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Leveraging coherent wave field analysis and deep learning in fiber-optic seismology

Benjamin Schwarz[1], Korbinian Sager[2], Philippe Jousset[1], Gilda Currenti[3], Charlotte Krawczyk[1,4], and Victor Tsai[2]

[1]GFZ German Research Centre for Geosciences, Potsdam, Germany (bschwarz@gfz-potsdam.de)
[2]Brown University, Providence, USA
[3]INGV - Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo, Italy
[4]Technical University Berlin, Berlin, Germany

Fiber-optic cables form an integral part of modern telecommunications infrastructure and are ubiquitous in particular in regions where dedicated seismic instrumentation is traditionally sparse or lacking entirely. Fiber-optic seismology promises to enable affordable and time-extended observations of earth and environmental processes at an unprecedented temporal and spatial resolution. The method’s unique potential for combined large-N and large-T observations implies intriguing opportunities but also significant challenges in terms of data storage, data handling and computation.

Our goal is to enable real-time data enhancement, rapid signal detection and wave field characterization without the need for time-demanding user interaction. We therefore combine coherent wave field analysis, an optics-inspired processing framework developed in controlled-source seismology, with state-of-the-art deep convolutional neural network (CNN) architectures commonly used in visual perception. While conventional deep learning strategies have to rely on manually labeled or purely synthetic training datasets, coherent wave field analysis labels field data based on physical principles and enables large-scale and purely data-driven training of the CNN models. The shear amount of data already recorded in various settings makes artificial data generation by numerical modeling superfluous – a task that is often constrained by incomplete knowledge of the embedding medium and an insufficient description of processes at or close to the surface, which are challenging to capture in integrated simulations.

Applications to extensive field datasets acquired with dark-fiber infrastructure at a geothermal field in SW Iceland and in a town at the flank of Mt Etna, Italy, reveal that the suggested framework generalizes well across different observational scales and environments, and sheds new light on the origin of a broad range of physically distinct wave fields that can be sensed with fiber-optic technology. Owing to the real-time applicability with affordable computing infrastructure, our analysis lends itself well to rapid on-the-fly data enhancement, wave field separation and compression strategies, thereby promising to have a positive impact on the full processing chain currently in use in fiber-optic seismology.