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Monitoring the Groningen gas field by seismic noise interferometry

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The Groningen gas field in the Netherlands is the world's 7th largest onshore gas field and has been producing from 1963. Since 2013, the year with the highest level of induced seismicity, the reservoir has been monitored by two geophone strings at reservoir level at about 3 km depth. For borehole SDM, 10 geophones with a natural frequency of 15-Hz are positioned from the top to bottom of the reservoir with a geophone spacing of 30 m.
We used seismic interferometry to determine, as accurately as possible, the inter-geophone P- and S-wave velocities from ambient noise. We used 1-bit normalization and spectral whitening, together with a bandpass filter from 3 to 400 Hz. After that, for each station pair, the normalized cross-correlation was calculated for 6 seconds segments with 2/3 overlap. These segmented cross-correlations were stacked for every 1 hour, 24(hours)*33(days) segments were obtained for each station pair. The cross-correlations show both day-and-night and weekly variations reflecting fluctuations in cultural noise. The apparent P-wave travel time for each geophone pair is measured from the maximum of the vertical component cross-correlation for each of the hourly stacks. Because the distribution of these (24*33) picked travel times is not Gaussian but skewed, we used Kernel density estimations to obtain probability density functions of the travel times. The maximum likelihood travel times of all the geophone pairs was subsequently used to determine inter-geophone P-wave velocities. A good agreement was found between our estimated P velocity structure and well logging data, with difference less than 5%. The S-velocity structure was obtained from the east-component cross-correlations. They show both the direct P- and S-wave arrivals and, because of the interference, the inferred S-velocity structure is less accurate. From the 9(3x3)-component cross-correlations for all the geophone pairs, not only the direct P and S waves can be identified, but also reflected waves within the reservoir for some of the cross-correlations. It is concluded that noise interferometry can be used to determine the seismic velocity structure from deep borehole data.