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Enhanced seismograms from borehole arrays

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The Groningen gas field is a giant natural gas accumulation in the northeast of the Netherlands. Decades of production have led to significant compaction of the reservoir rock. The (differential) compaction is thought to have reactivated existing faults and to be the main driver of induced seismicity.
Most earthquake detections to date were made with a sparse pre-2015 seismic borehole network consisting of a set of vertical arrays in the near surface. At each array there are 4 to 5 geophones at depths varying from 0 to 300 m. Primarily the deepest geophones were used for detection, as they have the best signal-to-noise ratio (SNR). We investigate the use of all depth levels simultaneously to improve detection and characterization.
Recordings at the free surface suffer from noise in the frequency band of interest. Recordings at depth suffer from destructive interference between upgoing and downgoing waves. We implement a pragmatic scheme to invert downhole recordings to obtain the P- or S-wave response as if measured at the free surface. We show that a large part of the seismograms obey a simple propagation model between different depth levels. Using this model yields high SNR inverted traces for compressional waves. Shear waves undergo more anelastic attenuation and multiple reverberations in the near surface and the inversion scheme is less successful. Next, we estimate the more complete P- and S-wave propagation using seismic interferometry. Using the more complex propagators, we investigate whether the P-wave seismograms are further improved and the S-wave seismograms are enhanced.