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Vadose zone controls on damping of climate-induced transient recharge fluxes in U.S. agroecosystems

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Understanding the physical processes in the vadose zone that link climate variability with transient recharge fluxes has particular relevance for the sustainability of groundwater-supported irrigated agriculture and other groundwater-dependent ecosystems. Natural climate variability on interannual to multidecadal timescales has well-documented influence on precipitation, evapotranspiration, soil moisture, infiltration flux, and can augment or diminish human stresses on water resources. Here the behavior and damping depth of climate-induced transient water flux in the vadose zone is explored. The damping depth is the depth in the vadose zone that the flux variation damps to 5% of the land surface variation. Steady-state recharge occurs when the damping depth is above the water table, and transient recharge occurs when the damping depth is below the water table. Findings are presented from major agroecosystems of the United States (U.S.), including the High Plains, Central Valley, California Coastal Basin, and Mississippi Embayment aquifer systems. Singular spectrum analysis (SSA) is used to identify quasi-periodic signals in precipitation and groundwater time series that are coincident with the Arctic Oscillation (AO) (6–12 mo cycle), Pacific/North American oscillation (PNA) (<1–4 yr cycle), El Niño/Southern Oscillation (ENSO) (2–7 yr cycle), North Atlantic Oscillation (NAO) (3–6 yr cycle), Pacific Decadal Oscillation (PDO) (15–30 yr cycle), and Atlantic Multidecadal Oscillation (AMO) (50–70 yr cycle). SSA results indicate that nearly all of the quasi-periodic signals in the precipitation and groundwater levels have a statistically significant lag correlation (95% confidence interval) with the AO, PNA, ENSO, NAO, PDO, and AMO indices. Results from HYDRUS-1D simulations indicate that transient water flux through the vadose zone are controlled by highly nonlinear interactions between mean infiltration flux and infiltration period related to the modes of climate variability and the local soil textures, layering, and depth to the water table. Simulation results for homogeneous profiles generally show that shorter-period climate oscillations, smaller mean fluxes, and finer-grained soil textures generally produce damping depths closer to land surface. Simulation results for layered soil textures indicate more complex responses in the damping depth, including the finding that finer-textured layers in a coarser soil profile generally result in damping depths closer to land surface, while coarser-textured layers in coarser soil profile result in damping depths deeper in the vadose zone. Findings from this study improve understanding of how vadose zone properties influences transient recharge flux and damp climate variability signals in groundwater systems, and have important implications for sustainable management of groundwater resources and coupled agroecosystems under future climate variability and change.