4D simultaneous full waveform inversion (FWI) for integrated reservoir monitoring?

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Abstract

Reservoirs are complex and heterogeneous systems that respond to production/injection of fluids with changes in fluid saturation, pressure, temperature, and stress fields. Repeated, or continuous, seismic surveys provide a wealth of information on these dynamic reservoir phenomena. Ideally, we would like to integrate the analysis of the repeated seismic data with the analysis of other geophysical or engineering data based on common numerical inverse modelling of all the reservoir relevant physical processes. In practice, current practices for analysing time-lapse data are interpretation-driven because they enable to tease out the most important elements and quickly yield useful actionable information. However, in many cases the different physical processes are linked in ways that render interpretation ambiguous and/or dependent on highly specialized skills. To further challenge current practices, the industry is ramping-up deployment of permanent reservoir monitoring (PRM) systems that enable more frequent acquisition of seismic surveys, and possibly, “on demand” surveys. PRM systems also enable continuous listening to the reservoir and the overburden for timely identification of unexpected events and developing hazards.

Full waveform inversion (FWI) is a natural platform to “automatically” extract from seismic data information on all the interlinked physical reservoir phenomena that have an influence on observable seismic properties. In theory, we could include in the wave-propagation model all the physical parameters that are relevant to the individual reservoir, and at least theoretically, invert for all the relevant parameters. A practical challenge is that the wave-propagation model should be fully visco-elastic and anisotropic, making it challenging with current, but not future, computational capabilities. A more fundamental hurdle to overcome is that unless FWI waveform inversion is properly constrained, it will not yield useful estimates of reservoir dynamics because of the incompleteness of the information contained in the data. Compared to static full-wavefield imaging, 4D waveform inversion has the advantage that we can constrain the inversion by assuming the time-evolution of reservoir parameters to be continuous. This consideration leads to formulating the problem as simultaneous inversion of all the seismic surveys with an additional regularization constraint on the time variations of reservoir parameters.

We have applied these ideas to the estimation of velocity variations related reservoir compaction and consequent stretching of the overburden above, or the underburden below, the reservoir. To improve resolution and converge towards useful results we have applied a total-variation regularization of the velocity differences between baseline and monitor surveys (Maharramov et al., 2016) and simultaneously inverted two seismic surveys recorded over the Genesis Field in the Gulf of Mexico. The estimated velocity decreases are concentrated above the reservoir, and in particular in the Illinoisan sands that are known to be particularly prone to stretching. These results do not show any velocity increase at the reservoir caused by compaction probably because of insufficient spatial resolution. To overcome this problem, more recently we have developed, and tested on synthetic data, a sequential regularization scheme where TV regularization is followed by a conventional L1 regularization that promotes sparseness and increases resolution (Maharramov and Biondi, 2017). We will show results from this experiment on filed data during the oral presentation, if we receive permission by the data owners.

Highly heterogeneous stress fields are known to cause changes in anisotropic velocity parameters, as well as in “average isotropic” velocity. Therefore, we are now in the process of estimating anisotropic (VTI) velocity changes starting from a baseline anisotropic (VTI) smooth model. The expected anisotropic changes are more complex than simple VTI, but it is not obvious that even simple VTI variations are sufficiently constrained by the observed data. The maximum offset of the two surveys is limited: ~5 km for the baseline survey and ~7 km for the monitor one.

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References

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