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A missing piece of the puzzle in climate change hotspots: Near-surface turbulent interactions controlling ET-soil moisture coupling in semiarid areas

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Being located in the transitional zone between dry and wet climate areas, semiarid ecosystems (and their associated ecohydrological processes) play a critical role in controlling climate change and global warming. Land evapotranspiration (ET), which is a central process in the climate system and a nexus of the water, energy and carbon cycles, typically accounts for up to 95% of the water budget in semiarid areas. Thus, the manner in which ET is partitioned into soil evaporation and plant transpiration in these settings is of practical importance for water and carbon cycling and their feedbacks to the climate system. ET (and its partitioning) in these regions is primarily controlled by surface soil moisture which varies episodically under stochastic precipitation inputs. Important as the ET-soil moisture relationship is, it remains empirical, and physical mechanisms governing its nature and dynamics are underexplored.

Thus, the objective of this study is twofold: (1) to provide observational evidence for the influence of surface cover conditions on ET-soil moisture coupling in semiarid regions using soil moisture data from NASA's SMAP satellite mission combined with independent observationally based ET estimates, and (2) to develop a relatively simple mechanistic modeling platform improving our physical understanding of interactions between micro and macroscale processes controlling ET and its partitioning in partially vegetated areas. To this end, we invoked concepts from recent progress in mechanistic modeling of turbulent energy flux exchange in bluff-rough regions, and developed a physically based ET model that explicitly accounts for how vegetation-induced turbulence in the near-surface region influences soil drying and thus ET rates and dynamics. Model predictions revealed nonlinearities in the strength of the ET-soil moisture relationship (i.e., $\partial ET/\partial\theta$) as vegetation cover fraction increases, accounted for by the nonlinearity of surface-cover-dependent turbulent interactions. We identified a (predictable) critical vegetation cover fraction (as a function of vegetation stature and environmental conditions) that yields the strongest ET-soil moisture relationship under prescribed atmospheric conditions. Overall, the results suggest that $\partial ET/\partial\theta$ varies more widely in regions with tall-stature woody vegetation that experience higher rates of change in turbulence intensity as the cover fraction increases. Our results facilitate a mathematically tractable description of $\partial ET/\partial\theta$, which is a core component of models that seek to predict hydrology-climate feedback processes in a changing climate.