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FWI Velocity Model Building Experiences

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Summary

Full Waveform Inversion has been used to generate detailed models of shallow, subsurface velocity variations in some challenging areas.
An accurate starting model was typically required to avoid cycle skipping. This could be minimised by incrementally increasing maximum offset, depth and traveltime over a number of iterations. We now incorporate dynamic warping into the early iterations of FWI to get around this problem, allowing us to start model building at the same time as time processing.
Image-guided smoothing has also been utilised within FWI to minimise the effect of the acquisition footprint on the resulting velocity model and at the same time, provide structural constraints which further enhance the detail preserved within the model.
Initially only diving wave energy was used, which limited the maximum update depth, dependent on offset. Recently we have been able to utilise WavePath FWI, which allows us to reliably use reflection events and constrain deeper updates into a more plausible model of the subsurface.
Here we present some examples of our approach to model building with FWI over the past few years.

Introduction

TGS have been utilising Full Waveform Inversion for several years now to generate detailed models of shallow subsurface velocity variations in some particularly challenging areas. These challenges have included shallow channels, Karst geology, gas chimneys and fault shadow zones.

Here we present some examples of model building with FWI in such areas and discuss how our approach has evolved in recent years, along with improvements in technology.

Jackdaw (North Sea, 2014)

FWI update of an Ocean Bottom Node survey located in the North Sea. Large crossline spacing (500 m) resulted in a noticeable acquisition footprint in the shallow velocity model.

The starting velocity model, built using traveltime tomography, lacked detail and wasn't particularly representative of the true velocity. The initial synthetics built with this model showed a poor match with the observed data, and cycle skipping among mid to far offsets.

To avoid cycle skipping, multiple passes of FWI were performed at incrementally increasing offset ranges, maximum depth and traveltime. A mild smooth was applied between each inversion. Footprints in the model were subsequently removed with Kx-Ky filtering. This workflow produced a highly detailed shallow velocity model.

Hernando (Gulf of Mexico, 2014)

Multistage FWI with both diving waves and reflections was used to resolve low velocity variations arising from Karst features and gas chimneys in the deep-water Gulf of Mexico (800-1500 m). Four diving wave FWI runs with four increasing frequency bands updated the low wavenumber background velocity, some detailed karst features were added to the velocity as the input includes more reflection events with conventional reflection FWI, and the migration image beneath those features was improved.

Hoop Fault Complex (Barents Sea, 2016)

Large velocity variations across the Hoop Fault Complex in the Norwegian Barents Sea lead to imaging problems in the fault shadow zone. Sags were evident in the underlying layers, which can't be entirely resolved with conventional traveltime tomography.

A multistage FWI workflow was used to update the shallow model and preserve the velocity contrast across the main fault, as well as defining the more complex faulting in the high-velocity Lower Cretaceous overburden.

Dynamic Warping FWI (DWFWI) was used for the initial update which helps limit the problem of cycle skipping and reduce FWI runs for different offset ranges. Here, the data residual was computed by subtracting the modelled synthetic from a copy that has been warped to match the observed data - as opposed to directly computing the residual from the observed and synthetic data in conventional FWI. This theoretically allows us to start model building at the same time as the time processing, as soon as raw shot gathers are available.

The next stage was a pass of image-guided FWI (IGFWI), which produced a detailed model and at the same time avoided introducing an acquisition footprint. In conjunction with illumination compensation, this removed the need for Kx-Ky filtering of the resulting model. The image-guided smoothing also helped preserve the high-contrast velocity variations across the fault. Migrating with this model drastically reduced the fault-shadow issues previously seen on the stacks and gathers.

Fusion (Gulf of Mexico, 2017)

Multistage FWI (DWFWI + IGRFWI) was applied to a 100 OCS block area in the Gulf of Mexico Mississippi canyon shallow water area. The survey was WAZ acquisition with an 8 km maximum offset. The starting model was legacy velocities with checkshot calibration and TTI tomography. Diving-wave dynamic warping FWI updated the long wavelength part and image-guided reflection FWI provided high resolution details. From the update, some channel and gas pocket features were well inverted in the shallow part. We can clearly see the uplift on both stacked image and migration gathers with FWI model.

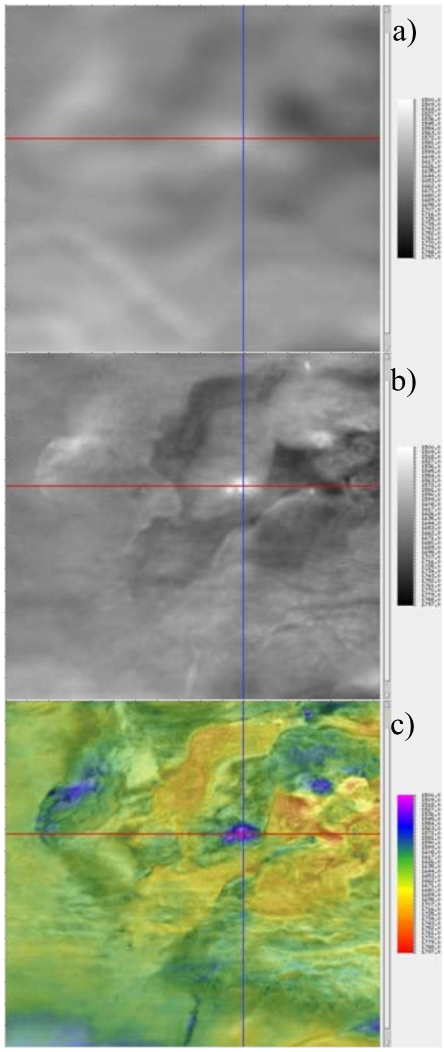

Figure 1 *Fusion GoM depth slice at 720 m. a) Initial model b) WPFWI model c) WPFWI velocity RTM overlay.*

For deep water areas, the diving waves are limited and can only penetrate to around 1-2 km beneath water bottom. To overcome these limitation, wave path FWI (WPFWI) was applied to update the deeper velocity background through reflection wave paths or "rabbit ears" (Xu et al., 2012), and a local correlation-based misfit function was used to focus more on kinematic information. Image-guided reflection FWI (IGRFWI) was later carried out to provide sharper boundaries. After this multistage FWI for the deep part (WPFWI + IGRFWI), the migration image is better focused and gather flatness is improved.

Conclusion

We present multistage FWI for shallow updates (DWFWI + IGRFWI) and for deep updates (WPFWI + IGRFWI), to update both the long wavelength background velocity and retain sharp boundaries or high-resolution details. This approach allows us to start model building at the same time as the time processing, as soon as raw shot gathers are available.

References

Xu, S., Wang, D., Chen, F., Lambaré, G. and Zhang, Y. [2012] Inversion on Reflected Seismic Wave. 82nd Annual International Meeting, SEG, Expanded Abstracts, 1-7, https://doi.org/10.1190/segam2012-1473.1