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Carbon-cycle implications of asymmetry in response of semi-arid ecosystem phenology and productivity to rainfall

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Semi-arid savannahs and shrublands of the tropics and subtropics play a key role in the inter-annual variability of the global carbon cycle and are emerging as an important player – comparable with tropical forests – in terms of their contribution to the ongoing sink trend of the carbon exchange between the global land surface and atmosphere. Both the variability and carbon balance trend of the savannah-shrubland biome are characterised by shifting phenology, mediated by changes in the seasonality and relative contributions to ecosystem productivity of woody vegetation elements and grasses. Shifts in water availability associated with the impacts of global circulation systems on the distribution and amount of rainfall are a key driver of vegetation response in these ecosystems, which tolerate drought, but spring to life, becoming highly productive, during episodes of ample water supply. This "boom or bust" behaviour with respect to water availability may be expected to translate into an asymmetric response to rainfall change, positive anomalies in rainfall tending to lead to larger increases in productivity compared with the corresponding decrease in productivity resulting from a negative anomaly of comparable size. As rainfall distributions over time themselves exhibit asymmetry, an 'intrinsic' (ecosystem response-driven) and 'extrinsic' (climate or weather forcing-driven) component of asymmetry may be distinguished. We investigated the prevalence of asymmetry in forcing and response of ecosystem productivity to rainfall variability globally and for the illustrative case of Australia, which emerges as a global 'hot spot' for rainfall-driven variability in ecosystem gross primary production (GPP) and associated net ecosystem productivity (NEP). Employing two climate-driven ecosystem models, informed by multiple observation types (land-atmosphere fluxes, biomass, streamflow and remotely-sensed vegetation cover), we show that the inland region of Australia, dominated by semi-arid savannah and shrubland, robustly exhibits positive asymmetry of GPP and NEP, with both extrinsic forcing and intrinsic response contributing importantly to the overall asymmetry. Mesic ecosystems (woodlands and forests) characteristic of the Australian eastern seaboard and south-east, lacking drought-adapted species, did not show an intrinsic asymmetric response. Implications for the semi-arid biome under future climate and CO_2 are discussed.