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Long-range fiber-optic earthquake sensing by active phase noise cancellation

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We introduce a novel fiber-optic environmental deformation sensor operating on active phase-noise cancellation (PNC). Networks with PNC have been established over the last decade by national metrology institutes to enable state-of-the-art frequency dissemination of atomic clock signals. Utilizing this infrastructure, PNC sensing exploits recordings of a compensation frequency that arises in the frequency dissemination. As the recording operates simultaneously with the metrological service, the existing phase-stabilized metrological networks can be co-used with minimal effort as environmental sensors. The compatibility of PNC sensing with inline amplification enables the interrogation of cables with lengths beyond 1000 km, potentially contributing to earthquake detection and early warningsystems in the oceans.

In a practical application, we analyze the recordings of a magnitude 3.9 earthquake in eastern France on a 123 km fiber-optic link between Bern and Basel, Switzerland. Through spectral-element seismic wavefield simulations, we compute the theoretical compensation frequency time series on the in-line strain rates resulting from the seismic wavefield and compare it to the observations. Simulations account for the complex cable geometry and topography. Observed and computed recordings match for periods above 3 s.

As simulations appear to explain the data, we further deploy a moment tensor inversion for the same event. This involved computing Green's functions for all moment tensor components based on the full waveform. Comparing the inversion results to conventional source solutions from public earthquake databases yields a good fit, despite relying on a single data trace only, suggesting that PNC can be used for quantitative seismology. We discuss the detection of other earthquakes with this instrument and future research directions, including tomography.