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Effect and Reconstruction of Attenuation in Acoustic FWI - Method and Field Data Application

N. Kamath[1]*, R. Brossier[1], L. Metivier[1], P. Yang[2]

[1] University Of Grenoble Alps; [2] Electromagnetic Geoservices ASA

Summary

Our contribution is divided into two parts: in the first we discuss the mechanism (based on generalised Zener body) used to incorporate attenuation into our forward modelling engine, and the manner we manage the efficient building of the FWI gradient in 3D. The second part deals with the application of mono- and multi-parameter (velocity only in visco-acoustic media, and velocity-attenuation joint inversion, respectively) FWI to a 3D OBC dataset from the Valhall field.

Abstract

When imaging or inversion is performed with data obtained over a region where viscous effects are known to exist, it is essential to take attenuation into account. It is rather straightforward to incorporate attenuation in a frequency domain visco-acoustic wavefield modeling engine when the medium is 2D. However, for 3D media, in order to circumvent the use of a sparse direct solver such as, for example, MUMPS (Amestoy et al., 2000), which often leads to large memory requirements (Operto et al., 2014; Amestoy et al., 2016), the wavefield can be computed in the time domain. Among various existing mechanisms describing wavefield propagation in viscous media, the Generalized Zener Body (GZB), with superposition of three relaxation mechanisms, is employed to obtain a uniform value of quality factor Q_p in the frequency range of interest (Yang et al., 2016). In our formulation, the P-wave velocity fed to the modeling engine corresponds to the unrelaxed modulus, i.e., the modulus at frequencies approaching infinity. An advantage of our technique is the decoupling of the terms containing velocity and Q_p in the equations, which proves useful for inversion and interpretation of the results.

Full-waveform inversion (FWI) has proved successful in estimating not only the velocity but also Q_p, provided the data are relatively noise-free (especially, the lower frequencies) and the initial velocity model ensures that the data are not cycle-skipped. We use a least-squares data misfit objective function and investigate the influence of attenuation as a passive parameter (i.e., velocity-only inversion), as well as invert for it along with the P-wave velocity. The limited-memory BFGS algorithm, available in the SEISCOPE optimization toolbox (Métivier and Brossier, 2016), is used to perform model updates and we test different preconditioners to accelerate convergence and improve the decoupling of the updated models.

We apply visco-acoustic FWI on 3D ocean bottom cable (OBC) data acquired in the Valhall field, North Sea. Storing the source wavefield at every time-step to compute the gradient is not feasible. Hence, the checkpoint assisted reverse forward simulation (CARFS) technique (Yang et al., 2016) is employed to ensure that the reconstruction of the source wavefield in reverse time is stable. Judicious use of available computational resources while, at the same time, inverting for all available data necessitates a data-subsampling strategy (Kamath et al., 2018).

The Valhall field exhibits transverse isotropy with a vertical symmetry axis (VTI) and there exist regions of low velocity, indicative of gas clouds. Starting from a smooth initial P-wave vertical velocity V_{P0} and constant values of attenuation (1000 in the water column, and 200 in the sediments), V_{P0} and Q_p are updated simultaneously while the density ρ and anisotropy coefficients ε and δ are kept constant. Inverting data up to 7 Hz leads to a clear delineation of the underground channels in shallow depth at $z = 200$ m (Fig. 1b). Figures 1e and 1f indicate a correlation between low values of velocity and Q_p for $z = 1$ km.

As we incorporate higher frequencies in the data into the inversion, we expect the resolution of the velocity to increase, along with an improvement in the values of Q_p, as the influence of attenuation is larger at higher frequencies. Migrating the data with velocity and Q_p models obtained from different inversion experiments ought to help assess the accuracy of the models.

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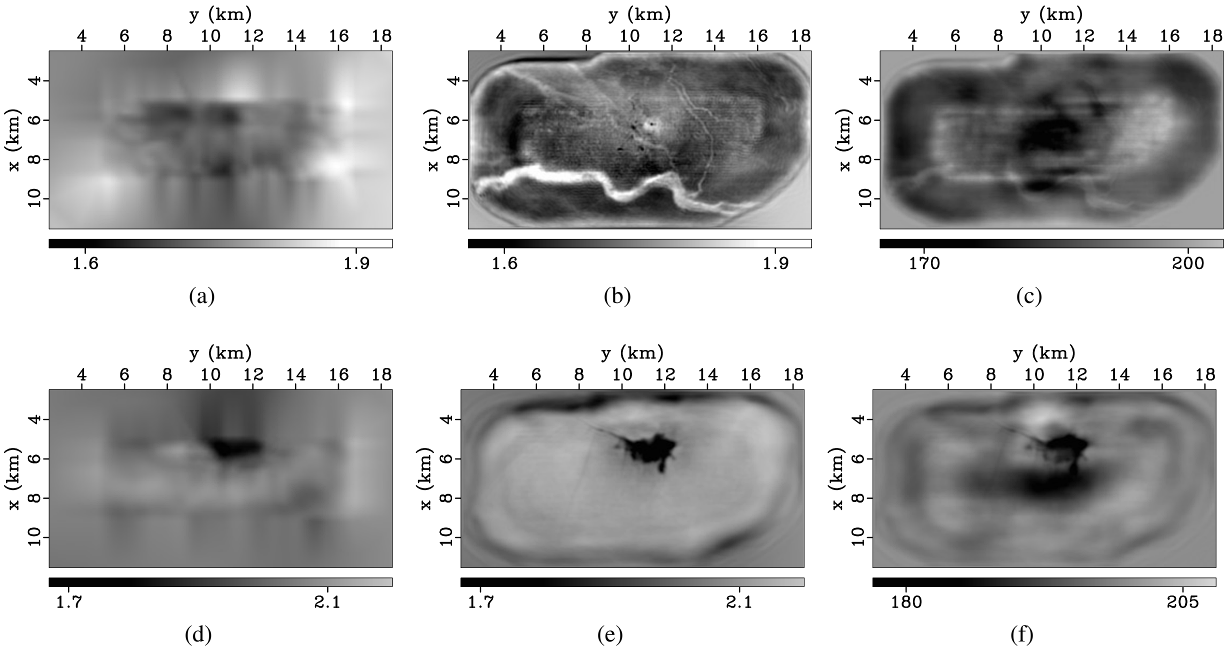

Figure 1: (a) Initial velocity, (b) updated velocity V_{P0} and (c) updated attenuation Q_p at depth $z = 0.2$ km. (d), (e) and (f) are the same at depth 1 km. The units of velocity are km/s.

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