Soil moisture interacts with temperature to affect plant phenology

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Abstract

Introduction

1. Phenology has shifted earlier with climate change. These shifts, which have occurred around the world, are generally attributed to warming temperature, since temperature is a well-studied driver of phenology. Chilling, forcing.

2. In addition to warmer temperatures, climate change is expected to alter precipitation patterns. Some places may get wetter, others may get drier. The ways that changes in precipitation will affect phenology has recieved less attention.

3. Tree water status can affect phenology, particularly in dry, tropical forests. Budburst,flowering and leaf drop phenology have also been related to tree water status in dry ecosystems (Essiamah & Eschrich, 1986; Reich & Borchert, 1984; van Schaik *et al.*, 1993).

4. Physiology and mechanisms for soil moisture to affect phenology. Budburst can be slowed by water stress through inhibiting cell elongation (Essiamah & Eschrich, 1986).

5. Climate change experiments offer a valuable tool to study climate change impacts on phenology, especially because they often manipulate precipitation, in addition to temperature, have been used to understand how global warming may affect phenology. Previous analysis of phenology in climate change experiments have generally focused on effects of warming.

6. Do we need to discuss discrepencies between observations and experiments?

7. Here we use two databases of experimental climate change and phenology data to understand how soil moisture affects plant phenology. We also compare phenological sensitivity to temperature and soil moisture in experiments to sensitivity in observational studies.

We ask three specific questions:

1. How do climate manipulations (target warming, precipitation manipulations) affect soil moisture?

2. How does soil moisture interact with temperature to affect phenology?

3. Does warming affect soil moisture similarly in experimental and non-experimental data?

Methods

Data: Experimental data from MC3E and ExPhen databases, observational data from Duke (soil moisture, temp data) and Harvard Forest (soil moisture and O'Keefe phenology data). Analysis:

1. How do climate manipulations affect soil moisture and temperature?

   (a) Fit a multilevel model: response variable is soil moisture (from experiments in MC3E database), explanatory variables are temperature, precipitation, and their interaction. Random slopes and intercepts for site; random intercepts only for doy nested within year. We the following equations to understand effects of experimental temperature (eT) and experimental preciptation (eP) treatments on soil moisture .

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

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

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

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

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

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

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

2. How does soil moisture affect phenology?

   (a) Fit models with soil moisture (SM), temperature (T), and interaction to phenology response data (budburst, leafout, flowering, fruiting, senesence). Data are from experiments (MC3E and ExPhen). Note: excluding conifers for now.

   (b) **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).

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

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

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

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

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

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

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

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

   (a) 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.

$$y_i = \alpha_{doy[i]} + \beta_{1site[i]} T_i + \beta_{2site[i]} P_i + \beta_{3site[i]} T_i P_i + \epsilon_i \quad (15)$$

$$\alpha_{doy} \sim N(\mu_{doy}, \sigma_{doy}) \quad (16)$$

$$\alpha_{site[year]} \sim N(\mu_{sy}, \sigma_{sy}) \quad (17)$$

$$\mu_{sy} \sim N(\mu_s, \sigma_s) \quad (18)$$

$$\alpha_{sp} \sim N(\mu_{sp}, \sigma_{sp}) \tag{19}$$

(b) We can compare β_1,β_2, and β_3 in experiments and observations.

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 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?**

Discussion

Conclusions

References

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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.

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Figures

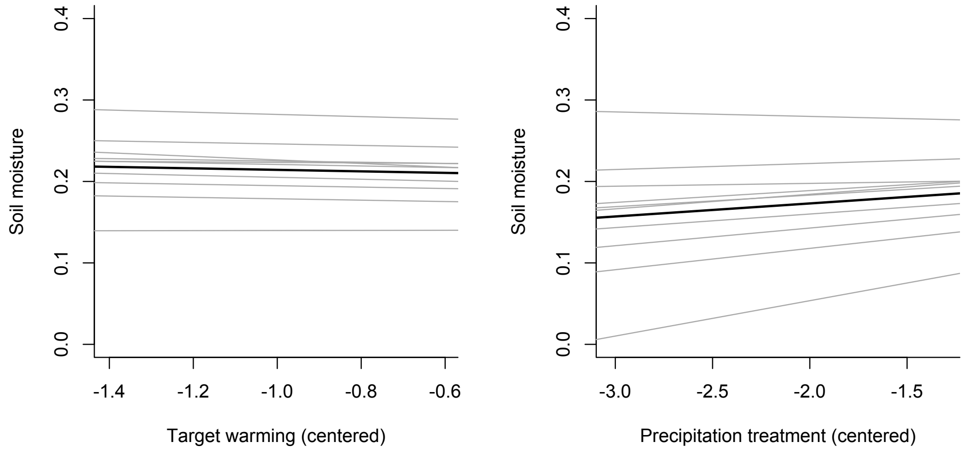

Figure 1: **Effects of target temperature and precipitation treatments on soil moisture.**

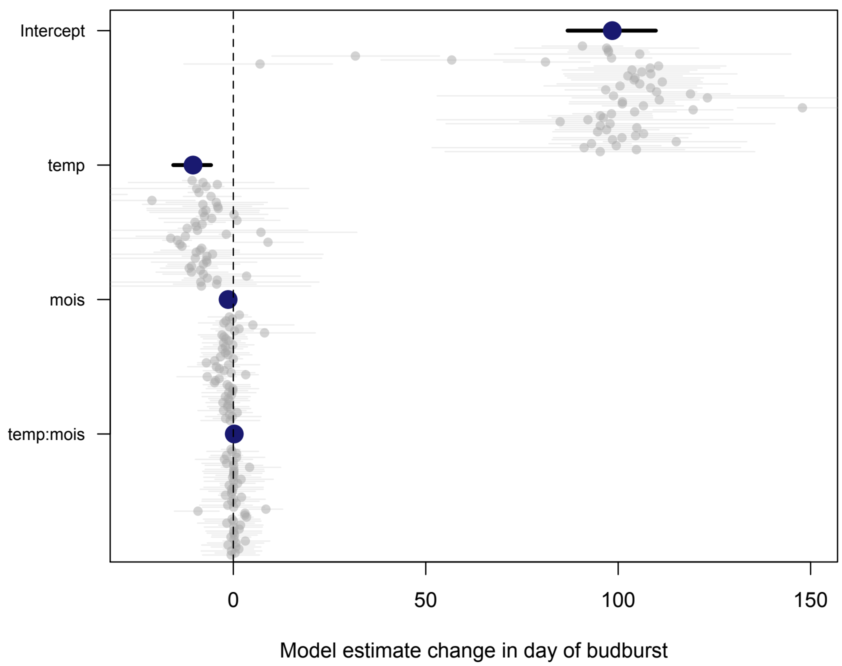

Figure 2: **Model coefficients from budburst model (with centered predictors).**