Linear and non-linear AVO for poroelastic targets

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Abstract

AVO techniques permit the variations in seismic amplitudes with angle or offset to be used to deduce subsurface target properties. Linearized AVO is parameterized in several different ways. One, introduced this year focuses on changes in the P-wave reflection strength associated with poroelastic medium variations. In this paper we review a newly proposed poroelastic AVO technique, and reproduce the methodology and basic conclusions of those authors. We formulate the poroelastic AVO inverse problem in terms of least-squares, and take some initial steps towards extending the model to nonlinear (i.e., large contrast) regimes.

Poroelastic AVO inversion

In the AVO equations discussed by Aki and Richards (2002) and Russell et al. (2011), there are three unknown parameters. We numerically test inversion for Russell's poroelastic parameters using a large range of triplets of input reflection coefficient data. The triplets are chosen as follows. The reflection coefficient at normal incidence is always the first datum, and the third is always the coefficient at an angle just below critical. A mobile second data point moves between them. We are interested in the poroelastic properties of the subsurface, the equation provided by Russell et al. (2011) will be used to linearly invert for fluid, shear rigidity, and density.

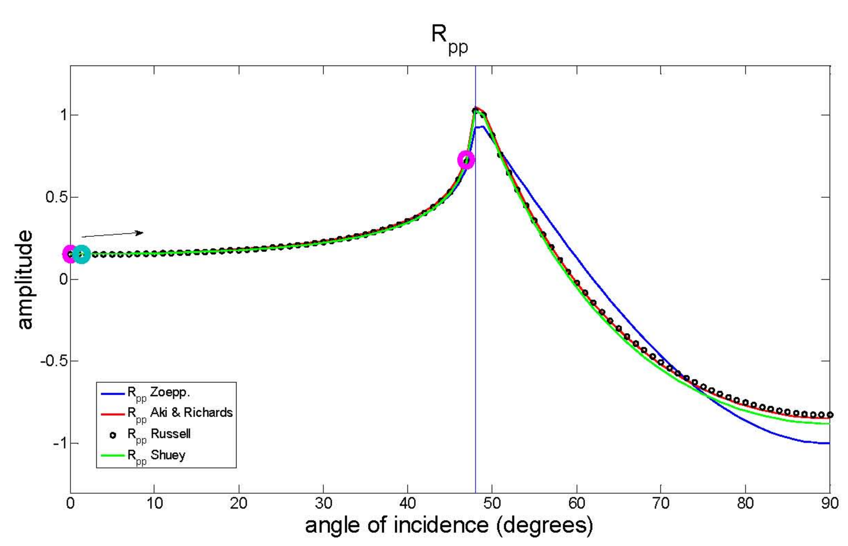

FIG. 1: Linear inversion procedure.

A series of inversions were performed on the synthetic reflection coefficient data. The first data point is at angle of incidence zero; the second data point starting where the angle of incidence is 1 degree, and the third data point located just before the critical angle. Figure (1) shows the first iteration of the series of inversions for model 1 provided by Russell et al. (2011). The next arrangement of equations would then involve the second data point an angle of incidence of 2 degrees. And so on. This procedure is better represented in figure (1) where the magenta circles represent the static points and the teal circle represents an intermediate point, that increases in angle with each successive inversion. The known poroelastic constants for the first geological model are 1.657, 0.0, and 0.012 respectively. From the first iteration, the estimates for these reflectivities were 1.627, -0.036, and 0.059 respectively.

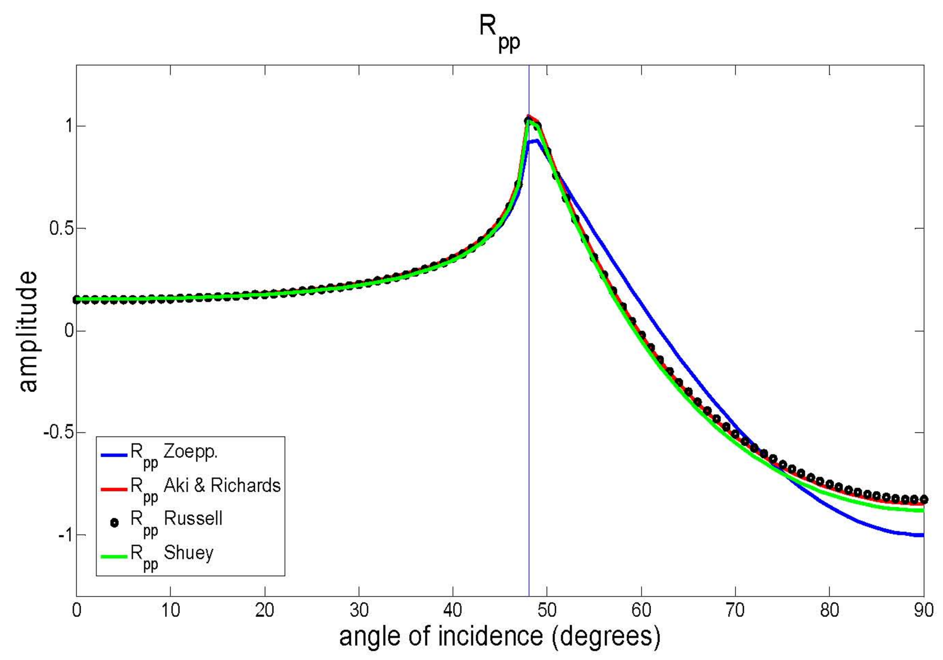

FIG. 2a: AVO curves for model 1.

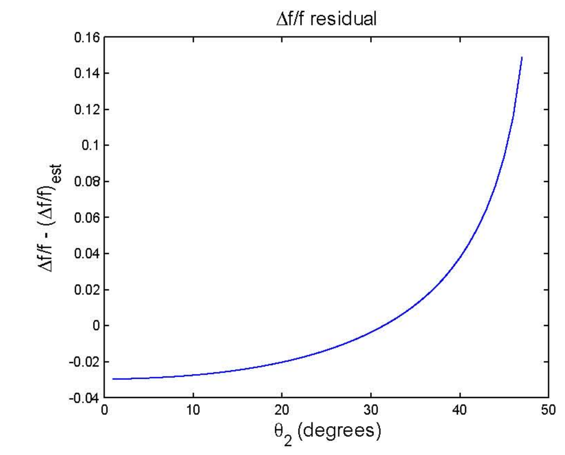

FIG. 2b: Residual between the known and estimated fluid reflectivity.

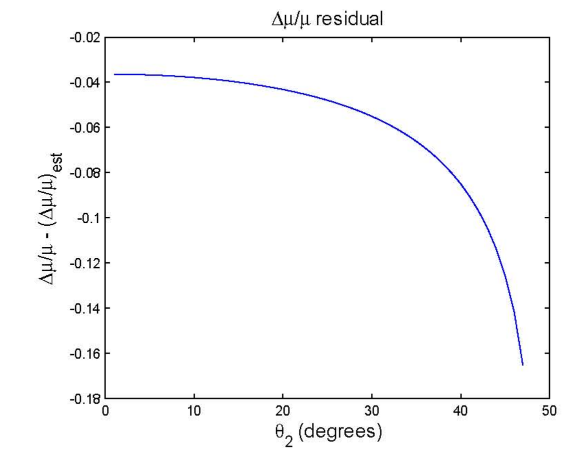

FIG. 2c: Residual between the known and estimated shear reflectivity.

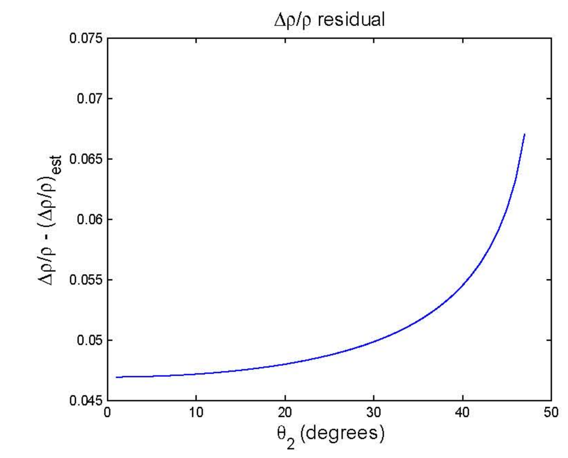

FIG. 2d: Residual between the known and estimated density reflectivity.

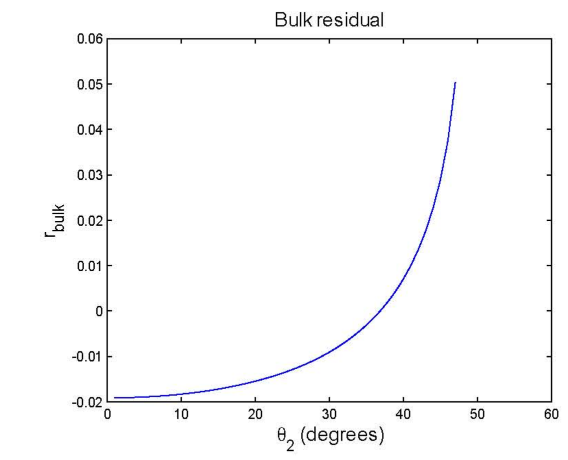

FIG. 2e: Residual between the known and estimated bulk reflectivity.

Poroelastic Model 1

Poroelastic model 1 has been modelled as a gas saturated sand overlying a brine saturated sand. Figure (2a) represents the reflection coefficients (or amplitudes) as a function of the angle of incidence of a P-wave. The fluid, shear, and density reflectivities using Russell's AVO formulation are 1.657, 0.0, and 0.012 respectively. Figures (2b)-(2d) each show the difference between an estimated reflectivity and its corresponding forward modelled reflectivity. Figure (2e) shows the sum of the previous three figures.

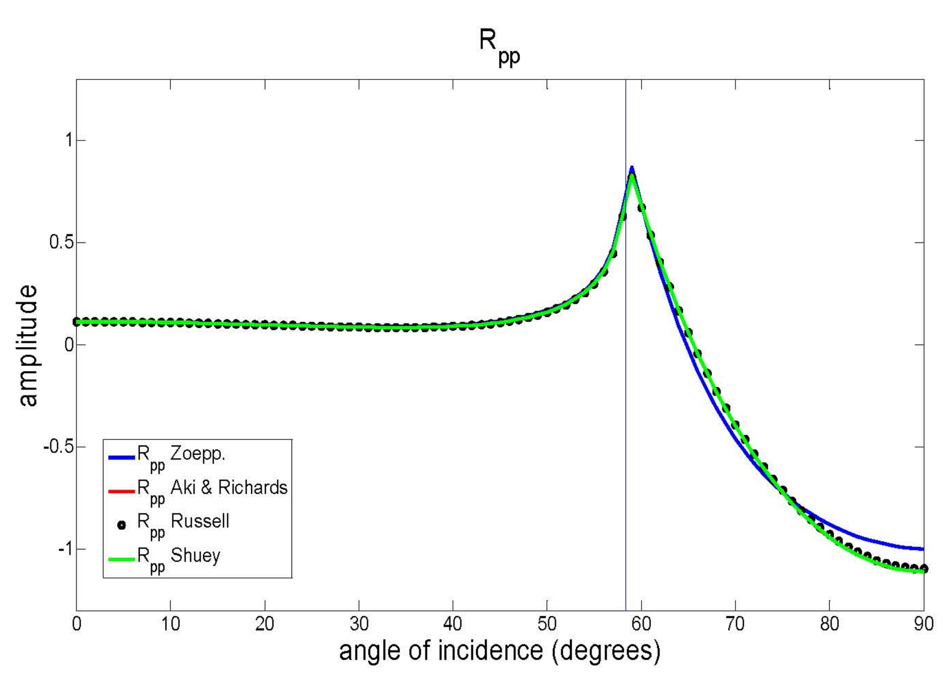

FIG. 3a: AVO curves for model 2.

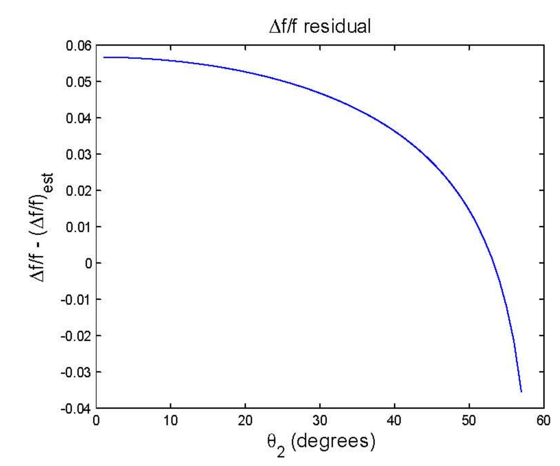

FIG. 3b: Residual between the known and estimated fluid reflectivity.

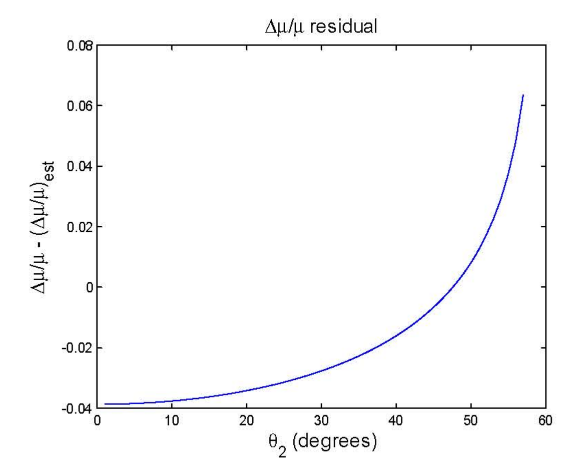

FIG. 3c: Residual between the known and estimated shear reflectivity.

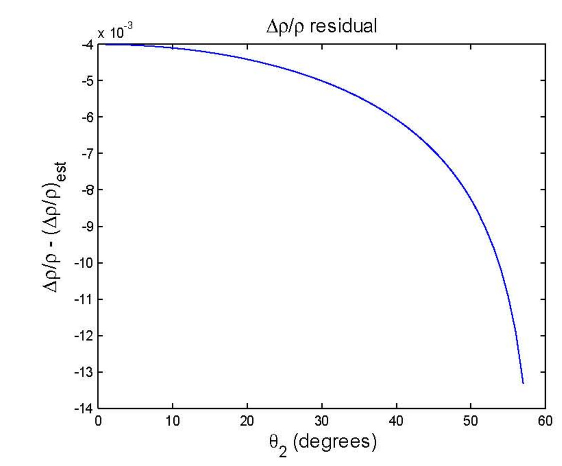

FIG. 3d: Residual between the known and estimated density reflectivity.

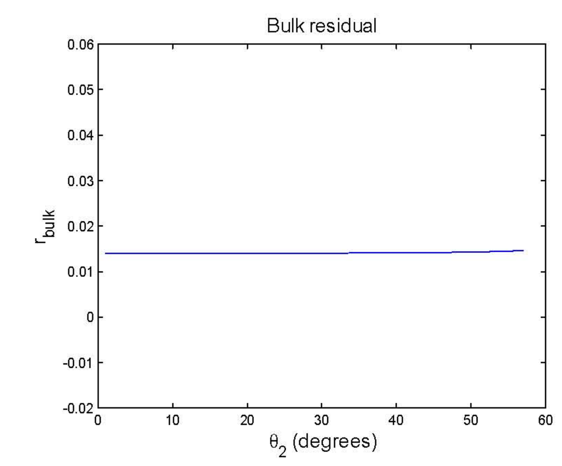

FIG. 3e: Residual between the known and estimated bulk reflectivity.

Poroelastic Model 2

Poroelastic model 2 has been modelled as a brine saturated sand overlying a brine saturated sand. Figure (3a) represents the reflection coefficients (or amplitudes) as a function of the angle of incidence of a P-wave. The fluid, shear, and density reflectivities using Russell's AVO formulation are 0.305, 0.454, and 0.066 respectively. Figures (3b)-(3d) each show the difference between an estimated reflectivity and its corresponding forward modelled reflectivity. Figure (3e) shows the sum of the previous three figures.

Conclusions and Research Plans

A series of three equation inversions were applied to the Zoeppritz equations using Russell's AVO linear approximation. The inversions were performed on estimating three poroelastic properties from three different equations. These three equations were chosen where the first and last equations depicted the minimum and maximum value of the Zoeppritz derived AVO and the second equation would be a point in between. The optimally expected inversion result should be located where maximum coverage of the Zoeppritz curve occurs by the three equation arrangement. This was expected to be where the conditioning of the matrix inversion was greatest which would be where the second equation is located at maximum curvature of the Zoeppritz curve but was not the case. Typically in AVO inversion, using reflection coefficients at higher angles is not valid as the linearized approximations have more difficulty predicting those amplitudes. Thus data points at smaller angles are used instead of data found closer to or beyond the critical angle. With that, Russell et al. (2011) shows promising results in which the direct incorporation of fluid into AVO inversion provides a more comprehensive look into subsurface property behaviour. We propose an extension to Russell et al. (2011) by devising a non-linear AVO inversion scheme that may show differential benefit which will then be applied both theoretically and empirically.

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References

- Aki, K., and Richards, P.G., 2002, Quantitative seismology, 2nd ed.
- Russell, B. H., Gray, D., and Hampson, D. P., 2011, Linearized AVO and poroelasticity: Geophysics, **76**, C19-C29

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