Jointly inverting resistivity and seismic data and jointly interpreting separate results to reduce single-method uncertainty

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Abstract

Multi-geophysical methods with different subsurface sensitivities complement each other to yield more relevant results. I numerically invert electrical resistivity tomography (ERT) and seismic refraction tomography (SRT) data (SRT). Joint inversion methods detect horizontally stratified sedimentary strata. ERT and SRT inversion layer interfaces are ambiguous and substantially merged. Jointly inverted results provide clear layer boundaries, reducing model uncertainty. The numerical test demonstrates that regularization selection improves model resolution.

Keywords: Electrical resistivity tomography, seismic refraction tomography, joint inversion, uncertainty

Introduction

Seismic and resistivity methods are complementary and often employed in various ways (Garofalo et al., 2015). For instance, Wagner et al. (2019) developed a petrophysical joint inversion for permafrost measurement using electrical resistivity tomography (ERT) and seismic refraction tomography (SRT) data. I apply joint inversion for three-phase (rock matrix, water, and air) volumetric fraction to saturated sedimentary units to numerically analyze its effect on single-domain inversion. Moreover, this study uses the possibility of reconstructing horizontal or vertical structures using adequate anisotropic smoothing (zWeight regularization). Thus, the current research performs numerical petrophysical joint inversion of the ERT and SRT and assesses regularization parameters on model resolution.

Method

I simulate horizontally stratified sediments such as mud, gravel, clay, and sand from top to bottom (Fig. 1a). The mud layer is vadose and saturated since the groundwater level is at 3 m. Wagner et al. (2019) and Mollaret et al. (2020) employed a four-phase volumetric fraction (rock matrix, water, ice, and air) for saturated sedimentary rock units; however, this study utilizes a three-phase fraction. Apparent numerical data generation and inversion follow Wagner et al. (2019).

Results

Conventional inversion: Figure 1b exhibits apparent resistivity and travel time inversion separately. Inversion indicates that horizontally stratified strata are not well reproduced, especially for refraction tomography. Instead of low-velocity clay and sand layers, the inverted velocity model increases with survey depth. Seismic refraction tomography cannot detect low-velocity (hidden) layers. Resistivity tomography recovers the clay and sand layers as a single low-resistivity layer. Transforming inverted resistivity and seismic travel time data yields water saturation, air saturation, and rock matrix.

Joint inversion: Figure 1c shows layered sedimentary model jointly inverted results. The jointly inverted SRT model shows four layers: very low-velocity dry mud, low-velocity wet mud, and high-velocity gravel. Unlike conventional inversion, the bottom clay and sand layers are recovered as a single layer with a low-velocity signature. Jointly inverted ERT identifies four layers. Dry mud top layer, moist mud second layer, third gravel layer, and clay and sand bottom layer. Jointly inverted SRT and ERT model better resolve layered structures and interfaces than conventional inversion. The joint inversion model additionally recovers transformed saturation, air content, and rock matrix (Fig. 1c).

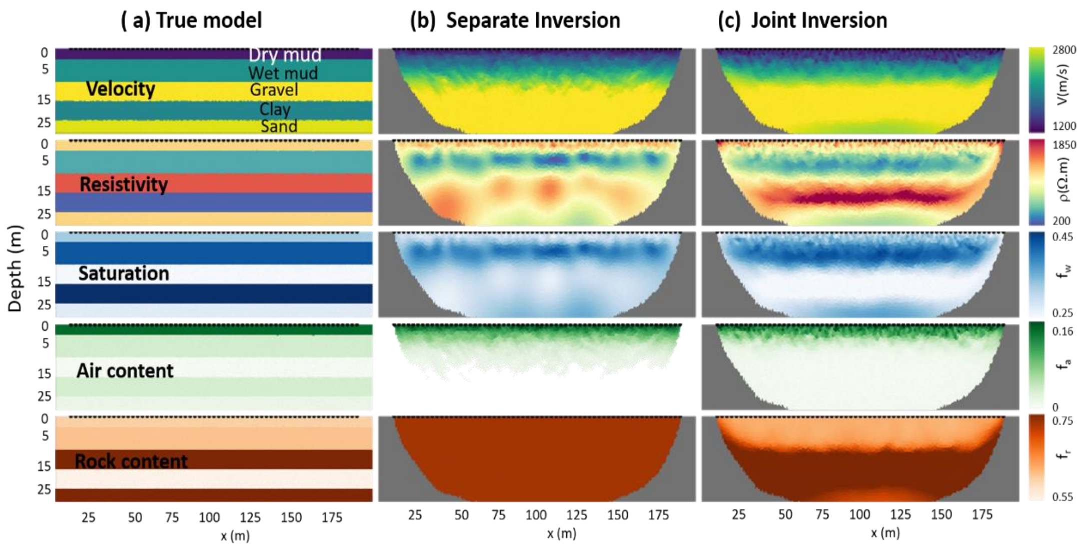

Figure 1 (**a**) True model for layered sedimentary units, (**b**) conventional inversion, and (**c**) petrophysical joint inversion.

Regularization constraints: Joint inversion regularization weights and model resolution are tested based on Mollaret et al. (2020). A high model resolution recovers layer structures and interfaces in the inversion using 0.25 zWeight anisotropy smoothing (Fig. 2a). As shown in Figure 2b, the inversion using 0.5 zWeight shows smeared quality with reduced layer accuracy. Inversion with 0.75 zWeight yields low model resolution (Fig. 2c). Thus, appropriate anisotropic smoothing improves model resolution. If geologic data is available, horizontal structures can use 0.25 anisotropy smoothing weight and vertical structures 0.75. Unknown prior geologic information can use 0.5 anisotropic weight.

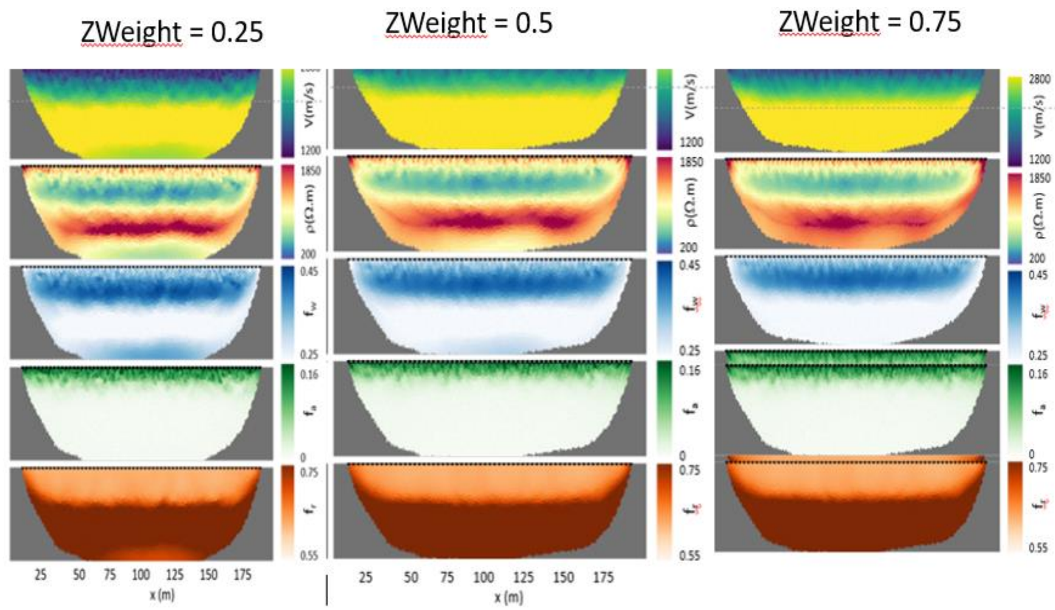

Figure 2 Models for joint inversion of ERT and SRT for different anisotropic smoothing (zWeight): (**a**) zWeight = 0.25, (**b**) zWeight = 0.5, (**c**) zWeight = 0.75.

Conclusions

This study examines how petrophysical joint inversion of the ERT and SRT minimizes model ambiguity of single method. Joint inversion enhances model resolution because the ERT and SRT have different sensitivities. SRT detects gravel-clay boundary that ERT misses. ERT identifies an SRT-hidden clay layer. An adequate anisotropic smoothing regularization (zWeight) can also affect model resolution. Horizontal structures use 0.25 zWeight, unknown subsurface conditions use 0.5, and vertical structures use 0.75. This study shows how joint inversion and adequate regularization parameters can significantly reduce model ambiguity.

References

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