Optimized geophysical survey design for CO₂ monitoring – A synthetic study

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Abstract

The Norwegian Continental Shelf offers substantial volumes of potential storage capacity for CO₂ in saline aquifers (Gassnova, 2016). To enable large-scale CO₂ storage, improved monitoring technologies are required to make operations faster and cost-effective (Tangen et al., 2014). At the same time, their selection as part of a Measurement, Monitoring, and verification (MMV) framework should be justified by their contribution to ensure conformance, containment, and early detection of potential leakages in addition to other undesired effects such as uplift, subsidence, and excessive pressure build-up.

Geophysical monitoring plays a key role in any proposed MMV plan due to its ability to derive from measured data estimates about the spatial distribution of selected geophysical properties of the subsurface (e.g. velocity, density, and resistivity). A combination of seismic and non-seismic prospecting technologies is usually part of the proposed CO₂ monitoring plan throughout the project lifecycle (pre-injection, injection, and post-injection phases). In this context, while improved data processing, imaging, and inversion techniques have been subject to large research efforts, little attention has been paid to improving survey design where standard procedures are usually used. Furthermore, data redundancy is often suggested as a mean to mitigate issues related to data inadequacy. This results in high additional costs which can be a major hurdle to propose large scale CO₂ storage as an affordable technology.

In this work, we evaluate strategies to propose fit-for-purpose survey-design strategies that allow acquiring optimal measurements while maintaining a sufficient level of resolution or accuracy of the parameters to be recovered. The objective is to determine an optimized field layout based on our knowledge of the subsurface prior to data acquisition. The proposed method is based on the analysis of the eigenvalue spectrum of the Hessian matrix (second order derivative of the misfit function with respect to the model parameters) which provides a simple and intuitive means to evaluate the quality of a given survey design (Maurer et al., 2010). It requires the computation of the Jacobian matrix which has a structure that is governed by the choice of the acquisition layout. The analysis of the eigenvalue spectrum allow differentiating the resolved model space portion (which should be maximised by the optimal survey design) from the unresolved null space (which should be minimised).

Examples from seismic and EM monitoring are included. We use Full Waveform Inversion and Controlled Source Electromagnetic Method (CSEM) to perform synthetic studies and assess whether a sequential experimental design can be used to help determine if only a small amount of data is sufficient to achieve comparable resolution to the one obtained when the comprehensive dataset is used. Comparison between various acquisition layouts is performed using both the true synthetic
model and the model used as a starting model for the inversion. The results suggest that the method is quite robust with respect to the model used for the analysis. It also offers a powerful means to maximize information content at a minimal cost and analyse the pattern of the optimum acquisition design for a given tomographic method. Future work will evaluate the benefit of combining sparse and local dense acquisitions and the link between optimal survey design and rock physics properties.

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