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Time-lapse seismic monitoring of the CO_2 injection at Ketzin, Germany: Inversion of 3D surface- and VSP-data for acoustic impedances

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The Ketzin test site, Germany, is Europe's longest operating on-shore CO_2 storage site. Between 06/2008 and 08/2013 about 70 kt of CO_2 were injected in an anticlinal structure. The target reservoir is a sandstone saline aquifer at $\sim$630 - 650 m depth. To enhance the understanding of the structural geometry of the site and to investigate the extension of the CO_2 plume, several geophysical monitoring methods are applied at the Ketzin site, among
which are seismics, geoelectrics and borehole measurements. Here, we focus on seismic methods, both surface as well as zero-offset VSP. Prior to injection the baseline surveys of 3D seismic and zero-offset VSP were measured in 2005 and 2007, respectively. The 1st repeat measurements of 3D surface seismics were performed in 2009 after injection of about 22 kt of CO_2, followed by the repeat of zero-offset VSP in 2011 after 46 kt of CO_2 injection. The 2nd repeat of 3D surface seismic was measured in 2012 after about 61 kt of CO_2 were stored in the target formation. Interpretation of these measurements allowed the characterization of the CO_2 plume's geometry and westward propagation direction. The amplitudevariation is situated at the top of the reservoir near the injection well with a lateral extent of $\sim$300-400 m after 1st repeat and $\sim$400-600 m after 2nd repeat survey and a thickness of about 5-20 m. The amplitude anomaly matches the expected distribution of the CO_2 plume derived from reservoir simulations, considering detection limits of seismic surface measurements. To increase the resolution and reliability of the data, to improve the estimation of rock properties, and especially to enhance the imaging resolution of
the CO_2 plume, the time-lapse 3D seismic and zero-offset VSP data have been inverted for acoustic impedances. The applied inversion algorithms were Model Based Inversion and Band Limited Impedance Inversion for the 3D surface seismic and zero-offset VSP, respectively. The surface data and obtained impedances are compared with time-lapse VSP measurements and results of their inversion. The zero-offset VSP is inserted into an inline of
3D surface seismic crossing the receiver well, what makes a direct comparison of time-lapse amplitude difference and impedances possible. The comparison shows good agreement between these datasets regarding the impedances values. The high-resolution zero-offset VSP data complement the lateral image of the CO_2 plume derived from 3D surface seismic in the vicinity of the well.