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Mechanistic modeling of plant gas exchange resolves carbon-water relation dynamics under water-limited conditions

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Plant gas exchange through leaf stomata plays a critical role in terrestrial water and carbon cycles, regulating the trade-off between photosynthetic carbon gain and transpirative water loss. This is often characterized by plant water use efficiency (WUE – the ratio of carbon gain to water vapor loss), a critical ecosystem indicator for how plants have and will adapt to the physical limitations of their changing environments. Given the assumption that carbon gain and water loss are linearly proportional to stomatal conductance, the conventional WUE parametrization fails to account for the information concerning plant stomatal configuration in response to environmental variabilities, and the resulting plant WUE becomes a nearly-linear function of atmospheric CO_2 partial pressure. Although this may work reasonably well under moderately wet ecosystem conditions (i.e. energy-limited evaporation regime), stomata and transpiration are likely to increasingly respond to not just atmospheric condition, but also soil moisture, as the ecosystem shifts from energy- to moisture-limited regime. This has implications for understanding and predictability of water and carbon cycles during drought, reflected in relatively large errors and uncertainties propagated into estimates of evapotranspiration partitioning and/or gross primary productivity. Capitalizing on recent progress made in mechanistic modeling of leaf-level processes, this study aims to provide an improved WUE parametrization with explicit incorporation of stomatal response to environmental change accounted for by a varying soil-plant resistance under different atmospheric and soil moisture conditions. To this end, we develop a physically based transpiration model that couples stomatal control of leaf gas exchange to the leaf surface energy balance and the entire plant hydraulic system by considering the interdependence of the guard cell water potential (or turgor pressure) and transpiration rates. Potential benefits of our outcomes for enhancing the utility of remotely sensed photosynthetic proxies (such as solar-induced chlorophyll fluorescence) for monitoring and/or predicting plant-water relations under a changing environment will be discussed.