Depth Velocity Model Building on Blended Data via Beam Tomography

Introduction

Seismic surveys play a critical role in oil and gas reservoirs discovery and monitoring. The seismic data life cycle consists of data acquisition, processing in time/depth and interpretation. The cycle is very much static with minimal change imposed by interpreters/processors on the seismic acquisition crew. Expediting the processing solution would allow while-acquiring evaluation and if need be acquisition parameters adjusting, rendering the geophysical cycle more dynamic. In the processing shop, time/depth velocity model building is the most time consuming step. Conventionally, Prestack Time Migration (PSTM) is used to produce images used for horizons interpretations and prospect generation. However, PSTM does not image lateral velocity variations and tight carbonate formations and could not be ideal to evaluate acquisition parameters. Prestack Depth Imaging (PSDM) has been overlooked on land in non-complex geology areas although it is capable of addressing the limitations of PSTM (Rauch-Davies et al., 2018). Building a velocity model in depth is even more effort and time intensive. We highlight below the most common techniques used to building a velocity model in depth and their associated challenges and limitations. Full-Wave-Inversion (FWI) (Tarantola, 1984; Virieux and Operto, 2009) is a well-established data-fitting technique to reconstruct a detailed velocity model. FWI requires a suitable accurate initial model and low-frequencies data to avoid the infamous “cycle-skipping” problem. Despite the considerable success in the literature, the lack low-frequency, computational inefficiency and the starting velocity model inaccuracy can limit the applicability of FWI in many cases. The second approach is via Migration Velocity Analysis methods (MVA) (Al-Yahya, 1989; Biondi and Sava, 1999; Sava et al., 2005) which are well established techniques that rely on analyzing the departure from flatness of the gathers. MVA requires significant resource allocation and human interaction to build a velocity model. A final approach is via deep-learning which relies on big-data training rather than prior-knowledge and physical models (Yang and Ma, 2020). Significant success is documented in the literature but this approach requires an intensive training stage to build meaningful models which is not always achievable.

We utilize in this publication a novel Beam tomography approach that will allow an expedited depth velocity model building to generate a quality brute stack in depth using field (unprocessed) data. In return, it allows a semi- instantaneous evaluation from the interpreter while more data is being acquired.

Method

Beam tomography is a hands-free approach that combines Fast Beam Migration (FBM) with an optimized Beam-domain Reflection Tomography. Beam-based techniques are overstudied in the literature and the accuracy of the beam-based methods generally is controlled by the beamforming parameters (Červený et al., 1982; Weber, 1988; Hill, 2001). FBM is faster than conventional migration techniques via beamforming of the input data where the traces are converted into beams representing locally coherent events characterized by an arrival time, source and receiver locations, amplitude, dip orientation and curvature (Fomel and Tanushev, 2009). Beam-domain Reflection Tomography replaces the conventional steps in reflection tomography, such as picking of residual moveout and semblance analysis by automated 3D residual time shifts in the beam domain. If the image generated by a beam pair is not in agreement with the image produced by other beams, a shift is needed in the direction perpendicular to the reflector that the beam is imaging. Converting those shifts into local velocity perturbations allows us to build an azimuthally-dependent tomographic solution (Tanushev et al., 2017).

We demonstrated Beam Tomography’s efficiency in building a high resolution velocity model and benchmarked it against check-shot in (Alali et al., 2021). In this application, we challenge the Beam Tomography to build a velocity model using field blended data in an attempt to show how the technique can accelerate the geophysical cycle.

Example

The data are acquired via an unconstrained and decentralized blended acquisition design, namely, 3D Dispersed Source Array (DSA) (Tsingas et al., 2020). Multiple sources are triggered simultaneously resulting in the collection of a high density broadband blended data. The blended acquisition style significantly shortens the operational time in the field and improves the frequency and density of the data. It also generates a significant amount of crosstalk noise (blended data). Deblending methods to suppress crosstalk are time-consuming as they require manual parametrization or expensive data-driven inversion solutions to obtain acceptable results (Richardson and Feller, 2019). Tsingas et al. (2020) presented full details on the processing workflow using novel techniques to deblend the data in this example. We refer to data that has been parsed and correlated in the field with cross talk present as (field data) and the deblended data as (processed data). Figure 1 shows the gathers before (field data) and after deblending.

The challenge is to produce a meaningful depth stack using the field data directly. For comparison, 3 months in the processing shop were needed to produce the processed data. We run Beam Tomography on both the field and processed data in order to examine the robustness of the Beam Tomography workflow in the presence of crosstalk noise. Nine (9) iterations were needed for the processed data vs ten (10) iterations for the field data to produce flat FBM angle gathers and a corresponding velocity model that reflects the shallow high velocity zone (Figure 2). Illumination on the edges of the survey was an issue for both data sets due to low acquired fold. The blended noise characteristics are different on the source and receiver beams. Hence, the beam imaging indirectly reduces the impact on the final image prior to tomography. We still struggle with the noise in the far offset (shallower than the reflection) where it might resemble a prefect beam that leaks into the data.

We further evaluate the accuracy of the velocity model built via Kirchhoff depth migration to image and stack each data with its respective updated velocities. The target in this survey is a low offset faults zone. Figure 3 shows the stacks with the low offset faults zone highlighted on both depth stacks in a red square. No significant update was made on the deeper section due to illumination limitations of the survey (lack of far offsets). The illumination challenges are better described in Figure 4.a and 4.b where we illustrate the beam migration stack co-rendered by the illumination i.e., a measure of how many beams have been used to image/update a point in the subsurface. We evaluate the field results by the center zone of the stack. The yellow line highlights the dominant illumination confidence in both stacks. Multiple factors control the illumination, namely: the acquisition design and, which would indicate longer offsets are needed, the shallow velocity anomaly that makes it difficult to image the deeper section. The most significant aspect of this whole exercise is the time needed to generate both stacks.

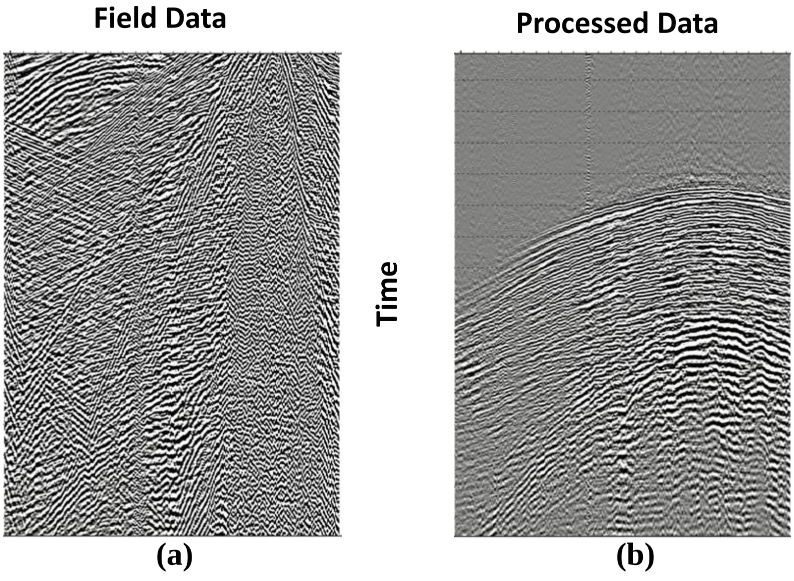

Figure 1 *(a) Field data (blended). (b) Processed data (deblended).*

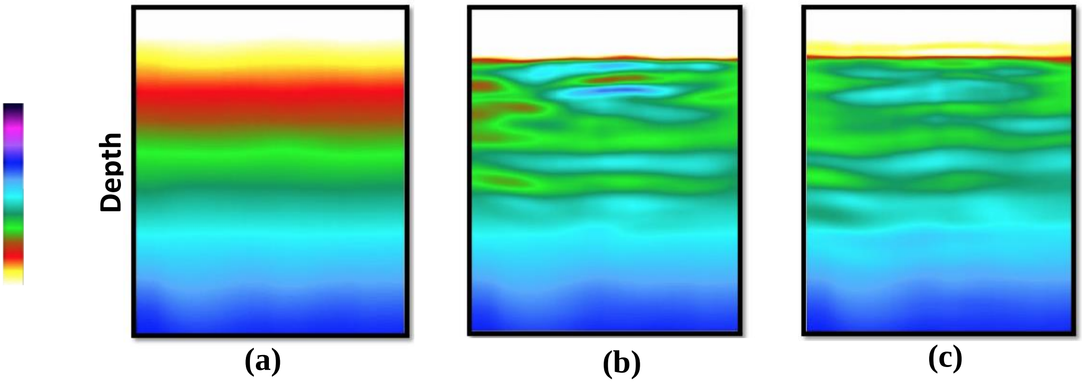

Figure 2 *(a) Initial depth interval velocity model. (b) 10th iteration using field data. (c) 9th iteration using the processed data.*

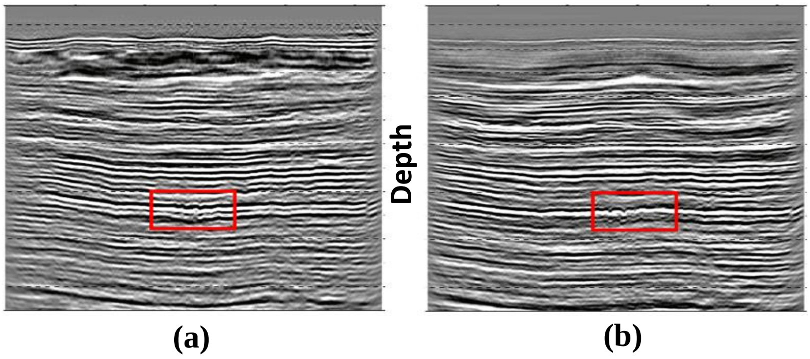

Figure 3 *Prestack depth migrated stacked data using (a) field data and (b) processed deblended data.*

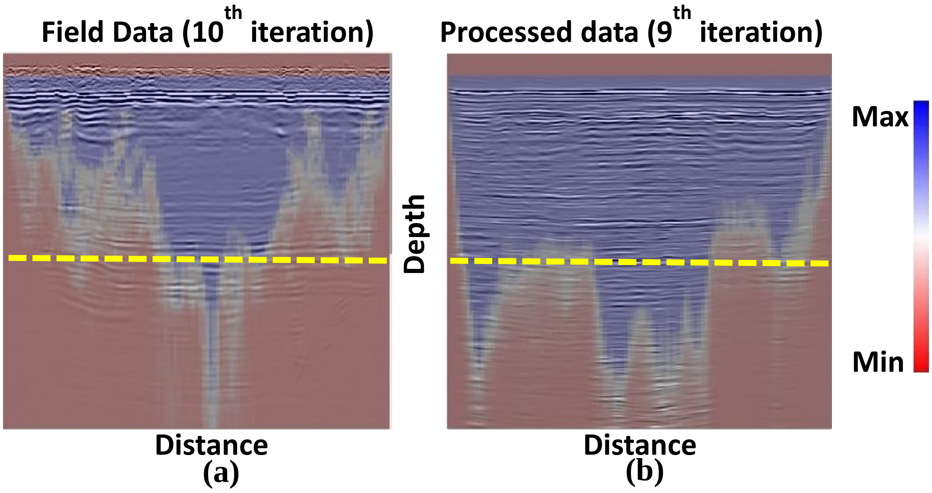

Figure 4 *(a) FBM stack co-rendered by illumination using (a) field data and (b) processed data.*

Conclusions

Using Beam Tomography allows a significant fast turnaround time for 3D land seismic depth imaging projects expediting the laborious manual components of velocity-depth model building. We have demonstrated the efficiency of the method on a blended field data. As a novel approach, Beam Tomography increases the reliability and estimation of target-oriented velocity model updates and subsequently the corresponding depth images. The demonstration showed a quality brute depth stack producible in a matter of days that would enable interpreters to assess the quality during the acquisition time. Beam Tomography paves the way for almost real time depth imaging application impacting acquisition geometries, which in turn can be beneficial for infill acquisition to mitigate illumination issues as well as monitoring purposes.

References

Alali, A., R. Alzayer, C. Tsingas, N. Tanushev and A. Popovici [2021] High-resolution beam tomography on 3D land data applications. *First International Meeting for Applied Geoceince & Energy Expanded Abstracts*, 3385-3389

Al-Yahya, K. M. [1989] Velocity analysis by iterative profile migration. *Geophysics*, **54(6)**, 718-729.

Biondi, B., and P. Sava [1999] Wave-equation migration velocity analysis. *69th Annual International Meeting, SEG, Expanded Abstract*, 1723-1726.

Červený, V., M. M. Popov, and Psencik [1982] Computation of wave fields in inhomogeneous media Gaussian beam approach. *Geophysics Journal International*, **70**(1), 109-128.

Fomel, S., and N. Tanushev [2009] Time-domain seismic imaging using beams. *79th Annual International Meeting, SEG, Expanded Abstracts*, 2747–2752.

Hill, N. R. [2001] Prestack Gaussian-beam depth migration. *Geophysics*, **66**(4), 1240-1250.

Rauch-Davies, M., and S. Randazzo [2016] Poststack depth-impedance inversion over the Woodford Shale Anadarko Basin. *86th Annual International Meeting, SEG, Expanded Abstracts*, 3558–3562.

Richardson, A., and C. Feller [2019] Seismic data denoising and deblending using deep learning.

Sava, P., B. Biondi, and J. Etgan [2005] Wave-equation migration velocity analysis by focusing diffraction and reflection. *Geophysics*, **70**(3), U19-U27

Tanushev, N., A. M. Popovici, and S. Hardesty [2017] Fast, high-resolution beam tomography and velocity-model building. *The leading edge*, **36**(2), 140-145.

Tarantola, A. [1984] Inversion of seismic reflection data in the acoustic approximation. *Geophysics*, **49**(8), 1259-1266.

Tsingas, C., M. Almubarak, W. Jeong, A. Al Shuhai, and Z. Trzesniowski [2020] 3D distributed and dispersed source array acquisition and data processing. *The leading edge*, **39**(6), 392-400.

Virieux, J., and S. Operto [2009] An overview of full-waveform inversion in exploration geophysics. *Geophysics*, **74**(6), WCC1-WCC26.

Weber, M. [1988] computation of body-wave seismograms in absorbing 2-D media using the Gaussian beam method: comparison with extract method. *Geophysical Journal International*, **92**, 9-24

Yang, F. and Ma, J. [2019] Deep-learning inversion: A next-generation seismic velocity model building method. Geophysics, **84**(4), R583-R599.