Scaling climate change experiments across space and time

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Observations and experiments in terrestrial ecosystems are important tools for obtaining a fundamental understanding of plant and ecosystem responses to changing climate, and for informing model design and parameterization. Models can complement empirical research by providing access to temporal and spatial scales that are otherwise inaccessible. Thus, close communication between modellers and empiricists is beneficial to both communities, and can facilitate the incorporation of the observed phenomena and processes into the models (Beier, 2004; Rustad, 2008). This workshop, co-hosted by ClimMani (Climate Change: Manipulation Experiments in Terrestrial Ecosystems) and INTERFACE (Integrated Network for Terrestrial Ecosystem Research on Feedbacks to the Atmosphere and ClimateE), brought together empiricists and modellers to report on the current state of ecosystem research and discuss how future observations and in situ experiments could best inform the development of global-scale models relevant to climate change research.

The workshop focused on four themes:
- Scaling from small plots to landscapes and regions: what works, and what doesn’t?
- What have we learned from work on elevational and environmental gradients?
- Drivers of biome shifts: making small-scale measurements of disturbance, tipping points, thresholds and mortality relevant for large-scale models.
- Trait responses to environmental change: maximizing the benefits of trait information and moving from static to dynamic traits.

What is scaling?
‘Without a sound theoretical and conceptual background, the solution of problems (observations and experiments) will fail.’

Carl Beierkuhnlein (University of Bayreuth, Germany)

Observations and experiments typically focus on drivers and responses at relatively small scales. Scaling the information from these plot-level experiments to landscape- or global-scale models operating over decades or centuries provides a significant challenge. At the workshop, Carl Beierkuhnlein (University of Bayreuth, Germany) classified three categories of scales in studies of nature: spatial (e.g. distance, autocorrelation, heterogeneity and homogeneity), temporal (e.g. history, intra- and interannual variability, short-term and long-term events) and ecological (e.g. species, communities, ecosystems). He suggested that experiments should be designed for upscaling not only of spatial aspects, but also of temporal and ecological scales for broad generalization of the results. For instance, the use of the big-leaf approach in modelling of carbon uptake can be viewed as an example of ecological upscaling.

Understanding ecosystem response to climate change

Well-designed manipulation experiments and gradient studies can further our understanding of variability in ecological responses to climate change. For instance, free-air CO2 enrichment (FACE) experiments provided knowledge on ecosystem response to changing atmospheric CO2 concentrations that would otherwise not have been gained in such a time frame (Ainsworth & Long, 2005). Introducing a set of grassland elevated CO2 and drought experiments conducted in Texas and the Mojave Desert (USA), Philip Fay (Agricultural Research Service, USA) suggested that local soil types and regional climate are two important sources of spatial variability driving ecosystem responses to CO2 enrichment (Fay et al., 2012). Experimental manipulations are typically ‘bringing climate change to the soil’, but Michael Zimmerman (University of Natural Resources and Life Sciences, Vienna, Austria) presented translocation experiments as an alternative, ‘bringing climate change to the soil’. Translocations along latitudinal and/or altitudinal gradients can simulate changes in environmental conditions, such as temperature, thereby facilitating our understanding of the climate change responses of soil carbon and nutrients, as well as of microbial community composition and activity. Christian Körner (University of Basel, Switzerland) noted that most soil temperature manipulation studies are established as step changes of temperature, while past and current climate changes are more gradual. Step change experiments may not be able to address accurately the important questions of plant and microbial acclimation under changing environmental conditions.

Existing datasets (e.g. FLUXNET) can be used to validate and enhance ecosystem and Earth system models. Two examples were presented using large datasets to improve global models. Melanie Hartman (Colorado State University, USA) used environmental gradient datasets (e.g. LIDET data) to evaluate the description of biogeochemical processes within the Community Land Model (Bonan et al., 2013). She showed that there is a discrepancy between laboratory-derived decomposition rates and those measured in field experiments. Simon Scheiter (Biodiversity and Climate Research Centre, Germany) developed aDGVM2, a trait-based dynamic global vegetation model (DGVM) (Scheiter et al.,...
in order to improve the representation of functional diversity and take advantage of trait databases such as TRY (Kattge et al., 2011). Caroline Farrior (Princeton University, NJ, USA) recommended developing tractable models by adding mechanistic complexity to a simple model to validate descriptions of processes and improve predictive capacity (Dybzinski et al., 2011). Large-scale datasets are a great resource for model validation, but more effort is needed, with the help of experiments, to identify and understand the mechanistic effects of climate change on ecological processes for successful upscaling.

Ecological response to extreme climate events

‘Studies of climate extremes, even unrealistic ones, can teach us about processes and potentially about thresholds and tipping points.’

José Grünzweig (The Hebrew University of Jerusalem, Israel)

In recent years, climate change research has increasingly acknowledged the importance of extreme events as significant components of climate change (IPCC, 2007). This provides an additional and significant challenge in both experimentation and modelling. While we expect an extreme climatic event to result in an extreme ecological response, in some cases it may result in a ‘normal’ or moderate ecological response. Extending the duration of experiments may help to identify the conditions that lead to each type of response; also, it is necessary to bear in mind that ‘extremeness’ of climatic conditions is a relative term that needs to be placed in the context of both ecological thresholds and long-term climatic records (Hegerl et al., 2011).

Melinda Smith (Colorado State University, USA) showed how extreme drought dramatically reduced primary production at the Konza Prairie Long-Term Ecological Research site (Kansas, USA), and that the system then recovered rapidly; she hypothesized that ecosystems exposed to extreme climatic events can experience rapid or slow recovery, or undergo state changes, depending in large part on how species composition responds (Smith, 2011). José Grünzweig (The Hebrew University of Jerusalem, Israel) suggested that plants change strategies with increasing aridity, as indicated by shifts in the values of foliar traits along a precipitation gradient in the Levant, in the southeastern Mediterranean. Grünzweig also promoted the use of extreme manipulations for identifying ecological ‘tipping points’. Chelsea Arnold (University of California at Merced, USA) observed such a tipping point in the meadows of Yosemite National Park (USA); an extreme drought altered the soil structure, causing irreversible loss of soil permeability and porosity, leading to changes in plant productivity, species diversity and distribution, and increases in decomposition and soil respiration. William Parton (Colorado State University, USA) reminded the group that the challenge in scaling the extreme events is not in understanding the driver, but in understanding whether the response is going to be the same every time. Therefore, research design in extreme events should push the boundaries to gain the most knowledge about the response and recovery.

Plant trait responses to environmental change

An ecosystem’s potential to be resilient to extreme events could be viewed through the prism of inter- and intraspecies biodiversity. However, existing models do not capture the complexity of plant responses under changing climate, partially due to their static Plant Functional Type (PFT)-based approach. Trait variability can serve as a basis for more flexible representation of vegetation in DGVMs (Van Bodegom et al., 2012), as was shown by Simon Scheiter and Peter van Bodegom (VU University Amsterdam, the Netherlands). Jeanne Osnas (University of Florida, USA) warned that careful attention is needed when using mass- or area-normalized leaf trait relationships, and suggested representing functional diversity in models via a two- or three-axis continuum that includes specific leaf area, leaf longevity and possibly the first principal component of normalization-independent quantities of traits such as nitrogen (N) and phosphorus (P) concentrations, maximum photosynthetic rate and dark respiration (Osnas et al., 2013); this issue was also discussed recently by Lloyd et al. (2013) and Westoby et al. (2013).

Jordi Sardans (Universitat Autònoma de Barcelona, Spain) discussed how plants growing under different climates adapt their metabolism, and how anthropogenic shifts in global N and P cycles alter ecosystem function and biodiversity (Rivas-Ubach et al., 2012). A longer-term evolutionary prospective taken by William Hoffmann (North Carolina State University, USA) demonstrated the need to account for phenomena such as water deficit, nutrient deficiencies and seasonal flooding, among others, to robustly simulate vegetation and the effects of recurring fires in savannas (Hoffmann et al., 2012). The incorporation of trait-based approaches into global models might help to better capture dynamic plant responses in a changing climate.

Future directions

The participants outlined the limitations of scaling in past and present climate change research, but also proposed several future directions to overcome these limitations. First, empiricists need to design experiments while keeping in mind spatial, temporal and ecological scales in order to provide the needed or wanted mechanistic understanding of ecological response to climate change. Modelling should become an essential part of such multifactorial studies to both guide experimental decisions and allow them to be evaluated by empirical results. Second, in order to better understand recovery trajectories of ecological responses after extreme climate events, experimental treatments need to push beyond the limits of extreme conditions. However, it is recognized that such studies would have to extend beyond present research funding cycles of 3 yr. Commitment to investment in research infrastructure and funding of long-term programmes (e.g. ICOS and NEON) becomes crucial if progress is to be made in the study of extreme climate and ecosystem events. Third, the empirical community needs to consider the combined effects of multiple stressors in attempting to understand climate change response. Finally, previous experiments and existing datasets that can enrich new and ongoing studies are often underanalysed. Current efforts
in large-scale synthesis using a number of existing large-scale databases (e.g. the TRY database) can facilitate the movement of models beyond static or foliar-only traits and towards more flexible DGVMs. In addition, future generations of ecosystem scientists must be trained to effectively link observations, experiments and models in order to improve their approach to scaling issues in climate change research.

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References


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