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Characterizing watershed soil moisture heterogeneity using fine-scale simulations and temporal evolution of soil moisture fractal

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Hydrologic scaling and heterogeneity have for decades been recognized as among the most significant challenges in hydrologic modeling. Even in very homogeneous landscape, the topography-induced redistribution of water tends to concentrate moisture across a wide range of spatial scales. It has been widely known that moments of observed soil moisture exhibit power-law decay which resembles a self-similar structure, or fractal, in a statistical sense. This scale-invariant relationship may hold the very key that enables us to predict small-scale states from large scale dynamics. However, we have very limited understanding of the temporal evolutionary pattern of the soil moisture fractal (SMF). In this work, using a tested process-based surface-subsurface processes model, we examine how SMF varies from non-frozen to frozen time periods, how it reacts to precipitation event and how it evolves over rainfall hiatus. The evolution of the SMF shows very complex, chaotic patterns that challenges the use of stationary environmental predictors. We also show how fine resolution models can be used to predict coarse model moments. We tested sixteen system attributes hypothesized to explain the negative relationship between soil moisture mean and variance toward the wetter end of the distribution, and found that, in the model, 59% of the variance of this relationship can be explained by the elevation gradient convolved with the mean evapotranspiration flux. Carefully designed modeling experiments that isolate in turn the various processes impacting relationships between soil moisture mean and higher-order moments are the next step toward improving understanding of the controls on these relationships.