Visco-acoustic FWI for Q model building

G. Huang, J. Ramos-Martinez and N. Chemingui, PGS

Abstract

Estimating heterogeneous Q models is valuable not only for characterizing gas bodies but also for compensating for visco-acoustic effects during imaging, enabling a better quatitative interpretation. In this work, we introduce a novel approach to invert for the quality factor Q using FWI, by separating the visco-acoustic effects of absorption and dispersion during propagation, as well as in the derivation of sensitivity kernels used for the inversion. This separation is critical for accurately estimating Q, given that in the frequency bandwidth commonly used in FWI, velocity dispersion effects are stronger than those related to absorption.

Efficient and accurate time-domain solutions to the visco-acoustic wave equation are challenging due to the requirement of solving a fractional differential equation, especially when trying to achieve an accurate Q behavior in the frequency bandwidth of the data. Compared to finite differencing methods that require numerous memory variables to obtain accurate solutions, the pseudo-analytic method employed in this work offers an efficient and accurate alternative by converting the fractional time derivative to the spatial Laplacian operator, which can be computed readily in the wavenumber domain. The resulting visco-acoustic equation comprises terms that separately account for dispersion and amplitude decay, allowing for the derivation of two sensitivity kernels based on the adjoint-state approach: one for absorption and another for dispersion. Inverting for Q is more robust when considering dispersion effects rather than absorption, as dispersion sensitivity is stronger in the frequency bandwidth used in FWI. Additionally, while visco-acoustic effects improve the representation of the subsurface, there are missing (visco)-elastic phenomena that can result in inaccuracies in the modeled amplitudes. A cascaded approach is proposed for performing multiparameter inversion.

We initially validate our approach through controlled experiments and observed that using the dispersion kernel yields a good Q solution when the FWI velocity approximates a reasonable model. Then, we present a field data example from West Shetland, UK, which was acquired using multi-sensor technology with a maximum inline offset of 8.1 km. Previous Q-tomography analysis had revealed the presence of gas clouds embedded in a low background Q model. For velocity estimation, FWI was applied up to 12 Hz maximum frequency starting from a reflection tomography model. We used this velocity model and our newly developed dispersion sensitivity kernel to invert for a Q model with FWI from a constant Q model below the waterbottom. The inverted Q-FWI model delineates the shallow gas clouds with Q values as low as 40. To validate the results, we compute migrated stacks for the initial and inverted velocity and Q models. Results demonstrate a significant improvement in the image resolution and coherence below the low Q anomalies after the cascade inversion scheme.