

Points of attention when transferring STICS formalisms to another model: the case of Growing Degree-Days in a grassland model

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Introduction

The relationship between environment and plant development has been established for a long time and mechanistic phenology modeling has therefore become a central component of crop growth modeling. The complexity of existing models varies according to the number of developmental phases represented and the environmental variables considered (Chuine et al., 2024). Among these models growing degree-days (GDD) is one of the most used method and may be considered as a single-phase, temperature-only formulation (Chuine et al., 2024; Paredes et al., 2025). However, McMaster & Wilhelm (1997) highlighted that even when using the same canonical equation for GDD (Eq. 1), different assumptions can be made. In the GDD equation, the $[(T_{\min} + T_{\max})/2]$ term is sometimes replaced by the average daily temperature (T_{avg}), which, if computed from hourly temperature measurements, represents better the integral of the diurnal temperature curve (McMaster & Wilhelm, 1997). In addition to the base temperature (T_{base} or TDMIN in STICS), which is the lower temperature required for plants to grow, some methods use a ceiling temperature (T_{upper} or TDMAX in STICS), for a maximal contribution to GDD (Eq. 2), to represent a termination of the growth above it. Models such as STICS use another formalism instead: T_{upper} is considered rather as an optimum than a ceiling (Eq. 3). Above this temperature, the contribution to GDD (UDEVCULT in STICS) decreases linearly until a temperature of interruption (T_{stop} or TCXSTOP) (Brisson et al., 2009). In addition to the calculation methods detailed above, temperature thresholds values (T_{base} and T_{upper}) also critically affect GDD calculation. While species-dependent, they also depend on other factors such as the phenological stage or the cultivar (Wang & Engel, 1998). For simplicity, they are often considered constant throughout the full cycle for the same species which might not always be true (Paredes et al., 2025).

$$GDD = \left(\frac{T_{\max} - T_{\min}}{2} \right) - T_{\text{base}} \quad (1)$$

$$GDD = \begin{cases} 0 & \text{if } T_{\text{avg}} \leq T_{\text{base}} \\ T_{\text{avg}} - T_{\text{base}} & \text{if } T_{\text{base}} < T_{\text{avg}} \leq T_{\text{upper}} \\ T_{\text{upper}} - T_{\text{base}} & \text{if } T_{\text{avg}} > T_{\text{upper}} \end{cases} \quad (2)$$

$$GDD = \begin{cases} 0 & \text{if } T_{\text{avg}} \leq T_{\text{base}} \\ T_{\text{avg}} - T_{\text{base}} & \text{if } T_{\text{base}} < T_{\text{avg}} \leq T_{\text{upper}} \\ \frac{T_{\text{upper}} - T_{\text{base}}}{T_{\text{upper}} - T_{\text{stop}}} * (T_{\text{avg}} - T_{\text{stop}}) & \text{if } T_{\text{avg}} > T_{\text{upper}} \\ 0 & \text{if } T_{\text{avg}} > T_{\text{stop}} \end{cases} \quad (3)$$

In this context, borrowing equations across process-based plant models requires caution, as variations in GDD computation and base temperature can modify phenological thresholds and lead to parameters sets that differ in value while giving similar statistical performance (Chuine et al., 2024; McMaster & Wilhelm, 1997). While this study does not aim to provide an exhaustive comparison of existing phenological models, it, nevertheless, uses a case study to illustrate the bias that can arise when GDD equations from the STICS model (Brisson et al., 2009) are applied within the GRASSIM model, whose phenological stages parameterization relies on different assumptions (Kokah et al., 2023).

Material and methods

Meteorological data from the year 2017 were collected in Belgium by meteorological stations from the PAMESEB network in Michamps (50.038°N, 5.808°E) and Louvain-la-Neuve (50.401°N,

4.383°E) to compare two regions with different climates. Hourly air temperature (°C) at 1.5 m was used to compute daily T_{avg} (°C). Different GDD computation methods were tested to assess their influence on simulated phenology: (i) the GRASSIM approach, using a T_{base} fixed at 0 °C and no T_{upper} ; (ii) a more mechanistic variant with species-specific thresholds (e.g. T_{base} at 4 °C vs. 8 °C); and (iii) a formalism including a T_{stop} parameter that reduces GDD accumulation at high temperatures, as in STICS. Threshold values were based on Brisson et al. (2009), Ollerenshaw & Baker (1981), and Paredes et al. (2025).

Results and discussions

In 2017, climate was milder in Louvain-la-Neuve ($T_{avg-annual} = 10.9^{\circ}\text{C}$) than in Michamps ($T_{avg-annual} = 8.8^{\circ}\text{C}$) globally explaining a bigger GDD accumulation at the end of the year. When changing T_{base} from 0°C to 4°C and from 4°C to 8°C, fewer GDD were accumulated (up to 2.5 times lower). This change had more effect in Louvain-la-Neuve due to milder T_{avg} in spring. Concerning the increase in T_{upper} , it had a reduced effect (less than one GDD) because only one day had T_{avg} above 25°C. This also explains why using STICS formalism (Eq. 3) with a T_{stop} set to 35°C and 40°C did not affect the GDD computation under this temperate climate (not shown in Figure 1, as no differences were observed with Eq. 2). The respective effect of changing T_{base} , T_{upper} , and T_{stop} should thus be considered relative to the climate conditions of the case-study. For instance, introducing a T_{stop} parameter would have stronger consequences in warmer climates, where it would better account for heat-related reductions in development. In this context, transferring formalisms and temperature thresholds to another model such as the GRASSIM grass-growth model (Kokah et al., 2023), in which phenological stages are parametrized in thermal time with a base of 0°C, may introduce bias. For example, in Michamps, the “ear at 10 cm” stage, which occurs at 500 GDD when calculated with a 0 °C base temperature, moves from April 30th to June 1st when T_{base} is increased to 4 °C. This shows that a phenological stage calibrated at 0 °C becomes inconsistent when another base temperature is used to compute GDD, with major implications for simulated grass growth.

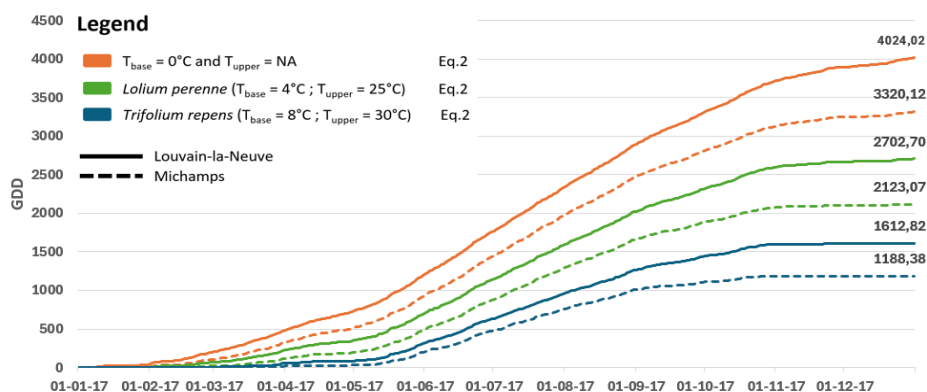


Figure 1: Comparison of GDD according to the method and temperature thresholds used for 2017.

Solutions include using the parametrization associated with the chosen formalism, but since GRASSIM covers four grasses functional types (Kokah et al., 2023), supplementary specific parametrization of phenological stages could be needed. This should rely on datasets with at least 20 observations from 3 to 5 sites to capture diverse environmental conditions, as parameter values are highly dataset-dependent (Chuine et al., 2024). As the aim is to improve legumes modeling in GRASSIM, future work should also explore the inclusion of photoperiod effects on phenology, as in STICS (cf. UPVT) (Brisson et al., 2009) or in Wang & Engel (1998).

Conclusion

This work therefore highlights the importance of consistency in thermal time calculation methods and temperature thresholds when transferring parameterizations between models. Ensuring methodological coherence is essential to avoid biases in phenological predictions and to improve the reliability of modeling across contrasting climates.

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