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Spring Phenological Grid Dataset of Eight Deciduous Broad-leaved Woody Plants in the Warm Temperate Zone of China (1963–2015)

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Abstract: Plant phenology is important in assessing the effects of global change and in studying ecosystem structure and function, as well as in developing climate and land surface models. The leaf unfolding date (LUD) and the first flowering date (FFD) of eight woody plants, *Fraxinus chinensis* Roxb. (Oleaceae), *Salix babylonica* L. (Salicaceae), *Robinia pseudoacacia* L. (Leguminosae), *Albizia julibrissin* Durazz. (Leguminosae), *Morus alba* L. (Moraceae), *Ulmus pumila* L. (Ulmaceae Mirb.), *Armeniaca vulgaris* Lam. (Rosaceae), and *Cercis chinensis* Bunge. (Leguminosae), from 1963 to 2015 were obtained from the Chinese Phenological Observation Network. The 0.5° × 0.5° grid data of the LUD and FFD were developed for each species in the past 50 years by building and testing three phenological models: Unified, UniChill, and Temporal–Spatial Coupling (TSC) model. The validation results showed that the average simulation error of the LUD was approximately 5–9 days and that of the FFD was approximately 5–12 days. The dataset includes the following: (1) header file, containing grid data header information of the species phenophase and spatial distribution; (2) phenophase, containing the LUD and FFD of each species from 1963 to 2015; and (3) spatial distribution, containing the actual spatial distribution range grid of each species. The dataset consists of 1,713 files in three folders. The data files are archived in .txt, GEOTIFF, and ARCGIS ASCII formats. The data size is 74.5 MB (8.84 MB after compression).

Keywords: warm temperate zone; spring phenology; woody plants; leaf unfolding date; first flowering date; China

1 Introduction

Plant phenology is the seasonal behavior of plants during an annual cycle that is influenced

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[2] Dai, J. H., Zhu, M. Y., Wang, H. J., *et al*. Spring phenological grid dataset of typical deciduous broad-leaved woody plants in the warm temperate zone of China [DB/OL]. Global Change Research Data Publishing & Repository, 2019. DOI: 10.3974/geodb.2019.06.04.V1.

by diverse environmental factors (including climate, hydrology, and soil)[1]. Because of the influence of the environment, phenology is highly sensitive to climate change and has become an important indicator for recording and evaluating the effects of global changes on ecosystems[2]. In recent decades, the increase in spring temperature has led to a substantial advance in plant spring phenology in the Northern Hemisphere, thereby substantially influencing carbon and water cycles and the nutrient balance in terrestrial ecosystems[3]. Therefore, plant phenological data are also important in indicating the impact of global change, in understanding the structure and function of ecosystems, as well as in developing climate and land models. The authors developed and published grid data of the spring phenology of individual species based on the Chinese Phenological Observation Network (CPON)[4]. Then, using primarily the manual observation data of CPON, we greatly improved understanding of the phenological temporal–spatial patterns and their causes in China[5–6]. According to the experience of other researchers, widely distributed and well observed plant species were selected to produce multispecies grid datasets, which displayed the changes in the phenological spatial–temporal patterns of Chinese woody plants in spring. The grid datasets also improve the use of Chinese phenological data in understanding global change. In addition, the team is currently participating in the special project of “Earth big data science and engineering”, in which Chinese phenological data products are an essential part of gathering and sharing ground monitoring data. Therefore, the purpose of this paper is to publish the methods and basic results of the spring phenological spatial–temporal dataset of Chinese woody plants. The dataset contains the grid data of the spring phenophase, including the leaf unfolding date (LUD) and the first flowering date (FFD), of eight typical deciduous broad-leaved woody plants in China from 1963 to 2015 and provides the scale transformation from station phenology to regional phenology in China.

2 Metadata of Dataset

The metadata of the “Spring phenological grid dataset of typical deciduous broad-leaved woody plants in the warm temperate zone of China”[7] are summarized in Table 1. It includes the dataset full name, short name, authors, year of the dataset, temporal resolution, spatial resolution, data format, data size, data files, data publisher, and data sharing policy, etc.

Table 1 Metadata summary of the “Spring phenological grid dataset of typical deciduous broad-leaved woody plants in the warm temperate zone of China”

Items	Description
Dataset full name	Spring phenological grid dataset of typical deciduousbroad-leaved woody plants in the warm temperate zone of China
Dataset short name	SpringPhenologyWoodyPlantWarmTZChina
Authors	Dai, J. H., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, daijh@igsnrr.ac.cn Zhu, M. Y. AAA-7619-2019, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, zhumy.16b@igsnrr.ac.cn Wang, H. J. AAA-7674-2019, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, wanghj@igsnrr.ac.cn Tao, Z. X. AAA-7688-2019, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, taozx.12s@igsnrr.ac.cn Hu, Z. AAE-4801-2019, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, huz.18b@igsnrr.ac.cn Dong, X. Y., Chang’an University, dongxy@igsnrr.ac.cn
Geographical region	China: 18°N–54°N, 72°E–136°E
Year	1963–2015 Temporal resolution day

(***To be continued on the next page***)

(*Continued*)

Items	Description
Spatial resolution	0.5 °×0.5 °
Data format	.txt, GEOTIFF, ARCGIS ASCII
Data size	74.5 MB (8.84 MB after compression)
Data files	The dataset consists of header file, phenophase, spatial distribution; Phenophase: the leaf unfolding date (LUD), the first flowering date (FFD); Species: *Fraxinus chinensis*, *Salix babylonica*, *Robinia pseudoacacia*, *Albizia julibrissin*, *Morus alba*, *Ulmus pumila*, *Armeniaca vulgaris*, *Cercis chinensis*
Foundations	Ministry of Science and Technology of P. R. China (2018YFA0606102); Chinese Academy of Sciences (XDA19020303); National Natural Sciences Foundation of China (41771056)
Computing Environment	MATLAB, campus license of Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences ArcGIS campus license of Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	***Data*** from the Global Change Research Data Publishing & Repository includes metadata, dataset (data products), and publications (in this case, in the *Journal of Global Change Data & Discovery*). ***Data*** sharing policy includes: (1) ***Data*** are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use ***Data*** subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute ***Data*** subject to written permission from the GCdataPR Editorial Office and the issuance of a ***Data*** redistribution license; and (4) If ***Data*** are used to compile new dataset, the 'ten per cent principal' should be followed such that ***Data*** records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[8]
Communication and searchable system	DOI, DCI, CSCD, WDS/ISC, GEOSS, China GEOSS

3 Methods

3.1 Basic Data Collection

The LUD and the FFD of eight woody plants from 1963 to 2015 were extracted from the Chinese Phenological Observation Network (CPON). The eight plants were *Fraxinus chinensis* Roxb. (Oleaceae), *Salix babylonica* L. (Salicaceae), *Robinia pseudoacacia* L. (Leguminosae), *Albizia julibrissin* Durazz. (Leguminosae), *Morus alba* L. (Moraceae), *Ulmus pumila* L. (Ulmaceae Mirb.), *Armeniaca vulgaris* Lam. (Rosaceae), and *Cercis chinensis* Bunge. (Leguminosae), which are typical species of deciduous broad-leaved forests in the warm temperate zone of China[9]. The temperature data were derived from the China Meteorological Data Service Center (CMDSC, data.cma.cn). The daily temperature data of the corresponding stations and time periods in the "China surface daily climate dataset (v3.0)" were used for the parameterization of phenological models, whereas the grid average daily temperature data obtained from the "China surface 0.5°×0.5° daily temperature grid dataset (v2.0)" were used for phenophase simulation and scale expansion.

3.2 Algorithm Principle

To develop the spring phenological grid data, three steps were included: building phenological models, estimating the corresponding parameter values, and validating the models[10]. To obtain the most accurate simulation of phenophase, three models were tested: the Unichill model[11], the Unified model[11], and the Temporal–Spatial Coupling (TSC) model[12] which is based on the spring warming (SW) model. The minimum root mean square error (RMSE) of the three spring phenological models was used to select the optimal phenological model to simulate the LUD and FFD spatial–temporal patterns of each species in the past 50 years[13].

(1) The Unified model divides the process of bud burst into two phases: dormancy and quiescence, with nine species-specific parameters (*a, b, c, d, e, w, k,* C^*, and t_c) fit to phenological observations. Parameters *a, b,* and *c* define the response function to temperature ($R_c(x_t)$, also called "chilling units", Equation 1). Parameters *d* and *e* define the other response function to temperature ($R_f(x_t)$, also called "forcing units", Equation 2). Parameter t_0 is the time when $R_c(x_t)$ begins to accumulate, which determines the threshold C^* of the cumulative sum of chilling units (Equation 3). Parameters *w, k,* and t_c determine the threshold F^* of the cumulative sum of forcing units (Equation 4). t_b is the time of LUD or FFD when $\sum_{t_1}^{t_b} R_f(x_t)$ reaches the threshold F^*.

$$R_c(x_t) = \frac{1}{1+e^{a(x_t-c)^2+b(x_t-c)}} \quad (1)$$

$$R_f(x_t) = \frac{1}{1+e^{d(x_t-e)}} \quad (2)$$

$$\sum_{t_0}^{t_1} R_c(x_t) = C^* \quad (3)$$

$$\sum_{t_1}^{t_b} R_f(x_t) = F^*, \text{where } F^* = we^{kC_{tot}}, C_{tot} = \sum_{t_0}^{t_c} R_c(x_t) \quad (4)$$

(2) The UniChill model is a simplified version of the Unified model, which contains seven parameters: *a, b, c, d, e,* C^*, and F^*. On the basis of Unified model, this model fixes the time t_1 for the start of the forcing units as September 1 of the previous year and assumes that the accumulation of forcing units (F^*) required for the start of the spring phenology each year is fixed.

(3) The TSC model is built based on the SW model[14] (Equations 5, 6), which uses the winter average temperature to reflect the difference in the accumulated temperature threshold[15] (Equation 7). The TSC model includes six parameters: T_{b1}, F^*, t_0, *a*, *b*, and *f*. $R_f(x_t)$ is the forcing unit, x_t is the average daily temperature on day *t*, and T_{b1} is the critical temperature. F^* is the threshold value of temperature accumulation. The temperature accumulation threshold F_i of different sites is determined by the winter (December of the previous year to February) temperature $\overline{T}_i^{WI}$ of site *i* and parameters *a, b,* and *f*. t_0 is the time when the forcing unit begins to accumulate, and *y* is the time of LUD or FFD when $\sum_{t_0}^{y} R_f(x_t)$ reaches F^*.

$$R_f(x_t) = \begin{cases} 0 & x \leqslant T_{b1} \\ x_t - T_{b1} & x \geqslant T_{b1} \end{cases} \quad (5)$$

$$\sum_{t_0}^{y} R_f(x_t) = F^* \quad (6)$$

$$F_i = a + b \times e^{\frac{\overline{T}_i^{WI}}{f}} \quad (7)$$

3.3 Technical Route

The main steps in the technical route are shown in Figure 1. First, the *in situ* spring phenological observation data of the eight woody plants from 1963 to 2015 were obtained from 45 sites in CPON. Second, three models of spring phenology were established from the spatial–temporal phenophase and corresponding temperature data, and the parameters were estimated using the simulated annealing algorithm[16]. Next, the goodness of fit (R^2) and root mean square error (RMSE) of the three models were compared by both internal and cross validation to select the optimal model. Finally, the spring phenological 0.5°×0.5° grid data of the eight woody plants in China were developed by simulation and scale expansion from temperature grid data and spatial distribution grid data.

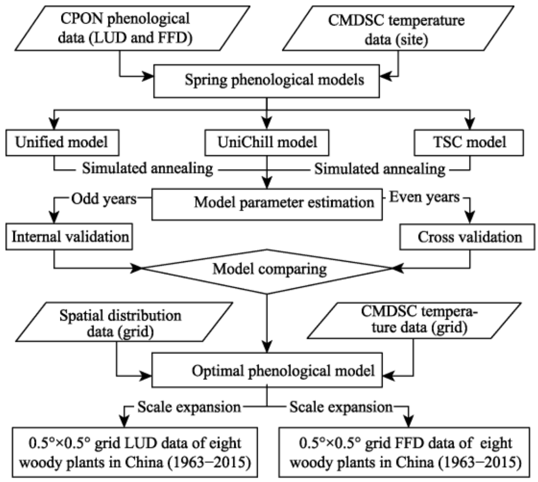

Figure 1 Technical route to develop spring phenology grid data for eight woody plants in China

4 Results and Validation

4.1 Data Composition

The grid dataset of spring phenology consists of three groups of files: header file, phenophase, and spatial distribution. The naming format, data description, data format, file number, and data size of data files are shown in Table 2.

(1) Header file contains grid data header information of the species phenophase and spatial distribution.

(2) Phenophase contains LUD and FFD folders, each of which consists of eight species subfolders. Each species subfolder contains 106 phenophase files from 1963 to 2015. The data files are stored in ARCGIS ASCII and GEOTIFF formats. By copying the grid data header file in front of each ASCII phenophase file, it can be converted into a visual grid format using the “ASCII to Raster” tool in ArcMap.

(3) Spatial distribution contains the actual distribution grid of each species[4]. The phenophase data outside the distribution range need to be masked by the user. Data files are stored in ARCGIS ASCII and GEOTIFF formats, which can also be transformed into visual GRID format in ArcMap after copying header files.

Table 2 Short form of the spring phenological grid dataset of eight typical deciduous broad-leaved woody plants in the warm temperate zone of China (1963–2015)

Main files	Naming	Description	Format	File number	Data size
Header file	Headfile.txt	Line 1: column number 64 Line 2: row number 36 Line 3: lower-left corner’s longitude 72 °E Line 4: lower-left corner’s latitude 18 °N Line 5: spatial resolution 0.5 ° Line 6: null value 999	.txt	1	1 KB
Phenophase	Phenophase_species_year.txt	Phenophase: day of year No data value: 999 Projection: WGS84	ARCGIS ASCII GEOTIFF	848 848	73.8 MB
Spatial distribution	Spatial_species.txt	Distributed value: 1 Undistributed value: 999 Projection: WGS84	ARCGIS ASCII GEOTIFF	8 8	0.7 MB

4.2 Data Products

(1) Products of leaf unfolding date data

The average LUD of each species from 1963 to 2015 is shown in Figure 2. According to the spatial distribution pattern, the LUD of each species differentiated by latitude and altitude, arriving earlier in the southeast and later in the northwest. In terms of temporal distribution, the first species with leaf unfolding was *Armeniaca vulgaris* (Figure 2g), which was followed by *Salix babylonica, Robinia pseudoacacia, Ulmus pumila, Fraxinus chinensis, Morus alba,* and *Cercis chinensis*, with *Albizia julibrissin* the last species with leaf unfolding (Figure 2d). A linear regression between LUD and year was used to determine the trend of LUD. The results indicated that the LUD of each species advanced from 1963 to 2015 (Table 3), with an average trend of 0.9–3.4 days per decade. Specifically, in 83.1%–99.7% of the cells the LUD were advanced, whereas in 22.0%–79.8% of the cells the advance were significant (P<0.05).

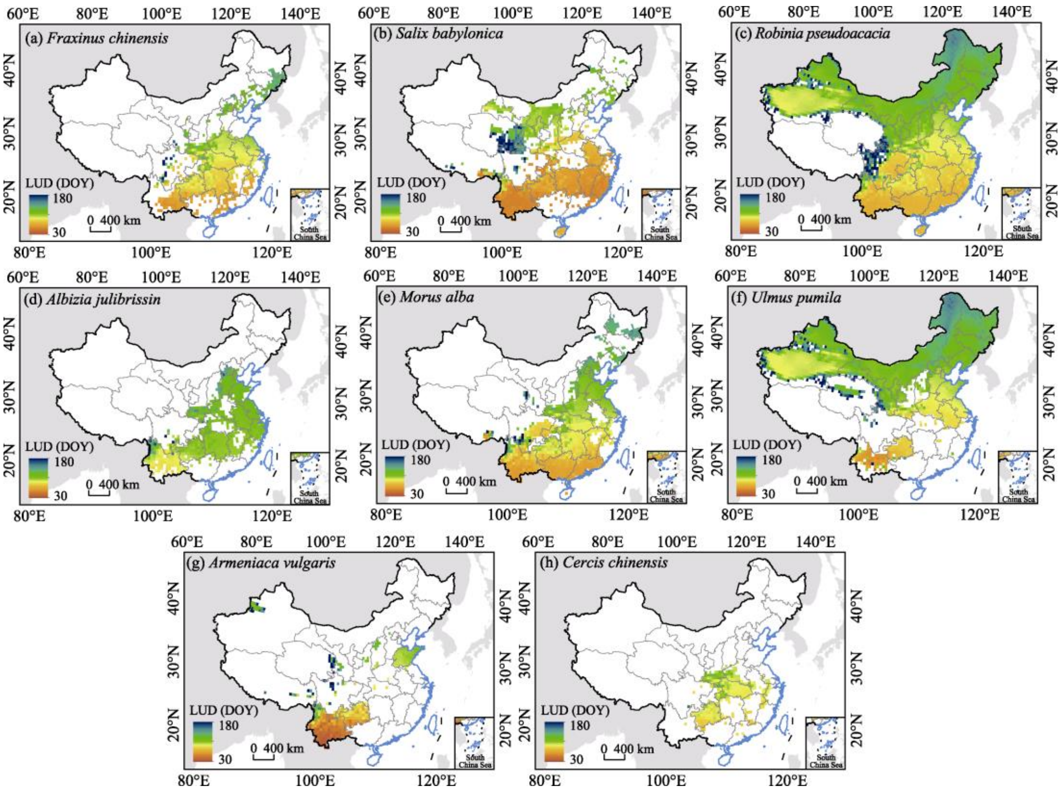

Figure 2 Average leaf unfolding date (LUD) of eight typical deciduous broad-leaf woody plants in the warm temperate zone of China from 1963 to 2015. Panels (a)–(h) represents mean LUD of each species. DOY represents the sequential day number in the Julian calendar.

(2) Products of first flowering date data

The FFD of the eight plants from 1963 to 2015 is shown in Figure 3. According to the spatial distribution pattern, for all species, the latitudinal differentiation of the FFD was less than that of the LUD. *Albizia julibrissin* (Figure 3d) and *Cercis chinensis* (Figure 3h) showed little spatial difference, whereas the other species showed distinct differences. In terms of temporal distribution, the sequence of the FFD for each species in the same area varied. *Ulmus pumila* (Figure 3f) and *Armeniaca vulgaris* (Figure 3g) had the earliest FFD, whereas *Robinia pseudoacacia* and *Albizia julibrissin* had the latest FFD. A linear regression between FFD and year was used to determine the trend of FFD. The results of trend analysis indicated that the FFD of the eight woody plants in China was also earlier in the past 50 years, with an average advance of 0.7–3.3 days per decade. In the grid scale, the FFD in 77.1%–97.7% of the cells were advanced, whereas in 32.5%–79.7% of the cells the advance was significant (P<0.05).

Table 3 Statistics on the shifting trend in the spring phenophase of eight typical deciduous broad-leaved woody plants in China from 1963 to 2015

Phenophase	Species	Trend (d/10a)	Advanced	Delayed	Significantly delayed	Significantly advanced
LUD	*Fraxinus chinensis*	–1.0	90.3%	9.7%	43.7%	0.5%
	Salix babylonica	–1.1	93.3%	6.7%	48.0%	2.6%
	Robinia pseudoacacia	–1.1	94.1%	5.9%	62.4%	0.4%
	Albizia julibrissin	–3.3	99.7%	0.3%	66.6%	0.0%
	Morus alba	–0.9	86.6%	13.4%	43.6%	0.3%
	Ulmus pumila	–3.4	97.5%	2.5%	79.8%	0.3%
	Armeniaca vulgaris	–1.4	98.1%	1.9%	64.3%	0.0%
	Cercis chinensis	–0.6	83.1%	16.9%	22.0%	2.4%
FFD	*Fraxinus chinensis*	–1.2	77.1%	22.9%	37.1%	0.4%
	Salix babylonica	–0.7	78.8%	21.2%	44.2%	6.5%
	Robinia pseudoacacia	–3.3	97.7%	2.3%	79.7%	0.3%
	Albizia julibrissin	–1.1	96.2%	3.8%	64.8%	1.5%
	Morus alba	–1.7	94.7%	5.3%	58.5%	0.4%
	Ulmus pumila	–1.8	94.4%	5.6%	65.1%	0.8%
	Armeniaca vulgaris	–1.0	89.2%	10.8%	47.7%	1.1%
	Cercis chinensis	–0.8	89.3%	10.7%	32.5%	0.7%

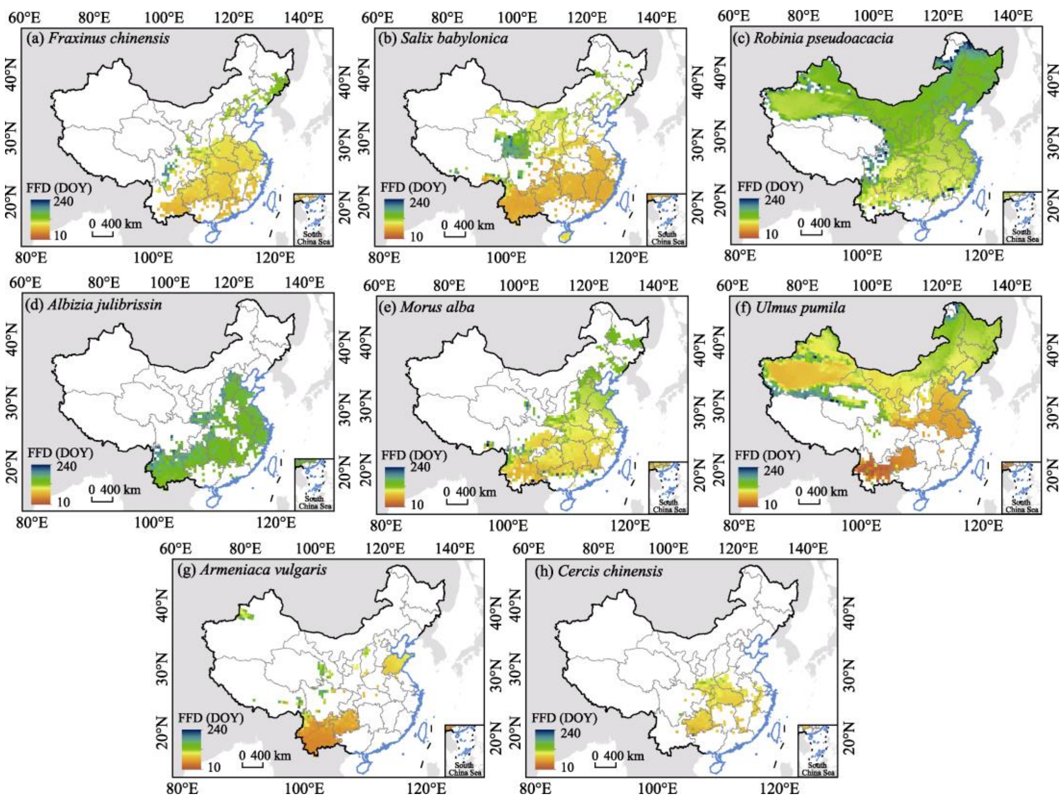

Figure 3 Average first flowering date (FFD) of eight typical deciduous broad-leaf woody plants in the warm temperate zone of China from 1963 to 2015. Panels (a)–(h) represents mean FFD of each species. DOY represents the sequential day number in the Julian calendar.

4.3 Data Validation

(1) Leaf unfolding date validation

Internal and cross validation were used to verify the reliability of the LUD (Figure 4). According to internal validation results, the fit of all three phenological models to the data was good. The R^2 values of the three models of the eight species were greater than 0.81, except for *Albizia julibrissin* (R^2=0.47, 0.51, 0.45) and *Cercis chinensis* (R^2=0.51, 0.59, 0.53). For most species, the UniChill model had a relatively better fit to the LUD data, with RMSE values ranging from 5.07 to 9.90 days. The TSC model had the best fit for *Salix babylonica* and *Robinia pseudoacacia*, with RMSE values of 5.27–8.36 days. The Unified model was a relatively poor fit to data of all species. According to the cross validation results, the simulations of the LUD by the UniChill and TSC models were similar for most species. Except for *Albizia julibrissin* (R^2=0.50 and 0.46, respectively) and *Cercis chinensis* (R^2=0.60 and 0.64, respectively), the R^2 values of other species reached 0.84–0.91, with RMSE values of 5.09–11.04 days. The simulation results of the Unified models were relatively poor, with RMSE values ranging from 5.30 to 12.56 days. Overall, the cross validation results indicated that the simulation error of the optimal phenological model of the LUD of each species was 5.09–8.97 days.

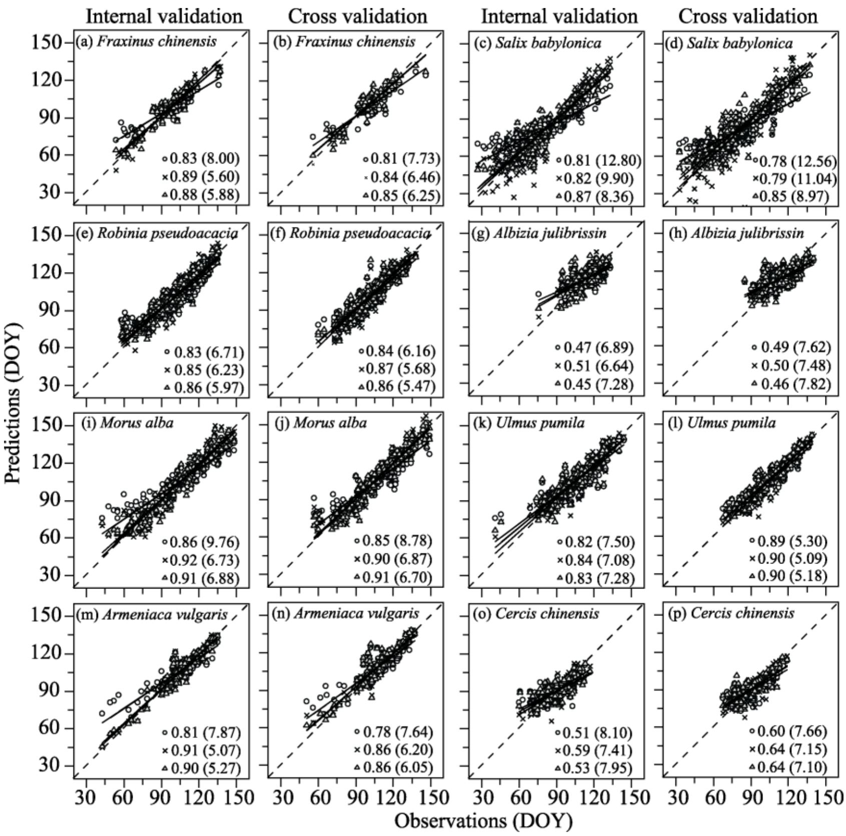

Figure 4 Internal and cross validation of the simulation results of the leaf unfolding date (LUD) of eight species by three phenological models. Panels (a)–(p) represents internal and cross validation on LUD of each species. DOY represents the sequential day number in the Julian calendar.

Note: The ○, ×, and △ represent the simulation results of the Unified, UniChill, and TSC models, respectively. Solid lines are linear regression curves fitting to observed and predicted values. The number after the symbol and the number in parentheses represent the R^2 and root mean square error, respectively. The minimum value of root mean square error represents the simulation result of the optimal phenological model.

(2) First flowering date validation

The results of the FFD were similar to those of the LUD. Internal validation showed that the fit of the models to the FFD of the eight woody plants differed (Figure 5). Except for *Albizia julibrissin* (R^2=0.45), the average R^2 of the optimal model was 0.68–0.92. The UniChill model had the best fit for the FFD of most species, with RMSE values ranging from 5.05 to 11.34 days. The fit of the TSC model was better than that of the other models for *Salix babylonica* and *Robinia pseudoacacia*, with RMSE values ranging from 5.26 to 13.48 days. According to cross validation results, the simulations of the different models were obviously different. The simulations of the FFD of the UniChill model were more accurate for half of the study species, and RMSE values were 4.78–8.38 days. The TSC model was the most suitable for *Salix babylonica* and *Robinia pseudoacacia*, whereas the Unified model was the best for *Fraxinus chinensis* and *Albizia julibrissin*. The cross validation results indicated that the simulation by the optimal phenological model for the FFD was inferior to the simulation by the optimal phenological model for the LUD, with an error of 4.78–12.35 days.

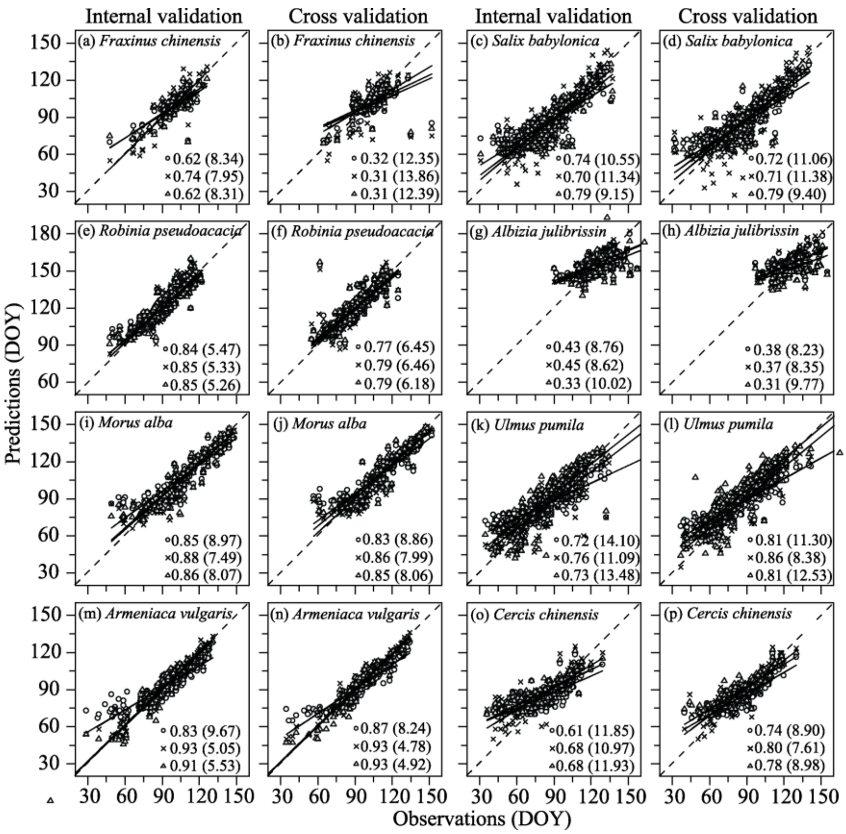

Figure 5 Internal and cross validation of the simulation results of the first flowering date (FFD) of eight species by three phenological models. Panels (a)–(p) represents internal and cross validation on FFD of each species. DOY represents the sequential day number in the Julian calendar.

Note: The ○, ×, and △ represent the simulation results of the Unified, UniChill, and TSC models, respectively. Solid lines are linear regression curves fit to observed and predicted values. The number after the symbol and the number in parentheses represent the R^2 and root mean square error, respectively. The minimum value of root mean square error represents the simulation result of the optimal phenological model.

5 Discussion and Conclusion

In this paper, *in situ* phenological data from the China Phenological Observation Network from 1963 to 2015 were used in three common spring phenological models to develop a spring phenological grid dataset of eight typical deciduous broad-leaved woody plants in the warm temperate zone of China. The dataset provides grid data of the LUD and the FFD of the eight species. The temporal and spatial resolution are one year and 0.5°×0.5°, respectively. For each species, the mean simulation error was approximately 5–9 days for the LUD and approximately 5–12 days for the FFD. The dataset represents the spatial–temporal patterns of plant phenology in China over the past 50 years, which can provide basic data for many areas of research, such as global change, meteorology, ecology, natural resources, the environment, tourism, and human health.

Author Contributions

Dai, J. H. was responsible for the overall design and development of the dataset. Hu, Z. and Dong, X. Y. collected and processed spring phenological data. Wang, H. J. and Tao, Z. X. designed the models and the algorithm. Zhu, M. Y. and Hu, Z. performed data validation. Zhu, M. Y. and Dai, J. H. wrote the data paper.

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