033x+0.386	53	-0.475**	0.724

First date of snow	y=0.010x-0.023	26	0.467*	0.321
Last date of snow	y=-0.006x-0.019	26	-0.335	0.336
First sing date of *Cryptotympana atrata*	y=0.013x+0.012	15	0.638	0.216
Beginning date of spring cultivation	y=-0.030x+0.232	62	-0.396**	0.792
Beginning date of winter wheat harvest	y=-0.084x+1.284	22	-0.570**	0.584
Beginning date of millet harvest	y=0.024x+0.336	61	0.231	0.806
First flowering date of *Amygdalus davidiana*	y=-0.075x+0.361	38	-0.573**	0.667
Full-flowering date of *Amygdalus davidiana*	y=-0.086x+0.331	38	-0.634**	0.630
End flowering date of *Amygdalus davidiana*	y=-0.069x+0.441	37	-0.531**	0.691
Fruit maturity date of *Amygdalus davidiana*	y=0.022x+0.740	13	0.495	0.505
First flowering date of *Armeniaca mume*	y=-0.044x+0.626	14	-0.436	0.785
Full-flowering date of *Armeniaca mume*	y=-0.055x+0.590	14	-0.507	0.752
First flowering date of *Armeniaca vulgaris*	y=-0.029x+0.119	24	-0.320	0.467
Full-flowering date of *Armeniaca vulgaris*	y=-0.045x+0.196	20	-0.517*	0.402
End flowering date of *Armeniaca vulgaris*	y=-0.028x+0.135	24	-0.331	0.466
Full-flowering date of	y=-0.011x+0.770	25	-0.218	0.813

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Chimonanthus praecox				
First flowering date of *Hibiscus syriacus*	$y=-0.014x+0.060$	18	-0.457	0.456
Full-flowering date of *Juglans regia*	$y=-0.076x+0.441$	33	-0.663^{*}	0.612
Full-flowering date of *Osmanthus fragrans*	$y=-0.069x+0.306$	17	-0.611^{**}	0.716
End flowering date of *Osmanthus fragrans*	$y=0.044x+0.486$	22	0.497^{*}	0.728
Full-flowering date of *Paeonia suffruticosa*	$y=-0.088x+0.307$	38	-0.703^{**}	0.581
End flowering date of *Paeonia suffruticosa*	$y=-0.065x+0.493$	36	-0.446^{**}	0.731
First flowering date of *Paulownia fortunei*	$y=-0.062x+0.688$	22	-0.607^{*}	0.813
End flowering date of *Paulownia fortunei*	$y=-0.055x+1.103$	18	-0.382	0.901
First flowering date of *Paulownia tomentosa*	$y=-0.062x+0.688$	12	-0.607^{*}	0.813
End flowering date of *Paulownia tomentosa*	$y=-0.055x+1.103$	12	-0.382	0.901
First flowering date of *Prunus salicina*	$y=-0.068x+0.585$	13	-0.740^{**}	0.515
Full-flowering date of *Prunus salicina*	$y=-0.068x+0.591$	13	-0.779^{**}	0.480
Full-flowering date of *Punica granatum*	$y=-0.053x+0.321$	21	-0.723^{**}	0.639
Full-flowering date of *Pyrus betulaefolia*	$y=-0.076x+0.441$	27	-0.698^{**}	0.608

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First leaf date of *Salix babylonica*	y=-0.052x+0.745	31	-0.471^{**}	0.711
Full leaf expansion date of *Salix babylonica*	y=-0.042x+0.511	37	-0.384^{*}	0.753
Beginning date of fruit drop of *Salix babylonica*	y=-0.091x+1.312	17	-0.707^{**}	0.602

*: P<0.05, **: P<0.01