



## Meetings

# Using results from global change experiments to inform land model development and calibration

### INTERFACE Workshop, Beijing, China, May 2014

For more than two decades, ecologists have studied how ecosystems will respond to environmental changes, such as the ongoing increase in atmospheric carbon dioxide concentration ( $[\text{CO}_2]$ ), the accompanying increase in Earth's surface temperatures, changes in precipitation regimes, and unintended fertilization of the globe with reactive nitrogen (N) compounds, by building experiments that simulate these changes at small scales. While much of this research has been targeted at understanding how the functioning of ecosystems may change, and determining which species are likely to be 'winners' and 'losers' in future conditions, an undercurrent of this research (and also often the stated goal) has been to determine how ecosystem responses themselves may alter the rate of climate change by altering the exchanges of carbon and energy between land and atmosphere. But identifying exactly how small-scale experiments can inform large-scale climate feedbacks is not always simple. Responses measured at the leaf level, for instance, may be quite different from what occurs at the canopy or landscape scale. And landscape-scale processes do not operate in small plots. Integrating results from plot-scale global change manipulations with the Earth system models that now provide state-of-the-art climate projections, and which operate on a scale of *c.*  $1^\circ$  grid cells, can provide a challenge. To date, few clear examples of such research exist (but see Bonan, 2014). To address these challenges, 48 experimentalists and modelers from around the world gathered in Beijing for a workshop on 'Using results from global change experiments to inform land model development and calibration.' The workshop, organized by Jeffrey Dukes, Aimée Classen, and local host and co-sponsor Shiqiang Wan, began with short talks from both the experimental and modeling perspectives, which led into longer, focused small group discussions.

### Participants expect a weaker $\text{CO}_2$ response than models or experimental data would suggest

Adam Langley (Villanova University, PA, USA) introduced a series of talks on elevated  $\text{CO}_2$  by reviewing long-term data on changes in net primary productivity (NPP) under elevated  $\text{CO}_2$ , noting that responses have varied dramatically across systems, and over time within experiments, and that interactions with other environmental

variables could further limit the strength of the  $\text{CO}_2$  response (Leuzinger *et al.*, 2011). Before summarizing the experimental data, he asked the audience to predict how global NPP would change with a doubling of current  $[\text{CO}_2]$ . His anonymous survey of participants, presented at the end of the meeting, showed that respondents expected the long-term stimulation of NPP would be less than one-third as strong as would be expected from most models and from forest free-air  $\text{CO}_2$  enrichment (FACE) studies. (Respondents expected a mean increase of  $4\% \text{ } 100 \text{ ppm}^{-1}$ , assuming a logarithmic response between 400 and 800 ppm; range 2–7%;  $n = 21$ , vs mean increases of 16% and 13%  $100 \text{ ppm}^{-1}$  for models and FACE experiments, respectively; Piao *et al.*, 2013.) Results from this quick, informal survey should be interpreted cautiously, but suggest that researchers at the workshop suspect that most models overestimate the capacity of the terrestrial biosphere to slow climate change. To examine one potential part of this discrepancy, the group explored how water availability influences the  $\text{CO}_2$  response. Participant Mark Hovenden (University of Tasmania, Hobart, Australia) showed that the productivity of Tasmanian grasslands responds to  $\text{CO}_2$  most strongly at intermediate soil moisture values (Hovenden *et al.*, 2014). It is not known how commonly water availability constrains the  $\text{CO}_2$  response, and so a group of participants is currently sifting through data from past  $\text{CO}_2$  experiments to characterize the strength of this relationship in grasslands around the globe.

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### Challenges and keys to progress in model-experiment integration exercises

Many participants from the experimental community wanted to better understand why experimental data were not being more widely used by modelers. The conversations with the modeling community made clear that there were many reasons for this. Few of the experimental data prove useful for modeling, for a wide variety of reasons. In addition to the issues with spatial and temporal scaling that have been widely discussed elsewhere (e.g. Lee & Mishurov, 2013), these reasons include: (1) the idiosyncrasies of and shortcomings inherent in single experiments, (2) the lack of relevant synthesis metrics, and (3) hurdles in getting access to

experimental data. Fortunately, each of these issues can be addressed.

First, the response to an environmental manipulation measured at one site, or the mechanism behind that response, may not be common across sites, even within a biome. Patterns of ecosystem response can change over time, data collection protocols vary among groups, and the manner in which a treatment is implemented may vary across experimental sites. For example, Lara Kueppers (Lawrence Berkeley National Laboratory, CA, USA) noted that warming treatments can be achieved passively or actively, in a variety of ways that each uniquely alter other important driving factors such as wind speed and relative humidity. Additionally, experiments ramp up temperature at different rates and warm ecosystems to different degrees. These site-level idiosyncrasies lead to uncertainties in model representation, if the model is parameterized using data from one or few sites. Also, Sara Vicca (University of Antwerp, Belgium) pointed out that in many cases, researchers conducting experimental manipulations have not recorded enough types of environmental data, or recorded ecosystem process data frequently enough to characterize responses sufficiently for generalization and synthesis (Vicca *et al.*, 2014). If experimentalists choose representative sites and comprehensively measure response and environmental variables (see De Kauwe *et al.*, 2014), this will increase the utility of experimental data for modelers.

Second, relatively few useful synthesis metrics have been generated from experimental data. Data from meta-analyses and syntheses can identify realistic degrees of response to a perturbation (e.g. Piao *et al.*, 2013), but should be used with caution. For instance, questions of lag times can arise; experiments typically impose a full-strength manipulation from the start, whereas models typically ramp up environmental changes in accordance with scenarios for the future. Participants also voiced concern that, even when models replicate responses from synthesis data, it could be for the wrong reason, as errors in one process might compensate for opposing errors in another (Zaehle *et al.*, 2014). Participants thus urged a strong focus on understanding the mechanisms responsible for the observed responses. However, Yiqi Luo (University of Oklahoma, Norman, OK, USA) demonstrated how the thoughtful use of experimental data in data assimilation and synthesis exercises can produce useful, simplified metrics against which to gauge model results. For instance, van Groenigen *et al.* (2014) used data assimilation techniques to incorporate results from many experiments into synthetic data products (estimated changes in carbon uptake and turnover under elevated CO<sub>2</sub>) that can easily be used to constrain predictions of future change.

Third, modelers might take advantage of insights from experiments more frequently if it were less cumbersome to do so. There are a variety of barriers to accessing experimental results that should be addressed by the community. While the observational science community has developed networks and databases that facilitate data sharing (e.g. FLUXNET, TRY), such networks do not yet exist within the experimental global change research community. One modeler put it bluntly: 'Experimentalists can't wait for somebody to ask for your data. Unless it's readily available and in the correct format, it will not be used.' A global, open-access data repository would stimulate data assimilation and synthesis work such as meta-

analyses, allowing experimental data to rapidly be turned into the synthetic measures of most use to modelers. The recently re-funded European CLIMMANI network will develop a comprehensive database along these lines over the next few years.

Despite the barriers to using experimental data, these data have increasingly been used to inform models in several ways. One current focus is on benchmarking; comparing model results to data from experiments to identify whether the models can reproduce observed responses (Luo *et al.*, 2012). Models can be benchmarked against experimental data (e.g. De Kauwe *et al.*, 2013) or against synthetic data products (e.g. van Groenigen *et al.*, 2014). Such benchmarking exercises, which have rarely been undertaken, help to identify whether models are realistically simulating responses to environmental changes. Experimental results can also be used to help inform the representation of ecosystem processes within models (e.g. Smith & Dukes, 2013; Sistla *et al.*, 2014; Smith *et al.*, 2014).

The meeting in Beijing identified ways in which experimentalists can collaborate with modelers to reduce the uncertainty in the magnitude of land carbon feedback, and in land processes in general, and kicked off several such collaborations. Model-data comparisons (e.g. benchmarking) will be critical. Hypothesis-driven model intercomparison projects can be bolstered by new and powerful approaches to data assimilation. Meetings can catalyze these activities, and help publicize the need to use common metrics in data collection, the collection of minimum sets of data types, and the collection of data at adequate time steps, all of which eventually ensure experimental data can and will be used to help constrain modeled processes. The research community can begin to overcome current gaps in communication and understanding between the modeling and experimenting research communities by training the next generation of scientists to be at least conversant, if not fluent, in both areas. Meetings such as the one in Beijing provide small opportunities for cross-disciplinary activities, but integration will be more rapidly achieved through explicit funding of graduate student and post-doctoral training across these areas.

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