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Assimilation of soil moisture data from cosmic-ray neutron sensors into the integrated Terrestrial System Modeling Platform TSMP (case study: Rur catchment in Germany)

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Cosmic-ray neutron sensors (CRNS) measure soil moisture in real-time at the field scale, bridging the gap between in situ measurements and remote sensing products. This is promising and has the potential to enhance hydrological model predictions through the assimilation of CRNS data and improve the estimation of model parameters. In this study, soil moisture measurements from a network of 13 CRNS in the Rur catchment (~2000km^2, Germany) were assimilated into the integrated model Terrestrial System Modelling Platform (TSMP) by the ensemble Kalman filter (EnKF). In total 128 ensemble members were generated by perturbing atmospheric forcing variables and soil textures to account for the uncertainties. The data assimilation experiments (with and without soil hydraulic parameter estimation) were carried out in both a wet year (2016) and a dry year (2018), and later validated using an independent year (2017) without assimilation. The objectives of this study were to investigate the potential of CRNS assimilation for improving soil moisture and evapotranspiration (ET) characterization, estimation of soil hydraulic parameters at the catchment scale, and analysis of whether the data assimilation performance differs between wet and dry years. The data assimilation experiments showed that soil moisture estimation was significantly improved during the assimilation period at measurement locations, with a root mean square error (RMSE) reduction (compared to open loop simulations without assimilation) in the range of 36-60% either in the dry or wet year, and the improvements were limited by the measurement error of CRNS (0.03 cm^3/cm^3). The joint state-parameter estimation gives better performance than state estimation alone (more than 15% RMSE reduction), and 9% RMSE reduction in the verification period with the updated parameter. The jackknife experiments revealed that the measurement network (~1 site per 200 km^2) was insufficiently dense because soil moisture characterization at independent verification locations only improved marginally with large differences between wet and dry years (with an RMSE reduction of 40% in 2016 and 16% in 2018). The improved predictions from the jackknife experiments, however, imply that the assimilation of soil moisture data from a CRNS network still has the potential to improve the soil moisture characterization on the catchment scale by updating the spatially distributed soil

hydraulic parameters of the subsurface model. The comparison of simulated ET with the data from eddy covariance (EC) stations demonstrates that it is challenging to achieve great improvements in ET simulations through CRNS soil moisture assimilation (with the RMSE reduction of monthly ET ranging between 6% and 21%).