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The first 4D triple OBN processing for presalt Tupi Pilot field in Santos basin

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Abstract Summary

The Tupi field, one of the most significant pre-salt fields in the Santos basin, underwent a baseline acquisition in 2022, consisting of over 10,000 ocean-bottom nodes (OBN). In the central region of the field, this acquisition was strategically planned to be used as monitor 2 (M2) over focused area, designated as Pilot, which featured the first OBN acquisitions, both baseline (2015) and monitor (2017), with an emphasis on the pre-salt of the Santos basin. One of the challenges of the triple 4D project (2022) in the Pilot area is to maintain the high repeatability observed in the first 4D project. In the first monitor (M1) campaign (2017), the same equipment and the same company were employed for the OBN acquisitions. The results of this first 4D test demonstrated the feasibility of using this technology for monitoring pre-salt reservoirs in Santos Basin (Cruz et al., 2021). However, in the 2022 campaign, several changes were implemented, including the decimation of the node carpet, the transition from a single source to a triple source, and the use of different receiver and source equipments. Such modifications were essential to enable the mega baseline acquisition of Tupi, covering approximately 2,488 km² in the node carpet and 3,000 km² in the shot carpet.

Analyses were conducted with the data from the first 4D (2018) regarding the expected signal degradation due to the decimation of the node carpet. The raw data, after migration, showed a 20% increase in NRMS, indicating that the median calculated in the reservoir window increased from 2.4% to 3.0%. Considering this deterioration in repeatability and other factors that could contribute additionally, a seismic processing contract was planned to include the 4D least-squares reverse-time migration (LSRTM) step, aiming to minimize irregular illumination results of geological complexity (Shadrina et al., 2024), furthermore some of the necessary changes in the M2 acquisition. This step proved to be extremely important, as it allowed for the improvement of the NRMS amplitude results, which were reduced from 3.89% to 2.57% (M1, Base) and from 8.01% to 3.88% (M2, Base). The final NRMS values showed a slight additional improvement due to post-processing, which contributed to the reduction of coherent noise (internal multiples) and random noise.

Introduction

The Tupi field, located in the pre-salt of the Santos basin, has been in production for over a decade. With advances in seismic acquisition and processing technologies, a baseline OBN acquisition was planned for this field, covering more than 10,000 nodes. Due to the extent of the field and the need to optimize the parameterization in terms of coverage and ultra-long offsets, it became necessary to employ a less dense grid compared to other projects in the Santos basin. In this context, the spacing between the stations was set at 650 m x 375 m, resulting in a survey with the largest spacing between receiver lines of 650 m. Before this project, the largest recorded spacing was 500 m x 500 m. Regarding 3D imaging, the spacing adopted in the 2022 survey did not raise concerns, however it represented a substantial challenge in terms of 4D noise. Many scenarios have been tested in the context of pre-salt and OBN acquisition in modeling studies (Borges, 2021). This area received two dedicated acquisitions, baseline and M1, which exhibited exemplary repeatability in terms of receiver positioning (node carpet of 111 km^2), source positioning (shot carpet of 350 km^2), and seismic source. The receiver spacing was 325 m x 375 m, characterizing a dense OBN seismic acquisition, meticulously planned for 4D, facing the known challenges of the pre-salt, such as low response to production effects and high geological complexity, which includes deep water, thick evaporite layers, and high velocity contrasts.

For the 2022 baseline acquisition to be used in the triple 4D processing, it was necessary to decimate the receiver lines. As a result, the number of nodes covering the focused area was reduced from 970 to 485, with a spacing of 375 m x 650 m. Only by decimating the data from the Legacy double 4D processing we observed a 20% decrease in NRMS (from 2.5% to 3.0%) after a 45 Hz RTM migration, without any post-processing. Therefore, this situation would still be considered an ideal scenario, as the M2 acquisition in the focused area presents other variables that compromised repeatability, such as the seismic source (triple compared to single), the differences in of shot line direction, the recording equipment (distinct models in M2), and primarily, the positioning of the receivers, which experienced an increase in the average distance from M1-Base of 3.0 meters to M2-Base, reaching 7.5 meters.

Project workflow

The data from the three OBN acquisitions (Baseline, M1, and M2) underwent rigorous pre-processing. During this process, we faced various challenges that required special care to prevent 3D residuals from turning into 4D noise. For instance, in the M2 vintage, a triple-source configuration was employed, resulting in a minimum interval of 7.5 seconds between shots. Therefore, effective attenuation during the Deblending stage was necessary to mitigate noise spreading during the migration step.

The time travel inversion (TTI) stage, concerning the water column correction (WCC) among other corrections, is also crucial and demands a robust process to improve the 4D results. In this project, an approach was tested that involved using a reference bathymetry for the three acquisitions. In this sense, the depths of the nodes were fixed according to the bathymetry values, with only the variables related to water velocity, source positioning, and clock drift being updated. This methodology has already proven effective in the first 4D processing conducted in 2018.

Two additional relevant processing steps were shear noise attenuation in the Z component and Wavelet processing. The data from the M2 acquisition exhibited inferior coupling and consequently a high level of Vz noise. Regarding Wavelet processing, we faced challenges related to using a different source in M2, in addition to issues with Near Field Hydrophone (NFH) data in the first two acquisitions. Therefore, it was essential to conduct 4D quality control (QCs) tests to determine the best strategy: to opt for a data-driven approach for all three vintages or to use NFH data in estimating the farfields for M2 in the De-bubble shot-to-shot. The comparison between the two approaches revealed that the most efficient strategy would be to use M2 data with the best possible bubble attenuation, incorporating NFH data.

All the previously mentioned steps constituted the pre-processing and were fundamental in minimizing repeatability differences in the acquisitions. However, in the context of carbonate rocks in the pre-salt, we encountered a combination of challenges that require optimal NRMS levels at the end of processing; otherwise, the 4D noise may be equal to or exceed the anomalies in the field. For this reason, the LSRTM step proved to be extremely important. It utilized 3D constraints in the inversion of the Baseline volume and constraints in the 4D inversion by considering the difference volumes as perturbations concerning the Baseline reflectivity. This process helped minimize the repeatability differences of the M2 vintage, which had a higher average error in node positioning, different azimuths in the shot carpet, as well as differences in the source and receiver parameters, resulting in significant variations between the wavelets of the vintages.

Results

This section presents part of the results obtained from the triple 4D processing. The results summarized here correspond to distinct sections from the RTM and LSRTM migration, aiming to highlight the improvement in terms of monitoring the 4D anomalies and the signal-to-noise ratio, which contributed to the reduction of coherent 4D noise. The 4D difference results between M1 and the Baseline are illustrated in figure 1, while the 4D difference results between M2 and the Baseline are presented in figure 2. The M1 data relative to the Baseline served as a significant reference throughout the processing, in terms of the signal-to-noise ratio, and were essential for understanding the magnitude of the improvements required in the 4D results concerning M2, considering the decrease in repeatability mentioned earlier.

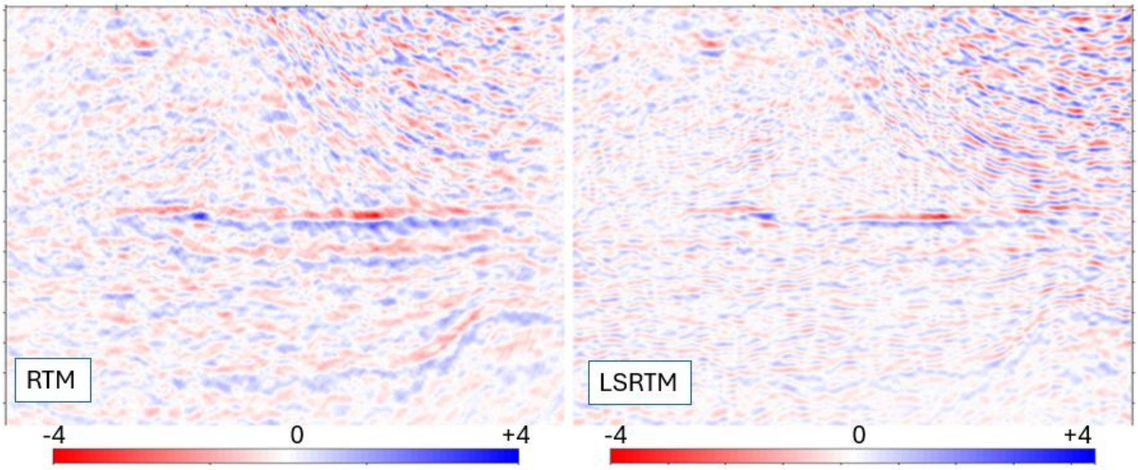

Figure 1: Seismic sections showing the difference from the triple 4D processing. These sections are M1 minus Baseline before (RTM, left) and after (LSRTM, right).

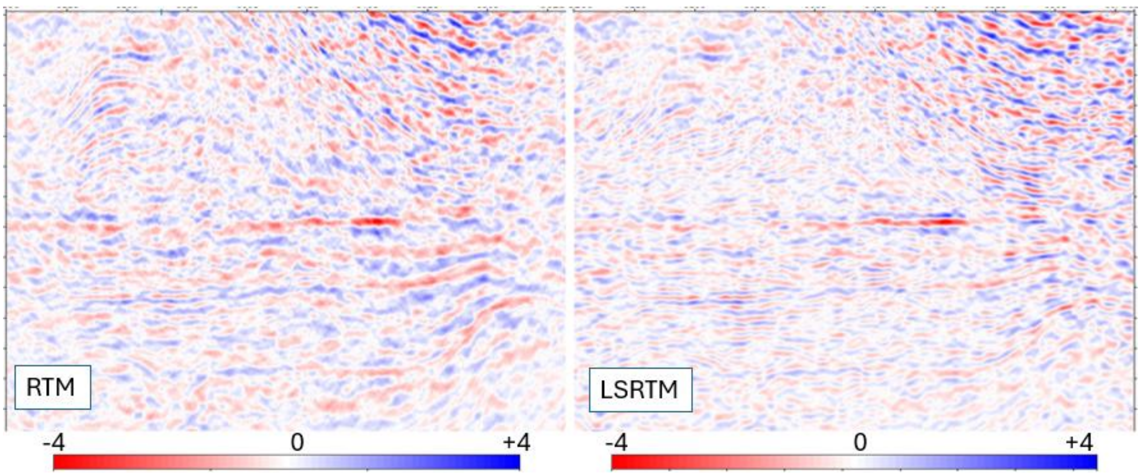

Figure 2: Seismic sections showing the difference from the triple 4D processing. These sections are M2 minus Baseline before (RTM, left) and after (LSRTM, right).

Conclusions

This work aimed to present the essential steps of the 4D processing that were necessary to achieve higher quality results, due to the flexibility in the parameterization of the M2 acquisition. The advancement of processing technologies, such as water column correction (WCC, use of bathymetry), Wavelet Processing with NFH, and 4D least-squares migration (LSMi), resulted in significant improvements, as evidenced by the results presented. The LSMi step was responsible for reducing the NRMS from 3.89% to 2.57% (M1, Base) and from 8.01% to 3.88% (M2, Base) in the window of geological objectives.
There are still opportunities to enhance the results obtained regarding the comparison of data using M2, since the applied LSMi was a process conducted in the image domain. However, we already have new technologies available, such as 4D FWI inversion, which are executed in the data domain and can provide superior results, both in terms of anomaly continuity and the 4D signal-to-noise ratio.

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