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One-dimensional analysis of temperature-depth data from groundwater boreholes for surface warming and groundwater flow

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A one-dimensional analysis of temperature-depth profiles can constrain the timing and character of warming events or trends that can be indicative of a suite of environmental processes such as land-use change, regional climate warming or urbanization. However, vertical groundwater flow can also exert a significant influence on the shape of temperature depth profiles. Simple analytical solutions to the applicable heat flow equations have been proposed in the past to interpret TD data. We show here however that the simplistic assumptions that can come with these approaches lead to significant errors when these are not applied with care. We demonstrate this by using a set of type curves derived by Taniguchi et al. (1999) and evaluating it using a numerical model. Taniguchi derived these type curves from the analytical solution obtained by Carslaw and Jaeger for temperature with depth using a one-dimensional heat conduction-advection equation under the condition of a linear increase in surface temperature. With the use of the depth of minimum temperature the vertical groundwater flux can be quantified. We applied the type curves as well as the analytical solution by Carslaw and Jaeger to temperature-depth profiles that where obtained in 1978-1980 and repeated in 2016. However, as Taniguchi also mentions briefly, zero flow and a linear temperature profile are taken as initial conditions. This results in an error when interpreting the TD data with these type curves. The system is moving towards an equilibrium with a new surface temperature while it simultaneously moves towards an equilibrium with the new vertical groundwater flux. We ran a numerical model from a steady state which confirmed that the error caused by the simplistic assumptions is indeed significant.