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On the limits and capability of modeling water, energy and carbon fluxes in deciduous forest exposed to elevated CO_2

Simone Fatichi (1) and Sebastian Leuzinger (2)

(1) Institute of Environmental Engineering, ETH Zürich, Switzerland (simone.fatichi@ifu.baug.ethz.ch), (2) School of Applied Sciences, Auckland University of Technology, New Zealand

Understanding future patterns of carbon cycle is strongly connected to forest behavior in an atmosphere with increasing CO_2. Observations in mature, steady-state forests are logistically challenging and difficult to upscale, therefore most of our experimental knowledge is derived from results obtained for young trees or homogenous stands. A combination of numerical modeling and observations can complement our knowledge on the behavior of heterogeneous forests where the leaf-level photosynthetic response to elevated CO_2 typically does not translate into a proportional increase in plant growth. We compare data from a free air CO_2 enrichment (FACE) experiment in a mature deciduous forest in Switzerland with realizations from a state-of-the-art ecohydrological model (Tethys-Chloris). Model realizations compare favorably with field observations of photosynthesis, stomatal conductance, sap flow, leaf and fruit litter, and stem growth. The model captures the observed CO_2-induced difference in transpiration and its sensitivity to atmospheric demand, as well as qualitative changes in soil moisture. The simulated differences between CO_2 scenarios for both the carbon and water balance are generally less than 10% and fall within the uncertainty of experimental observations. Simulated allocation to stem growth is c. 50 $gC\,yr^{-1}\,m^{-2}$ higher in the modeled CO_2 scenario, which is within the uncertainty of stand upscaled observations. These results demonstrate that while ecohydrological models can be used to reliably simulate multi-year energy, water, and carbon fluxes, evaluating the modeled carbon allocation remains critical. Simplified and rather empirical carbon allocation rules used in the model cannot be confirmed or rejected given the current accuracy of field measurements. Despite such uncertainties we conclude that, taken together both modeling and experimental results, for this type of forest, ecosystem responses to elevated CO_2 in terms of energy and water fluxes are likely to be very small.