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Enhancing 4D Seismic Signal-to-Noise Ratio through Weighted Stacking of Upgoing and Downgoing Migrations in a Santos Basin Dataset

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Abstract

This paper describes the application of the Similarity Stack 4D method, as presented by Nacchini et al. (2012), in the context of 4D seismic processing. The technique combines upgoing and downgoing migrations to improve the signal-to-noise ratio of the 4D seismic response, defined as the difference between the monitor and base data volumes. The NRMSD (Normalized Root Mean Square Deviation) metric, regularized with a small positive constant, is used to quantify the similarity between the data and ensure numerical stability. The method was evaluated using real 4D seismic data from the Santos Basin.

Introduction

The 4D seismic response is an essential tool for reservoir monitoring, defined as the difference between seismic volumes acquired at different times (monitor and base data). The quality of this response depends on the consistency of the processing and the seismic image. The Similarity Stack 4D method proposes the weighted combination of upgoing and downgoing migrations, which illuminate the same unchanged geology. The differences between these migrations are attributed to peculiarities of the respective processing. The technique aims to improve the signal-to-noise ratio of the 4D response without introducing artificial effects.

Method and Theory

The method used in this work follows the formulation presented by Nacchini et al. (2012). The first step involves calculating the average energy of each seismic volume using the root mean square (RMS) formula:

$$\mathrm{RMS(X)} = \sqrt{\frac{1}{N}\sum_i x_i^2}$$

Based on this, the NRMSD (Normalized Root Mean Square Deviation) is calculated between the upgoing (U) and downgoing (D) volumes:

$$\mathrm{NRMSD(U,D)} = \frac{2\ \mathrm{RMS(U-D)}}{\mathrm{RMS(U)} + \mathrm{RMS(D)} + \epsilon}$$

where ϵ is a small positive constant added to ensure numerical stability. The NRMSD quantifies the dissimilarity between the volumes and is used to derive the weight function W, which regulates the relative contribution of each migration in the combination:

$$W = 1 - \frac{NRMSD}{2}$$

With the weights defined, the migrated volumes are combined separately for the monitor and base data times. For the monitor data, the weighted combination is given by

$$S_{4D,\mathrm{monitor}} = (U_{\mathrm{monitor}} + D_{\mathrm{monitor}})W_{\mathrm{monitor}}$$

and for the base data

$$S_{\_4D,base} = (U_{base} + D_{base})W_{base}$$

These combined volumes represent the 3D seismic image resulting from the weighted sum of the upgoing and downgoing migrations. The combined 4D seismic response is then obtained by subtracting the combined volumes of the monitor and base data:

$$\Delta_{4D,UD} = S_{4D,\mathrm{monitor}} - S_{4D,base}$$

For comparison purposes, the individual 4D responses for the upgoing and downgoing volumes are also calculated

$$\Delta_{4D,U} = U_{\mathrm{monitor}} - U_{base}$$

$$\Delta_{4D,D} = D_{\mathrm{monitor}} - D_{base}$$

The NRMSD calculation window was defined around each sample of the seismic trace, sliding along the time axis with a fixed size. This procedure allows the similarity between the upgoing and downgoing volumes to be evaluated point by point, respecting the local variation of seismic amplitudes. Figure 1 illustrates this concept, showing the calculation window centered on a specific sample, where the upgoing (U) and downgoing (D) traces are compared to generate the combined response S_{4D}.

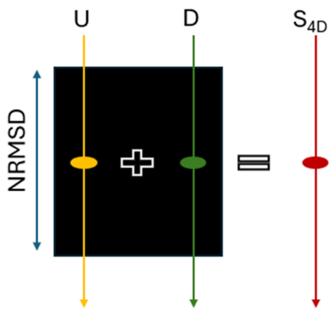

Figure 1: Schematic representation of the similarity stack computation for a single seismic sample. The upgoing (U) and downgoing (D) traces are compared within a fixed-size sliding window (black square), centered on the sample, for NRMSD calculation. The resulting similarity is used to compute the weighted 4D response S_{4D}.

Results

Figure 2 presents the results of applying the Similarity Stack 4D method to the migrated data from a real 4D seismic dataset in the Santos Basin. The resulting images show that, although the downgoing migration provides superior quality in the 3D image, the upgoing migration plays a significant role in constructing the 4D response, as it captures relevant temporal variations between the monitor and base data volumes. This contribution enhances the signal of true 4D events, reinforcing their visibility in the final combined response.

The combined 4D response, obtained through the weighted sum of upgoing and downgoing migrations, demonstrated an improved signal-to-noise ratio compared to the individual responses. Two different window sizes were tested for the NRMSD calculation — 40 and 400 coefficients.

Although the larger window produced slightly more stable results, the improvements were marginal, indicating that a window of 40 coefficients was sufficient for this study.

The regularization applied to the NRMSD ensured numerical stability, particularly in regions where the window encompassed only zero amplitudes — such as above the seafloor — thus avoiding divisions by near-zero values that could compromise the robustness of the method. While the method did not completely eliminate noise, it improved the coherence of the 4D response in a controlled and interpretable manner.

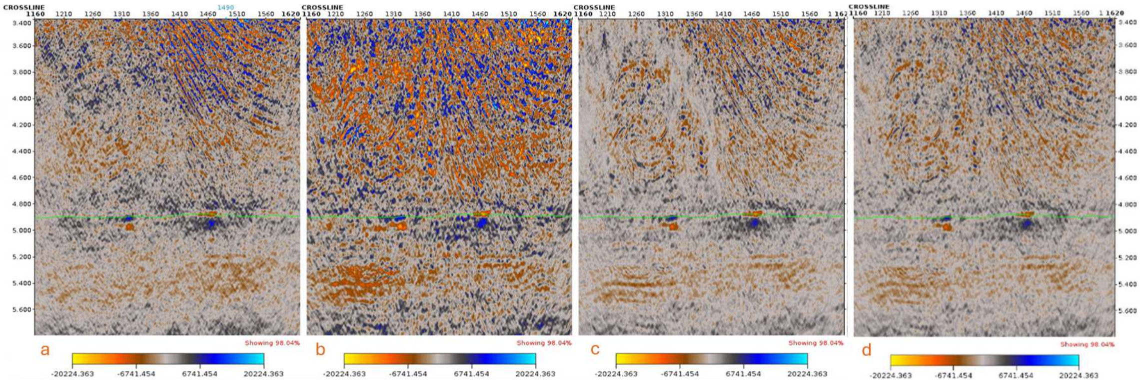

Figure 2: (a) 4D response obtained from downgoing migration. (b) 4D response obtained from upgoing migration. (c) Combined 4D response by Similarity Stack with 40 coefficients in the NRMSD calculation window. (d) Combined 4D response with 400 coefficients in the NRMSD calculation window.

Conclusions

The Similarity Stack 4D method proved effective in improving the quality of the 4D seismic response by combining upgoing and downgoing migrations. The regularization of the NRMSD ensured stability in the similarity calculation, and the weighting allowed the integration of complementary information from both volumes. Although the downgoing image is generally of better quality in the 3D migration, the upgoing migration contributes significantly to the 4D response. The application to real seismic data from the Santos Basin demonstrated that the technique can be a useful tool for reservoir monitoring.

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References

Nacchini, P., Tsakoma, M., & Ewen, A. (2012). Specifying 4D-noise by weighted stacking of up-going and down-going migrations. Proceedings of the SEI-AS Las Vegas 2012 Annual Meeting. IEEE. DOI: 10.1109/segan.2012.6747161