Evaluation of Full Waveform Inversion Derived Reflectivity volumes – Operator's Perspective

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SUMMARY AND MOTIVATION

With the advancement of Full Waveform Inversion (FWI, Shen et al., 2018) and the introduction of FWI Derived Reflectivity (FDR) or FWI Imaging (Huang et al., 2021), the imaging of the subsurface has taken another step forward. These volumes have caused a breakthrough in structural imaging of areas beneath complex overburden including Trinidad and the Gulf of Mexico (Buist et al., 2023; Liu et al., 2023) with general agreement that these new volumes are superior to traditional imaging methods. However, these volumes raise questions about the meaning of their seismic amplitudes and whether they can be used reliably for seismic reservoir characterization. We share how we should evaluate these volumes for usage for this purpose. This evaluation goes through the various steps of the evaluation of these FDR volumes from acquisition to processing to analysis.

ACQUISITION

The first step to consider when evaluating FDR volumes is to consider how the input data to FWI were acquired. The breakthrough in FWI was largely triggered by the introduction of ocean bottom nodes acquisition. This acquisition style allows for multi-azimuth and long offset (up to 35 km, Buist et al., 2023) seismic data acquisition. Low frequency diving waves can be acquired, which provide the starting point for FWI processing. Since, FWI has also been successful with streamer seismic data acquisition, but the diving waves are still important. For the evaluation of the final FDR volumes, it is important to understand the geometry of the acquisition so we can model where the diving wave is illuminating the subsurface (Ni et al., 2019). This kind of study shows how deep the diving waves are penetrating and where we can expect to have good results from FWI and FDR volumes. While generating FWI volumes we should compare the results to the predictions from modeling to confirm a match between observations and expectations. Any mismatches require additional attention to conform the validity of the volumes.

PROCESSING

Once we understand the potential and the limitations of the data acquisition, the next step to evaluate is the FWI processing. As with any processing step, FWI needs to be evaluated carefully. 1) Ensure the processing works well on simple data before moving to more complex areas. 2) Review the resulting FWI velocity model first before generating the FDR volumes. 3) Confirm the velocity volumes look geological and add detail especially in areas of rapidly varying velocity contrasts, for example around salt and shallow gas pockets. 4) Verify that the FWI velocity model results in an improved image using conventional imaging. 5) Compare the resulting velocity model to any available directly measured velocity data from well logging and borehole seismic data.

FDR VOLUME EVALUATION

After we have gained confidence in the FWI velocity models using the analysis described above, we now generate FDR volumes from these FWI models. This process is straightforward using a directional derivative (Huang et al., 2021). These volumes should look similar to conventional migrated stacks in simple geology and should provide improved imaging in complex areas. These improvements should make the final volumes look more geological. If any Q compensation (phase or amplitude; the later one is rarely applied pre-migration) was applied to the migrations, a similar correction needs to be applied to the FDR volumes.

AMPLITUDE RESPONSE

If the volumes have given us confidence that they show improved imaging, we can start the evaluation for more quantitative usage. As with any new imaging algorithm, we should compare the output to the available well data using a seismic well tie. This well tie should show if the observed reflections in the FDR volumes match the expected reflections from the synthetics generated from the well logs. In theory, FDR volumes show the derivative from the velocity model and should be compared to velocity logs. However, we have observed density crosstalk in the FDR volumes from different observations in various basins: 1) modeling; 2) seismic well ties; 3) comparisons to well logs. Therefore, we recommend using the impedance log for tieing to FDR volumes. In class III environments there is little confusion, but in other classes we have to do a more careful evaluation. Always compare your FDR amplitudes extractions to the conventional migrated stacks and observe similarities and differences. Future developments like multi parameter FWI (Wang et al., 2021; McLeman et al., 2023) and FWI gathers (Jin et al., 2024) will improve understanding of the FDR amplitude response.

CONCLUSIONS

FDR volumes are an improved way to image the subsurface. These volumes need carefully evaluation from acquisition to processing to analysis. Comparison to calibration data such as well data is critical as well as comparisons to conventional imaging products. Diving wave illumination, FWI velocity model evaluation and seismic well ties are some of the key steps in this process. With these careful evaluation steps, FDR volumes have shown promise to provide improved amplitude extractions due to better illumination.

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