A velocity-based earthquake detection system using downhole DAS arrays – examples from SAFOD

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Distributed acoustic sensing (DAS) has emerged as a reliable and high-resolution seismic sensing technology for passive and active surveys, both on- and off-shore, and in deep boreholes as well as in shallow, horizontal telecommunication conduits. In all these applications, DAS has been shown to be an enticing alternative to conventional acquisition technology. One of the most promising applications of DAS to the field of seismology is the ability to incorporate high spatial resolution downhole arrays in earthquake monitoring.

We analyze about 20 days of data, recorded using an OptaSense ODH 3.1 interrogator at the San Andreas Fault Observatory at Depth (SAFOD) during June-July 2017. Data were sampled at 1 m spacing and a gauge length of 10 m in a tubed downhole fiber cemented between casing strings between 10 and 800 m depth.

As a first step, we utilize near-vertical incidence earthquakes, traveling parallel to the vertical array, to estimate P- and S- velocities. We compare the estimated P-wave model to those derived from a surface refraction survey and a conventional vertical seismic profiling (VSP) survey. We also obtained a P-wave model using the ambient field with just one day worth of data. The continuous nature of the DAS array allows us to accurately retrieve a high-resolution P-velocity model and extract an S-velocity model that couldn't be estimated from the VSP data.

Earthquakes recorded by the downhole DAS array display a depth-dependent moveout that is affected by the velocity structure at the location of the array as well as the angle of incidence at which wave-fronts cross the DAS fiber. We implement a moveout-based detection algorithm using previously estimated velocities. It is a pick-free, waveform-based, fast, simple to code, and fully automatic method. The technique scans a range of acceptable incidence angles, yielding the estimated incidence angle as a by-product. We apply the method to 20 days of recorded passive data, aiming at detecting both P and S phases. P and S detection results are combined and compared to the USGS catalog. We find that using a single, uniaxial downhole DAS system, we are able to detect above 70% of cataloged events within a radius of 15km as well as one weak uncatalogued event. These encouraging results set the path for downhole DAS monitoring of earthquakes.