Finite difference modeling to evaluate the improvements associated with a multicomponent towed streamer measurement in Espirito Santo basin offshore Brazil

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Abstract

The paper details a modeling project to understand the uplift associated with a multicomponent towed streamer acquisition and processing workflow in the Espirito Santo basin offshore Brazil. A complex model was built representing many of the common geological features in the Espirito Santo basin including allochthonous salt bodies, post-salt anticlinal generated fractures, volcanic intrusions, and shallow meandering channels. Synthetic seismic data was generated for a number of geometries, both single and multicomponent, including a very densely sampled control measurement. The synthetic measurements were reconstructed/interpolated to a 12.5-m crossline surface receiver sampling interval. The various datasets were compared both pre- and post-migration. The results suggest that the multicomponent measurement in conjunction with multicomponent reconstruction better samples the complex waveforms.

Introduction

Multicomponent towed-streamer seismic systems have recently become available for hydrocarbon exploration projects. A multicomponent towed streamer measures the pressure field and the vertical and crossline particle acceleration fields. The particle acceleration measurements allow for derivation of the pressure gradient in the vertical and crossline directions, which accommodate true 3D receiver deghosting and reconstruction to spatial frequencies well beyond those predicted by nyquist theory (Robertson 2008). As with any new technology, the industry has to go through the process of understanding where the technology will provide the most uplift and which geological and geophysical challenges it will best address.

This paper summarizes a project in which the multi-component towed streamer technology was evaluated using computer simulations rather than in-field experiments. A model was built which was representative of the geophysical challenges in the Espirito Santo basin, and this model was used to generate multicomponent synthetic seismic data as well as conventional single-component synthetic seismic data. The datasets were processed through to final image after maximizing the spatial bandwidth of the data to provide a number of different comparisons.

Earth Model Building Strategy

Accurate 3D velocity and density models are required to generate seismic synthetic data. An area on the continental rise of the Espirito Santo basin was selected to build these models. The Espirito Santo basin is characterized by thick autochthonous salt and shallower allochthonous salt bodies with complex shapes which can be attached or separated from the original salt. The shallow section is characterized by faulting associated with the salt deformation which could form hydrocarbon migration routes. Additionally, the water bottom can be complex with wide canyons.

The velocity model was derived from a dense 3D velocity field available in the area of interest. The deeper portion of the 3D density model was built from well log data extrapolated along interpreted horizons. An updated version of Gardner’s relation was derived to convert the velocity model to density, which was then used to populate the shallow sediment layers of the density model. The overall model size was around 19 x 11 x 5 km (Figure 1).

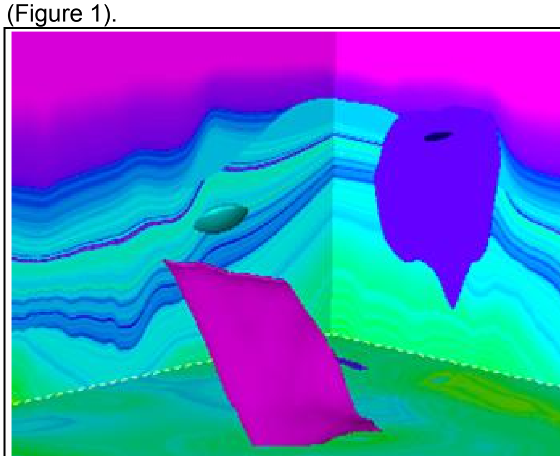

Figure 1: Earth model showing main geological structures and density sections.

The model incorporated a complex allochthonous salt body of constant velocity and density. This structure appears on the North East corner of Figure 1. A 60-m thick, 2000-m long and 3000-m wide surface was introduced into the model to emulate a fractured zone along a fault plane angled away from the salt diaper vertical axis by 30°. The shallow section complexity was simulated with two small, slightly elongated spherical bodies (respectively 700 and 300 m in diameter), representing volcanic intrusions, with a large contrast to the surrounding sediment and a near- surface channel flowing in zigzags on the seafloor. The velocity and density values of the main geological structures incorporated into the model are listed in Table 1.

Structures	Velocity (m/s)	Density (g/cm^3)
Allochtonous salt	4500	2.17
Fault plane	Same as surrounding	2
Volcanic intrusions	5000	2.7

Table 1: Property values of main earth model structures.

To validate the model, a set of common shot gathers was synthetically generated. They were compared to existing in-field gathers in terms of amplitude and propagation time of the main reflection events.

Synthetic Modeling

The seismic synthetic data was generated using a state-of-the-art shot-based finite-difference modeling code. Prior to starting the production effort some pre-work was performed to optimize the key modeling parameters such as aperture, maximum frequency, record length, and shot- point interval. The final parameters are listed in Table 2. The amplitude spectrum of the injected source wavelet was flat, covering a frequency band of 1 Hz up to 56 Hz.

Parameters	
Modeling aperture	3000
Maximum frequency (Hz)	60
Record length (ms)	5000

Table 2: Modeling and migration parameters.

For efficiency purposes, a single high-density multi-component dataset, consisting of a single source fired every 25 m, 69 streamers separated by 12.5 m, and traces every 12.5 m, was modeled and then decimated to the following three simulated acquisition datasets:

- Multicomponent streamer (dataset 1): single source with 4 component sensors P, Vx, Vy, and Vz (Figure 2) with 12 streamers at 75-m separation (Figure 3). The inline shot separation was 25 m and the inline trace interval was 12.5 m.
- Single-component streamer (dataset 2): single-source and pressure-only measurement with 20 streamers at 50-m separation (Figure 4). The inline shot interval was 50 m and the inline trace interval was 12.5 m. This geometry is equivalent to a dual flip-flop geometry with 10 streamers separated by 100 m.
- Control measurement without decimation (dataset 3): single-source and pressure-only measurement with 69 streamers at 12.5-m separation (Figures 3 and 4). The inline shot interval was 25 m and the inline trace interval was 12.5 m. This geometry is equivalent to the final high spatial fidelity dataset obtained from datasets 1 and 2 after reconstruction/interpolation and acted as the reference for the experiment.

The original high-density dataset consisted of 10,230 multi- component common shot gathers, synthetically generated along 22 sail lines. A sail-line interval of 418.75 m was adopted to make sure that the multicomponent reconstruction of dataset 1 would produce a total number of 67 subsurface sail lines separated by 6.25 m without gap or overlap between adjacent sail lines (Figure 3).

Processing and Imaging

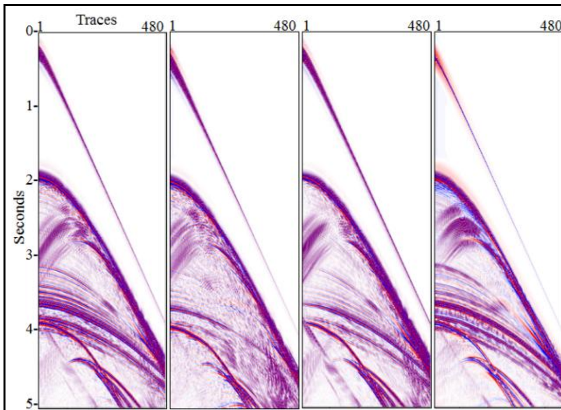

Figure 2: Collection of traces along selected cable extracted from a common shot gather; from left to right, P, Vx, Vy, and Vz components.

The primary goal of this effort was to understand the benefit of the additional particle motion measurements in reconstruction to a high spatial frequency. Two additional datasets were produced:

- Dataset 4: the multicomponent data was reconstructed to 12.5-m streamer separation using a multicomponent matching pursuit technique (Özbek 2011), termed a general matching pursuit (GMP).

- Dataset 5: the single-component data was interpolated to 12.5-m streamer separation using state-of-the-art single-component matching pursuit techniques (Özdemir 2008).

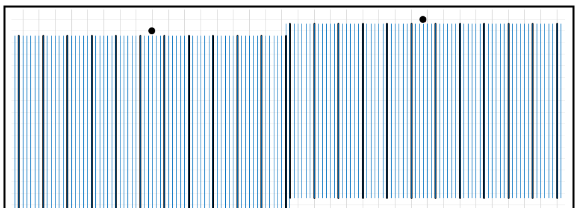

Figure 3: Source and common mid-point locations of two adjacent common shot gathers: extracted from dataset 1 (black); extracted from dataset 3 (blue). The inline shift between adjacent gathers was introduced for visualization.

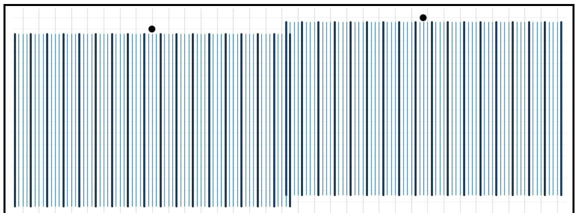

Figure 4: Source and common mid-point locations of two adjacent common shot gathers: extracted from dataset 2 (black); extracted from dataset 3 (blue). The inline shift between adjacent gathers was introduced for visualization.

As a pre-migration regularization effort to eliminate amplitude inconsistencies, the common shot gathers of the three 12.5-m cable separation datasets (datasets 3, 4, and 5) were edited to limit the total number of cables to 67 by removing any common mid-point overlap between adjacent sail lines.

Following this effort, all three datasets were processed though the same workflow: migration preparation and reverse-time migration. Each dataset was migrated with the same velocity and aperture as implemented during the modeling phase and output to a full-fold volume of 9x9x5-km on a 25x25-m grid. Figure 7 shows an inline section extracted from each one of the three migrated volumes.

Results

To qualify the benefits of the multicomponent interpolation, the data was analyzed in the pre-stack and post-stack domains.

Figure 5 shows a crossline section of two adjacent common shot gathers extracted from dataset 1 (top) and dataset 4 (bottom) before and after multicomponent reconstruction. Figure 6 presents the crossline section of the equivalent two adjacent common shot gathers extracted from dataset 2 (top) and dataset 5 (bottom) before and after single- component interpolation. Figure 6 (bottom) reveals the presence of aliased events on top of and in the opposite dip of the main steeping events around 3.6 seconds, which tends to indicate better interpolation results in favor of the multicomponent reconstruction scheme.

Conclusions

This study demonstrates that multicomponent reconstruction of finite difference modeling synthetic data produces better interpolation of steeping events than single-component interpolation. It provides better protection against alias and as a result produces a better image around the main modeled structures.

Acknowledgements

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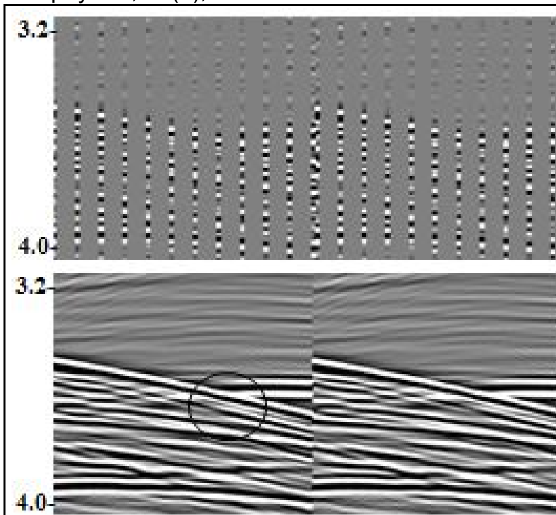

Figure 5: Crossline section of two adjacent common shot gathers: before reconstruction (top), after multicomponent reconstruction (bottom).

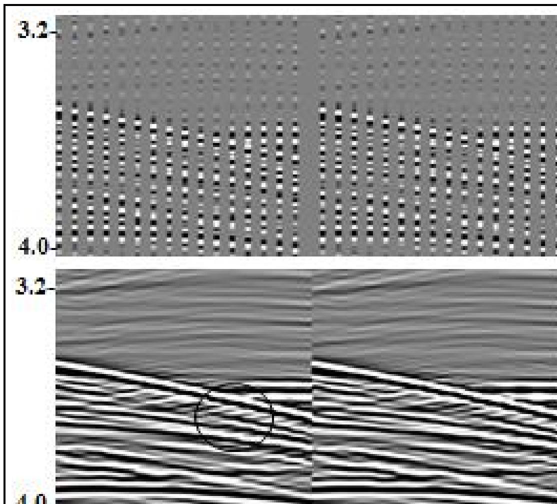

Figure 6: Crossline section of two adjacent common shot gathers: before interpolation (top), after single-component interpolation (bottom).