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Application of Coloured Inversion to 4D Seismic Difference Cube from a Pre-Salt Reservoir

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Introduction

Time-lapse seismic (4D seismic) is a geophysical technique for monitoring dynamic changes in fluid saturation and pressure within reservoirs by comparing baseline and monitor seismic surveys. By highlighting production-induced variations while minimizing lithological effects, 4D seismic provides valuable insights into reservoir behavior, fluid migration pathways, and the efficiency of recovery processes. In this work, Coloured Inversion was applied directly to a 4D seismic amplitude difference cube from the Tupi field, located in the Santos Basin, offshore Brazil. Although more sophisticated approaches provide better delineation of impedance changes for such a complex case, as discussed in Rebelo et. al. (2025), the use of colored inversion still provides improvements over conventional 4D amplitude or quadrature attribute analysis. The results of our inversion of 4D seismic difference amplitude could provide a direct workflow for investigating production-related anomalies in dynamic reservoir systems. To assess the performance of this method, its results were systematically compared with those obtained from the 4D quadrature attribute analysis, allowing an evaluation of its ability to capture softening and hardening anomalies associated with reservoir dynamics.

Method

The dataset used in this study consisted of two full-stack seismic surveys, a baseline acquired in 2015 and a monitor-1 survey acquired in 2018, both migrated using the Least-Squares Kirchhoff method. Additionally, acoustic impedance logs from 11 wells were integrated into the workflow. A 4D seismic amplitude difference cube was generated by subtracting the baseline and monitor surveys, and the Coloured Inversion operator was derived based on the impedance-frequency relationship analyzed on a logarithmic scale. Frequency calibration indicated that the optimal range for balancing vertical resolution and coherence was between 8 and 60 Hz, resulting in the creation of a relative impedance difference cube (ΔRI). In parallel, the quadrature attribute was computed separately for each seismic survey and subsequently subtracted to obtain a 4D quadrature amplitude difference volume. Spatial comparisons between the anomalies identified by (ΔRI) and those observed in the 4D quadrature difference volume were conducted through detailed 4D map analysis. Furthermore, key vertical sections crossing the main producing wells were examined to assess anomaly continuity, lateral resolution, and the clarity of softening and hardening zones within the reservoir.

Results and Conclusions

The application of Coloured Inversion to the 4D seismic amplitude difference cube resulted in enhanced lateral continuity of anomalies, improved coherence, and a reduction in high-frequency noise compared to the quadrature attribute. The technique provided a clearer and more continuous representation of production-related softening and hardening anomalies, allowing a more consistent interpretation of dynamic reservoir behavior. Additionally, the (ΔRI) volume generated through this approach exhibited less ambiguous 4D signals. These results demonstrate that the direct application of Coloured Inversion offers a simplified yet useful methodology for 4D seismic interpretation. By providing reasonable estimations of 4D seismic variations, it has the potential of supporting reservoir modeling and monitoring efforts.