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Subsurface warming trends in response to climate change and local heat sources in Central Europe

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Under natural conditions the thermal signature at the Earth´s surface equilibrates with the geothermal heat flux. Given that downward propagation of heat by conduction and advection is magnitudes lower than the daily and seasonal variation at the surface, these short-phased patterns impart a dampened and long-phased temperature response in the shallow subsurface. While climate change manifests in temperature trends that correlate at decade scale this signature is integrated by the slow heat transfer in gradual subsurface warming. In many places land use and small scale anthropogenic structures overprint the thermal response of the subsurface to climate change at the surface. In our contribution we present evidence of subsurface warming in natural and anthropogenic settings for different case studies in Central Europe. Repeated temperature depth logs reveal that in natural environments shallow subsurface temperature rise is trailing when compared to the rise in surface temperature and diminishes towards greater depths (e.g. +0.35 K per decate at the surface, +0.28 at 20 m, and +0.09 at 60 m below ground level for 32 wells in Bavaria). While in general a coherent pattern is found for different locations in natural environments, site-specific trends have a high spread (e.g. +0.36±0.44 K per decade for 227 wells in Austria) and temperature can also be dependent on vertical or lateral groundwater flow in the region. In built-up areas temperature rise in the subsurface is characterised by a higher variance and often exceeds the rise of surface temperature. Especially in dense urban areas ground temperature is elevated indicating local extreme temperature rises that are magnitudes higher than temperature rise at the surface. The high variance originates partially from the scarcity of reliable and long-term monitoring. Monitoring data typically lacks either depth or time resolution as temperature is either continously logged at a single-depth, erratically measured as depth profile, or measured at the surface during groundwater quality measurements.