Permanent seismic installation with buried receivers for seismic monitoring of CO2 injection in desert environment: Lessons learned

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In 2015, Saudi Aramco started a CO_2 WAG EOR pilot project in an onshore carbonate reservoir. To monitor lateral expansion of the CO_2 plume, the area was instrumented with a hybrid surface/downhole permanent seismic monitoring system. This system consists of 1000 buried seismic sensors at a depth of around 70 m. A dense grid of surface vibroseis source points is acquired in a unique continuous acquisition program where a survey is completed every month. Buried receivers and the fine source spacing allows to process out undesired noise dominant on land seismic data from this region. Due to the high bulk modulus of the carbonate reservoir, small changes in acoustic impedance of around 5-6% are expected when CO_2 replaces water and oil. Moreover, WAG injection is expected to create cyclical softening and hardening changes during CO_2 and water injection respectively. In order to detect small changes, system has to be highly repeatable. This goal was achieved using receivers buried below the water table and major near-surface heterogeneity, thus minimizing signal scattering and greatly reducing the effects of seasonal changes on the seismic data. In addition, the receivers are placed deep enough to avoid recording surface waves which can be strongly affected by season to season changes in the near surface. Despite this the seismic data still contains significant amounts of other noise (guided waves, mode conversions and scattered energy) typical for a desert environment in the Middle East. As a result, dense surface carpet shooting is required to be able to remove such noise in processing and uncover target reservoir reflections as well as to improve their repeatability. Ultimately, the combination of buried receivers and carpet shooting delivered seismic repeatability of around 5% NRMS (normalized root-mean square) which is much better than any land surface 4D seismic and rivals the repeatability achieved in marine 4D seismic. Additional challenges come from seasonal near-surface variations between dry and wet seasons that alter signals of surface vibroseis sources up to 4 months following rain (Figure 1). These variations are clearly captured with monthly repeat surveys over the calendar year. While surveys within the wet season exhibit deterioration in repeatability (high NRMS values), when the dry season returns, repeatability returns to the same level as it was within the same dry season. This is a first of its kind, single-sensor permanent monitoring system combined with an innovative multi-survey processing workflow. Careful design and execution of the seismic monitoring program has allowed to observe small reservoir variations related to CO_2 injection into a challenging carbonate reservoir.

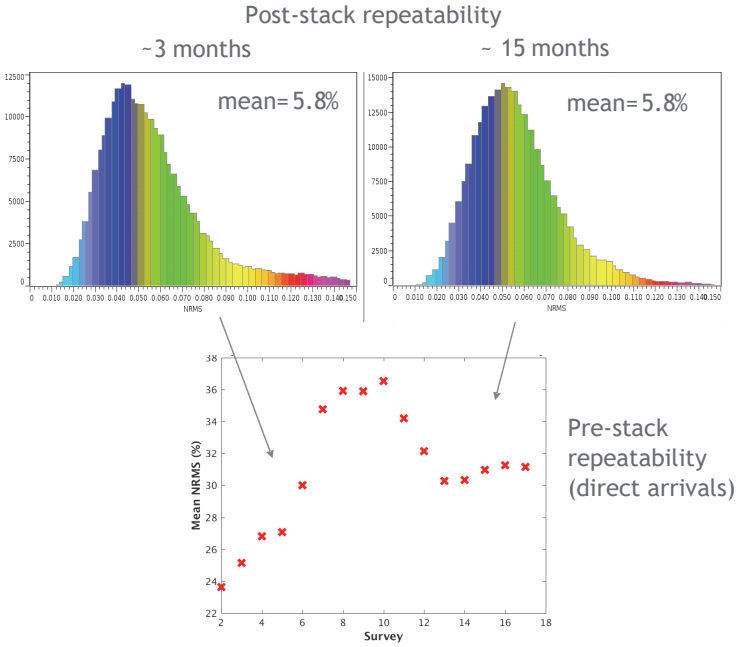

Figure 1. Pre-stack seismic repeatability (estimated using near-offset direct arrivals) achieved within a calendar year with monthly seismic surveys (bottom). Post-stack seismic repeatability (top) shows that from year to year (over 15 months) similar repeatability is achieved as that within the same dry season (over 3 months).