Multiple response nonlinear regression applied to simultaneous density, vp and vs rock physics calibration and related statistical analysis

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Introduction

The present abstract focus on a robust rock physics analysis workflow. Rock physics calibration is performed by a coupled non-linear least-squares scheme, so that all the elastic properties are simultaneously taken into account. Then, a Markov Chain Monte Carlo algorithm is used to simultaneously estimate both the model's parameters and the prediction uncertainties. Further, statistical analysis of the calibrated model is presented as a tool to assist model selection. A robust rock physics analysis, as presented in this paper, is an important input for any geophysical interpretation and uncertainty assessment, from exploration prospects to reservoir characterization.

Methods

The mathematical tool used for the calibration step is non-linear multiple response (or multivariate) regression, as explained in Bates and Watts (1988). As such, we optimize the model parameters by minimizing the normalized sum of squared errors coming from different output variables (in the present paper, density, and). The error of each variable is normalized by its corresponding standard deviation, which is re estimated in each step of the optimization algorithm. To make uncertainty assessment, it is important to estimate the residuals standard deviation, but also, the uncertainty in the model parameters. In the present work, we use a Markov Chain Monte Carlo strategy to sample simultaneously the parameter space and the output predictions, as discussed in Mazumdar (1995), and Sinay and Hsu (2014). Finally, we apply statistical tools to compare two rock datasets elastic behaviors. Specifically, we apply two techniques: significance tests (t, and F) and effect size. Significance tests, as explained in Rawlings et al. (1932), compare the models' parameters normalized by their uncertainties; and effect size compares the models' predictions normalized by their uncertainties.

Results

We apply the methodology to compare two reservoirs, in terms of their calibrated rock physics models. The Figure shows the models differences, measured in terms of parameters and predictions. The comparison in terms of the parameters shows significant differences, which means different microstructures. The comparison in terms of the predictions shows moderate, but not negligible effect size. In this case, is not advisable to use a single rock physics model to describe both reservoirs.

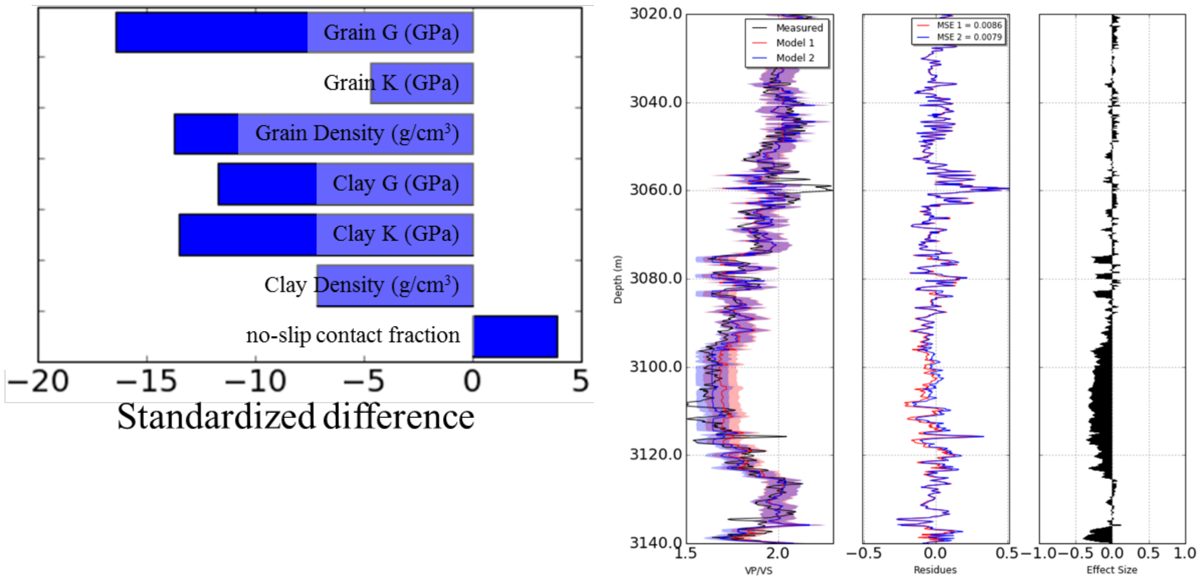

Figure: Comparison of the model calibrations for two reservoirs. The left bar plot shows the comparison in terms of model parameters, with significant differences. The right plot shows the comparison in terms of prediction of the property vp/vs, overlaying the measurements of the lower reservoir (fitted by Model 2). The confidence bands are represented by shaded areas around the predictions.

Conclusions

The present workflow exemplifies how to analyze rock physics models using statistical tools, and taking into account the models' uncertainties. The authors believe that the presented multivariate model regression and MCMC techniques are useful for quantitative rock physics analysis.

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