CHR: An Integrated Software Tool for chilling requirements

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Software

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Abstract

Background

Bud dormancy in deciduous fruit trees enables plants to survive cold weather. The buds adopt dormant state and resume growth after satisfying the chilling requirements. Chilling requirements play a key role in flowering time. So far, several chilling models, including ≤ 7.2 °C model, the 0–7.2 °C model, Utah model, and Dynamic Model, have been developed; however, it is still time-consuming to determine the chilling requirements employing any model. This calls for efficient tools that can analyze data.

Results

In this study, we developed novel software Chilling and Heat Requirement (CHR), by flexibly integrating data conversions, model selection, calculations, statistical analysis, and plotting.

Conclusion

CHR is a tool for chilling requirements estimation, which will be very useful to researchers. It is very simple, easy, and user-friendly.

Background

The chilling requirements (CR) [1] refer to the value of low temperature required for deciduous fruit trees to overcome their natural dormancy. It is an important quantitative index for measuring their dormant and dormant release characteristics. Only a deciduous fruit tree that satisfies a certain level of chilling requirements can break the dormancy and carry out a normal series of growth and development; otherwise, the germination, flowering, flower bud differentiation, fruit development, and yield will be adversely affected [2]. With the environmental pollution and global warming, the chilling requirements of fruit trees is affected, which leads to early germination, poor fruit development, small fruit volume and uneven ripening time, resulting in economic loss to farmers [3–6].

There are several models for calculating the chilling requirements. Based on their regularity, the models can be roughly divided into two types: distribution functions (type I) and dynamic models (type II). In type I, Weinberger [7] first proposed the low-temperature hour model (0–7.2), which is still widely used today. Some models have a smaller range of low temperature conversion than 0–7.2, so the calculation results conform well to the natural law. Due to the difference in temperature conversion range, some models such as North Carolina Model (NC) [8] and Positive Utah Model [9] are more effective for specific regions [10]. The dynamic model is different from other models in that it calculates chilling requirements through dynamic two-step processes [11–13]. In this model, since more factors are considered than other models, and the repeatability is excellent in both cold and warm regions, it is regarded as the best model [6]. However, due to its complexity, its application is limited.

At present, there is no independent interface visualization tool for the calculation of cooling demand. The traditional treatment method makes the statistics difficult for researchers and fruit growers. The developed CHR is an entirely independent tool. It offers robust statistical results for different models, only by providing temperature data. CHR carries out simple analysis and drawing functions to implement the rules of each model.

Implementation

We show an overview of the CHR workflow in Fig. 1. Firstly, the data are saved in .txt format, and the saved data can be used to calculate daily maximum, minimum, and average values, and the trend of change can be observed through the drawing function. The data can also be used to calculate the chilling requirements and GDH, and the results can be further used to draw or evaluate the model. 0–7.2, Utah, GDH, and dynamic models are compiled with python, and designed by pyqt5. The drawing tools are implemented by Matplotlib and Seaborn.

Variability setting of model parameters

In order to achieve the convenience of the model parameter setting, the model parameter is set to the default parameters and assigned to a variable. When researchers change parameters, the value of a variable is also altered, and the rationality of parameter settings is verified before the execution of the program.

Creation of custom model tool

In order to facilitate the researchers to set up a unique model for the region and to realize type I model, including 0–7.2 and Utah, we developed a custom model tool. When the researcher sets up the model, the conditions are grouped into arrays after importing the data. Then the data are traversed through the arrays and transformed into valid values.

Type I models

Type I models, namely, 0–7.2, Utah, low- chilling (LC), North Carolina (NC) and others, all conform to the law of distribution function, and the operation mode is similar. Researchers can modify the range of the model and the effective value corresponding to each range according to the characteristics of the area under study can be determined to obtain a unique model suitable for the area. The smaller the transformation is, the more natural and complicated the model is.

0–7.2 model

$$CH_t = \sum_{t=1}^{t} CH \begin{cases} T_t < 0\ ℃ & :0 \\ 0\ ℃ \le T_t \le 7.2\ ℃ & :1 \\ T_t > 7.2\ ℃ & :0 \end{cases} \quad (1)$$

Utah model

$$UCU_t = \sum_{i=1}^{t} T_U \begin{cases} T \le 1.4℃ & :0 \\ 1.4℃ < T \le 2.4℃ & :0.5 \\ 2.4℃ < T \le 9.1℃ & :1 \\ 9.1℃ < T \le 12.4℃ & :0.5 \\ 12.4℃ < T \le 15.9℃ & :1 \\ 15.9℃ < T \le 18.0℃ & :-0.5 \\ T \ge 18.0℃ & :1 \end{cases} \quad (2)$$

Low- chilling model (LC)

$$LCU_t = \sum_{i=1}^{t} T_U \begin{cases} T \le 1.7℃ & :0 \\ 1.7℃ < T \le 7.9℃ & :0.5 \\ 7.9℃ < T \le 13.9℃ & :1 \\ 13.9℃ < T \le 16.9℃ & :0.5 \\ 16.9℃ < T \le 19.4℃ & :0.0 \\ 19.4℃ < T \le 21.4℃ & :-0.5 \\ T \ge 21.4℃ & :-1.0 \end{cases} \quad (3)$$

North Carolina model (NC)

$$LCU_t = \sum_{i=1}^{t} T_U \begin{cases} T \le 1.5℃ & :0 \\ 1.5℃ < T \le 7.1℃ & :0.5 \\ 7.1℃ < T \le 12.9℃ & :1 \\ 12.9℃ < T \le 16.4℃ & :0.5 \\ 16.4℃ < T \le 18.9℃ & :0.0 \\ 18.9℃ < T \le 20.6℃ & :-0.5 \\ 20.6℃ < T \le 22.0℃ & :-1.0 \\ 22.0℃ < T \le 23.2℃ & :-1.5 \\ T > 23.2 & :-2.0 \end{cases} \quad (4)$$

Dynamic model

The dynamic model is different from other models. This model is based on the unit response curve of cold temperature and takes into account the nonlinear response of cold temperature to time [11–12, 14]. The level of dormancy completion depends on the accumulated level of dormancy breaking substances. This process is completed in two steps. First, intermediate products are induced by low temperature. At this time, the intermediate products are unstable and can be destroyed by hot temperature; their rate of formation and degradation follows the Arrhenius equation. When the intermediate reaches a certain threshold, it becomes a stable product. The complete equation was derived by [13].

$$x_i = \frac{e^{slp \cdot tetmlt \cdot \frac{T_K - tetmlt}{T_K}}}{1 + e^{slp \cdot tetmlt \cdot \frac{T_K - tetmlt}{T_K}}}$$

$$x_s = \frac{a0}{a1} \cdot e^{\frac{e_1 - e_0}{T_K}}$$

$$ak_1 = a_1 \cdot e^{-\frac{e_1}{T_K}}$$

$$inter_E = x_s - (x_s - inter_S) \cdot e^{-ak_1}$$

$$inter_S = \begin{cases} t = t_0 & : 0 \\ t > t_0 \wedge interE_{t\text{-}1} < 1 & : interE_{t-1} \\ t > t_0 \wedge interE_{t\text{-}1} \geq 1 & : interE_{t-1} \cdot (1 - xi) \end{cases} \qquad (5)$$

$$delt = \begin{cases} t = t_0 & : 0 \\ t > t_0 \wedge interE < 1 & : 0 \\ t > t_0 \wedge interE \geq 1 & : xi \cdot interE \end{cases}$$

$$CP_t = \begin{cases} t = t_0 & : delt \\ t \geq t_0 & : delt + CP_{t-1} \end{cases}$$

Parameters in the dynamic model can be calibrated for each individual cultivar. Its parameters are A0, A1, E0, E1, slp, and tetml, which are usually set to 1.395 × 105, 2.567 × 1018, 4153.5, 12888.8, 1.6 and 277.

Forcing model

GDH (Growing Degree Hours) was proposed by Anderson [15] and Luedeling [13] developed it further. It considers hourly temperatures (Th), as a function of a base (Tb), an optimum (Tu), and a critical (Tc) temperature. The underlying assumption is that heat accumulates, when temperatures range between Tb and Tc, with maximum accumulation at Tu. For temperatures between Tb and Tu, the corresponding equation is:

$$GDH=F\,\frac{T_u\text{-}T_b}{2}\left(1+\cos\left(\pi+\pi\,\frac{T_h\text{-}T_b}{T_u-T_b}\right)\right) \qquad (6)$$

whereas for temperatures between Tu and Tc, heat accumulates as

$$GDH=F\left(T_u-T_b\right)\left(1+\cos\left(\frac{\pi}{2}+\frac{\pi}{2}\,\frac{T_h-T_u}{T_c-T_u}\right)\right) \qquad (7)$$

Result

Data preparation

The temperature recorder continuously monitors the changes in temperature, which results in the recording of multiple temperatures in an hour. The tool averages data recorded per hour, helping researchers quickly obtain hourly data.

Chilling and Forcing model

The calculation method of the type I model is the same as that of the forced model. After inputting the data, the researcher obtains three calculation results, namely, chilling accumulation per hour, for the whole day, and cumulative from the first day. The calculation method of the dynamic model is different from other models, and the result of calculation gives the amount of stable productions. Researchers can further analyze the data obtained.

Model analysis and Drawing function

The choice of the chilling model in the planting area is very important. If the model is not appropriate, it will not help fruit growers to make correct decisions. The comparative analysis of the CHR model is based on the principle of the linear regression model. This function can be used to linearize the data (y = kX + b), determine 95% confidence intervals, observe the outliers, and select the appropriate model.

The tool also offers simple temperature data analysis and mapping. Researchers and fruit growers can use these two functions to calculate the maximum, minimum, and average values of the daily temperature, drawing function includes trend of the selected model▯maximum, minimum, and average values of the daily.

Discussion

The traditional calculation method of chilling accumulations is cumbersome. It also does not work well while analyzing complex models, such as dynamics. This led researchers to spend more time on model calculations rather than analysis. CHR tool is the first entirely independent interface visualization tool, which is easy to operate, set parameters, and does not require knowledge of the programming language.

This tool can realize most chilling models but incorporates only GDH model of heat requirements, which will be further improved in future development.

Conclusions

Here we report CHR, a tool for chilling requirements estimation, which will be very useful to researchers. It is very simple, easy, and user-friendly. All sample data, software instructions and software can be obtained from https://github.com/Chilling-requirements/Chilling-software/releases.

Declarations

Availability of data and materials

The tool is open source and available from Github.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

CC and WT implemented the software. WL and XY wrote the manuscript. GN and BS supervised the chilling requirements experiments. All authors read and approved the final manuscript.

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CHR.

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Figures

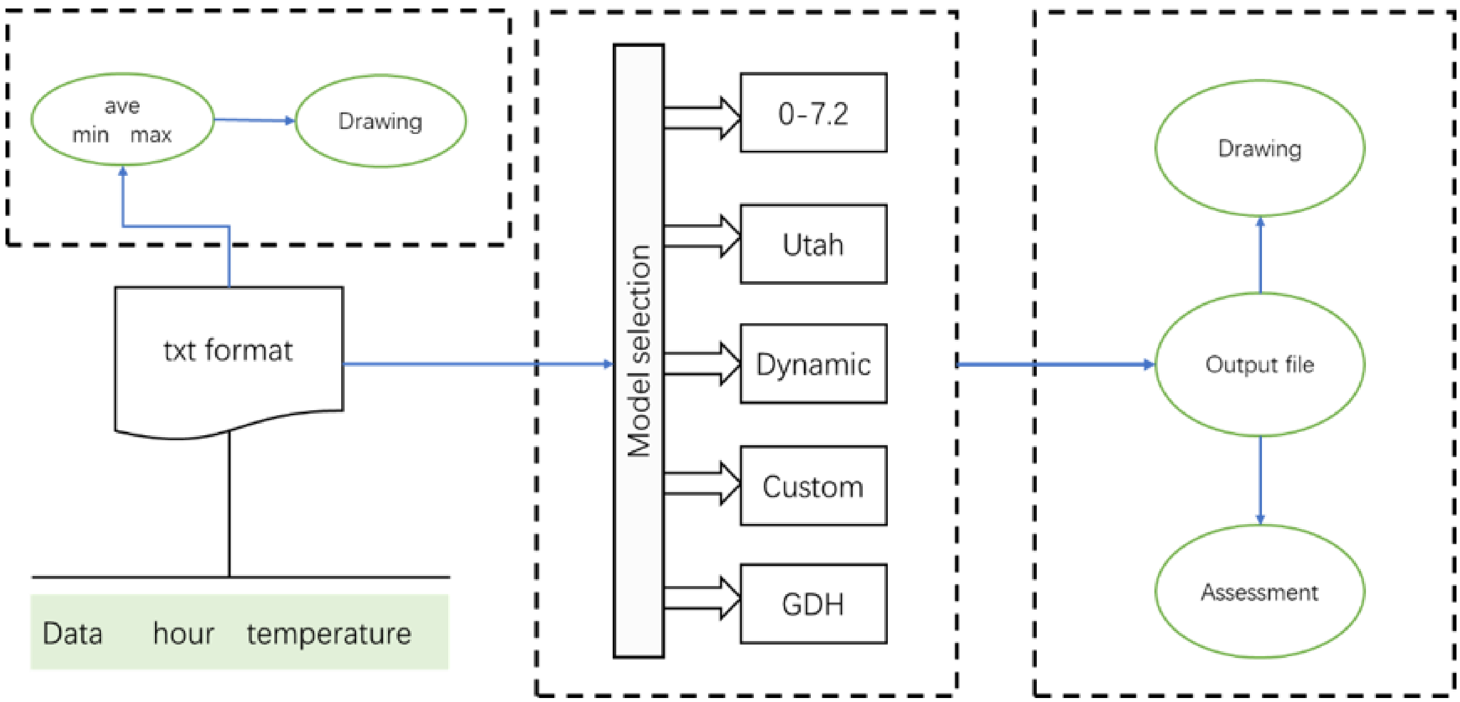


Figure 1

An overview of the CHR workflow

time	temperature
2020-01-01 00:02:00	0
2020-01-01 00:14:00	0
2020-01-01 00:26:00	0
2020-01-01 00:38:00	0
2020-01-01 00:50:00	0
2020-01-01 01:02:00	0
2020-01-01 01:14:00	0
2020-01-01 01:23:00	0
2020-01-01 01:35:00	0
2020-01-01 01:46:00	-0.1
2020-01-01 01:58:00	-0.2
2020-01-01 02:04:00	-0.4
2020-01-01 02:10:00	-0.4
2020-01-01 02:13:00	-0.3
2020-01-01 02:25:00	-0.5
2020-01-01 02:37:00	-0.7
2020-01-01 02:40:00	-0.8

Figure 2

Recorded data

data	hour	temperature
2020-01-01	00	0.0
2020-01-01	01	-0.05000000000000001
2020-01-01	02	-0.7555555555555554
2020-01-01	03	-2.0599999999999996
2020-01-01	04	-3.7153846153846155
2020-01-01	05	-4.3500000000000005
2020-01-01	06	-4.154545454545455
2020-01-01	07	-4.886666666666666
2020-01-01	08	-1.783333333333334
2020-01-01	09	2.212500000000001
2020-01-01	10	4.8578947368421055
2020-01-01	11	7.199999999999999
2020-01-01	12	6.884210526315789
2020-01-01	13	6.313333333333333
2020-01-01	14	5.927272727272728
2020-01-01	15	5.525000000000001
2020-01-01	16	4.542857142857144
2020-01-01	17	3.3625000000000003
2020-01-01	18	2.6333333333333333

Figure 3

Transformed data

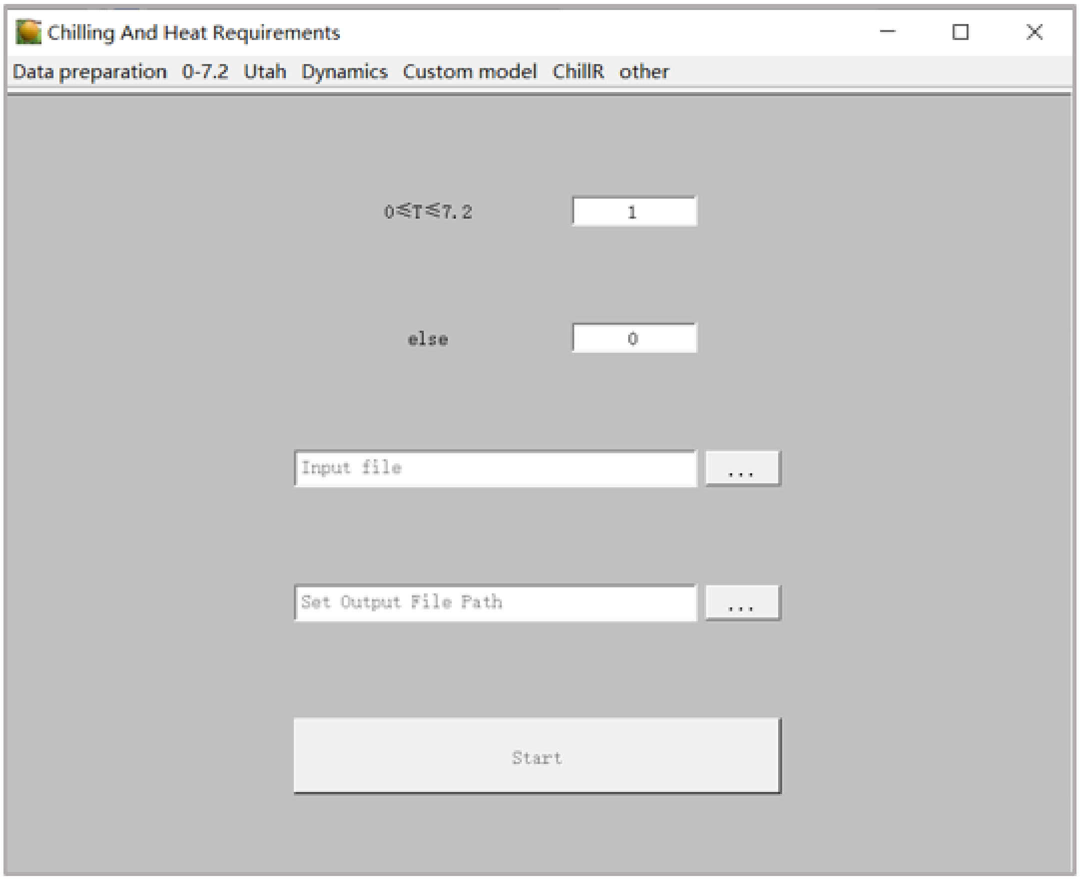


Figure 4

0-7.2 model

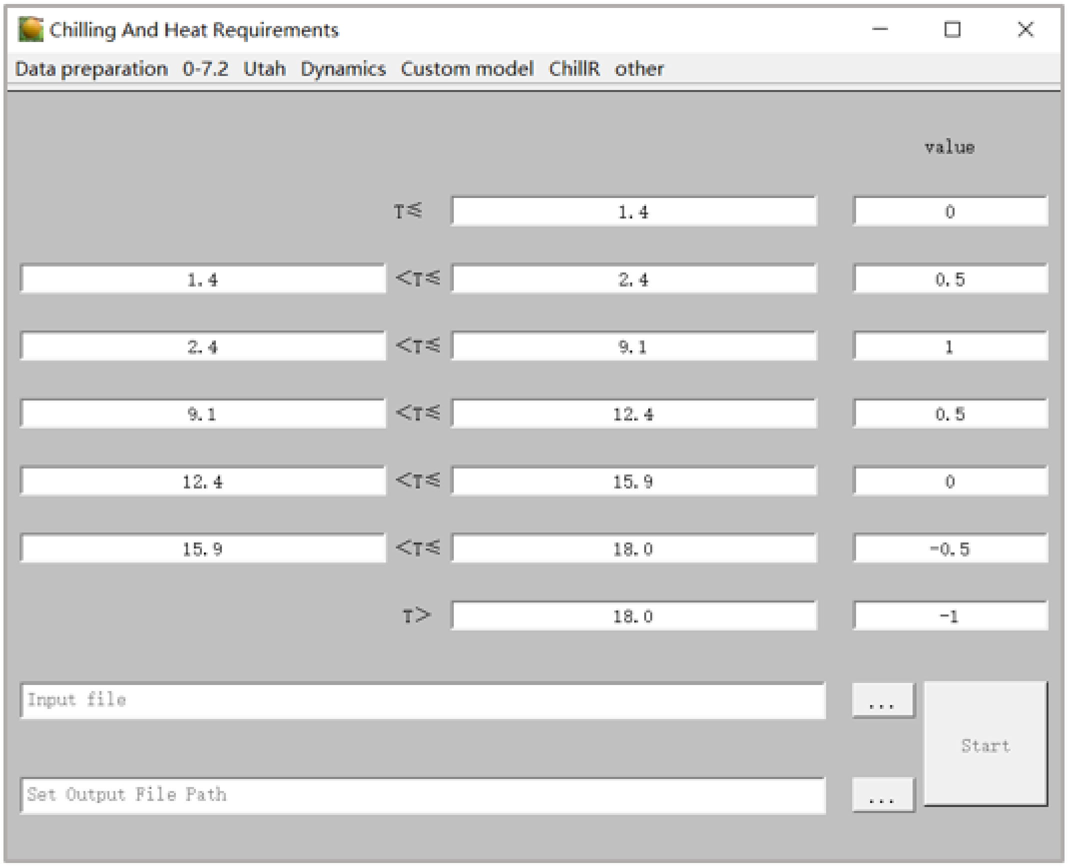


Figure 5

Utah model

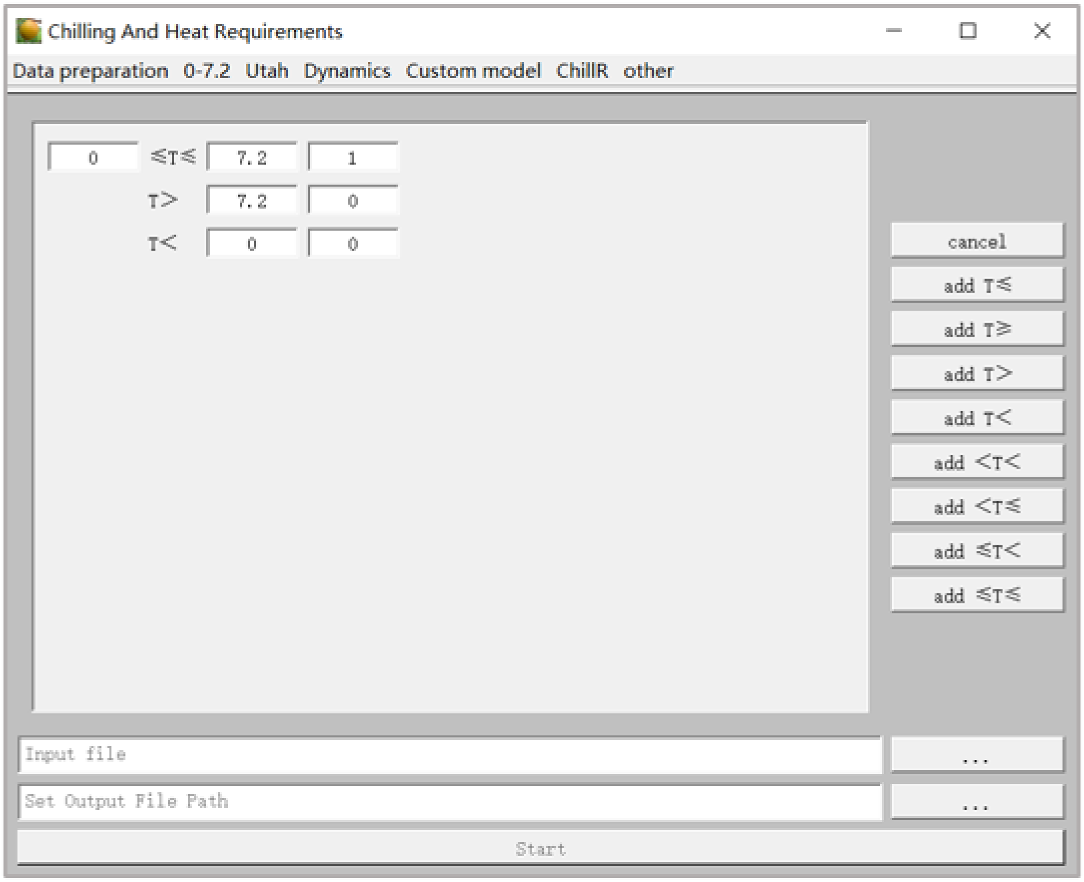


Figure 6

Custom model

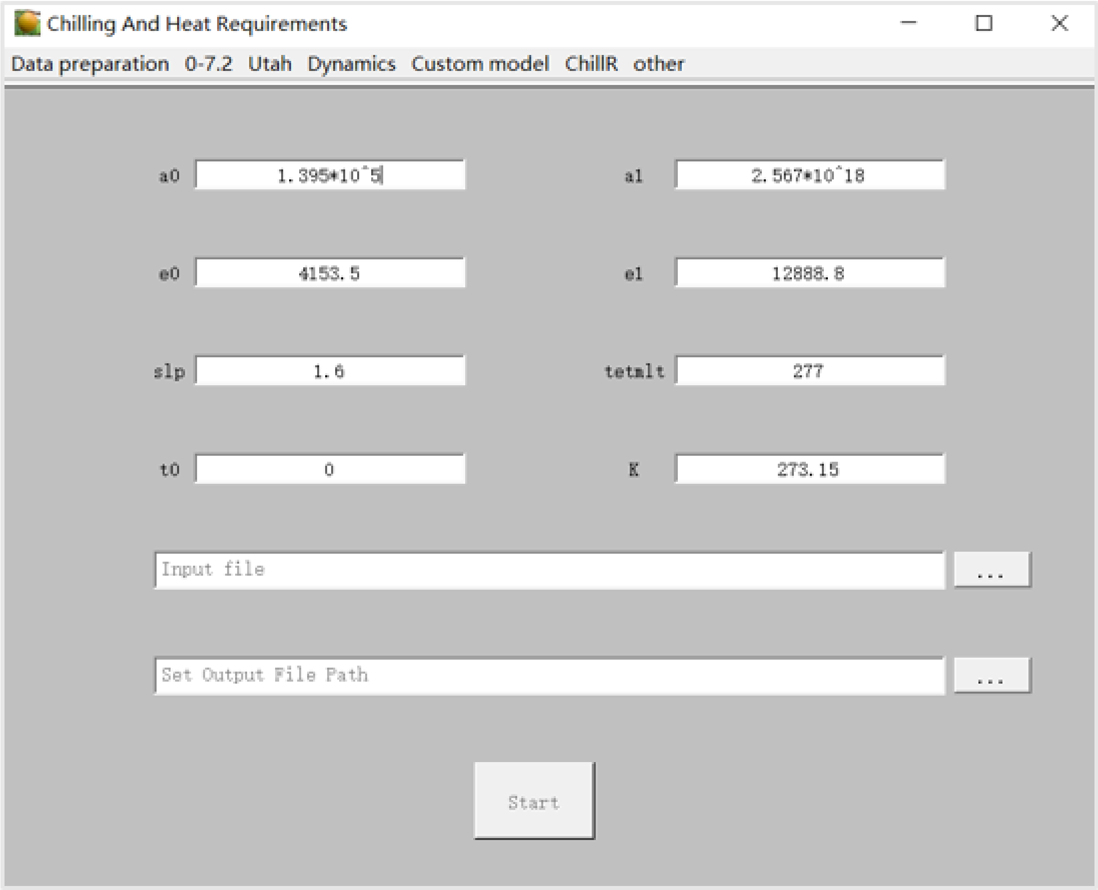


Figure 7

Dynamic model

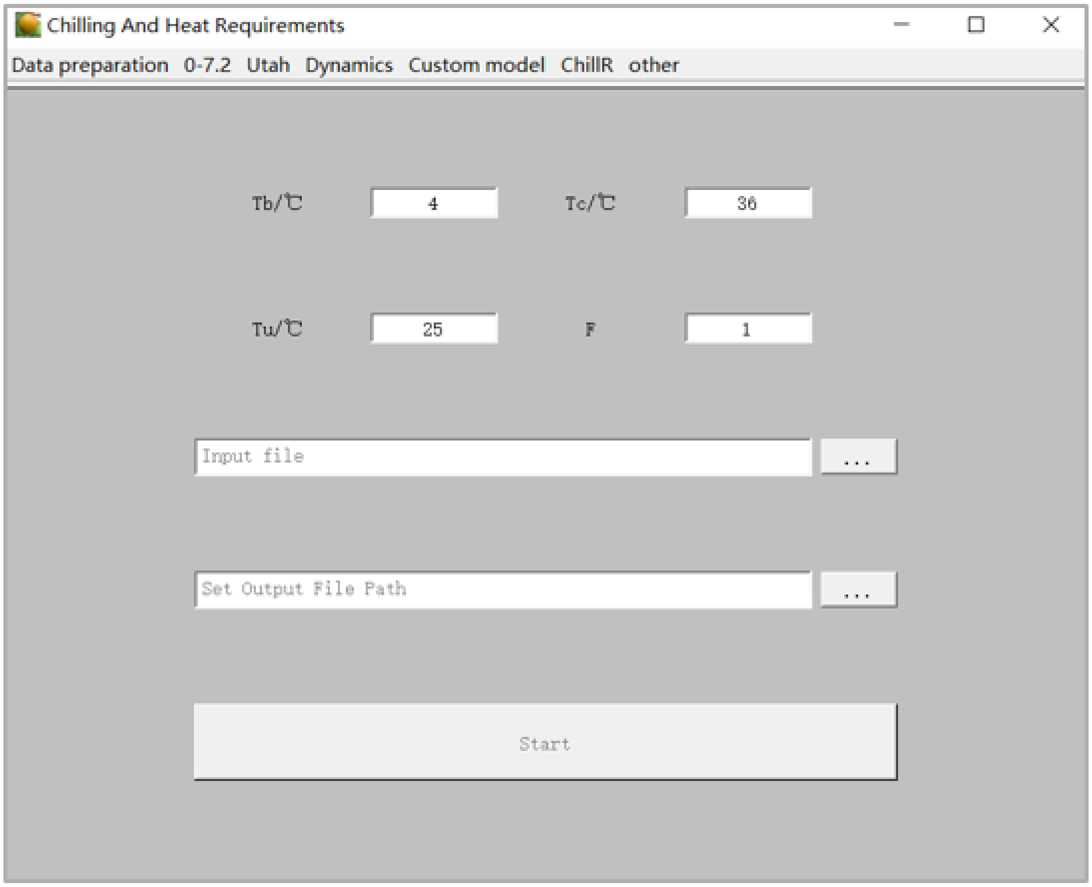
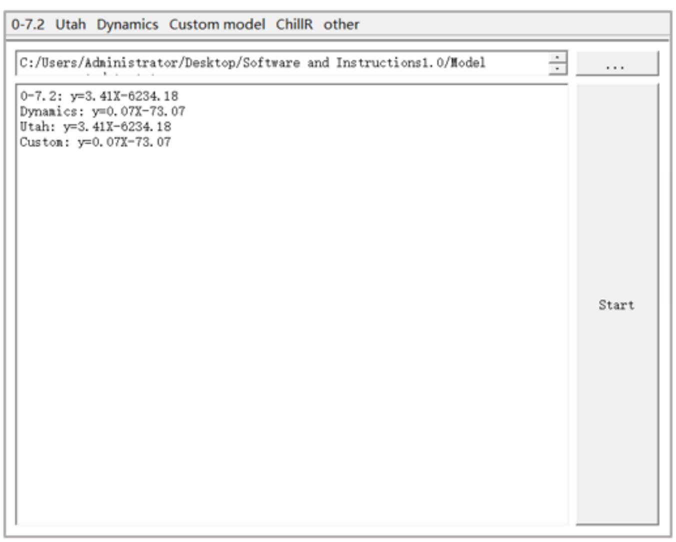


Figure 8

GDH model



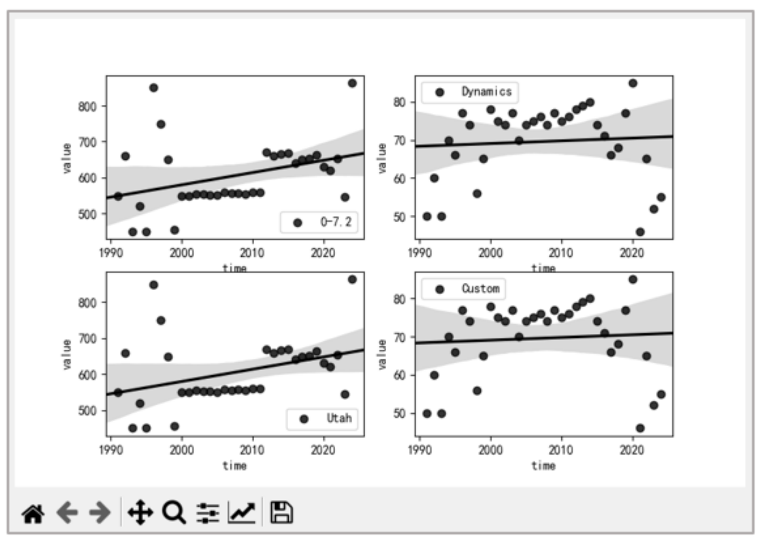


Figure 9

Model analysis

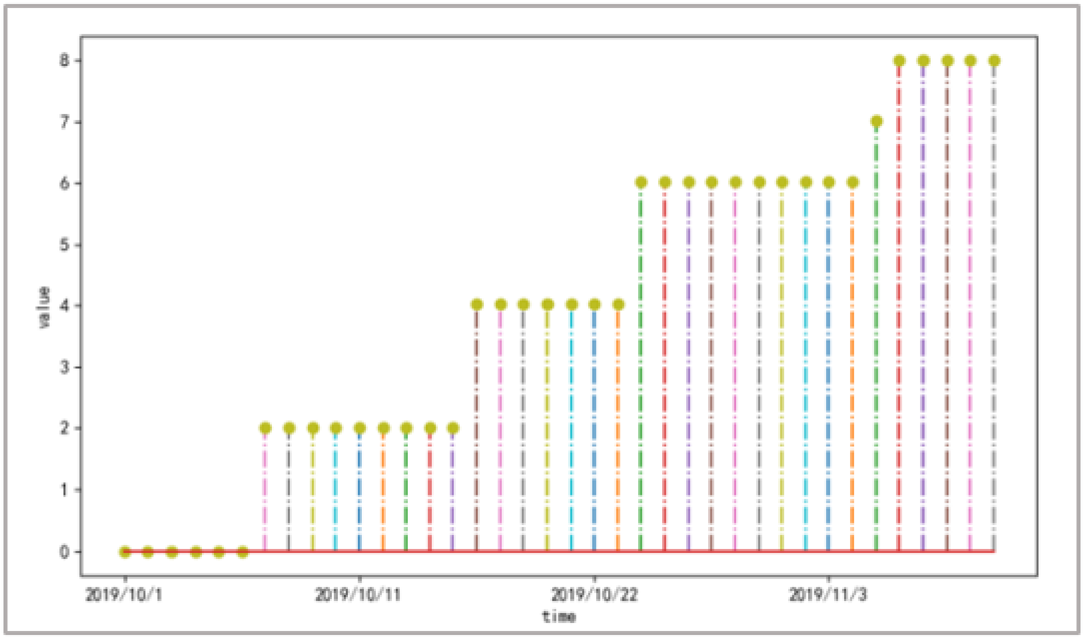


Figure 10

Change trend of CR

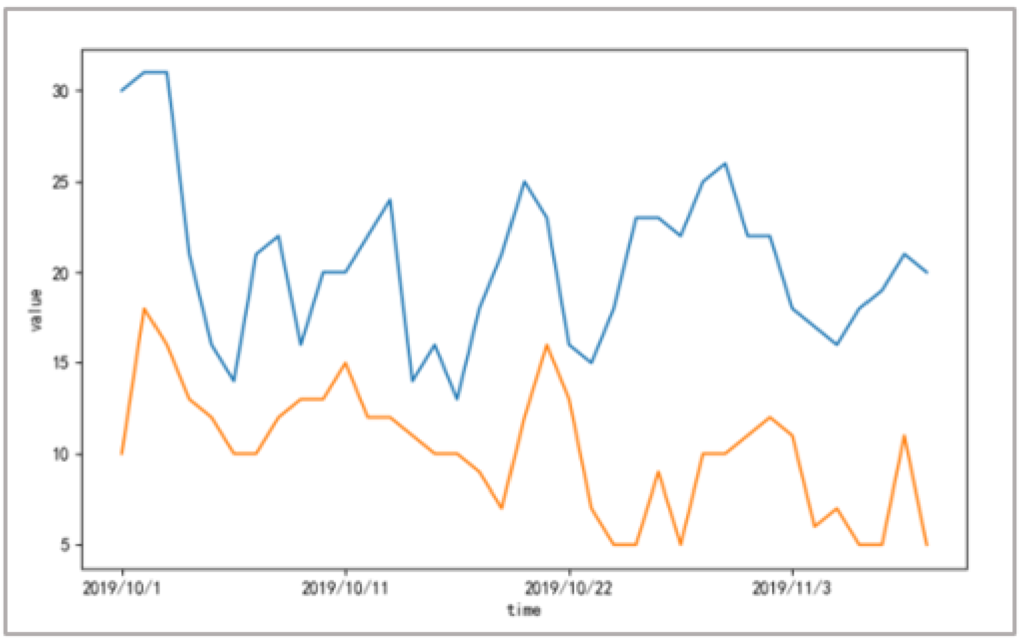


Figure 11

Change of the max and min temperature

Supplementary Files

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- ChillingandHeatRequirementManual.docx