Detailed Velocity Model Building with Full Waveform Inversion

An accurate earth model is key to any successful depth imaging effort. Full-waveform inversion (FWI) is an advanced velocity model building process that uses the full two-way wave equation. Traditional methods use a ray-tracing approach to distribute velocity errors within the model.

The industry has moved to using two-way wave-equation migrations commonly known as reverse time migration (RTM), especially in areas of complex geology such as the salt bodies in the Gulf of Mexico, offshore West Africa, Brazil, and the Red Sea. The velocity model, including velocity anisotropy, is key to any depth migration effort. The natural next step is to use the two-way wave equation for velocity model building too. One of the most advanced tools for velocity model building using the two-way wave equation is full-waveform inversion. Full-waveform inversion uses computer-intensive forward modeling of the seismic measurement combined with residual wavefield back propagation to iterate to a final velocity model, which can provide greater detail than tomographic ray-tracing approaches.

FWI has recently emerged as one of the most exciting new techniques in the seismic industry thanks to its potential to deliver very detailed velocity models. It is also a paradigm shift in a way we process seismic data since it allows us to start the velocity model building phase on raw shots, with little need for pre-processing steps.

Most of the examples shown in literature are based on FWI applications where the starting velocity models for the inversion are derived by several iterations of traveltime tomography and are kinematically accurate. The reason for this is that FWI relies on solving a highly non-linear inverse problem using a gradient based technique; therefore it is very sensitive to the presence of local minima. These occur when the data predicted by the starting model differ in arrival time by more than half a cycle with respect to the real data.

Comparison between migrations using FWI velocities derived in this way and migrations using the starting tomographic models often yield disappointingly small differences, even though the FWI velocities appear to contain a lot more “geological” detail. Analysis of Common Image Point (CIP) gathers shows traveltime tomography is usually doing a good job at recovering long wavelengths of the velocity model which account for the bulk of the gather flattening required for a good image. There are particular settings where tomography struggles and where FWI can instead provide an accurate solution. We include two different examples below where we see FWI as a real game changer:
Figure 1. The traditional ray-based traveltime tomography result, and Figure 2. FWI in the low frequency (~25Hz) range, used for imaging but starting from a smooth RMS velocity model in order to bypass the traveltime tomography phase.

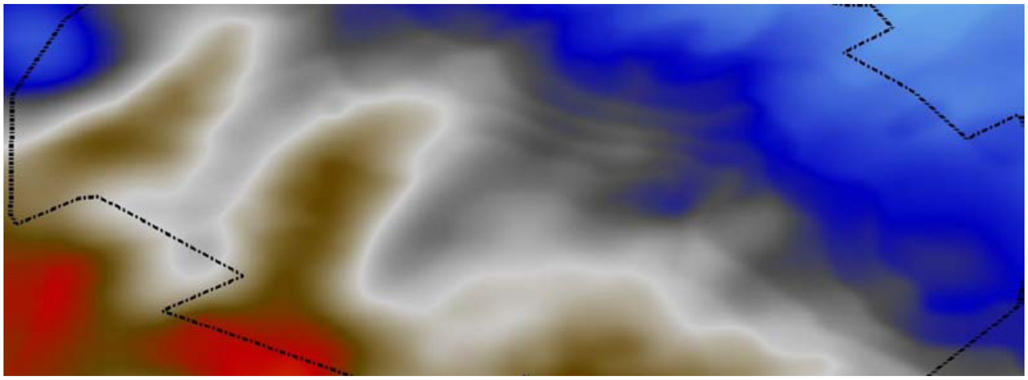

Figure 1. Traveltime tomography result

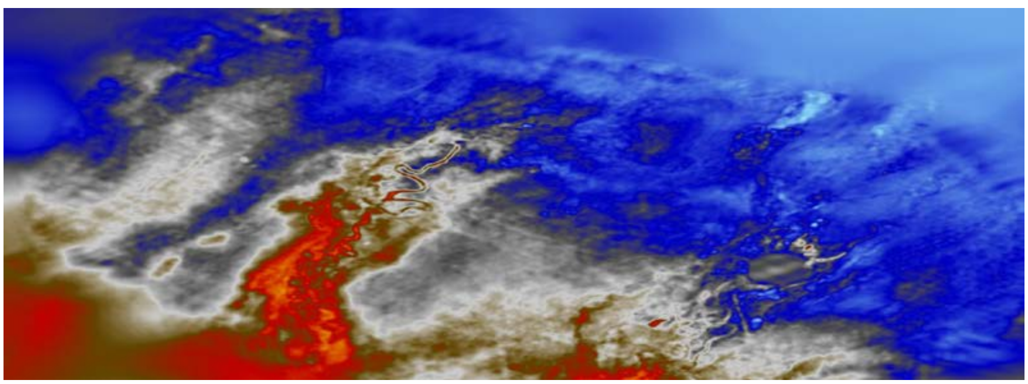

Figure 2. FWI result