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Multi-decadal changes in root zone water storage capacity through vegetation adaptation to hydro-climatic variability

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Climate change can considerably affect catchment-scale root zone storage capacity (S_{umax}) which may further influence the moisture exchange between land and atmosphere, as well as stream flow and biogeochemical processes in terrestrial hydrological systems. However, direct quantification of the evolution of S_{umax} over multi-decadal time periods at the catchment scale has so far been rare. As a consequence, it remains unclear how climate change affects S_{umax} (e.g., precipitation regime, canopy water demand) and how changes in S_{umax} may control the partitioning of water fluxes as well as the hydrological response at catchment scale. The objectives of this study in the upper Neckar river basin in Germany are therefore to provide an analysis of muti-decadal changes in S_{umax} that can be observed as a result of changing climatic conditions over the past century and how this has further affected hydrological dynamics. More specifically, we test the hypotheses that (1) S_{umax} significantly changes over multiple decades reflecting vegetation adaptation to climate variability, (2) changes in S_{umax} control water availability for evapotranspiration and thus multi-decadal deviations from long-term average positions in the Budyko framework, (3) a time-dynamic implementation of S_{umax} affects the hydrological response, which in return can improve the performance of a hydrological model.

We found that, indeed, a hydroclimatic condition considerably changed over time in the 1953 to 2022 study period, which was reflected by related fluctuations in the values of S_{umax} derived directly from observed water balance data These ΔSumax values varied by up to -20% in relatively wet decades to +20% in drier decades, which was very similar to ΔSumax obtained from calibration of a hydrological model (R^2=0.95, $p<0.05$) in individual decades. However, evaporation estimated by the hydrological model using a long-term average S_{umax} for the study period was almost the same as that reproduced by the model when allowing dynamically changing root-zone storage capacities over multiple decades. In addition, no significant improvement in the reproduction of the hydrological response was observed when implementing a time-variant representation of decadally varying S_{umax} in the model compared with the implementation of a stationary S_{umax} irrespective of the hydroclimatic conditions in the individual decades.

Overall, this study provides quantitative evidence that S_{umax} significantly changes over multiple decades reflecting vegetation adaptation to climate variability. However, these changes are not responsible for deviations from the Budyko curves in different climatic conditions, in other words,

the temporal evolution of S_{umax} in the study region is not a major control on the partitioning of water fluxes into evapotranspiration and drainage and does have therefore no significant effects on fundamental hydrological response characteristics of the upper Neckar catchment. This suggests that model predictions of future stream flows remain rather insensitive to uncertainties introduced by the use of time-invariant long-term average values of Sumax as model parameters.