TEMPERATURE MODEL FOR SPRING PHENOLOGICAL PHASES OF GIVEN TREE AND SHRUB IN CENTRAL EUROPE

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The bud bursting of trees and flowering of shrubs are creating important part of ecosystem structure and are sensitive to environment. The most sensitive driving factor for bud bursting and also for flowering phenology is consider to be the temperature. In this study we present and elaborate two phenological datasets (bud bursting of oak tree – Quercus robur, L. and flowering of hawthorn Crataegus oxyacantha, L.) from 4 experimental sites (within the area of Czech Republic and Slovakia) during period 1987-2013 and their sensitivity to temperature. We used thermal time model, sin wave model and best combination model to calculate and set the accurate values of temperature thresholds and temperature sums for given phenological phases with the lowest value of RMSE, MBE and highest value of correlation coefficients. The results showed the methods of sin wave calculation together with best combination model as the most precise (RMSE = 2.9, MBE = 0.1, r^2 = 0.81) for oak tree. The lowest values of errors for phenological phases of hawthorn showed the best combination model (RMSE = 3.61, MBE = -0.21, r^2 = 0.81).

Keywords: TTM, sin of temperatures, T mean, T max, oak, hawthorn, climate change

INTRODUCTION

The fact that the phenological phases are getting earlier is well known (e. g. Rosenzeweig et al., 2008). Also many papers deal with the fact that growing season is getting larger; an extend of growing season has been observed from satellite data in northern high latitudes (e.g. Myneni et al., 1997; Slayback et al., 2003; Karlsen et al., 2008) and also from ground based phenological observations (e.g. Menzel, 2000; Ahas et al., 2002; Schwartz et al., 2006; Nordli et al., 2008).

The role of the temperature, in temperate regions, is often dominant as it affects the rates of the most biological and chemical processes within the plant body. Accumulated degree-days, calculated as the sum of the ambient temperatures above a base temperature, provide a measure of biological or thermal time. The concept of growing degree-days is well established having been used for over 200 years (Clark and Thompson, 2010) and also the use of degree-days for calculating the temperaturedependent 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 (e.g. Chmielewski et al. 2005, Chmielewski et al. 2013).

In this article we applied simple phenological model – PhenoClim, for calculating temperature sums (T_S) and base temperatures (T_{base}) (Bartošova et al., 2010). The T_S and T_{base} were calculated by three different method – simple thermal time model (TTM), sine wave model (SWM) and so called best combination model (BCM).

The aim of this contribution is to analyze the shifts of phenological dates for shrub (*Crataegus oxyacnatha*) flowering and tree (*Quercus robur*) bud breaking. For both phenophases the phenological model PhenoClim were used and the most accurate model were set for each phase. Subsequently were calculated the temperature and phenological trends in period 1987-2013.

MATERIALS AND METHODS

Phenological data which are used in this study were observed in southern Moravia at three experimental plots Lanžhot, Lednice, Vranovice and in Slovakia at one experimental plot Zvolen (tab I). Data were observed during the period 1987-2013 for two wild grown species – oak tree (*Quercus robur*) and hawthorn (*Crataegus oxyacantha*) and its phenological phases – bud bursting for oak tree and start of flowering for hawthorn.

The key meteorological data (average temperature, maximal and minimal temperature and precipitation) were used in this study for calculating climate trends during 1987-2013.

Table I The description of experimental phenological sites

Term	Name	Altitude/m	Description
Site 1	Zvolen/SK	300	botanical garden_forest
Site 2	Lanžhot/CZE	152	flood-plain forest
Site 3	Lednice/CZE	161	flood-plain forest
Site 4	Vranovice/CZE	170	flood-plain forest

Meteorological and phenological data were elaborated using computer tool PhenoClim. Within this study the software allowed us to carry out quality control of observed dataset. 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. PhenoClim calculate the base temperature (T_{base}) and temperature sums (T_S) by three different methods. 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. 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). The third method work with three values – T_{base}, T_S and Start day (it is the day since the PhenoClim start to calculate the the T_S) and looking for the best combination of these three parameters to set up the terms of phenophases with lowest errors. Based on the calibration dataset the software select most likely combination of T_S and T_{base} or combination of T_S, T_{base} and Start day 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).

More detailed information about software Phenoclim could be find in Bartošová et al. (2011), Černá et al. (2012).

Climate trends were elaborated by software STATISTICA version 10, StatSoft.

RESULTS

The results showed the significant temperature trends for given motnhs. The mean April air temperature indicated a significant increase at all four experimental sites (from 2.2 °C to 2.6 °C); maximal April temperature also showed siginificant trend (from 3.0 °C to 3.9 °C). Warming trends were also observed during May, conversely air temperature during March did not show any or small changes (Tab. II).

Table II Linear trends for meteorological parameters [temperature (°C), precipitation (mm)] at experimental sites during the period from 1987 to 2013

	Time period	Linear trends			
		Lanžhot	Lednice	Vranovice	Zvolen
Mean air temperature (°C)	March	-0.2	0.0	0.4	-0.5
	April	2.2*	2.5**	2.6**	2.6**
	May	1.6	1.9*	2.2*	1.4
Maximum air temperature (°C)	March	0.7	0.8	0.9	-0.5
	April	3.2**	3.0**	3.1**	3.9**
	May	2.7*	2.4	2.5*	1.7
Minimum air temperature (°C)	March	0.8	-0.8	-0.5	-0.6
	April	1.0	1.5	1.5	1.3
	May	1.2	1.4	1.6	1.6*
Precipitation (mm)	March	25.8	22.5	20.2	13.6
	April	2.7	4.7	-0.6	-28.8
	May	-13.9	-11.9	-13.4	-0.1

The average terms of phenophase bud breaking of oak tree were observed on the mid-term of April. The average term of first flower of hawthorn was observed later at the very end of April and during the start of April. Flowering and also bud breaking was observed later at higher latitude (at experimental site Zvolen) then in flood plain forest areas of three other sites. Both phenophases of oak and hawthorn have advanced to the earlier time. Oak tree showed the change by 4.8 to 6.9 days; hawthorn showed shifting by 7.5 to 11.3 days (tab. III).

The processing of phenological and meteorological data with using software PhenoClim showed the best model for timing of phenolofgical terms for oak tre and also hawthorn is the best combination model. The lowest values of errors (RMSE and MBE) were detected just for Best combination model (BCM), followed by Thermal time model (TTM) and Sin wave model (SWM). The Best combination method use three parameters (T_{base}, T_S and Start day) and looked for their best combination for calculating the terms of phenophases as precise as possible (with lowest values of RMSE and MBE). The results for oak tree showed the values of errors 2.92 days (RMSE), while the results for silver birch showed higher errors (3.61 days RMSE). With using this method the T_{base} for tree is 0.2 °C and for shrub is 2.8 °C (Tab. IV). Another two methods (the thermal time model and sin wave method) evaluated higher values of errors and lower values of coefficient of determination.

Table III Average terms of phenological phases for both species with minimal and maximal terms and values of standard deviations; and linear trends for phenological phases

	Oak tree (*Quercus robur* , L.)				English hawthorn (*Crataegus oxyacantha,* L.)			
	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4
Average date/ *day of year*	110	103	105	107	130	118	119	121
Earliest date/ *day of year*	99	92	93	95	119	107	107	110
Latest date/ *day of year*	118	115	115	117	145	129	130	132
Standard deviation/ *days*	4.6	6.4	6.4	6.1	5.9	6.2	6.4	6.2
Linear trend/ *days (1987-2013)*	4.8	6.8	6.9	6.1	11.3**	8.0*	7.5	8.4*

Table IV The Root Mean Square Error (RMSE) and Mean Bias Error (MBE) for three phenological models – BCM (Best Combination Model), TTM (Thermal Time Model) and SWM (Sin Wave Model) and calculated values of base temperature (T_{base}) and temperature sums (T_S) for two observed species

	Method	RMSE	MBE	r2	Tbase/°C	TS/°C	Start day
Oak tree (*Quercus robur* , L.)	BCM	2.92	0.1	0.8	0.2	304	59
	SWM	4.19	-1.7	0.8	7	111.8	x
	TTM	3.76	-0.4	0.8	7.4	59.0	x
English hawthorn (*Crataegus oxyacantha,* L.)	BCM	3.61	-0.2	0.8	2.8	356	30
	SWM	3.69	-1.8	0.8	3.2	397.0	x
	TTM	3.47	-1.3	0.9	3.1	361.8	x

Chmielewski et al. (2013) worked with phenophases of great tit (*Parus major*) and selected a phenological model that is able to calculate the beginning of egg laying of great tit. They used four type of thermal time model and finally set as the usable the model which worked with air temperature and photoperiod and with a starting date of temperature accumulation on 1 January. The error (RMSE) for this model was 3 days. The simple thermal time model Chmielweski et al. (2011) used earlier for the beginning of apple blossom. The RMSE between modelled and observed apple blossom data varied from 4.6 to 5.6 days in this study.

Fu et al. (2012) used five type of phenological model (also the thermal time model) to predict bud bursting for deciduous trees (also for birch). As the likely most appropriate model to predict budburst data in a future warmer climate they recommended Sequential model (model which uses a triangular chilling function and a sigmoid forcing function) with RMSE from 3.4 to 4 days.

CONCLUSION

Results of this paper showed warming trends of air temperature at experimental site and also the shifting trends to the earlier time for phenological phases of oak tree and Englich hawthorn during the experimental period 1987-2013. Computer tool PhenoClim calculated the lowest values of errors (statistical parameters RMSE and MBE) for “best combination method” and should be used for further modelling of phenophases. The thermal time model and sin wave method showed higher values of RMSE and MBE which are not usable for next elaboration.

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LITERATURE

Ahas, R., Aasa, A., Menzel, A., Fedotova, V. G., Scheifinger, H., 2002, Changes in European spring phenology. International Journal of Climatology 22, 1727–1738.

Bartošova, L., Bauer, Z., Trnka, M., Štěpanek, P., Žalud, Z., 2011, Klimatické faktory ovlivňující nástup a délku trvání fenofází vybraných rostlinných druhů na lokalitách jižní Moravy v letech 1961–2007, Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis 2: 1–10.

Chmielewski, F.M., Blümel K., Scherbaum-Heberer C., Koppmann-Rumpf B., Schmidt K. H., 2013, A model approach to project the start of egg laying of Great Tit (Parus major L.) in response to climate change. International Journal of Biometeorology 57: 287–297.

Chmielewski, F.M., Müller, A., Kuchler, W., 2005, Possible impacts of climate change on natural vegetation in Saxony (Germany). Int Jour of Biomet, 50, 96–104.

Clark, R. M., Thompson, R., 2010, Predicting the impact of global warming on the timing of spring flowering, Int. J. Climatol. 30: 1599–1613.

Černá, H., Bartošová, L., Trnka, M., Bauer, Z., Štěpánek, P., Možný, M., Dubrovský, M., Žalud, Z., 2012, The analysis of long-term phenological data of apricot tree (Prunus armeniaca l.) in southern Moravia during 1927–2009. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis 3: 9–18.

Fu Y. H., Campioli M., Deckmyn G., Janssens I.A., 2012, The Impact of Winter and Spring Temperatures on Temperate Tree Budburst Dates: Results from an Experimental Climate Manipulation. Plos One, 7, DOI: 10.1371/journal.pone.0047324

Karlsen, S. R., Tolvanen, A., Kubin, E., Poikolainen, J., Hogda, K. A., Johansen, B., Danks, F. S., Aspholm, P., Wielgolaski, F. E., Makarova, O., 2008, MODIS-NDVI-based mapping of the length of the growing season in northern Fennoscandia, Int J of Applied Earth Observation and Geoinformation 10: 253–266.

Menzel, A., 2000, Trends in phenological phases in Europe between 1951 and 1996. International Journal of Biometeorology 40, 76–81.

Myneni, R. B., Keeling, C. D., Tucker, C. J., Asrar, G., Nemani, R. R., 1997, Increased plant growth in the northern high latitudes from 1981 to 1991. Nature 386, 698–702.

Nordli, O., Wielgolaski, F. E., Bakken, A. K., Hjeltnes, S. H., Mage, F., Sivle, A., Skre, O., 2008, Regional trends for bud burst and flowering of woody plants in Norway as related to climate change, Int J of Biomet 52: 625–639.

Roltsch, W. J., Zalom, F. G., Strawn, A. J., Strand, J. F., Pitcairn, M. J., 1999, Evaluation of several degree-day estimation methods in California climates, Int J of Biomet 42: 169–176.

Rosenzweig, C., Karoly, D., Vicarelli, M., Neofotis, P., Wu, Q., Casassa, G., Menzel, A., Root, T. L., Estrella, N., Seguin, B., Tryjanowski, P., Liu, Ch., Rawlins, S., Imeson, A., 2008, Attributing physical and biological impacts to anthropogenic climate change, Nature 453: 353–357.

Schwartz, M. D., Ahas, R., Aasa, A., 2006, Onset of spring starting earlier across the Northern Hemisphere, Global Change Biology 12: 343–351.

Slayback, D. A., Pinzon, J. E., Los, S. O., Tucker, C. J., 2003, Northern Hemisphere photosynthetic trends 1982–99. Global Change Biology 9, 1–15.