



Phenology in climate change experiments



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

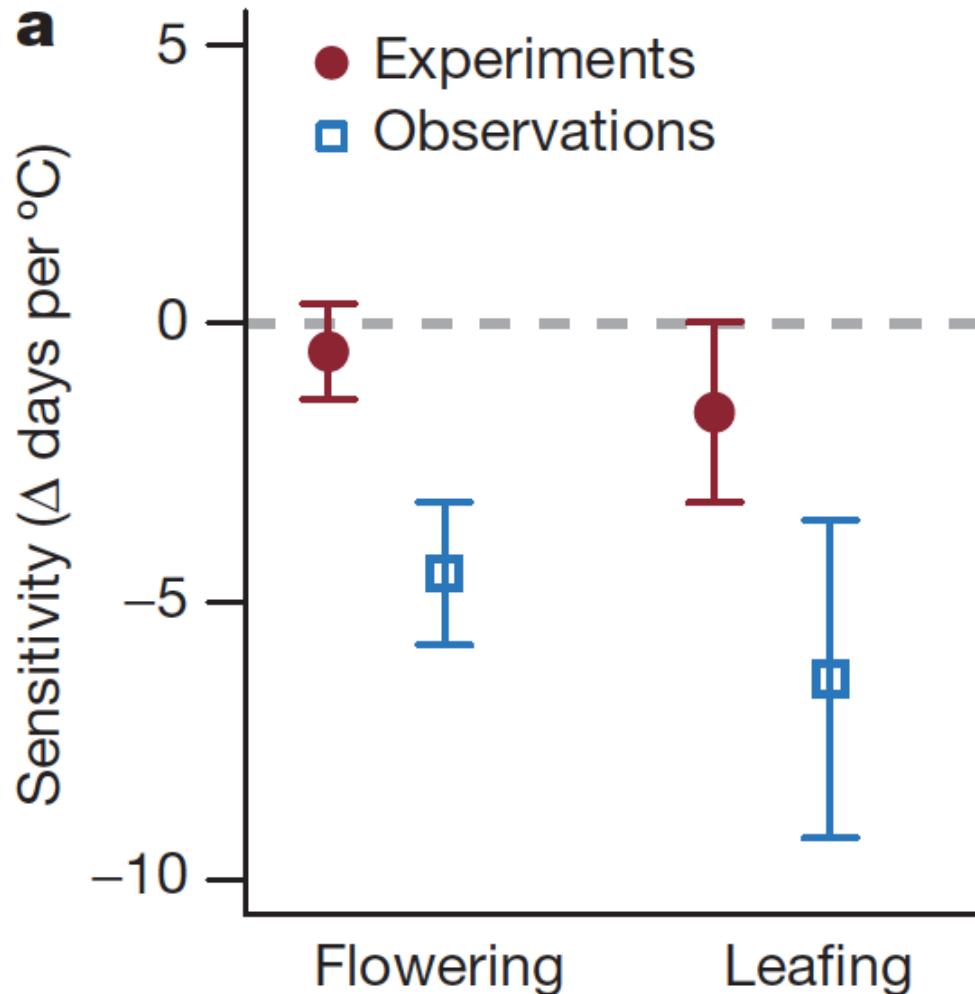
Warming experiments underpredict plant phenological responses to climate change

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Warming experiments are increasingly relied on to estimate plant responses to global climate change^{1–3}. 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^{4–5}. 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 used to predict climate conditions for more than 20 years. However, the critical but little-tested assumption that warming experiments accurately predict long-term responses to warming has not been tested. Testing this assumption is an important step toward improving the utility of warming experiments for long-term climate change projections. Recent studies have compared experimental results at single sites^{2,11}, and one study found that warming experiments underpredicted changes in plant responses to warming¹⁰; however, this study proved more challenging.

Here we present two new spatially explicit databases of plant phenology for 1,634 species. The observational database includes short-term warming experiments and long-term observational data from field surveys. The experimental database was developed specifically to



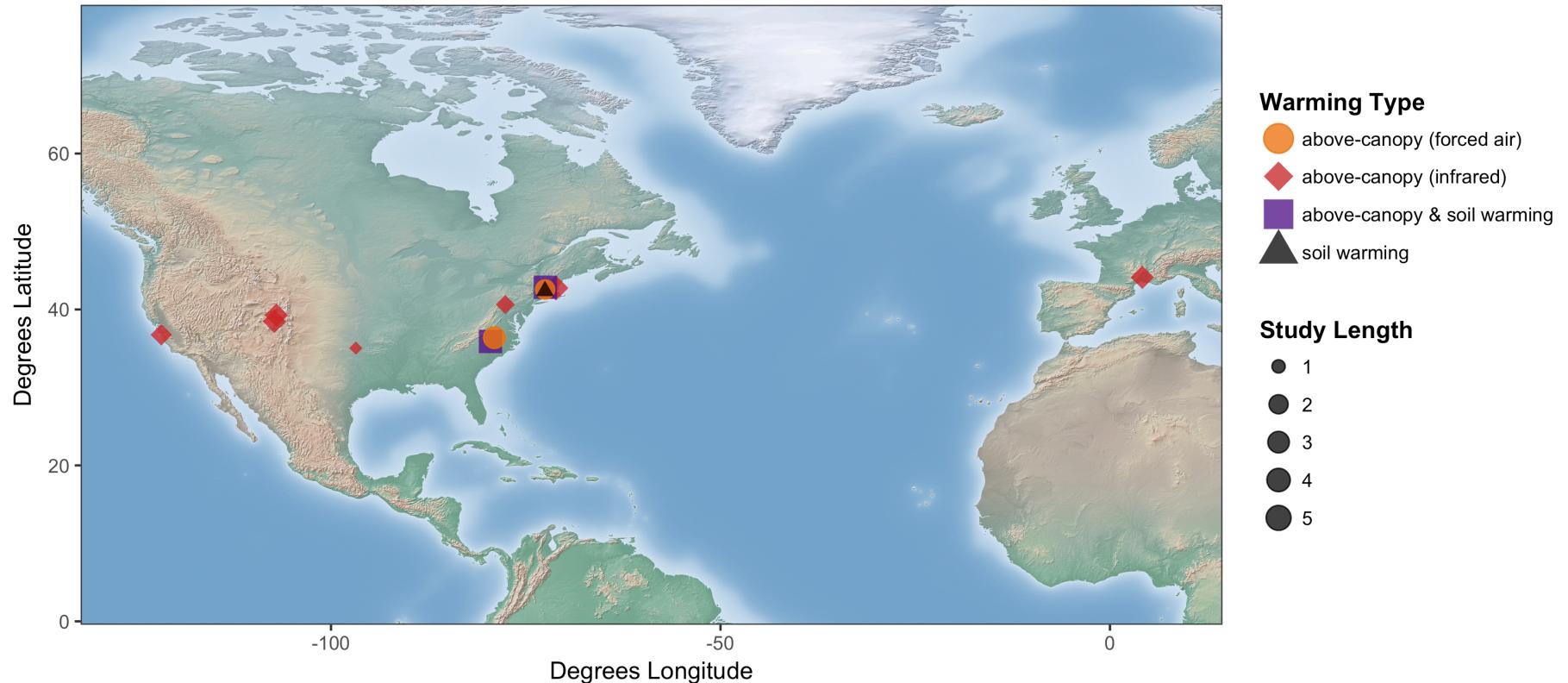
Wolkovich et al 2012

What is the underlying cause of this discrepancy?

Hypothesis:

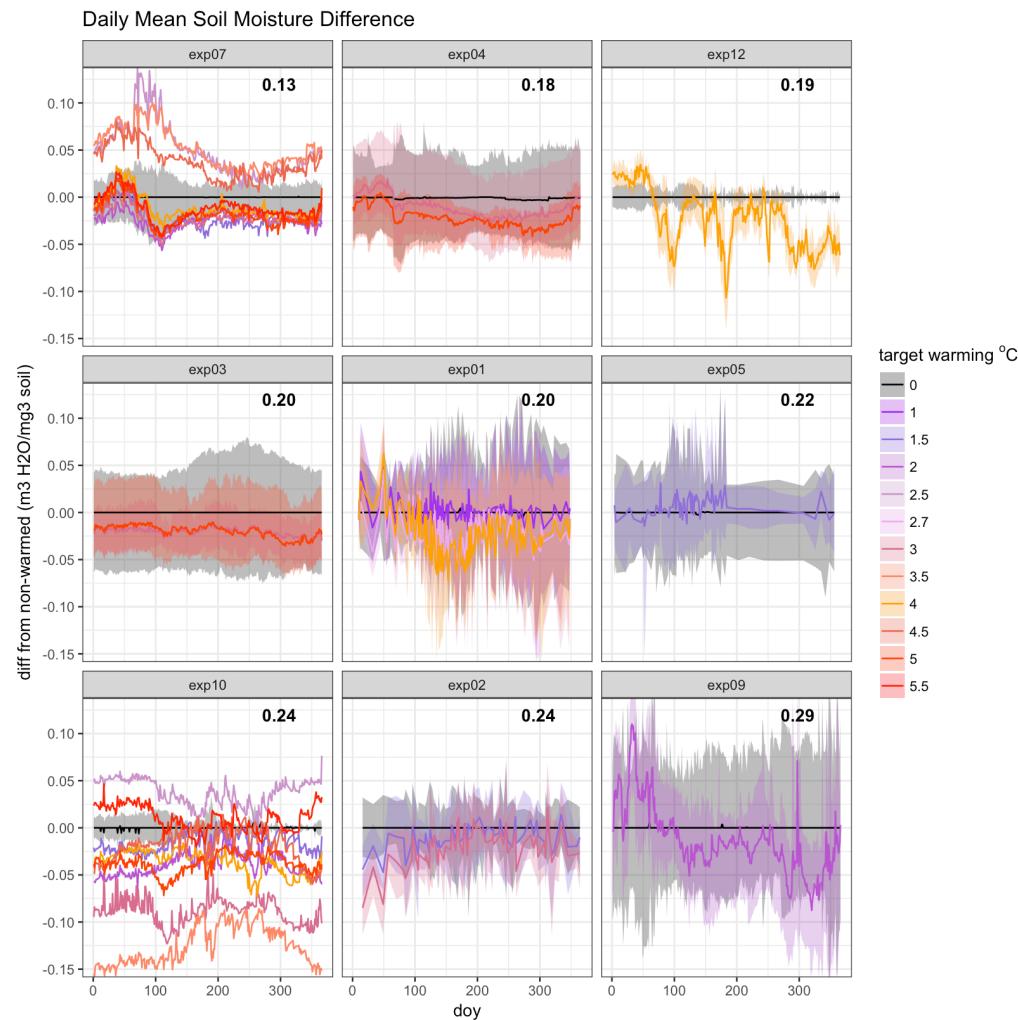
Experimental warming reduces soil moisture, which delays phenology.

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 hierarchical 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:

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

The multilevel parts of the model are:

$$\alpha_{j1} \sim N(\mu_{\alpha_1}, \sigma_{\alpha_1}^2) \quad (2)$$

$$\alpha_{k2} \sim N(\mu_{\alpha_2}, \sigma_{\alpha_2}^2) \quad (3)$$

$$\alpha_{l3} \sim N(\mu_{\alpha_3}, \sigma_{\alpha_3}^2) \quad (4)$$

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: