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Guiding the Next Generation of Forest FACE Experiments with Lessons from the Past

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The free air CO_2 enrichment (FACE) experiments that were initiated in forest ecosystems 20 years ago represented a large commitment of time and energy of many students, early career, and senior scientists, and they were a substantial investment of funding from government science agencies. The experiments produced hundreds of primary research papers and dozens of synthesis and review papers, so it is highly appropriate to ask: What did we learn from this enterprise about how trees and forests will respond to an ever increasing concentration of CO_2 in the atmosphere? The diversity of sites and species preclude any single, simple answer. Nevertheless, the FACE experiments were successful in building upon earlier, smaller scale elevated CO_2 experiments to provide the data needed to evaluate hypotheses derived from past results, and they provided novel insights into the ecological mechanisms controlling the cycling and storage of carbon in terrestrial ecosystems. Important lessons include: (1) Net primary productivity is increased by elevated CO_2, but the response can diminish over time. (2) Carbon accumulation is driven by the distribution of carbon among plant and soil components with differing turnover rates and by interactions between the carbon and nitrogen cycles. (3) Plant community structure may change, but elevated CO_2 has only minor effects on microbial community structure. However, despite these insights, the size and longevity of forests preclude experimental evaluation, even in decade-long experiments, of the critical global-scale issues associated with forest responses to rising atmospheric CO_2 concentration and the feedbacks provided to the climate system. Instead, we must rely on models that simulate the exchange of carbon, water, and energy in the terrestrial biosphere. An important objective of FACE experiments has always been to provide data and evaluation tools for ecosystem models and thereby contribute to our ability to project how ecosystems will respond to future CO_2 concentrations. The FACE model–data synthesis (FACE-MDS) project challenged 11 terrestrial ecosystem models with data from the Oak Ridge National Laboratory FACE experiment in Tennessee, USA, and Duke FACE in North Carolina, USA. This exercise was valuable in identifying critical model assumptions and evaluating whether the assumptions were supported by the experimental data, and it provided a framework to evaluate forest processes that occur over much longer time frames than the duration of the experiments. The next generation of forest FACE experiments will greatly expand the breadth of our knowledge base on responses to elevated CO_2 by investigating responses of mature forest ecosystems in boreal to tropical biomes over a wide range of climatic and edaphic conditions. Our experience with the FACE-MDS has shown the value in initiating the model-data interaction as an integral part of experimental design. The FACE-MDS framework has led to a set of model-guided, cross-site science questions for new FACE experiments, including responses of mature forests; interactions with temperature, water stress, and phosphorus limitation; and the influence of biodiversity. This sets an exciting research agenda for the next decade.