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JGR – Earth Surface

Supporting Information for

A river on fiber: spatially continuous fluvial monitoring with distributed acoustic sensing

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Introduction

This supporting information contains supporting details on tap testing and georeferencing procedures, the Shield's stress calculation, turbulent eddy frequencies, and the "knocking" signal propagation velocity and distance optimization.

Text S1. Tap tests and cable georeferencing

To map along-cable distances to georeferenced positions on the creek, we conducted "tap tests" at 17 points outside the flow, tugging the cable in opposing directions to produce a sharply polarized, high-amplitude strain signal (positive/negative) on either side of the closest DAS channel. Tap tests were documented with time- and Global Positioning System (GPS)-tagged photographs. Each tap test was then identified in the downsampled, 0.1–1 Hz bandpassed DAS data and associated with its tap test location.

We manually validated the tap test GPS locations and reconstructed the cable path in Google Earth Pro (Figure 1a) using deployment photographs (e.g., Figure 1b) and satellite imagery (Google Earth Pro, 2019) cross-validated with a 1 m resolution United States Geological Survey's 3D Elevation Program (3DEP) lidar-derived digital surface model (U.S. Geological Survey, 2015). Estimated confidence in the tap test locations is ±1 m. Along-path and along-cable distances agree within 2.45 m.

Text S2. Shields stress

We used river flow depths collected concurrent with DAS deployment to estimate the riverbed shear stress and the associated potential for grain motion. We calculated a dimensionless Shields stress, τ^*, criteria, which approximates the ratio of driving and resisting stresses acting on a particle as

$$\tau^* = \frac{\rho h S}{(\rho_s - \rho) D_{50}}, \tag{1}$$

where ρ is the fluid density (kg/m^3), ρ_s is the sediment density (kg/m^3), h is flow depth (m), S is the bed slope (m/m), and D_{50} is the median grain size of particles on the riverbed (m). It is generally accepted that the threshold for particle transport, often called critical Shields stress, τ_c^*, is well-described by a narrow range of Shields stress values, τ_c^* = 0.03 – 0.08 (Buffington and Montgomery, 1997). We thus computed a range of Shield's stresses during deployment as a fraction of τ_c^* by solving Eq. 1 using an assumed sediment density of ρ_s = 2700 kg/m^3 and measured channel bed slope (S = 0.003), median grain size (D_{50}= 0.05 m) and minimum and maximum surveyed thalweg flow depths (h = 0.21 – 0.55 m) in the study reach. Estimated τ^* / τ_c^* during deployment fell between 9.3% (for τ_c^* = 0.08) and 64.7% (for τ_c^* = 0.03).

Text S3. Turbulent eddies

By Taylor's frozen turbulence hypothesis (Taylor, 1938), the period of velocity fluctuations at a given point represents the time for an eddy of a given size to advect past at the mean flow velocity u. The frequency of velocity fluctuations generated by eddies with characteristic length scale L is therefore $f \sim u/L$. The maximum frequency, associated with the smallest turbulent length scale, i.e., the Kolmogorov microscale, is ~10^3-10^4 Hz for typical Reynolds numbers found in rivers (Tennekes and Lumley, 1972), and the minimum frequency varies with position within the water column. Far from the bed, the largest eddy size can be approximated as the flow depth $L \sim h$ (Jerolmack and Paola, 2010), whereas eddies in the boundary layer at the bed are represented by the roughness-dependent turbulent mixing length (Schlichting, 1979) approximated as $L \sim 3\pi D_{50}$ (Gimbert et al., 2014). Using the range of measured flow velocities, corresponding flow depths and median grain size for Clear Creek, we estimate a minimum frequency range between ~0.4 and ~6 Hz throughout the study reach. Since the DAS data records frequencies in the ~10^{-1}-10^4 Hz range, we assume the observed signal includes acoustic information about turbulent length scales and associated velocity fluctuations.

Text S4. "Knocking" analysis

We investigated the "knocking" signals by manually picking arrival times for 82 events. Picking was semi-automated by cross-correlation of all traces with an analyst-selected reference trace. Earliest arrivals consistently occur at DAS channel 596 (Figure S3a). Assuming propagation through a homogeneous medium, the arrival time of the knocking signal at each channel is $t = t_0 + \sqrt{(x - x_0)^2 + z^2}/v$, where t_0 is the event origin time, x is the along-cable position, x_0 is the along-cable position of the source, z is the shortest distance from source to cable, and v is the homogeneous wave propagation velocity. We grid-searched over z and v values for each event to minimize misfits between observed and calculated times. Optimized velocities were consistently around 2,000 m/s (Figure S3b), and optimized source-cable distances were bimodally distributed with peaks at 0 m and ~2 m (Figure S3c). We note, however, that because strain rate at each channel is averaged over 3.24 m (4 channels), the apparent travel time curves are artificially rounded near the apex close to x_0, which would tend to increase the z value found by the grid search.

The optimal propagation velocities are substantially above the propagation velocity of sound in water, suggesting they are propagating through the cable itself. To explore this hypothesis, we conduct two more limited grid searches. In the first we assume "knocks" originate from cable impacts on the bed and fix the distance from the cable to zero. We find similar optimal velocities (Figure S3b) and misfits (Figure S3d) relative to the unconstrained grid search. Second, we assume an external source and optimize only the distance away from the cable, setting the propagation velocity to that of sound in water (1,450 m/s). This leads to substantially higher misfits than in the previous two analyses (Figure S3d), indicating that this signal is not propagating through the water and that its source is co-located with the cable.

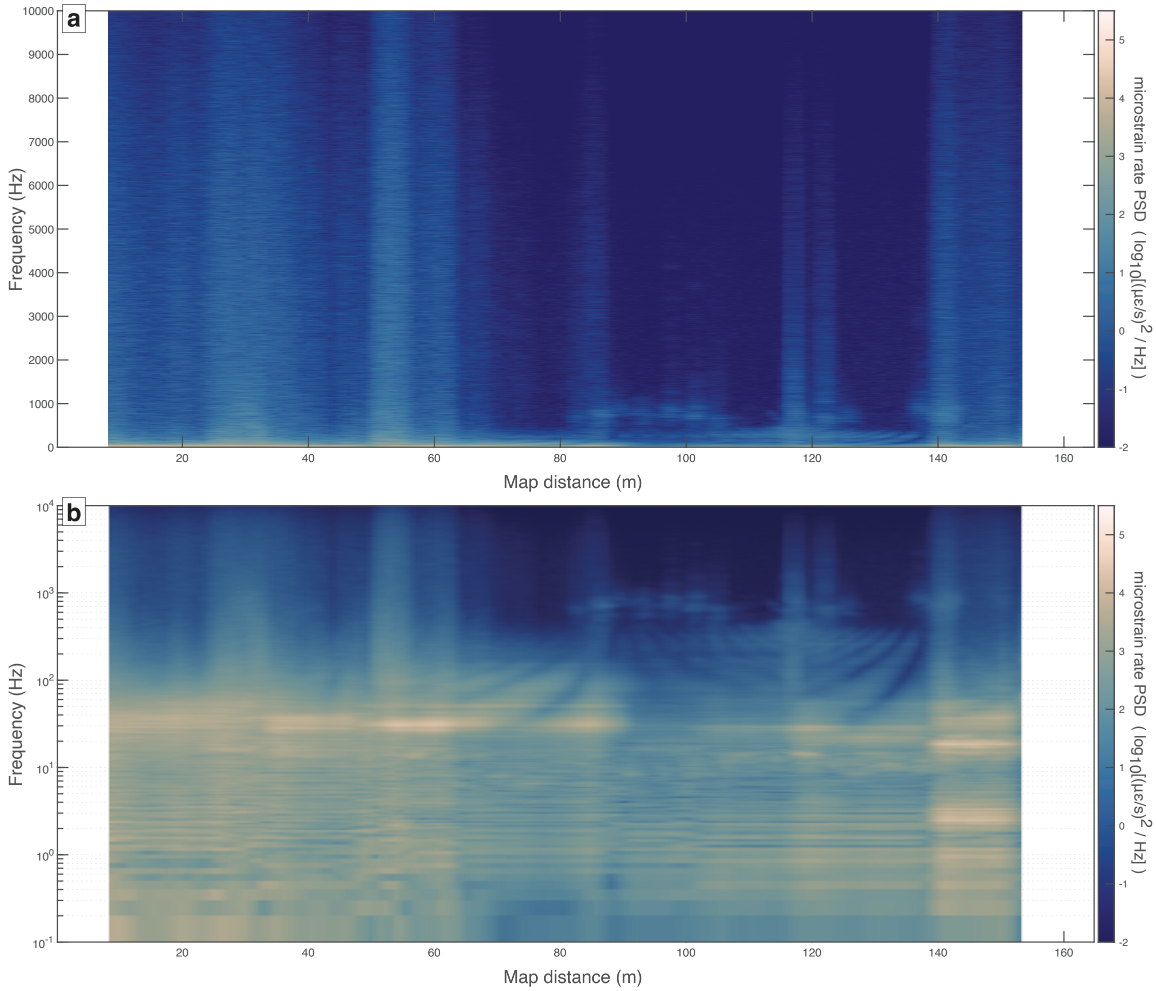

Figure S1. Spatial spectrograms showing power spectral density (PSD) averaged over three 10 s segments of microstrain rate data at each position. Spectrograms shown up to 10 kHz on both **a)** linear and **b)** log frequency axes.

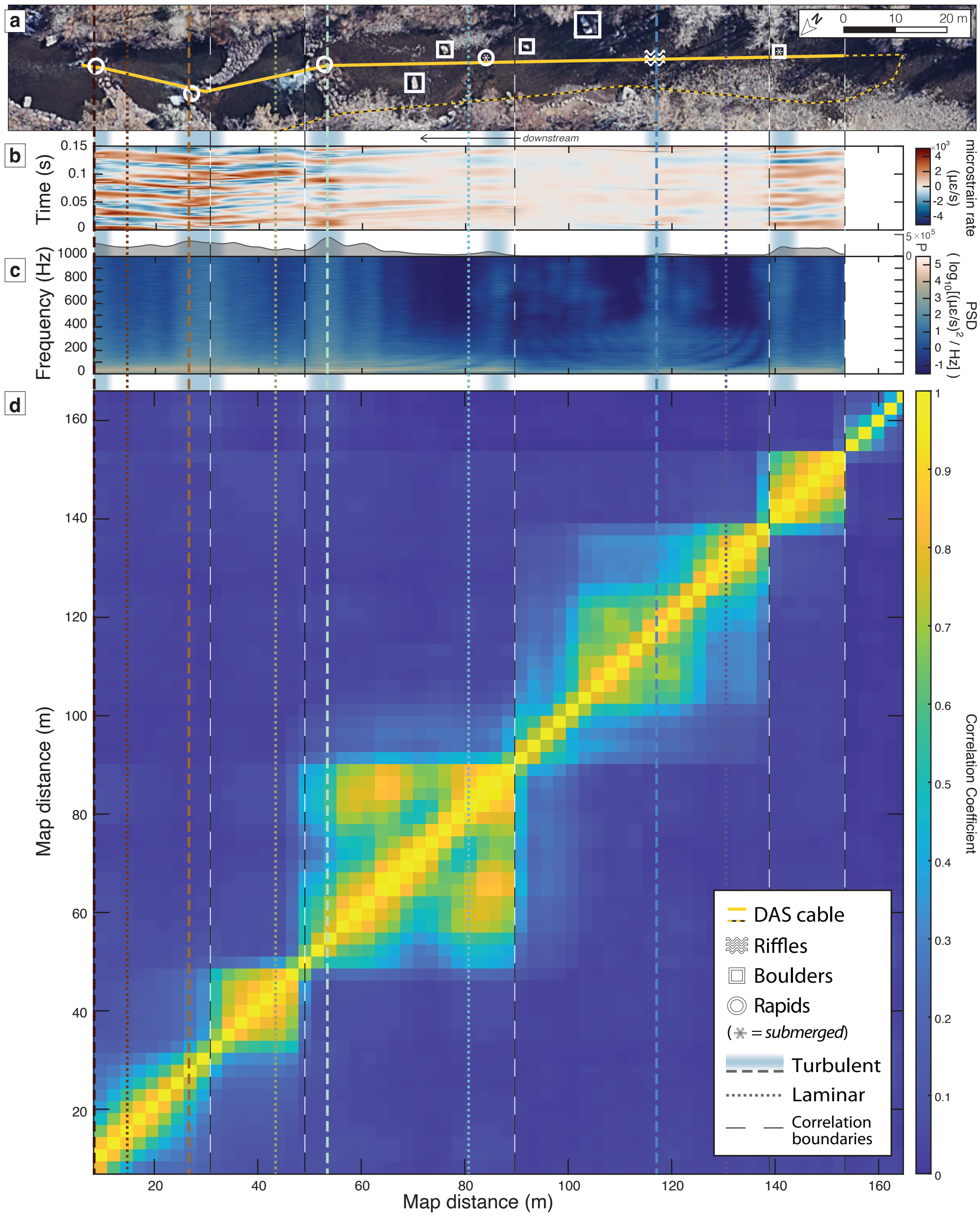

Figure S2. All spatially aligned DAS data from Figures 1 and 2 (main text), shown together for ease of spatial referencing. **a)** Site map, **b)** microstrain rate, **c)** power spectral density (PSD) and total signal power (P) (gray) (shown in Figure 1), and **d)** along-stream wave coherence (shown in Figure 2). Vertical dashed and dotted lines indicate locations of example spectra shown in Figure 3; long dashed lines mark approximate boundaries between regions of high coherence.

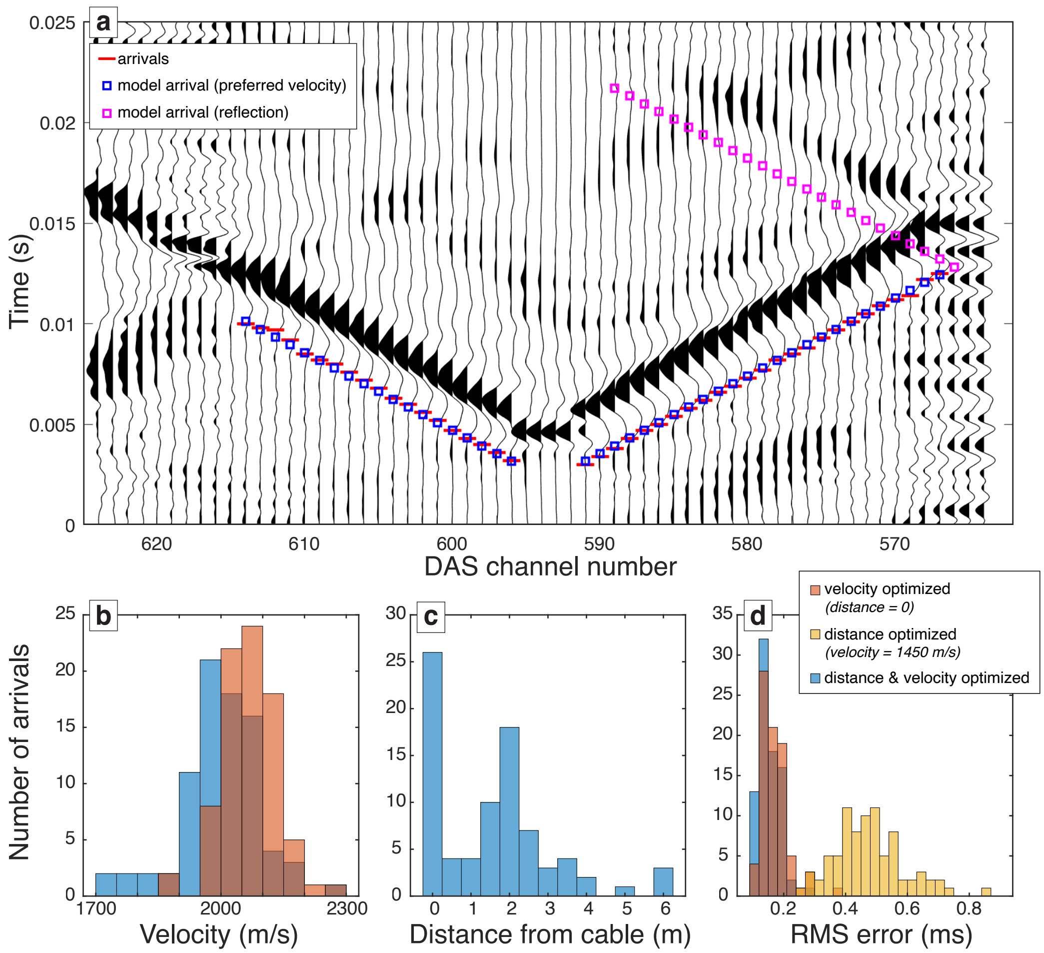

Figure S3. a) Waveforms for one "knocking" event with picked arrival times (red dashes), calculated arrival times for the preferred propagation velocity (blue squares), and calculated arrival times for a reflection (purple squares). Each trace is individually normalized by its maximum amplitude. **b)** Histogram of best-fitting propagation velocities for all 82 "knock" signals when the source distance from the cable is optimized (blue) or set to zero (orange). **c)** Best-fitting distance from the cable. **d)** Misfit between observed and calculated travel times when both velocity and distance from the cable are optimized (blue), when only velocity is optimized and distance from the cable is set to zero (orange) and when distance away from the cable is optimized and the propagation velocity is set to 1450 m/s — the velocity of sound in water (yellow).