Appendix for Soil moisture interacts with temperature to affect plant phenology

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Supplemental Methods

Equations for soil moisture and temeprature models: The equations below represent the models we used to understand effects of experimental temperature (eT) and experimental preciptation (eP) treatments treatments on soil moisture and temperature. Since the model structures for our analyses of moisture and temperature were identical, y represents either moisture or temperature.

$$y_i = \alpha_{site[year[doy[i]]]} + \beta_{1site[i]} eT_i + \beta_{2site[i]} eP_i + \beta_{3site[i]} eT_i eP_i + \epsilon_i \tag{1}$$

$$\alpha_{site[year[doy]]} \sim N(\mu_{site[year]}, \sigma_{site[year]}) \tag{2}$$

$$\mu_{site[year]} \sim N(\mu_{sy}, \sigma_{sy}) \tag{3}$$

$$\mu_{sy} \sim N(\mu_s, \sigma_s) \tag{4}$$

$$\beta_{1site} \sim N(\mu_{\beta 1}, \sigma_{\beta 1}) \tag{5}$$

$$\beta_{2site} \sim N(\mu_{\beta 2}, \sigma_{\beta 2}) \tag{6}$$

$$\beta_{3site} \sim N(\mu_{\beta 3}, \sigma_{\beta 3}) \tag{7}$$

Equations for phenology models: Response variable (y) is day of year of the phenological event (budburst, leafout, flowering, fruiting, or senesence). Predictors are measured air temperature (T) and soil moisture(SM). Random effects are species (sp, random slopes and intercepts); site and year nested within site (random intercepts).

$$y_i = \alpha_{sp[i],site[year[i]]} + \beta_{1sp[i]} T_i + \beta_{2sp[i]} SM_i + \beta_{3site[i]} T_i SM_i + \epsilon_i \tag{8}$$

$$\alpha_{sp} \sim N(\mu_{sp}, \sigma_{sp}) \tag{9}$$

$$\mu_{site[year]} \sim N(\mu_{sy}, \sigma_{sy}) \tag{10}$$

$$\mu_{sy} \sim N(\mu_s, \sigma_s) \tag{11}$$

$$\beta_{1sp} \sim N(\mu_{\beta 1}, \sigma_{\beta 1}) \tag{12}$$

$$\beta_{2sp} \sim N(\mu_{\beta 2}, \sigma_{\beta 2}) \tag{13}$$

$$\beta_{3sp} \sim N(\mu_{\beta 3}, \sigma_{\beta 3}) \tag{14}$$

Results

1. **How do climate manipulations affect soil moisture and temperature?**
   (a) 12 sites included: exps 1-5, 7-9,10 and 12-14
   (b) Target temp has a negative effect on soil moisture. (Figure 1)
   (c) Precip treatment has a positive effect on soil moisture.(Figure 1)
   (d) Effects vary by site. (One site, exp07, has positive effect of temperature).
   (e) For supplement: Fit different models for different seasonal temperatures used in Question 2 (phenology models).
2. **How does soil moisture affect phenology?**
   (a) Air temperature (seasonal) has a negative effect on phenology for all phenophases except senescence, which has a positive effect (Figure 2). Magnitude varies among sites and species.
   (b) Moisture has a negative effect on phenology for all phenophases,. Magnitude varies among phenophases (e.g., LOD is weaker than BBD), sites, and species.
   (c) For supplement: Figures of fruiting and senescence (fewer sites)
3. **Does warming affect soil moisture and phenology similarly in experimental and non-experimental data?** OR **Does soil moisture affect phenology similarly in experimental and non-experimental data?**
4. Soil moisture effect size is bigger in full dataset than in controls only, for BB. Mean and range of SM is similar (though max is a bit higher in full dataset; min is similar).

Discussion

1. Soil moisture affects phenology, budburst, and leaf-out

Conclusions

References

Essiamah, S. & Eschrich, W. (1986). Water uptake in deciduous trees during winter and the role of conducting tissues in spring reactivation. *IAWA Journal*, 7, 31–38.

Reich, P.B. & Borchert, R. (1984). Water stress and tree phenology in a tropical dry forest in the lowlands of costa rica. *The Journal of Ecology*, pp. 61–74.

van Schaik, C.P., Terborgh, J.W. & Wright, S.J. (1993). The phenology of tropical forests: adaptive significance and consequences for primary consumers. *Annual Review of ecology and Systematics*, 24, 353–377.

x

Tables

Table 1: **Comparison of coefficients from budburst models fit to data from all plots versus control plots only**.

X	m5	m5cont	m5.cent	m5cont.cent
int	108.30	95.88	98.98	101.82
temp	-3.79	-4.82	-10.43	-8.83
mois	-31.74	25.68	-1.21	1.02
temp:mois	2.85	6.29	0.39	0.66

Figures

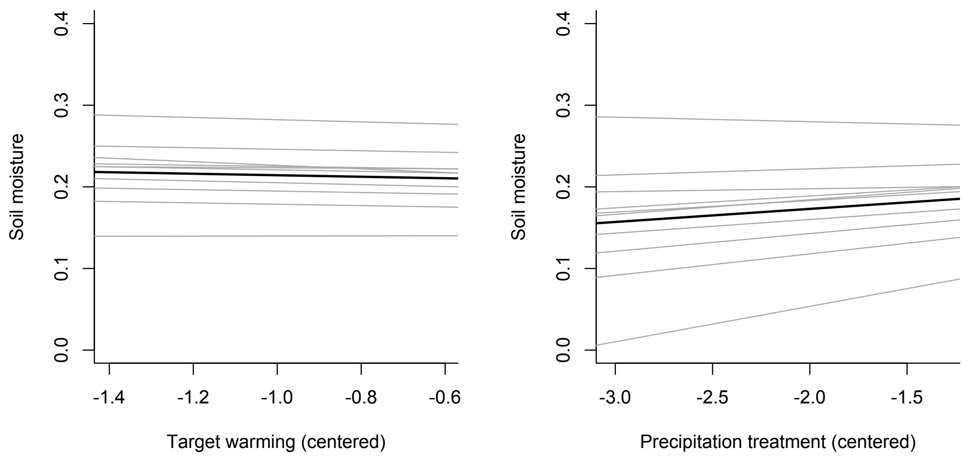

Figure 1: **Effects of target temperature and precipitation treatments on soil moisture.**

To do

1. Test Yann's theory (that soil moisture affects phenology through its effects on air temperature): fit models with soil temperature instead of air temperature (using same data)- compare coefficients
2. Why is x-axis negative in soil moisture model with centered predictors?
3. Modify Figure 1: color code lines by site, calculate how big effect of precip is and temp is, plot interaction
4. Figure 2: color code dots by species (by BB day of year, from early to late)
5. analyze experimental controls a bit more, before delving into observational comparisons

References to include

Later flowering is associated with low precipitation, at least in part (Crimmins et al 2010)

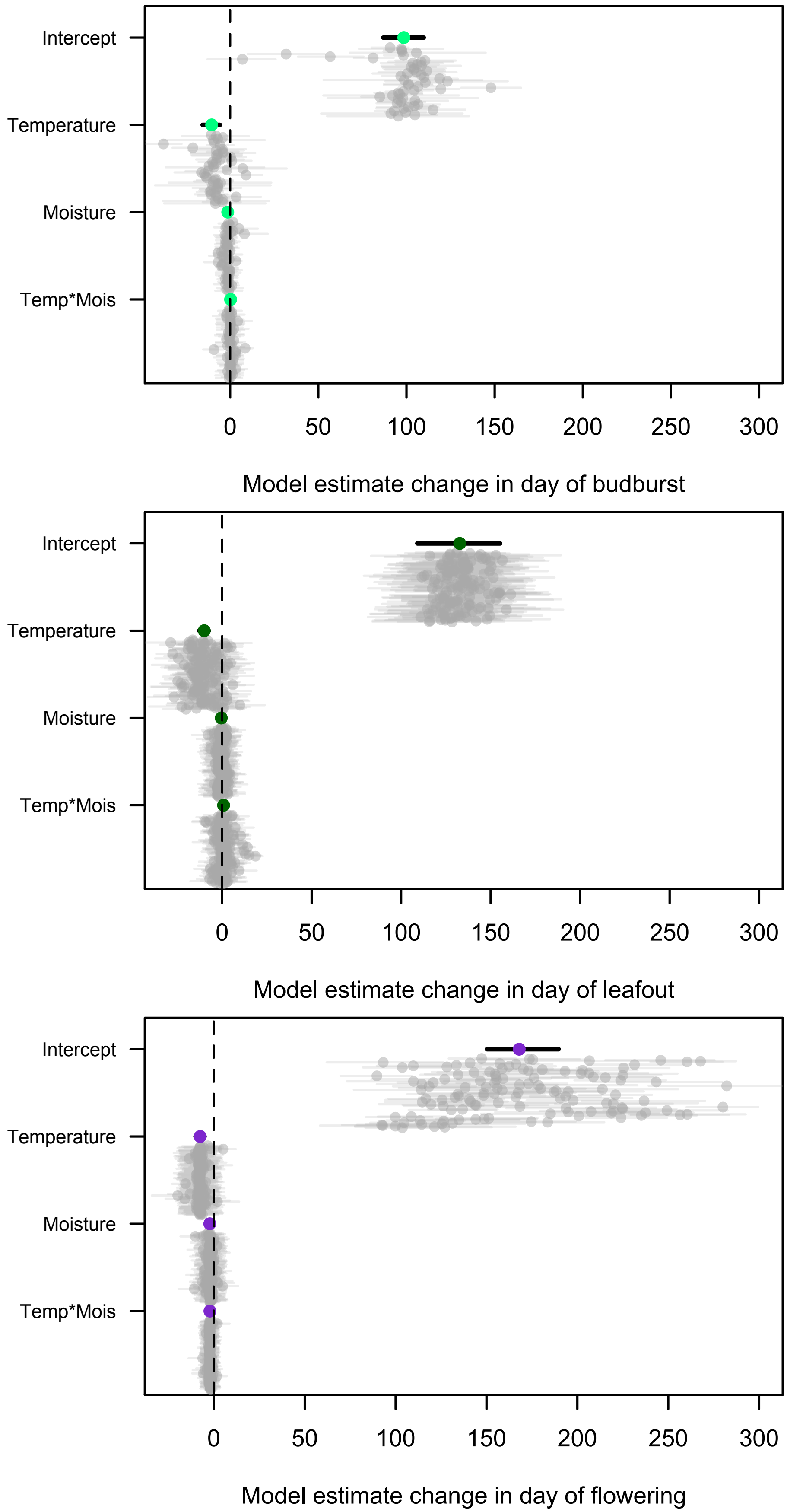

Figure 2: **Model coefficients from budburst, leafout, and flowering models (with centered predictors).**

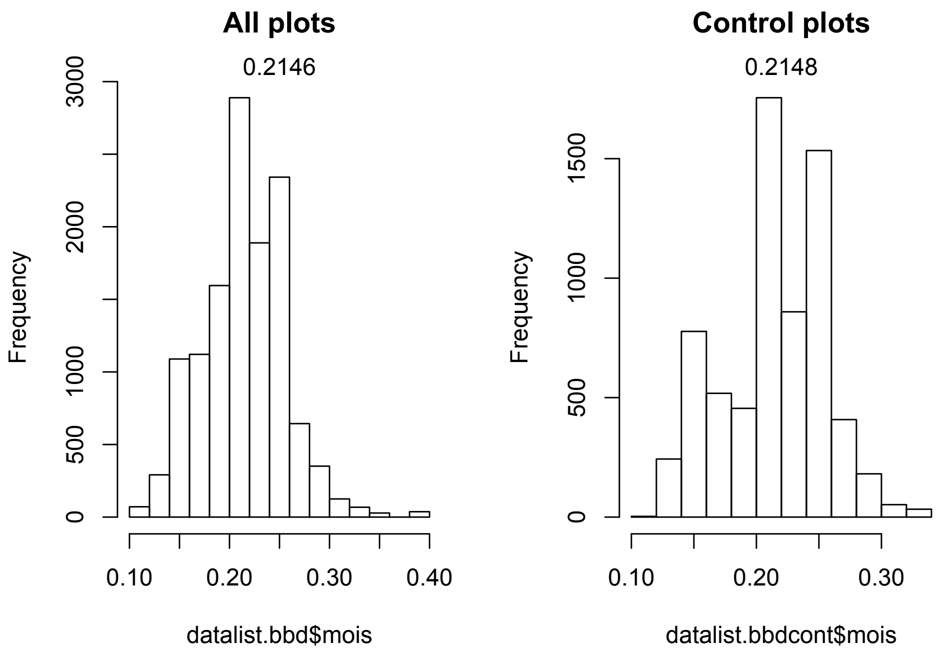

Figure 3: **Observed daily soil moisture in all plots verus control plots.**