Modified Stochastic Inversion (MSI)

Anat Canning, Dominique Mouliere, Yuval Weiss, Henrique Mageste, Taehee Kim, João Muniz, Fernando Vizeu and Anastasya Teitel, Emerson E&P; Miles Leggett and Astrid T. Fernandez, Galp E&P*

Summary

A spectral method for performing stochastic inversion through the integration of deterministic inversion with the stochastic process is presented. The result is equivalent to the Stochastic Inversion in terms of resolution, it matches the seismic data, and it enables uncertainly estimation via the generation of multiple realizations. In addition, it provides excellent flexibility and QC capabilities, to help the user optimize results. The process is very fast and therefore very attractive.

Introduction

The inversion of prestack seismic data is a common procedure used to extract elastic properties from seismic data, and indirectly predict additional rock properties. We generally classify seismic amplitude inversions into two classes: deterministic and probabilistic, each with its strengths and limitations. In the context of this paper, “inversion” means prestack amplitude inversion of migrated seismic gathers. It is important to note that the prestack migration which is a prerequisite for this inversion is expected to be amplitude preserving.

Deterministic methods operate largely within the bandwidth of seismic data, with bandwidth extensions provided by a background impedance model. The impedance model is normally constructed using well data, interpretation data, and some form of spatial modeling (e.g. using geostatistics). In principle, deterministic inversion is either a sort of spectral extension of the seismic data, or it is based on the principle of minimizing the difference between the amplitude in the seismic gather and the synthetic gather that was constructed from the estimated impedance model. Stochastic inversions (Haas and Dubrule 1994, Francis 2005, Leggett and Chesters, 2005, Grana *et al.*, 2012, Zhang *et al.*, 2012, Fernandez *et al.*, 2016), on the other hand, are popular because of their ability to extend or broaden the operational frequency so that reservoir heterogeneities and thin beds can be resolved and modeled. Stochastic inversions create a suite of equi-probable and alternative impedance models that are consistent with the seismic data. These alternative realizations are created by the inversion as an extension of the Sequential Gaussian Simulation (SGS). Collectively, the suite of possible impedance models or realizations captures the uncertainty or non-uniqueness of the seismic inversion process. While theoretically attractive, it is an expensive alternative, and therefore, geoscientists often settle for too few realizations.

We present here an alternative procedure which is a combination of both approaches and is computationally less expensive than standard stochastic inversions. It provides better flexibility and QC opportunities for the user, while still creating a large number of scenarios for uncertainty analysis. The principle idea behind this algorithm is based on the following realizations:

- The seismic data contributes to the stochastic inversion mainly within the seismic frequency band.
- Within the seismic frequency band, both stochastic and deterministic approaches are very similar, as they use the same criteria for convergence – the best match of the synthetic seismogram to the seismic data.

We present here an inversion method that is an integration of the deterministic and stochastic approaches. It unifies deterministic inversion and SGS spectrally and produces results that are equivalent to stochastic inversion, but with much better run times and flexibility. The goal of the inversion is to estimate the elastic and rock property in a manner that ties the well data, honors the seismic data, provides broad frequency content, and enables uncertainty estimation.

Theory and Method

Stochastic inversion is an extension of Sequential Gaussian Simulation (SGS). With SGS, well data is normally extrapolated along the interpreted structure in a stochastic manner using a variogram which is a result of the statistical analysis of well and seismic data. The standard stochastic inversion involves many iterations of SGS per location aimed at finding the model which best minimizes the difference between the seismic and the synthetic data. The process of generating the synthetic data $S(t)$ comprises two steps: converting impedance $I(t)$ to reflectivity $R(t)$ and convolving with a wavelet $w(t)$:

$$R(t) = \Delta I(t) / I(t) \quad (1)$$

$$S(t) = R(t) * w(t) \quad (2)$$

Modified Stochastic Inversion (MSI)

The wavelet *w(t)* is extracted from the seismic data and is therefore limited to the seismic bandwidth. Consequently, the convolution with the wavelet acts as a frequency filter applied to the reflectivity function, and indirectly to the impedance trace. This implies that the contribution of the seismic data to the stochastic inversion is limited to the seismic bandwidth. Moreover, this contribution is in principle the same as what deterministic inversion does within the seismic bandwidth – minimizing the differences between the synthetic and seismic data. Therefore, we can safely say that the impedance resulting from classic Stochastic Inversion has contributions from well data and seismic data in different spectral bands. The well data contributes mainly to the low and high frequencies, while the seismic data mainly affects the central frequency band, as is illustrated in Figure 1. Note that equations 1) and 2) represent a simplified schematic description of the synthetic generation process and are used to illustrate the concept of filtering the impedance model to the seismic bandwidth. P-Impedance, S-Impedance, and Density are involved in the generation of the synthetic gather so that the AVO response is modeled as well. All three components - P, S and Density - are inverted simultaneously.

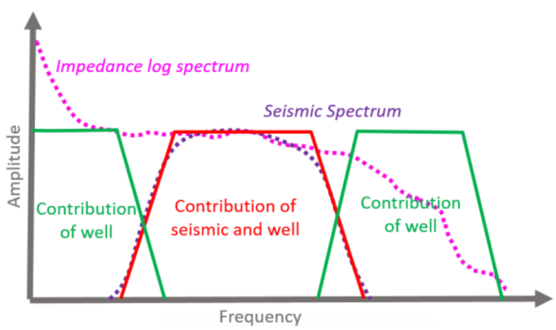

Figure 1: Stocastic inversion analyzed in the frequency domain.

The Modified Stochastic Inversion (MSI) integrates the impedances derived from deterministic inversion with the ones derived from SGS in the frequency domain. We start with well logs of the elastic parameters (P-Impedance, S-Impedance and Density), interpreted horizons, and the migrated prestack seismic data. We separate the "impedance field" into three frequency zones: low, medium, and high. The low and high frequencies are mainly contributed from the well data while the middle frequency band is mainly contributed from the seismic data via a standard deterministic prestack seismic inversion. In similarity to the classic stochastic inversion, we use SGS to build multiple realizations of the impedance field around the reservoir zone. These multiple realizations are used for the low and high frequency components. In fact, we can use a different procedure for the low and high frequency components. The result is an integration of the three different components in the frequency domain. The benefits of this methodology are twofold. It provides a huge improvement in speed, making stochastic inversion easily affordable for any project. But the main advantage is providing flexibility in building the reservoir impedance model, as it controls the effects of the low frequency model, the seismic data, and the high frequency contributions from the well logs separately. The process is shown in Figure 2. The separation into three components enables us to carefully build the MSI result, selecting optimal procedures for each of the components. The low frequency has the highest impact on the structure of the reservoir, the deterministic inversion ensures the tie with the seismic data, and the high frequency provides the high-resolution details. The flexibility in separating these components is one of the strengths of this methodology.

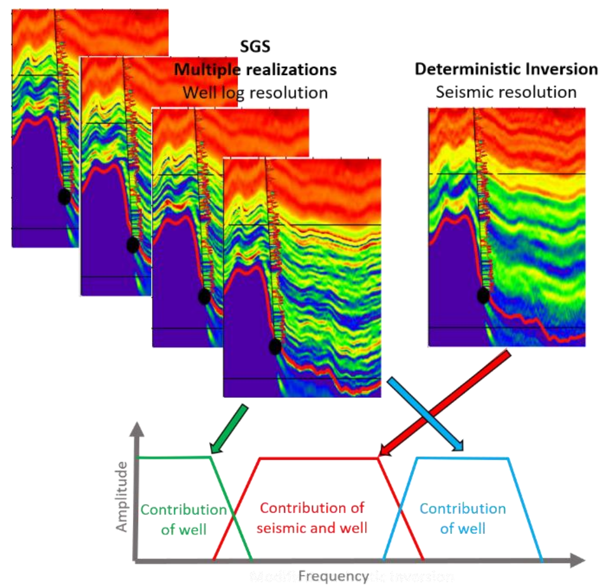

Figure 2: Modified Stocastic Inversion (MSI) analyzed in the frequency domain.

Example

We demonstrate the methodology with a data example from Sara - Myra blocks, located in the East Mediterranean Sea. This example is mainly used to illustrate the method, as we are limited by publication permissions. Figure 3 shows a stacked cross-section through the main Myra structure. The well-used in this example is overlaid, displaying P-Impedance. This well was drilled into the "Tamar Sands", which proved to be gas bearing sands in a neighboring region which have similar structures (Gardosh and Tannenbaum, 2014, Sagy, *et al.* 2015, Gvirtzman *et al.* 2017, Ben-Gai, 2018). Unfortunately, this well did not find hydrocarbons. Inversion of the seismic data had suggested possible hydrocarbons to the left of the well at the top of the structure, but this feature is quite small.

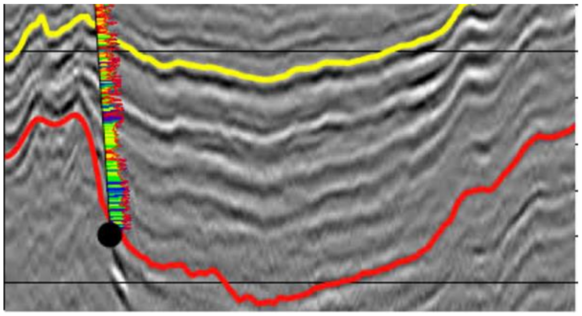

Figure 3: Seismic section through "Myra High". Well log display - P-Impedance.

Figure 4 shows the result of deterministic inversion. A Prestack Maximum Likelihood Inversion (PMLI) was used in this study (Konyushenk, 2014). Note the low impedance interval at the top of the structure. This feature also exhibits low Vp/Vs (not displayed here) and could indicate the existence of gas. Here only the P-Impedance data is presented. The objective of this study was to try to estimate the potential extent of this feature in a probabilistic manner.

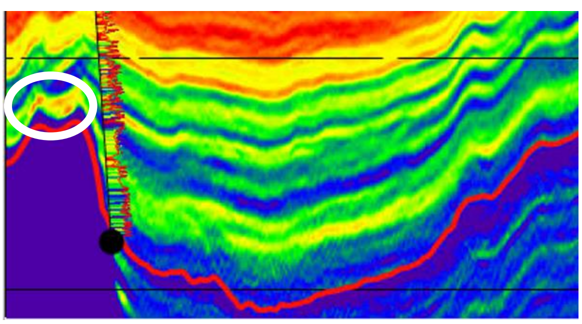

Figure 4: P-Impedance, a result of deterministic inversion.

SGS is normally performed separately for the low and high frequencies, using different procedures and parameters. The method enables this kind of flexibility and is one of its main advantages. For example, we often use co-SGS with seismic velocity as co-data for the low frequency, while for the high frequency we use co-SGS with deterministic inversion as co-data. We also select different parameters for variograms and for log pre-processing for the low and high frequency to best capture the different characteristics of each of the frequency bands. Figure 5 displays multiple realizations of SGS, used for the high frequency in this example.

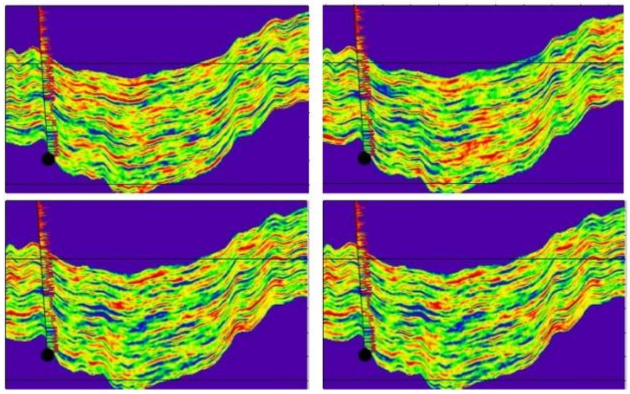

Figure 5: P-Impedance, multi-realizations of SGS representing the high frequency component of the impedance field.

The next step is the spectral merge, done in the frequency domain. Figure 6 in an example of the process displaying the impedance spectrum of the three different components that are part of the MSI spectral integration phase: low, medium and high. Green is the medium frequency which comes from the deterministic inversion. Note the limited frequency range on the high end of the spectrum. The magenta line is the MSI result. Note the spectral increase on the high frequency compared with the deterministic inversion.

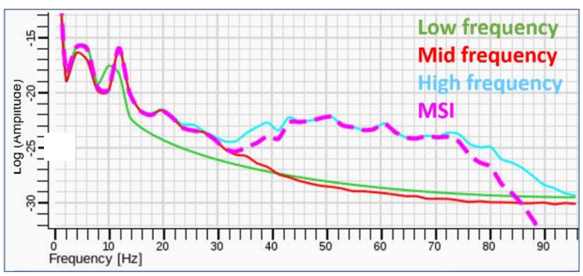

Figure 6: P-Impedance, result of deterministic inversion.

In the Myra example, we only used the medium and high frequency components. So, the low frequency comes from the deterministic inversion as well. This is an optional workflow, it provides a more stable result, as the low frequency controls the main component of the variability and here it is not changing between realizations. This flexibility will be demonstrated in the oral presentation with another dataset that uses three frequency bands. Figure 7 shows the MSI result, displaying four realizations. Note the significant increase in frequency content compared with the deterministic inversion displayed in Figure 4. Note also the variability in details between the realizations. The main interest in this dataset is the investigation of the low impedance zone at the top of the structure (marked in Figure 4).

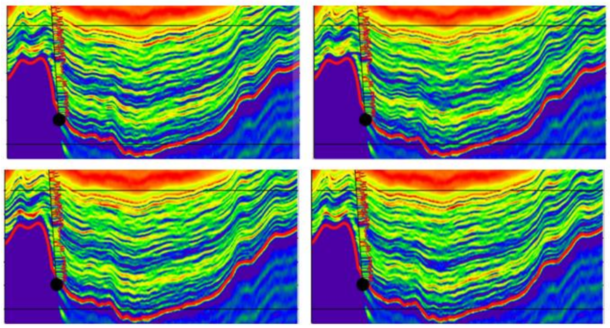

Figure 7: P-Impedance, multiple realizations of MSI.

A more detailed inspection of the effect of MSI is presented in Figure 8. Here we display the P-Impedance extracted along the well trajectory. The real well log is displayed in blue. Super imposed on it are the low and high SGS simulations. The background model used for deterministic inversion is also displayed, enabling the analysis of the effects of the deterministic inversion (PMLI). The deterministic Inversion is much lower in frequency compared with the well log and the main objective of MSI is to increase its frequency band, which is successfully done as the light blue line demonstrates – better match and more details when compared with the real well log data.

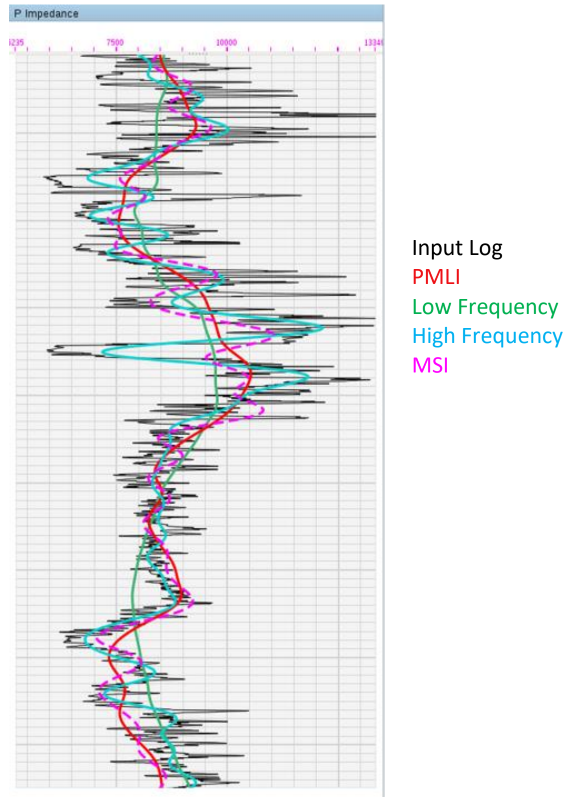

Figure 8: P-Impedance, extracted along well trajectory for the various components involved in the MSI procedure.

Conclusions

We showed successful integration of deterministic inversion with SGS in the frequency domain as a fast and flexible alternative to the conventional approach used in Stochastic Inversion. We showed improved frequency content compared with deterministic inversion, a multiple realization framework which can enable uncertainty analysis, improved QC capabilities and great flexibility in optimizing the workflow and the results. The process is very fast and therefore very attractive.

Acknowledgements

We would like to thank GALP E&P, for their contribution and advice. GALP E&P has sponsored this project and helped to turn the idea of MSI into a reality.

In addition, we would like to acknowledge the Israeli Ministry of Energy and Water Resources for permission to use seismic and well data in this paper.