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Exploring the mechanism behind successive droughts: Intensification of continental droughts due to positive feedbacks between subsurface water storage anomalies and atmospheric process

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In the year 2018, Central Europe experienced a meteorological drought and a heatwave, which led to a subsequent evolution of a hydrological drought that is still detectable in subsurface water storage anomalies today. Most likely, the drought also led to significant changes in the energy balance between solar radiation, latent and sensible heat fluxes. In conjunction with water scarcity in the subsurface, these changes may lead to feedbacks that mitigate or enforce drought conditions in the context of land-atmosphere coupling. Understanding these feedbacks is of great interest, especially under various large-scale weather patterns that strongly influence the water and energy budgets over Europe at the interannual time scale. We improve our understanding by applying the Terrestrial Systems Modeling Platform (TSMP) over the 12km resolution pan-European CORDEX model domain simulating the water and energy cycles from the groundwater to the top of the atmosphere. TSMP couples a hydrological, land-surface and atmospheric model, facilitating studies of feedbacks between total water storage anomalies, the energy budget and atmospheric processes. To investigate the feedbacks, we performed TSMP ensemble simulations of three anomalously dry water years (September to August) over Central Europe. The ensembles were initialized with the surface and subsurface states of the end of August of the drought years 2011, 2018 and 2019 from an ERA-Interim driven climatology simulated continuously with TSMP from 1989 to 2019. Every ensemble consists of 22 members, each representing a full subsequent water year, sampled from ERA-Interim reanalysis meteorological boundary conditions from 1996 to 2019, thereby simulating the influence of drought conditions over a wide range of large-scale weather patterns that occurred in Europe since 1996. In addition, to illustrate the potential range of feedbacks we also ran idealized experiments with a completely dry or wet subsurface. The results show that drought conditions may have a significant impact on cloud water and solar radiation at interannual timescales. Effects in winter are negligible, while in summer, an impact of the drought conditions of the previous year on cloud water and solar radiation is detectable in all three ensembles. The results suggest that positive feedbacks between dry subsurface water storage anomalies and atmosphere processes are not negligible and may intensify drought conditions also at the interannual time scale.