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Global assessment of steady and transient groundwater recharge rates

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Groundwater recharge rates fluctuate in response to climatic patterns that can be described as (quasi-) periodic oscillations on various timescales. These local-to global-scale climate patterns affect groundwater availability. Therefore, understanding the relationship between climatic conditions and recharge rates becomes essential. Due to the general lack of long-term field observations, the relationship between climate and recharge is generally investigated with mathematical models. Although these models generate important recharge predictions, large-scale models typically simplify recharge processes with lumped inter-relationships between climatic and hydrological fluxes. Due to the extensive data requirements and long model run times, simplified models are often the only means to simulate transient large-scale processes.

However, under some circumstances, the transient and episodic variations in fluxes at land surface are dampened with increasing depth in the vadose zone. Due to this damping, a constant recharge rate can be assumed below a certain depth. This steady-state rate can help to reduce the model development and computational time that is currently a crucial requirement to simulate recharge rates from regional- to global-scale models. Because key uncertainties in the spatial and temporal distribution of climatic forcing and unsaturated zone parameters becomes less crucial when a steady-state recharge rate can be assumed, model reliability may also be enhanced.

Here we present results from a global assessment of the spatial and temporal extent of steady-state recharge rates based on an analytical solution. The analytical solution for hydraulic conductivity and soil moisture is based on the use of the Gardner–Kozeny model, along with a linearization of diffusivity and advective terms in the governing differential equation. We demonstrate how variability in fluxes at land surface are damped with depth in the vadose zone for monthly, seasonal, annual, inter-annual, and longer teleconnection time periods, such as the North Atlantic Oscillation (NAO) and the El Niño-Southern Oscillation (ENSO). Our analysis was validated against a new global dataset of site investigated recharge rates (>500 sites). A good agreement between estimated global- and field-scale damping depths was obtained (R2=>0.6). With this method we provide general guidelines about the damping depth of transient recharge rates on a global scale, while also indicating where and when signals of climate teleconnections can be observed in recharge fluxes.