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Eco-evolutionary responses of plant communities to drought and rainfall variability

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The future Earth is projected to experience elevated rainfall variability, with more frequent and intense droughts, as well as high-rainfall events. Increasing CO_2 concentrations are expected to raise terrestrial gross primary productivity (GPP), whereas water stress is expected to lower GPP. Plant responses to water stress vary strongly with timescale, and plants adapted to different environmental conditions differ in their functional responses. Here, we embed a unified optimality-based theory of stomatal conductance and biochemical acclimation of leaves we have recently developed [Joshi, J. et al. (2020) Towards a unified theory of plant photosynthesis and hydraulics. bioRxiv 2020.12.17.423132] in an eco-evolutionary vegetation-modelling framework, with the goal to investigate emergent functional diversity and associated GPP impacts under different rainfall regimes.

The model of photosynthesis used here simultaneously predicts the stomatal responses and biochemical acclimation of leaves to atmospheric and soil-moisture conditions. Using three hydraulic traits and two cost parameters, it successfully predicts the simultaneous declines in CO_2 assimilation rate, stomatal conductance, and leaf photosynthetic capacity caused by drying soil. It also correctly predicts the responses of CO_2 assimilation rate, stomatal conductance, leaf water potential, and leaf photosynthetic capacity to vapour pressure deficit, temperature, ambient CO_2, light intensity, and elevation. Our model therefore captures the synergistic effects of atmospheric and soil drought, as well as of atmospheric CO_2 changes, on plant photosynthesis and transpiration.

We embed this model of photosynthesis and transpiration in a trait-height-patch structured eco-evolutionary vegetation model. This model accounts for allometric carbon allocation, height-structured competition for light, patch-structured successional dynamics, and coevolution of plant functional traits. It predicts functional species mixtures and emergent ecosystem properties under different environmental conditions. Using this model, we investigate the evolution of plant hydraulic strategies under different regimes of drought and rainfall variability. Our approach provides an eco-evolutionarily consistent framework to scale up the responses of plant communities from individual plants to ecosystems to provide ecosystem-level predictions of functional diversity, primary production, and plant water use, and could thus be used for reliable projections of the global carbon and water cycles under future climate scenarios.