VALIDATION OF PHENOLOGICAL MODELS FOR GRAPEVINE IN THE VENETO REGION

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ABSTRACT

In this study we have compared the predictive ability of two phenological models: a traditional Thermal Time (TT) and a version of the more recently develop Unified Model (UM). Unlike TT, which quantifies the accumulation of heat units which trigger bud break and the subsequent development phases, the UM describes also the fulfilment of chilling requirements, predicting the date of dormancy break, and implements a finer description of the plant development temperature-dependency. The models were fitted and validated on phenological observations collected from 1986 and 2008 in a site of North-Eastern Italy, on the cultivars Glera, Chardonnay, Merlot and Cabernet Sauvignon.

The UM fitted better to observations than TT, and yielded more accurate estimates on the validation dataset. In both models, the accuracy of estimates decreased from bud break to veraison.

KEYWORDS

Grapevine phenology, modelling

INTRODUCTION

Modelling techniques are gaining prominence in terroir studies, since they have the capability to analyse complex systems which integrate information from vegetation, climate, soil and terrain morphology. If coupled to a Geographical Information System (GIS), model-based estimates can be scaled up to the spatial level to support viticultural zoning or management decision-making.

Given the worldwide concern about global changes, spatially-explicit analysis of phenology are often carried out in relation to spatio-temporal climate variability, to explore future scenarios of crop distribution. In both these research areas, models are extensively used to extrapolate estimates in different locations or times other than those where they were calibrated. For this reason, model robustness, i.e. the ability to yield accurate estimates in most situations, has become a critical issue in model development.

Model robustness can be achieved in one or both the following ways: by training the model on larger datasets, and/or by widening their explanatory basis including additional processes and driving variables. The need of studying plant development in a changing climate context for example, has motivated the development of models accounting for the fulfilment of chilling requirements. Respect to the traditional thermal time models, they compute also the accumulation of chilling units to predict the date of the end of dormancy, from which the subsequent forcing phase is started. Concerns about the expected increasing frequency of mild winters in temperate zones, keep high the interest on these models, which are being currently studied and improved.

In this work, we have compared the predictive ability of a typical Thermal Time model, to that of the Unified Model (Chuine, 2000), which accounts also for the dormancy phase.

MATHERIALS AND METHODS

Data set - The phenological observations were recorded at Istrana, a village in North-Eastern Italy (45.671N, 12.082E), on four grapevine cultivars: Chardonnay, Merlot, Cabernet Sauvignon and Glera (formerly "Prosecco"). For the first three cultivars, historical records were available between 1986 and 2009, while for the last one the observations began in 1991. For this work we considered data about bud break, flowering and veraison, which were classified according to the scale of Baggiolini (1952).

The observations had been carried out always by the same person (P. Belvini), so they were very homogeneous and consistent throughout the years. Daily weather measurements of rainfall, maximum and minimum temperature were recorded with an automatic station installed in the vineyard.

Models - The first model under study is a version of the established Thermal Time (TT), based on the accumulation of heat units, or Growing Degree Days (GDD) starting from the 1st of January (Table 1).

The second one was a modification of the Unified Model in its simplified form, termed "Unichill" by its author (Chuine, 2000; Table 2). This model computes accumulation of chilling units from the 1st of September, whose value changes according to a three parameters temperature-dependent function. After the fulfilment of chilling requirements, the accumulation of heat units is started, deriving their values from a two-parameters function of temperature. Respect to the original model, which was referred only to bud break, we have extended it to the phases of flowering and veraison, under the assumption that the temperature-dependent forcing function remains the same.

Fitting and validation procedure – The available measurements were split into two data subsets: the odd years were used to fit models, while the even ones for validation. The models were fitted to calibration dataset through a simulated annealing method (Kirkpatrick et al., 1983). We used the implementation of Corana et al. (1987) associated to the Marsaglia random number generator (Marsaglia et al. 1990). The algorithm was programmed to minimize the Root Mean Square Error (RMSE) between estimates and observations.

Table 1 – Description of the Thermal Time (TT) model

Daily forcing rate	$Tavg - Tb$
Tavg = mean daily temperature Tb = base temperature Heat unit accumulation starts on 1st January Bud break (bb), flowering (fl) and veraison (ve) occurs when specific values of cumulated heat units are reached: GDDbb, GDDfl; GDDve Total number of parameters:4	

Table 2 – Description of the modified Unified Model (UM)

Daily chilling rate	$$\frac{1}{1+e^{a_c \cdot (Tavg-c_c)^2 + b_c \cdot (Tavg-c_c)}}$$
Daily forcing rate	$$\frac{1}{1+e^{b_f \cdot (Tavg-c_f)}}$$
Tavg = mean daily temperature a_c, b_c, c_c, b_f, c_f – empirical parameters Chilling units accumulation starts on 1st September Dormancy ends when a specific sum of chilling units (C_{crit}) is reached. Budburst, flowering and veraison occurs when specific values of cumulated heat units are reached: Fbb, Ffl and Fve. Total N. of parameters: 9	

RESULTS AND DISCUSSION

The adherence of estimates to observations was quantified by means of RMSE and the coefficient of determination R^2. Thanks to its higher number of degrees of freedom, the UM fitted to observations better than TT (Figs. 1 and 2, left panes), with lower RMSE and higher R^2 values. Considering the average of the four cultivars, in the UM the RMSE was 1.80 and 1.85 days for bud break and flowering, and 4.2 days for veraison, while R^2 varied between 0.93 and 0.97. In TT the average RMSE ranged between 2.65 (flowering) and 5.12 days (veraison), while R^2 varied between 0.81 and 0.92.

At validation (Figs. 1 and 2, right panes), UM and TT showed comparable RMSE values, but widely differed in R^2: from bud break to veraison, R^2 decreased from 0.83 to 0.63 with UM, while in TT it decreased from 0.77 to 0.20.

A higher uncertainty in the estimation of the late phenological phases was expected, because models with temperature as the only driving variable cannot capture the effects of water stress, which tend to cumulate with the advancement of the growing season, and which is highly variable throughout the years. However, the higher accuracy obtained by UM indicates that estimates were improved by a refined modelling of the temperature-dependency of grapevine development.

Both models do not consider the possible depressive effect of excessively high temperatures. We have tried to modify UM forcing function by introducing a third parameter, so to make the function equivalent to that used for calculating the chilling rate, with a decreasing range after an optimal temperature peak. Since no improvements were obtained with this modification (not shown), likely due to the low frequency of summer extreme temperatures in our environment, we kept the simpler two-parameters form.

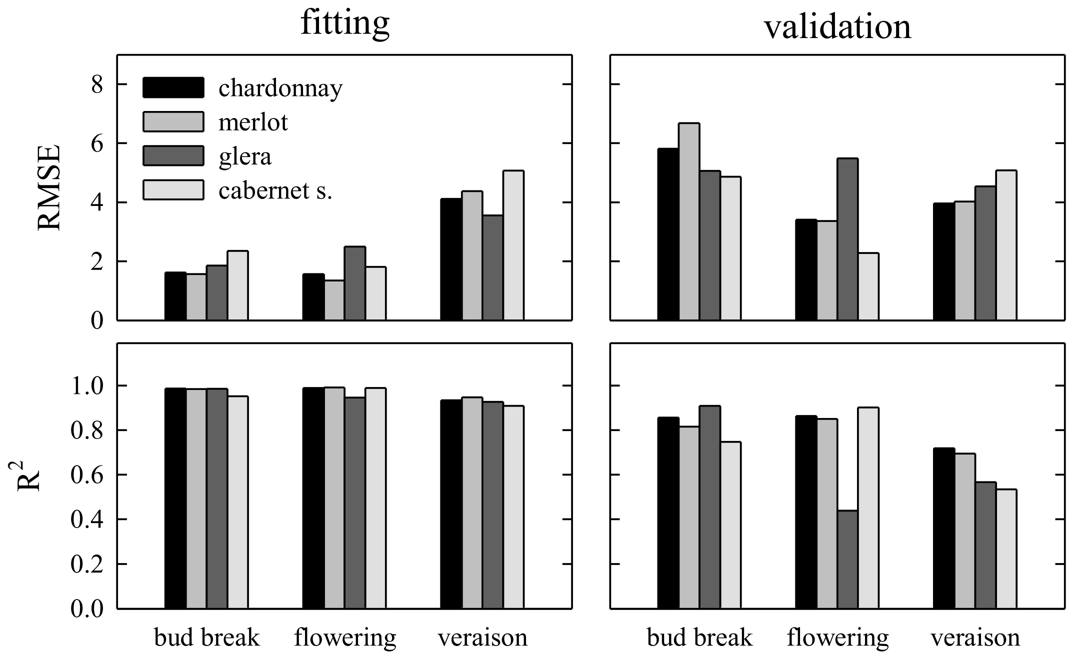

Figure 1 – Evaluation of the estimates accuracy obtained with the modified Unified Model after model fitting (left panes) and validation (right panes).

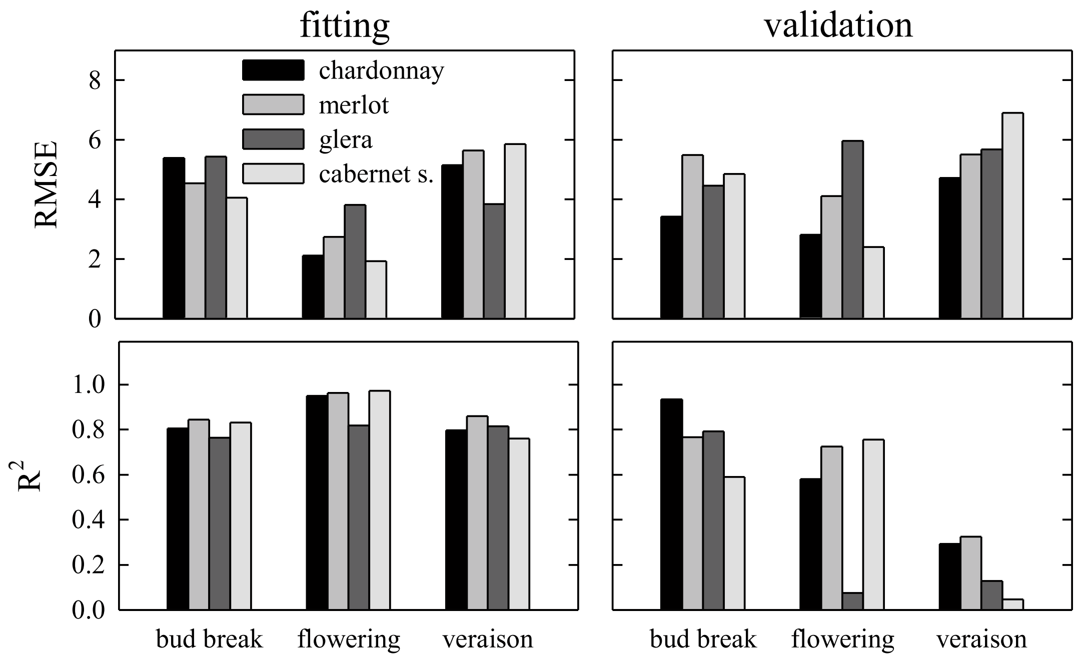

Figure 2 – Evaluation of the estimates accuracy obtained with the Thermal Time Model after fitting (left panes) and validation (right panes).

CONCLUSIONS

The performance of two phenological models were evaluated on four grapevine cultivars in a site of Veneto region, using a 23 years dataset of phenological observations.

The UM model, the one with the larger explanatory base, proved to be the most effective in predicting the dates of the principal phenological events, including the late-occurring ones, like veraison, where the TT model failed.

REFERENCES

1. Baggiolini M. 1952. Les stades répères dans le developpement annuel de la vigne et leur utilisation pratique. *Revue Romande d'Agriculture, de Viticulture, et d'Arboriculture*. 8:4-6.
2. Chuine I. 2000. A Unified Model for Budburst of Trees. *Journal of Theoretical Biology* **207**(3): 337-347.
3. Corana A., Marchesi M., Martini C., Ridella S. 1987. Minimizing Multimodal Functions of Continuous Variables with the 'Simulated Annealing" Algorithm. *CM Trans. Math. Softw*. **13**(3): 262-280.
4. Kirkpatrick S., Gelatt C. D. Jr., Vecchi M.P. 1983. Optimization by Simulated Annealing. *Science* **220**(4598): 671-680.
5. Marsaglia G., Zaman A., Tsang W. W. 1990. Toward a universal random number generator. *Statist. Probab. Lett.* 8, 35-39