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Rapid assessment of multi-directional 3D-flow fields using active heat pulse sensing in the streambed

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Application of heat as a tracer to hydrological studies has rapidly progressed in the last few decades driven by the simplicity of the methodology and low cost of sensor technology. Vertical temperature profiles using the 1D analytical solution are now widely used to determine hyporheic flow patterns and hydraulic dynamics within the shallow streambed sediment. One of the challenges in using a limited number of measurements to characterize processes that are not entirely vertical has been the determination of the horizontal or lateral flow component and how these components vary spatially and also their relative magnitude in 3D space. This study used a homemade portable 56 sensor, 3D temperature array with 3 heat pulse sources (the hot rod) to measure the flow direction and magnitude up to 230 mm below the water-sediment interface at a scale of a few centimetres in a range of sedimentary environments from fine silt to coarse gravels. Short heat pulses, typically 1 minute in duration were injected into the stream sediment and the response was monitored over a period of 20-30 minutes. Breakthrough curves from each of the temperature sensors was analysed using a version of the heat transport equation and a calibration objective function was used to estimate the x, y and z flow vector to determine the dominant direction and magnitude at the point of observation. A GUI in Python was developed to provide a user-friendly interface for processing the field data. The robust design of the hot rod and use of short duration heat pulses provides a rapid assessment technique for different heterogeneous stream environments and conditions which are crucial to determining dynamic and multi-directional flow patterns and understanding biogeochemical processes at the water-streambed interface.