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Supplementary material to "Taking the Temperature of Ecological Systems With Fiber Optics"

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Citation:
Selker, J. S. (2008), Taking the temperature of ecological systems with fiber optics, *Eos Trans. AGU, 89*(20), 187. [Full Article (pdf)]

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Fiber-optic distributed temperature sensing (DTS) is emerging as a powerful tool for observation of hydrological and ecological processes over a wide range of spatial and temporal scales. Several studies published over the last year suggest a broad range of applications (e.g., Selker et al., 2006a, b, Westhoff et al., 2007, Lowry et al., 2007, Moffett et al., 2008). DTS uses standard fiber-optic communication cables and can report the temperature of each meter of cable for distances exceeding 10 kilometers as frequently as every 3 seconds. With careful calibration, long integration times (>1 hour), and short cables (<4 kilometer), precision approaching 0.01ºC can be achieved at 1-meter spatial resolution. With the ability to precisely observe temperature at tens of thousands of locations, DTS holds potential for transformative observation of diverse processes throughout earth and ecological science. The technique involves many non-standard applications of component technologies that have not previously been employed within these communities, presenting challenges with respect to equipment selection, installation, and data analysis. A series of workshops is being put on by the Consortium for the Advancement of Hydrologic Sciences Incorporated (CUAHSI) Hydrologic Measurement Facility (HMF) to aid the successful application of DTS methods. Here we report on the first workshop, "Fiber Optic Distributed Temperature Sensing for Ecological Characterization," held 10–15 September 2007, and announce the next workshop, to be held 2–7 June 2008.

The 2007 workshop was supported by the NSF, in cooperation with the USGS Ground-Water Resources Program. The event was held at the H J Andrews Long-term Ecological Research (LTER) site in Blue River, Oregon. The instructors for the workshop were John Selker (Oregon State University), Scott Tyler (University of Nevada, Reno), and Fred Day-Lewis and John Lane (USGS, Office of Ground Water, Branch of Geophysics). There were 30 enrollees in the workshop, with a supporting field crew of 6 graduate students, for a total of 40 full-time participants. The participants received a hands-on introduction to DTS, which included coverage of cable and instrument selection, cable deployment, power requirements, fiber repair, data acquisition, measurement calibration, QA/QC, and data visualization and analysis. The participants took part in the design, installation, and analysis of three field experiments using DTS systems from leading DTS manufacturers: Agilent, Sensornet, and SensorTran[1]. These active-learning exercises sought to measure surface-water/ground-water interactions and airshed thermal processes using DTS methods. The workshop included a poster session with 16 contributions that presented a diversity of current and planned deployments.

Two of the three field installations were focused on stream temperatures at research watersheds within the LTER: Watershed 3 (WS3) was chosen for its contrasting bedrock and alluvial reaches, its considerable history of data collection, and as a test case for deployment in steep, challenging terrain. Fiber-optic cable was laid along the stream thalweg, with coils placed in larger pools to better constrain temperatures at those locations. The large number of boulder steps and log jams as well as occasional subterranean reaches in WS3 made cable deployment particularly challenging and required the exposure of many sections of cable to the air in order to negotiate such obstacles. These sections were used opportunistically by suspending the cable to measure variations in air temperature. As expected, the influence of hyporheic exchange was pronounced between the bedrock and alluvial reaches of the stream. Daytime water-bottom temperatures rose as the water flowed downstream over the bedrock, which represents an area of little or no hyporheic exchange, and fell in the alluvial reach, where surface-water interaction with the sediment is more pronounced; at night the reverse was true (Figure 1). Notably, the downstream end of the alluvial reach maintains the same temperature to within 0.1ºC throughout the period of observation. These processes were further explored using ice-pulses and chemical tracers, and will be the subject of upcoming publications.

The airshed fiber-optic array was installed in Watershed 1 with the goal of understanding the daily cycle of air movement in the valley, with particular interest in nocturnal cold-air drainage from higher elevations (e.g., Pypker et al., 2007). The experiment entailed installations of four different types of cable. One armored cable was set in the stream bed. A second cable was helically wrapped in a machined groove of a 3-inch, Schedule 80 PVC pipe so that there was 1 meter of fiber length per 0.0254 meter of pipe height, thus providing a high-resolution vertical profile of temperature immediately above the stream. A third 700-meter long cable crossed the width of the valley at elevations of 2.5, 5.0, 7.5, 10, 12.5, 15, 17.5, 20, 25, 30 and 37 meters perpendicular to the stream (Figure 2). The greatest logistical challenge for this deployment was threading the cable through the dense forest canopy, which was achieved by first positioning guide strings into place using a 8-bar 50-centimeter barrel PVC potato launcher fitted with a bow-fishing line (Gurstelle, 2001). The final cable was deployed by a Helium-filled blimp to a height in excess of 120 meters, providing continuous monitoring of the vertical temperature profile (data not shown).

Many technical issues were discussed during the course of the workshop, including the choice of DTS, fiber-optic cable, the need for additional test and repair tools (notably the expensive optical time domain reflectometers and fusion splicers) and the cost-benefit between fiber-optic versus conventional point-measurement instruments. The issue of cable selection received special attention, as cables vary greatly in cost (<$0.20 to >$10/meter), loss rate, flexibility, tensile strength, resistance to crushing, resistance to animals (e.g., squirrels, beaver, muskrats) and vandalism, weight, and even the durability of meter marks along the cable (a conversation based on painful experience...).

DTS has great promise for efficiently gathering precise, high-resolution environmental temperature data under many circumstances. The installations provided workshop participants with practical on-the-ground fiber-optic handling and deployment experience, as well as exposure to hydrologic and atmospheric applications of the DTS technology. The workshop provided an exciting and efficient venue for dissemination of this technology, but several key challenges remain for broadening its use. First, although costs continue to decrease, purchase and deployment of a DTS and high quality fiber-optic cable costs about $50,000, which excludes the technology from use in many studies. More importantly, the substantial knowledge base required to successfully design, deploy and troubleshoot a DTS installation commonly requires the involvement of highly experienced users. The participants indicated that expanded use of this innovative technology within the hydrologic community would be greatly facilitated through programs for DTS rental, lease, or cooperative purchase and through on-site support from experienced users. The CUAHSI HMF views DTS as a transformative technology that it intends to support to the greatest degree possible. A follow-on workshop will take place 2–7 June 2008, as described at the CUAHSI website (http://www.cuahsi.org).

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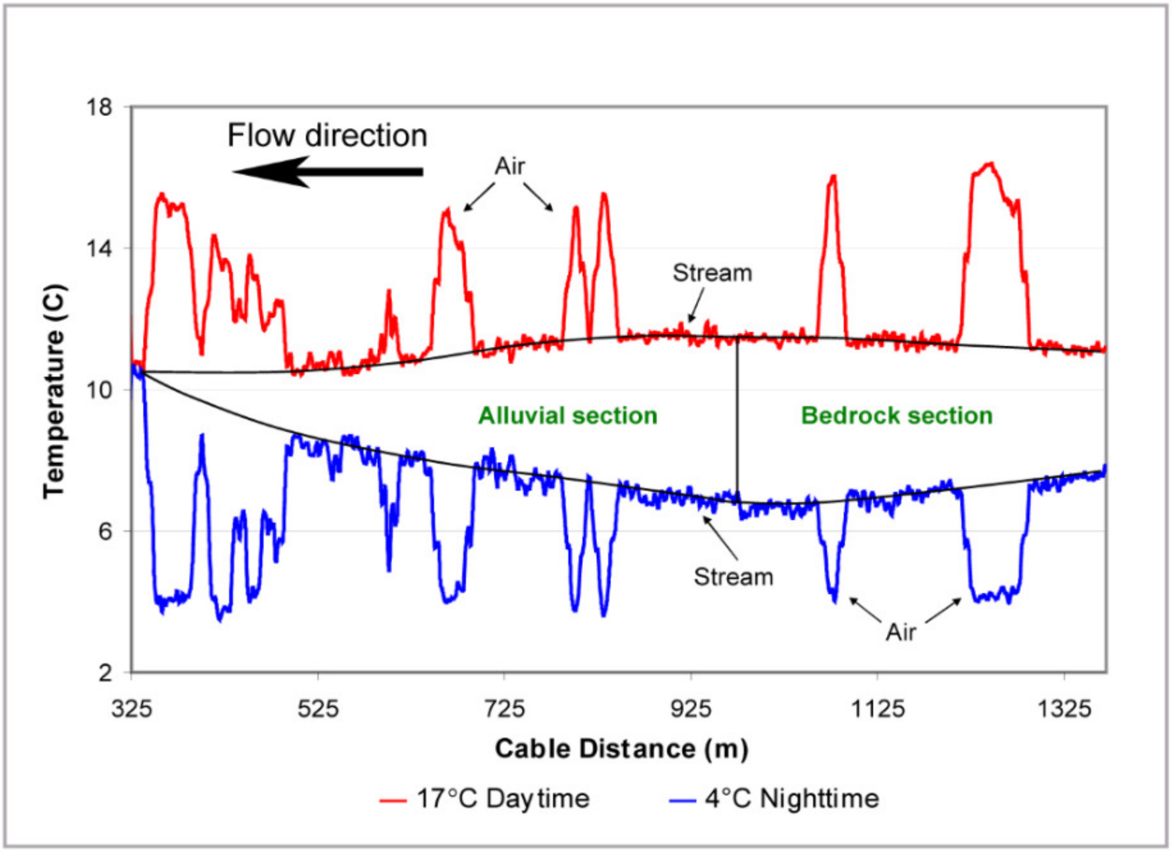

Figure 1. DTS data from coldest and warmest datasets obtained 27 September 2007–at 6 AM ("nighttime" when air temperature was 4ºC) and 5 PM ("daytime" when air temperature was 17ºC)–in Watershed 3 (Brugg BruSteel cable and Sensornet double-ended Sentinel DTS). Stream flows right to left. Sketched black lines are interpolated stream-bottom temperature along the reach. Data reflecting air deployments of the fiber are those far from the two black lines. The bedrock reach warms in the day and cools at night with distance downstream (towards the left), while the reach with deep alluvial fill has the opposite pattern due to hyporheic exchange with the bed material. Measurements at cable distance 325 meters are where the stream has re-emerged following a >10 meter section where the entire flow was carried sub-surface through a log and debris conglomeration. The cable distance includes air and coil deployments, thus does not directly reflect the stream distance, which was approximately 700 meters.

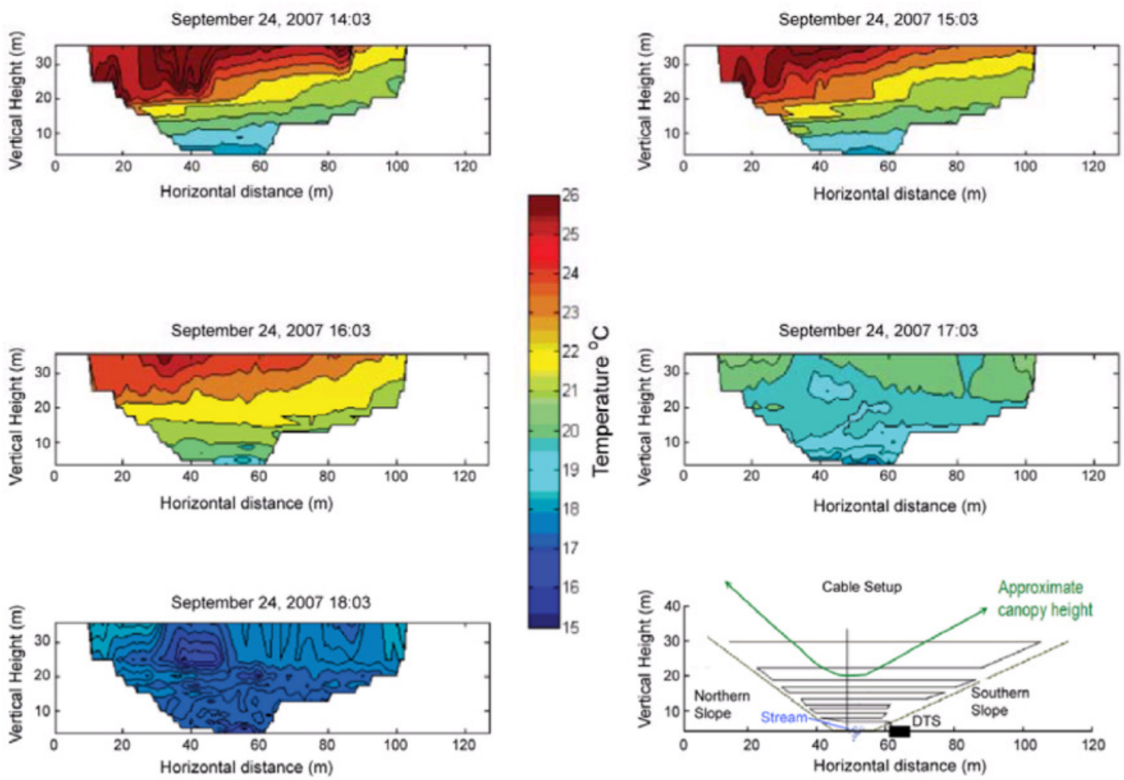

Figure 2. Interpolated temperature from the Airshed study based on 1-hour DTS data, 24 September 2007, from the cable setup shown in lower right panel (obtained with Brugg BruSteel fiber and Agilent double-ended NA4386A DTS) in Watershed 1. Cooling is seen in the late afternoon, with cold air masses immediately above the tree canopy and above the stream.

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[1]Use of brand names is for information purposes only and does not constitute endorsement by the U.S. Government or any other organization or individual among the authors.

 published 13 May 2008