Long offset aided full waveform inversion.

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Abstract

Full Waveform Inversion (FWI) has become a new tool in recent practice for velocity model updating. When using the FWI, the common scheme was to use data sets which have relatively large offsets up to 7 to 8 km and frequencies as low as 2.5 Hz. In marine environment Wide Azimuth towed streamer (WAZ) or Ocean Bottom Cable (OBC) acquisition provide the above mentioned specifications. Recent advances in data collection such as dual coil offers significant characteristics over WAZ and OBC such as better illumination, noise attenuation and lower frequencies which allow the FWI to more accurately determine a velocity field with the data's higher maximum offset and wider azimuth ranges. The methodology of the use of FWI in this paper follows the traditional layer striping approach where we developed the supra salt sediment followed by the top of salt, salt flanks, base of salt and finish with a limited subsalt update. This approach has been successfully applied in the Gulf of Mexico (GoM) using wide azimuth data and we propose the same workflow with the dual coil acquisition. With the dual coil data, the inversion stages were carefully QC'd through gather displays to ensure the kinematics were honored. In order to approximate the observed data, the acoustic inversion had attenuation, anisotropy, acquisition source and receiver depth incorporated in the propagator.

Introduction

Over the past few years we have been able to execute 3D FWI with the acoustic wave equation on real datasets in marine (Plessix, 2009, Sirgue at al., 2010, Vigh et al., 2010, 2011) and in land (Plessix, 2010) environments. These results have demonstrated that FWI can be used for velocity update if the acquired data have enough of the proper low frequencies and long offsets. In particular, the shallow section of the model can be significantly enhanced by using full-waveform inversion which can result in a more improved overall depth image. One of difficulties with FWI is the convergence to the local minima that makes the technique very sensitive to the starting velocity model especially when 3D is considered. To mitigate the sensitivity of the initial velocity field, low frequencies and long offsets are required (Bunks et al., 1995, Pratt, 1999) which enables FWI to update the low-frequency component of the velocity model.

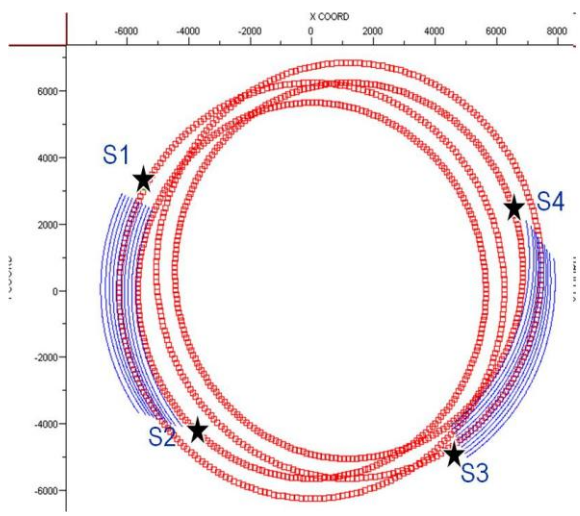

Figure 1. Data collection diagram.

GOM dual-coil data set

The data set is a result of dual-coil acquisition where the maximum offset is up to 14000 m with full azimuth distribution. The shooting is circular ten towed cables on each recording vessel. The output size exceeds more than 100 mi^2 with approximately 64,000 shots covering the area (Figure 2.) using the dual-coil layout mentioned above. The gun array, the shot depth, and cable depth allowed observing low frequencies of about 2.5 to 3 on field records. A 50 m X 60 m bin-size was selected to run the inversion.

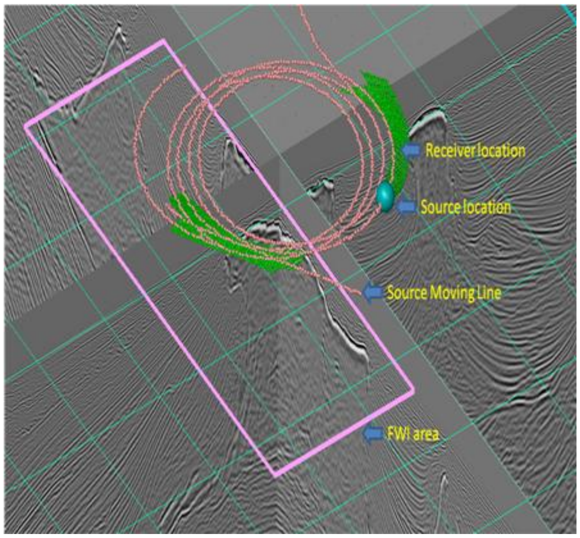

Figure 2. Shot Location map of the GOM area in Green Canyon 512.

Data Processing

Due to the long 14 km offset the dual-coil recorded data is rich in refracted energy (Figure 3.) which is essential to a successful full waveform inversion; therefore, the data processing was kept at a minimum with de-signature, de-bubble and surface consistent shot channel gain being applied to the input data prior to the FWI. The complex geology created multiples that are observed much later than the valuable refractions and diving waves energy. After spectral analysis of the observed data we concluded that the lowest frequency in the signal was about 3 Hz. The shot gathers were in batch sampling manner in order to increase computational speed since the number of shots are large compared to the area covered.

3D Waveform inversion flow and results

In the inversion there were two frequency bands used starting with 0-4 Hz and then extended to 0-6 Hz. Starting from a low frequency range to a higher frequency range is the multi-scale approach that minimizes the risk to converge to local minimum. The inversion was executed in the usual layer stripping manner where the sediment only FWI was the first step followed by the reinsertion of salt bodies to allow the inversion the opportunity to modify its definition to a small degree. An image gather flatness constraint was implemented which allowed us to freeze certain parts of the model where misfit energy has been minimized. Although the inversion only updates velocity, we utilized our anisotropic propagators using Tilted Transverse Isotropy (TTI) which accommodates velocity, density and the anisotropic parameters ε, δ, *dip*, and azimuth. The starting velocity was the result of ray-based topography followed by the sediment only inversion that had 5 iterations of FWI. The velocity slices at 5000 feet depth show significant differences when Figures. 4 and 5 are compared. The salt was reinserted in the model and salt body FWI iterations were run to enhance the definition of the previously developed top of salt and overhangs. Once completed with these additional iterations the data were migrated with the final model and QC was performed to check for gather flatness (Figure 6 a. and b.). Comparison of the velocity fields reveals a high resolution component of the FWI velocity field that was not present in the starting model.

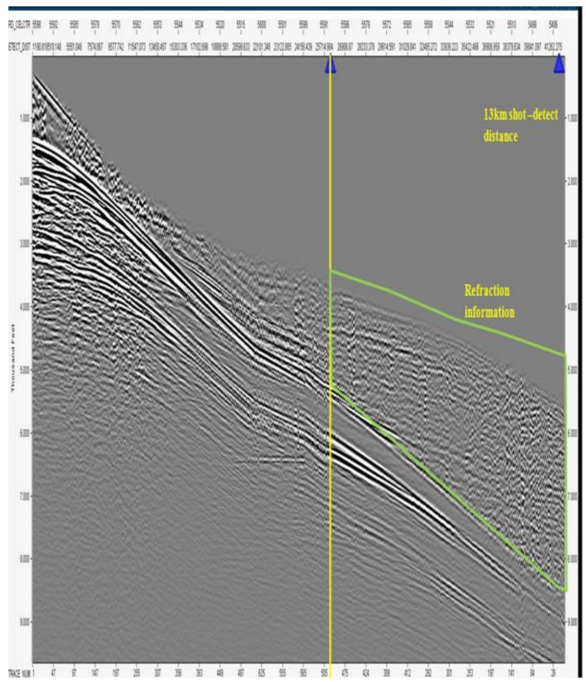

Figure 3. Dual-coil shot gathers.

Conclusions

We showed that waveform inversion using long offsets can be successful in deep water environment when the refracted energy and diving waves are present in the collected data. We further have demonstrated that FWI has its own significant role in the modern velocity model development process when the observed data supports the inversion process.

Acknowledgements

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Figure 6a. Gathers with ray-based tomographic velocity field.

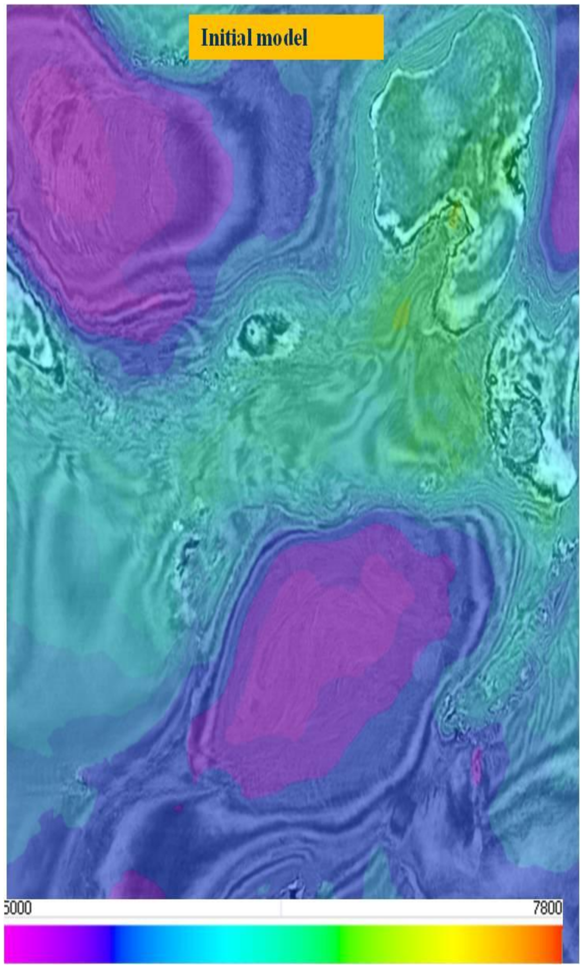


Figure 4. Traditional velocity field derived by ray based tomography 5000 feet depth

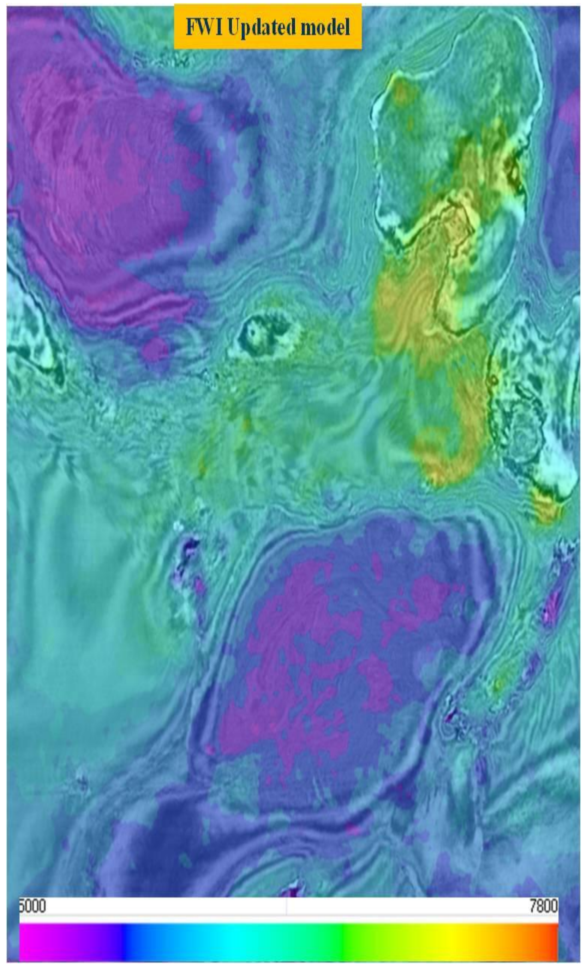
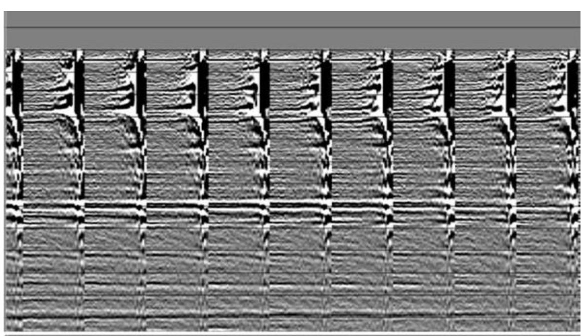


Figure 5. Waveform inversion velocity filed 5000 feet depth



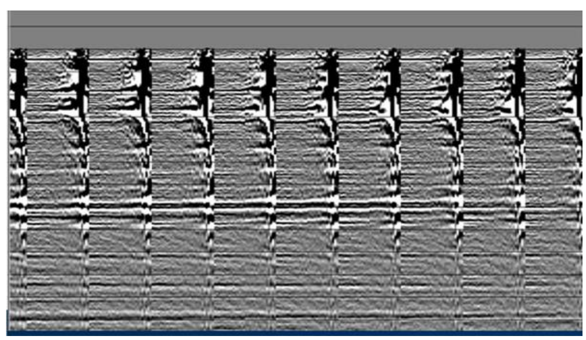


Figure 6b. Gathers with FWI developed velocity field.

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