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Increasing groundwater temperatures caused by climate regime shifts

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Variations in meteorological patterns due to climatic changes are known to have a substantial influence on the hydrological cycle. However, most studies focus on the hydrological processes at the surface and equivalent studies on groundwater response to recent climate change are limited. While the consequences for groundwater recharge and water availability were investigated by several studies, the implications for the long-term development of shallow groundwater temperatures, as an important driver for water quality, are not comprehensively understood. In this study, the coupling of aquifer and local annual air temperatures is statistically examined for a period of forty years with regard to abrupt shifts in the long-term annual mean. Groundwater temperatures were measured in four observations wells in two different aquifers in Germany. Hence, the observed temperatures represent mean temperatures of the upper aquifers, where the well screens are located. In order to bring the local changes in the context with large-scale climatic changes, we also analyze averaged time-series of air temperatures regionally and globally. In all time-series of groundwater temperatures two statistically significant abrupt upward shifts in the long-term mean temperature could be identified. These shifts are related to preceding shifts in the long-term mean of local air temperatures, which are in turn associated with abrupt increases in regional and global mean air temperatures. The shifts in groundwater temperatures occur with a retardation of 1-3 years after the abrupt increases in air temperature depending on the thickness of the unsaturated zone. The magnitudes of the shifts in groundwater temperature are smaller than in the time-series of air temperatures, indicating that temperature increase in groundwater is more gradual than in air temperature. Despite this delay and damping of the thermal signal by heat conduction and advection in the subsurface and the mixing of water from different depths during pumping, substantial abrupt shifts towards higher aquifer temperatures could be detected. The observed direct coupling of air and groundwater temperature development shows that not only aquifers influenced by the infiltration of surface water are profoundly influenced by climatic changes. Also groundwater temperatures in shallow aquifers, which are linked to the atmosphere through the unsaturated zone, exhibit a pronounced coupling to short-term changes in air temperature. These findings and the correlation of the identified local shifts with abrupt regional and global increases indicate that a large number of aquifers are prone to be influenced in a similar way. Thus, further atmospheric warming is likely to have a significant influence, not only on soil temperatures, but also on temperatures of subsurface water resources.