Identifying flow pathways with Fibre Optic Distributed Temperature Sensing (FO-DTS)

Tom Read[1]*, Victor Bense[1], Kevin Hiscock[1], Antoine Guéron[2]

[1]University of East Anglia, [2]University of Rennes 1, *corresponding author: tom.read@uea.ac.uk

Project aims

The measurement of stream and stream bed temperatures can tell us where there is exchange between stream water and groundwater, and how much of this exchange there is [*Constantz*, 2008]. Our aim is to investigate the processes generating stream flow and hence the transport of diffuse pollution using heat as a natural tracer. In the Wensum DTC there are potentially three major inputs to surface water courses: field drain discharge, unsaturated zone flow, and groundwater flow.

Taking the stream bed temperature at a shallow (<40cm) depth using a temperature probe (left), and a typical flowing field drain following a rainfall event (right)

Background

For the measurement of stream temperature Fibre Optic Distributed Temperature Sensing (FO-DTS) is being used. DTS is an emerging technology in stream and groundwater monitoring and offers many advantages over using traditional 'point' temperature sensors [*Selker et al.*, 2006].

DTS is the measurement of temperature along fibre optic cables. To take a measurement, a pulse of laser light is sent through the cable. The base unit then monitors for the backscattered signal generated as the pulse propagates through the fibre. From a frequency shift in the return signal, it is possible to calculate the temperature along the entire cable, with the location of each measurement obtained from the timing of the backscatter arrival.

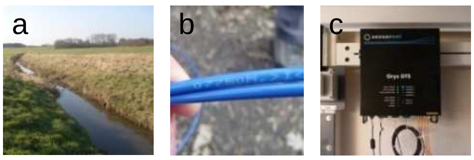


Figure 1. Channel looking north west from Kiosk E (a), BruSteel fibre optic cable (b), and Oryx DTS instrument (c)

Experimental set-up

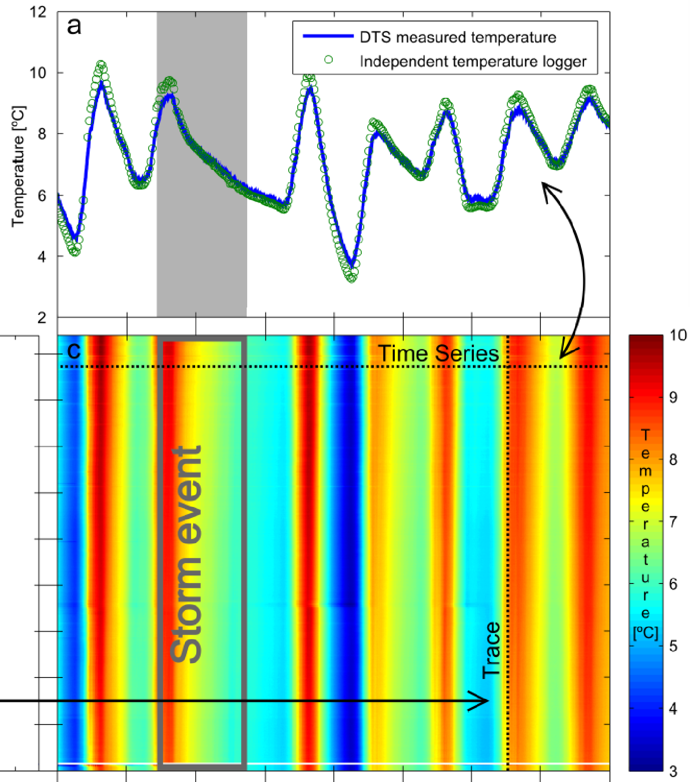
A fibre optic cable has been installed on the bed of a drainage channel starting at Kiosk E in the Blackwater catchment (Figure 1a and Figure 2). The cable is ruggedised and specifically designed for temperature monitoring in a range of environmental conditions (Figure 1b). The drainage channel flows from the west to the east, with the flow small enough that the cable remains on the stream bed under its own weight. The base unit is housed in Kiosk E which provides power and a relatively stable operating temperature (Figure 1c). The installation allows us to measure the stream temperature along the 1 kilometre long fibre optic cable every 2 minutes with a 1 metre spatial resolution. Once a measurement has been acquired it is automatically downloaded from the base unit. The cable was installed in March 2012 and measurements have been obtained since then.

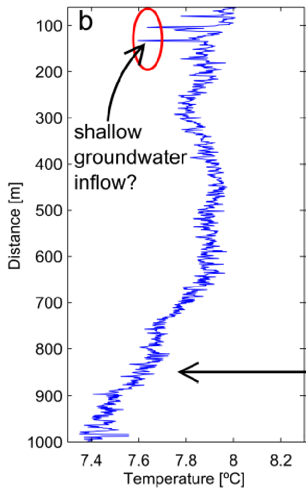
Reference temperatures are measured using thermocouples installed in and adjacent to Kiosk E. The temperature data from these are compared with the DTS data at the same locations, allowing the DTS data to be calibrated dynamically. Additional temperature loggers placed in the stream provide a validation of the DTS measured temperature.

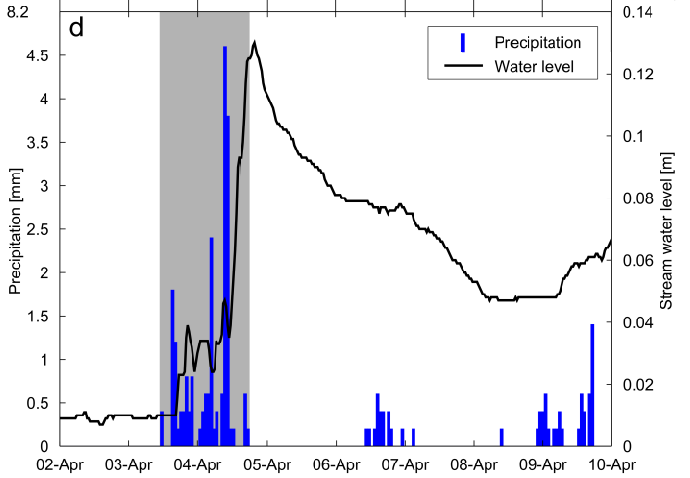
Figure 2. Fibre optic cable configuration with distance markings according to the distance reported by the DTS unit

DTS data set

Figure 3. Time series of the DTS measured temperature and temperature measured by an independent data logger at the same location (a), DTS measured temperature at 12:00 on the 8th April 2012 (b), colour plot of DTS data collected between 2nd April and 10th April 2012 (c), and precipitation (hourly intervals) and stream water level between 2nd April and 10th April 2012 at Kiosk E (d). The distance is the length along the fibre optic cable







The DTS data can either be considered as a time series at a single location (Figure 3a), or as a trace, which is a synchronous measurement along the entire cable (Figure 3b), or. Putting all of these data together yields Figure 3c, which allows us to look at variations in temperature over both space and time.

During storm events, the daily temperature variation is much reduced along the whole reach. This is especially apparent on the 4th April 2012 (Figure 3a and 3c), following around 21mm of rainfall and a resulting 0.12m Increase in water level (Figure 3d). Here the daily maximum in stream temperature is completely lost, potentially due to both a decreased atmospheric energy input and an advective input from direct precipitation. Additionally, in the first 400m there are subtle 'striping' effects, where the stream temperature is more stable over time. These are potential areas of shallow groundwater inflow and are the subject of future geophysical work.

Concluding Remarks

Through the use of DTS we are able to monitor in-stream temperature at a high level of spatial and temporal resolution. The large data set allows us to observe the stream temperature dynamics during storm events and to begin to investigate the different water sources. The stream temperature response to storm events of different magnitudes and intensities, with different antecedent conditions will be investigated as the DTS stream temperature data set is collected over an annual cycle. The temperature data collected are also of ecological significance and can potentially be used for the determination of gas flux estimates.

References

Constantz, J. (2008), Heat as a tracer to determine streambed water exchanges, *Water Resour. Res., 44*

Selker, J. S., L. Thevenaz, H. Huwald, A. Mallet, W. Luxemburg, N. Van de Giesen, M. Stejskal, J. Zeman, M. Westhoff, and M. B. Parlange (2006), Distributed fiber-optic temperature sensing for hydrologic systems, *Water Resour. Res., 42*