Internal Multiple Prediction and Attenuation in the Santos Basin using Inverse Scattering Series

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Abstract

The complex stratigraphy above the pre-salt reservoir target in the Santos Basin, composed of structural trend variations, evaporites with variable thickness amongst other formations, creates the perfect condition to create strong internal multiple reverberation crosstalk at the reservoir level. In such cases, internal multiples can range from a clear and interpretable/traceable event to a weak and proximal trend of conformable reverberation-like events perversely interacting with underlying primaries. These types of multiples are known to obscure primary reflection information from the seismic data, making earth model building, interpretation and inversion ambiguous at the producing target zones.

This work revisits and explores benefits and practical aspects of employing inverse scattering series (ISS) based algorithms to predict internal multiples in the Santos Basin region, under a new pre-processing, contamination analysis and parameterization perspective. The intricate nature and rapid variability of the multiple generating formations poses a limitation for methods relying on prior information about formations and/or boundaries responsible to for major internal multiples at the reservoir level. In some instances, thin layering with high impedance contrast makes every single sample of the seismic experiment a potential generator of internal multiples, making existing methods suboptimal for all formations, unless a certain number of interpretation and/or boundaries are taken into consideration during the prediction process.

For an underlying 2D earth assumption, the ISS internal multiple attenuation algorithm can be expressed as follows:

$$b_3(k_g, k_s, \omega) = \iint dk_1 dk_2 \int_{-\infty}^{\infty} dz_1\, b_1(k_g, k_1, z_1)\, e^{+i(q_g+q_1)z_1} \int_{-\infty}^{z_1-\varepsilon} dz_2\, b_1(k_1, k_2, z_2)\, e^{-i(q_1+q_2)z_2} \int_{z_2+\varepsilon}^{\infty} dz_3\, b_1(k_2, k_s, z_3)\, e^{+i(q_2+q_s)z_3} \quad (1)$$

where b_1 are the input data after a constant velocity (c_0) migration; b_3 is the predicted internal multiple and k_g and k_s are the horizontal wavenumbers at receiver and source sides, respectively. ω is temporal frequency. $k_j^2 + q_j^2 = \frac{\omega^2}{c_0^2}$, $j = g, s, 1,2$ and q_i is vertical wavenumber. ε ensures that the subevents meet a deeper-shallower-deeper relationship. The main advantage of this algorithm lies in the assumption that every sample acts as a multiple downward generator, overcoming the limitation commonly present on boundary-related methods.

Figure 1 shows stacked traces and common midpoint gathers comparisons between the recorded data and internal multiples predicted from the ISS method. It is possible to see that ISS can predict all internal multiples associated with the data with a consistent kinematic accuracy across all offsets, including mode-converted related multiples. Initial multi-dimensional adaptive adjustment successfully matches and suppress predicted multiples from the recorded data, providing a good framework for subsequent localized matching based on semi-sparse representation of the seismic data where we observe better discrimination between primaries and coherent noise.

This work shows that the inverse-scattering series framework is a viable option when predicting complex internal multiples, which is the case in the intra-salt sequency and pre-salt reservoirs in the Santos Basin region. This methodology does not have prior assumptions about generating formations; it is data-driven and insensitive to spatial changes while providing a complete solution for different internal multiple contamination scenarios.

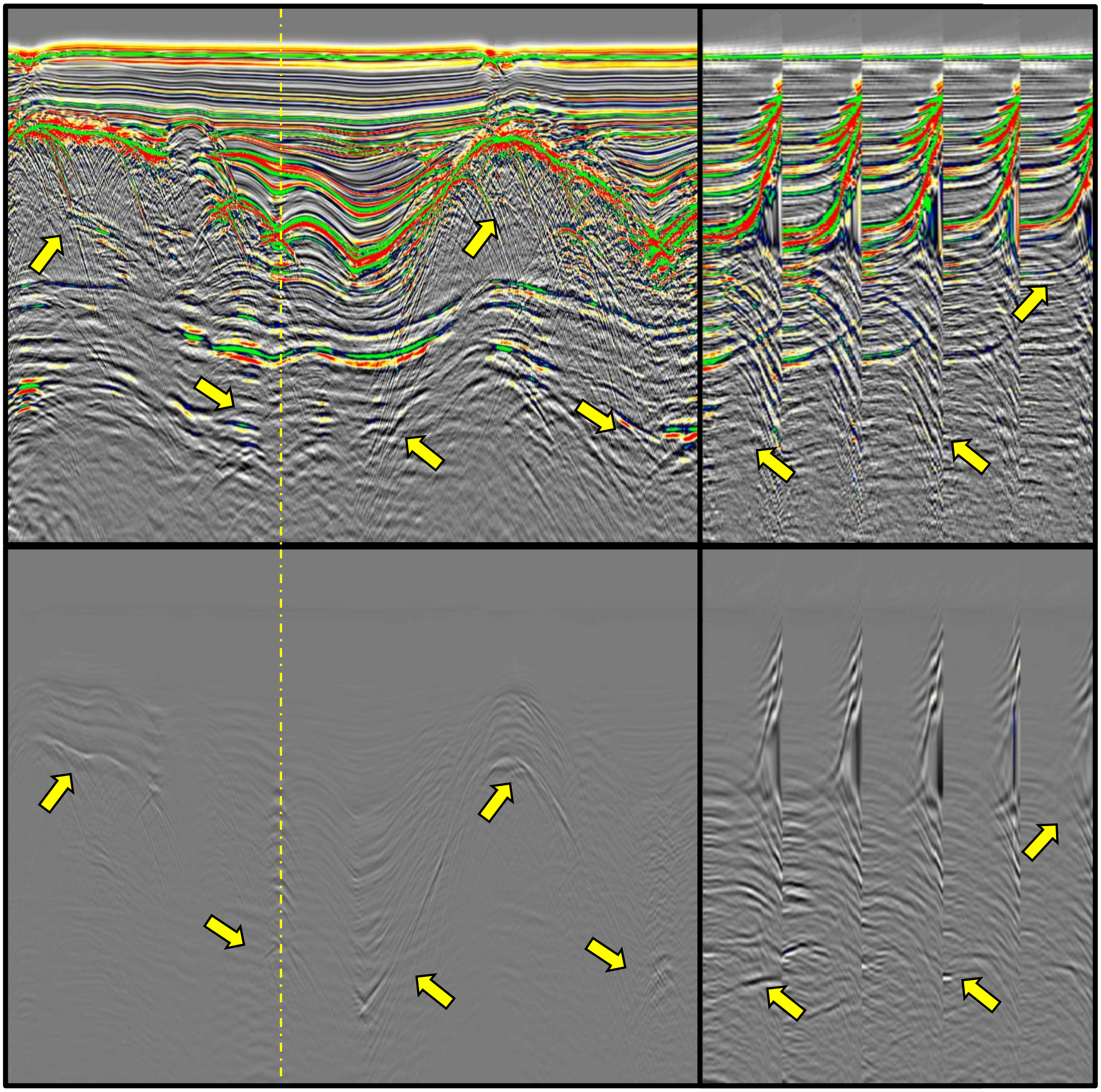

Figure 1 – Comparison of stacked traces (left) and CMP gathers (right) between the recorded data (above) and the internal multiple model derived from ISS with a maximum frequency of 50Hz (below). Yellow line on stacked section shows approximate location of CMP gathers. Yellow lines highlight good visual correlation between the complex internal multiples predicted by the ISS method.