How does soil moisture interact with temperature to affect phenology?

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1 Objective

We aim to understand generally how soil moisture may affect plant phenology, and specifically if experimental effects on soil moisture in warming experiments may be responsible for the discrepency in phenology temperature sensitivity between experimental and observational studies of plant phenology. To accomplish these aims, we have three study questions:

1. How do climate manipulations (target warming, precip manipulations) affect soil moisture (and temperature)?
2. How does soil moisture interact with temperature to affect phenology?
3. Does warming affect soil moisture similarly in experimental and non-experimental data?

2 How do climate manipulations affect soil moisture and temperature?

1. **Approach**: Use MC3E database. Fit multilevel models of soil moisture (and air temperature?) as a function of temperature and precipitation treatments. For this we need two equations where we evaluate the effects of experimental temperature (eT) and experimental preciptation (eP) treatments on soil moisture (and temperature, perhaps). There are two (or more!) possible random effects structures these models:

   (a) Random intercepts for doy nested within year nested within site

$$y_i = \alpha_{site[year[doy[i]]]} + \beta_1 eT_i + \beta_2 eP_i + \beta_3 eT_i eP_i + \epsilon_i \tag{1}$$

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

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

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

   (b) Random slopes and intercepts for site; random intercepts for doy nested within year

$$y_i = \alpha_{site[year[doy[i]]]} + \beta_{1site[i]} eT_i + \beta_{2site[i]} eP_i + \beta_{3site[i]} eT_i eP_i + \epsilon_i \tag{5}$$

$$\alpha_{site[year[doy]]} \sim N(\mu_{site[year]}, \sigma_{site[year]}) \tag{6}$$

$$\mu_{site[year]} \sim N(\mu_{sy}, \sigma_{sy}) \tag{7}$$

$$\mu_{sy} \sim N(\mu_s, \sigma_s) \tag{8}$$

$$\beta_{1site} \sim N(\mu_{\beta 1}, \sigma_{\beta 1}) \tag{9}$$

$$\beta_{2site} \sim N(\mu_{\beta 2}, \sigma_{\beta 2}) \tag{10}$$

$$\beta_{3site} \sim N(\mu_{\beta 3}, \sigma_{\beta 3}) \tag{11}$$

   (c) Random slopes and intercepts for site and year nested within site; random intercepts for doy. (I think we probably don't want this one...)

2. **Findings**:
   (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).

3. **Next steps and questions**:
   (a) Fit different models for different seasonal temperatures used in Question 2?
   (b) Decide on random effects structure
   (c) Models for air temperature

3 How does soil moisture affect phenology?

1. **Approach**: Compile ExPhen database (phenology data that goes with climate data in MC3E database). Fit models with soil moisture (SM), temperature (T), and interaction to phenology data (budburst, leafout, flowering, fruiting, senesence).
   (a) Exclude "lud" as a phenophases becuase we have much less data for this phase compared with lod.
   (b) Excluding conifers for now.

2. **Equations**Response variable (y) is day of year of the phenological event. PRedictors are measured air temperature (T) and soil moisture(SM). Random effects are species (random slopes and intercepts); site and for year nested within site (random intercepts).

$$y_i = \alpha_{sp[i],site[year[i]]} + \beta_{1sp[i]}T_i + \beta_{2sp[i]}SM_i + \beta_{3site[i]}T_iSM_i + \epsilon_i \tag{12}$$

$$\alpha_{sp} \sim N(\mu_{sp}, \sigma_{sp}) \tag{13}$$

$$\mu_{site[year]} \sim N(\mu_{sy}, \sigma_{sy}) \tag{14}$$

$$\mu_{sy} \sim N(\mu_s, \sigma_s) \tag{15}$$

$$\beta_{1sp} \sim N(\mu_{\beta 1}, \sigma_{\beta 1}) \tag{16}$$

$$\beta_{2sp} \sim N(\mu_{\beta 2}, \sigma_{\beta 2}) \tag{17}$$

$$\beta_{3sp} \sim N(\mu_{\beta 3}, \sigma_{\beta 3}) \tag{18}$$

3. **Findings**
   (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 sites and species.

4. **Next steps and questions**:

(a) What figures to make?

(b) How does soil moisture affect GDDcrit?

(c) Combine equations from Question 1 with equations from Questions 2 (at the annual scale) to answer: how much does 1 degree change in target temperature (eT) affect phenology, if this were the only effect of the experiment? Similarly, how much does 50% change in precipitation (eP) affect phenology, if this were the only effect of the experiment? And how big a change does each make acknowledging that they both change moisture and temperature together? We can do this by plugging in different values of eT (e.g., all 1 C, then try with all 2 C) and eP to calculate different outcomes of moisture and temperature which we can evaluate in the equations in Question 2 to assess changes in phenology.

(d) How do we do the above with centered models?

4 Does warming affect soil moisture and phenology similarly in experimental and non-experimental data?

1. Approach: Compile data from Duke (soil moisture, temp data) and Harvard Forest (soil moisture and O'Keefe phenology data). Think on best model and how to model soil moisture as a function of temperature (T, annual? seasonal?) and precipitation (P, annual? seasonal?). For now, y is daily moisture across multiple years and T is MAT and P is percent different than mean over available time series. We use this approach to make the observational data comparable to experimental data in Question 1 above.

$$y_i = \alpha_{doy[i]} + \beta_{1site[i]}T_i + \beta_{2site[i]}P_i + \beta_{3site[i]}T_iP_i + \epsilon_i \tag{19}$$

$$\alpha_{doy} \sim N(\mu_{doy}, \sigma_{doy}) \tag{20}$$

$$\alpha_{site[year]} \sim N(\mu_{sy}, \sigma_{sy}) \tag{21}$$

$$\mu_{sy} \sim N(\mu_s, \sigma_s) \tag{22}$$

$$\alpha_{sp} \sim N(\mu_{sp}, \sigma_{sp}) \tag{23}$$

2. **Next steps**:We can compare β_1,β_2, and β_3 in experiments and observations. We may not be able to look at the βs themselves to do this (for instance, if data are centered).

References

Ettinger, A. & Wolkovich, E. (2018). Microclimate from climate change experiments (MC3E). doi:10.5063/F1QV3JQR.

Figures

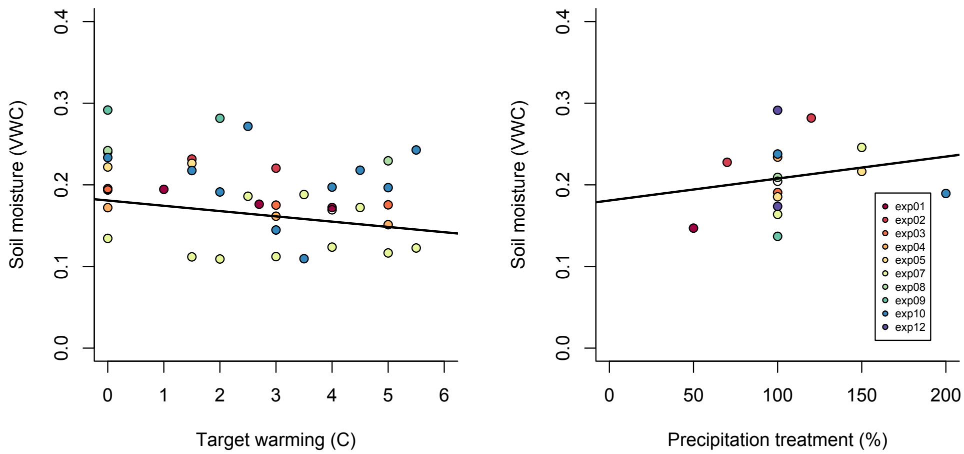

Figure 1: **Effects of target temperature and precipitation treatments on soil moisture.**

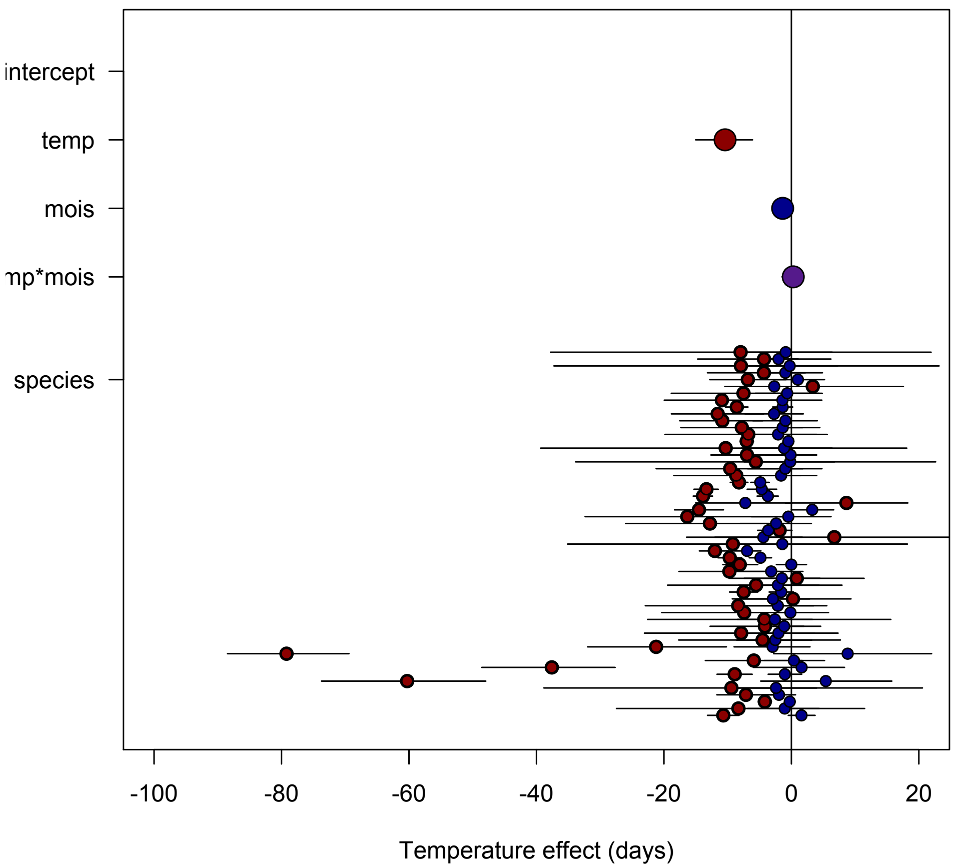

Figure 2: **Model coefficients from budburst model.**