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Environmental dependencies of plant CO_2 uptake in theory, data, and simulations

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The rate of carbon uptake by land plants depends on the light use efficiency (LUE) of photosynthesis. LUE is the ratio of primary production to light absorbed by foliage. This in turn depends on the ratio of leaf-internal to ambient carbon dioxide partial pressures (χ). However, current state-of-the-art land ecosystem models represent the environmental dependencies of these two key quantities in an empirical and incomplete way. Their modeled values have not been systematically tested against observations, a situation contributing to the many uncertainties afflicting current model estimates and future projections of terrestrial carbon uptake.

We present a theory for the dependencies of χ and LUE on growing-season air temperature, vapour pressure deficit (VPD), CO_2 concentration and elevation based on two hypotheses rooted in eco-physiological optimality. Theoretically derived environmental dependencies of χ and LUE are shown to be precisely and quantitatively consistent with global data sets of (a) stable carbon isotope measurements, and (b) gross primary production derived from CO_2 flux measurements. The modeled environmental dependencies of χ and LUE according to seven state-of-the-art land ecosystem models participating in the TRENDY2 model intercomparison project are then derived from model outputs and compared with the theoretical relationships as a benchmark. The results show large discrepancies among model-predicted relationships of χ and LUE to temperature and VPD both in spatial and temporal dimensions. The influence of elevation on χ and LUE is also inconsistent among models, as is their predicted sensitivity to CO_2 enrichment. This work suggests that a top-priority task for land ecosystem models should be to reformulate the environmental drivers of χ and LUE relationships to be consistent with observations. It also indicates that eco-physiological optimality hypotheses provide a promising route to an improved predictive understanding of terrestrial carbon and water cycling.