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Wireless probes for measuring vertical temperature profiles in borehole heat exchangers (BHEs)

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The measurement of the undisturbed ground temperature (UGT) serves to design low-temperature geothermal systems, in particular borehole heat exchangers (BHEs), and to monitor shallow aquifers. Wireless and miniaturized probes such as the Geosniff (GS) measurement sphere, which are characterized by an autarkic energy supply and equipped with pressure and temperature sensors, are increasingly being used for the measurement of highly resolved vertical temperature profiles. The measurement probe sinks along the course of the BHE with a selectable measurement frequency to the bottom of the BHE and is useable for initial measurements as well as long term groundwater monitoring. To ensure quality assurance and further improvement of this emerging technology, the analysis of measurement errors and uncertainties of wireless temperature measurements (WTMs) is indispensable. Thus, we provide an empirical laboratory analysis of random, systematic, and dynamic measurement errors, which lead to the measurement uncertainty of WTMs using the GS as a representative device. We subsequently transfer the analysed uncertainty to measured vertical temperature profiles of the undisturbed ground at a BHE site in Karlsruhe, Germany. The precision and accuracy of 0.011 K and -0.11 K, respectively, ensure a high reliability of the GS measurements. The largest measurement uncertainty is obtained within the first five meters of descent resulting from the thermal time constant τ of 4 s. The measured temperature profiles are qualitatively compared with common Distributed Temperature Sensing (DTS) using fiber optic cables and punctual Pt-100 sensors. Wireless probes are also suitable to correct temperature profiles recorded with fiber optics with systematic errors of up to -0.93 K. Various boundary conditions such as the inclination of the BHE pipes or changes of the viscosity and density of the BHE fluid effect the descent rate of the GS of up to 40 %. We additionally provide recommendations for technical implementations of future measurement probes and contribute to an improved understanding and further development of WTMs.