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Groundwater-soil moisture-climate interactions: lessons from idealized model experiments with forced water table depth

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Groundwater (GW) constitutes by far the largest volume of liquid freshwater on Earth. The most active part is soil moisture (SM), recognized as a key variable of land/atmosphere interactions, especially in so-called transition zones, where/when SM varies between wet and dry values. But GW can also be stored in deeper reservoirs than soils, in particular unconfined aquifer systems, in which the saturated part is called the water table (WT). The latter is characterized by slow and mostly horizontal water flows towards the river network, with well-known buffering effects on streamflow variability. Where/when the WT is shallow enough, it can also sustain SM by means of capillary rise, thus increase evapotranspiration (ET), with potential impact on the climate system (including temperatures and precipitation). The large residence time of GW may also increase the Earth system's memory, with consequences on the persistence of extreme events, hydro-climatic predictability, and anthropogenic climate change, particularly the magnitude of regional warming.

Here, our main goal is to explore the potential impacts of the water table depth (WTD) on historical climate through idealized model analyses. To this end, we force three state-of-the art land surface models (LSMs), namely CLM, ORCHIDEE, and SURFEX, with prescribed WTDs ranging from 0.5 to 10 m. The LSMs are run either off-line or coupled to their parent climate model, following LMIP/AMIP-like protocols for intercomparability. Within this framework, we want to assess the sensitivity of ET and the simulated climate to the WTD in a systematic way. In particular, we will identify and compare the patterns of the critical WTD, defined as the deepest one to achieve a significant change in ET. To this end, we estimate derivatives of ET with respect to WTD, which tell how the sensitivity of ET to a unit change in WTD evolves with WTD. In each grid-point, these derivatives can be used to define the critical WTD, given a threshold ET sensitivity value, below which we can assume that ET changes are small. We will analyze how the critical WTD patterns intersect with published WTD and hydrogeological maps, and whether the critical WTD has distinct features in soil moisture transition zones, known to be hot-spots of strong land-atmosphere coupling.