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Various methods of processing long-term phenological series

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Abstract. In this work we elaborated long-term phenological series with using computer tool PhenoClim. PhenoClim is software for calculating temperature tresholds (T_{base}) and sum of effective units (T_S) and subsequently for modeling the terms of phenophases at various experimental sites and also under future climate conditions. For evaluation the terms of phenophases of five wild shrubs from one experimental site were used. The two methods of calculation (thermal time model and method of sine wave) were tested and T_{base} and T_S were calculated as precise as possible. The accuracy of model were determined by statistical indicators – RMSE (root mean square error) and R^2 (coefficient of determination). Two used methods for five shrubs showed almost similar values of T_{base} and T_S with almost same statistical indicators. Using T_{base} and T_S the onset of phenophases were calculate and estimate for future climate conditions.

Introduction

The use of degree days for calculating the temperature dependent development of plants is widely accepted as a basis for building phenology and population dynamics models (Roltsch et al., 1999). The different methods of calculation degree days and temperature tresholds were published by various authors. Chmielewski et al. (2005) used simple phenological models (thermal time models and regression equations) to estimated shift of phenological phases nad effective temperature sum calculated for chosen species. Zalom et al. (1983) first described the methods of single-sine method.

The main aim of this work were to determine the values of T_{base} and T_S for five shrubs and subsequently modeled dates of phenophases at sites where only meteorological data are available and finaly estimate effect of future climate conditions on onset and duration of phenological stages.

Data and methods

Each species requires different sum of effective temperatures or degree days (T_S) (Chmielewski et al., 2005) above certain threshold (T_{base}) that might be also species/cultivar specific. As the values of T_S and T_{base} are only rarely available, one of the primary functions of PhenoClim is to allow calculation of both parameters. Six meteorological parameters in daily time steps are required for complex analysis as inputs: maximum and minimum air temperature (°C), global solar radiation ($MJ.m^{-2}.day^{-1}$), amount of precipitation (mm), water vapor pressure (hPa) and wind speed ($m.s^{-1}$). In addition various predictors could be used including monthly index data (e.g. North Atlantic Oscillation index).

Phenological data for PhenoClim are required for primary calibration of phenological model and usually consist of the date of analyzed phenological phase (e.g. first flower) or its duration (e. g. time from the first till full flowering) in each years. Input text file contains either one or two sets of dates (with years and first phenological phase, e. g. first flower) or two consequent phenological phases which are analysed together (e. g. first flower and full flowering).

To set up model the phenological and meteorological database should be (and it is highly recommended) splitted into two parts prior to the analysis. First part of the data is used for calibration of the phenological model and the second one for model validation. User selects e. g. even years for calibration and odd years for verification data or assess different time period (e. g. period 1961–1981 for calibration and 1982–2009 period for evaluation). Model user also select which experimental site(s) will be used for calibration and validation. PhenoClim enables based on the calibration dataset to select most likely combination of T_S and T_{base} for any particular species. This is done through set of statistical variables namely mean bias error (MBE), root mean square error (RMSE) and coefficient of determination (R^2). Statistical variables RMSE is defined as an indicator of both random and systematic error and MBE as an indicator of systematic error (Davies & McKay 1989) and are determined in the days. The same set of statistical variables are calculated for the verification dataset and model user is able to select the best predictor(s) of a given phenophase and its values of effective T_S and T_{base}.

Enhanced version of PhenoClim included two methods of calculations degree days and thresholds. First method is based on simple thermal time model, when PhenoClim determined T_{base} in set temperature range (e. g. 0-10°C in step 0.1°C). Start of calculation is set by temperature conditions and it is necessary to select which of available daily temperatures from input file (mean, maximum and minimum temperature) will be used to derive T_S. PhenoClim also allows, using this methodology, calculate sum of global radiation and sum of precipitation (number of rainy days respectively). Second method used simple sine wave. This method use daily minimum and maximum temperatures to produce sine-wave curve for 24-hour period, and then estimates a degree days for that day by calculating the area between the defined temperature tresholds and below the curve (e. g. Roltsch et al., 1999). For this study only lower treshold were set and ranged between 0-10°C (in step 0.1°C).

Results and disscussion

Common hawthorn (*Crataegus monogyna*) first flower and full flowering in 1961 and 2009 with daily meteorological data from experimental site Vranovice (170 a. s. l., 48°56´N, 16°35´E, fig. 3) were used as an example in this text.

Table 1. Statistical indicators for two type of calculation T_{base} and T_S methodology: TTM (Thermal Time Model) and SW (Sin Wave) and two phenological phases (P1 – first flower, P2 – full flowering) for common hawthorn. RMSE mean Root Mean Square Error and R^2 is coefficient of determination.

	TTM		SW	
	P1	P2	P1	P2
RMSE	2.62	2.35	2.85	2.56
R^2	0.86	0.87	0.88	0.88
Start day	set by user	set by user	set by user	set by user
T_{base} (°c)	2.6	2.9	2.6	2.9
T_S (°c)	457	488	483	517

Results of thermal time model and sine wave showed almost similar values of T_{base} and T_S and also almost same values of statistical determinants (Tab. 1). Therefore next results of the PhenoClim simulation will be shown only for thermal time model in this contribution. For hawthorn phenophase (first flower and full flowering) the relationship between observed and simulated data are shown in Fig. 1.

A

B

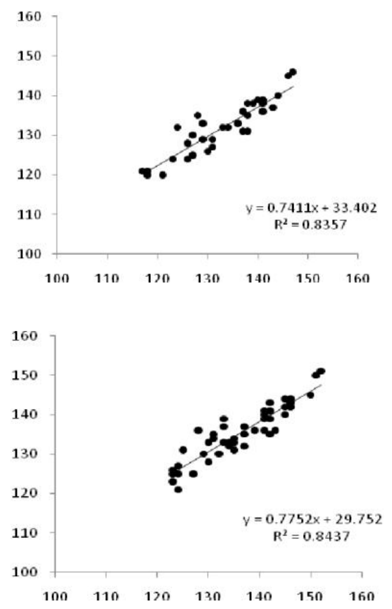

Fig. 1 Comparison of observed and simulated phenological dates (by PhenoClim model, A – first flower, B – full flowering) for site Vranovice using data from 1961 to 2009.

Based on the example results mean daily temperature was found to be the best predictor for first flower of Common hawthorn. Using this weather parameter (T_{base} nad T_S) the onset of phenophases was calculated for two experimental sites Lednice and Lanžhot (fig. 2). Mean values, standard deviations and maximum values differ relatively little in timing comparing with observed phenophases. As none data were taken out from calibration and validation operation. Common hawthorn phenological data are relatively continual over all period and RMSE reach rather lower values. Chmielewski et al. (2005) used similar simple phenological model for several species data from 1961 to 2000. RMSE values for their model range between 2.7 to 8.2 and MAE (Mean Absolute Error) range between 1.3 and 6.2 days. Authors mention that MAE is in range which is common for phenological models even if they are much more sophisticated. In our study the stabile database with long-term data (48 years) were used and model were set up on high-quality data (only one observer during the whole time) and could be used for simulations.

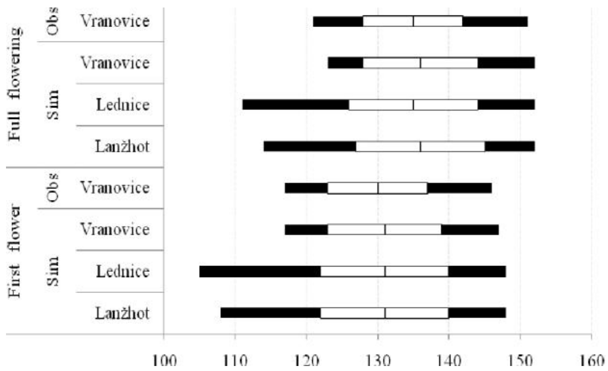

Fig. 2 Comparison of observed and simulated phenological dates (by PhenoClim model) for site Vranovice using data from 1961 to 2009.

The terms of phenophases in future climate conditions were also calculated. Results showed experessive shifting of phenophases to the earlier date. The estimated terms of phenophases in future climate were also specify with dates of last frosty days in each year.

Conclusions

Using computer tool PhenoClim the T_{base} and T_S values were calculated for chosen species. Two different methods were used for calculating the temperature parameters as precise as possible. Onset of phenophases were calculated for experimental sites where only meterological data are available and also the terms of phenophases were estimated for future climate conditions.

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