How do climate change experiments actually change climate?

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1 Aim

The aim is to write a Concept/Synthesis Paper about maximizing benefits of field-based climate change experiments by improved understanding of how climate is altered by these experiments. Experiments need to report what climate variables are modified by their experiment and how. This is particularly valuable for improving our understanding of biological impacts of climate change.

2 Introduction

Experimental in situ climate manipulations offer several advantages to understanding biological impacts of climate change: (controlled, relative speed- i.e. multiple manipulations can be conducted simultaneously, can hit higher temps such as those forecastest, can do them in places where other data collection is hard).

These advantages come at a cost, however. Experimental in situ climate manipulations are logistically challenging, and expensive.

Problem: People often want to extrapolate warming experiments to real life to understand (and forecast) biological impacts of climate change. Even in cases when this is not the explicit goal, it would be incredibly useful to be able to apply knowledge gained from these experiments to improve our understanding and forecasting of how anthropogenic warming will affect species' performance and distributions. However, our ability to make this application is limited because a detailed assessment of exactly how experimental warming treatments alter climate, and the extent to which these manipulations accurately model the real world, is lacking.

3 Experimental climate change vs. real climate: how do they compare?

3.1 Structures

The experimental structures themselves alter temperature, in ways that are not generally examined or reported in experimental warming studies. Compare sham and ambient data on temperature (mixed effects models).

- Soil temperature is LOWER in the shams, compared with the ambient air (Figure 1).

- Air temperature is HIGHER in the shams, compared with the ambient air (Figure 1).
- The pattern was consistent for min and max air and soil temperatures, as well (Figure 2).

3.2 Space

There is spatial variation in experimental warming effects, such that extrapoloation of experimental warming to forecast climate change impacts may not be a straightforward space-for-time subsitution.

- Analysis of plot vs. block level variation vs. treatment effects. Lizzie is working on this.
- Documented variation in warming within plots? (This is known for open-top chambers)

3.3 Time

In addition, there is often temporal variation in experimental warming, and this variation may be divergent from real (i.e. non-experimental) temperature pattersn so it should carefully be considered in extrapolating experimental warming to future climate change impacts.

- Seasonal variations in experimental warming effects (plots over time; Christy is working on this?).
- Daily variations in experimental warming effects (Tmin vs Tmax)
- Compare these seasonal and daily variations to observational data (i.e. plot seasonal and daily variations for warmest vs coldest years)
- Treatments arenâĂŹt applied consistently over the year- IR heaters can't apply consistent warming throughout the year, and some warming experiments turn off warming during some seasons (e.g. Clark et al.).

3.4 Secondary effects of warming

Temperature interacts with many other climatatic and nonclimatic factors to alterthe abiotic environment.

- Effects of experimental warming on soil moisture (Figure 3, and Miriam's analysis)
- Effects of experimental warming on air humidity (use Isabelle's data?).

4 Biological Implications

We have laid out several ways in which experimental warming alters more than simply the mean temperature. We argue that these largely unintended alterations are important for scientists to fully understand and report in their research because they are likely to have biological implications.

Examples:

- Plant phenology: likely to be altered in opposing ways by the increased air temperatures and decrease soil moisture/temperature, cite Wolkavich et al's earlier work finding discrepency between observation and experimental phenology responses to warming.

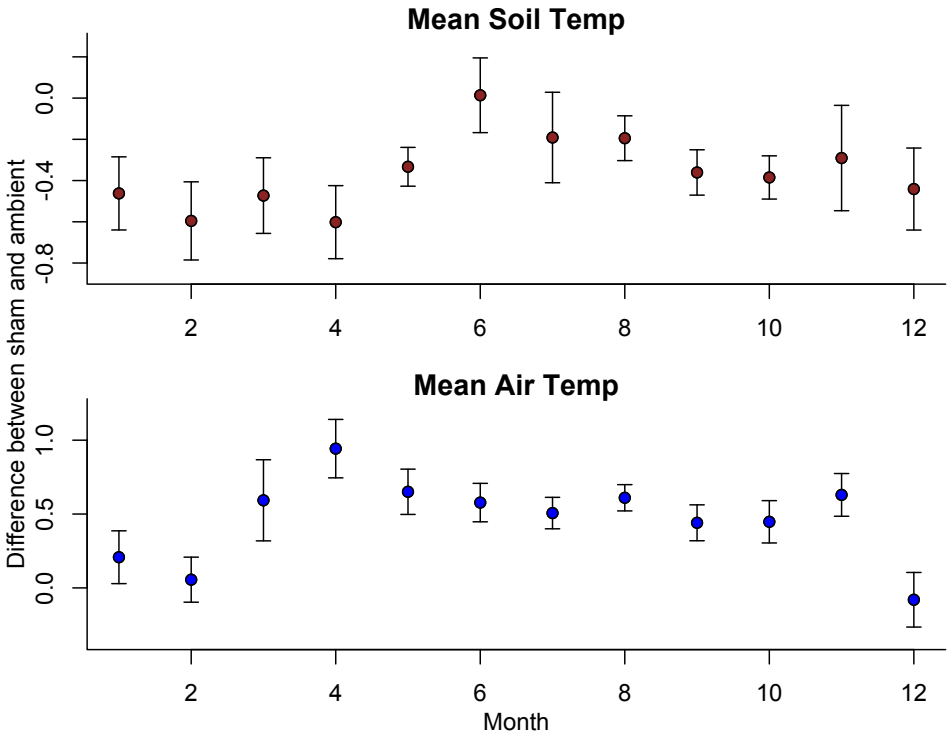

Figure 1: Difference between mean temperature in sham controls compared with ambient controls, with no sham chambers/warming infrastructure. Fixed effects from a mixed effects model are plotted in the above graph (see shamvambient.R for details). The same pattern is visible with simple box plots of ambient vs sham as well, but there are different magnitudes of differences among sites (aka studies), so i wanted to account for this statistically. Temperature data for both shams and ambient controls existed for soil in five studies, all of which are located at Harvard or Duke (clarkduke, clarkharvard,ellison,farnsworth, and marchin), and for air in only four of these studies (clarkduke, clarkharvard, ellison, and marchin).

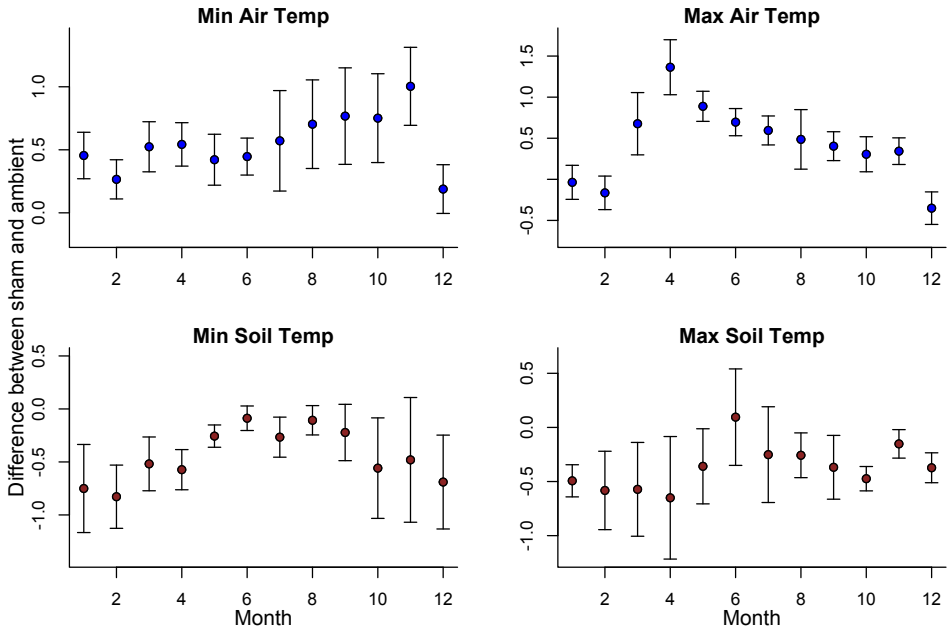

Figure 2: Difference between min and max temperature in sham controls compared with ambient controls, with no sham chambers/warming infrastructure. Fixed effects from the a mixed effects model are plotted in the above graph (see shamvambient.R for details).

- Soil respiration or other microbe studies?
- Plant growth- photosynthesis and transpiration are likely to be altered in opposing ways by the increased air temperatures and decrease soil moisture/temperature
- Other ideas?

5 Recommendations for future climate change experiments

The warming effects we describe are not meant to be criticisms or to imply that experimental warming studies are not worthwhile. On the contrary, we believe that climate change experiments provide invaluable information about biological responses to warming. We also believe that we need to more fully explore the ways in which these warming experiments are altering climate, as it is clearly not simply shifting the mean. Here we describe a few recommendations to improve implementation, interpretation, and communication of future climate change experiments.

- Include sham and ambient controls, and collect, use, and report data collectedwithin them.
- Carefully consider and report the timing of warming treatment applied, including exact start and end dates within and across years.
- Collect climate data at least twice daily, and ideally hourly; report these data, in particular, variations in daytime and nighttime and season variations in climate variables,
- Report the number and cause of missing data points for climate, especially those collected in warming treatments. For example, are data missing because the heaters went out, or because rodents at the sensors?
- Consider implementing and following community standards for reporting climate data (and phenology -Chuine et al. 2017)
- Construct regression designs to examine possible nonlinear responses to warming
- Publish data with good, useful metadata!

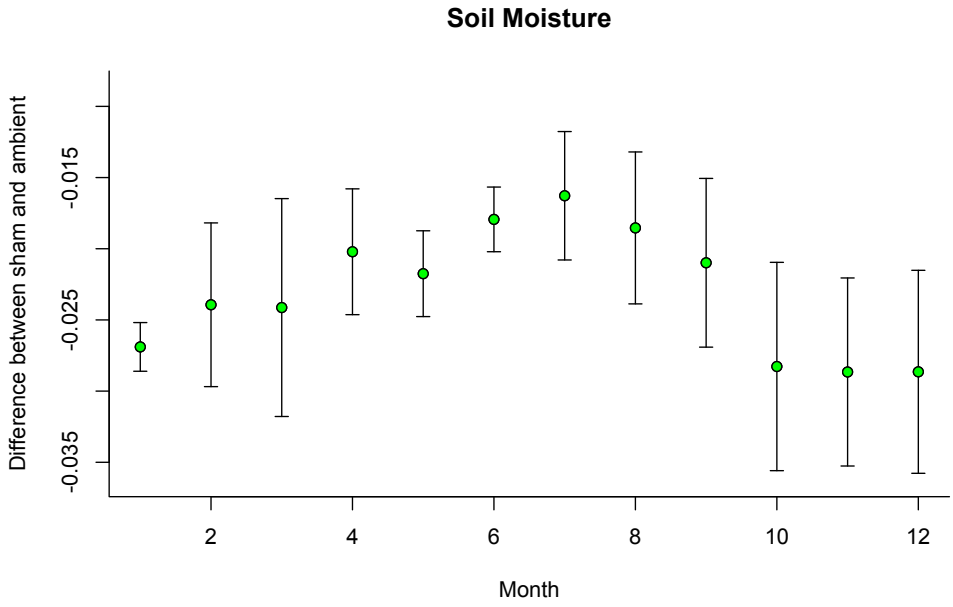

Figure 3: Difference between mean soil moisture in sham controls compared with ambient controls, with no sham chambers/warming infrastructure. Fixed effects from a mixed effects model are plotted in the above graph (see shamvambient.R for details).