How do climate change experiments actually change climate?

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Supplemental Materials

To realize the forecasting potential of climate change experiments, a nuanced understanding of how climate change experiments actually alter climate is critical. Here, we use plot-level daily microclimate data from 12 climate change experiments that manipulate temperature and precipitation to demonstrate the direct and indirect ways in which environmental conditions are altered by active warming technologies. We then highlight the challenges associated with quantifying and interpreting biological responses to these climate manipulations, and using these interpretations to forecast more widespread responses to contemporary climate change. Finally, we use findings from our synthesis to make recommendations for future climate change experiments. We focus on in situ active warming manipulations, because recent analyses indicate that active warming methods are the most controlled, consistent, and "true to climate change predictions" (Kimball, 2005; Kimball *et al.*, 2008; Aronson & McNulty, 2009; Wolkovich *et al.*, 2012). The data we use were collected between 1991 and 2014 from North American and European climate change experiments and have been merged into a new, publicly available Climate from Climate Change Experiments (C3E) database (see Supplemental Materials for details).

We carried out a full literature review to identify all active field warming experiments then obtained daily (or sub-daily) climate data from as many as possible (we obtained data for 12/XX total identified experiments. We are thus able to show, for the first time, the complex ways that climate is altered by active warming treatments, both directly and indirectly.

References

Kimball, B. Theory and performance of an infrared heater for ecosystem warming. *Global Change Biology* **11**, 2041–2056 (2005).

Kimball, B. A. *et al.* Infrared heater arrays for warming ecosystem field plots. *Global Change Biology* **14**, 309–320 (2008).

Aronson, E. L. & McNulty, S. G. Appropriate experimental ecosystem warming methods by ecosystem, objective, and practicality. *Agricultural and Forest Meteorology* **149**, 1791–1799 (2009).

Wolkovich, E. M. *et al.* Warming experiments underpredict plant phenological responses to climate change. *Nature* **485**, 494–497 (2012). PT: J; UT: WOS:000304344500041.

Supplemental Tables

	Chisq	Df	Pr(>Chisq)
(Intercept)	153.303	1.000	0.000
temptreat	463.345	3.000	0.000
block	3.955	2.000	0.138
temptreat:block	44.881	6.000	0.000

Table 1: Effects of warming vary by block, as summarized by a linear mixed effects model of mean soil temperatures, with year and site as nested random effects

	Chisq	Df	Pr(>Chisq)
(Intercept)	1455.294	1.000	0.000
temptreat	126.093	3.000	0.000
year	16.676	1.000	0.000
temptreat:year	61.646	3.000	0.000

Table 2: Effects of warming vary by year, as summarized by a linear mixed effects model of mean soil temperatures, with year and site as nested random effect

The below are all tables related to the sham and ambient comparisons. i want to include more information in the tables, probably (random effects- intercepts, and variance), and most will be in the supplemental (perhaps just the mean soil and air in the main text?) .

	Estimate	Std. Error	t value
(Intercept)	12.691	1.648	7.699
controltypeambient	-0.311	0.092	-3.380

Table 3: Summary of linear mixed effects model testing difference in mean air temperatures of structural controls compared with ambient controls (i.e.with no control chambers or warming infrastructure in place). The model included a fixed effect of control type and an intercept-only random effect of studysite to account for study and measurement, as well as environmental, differences.

	Estimate	Std. Error	t value
(Intercept)	11.315	1.373	8.243
controltypeambient	0.450	0.067	6.682

Table 4: Summary of linear mixed effects model testing difference in mean soil temperature (at the shallowest depth measured) of structural controls compared with ambient controls. The model included a fixed effect of control type and an intercept-only random effect of studysite to account for study and measurement, as well as environmental, differences.

	Estimate	Std. Error	t value
(Intercept)	7.178	1.397	5.138
controltypeambient	-0.343	0.092	-3.744

Table 5: Summary of linear mixed effects model testing difference in minimum air temperatures of structural controls compared with ambient controls (i.e.with no control chambers or warming infrastructure in place). The model included a fixed effect of control type and an intercept-only random effect of studysite to account for study and measurement, as well as environmental, differences.

	Estimate	Std. Error	t value
(Intercept)	10.503	1.343	7.823
controltypeambient	0.386	0.068	5.693

Table 6: Summary of linear mixed effects model testing difference in minimum soil temperature (at the shallowest depth measured) of structural controls compared with ambient controls. The model included a fixed effect of control type and an intercept-only random effect of studysite to account for study and measurement, as well as environmental, differences.

	Estimate	Std. Error	t value
(Intercept)	18.204	1.915	9.504
controltypeambient	-0.278	0.097	-2.851

Table 7: Summary of linear mixed effects model testing difference in maximum air temperatures of structural controls compared with ambient controls (i.e.with no control chambers or warming infrastructure in place). The model included a fixed effect of control type and an intercept-only random effect of studysite to account for study and measurement, as well as environmental, differences.

	Estimate	Std. Error	t value
(Intercept)	13.602	1.674	8.125
controltypeambient	0.588	0.076	7.770

Table 8: Summary of linear mixed effects model testing difference in maximum soil temperature (at the shallowest depth measured) of structural controls compared with ambient controls. The model included a fixed effect of control type and an intercept-only random effect of studysite to account for study and measurement, as well as environmental, differences.

Supplemental Materials

Description of database

Search terms used and criteria for selecting the 12 studies that we ended up with. Climate variables included, and where database and metadata are housed.

Supplemental Methods

Statistical methods

Need description of block and year analyses (see Tables 1 and 2) To account for differences in the type of warming and other unmeasured site/study differences (e.g. forced air for Ellison and Marchin; heating cables for Farnsworth and ??), we fit linear mixed effects models with random effect of study-site. Response variables were daily soil or air temperature (models with daily mean, minimum, and maximum were all fit) and , and the explanatory variable was control type (infrastructure or ambient). We used a random intercepts structure, so that the mean temperature was allowed to vary across study-sites. We fit models across the entire year, as well as separate models for each month to examine if effects varied seasonally.

Random stuff moved out of the main text

We also found higher coefficients of variation in air temperatures in actively warmed plots, compared with controls at the same sites in the same years. This was true for both minimum and maximum air temperatures (Figure 1)

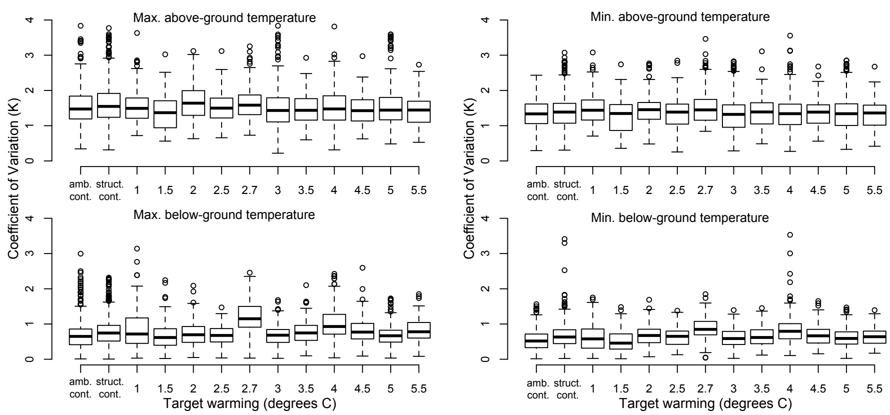

Figure 1: Ambient controls have reduced variation, compared with structural controls and nearly all warming treatments. I'm not happy with this figure- I've tried so many different ways of showing the (small but) significant differences in temperature range/variance among ambient controls, structural controls and warming treatments, in addition to the statistical analyses described in the text and supplement. Question for everyone (Lizzie/Ben/Miriam/Ann Marie/Aaron/Yann/Isabelle/Jeff/Christy): I need help with ideas for other ways to show this, or thoughts on if the point should be dropped, since the differences are minor and hard to see.