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# Time-lapse $CO_2$ monitoring using ambient-noise seismic interferometry: a feasibility study from Ketzin, Germany

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Seismic interferometry applied to ambient-noise measurements allows retrieval of the Green's function between two seismic receivers, by cross-correlating their recordings, as if from a source at one of the receivers. We propose to use ambient-noise seismic interferometry (ANSI) to retrieve reflection data. The time-lapse differences between different vintages of the retrieved data may help characterize property changes within a geologic reservoir with varying $CO_2$ saturation. We test the feasibility of this time-lapse passive seismic method with numerical experiments based on the $CO_2$-storage site of Ketzin, Germany. Ambient-noise recordings from Ketzin exhibit significant passive body-wave energy (from natural tremors or induced seismicity in the vicinity of the reservoir), which is advantageous to retrieve reflections with ANSI.

The ANSI numerical experiments aim to understand what the requirements are for the recorded body-wave noise to retrieve the time-lapse reflection signal caused by an increase of $CO_2$ saturation in the reservoir. For this purpose, we design two velocity scenarios at Ketzin: a base scenario before the injection of $CO_2$, and a repeat scenario corresponding to a P-wave velocity decline in the reservoir by 20 percent. For both scenarios, we simulate passive seismic experiments of body-wave noise recordings that may take several days or months to record in the field. The passive recordings are obtained by modelling global (direct wave, internal and surface multiples) transmission responses from band-limited subsurface noise sources, randomly triggered in space and time. The time-lapse reflection signal is obtained by taking the differences between the base and the repeat retrieved reflection data (virtual common-shot gathers). We found that the time-lapse signal is still recovered with ANSI even if the base and repeat retrieved reflection data are partially polluted with artifacts. This means that uneven illumination of the array does not necessarily exclude acceptable time-lapse signal retrieval. Furthermore, the clarity of the time-lapse signal at the reservoir level increases with increasing repeatability of the two passive experiments. The increase in repeatability is achieved when the contributing noise sources form denser clusters that share analogous spatial coverage.

To support the merits of the numerical experiments, we applied ANSI (by auto-correlation) to three days of Ketzin passive field-data and compare the retrieved responses with the modelling results. The data are recorded at a permanent array of sensors (hydrophones and geophones) installed above the injection site. We used the records from the buried line of the array that consists of sensors lying at 50-meters depth. These records are less contaminated with surface noise and preserve passive body-wave events better than surface-recorded data. The retrieved responses exhibit significant correspondence with the existing active-seismic field data as well as with our modelled ANSI and active responses. Key reflection events seem to be retrieved at the expected arrival times and support the idea that the settings and characteristics of the ambient noise at Ketzin offer good potential for time-lapse ANSI to monitor $CO_2$ sequestration.