Inverse Problem of Seismic waveform data

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Active and passive seismic data are routinely collected for obtaining images of the earth's deep interior. Nowadays seismic data are used not only to obtain depth images but also to estimate rock properties such as compressional and shear wave velocities, density, porosity and permeability. Seismic reservoir characterization has now become an active area of research.

Like most other remotely sensed data, seismic data are almost always incomplete, inconsistent and inadequate and thus there exists a significant 'null space'. Meaningful estimates of earth model parameters can only be obtained by using realistic a priori information together with regularization designed to address problems specific to estimating subsurface rock properties (Sen and Stoffa 1995; Sen 2006). Seismic data are often inverted using locally 1D earth model assumptions. The goal is to estimate broad- band distribution of elastic properties from seismic data that are inherently band limited and aperture limited. Therefore formulation of inverse algorithms requires careful choice of parameter to navigate the 'null space'. We identify three regions:

- Information below 3Hz can be estimated from interval velocity analysis
- Information within the passband 8-60Hz can generally be retrieved from seismic information
- Information in the band 3-8 Hz and beyond 60Hz are not recorded by the seismic data.

We have developed systematic procedures for addressing each one of these issues. First we carry out careful interval velocity analysis in the delaytime- ray parameter domain to estimate very low frequency (~3Hz) information. This procedure, is however, influenced largely by recording aperture. The information in the frequency band of 3 to 8Hz is generally supplied by careful interpolation of well logs. A Bayesian hyper prior based regularization (Calvetti and Somerselo 2007; Routh et al 2008) is applied in a gradient descent and global optimization algorithm (figure 1).

Finally to derive model parameter estimates beyond 80 Hz, we employ a stochastic inversion algorithm. Starting models are derived from a fractional Guassian distribution whose parameters such as mean, variance and Hurst coefficient (Srivastava and Sen 2009) are estimated from well logs. A global optimization scheme called very fast simulated annealing (VFSA) is used in search for optimal models (Figure 2). The inverse problem is cast in a Bayesian framework; multiple solutions are obtained from the posterior probability distribution, which are used to characterize uncertainty in the estimated models.

Although the null-space for 1D elastic inverse problem is well understood, resolution issues in multi-dimension are not well documented. We are investigating these using point spread functions enabling us to better define regularization operators.

References

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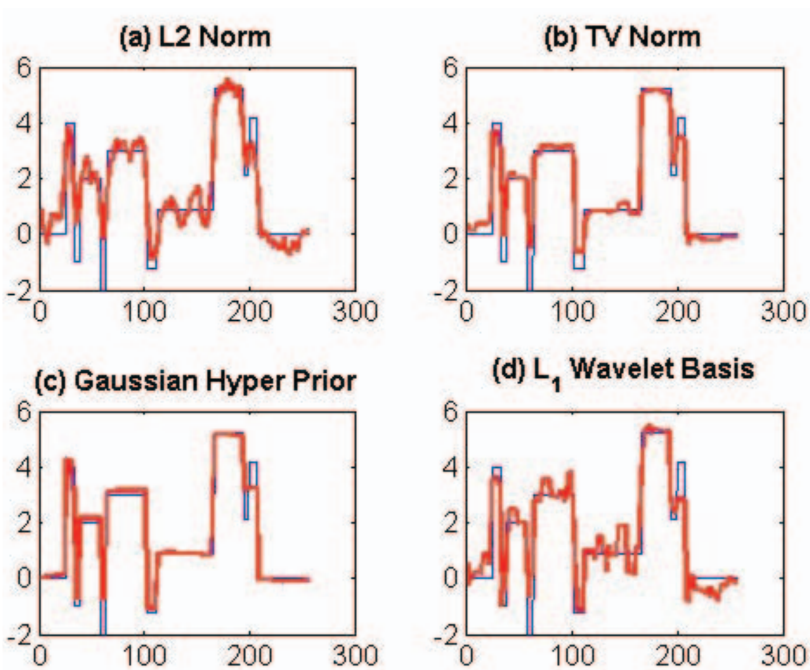

Figure 1: Inversion of seismic data for Acoustic impedance using different regularization techniques. The true model is shown in black while the inverted models are shown in red. Note the superior performance of Gaussian hyperprior compared to other well known regularization methods (modified from Routh et al 2008).

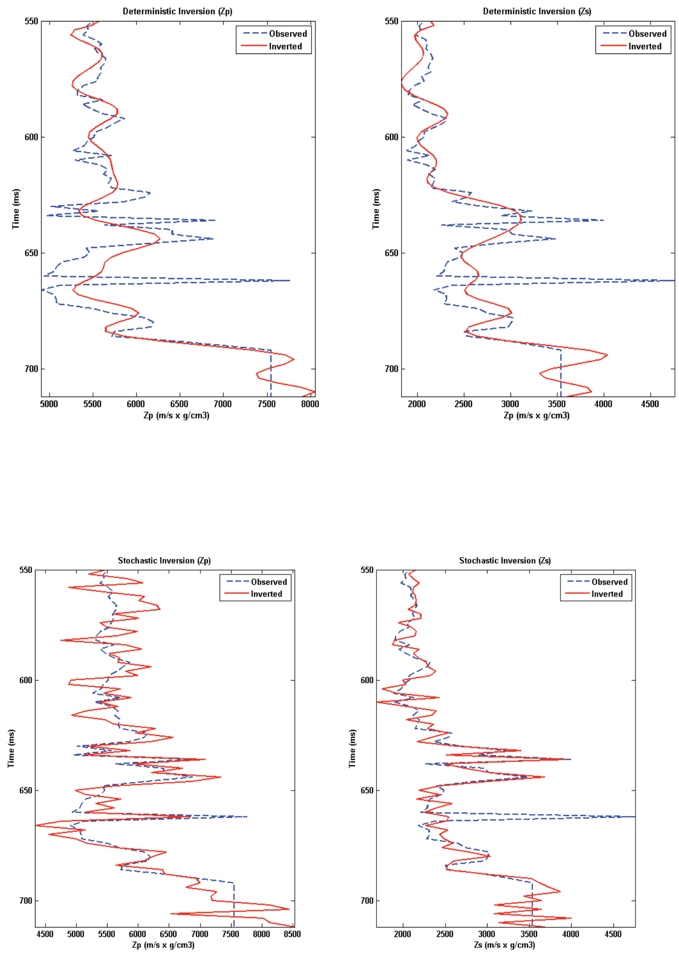

Figure 2: Pre-stack inversion results: Acoustic Impedance (left) and Shear Impedance (right) estimates from a deterministic (top) and fractal based stochastic (bottom) inversion. Note that the stochastic inversion is able to estimate high frequency variations. The red line shows the true well log and the blue is the estimated model.