This analysis applies a Bayesian threshold survival model framework developed in Betancourt (2024). Betancourt incorporates a warping function into the standard exponential survival model that suppresses the cumulative hazard function until some threshold value is reached. This framework naturally suits perennial spring phenology, the models for which typically involve some heat requirement (HR) that is met via forcing temperature accumulation.

The hazard function for this model is a logistic forcing function of daily mean 2-meter temperature measurements, with a midpoint defined by a temperature threshold parameter. For each location starting on February 1 of each year, the model accumulates daily temperature stimulus via the forcing function. The HR is the value beyond which the cumulative forcings influence the survival function normally and bloom events begin to occur.

Observational and experimental evidence suggests that prolonged chill accumulation (CA) in endodormancy lowers HR (Wang et al., 2020). Accordingly, HR is modeled as a quadratic function of winter CA to flexibly capture this CA-HR relationship, which necessitates intercept, linear, and quadratic parameters. CA is computed for each year and location by summing the output of a chilling function of daily mean 2-meter temperature from October 1 of the previous year through February 1. The chilling function is reverse logistic (such that it decreases with increasing temperature) with a midpoint defined by a chilling temperature threshold parameter. Betancourt's soft-hinge warping function, used here, implies logistically distributed bloom events centered at the HR, with a scale parameter controlling timing variability.

In order to propagate uncertainty about future temperature, daily temperature is modeled concurrently, informed by an ensemble of daily long-term climate forecasts for each location. Daily temperature is assumed to follow a normal distribution with mean equal to the forecast ensemble mean plus a bias parameter, and standard deviation equal to the root-sum-of-squares of the ensemble standard deviation and a baseline epistemic uncertainty parameter. Future bloom events are predicted by accumulating hazard using historical mean temperatures through February 26, after which forecast-informed posterior samples are used.

Priors for forcing and chilling temperature thresholds are based on ranges from past studies, while HR function priors ensure compatibility with the distribution of unmodeled (pre-1940) bloom events.

Bayesian inference was conducted in Stan. Posterior checks demonstrate adequate, if somewhat overdispersed, retrodictions. Posteriors of the HR function parameters reflect a negative, decelerating CA-HR relationship in the relevant covariate neighborhood.

Historical and climate forecast temperature data were sourced from Open-Meteo APIs (Zippenfenig, 2023).

References

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