Supplemental materials for Chilling outweighs photoperiod and forcing cues for temperate trees in experiments, but not in natural systems

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May need to move back to main text ...

The paucity of studies directly manipulating chilling—which our results suggest has the greatest effect on budburst—suggests a major gap in current research. While many studies (X out of Y here) directly manipulated forcing, far fewer directly manipulated chilling (Z out of Y). Our model highlights how the choice of chill units can affect model estimates and associated forecasts (reference supplemental figure with utah units vs chill portions in main manuscript). Given the limited manipulation of chilling in studies, we estimated chilling for all studies by combining chilling from the field (i.e., chilling before plants were sampled) and experimental chilling into two widely used metrics of chilling: Utah (citation) and Chill portions (citation). We found the effects of chilling and other cues remain qualitatively consistent across the two chilling units, though chilling and photoperiod estimates were slightly lower using chill portions compared to Utah (cite supplemental table comparing estimates with both units).

An additional important limitation is the rarity of studies designed to test interactions. Interactions between these cues are widely expected (cites) and, when examined, often found (cites), we were unable to estimate interactions in our meta-analysis because very few studies design experiments to test for interactions between chilling, forcing, and photoperiod (cite table with number of interactions from coding challenge!). The few that do incorporate interactions generally use the Weinberger method, which is not designed to robustly tease out of the effects of multiple cues (cites, Tables, figs). Our estimated effects average over interactions (citeGelman), but identifying them in future research will be critical to understanding and predicting budburst. For example, the most commonly observed interaction between chilling and forcing—that lower amounts of chilling increases forcing requirements for budburst (cite)—is the hypothesized cause of declining sensitivities in European trees (cites). As more data become available, it would allow additional tests of important interactions, such as how responses vary across latitudes (see Supp).

Things we'd like to discuss in main paper but don't have room for

Photothermoperiodicity, for example, is an ongoing challenge: chamber studies may seek to replicate patterns in nature, pairing daylength and temperature treatments such that night temperatures are always cooler than day temperatures (e.g., cite studies that do this). This results in daylength treatments that differ in temperature conditions (and therefore chilling and forcing treatments) as well, however.

Chilling: Current common models for chilling (i.e., Utah which was developed for XX species, chill portions which was developed for XX species) are *hypotheses* for how chilling may accumulate to affect the process of dormancy release, but are likely to be inaccurate for many species. Our model highlights how the choice of chill units can affect model estimates and associated forecasts (Figures 1,??2, 3).

Supplemental Methods

1. Data: search terms, etc
2. Equation of our model
3. Forecasting with the OSPREE model: We selected sites in Germany where temperature and budburst have been monitored since the 1950s. We extracted mean temperature data from 1951 through 1961 (pre warming time period) and used these values as baseline data. We then investigated model predictions of budburst given different levels of warming (from 1-7 °C) above this baseline, including altered chilling and forcing as well as potential declines in photoperiod due to advancing phenology. We did this for one common European species: *Betula pendula* (silver birch) at all lat/longs included in the PEP database between 1951 and 1961. We also did this for another common European species, *Fagus sylvatica*, for a subset of sites where it occured with *B. pendula*, in order to compare budburst responses of these two species when they experience the same baseline climate and warming levels.
4. To understand how experimental temperature, photoperiod, and budburst sensitivity compares to past and current conditions in nature, we used data from the PEP database (cite). We summarized forcing, chilling, and budburst doy for two common species: *Betula pendula* (silver birch) and *Fagus sylvatica* (European beech) during a pre-warming time-period (1950-1980) and post-warming period (1981-2014?).

Supplemental Results/Discussion

1. Surprising species-specific responses:
   (a) Positive Responses to chilling for Tilia and Salix. have positive response to chilling with chill portions model. T
   (b) Poisitive responses to forcing: Acer-complex, Fraxinus complex, Cornus alba.

Supplemental figures/tables

1. Map of study locations, shading or symbol coding for number of cues (Lizzie)
2. Map of species forecasting to justify sites
3. Heat maps for the main data, including by actual study design and by calculated chilling (our calculations)
4. Photoperiod x latitude effects figure

Reference list

A few categories:

Papers about contrasting results over what cues matter from growth chamber studies: Basler and Körner (2012, 2014); Caffarra et al. (2011*a*); Caffarra and Donnelly (2011); Caffarra et al. (2011*b*); Heide and Prestrud (2005); Koerner and Basler (2010); Laube et al. (2014); Vitasse and Basler (2013); Zohner et al. (2016). Get Nanninga *et al.* 2017: 'Increased exposure to chilling advances the time to budburst in North American tree species' and maybe Malyshev *et al.* 2018 'Temporal photoperiod sensitivity and forcing requirements for budburst in temperate tree seedlings.'

Papers about declining sensitivities (Ailene will update this list): Rutishauser et al. (2008); Fu et al. (2015). Also look for a Wang *et al.* article 'Impacts of global warming on phenology of spring leaf unfolding remain stable in the long run.' Vitasse paper on declining variation across elevation gradient. See Yu et al. (2010), but this is not temperate trees.

Papers about chilling units paper (Lizzie gets a list): Fu 2012 from OSPREE. Harrington and Gould (2015)Luedeling et al. (2011); Luedeling and Brown (2011); Luedeling et al. (2013)

References

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section* Figures

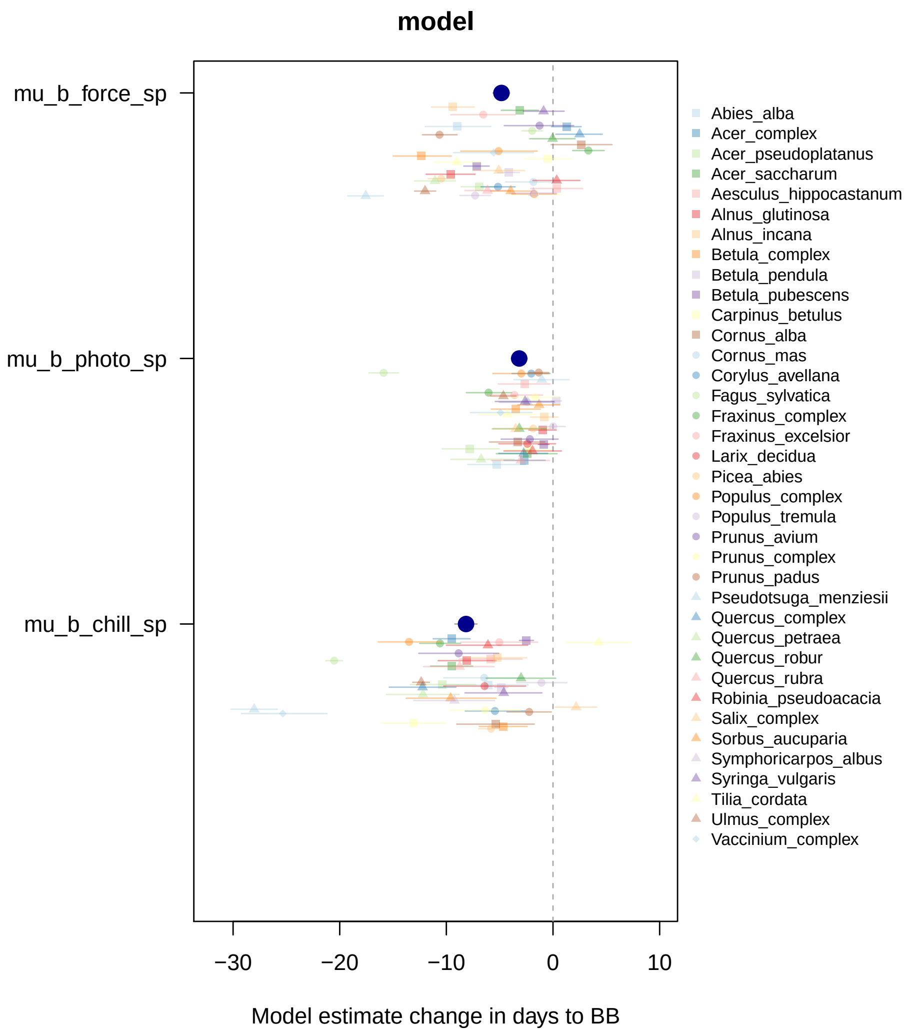

Figure 1: *Estimates for effects of chilling, forcing, and photoperiod from the model fit with Chill Portions*, with centered data, enabling comparisons of effect sizes across predictors. Coefficients were qualitatively similar to those in the model with Utah and can be found in the main text.

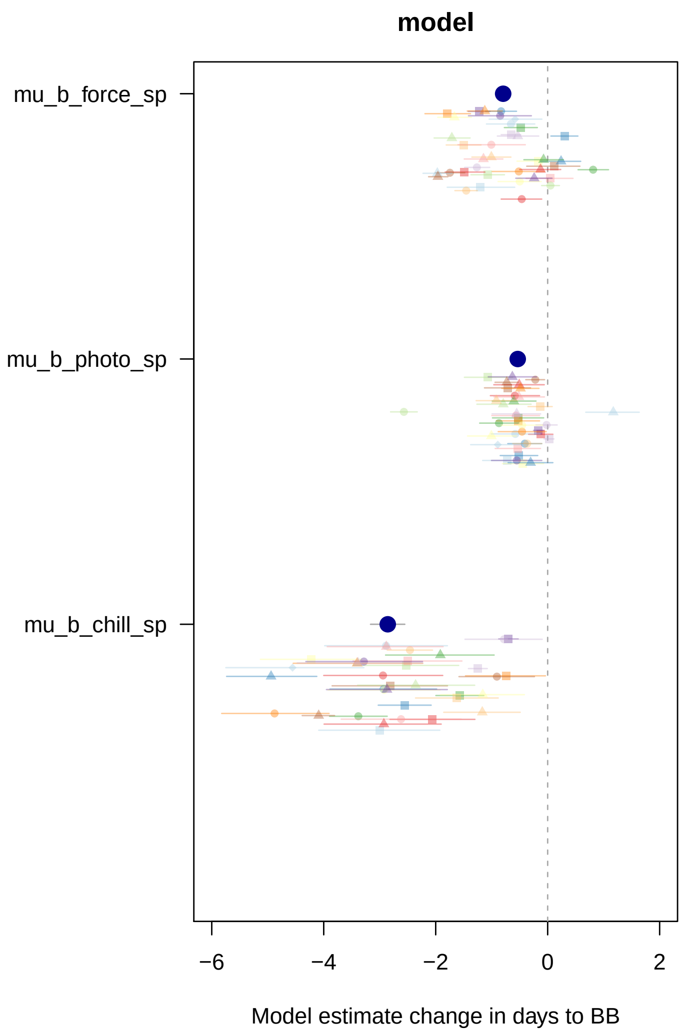

Figure 2: *Estimates for effects of chilling, forcing, and photoperiod from the models fit with uncentered predictors* using Utah units. Relationships of coefficients were qualitatively similar to those in the centered models (Figures 1, 1. (Should combing this and chil portions muplot into one figure.)

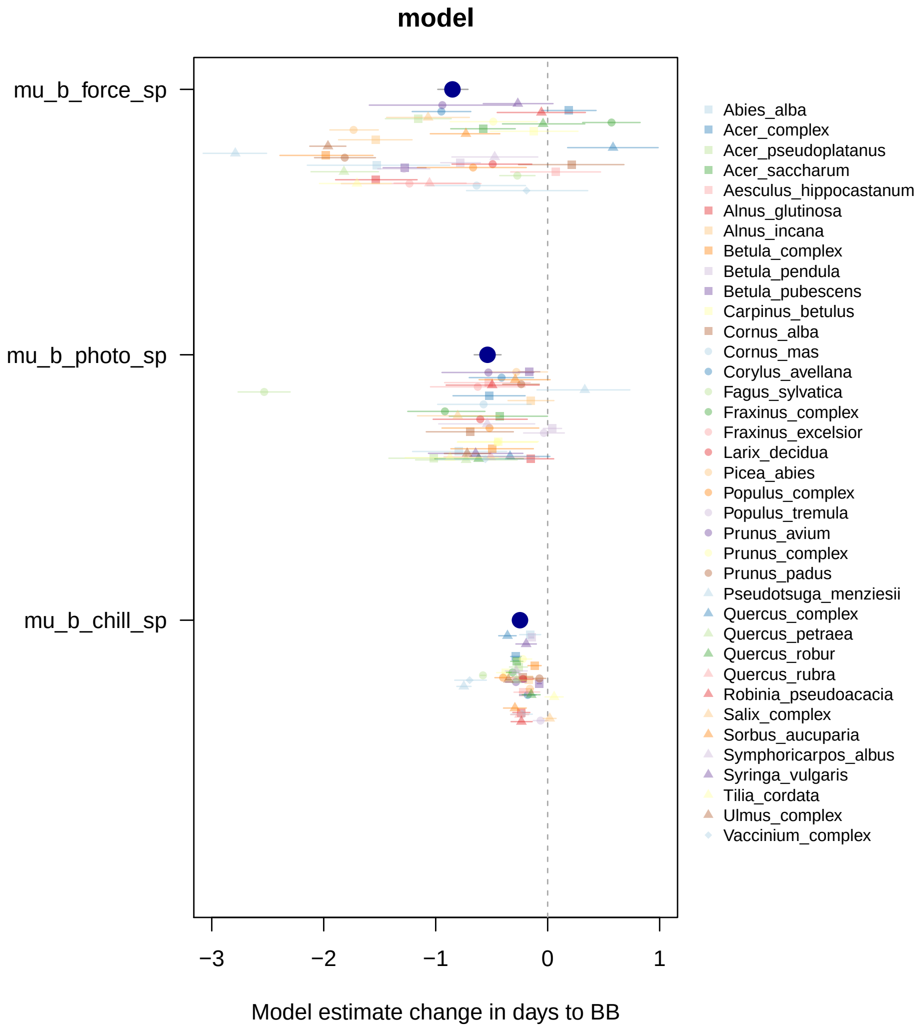

Figure 3: *Estimates for effects of chilling, forcing, and photoperiod from the models fit with uncentered predictors* using Chill Portions.