Comments on the *Geophysics* paper “Multiparameter $l_1$ norm waveform fitting: Interpretation of Gulf of Mexico reflection seismograms” by H. Djikpessé and A. Tarantola

Susan E. Minkoff* † and William W. Symes‡

**DISCUSSION**

In their recent paper, Djikpessé and Tarantola (*Geophysics* 64 (4) pp. 1023-1035, hereinafter D&T) raise a central question about geophysical inversion: how accurately must the physics of seismic waves in the Earth be modeled in order that inversion succeed? Two general criteria for successful inversion appear in D&T’s discussion: fit of predicted to observed data, and prediction of Earth structure. The hypothesis underlying inversion is that these criteria are inextricably linked, so that data fit should lead to accurate inference of subsurface features. We have also worked on the data discussed in D&T, using different modeling choices and inversion algorithms but also achieving quite successful inversions, in both senses. We feel that a brief comparison of methods and results might highlight the subtle relation between accuracy in modeling and success in inversion as well as raising questions about the appropriateness

*Sandia National Labs, Dept. 9222, MS 1110, PO Box 5800, Albuquerque, NM 87185-1110, seminko@sandia.gov

†Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

‡Rice University, Dept. of Computational and Applied Math, 6100 Main St. MS 134, Houston, TX 77005-1892, symes@caam.rice.edu
DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.
of D&T's modeling and inversion choices.

D&T is the most recent in a series of articles on the Mississippi Canyon dataset from the Gulf of Mexico, released to several research groups by Exxon Production Research Co. The authors invert for 2D maps of Poisson’s ratio and P-wave impedance via an \( l_1 \)-norm misfit criterion similar to traditional least-squares but which may prevent bias due to outliers. The forward model is isotropic elastic with cylindrical symmetry at each shot location, and the data to be matched is the complete seismic line (512 shots). D&T also use the direct-wave to invert for the seismic source. Minkoff and Symes (1997) (hereafter referred to as M&S) used full waveform inversion to invert for the P-wave background velocity, anisotropic seismic source, and three high-frequency elastic parameter reflectivities in a two-stage iterative optimization algorithm. For forward modeling we assumed isotropic viscoelastic wave propagation in a horizontally stratified medium, approximating wave propagation via high-frequency asymptotics in the plane-wave \((\tau - p)\) domain. We used a P-wave quality factor \( Q_p = 90 \), estimated via forward modeling from well logs; this value represents a very significant degree of attenuation over typical travel paths for this data. The data consists of CMP gathers (from the same seismic line as that used by D&T) which have been transformed into the plane-wave domain. (For further references to related work on this dataset see Symes and Carazzone (1991), (1992), Noble (1992), Tarantola et al. (1992), Igel (1993), Minkoff (1996), and Araya and Symes (1998).)

\( D&T \) (p.1033) state that one can use the \( l_1 \) norm “to cope with phenomena that are not modeled like attenuation and anisotropy”. The \( l_1 \) norm fit criterion permits the inversion to ignore outliers, i.e., a minority of data components deviating grossly from model predictions (Claerbout and Muir (1973)). However, neglect of attenuation and anisotropy seems far more likely to produce systematic and pervasive prediction errors than to remove random outliers. Further, the authors state (\( D&T \) p.1025) that “Since the analysis of observed data and previous works (Carazzone and Srnka, 1993; Igel et al., 1996) do not indicate (at first order) strong effects of attenuation or anisotropy, we
have chosen to compute the synthetic seismograms using the elastic wave equations in an isotropic nonattenuating medium." Our results directly contradict this statement. In M&S, we fit 90% of the energy around the gas sand target using viscoelastic inversion, and the residual (misfit) seismogram showed no coherent trend of energy with ray parameter. In contrast, we were able to fit only 75% using an elastic model. In fact the residual data from purely elastic modeling showed increasing energy with offset along the target horizon (as do D&T's results, see Figures 9 and 12).

Further, D&T assumed that the radiation pattern of the source is given correctly by an airgun modeling package. They then estimated a direction-independent wavelet from the horizontally traveling direct wave in the water. Figure 4 indicates that much of the direct wave was not accurately captured via this method. Note that the vertically traveling signal is often quite different from the horizontally traveling direct wave. In M&S we also began with a modeled airgun source. However, we were able to improve the data misfit between actual and predicted seismograms by 25% using non-linear joint inversion applied to the reflected (not direct) wave to estimate the source (both radiation pattern and direction-dependent wavelet) and reflectivity. Further, all other inversion measurement criteria improved after source inversion including better fit to data, prediction of subsurface characteristics as revealed by logging, and resolution analysis comparisons (see Minkoff (1996)). (Additional papers on source inversion include Harlan (1989), and Minkoff and Symes (1993), (1995).)

D&T present as their main evidence for success the "class III" behavior of P-wave impedance and Poisson's ratio. However nearly any reasonable version of AVO analysis will reveal this behavior in this very high quality data (see Araya and Symes (1998) in which several qualitatively less sophisticated processes applied to the very same data yielded quite similar results). The inversion in M&S, though based on quite different modeling choices, also revealed the expected fluctuations in elastic parameters through the gas sand. In fact we found that the complete inversion methodology we describe is important for obtaining a match to the Castagna and
Smith (1994) postulate of the most dependable AVO indicator. In particular, the anisotropic inversion-estimated source and reflectivities (from viscoelastic modeling) show that the reflectivity difference $R_P - R_S$ is relatively constant and near zero except at the gas sand where it is more negative than $R_P$ alone.

In conclusion, D&T use an isotropic elastic model to invert Gulf of Mexico data for 2D maps of Poisson’s ratio and P-wave impedance. They also invert for wavelet shape but not directivity. They use the $l_1$ norm in their optimization algorithm to prevent bias due to “noise”, i.e., physics which is not included in their earth model. The inversion result exhibits type III AVO behaviour. However, many less sophisticated (and less expensive) inversion techniques also reveal this behaviour. In our 1997 Geophysics paper, we used a viscoelastic model to invert the same Gulf of Mexico data for 1D maps of three elastic parameters and both the shape and directivity of the source. We provided a number of means of rating our results including data misfit, direct well-log comparisons, AVO analysis, and (in a related paper) resolution analysis. In every case, both attenuation and full source inversion had a considerable positive impact on the inversion results for this data. Therefore we do not find the assumptions of the D&T study compelling, nor do we believe that their conclusions strongly support these assumptions.

REFERENCES


