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Study of crosstalk reduction in multiparameter acoustic FWI

Qi Hu* and Kris Innanen
qi.hu1@ucalgary.ca

Abstract

Crosstalk is the phenomenon in which data signatures of different physical properties are confused in full-waveform inversion (FWI). We focus on acoustic media with variable density, and discuss about the reduction of crosstalk from three aspects: optimization method, acquisition geometry, and model parameterization.

Optimization Method

L-BFGS approximates the inverse Hessian iteratively and provides a suitable scaling of gradients. In our test, L-BFGS outperforms steepest-descent (SD) and conjugate gradient (CG) on both inversion accuracy and computational cost.

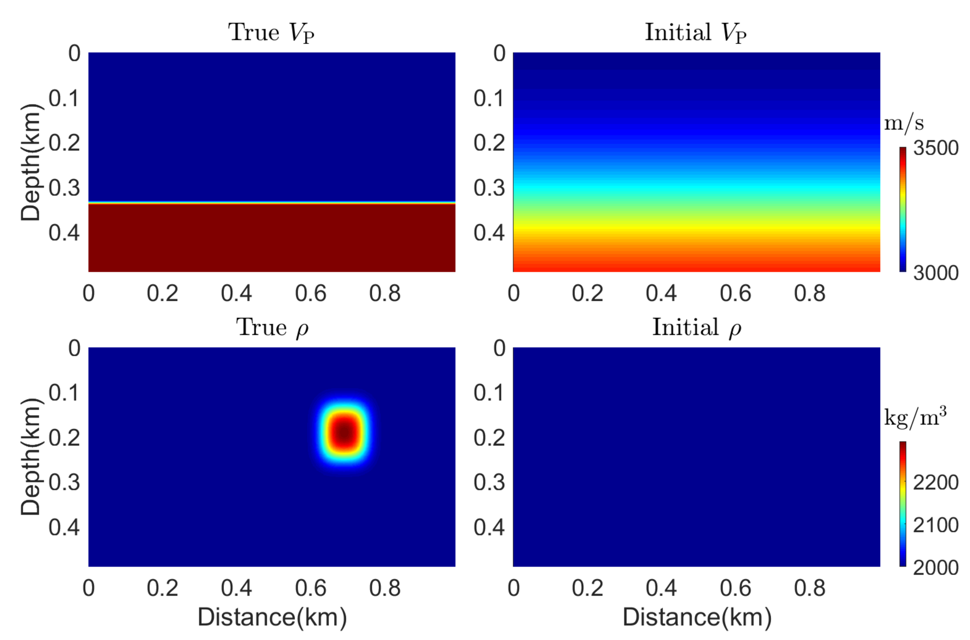

Fig. 1: True and initial models of velocity and density

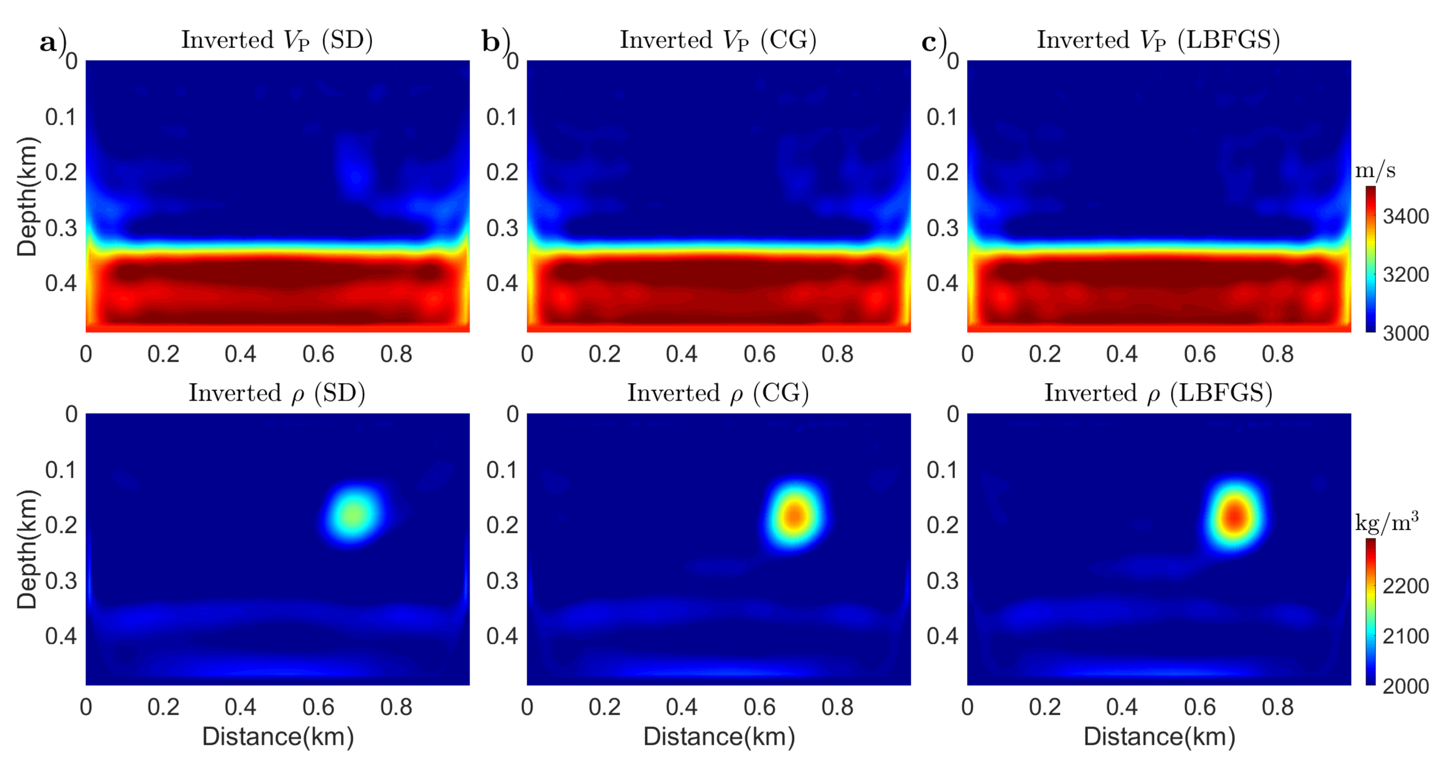

Fig. 2: Inversion results by a) SD, b) CG, and c) L-BFGS.

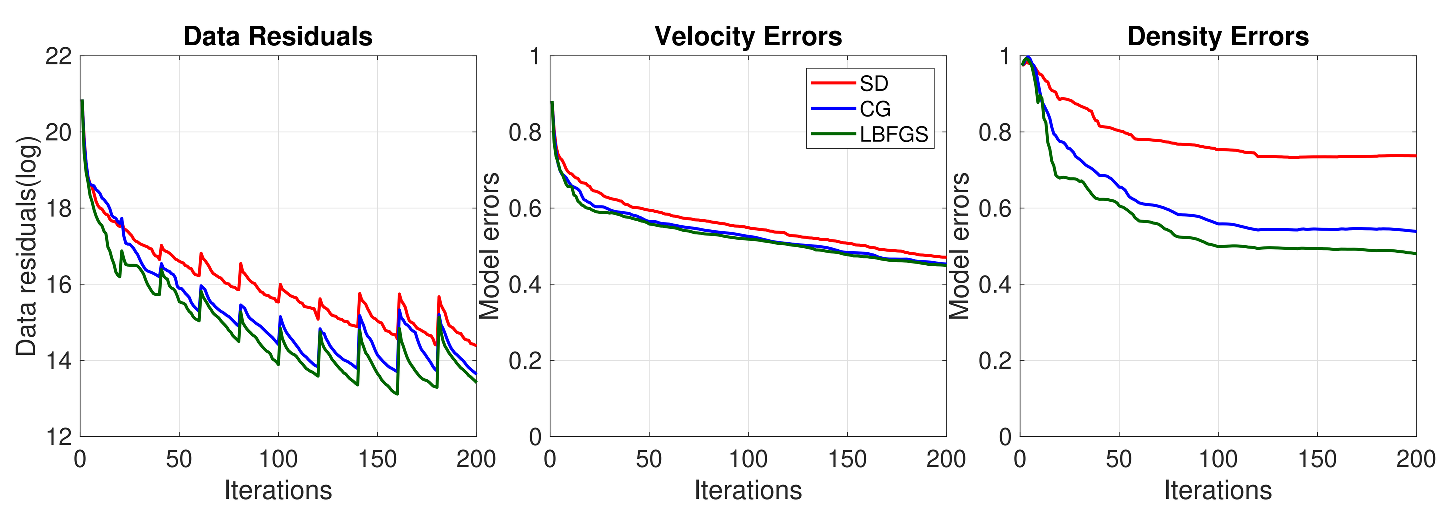

Fig. 3: Comparison of the convergence history and model error reductions for different optimization methods. The three methods have a similar reduction trend of data misfit and velocity errors, but L-BFGS takes a greater advantage of recovering density. Besides, the computation time of this example is 284 s for SD, 447 s for CG and 228 s for L-BFGS.

Acquisition Geometry

Velocity and density have similar scattering patterns at near offsets, making it difficult to decipher between the two with surface seismic data of limited offsets. We show how sub-surface sources and receivers provided by vertical seismic profile (VSP) and crosswell help mitigate the crosstalk from surface seismic.

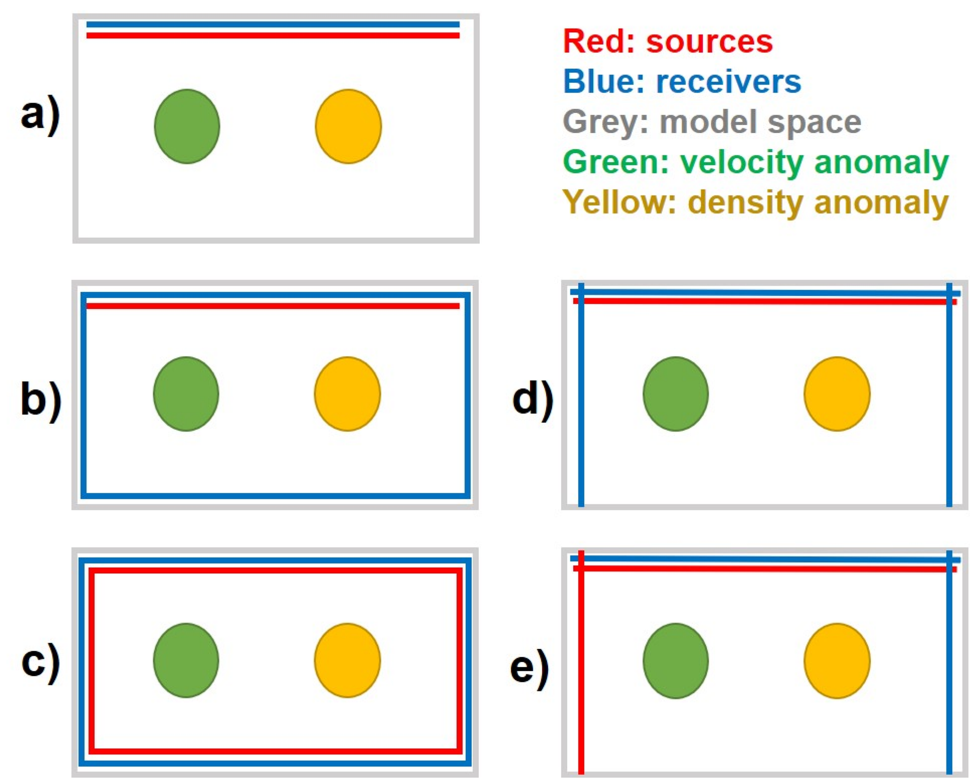

Fig. 4: We set up five configurations of sources and receivers to mimic different acquisition geometries. Cases **a**, **b**, and **c** represent surface-only sources and receivers, surface seismic + VSP, and surface seismic + crosswell. **d** and **e** denote two ideal geometries, where sources or receivers are spread to all boundaries.

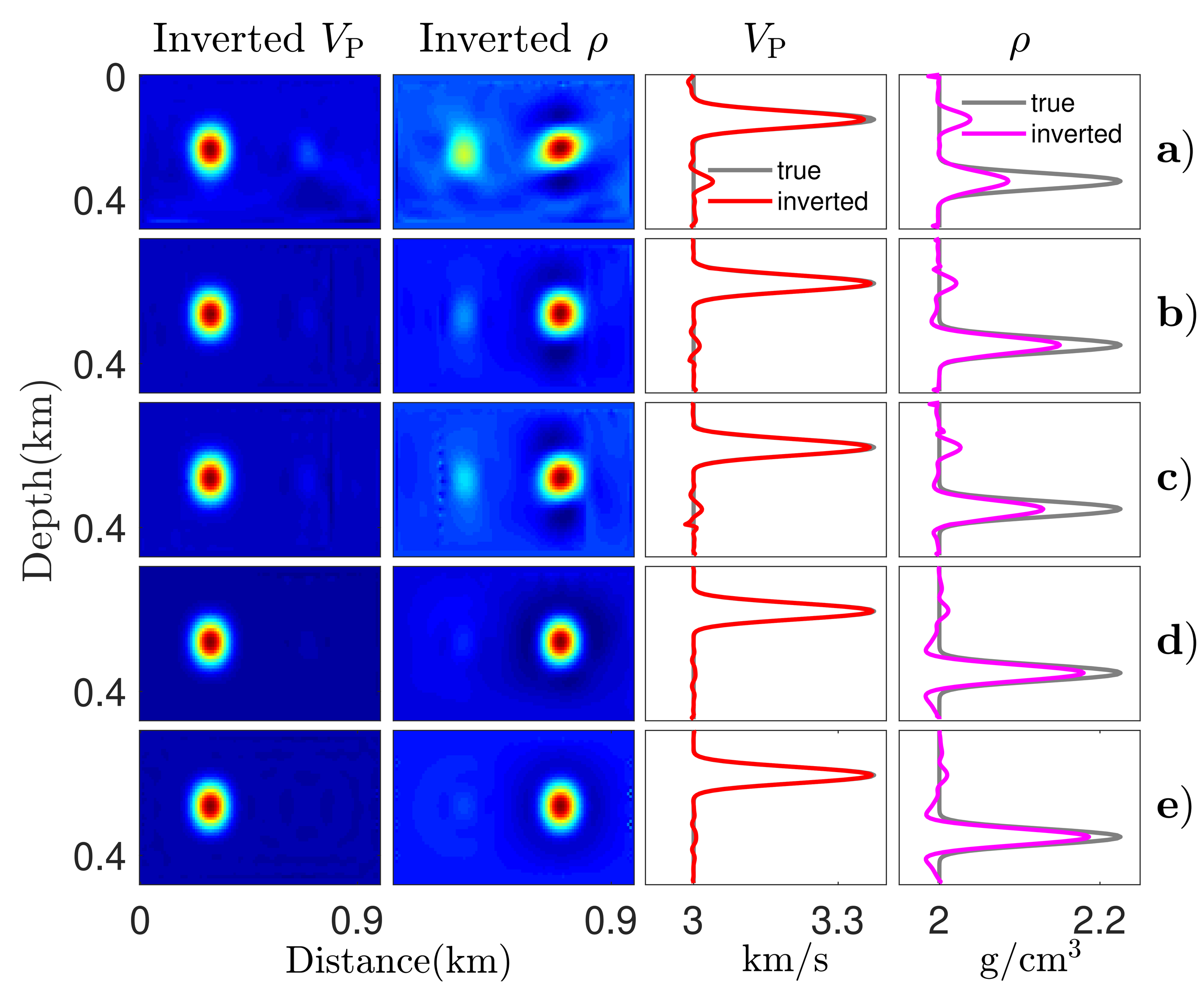

Fig. 5: Inverted models under the corresponding configurations in Fig.4. In case **a**, we see both the inverted velocity and density suffer from crosstalk, with density being more contaminated. Adding vertical receivers through VSP or crosswell, the mappings between velocity and density are suppressed in **b** and **c**. With the more powerful but impractical configurations in **d** and **e**, the results are further enhanced, with the velocity being perfectly recovered and density becoming comparable to the true value. The improvement is significant comparing **b** − **e** with **a**, but is minor comparing **e** with **d**. This is because we supplement surface seismic (case **a**) with transmission data in **b** − **e**, but a transition from **d** to **e** no longer introduces data of extra scattering angles.

Parameterization

In a suitable model parameterization, the classes of unknown properties should be as uncorrelated as possible.

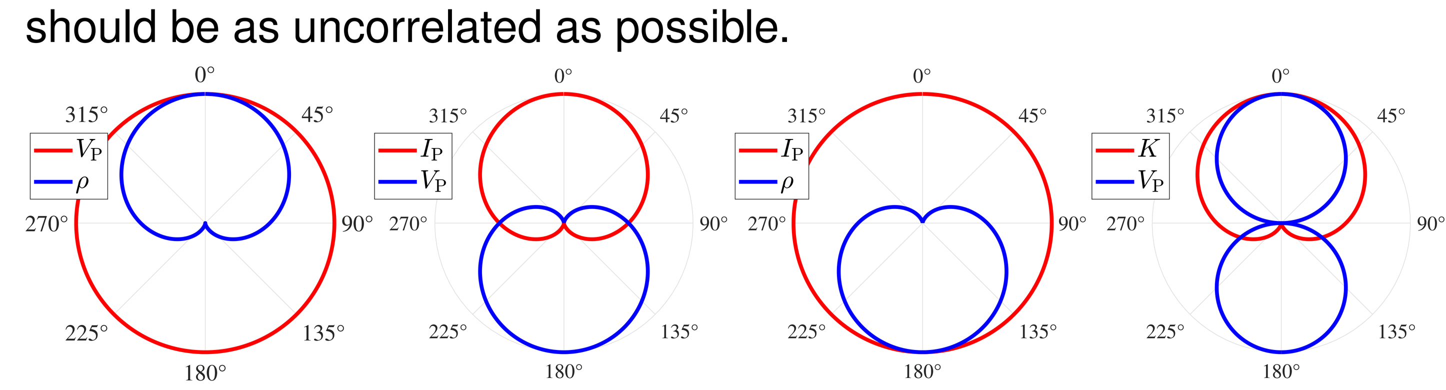

Fig. 6: Radiation patterns of different parameterizations. For surface seismic, $I_P - V_P$ might be the most effective because the two parameters have opposite scattering patterns. $K - V_P$ should be least favorable because the patterns overlap at short apertures.

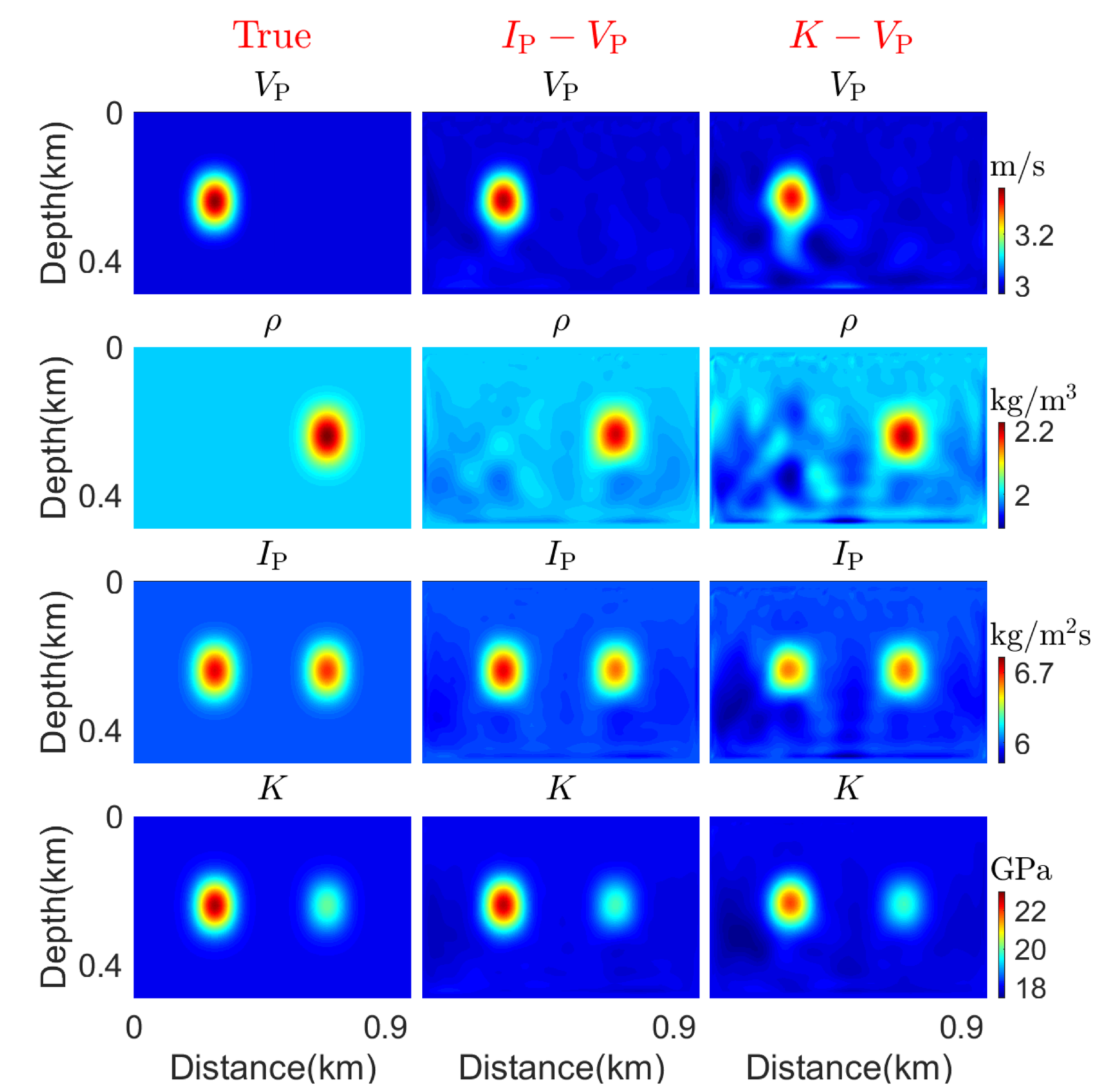

Fig. 7: $I_P - V_P$ does recover the models more accurately.

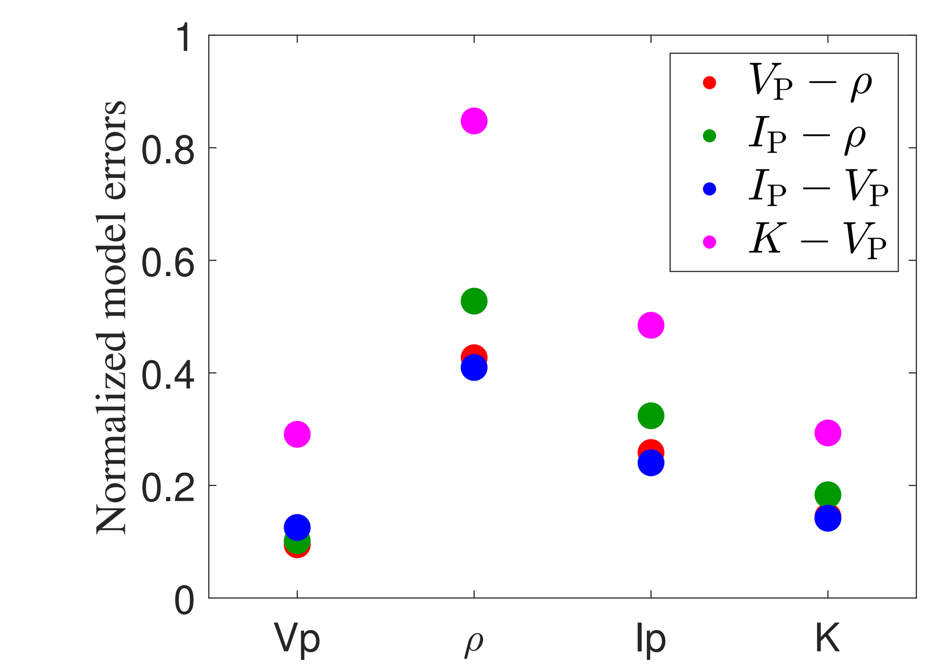

Fig. 8: Inverted model errors in different parameterizations. $K - V_P$ generates the largest error for estimating any parameter. The performances of $I_P - V_P$ and $V_P - \rho$ are close, and they can be considered the two most effective parameterizations in acoustic FWI.

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