Technical Note: Bed conduction impact on fiber optic DTS water temperature measurements

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Technical Note: Bed conduction impact on fiber optic DTS water temperature measurements

T. O'Donnell Meininger and J. S. Selker

Oregon State University, Department of Biological and Ecological Engineering, Corvallis, 97331, Oregon, USA

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Correspondence to: T. O'Donnell Meininger (tlodonnell@gmail.com)

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Abstract

Error in Distributed Temperature Sensor (DTS) water temperature measurements may be introduced by contact of the fiber optic cable sensor with bed materials (e.g., seafloor, lakebed, stream bed). Heat conduction from the bed materials can affect cable temperature and the resulting DTS measurements. In the Middle Fork John Day River, apparent water temperature measurements were influenced by cable sensor contact with aquatic vegetation and fine sediment bed materials. Affected cable segments measured a diurnal temperature range reduced by 10 % and lagged by 20–40 min relative to that of ambient stream temperature. The diurnal temperature range deeper within the vegetation–sediment bed material was reduced 70 % and lagged 240 min relative to ambient stream temperature. These site-specific results illustrate the potential magnitude of bed-conduction impacts with buried DTS measurements. Researchers who deploy DTS for water temperature monitoring should understand the importance of the environment into which the cable is placed on the range and phase of temperature measurements.

1 Introduction

Distributed Temperature Sensing (DTS) allows averaged temperature measurement at 0.25–2 m intervals along a fiber optic cable. The utility of DTS to characterize a wide variety of environmental systems has been demonstrated (e.g., Selker et al., 2006; Lowry et al., 2007; Henderson et al., 2009; Sayde et al., 2010). Accurate measurement requires that the temperature of the fiber optic cable equilibrates with the temperature of the measured media. Heat fluxes that are external to that media can significantly impact cable temperature depending on media properties, surrounding system characteristics, and the physical placement of the cable within the media. For instance, Neilson et al. (2010) reported bias in DTS water temperature measurements due to solar heating of the submersed fiber optic cable. Under conditions of minimal water

GID
4, 375–384, 2014

turbulence and shallow depth, cable absorption of shortwave solar radiation caused significant measurement error. A valuable contribution of the work was to quantify this temperature biasing effect based on water velocity and depth.

Conduction or convection of heat from external media to the fiber optic cable is another biasing influence on DTS measurements. Researchers who used DTS to measure pore-water temperature below stream beds have sought to increase measurement accuracy by burying fiber optic cable within the bed, rather than by placing it on top where contact with the stream water introduced an external heat flux (Lowry et al., 2007; Krause et al., 2012). Conversely, heat conduction from bed materials may influence apparent water temperature measurements. For DTS measurements in hydrologic systems, fiber optic cable has been deployed to the bottoms of estuaries, lakes, and rivers. The cable used in these installations is typically selected to be denser than water to keep the cable at the bottom of the water column and limit exposure to the air–water interface and solar radiation (e.g., Petrides et al., 2011). However, cable contact with seafloor, lakebeds, and stream beds introduces the potential for conduction heat flux from the bed material. In some cases, the bed material may partially or fully envelop the cable (Fig. 1), reducing and delaying the diurnal range of the water temperature measurements due to the heat transfer processes in the sediments.

Factors affecting bed conduction are themselves determined by several variables. First, equilibration of bed temperature and water temperature varies seasonally and diurnally, and also depends on bed material type and composition. Second, the surface area of cable contact with the bed depends largely on bed material type. Harder bed materials (stone, concrete, packed fine sediment) contact the cable minimally, while softer materials (loose fine sediment, aquatic vegetation) can partially or fully envelop the cable. Other factors, such as solar exposure and stratified water systems, are not treated here. Additionally, for a rich set of literature on phase and amplitude patterns in thermal signals as a function of depth, refer to Hatch et al. (2006) and Luce et al. (2013).

This paper presents observed thermal impacts on DTS data arising from contact with the stream bed based on fluvial temperature data from the Middle Fork John Day River, Oregon, USA. Supplementary temperature measurements made within and above the bed material quantified the differences in diurnal temperature signals of the bed and ambient stream water.

2 Data and observations

2.1 DTS water temperature measurements

In the summer of 2011, stream temperature was monitored on a 375 m reach ("study reach") of the Middle Fork John Day River using DTS. The upstream end of the study reach was located at 44.642362° N, 118.653738° W.

The installation employed a custom-built fiber optic cable manufactured by AFL Telecommunications, consisting of two Giga-Link 600 multimode fibers protected by a 1.0 mm o.d. stainless steel loose tube, a resin-stabilized fiberglass sheath, and a meter-marked polyurethane jacket, completing the cable to a 2.5 mm diameter. The cable was installed in the stream channel thalweg and was observed to sink and remain stable on the river bed in all water conditions except the most turbulent. Alluvial rocks were placed to secure the cable where the risk of cable movement was high. A SensorTran Gemini DTS instrument was used for data collection. The installation was powered by a photovoltaic system and housed in a 2 m × 3 m × 2 m trailer. The DTS temperature readings were calibrated to three point temperature measurements collected by Onset HOBO Water Temp Pro v2 dataloggers. One logger measurement was made within a 0 °C ice bath co-located with 30 m of cable, and two of the measurements were made within the stream itself at the upstream and downstream extremes of the installation, each co-located with 12–20 m of cable.

Visual assessments of cable position, channel bed type, and flow conditions were made. Channel bed material beneath most of the study reach consisted of cobbles and a few sections of hard-packed fine sediments. The only recorded exception to these bed conditions consisted of three 5 to 20 m long segments where aquatic vegetation

GID
4, 375–384, 2014

growing in beds had trapped fine sediments to create thick, soft and porous layers of suspended vegetation and mineral matter over the buried hard bed. The fiber optic cable (density: $1.6\,\mathrm{g\,cm^{-3}}$) installed over these vegetation–sediment layers became partially or fully enveloped in the soft material.

The apparent temperature dynamics of cable sections that intersected the vegetation–sediment layers were altered (purple-highlighted segments in Fig. 2) relative to adjacent sections of cable. The range of diurnal temperature variation was reduced typically by 10 % and lagged in time by 20–40 min relative to that of the ambient stream water.

2.2 Vegetation–sediment layer temperature measurements

To establish the magnitude of DTS stream temperature bias relative to cable position within the vegetation–sediment layer, temperatures within and above a layer were continuously monitored at three vertically distributed locations. The monitored vegetation–sediment layer was located at 44.596325° N, 118.523347° W. The experimental setup employed Onset HOBO Water Temp Pro v2 point temperature loggers to continuously measure temperature deep within the vegetation–sediment layer (*Location 1*), near the top of the layer (*Location 2*), and in the stream water above the layer (*Location 3*). According to field observations, the fiber optic cable generally rested closest to *Location 2*, though the cable may sink deeper into the layer (*Location 1*) or to remain above it (*Location 3*).

Over the two monitored days (24–26 August 2010), the temperature range at *Location 1* was reduced by 70 % relative to the range of the stream temperature and the extremum lagged those of stream temperature by 180–240 min (Fig. 3). At the top of the vegetation–sediment layer (*Location 2*) the diurnal temperature range was less affected, reduced by just 10 % and lagged by 10 to 20 min.

GID
4, 375–384, 2014

T. O'Donnell Meininger and J. S. Selker

3 Discussion

Vegetation–sediment layers on the Middle Fork John Day River stream bed impacted DTS water temperature measurements by reducing the measured diurnal temperature range by 10 % and by causing a 20–40 min lag. If the cable had been placed deeper within the layers, the diurnal range reduction may have been as high as 70 % of the stream temperature range and the lag may have been as long as 240 min. While these impacts were site-specific (unique to the location and stream bed material), DTS water temperature measurements in other hydrologic systems may be affected by related bed material effects. Researchers who deploy DTS to stream beds, seafloor, or lakebeds for water temperature monitoring would do well to understand the environment into which the cable is placed and to flag potential measurement error due to conduction from bed materials.

The Supplement related to this article is available online at doi:10.5194/gid-4-375-2014-supplement.

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GID
4, 375–384, 2014

Bed conduction impact on fiber optic DTS water temperature measurements

T. O'Donnell Meininger and J. S. Selker

References

Hatch, C. E., Fisher, A. T., Revenaugh, J. S., Constantz, J., and Ruehl, C.: Quantifying surface water–groundwater interactions using time series analysis of streambed thermal records: method development, Water Resour. Res., 42, W10410, doi:10.1029/2005WR004787, 2006.

Henderson, R. D., Day-Lewis, F. D., and Harvey, C. F.: Investigation of aquifer-estuary interaction using wavelet analysis of fiber-optic temperature data, Geophys. Res. Lett., 36, L06403, doi:10.1029/2008GL036926, 2009.

Krause, S., Blume, T., and Cassidy, N. J.: Investigating patterns and controls of groundwater up-welling in a lowland river by combining Fibre-optic Distributed Temperature Sensing with observations of vertical hydraulic gradients, Hydrol. Earth Syst. Sci., 16, 1775–1792, doi:10.5194/hess-16-1775-2012, 2012.

Lowry, C. S., Walker, J. F., Hunt, R. J., and Anderson, M. P.: Identifying spatial variability of groundwater discharge in a wetland stream using a distributed temperature sensor, Water Resour. Res., 43, W10408, doi:10.1029/2007WR006145, 2007.

Luce, C. E., Tonina, D., Gariglio, F., and Applebee, R.: Solutions for the diurnally forced advection–diffusion equation to estimate bulk fluid velocity and diffusivity in streambeds from temperature time series, Water Resour. Res., 49, 488–506, doi:10.1029/2012WR012380, 2013.

Neilson, B. T., Hatch, C. E., Ban, H., and Tyler, S. W.: Effects of solar radiative heating on fiber optic cables used in aquatic settings, Water Resour. Res., 46, W08540, doi:10.1029/2009WR008354, 2010.

Petrides, A. C., Huff, J., Arik, A., van de Giesen, N., Kennedy, A. M., Thomas, C. K., and Selker, J. S.: Shade estimation over streams using distributed temperature sensing, Water Resour. Res., 47, W07601, doi:10.1029/2010WR009482, 2011.

Sayde, C., Gregory, C., Gil-Rodriguez, M., Tufillaro, N., Tyler, S., van de Giesen, N., English, M., Cuenca, R., and Selker, J. S.: Feasibility of soil moisture monitoring with heated fiber optics, Water Resour. Res., 46, W06201, doi:10.1029/2009WR007846, 2010.

Selker, J. S., Thévenaz, L., Huwald, H., Mallet, A., Luxemburg, W., van de Giesen, N., Stejskal, M., Zeman, J., Westhoff, M., and Parlange, M. B.: Distributed fiber-optic temperature sensing for hydrologic systems, Water Resour. Res., 42, W12202, doi:10.1029/2006WR005326, 2006.

GID
4, 375–384, 2014

Bed conduction impact on fiber optic DTS water temperature measurements

T. O'Donnell Meininger and J. S. Selker

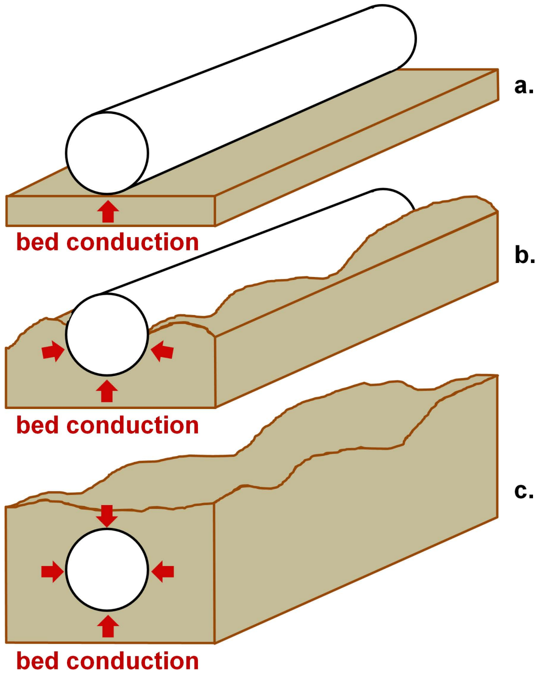

Figure 1. The impact of bed conduction on DTS measurements depends on the degree of fiber optic cable burial within bed materials, including **(a)** not buried, **(b)** partially buried, and **(c)** fully buried.

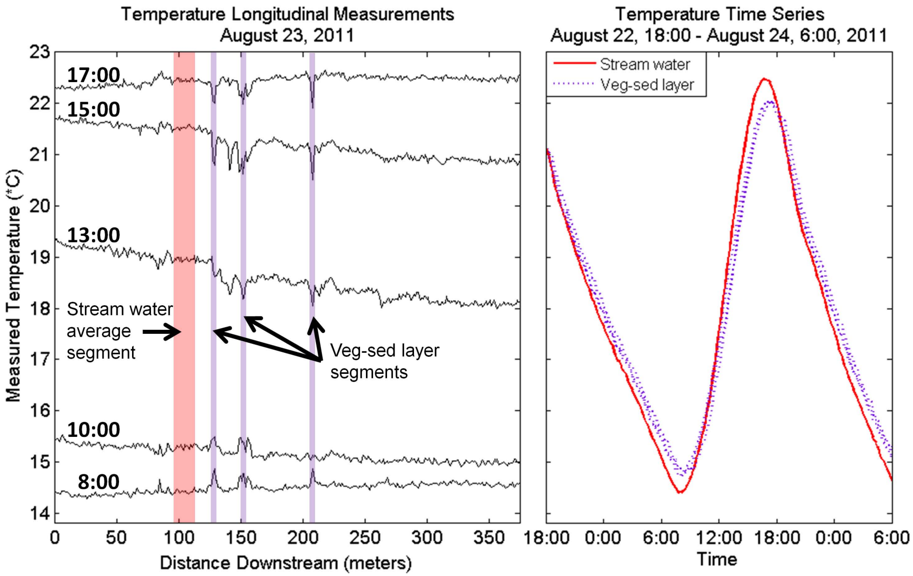

Figure 2. DTS stream temperature measurements taken at 08:00, 10:00, 13:00, 15:00 and 17:00 PST along 375 m of the Middle Fork John Day River are shown on the left, with segments that intersected vegetation–sediment layers (centered at 129, 152, and 208 m downstream) highlighted in purple. On the right, these temperature measurements within the layers were plotted temporally with average ambient stream water temperature (distance-averaged temperature from 96 to 116 m downstream).

GID
4, 375–384, 2014

Bed conduction impact on fiber optic DTS water temperature measurements

T. O'Donnell Meininger and J. S. Selker

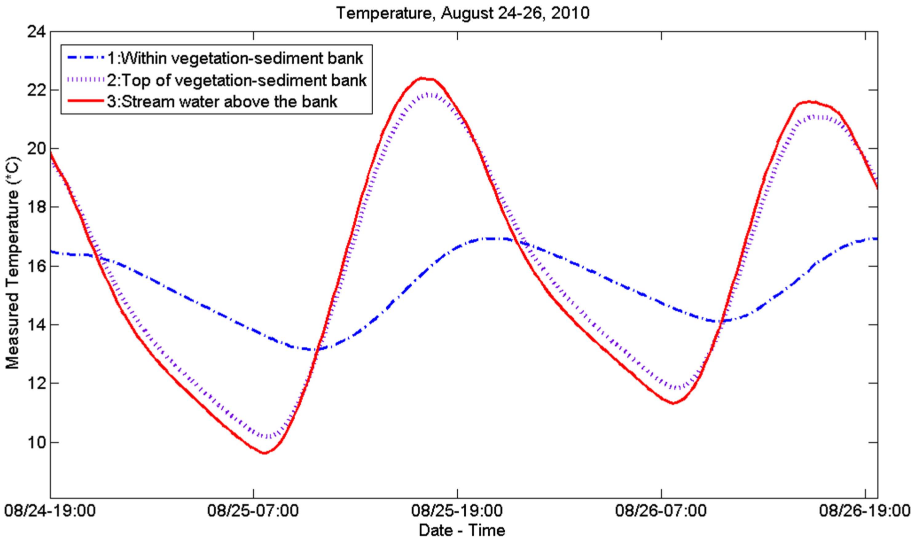

Figure 3. Two days of point temperature measurements from above, within and below the vegetation–sediment layer.

GID
4, 375–384, 2014