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Inversion Subversion - An analysis of the consequences of poor inversion input

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Summary

Prestack seismic inversion is a valuable tool for converting seismic amplitudes into elastic properties on the path to geological classification. However, the process of going through seismic inversion is not simply the application of an inversion algorithm to the data. The inputs into the process (initial models, wavelets, etc.) require their own processes with the contribution of user judgement to select appropriate parameters. In this analysis, I look at what happens when these inputs are varied through both reasonable and unreasonable parameters. The sensitivity to these changes of the final inversion results is compared, so that the geophysicist can take comfort or caution in their parameter selection as appropriate.

Method

The purpose of an AVO inversion is to transform prestack seismic amplitude changes into models of P-impedance, S-impedance, and density. In addition to the suitably prepared prestack seismic gathers, inversion also requires an initial model of the elastic properties and an estimate of the seismic wavelet. The tests performed cover a range of possibilities for these inputs. Inversion of numerical model data and example data sets are shown.

Initial Model

The initial model provides the starting point for the inversion algorithm to predict the earth's elastic properties. By providing the low frequencies unavailable from seismic data, the actual magnitude of the properties may be obtained in what would otherwise be a non-unique solution. However, depending on the choice of filter to apply, the frequency range of the initial model can just meet, partially overlap, or significantly overlap the seismic spectrum, which is not a uniform geometric shape. Within the seismic bandwidth, the seismic amplitudes should dominate the final response, so testing is designed to demonstrate whether this is indeed the case.

Wavelet

One of the benefits of seismic inversion is that the amplitude effects from partially overlapping wavelets can be reduced to better identify layer boundaries. To achieve this, an estimate of the seismic wavelet is needed as input into the inversion process. When estimating the wavelet, changes in the process will alter the wavelet spectrum and length. Wavelets with lengths and bandwidths of varied sizes are used to invert the test data sets to demonstrate the influence on the inversion results.

Phase

The seismic amplitudes are assumed to represent reflectivity, with peaks and troughs corresponding to elastic-property interfaces. Data preconditioning aims to ensure other amplitude effects are minimized, and a robust phase estimate and rotation should be performed. With sparse well control or noisy data, this phase estimate can be uncertain, affecting the inversion process. The test data are examined for the effects of using seismic data that are not zero phase along with wavelets that are matched or mismatched with the expected phase of the data.

Observations

Initial Model

Figure 1 shows the P-impedance from tests run on numerical data, which are inverted using a model with a matching bandwidth, a model whose bandwidth does not meet the data bandwidth, and a model that spectrally overlaps the input data. The effect of having insufficient low frequencies produces the largest discrepancy from the input model. Using overlapping bandwidths introduces some uncertainty, but to a lesser extent than the gap case.

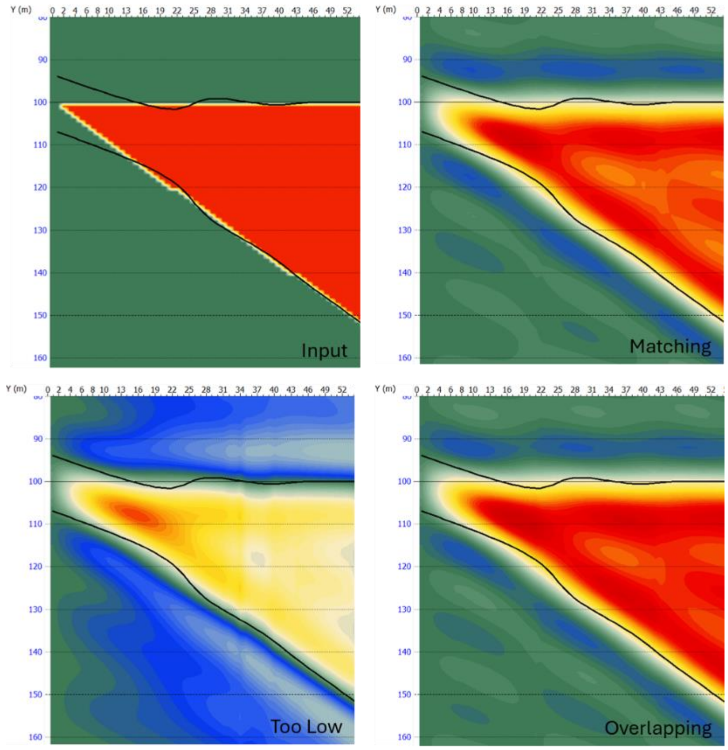

Figure 1. Numerical model showing the input I_P model (top left) along with inversion results for initial models of varying bandwidths. An initial model with a frequency content that is too low has significant disparities.

Wavelet

The wavelet length and frequency content both have impacts on the quality of layering in the inverted models. Tests on real data examples show that the wavelet length has one of the smallest impacts on the inversion values. Nevertheless, the inversion error is minimized when the wavelet length encompasses the full first side lobe. Truncated side lobes or inclusion of more sidelobe energy increase the error observed. Figure 2 shows a plot of RMS error of P-impedance and S-impedance at the well locations of an inverted data set compared to wavelet length. The minimum error occurs at a wavelet length of 32 ms, which meets the criteria described.

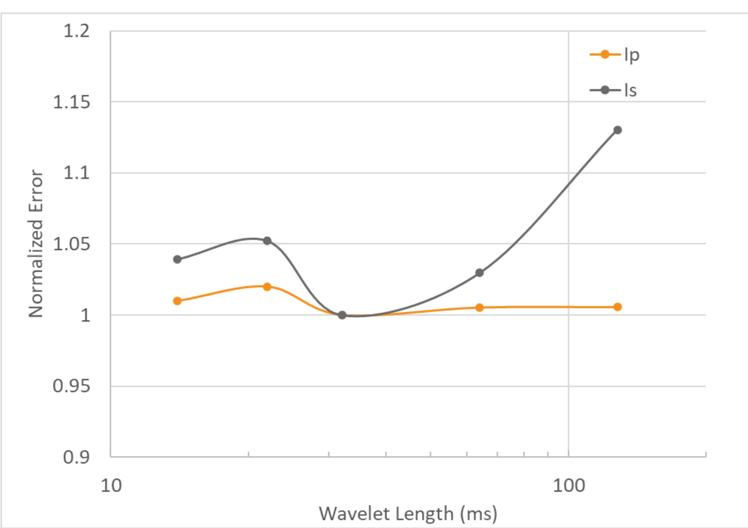

Figure 2. Normalized RMS error between inverted results and well data for a variable wavelet length. Minimum errors in both P-impedance and S-impedance are achieved when the wavelet is long enough to include the full extent of the first side lobe, but no longer.

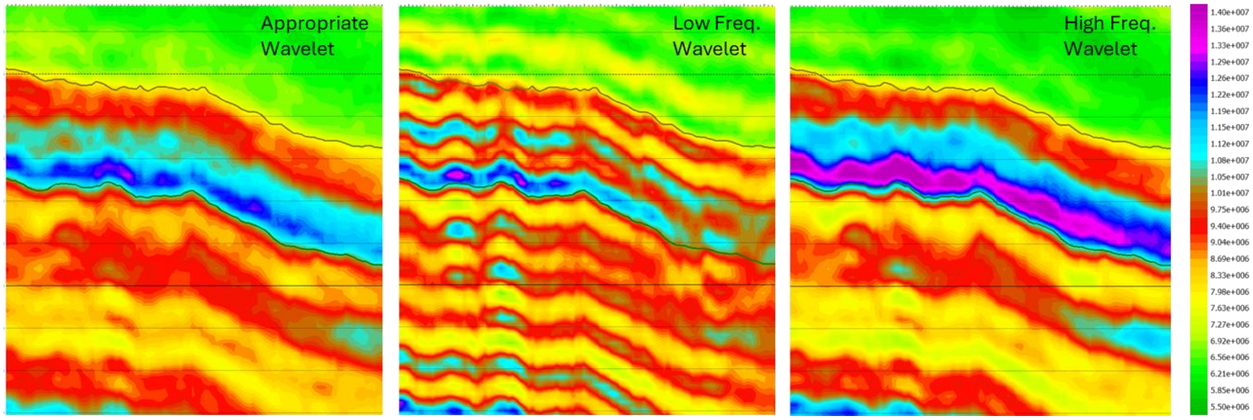

Figure 3. Change in P-impedance results from the choice of wavelet bandwidth. The low-frequency wavelet (centre) shows artifacts, while the high-frequency wavelet (right) shows a loss of resolution compared to the standard results (left)

The frequency content of the wavelet has a significant impact on the final inversion results. As shown in Figure 3, using a wavelet that is either too high or too low of a bandwidth reduces the resolution of the final model. In the case of a wavelet that is low-frequency compared to the data, 'ringing' artifacts are introduced into the results, while the high-frequency wavelet shows reduced layer definition.

Phase

Mismatch in phase between the data and the inversion wavelet results in erroneous layer values (Figure 4). Interestingly, even when non-zero phase data use the matching phase of wavelet, the inverted model still shows a higher mismatch than from zero phase results, though these differences are less than 5%.

Conclusions

While not an exhaustive analysis of every factor contributing to inversion uncertainty, this experiment highlights the need to pay attention to how the inversion inputs are determined. While the wavelet length has a comparatively low contribution to the uncertainty, the wavelet bandwidth is more significant. This observation is relevant when selecting the time window of the data for use in spectral analysis, which should be suited for the specific zone of interest. Further consideration should be made when the spectral content of the seismic data varies laterally or vertically.

Phase analysis and rotation of the seismic data prior to the inversion should also be a significant consideration in the data preconditioning. A robust phase estimate to rotate the data to zero phase will allow for more confidence in the results.

Though these results show that an overlap of the model and seismic bandwidths is less severe than having a gap between them, it can't be said for certain that this is a universal observation on all data. The frequency content of the initial model should be matched with the specific spectra of the seismic data being inverted, rather than using a standardized or default filter.

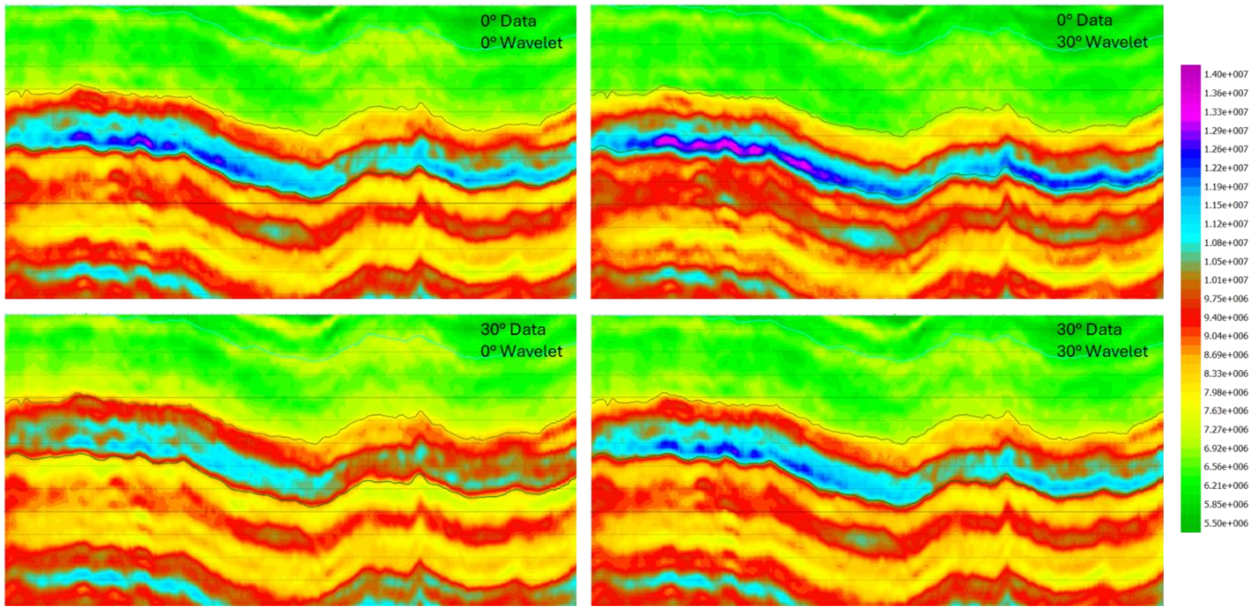

Figure 4. Data example showing the effects of mismatch between the data phase and inversion wavelet on P-impedance. When the data and wavelet phase do not match, there are erroneous values introduced.

Acknowledgements

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