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Diverging models introduce large uncertainty in future climate warming impact on spring phenology of temperate deciduous trees

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Spring phenology influences terrestrial ecosystem carbon, water and energy exchanges between the biosphere and atmosphere. Accurate prediction of spring phenology is therefore a prerequisite to foresee the impacts of climate warming on terrestrial ecosystems. In the present study, we studied the model performance of four widely used process-based models of spring leaf unfolding, including both a one-phase model (not considering a chilling phase: the Thermal Time model) and three two-phase models (all accounting for a required chilling period: the Parallel model, the Sequential model, the Unified model). Models were tested on five deciduous tree species occurring across Europe. We specifically investigated the divergence of their phenology predictions under future climate warming scenarios and studied the differences in the chilling periods. We found that, in general, the two-phase models performed slightly better than the one-phase model when fitting to the observed dates, with all two-phase models performing similarly. However, leaf unfolding projections diverged substantially among the two-phase models over the period 2070-2100. Furthermore, we found that the modeled end dates of the chilling periods in these models also diverged, with advances for both the Sequential and Parallel models during the period 2070-2100 (compared to the period 1980-2010), and delays in the Unified model. Nonetheless, in general all three models predicted an advanced leaf unfolding in the period 2070-2100. These findings thus highlight large uncertainty in the two-phase phenology models and confirm that the mechanism underlying the leaf unfolding process is not yet understood. We therefore urgently need an improved understanding of the leaf unfolding process in order to improve the representation of phenology in terrestrial ecosystem models.