Phenology in climate change experiments

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Field experiments are critical tools for understanding biological responses to climate change

But, can we use them to accurately forecast future climate change-induced shifts in phenology?

LETTER

Warming experiments underpredict plant phenological responses to climate change

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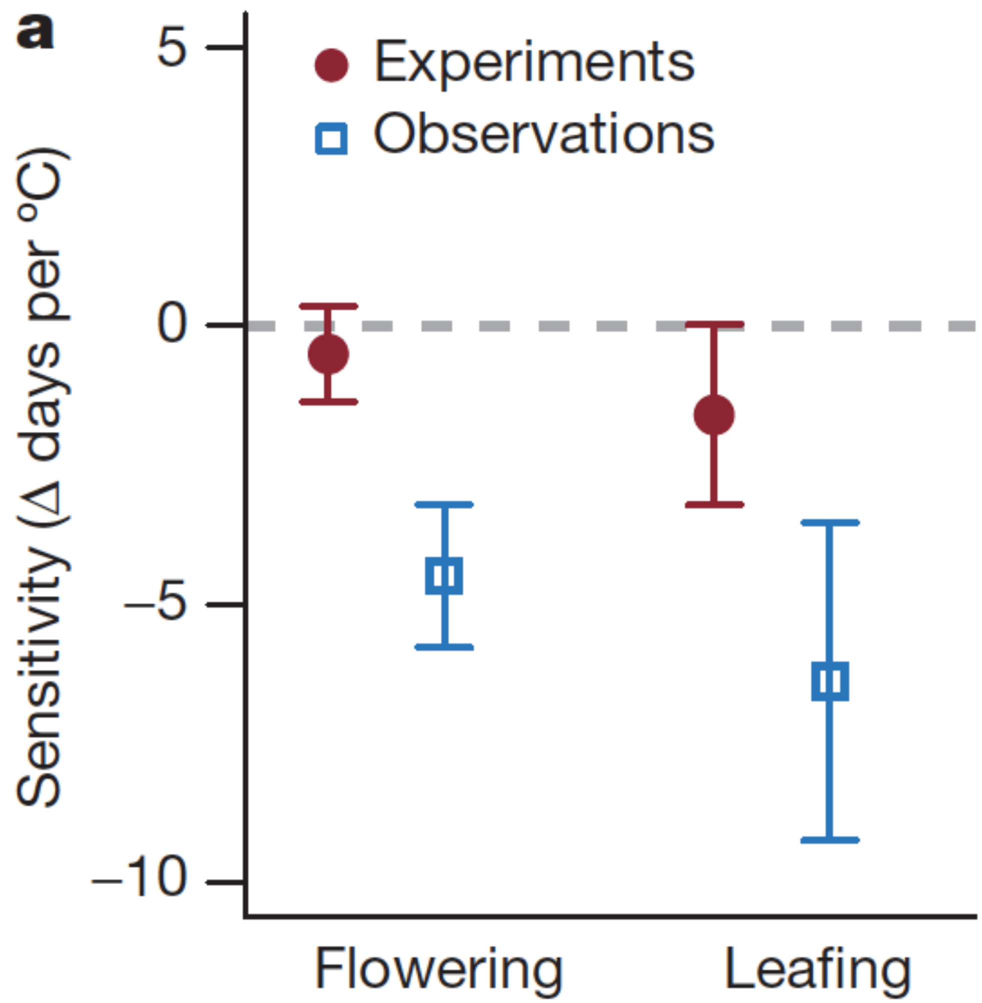
Warming experiments are increasingly relied on to estimate plant responses to global climate change[1,2]. For experiments to provide meaningful predictions of future responses, they should reflect the empirical record of responses to temperature variability and recent warming, including advances in the timing of flowering and leafing[3–5]. We compared phenology (the timing of recurring life history events) in observational studies and warming experiments spanning four continents and 1,634 plant species using a common measure of temperature sensitivity (change in days per degree Celsius). We show that warming experiments underpredict advances in the timing of flowering and leafing by 8.5-fold and 4.0-fold, respectively, compared with long-term observations. For species that were common to both study types, the experimental results did not match the observational data in sign or magnitude.

Warming experiments have been use climate conditions for more than 20 year the critical but little-tested assumption tha mental warming match long-term resp Testing this assumption is an importan utility of warming experiments for long-t tion. Recent studies have compared expe results at single sites[2,10], and one study foun in plant responses to warming[10]; however, proved more challenging.

Here we present two new spatially databases of plant phenology for 1,634 observations and short-term warming databases were developed specifically to

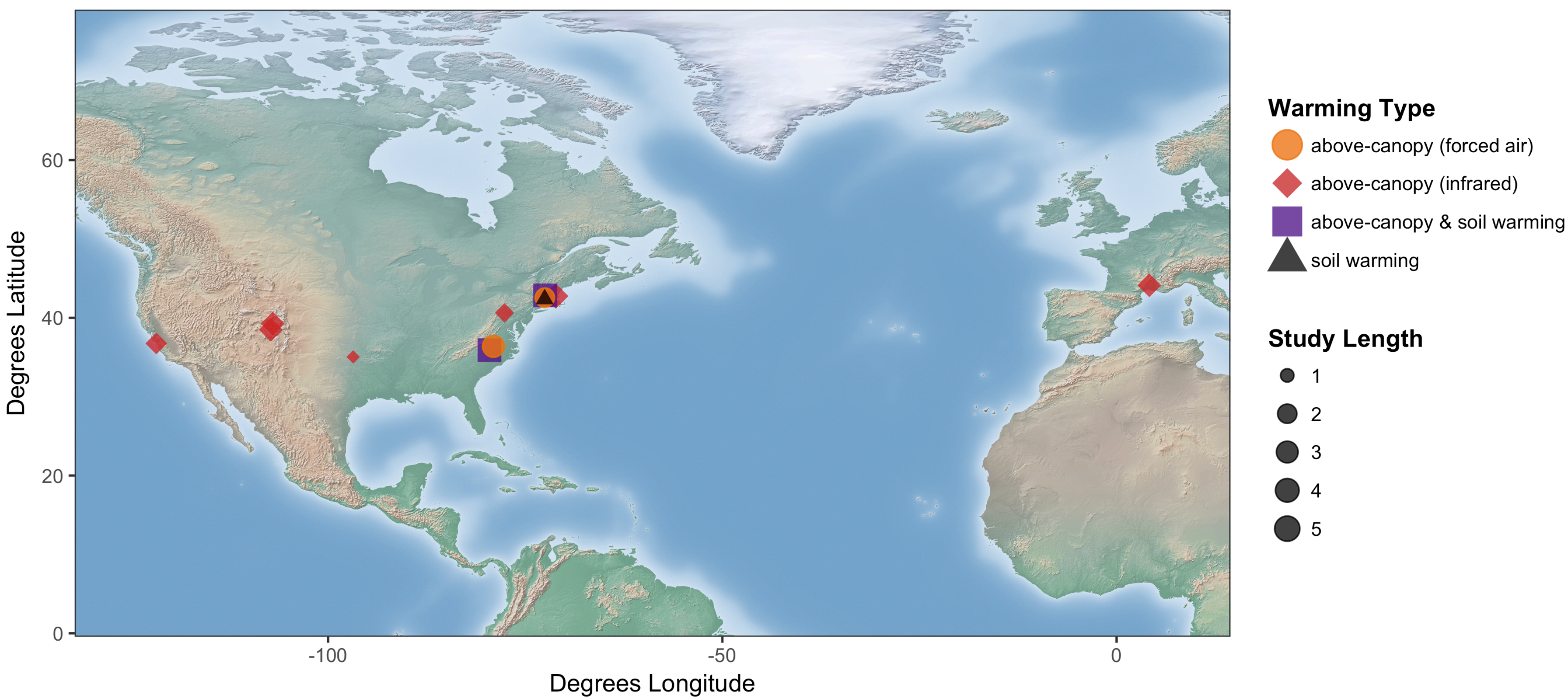


Wolkovich et al 2012

What is the underlying cause of this discrepancy?

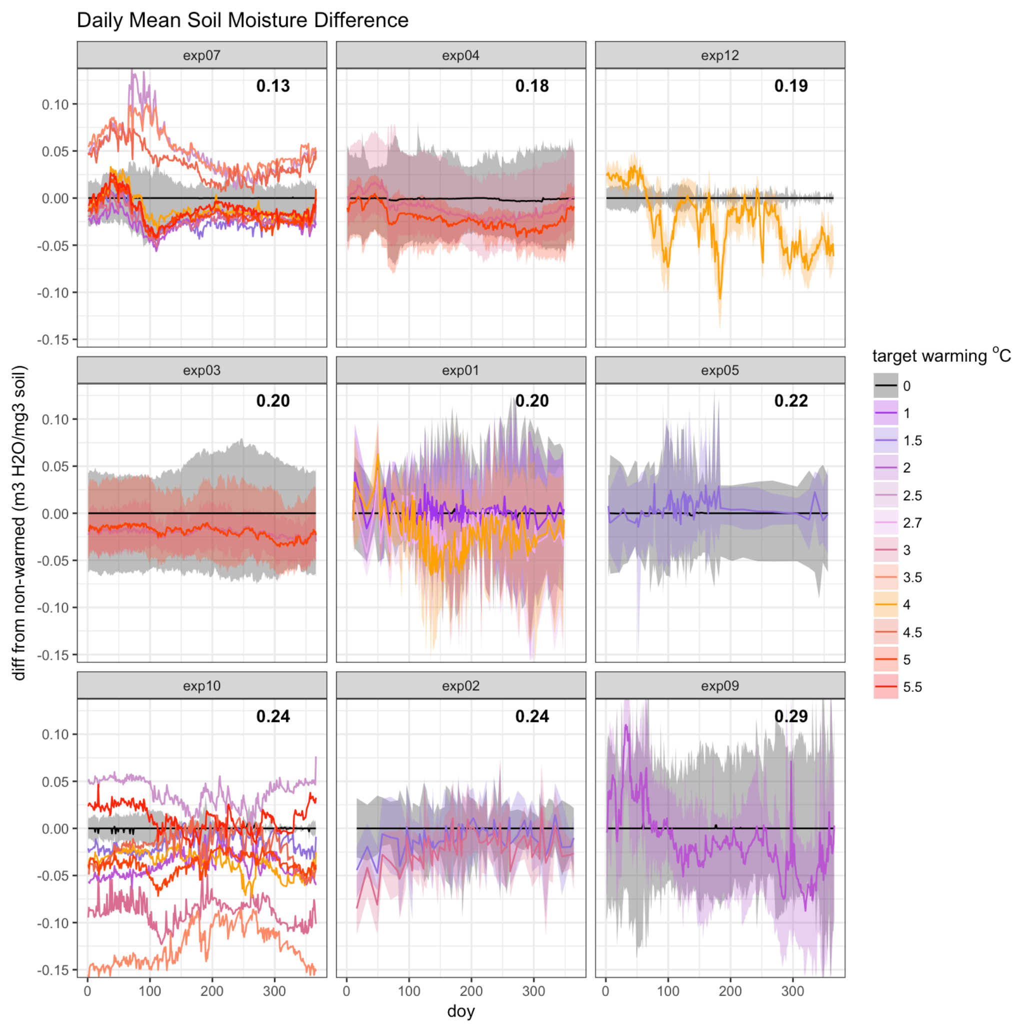
Hypothesis:
Experimental warming reduces soil moisture, which delays phenology.

Climate from Climate Change Experiments (C3E) Database



- 12 active warming experiments
- Daily climate data and phenology data

The C3E database has lots of detailed climate data:



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Current Approach: Address 2 questions:

1. How do experimental warming and precipitation treatments affect soil moisture?
2. How does soil moisture affect GDDcrit?

How do experimental warming and precipitation treatments affect soil moisture?

To understand how experimental warming and precipitation treatments affect soil moisture (y_i) I want to fit a hierachical model with 3 levels: one level for site, represented here by j; one level for year, represented here by k; and one level for day of year, represented here by l. β_1 is the warming treatment and β_2 is the precipitation treatment. I am also interested in their interactive effects. Each observation is i, and partial pooling on the intercept (α) only:

$$y_i = \alpha_{j[i]1} + \alpha_{k[i]2} + \alpha_{l[i]3} + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_1 \beta_2 X_{i1} X_{i2} + \epsilon_i \tag{1}$$

The multilevel parts of the model are:

$$\alpha_{j1} \sim N(\mu_{\alpha_1}, \sigma^2_{\alpha_1}) \tag{2}$$

$$\alpha_{k2} \sim N(\mu_{\alpha_2}, \sigma^2_{\alpha_2}) \tag{3}$$

$$\alpha_{l3} \sim N(\mu_{\alpha_3}, \sigma^2_{\alpha_3}) \tag{4}$$

How do experimental warming and precipitation treatments affect soil moisture?

In lmer:

```
lmer(soilmois~temp_cent*precip_cent +
(1|site)+ (1|year/doy))
```

OR:

```
lmer(soilmois~temp_cent*precip_cent +
(1|site)+ (1|year) + (1|doy))
```

How do experimental warming and precipitation treatments affect soil moisture?

In Stan:

How does soil moisture affect GDDcrit?

To understand how soil moisture affects GDDcrit(y_i) (the accumulated growing degree days on the day of a phenoogical event such as bud burst), I want to fit a hierachical model with 2 levels: one level for site, represented here by j; and one level for species, represented here by k; β_1 is soil moisture (averaged over the whole year- not sure if this is best). Each observation is i, and partial pooling could be on the intercept (α) only or on the slope and intercept. I'm not sure which is best....shown here for pooling on both slope and intercept for species, and intercept-only for site:

$$y_i = \alpha_{j[i]1} + \alpha_{k[i]2} + \beta_1 X_{k[i]1} + \epsilon_i \tag{5}$$

The multilevel parts of the model are:

$$\alpha_{j1} \sim N(\mu_{\alpha_1}, \sigma^2_{\alpha_1}) \tag{6}$$

$$\alpha_{k2} \sim N(\mu_{\alpha_2}, \sigma^2_{\alpha_2}) \tag{7}$$

$$\beta_{k1} \sim N(\mu_{\beta_1}, \sigma^2_{\beta_1}) \tag{8}$$

How does soil moisture affect GDDcrit?

In lmer:

```
gdd_lme4A<-lmer(cumgdd_air~sm + (1|site)+ (1|species),
REML=FALSE, data=expphen2)

#OR

gdd_lme4B<-lmer(cumgdd_air~sm + (sm|site)+ (sm|species),
REML=FALSE, data=expphen2)

#OR

gdd_lme4C<-lmer(cumgdd_air~sm + (sm|site/species),
REML=FALSE, data=expphen2)
```

How does soil moisture affect GDDcrit?

In Stan: