Common-Offset CRS for advanced imaging in complex geological settings

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Summary

Increasingly challenging exploration targets with respect to the geological complexity and data quality require more accurate seismic imaging. The common-offset CRS method provides an extension of the CRS technology to such targets as we demonstrate in this case study for complex 2D over thrust data. While both zero- and common-offset CRS stack provide similar noise reduction compared to the conventional PreSTM in areas with relatively simple structure and good coupling, the common-offset results are far superior on very poor data.
Moreover, using the CO CRS stack in depth velocity model building can help in event picking and provides a better defined semblance.

Introduction

Exploration targets become more and more complex and standard seismic imaging methods might no longer be adequate. This also holds for time imaging techniques as they constitute the input for depth migration and velocity model building or updating. Traditional time imaging methods are often based on simplifying assumptions and might fail for complex targets and / or long offsets.

Such challenging seismic settings can be found, e. g., in compressional regimes where geological complexity is often combined with poor data quality. The latter is often equally related to near surface problems, rugged topography, low frequency content and non-optimal acquisitional conditions, leading to weak or chaotic reflections. Standard time-domain noise reduction technologies like the zero-offset Common-Reflection-Surface (ZO CRS) Stack, a data-driven seismic imaging technique for signal-to-noise and structural enhancement, might no longer be adequate for such data where its underlying global hyperbolic approximation is strongly violated.

These limitations are overcome by an extension of the CRS technology called common-offset (CO) CRS which allows the enhancement of pre-stack data via regularization and signal-to-noise improvement. As the latter is based on a *local hyperbolic assumption,* it provides a higher level of structural accuracy and extends the applicability to data with complex move-out. The enhanced CDP gathers provide improved input for subsequent pre-stack time and depth migration and may be used to facilitate velocity model building or updating.

The Common-Offset CRS stack

The Common-Offset (CO) CRS has been first introduced by Zhang et al. (2001) to simulate common-offset sections with improved signal-to-noise ratio. Höcht et al. (2009) utilized the CO CRS technique for interpolation in the CS and CMP domain. The potential of the CO CRS method for regularization and improvement of complete pre-stack datasets has first been presented by Müller et al. (2010), who also showed the superiority of the method with respect to the ZO CRS-based pre-stack seismic data enhancement (Baykulov, 2009) for data containing non-hyperbolic move-out.

Like its well-known zero-offset counterpart, the Common-Offset CRS stack is a data-driven seismic imaging technique. Both methods are based on a multi-parameter traveltime formula in midpoint-offset coordinates which defines a spatial stacking operator in the data domain. Due to the high number of traces contributing in the stacking process, the signal-to-noise ratio and event continuity in the result is strongly improved with respect to the conventional NMO/DMO/Stack sequence.

While the zero-offset CRS provides a global hyperbolic move-out correction over the whole offset range, the common-offset CRS can be applied locally in the offset domain to simulate a finite offset - and if applied continuously for all considered offset bins, provides an enhanced and regularized pre-stack dataset. Both operators are compared to the NMO/DMO operator in Figure 1 for a simple model. In a conventional NMO/DMO/Stack sequence, a summation is performed along the response of the ZO isochrone (MZO operator). As can be seen from Figure 1 (left), the operator does not provide a spatial fit to the reflection response. The ZO CRS utilizes a spatial stacking operator with expansion point P0, corresponding to a whole reflector element around the actual reflection point in depth. As the summation over all offsets is carried out with this operator, it can be considered it as a global approximation.
In contrast, the CO CRS determines the stacking parameters for each output location in the finite offset domain independently. Thus, it can be considered as a local approximation. This local behavior is further supported by the use of relatively small stacking apertures which do not extend over the whole offset range as indicated in Figure 1 (right). The CO CRS traveltime approximation, which refers to a point in the common-offset domain associated with a finite-offset ray, is parameterized in the most general

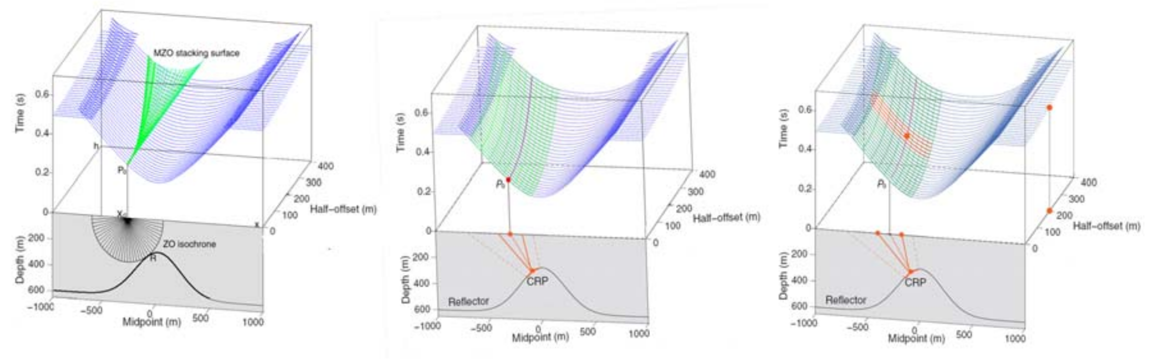

Figure 1: Comparison of traveltime operators in the midpoint-offset domain for NMO + DMO (left, corresponding to the MZO operator), ZO CRS (middle), and CO CRS (right). The blue curves represent the reflection traveltime curves for the dome-like reflector in the lower part, the green line indicate the MZO and ZO CRS operator, respectively. In the last picture, the CO CRS operator is represented in red. Picture modified after Baykulov (2009).

3D case in terms of 14 parameters (in confrontation of the 8 in the ZO case), the number reduces to 5 in 2D (the 2D ZO CRS is based on a total of 3 stacking parameters). One important aspect of the CO CRS is that it can handle a wider range of events, namely apex shifted and converted events in addition to the unconverted normal events.

Usually, the CO CRS is applied in sequence over the whole offset range of the data; the offset bin spacing is determined by the input geometry and migration needs. Common values for the spacing are 100-150 m in offset, leading to typically 80 CO CRS stacks to be carried out for one pre-stack dataset. In order to provide reasonable runtimes for the simultaneous estimation of the CO CRS stacking parameters, HPC strategies have to be exploited. Here, the CO CRS stack can benefit from previous research done regarding the ZO CRS as presented in Marchetti et al. (2011).

Integrated workflow for complex data

As processing workflows become increasingly integrated and final product is usually a pre-stack depth migration, the potential of the CO CRS technology can be useful, especially with regard to velocity model building.
Gentile et al. (2008) presented an integrated approach for depth velocity model building which utilized ZO CRS results to facilitate interpretation in areas of high noise level and lacking event continuity. The good interpretability of CRS PoSDM helped to reconstruct the subsurface and to reduce uncertainties in the analysis of low SN zones. Anyway that approach was not exploiting completely the potentiality of CRS technology since it was based just on stacked data interpretation.
In contrast, the CO CRS improves the S/N ratio and reflection continuity in the CDP gathers, which can directly enter into velocity analysis and pre-stack migration. Besides the improved interpretability, CO CRS stacked CDP gathers showed to provide better defined semblance plots and clearer velocity trends with respect to the original data. On the other hand, pre-stack migrated CO CRS results provide improved seismic images in time and depth with respect to conventional results and post-stack migrated ZO CRS sections combining the benefits of the CRS noise reduction capacity and the more precise velocity analysis technologies and pre-stack migrations.

2D overthrust example

The 2D lines stem from a geologically complex over-thrust environment further complicated by zones of rough topography, low frequency content and carbonate outcropping. To due non-optimal acquisition condition with poor geophone coupling in the mountainous Western part of the acquisition area comprising foldbelt with steeply dipping structural features, we exhibit a very high noise level and little to no reflections for part of the lines, while data quality is much better in the moderately flat Eastern part.

To all lines, the CO CRS stack has been applied over the whole offset range with offset bin spacing of 150m. Midpoint and offset aperture were chosen small enough to maintain the local character of the complex move-out in the

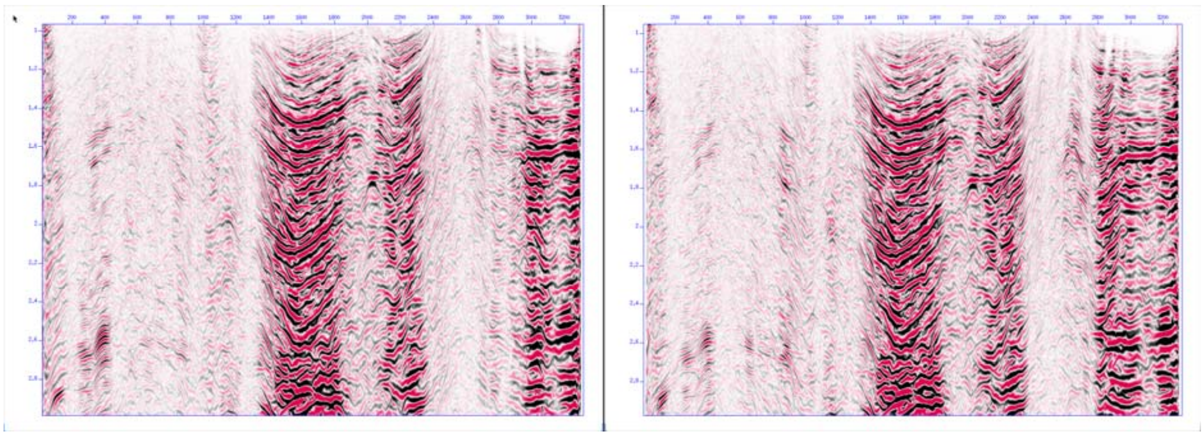

Figure 2: CO CRS stack result for offset 2000m (left) and -2000m (right). Structural differences are especially visible at steep flanks and in the noise areas, confirming the local character of the method.

gathers; and positive and negative offsets were treated separately. Stacking results for larger offsets show surprisingly strong structural differences emphasizing the local character of the simulation (Figure 2).

The CO CRS stacked entered into a PreSTM as well as depth velocity model building and PreSDM. In Figure 3 the CO CRS PreSTM results are compared to a conventional PreSTM and ZO CRS PoSTM for a line extending over both the very noisy data zones in the western mountainous area to the relatively good data with moderate topography in the East. Both CRS methods provide equal improvements in the Eastern part with respect to the conventional result. Here, the move-out is less complex and fits well with the hyperbolic approximation of the ZO CRS. However, for the more complex Western part the CO CRS stack provides far better imaging, benefiting from signal enhancement and the improved event continuity provided by the CRS technology. Consequently, it improves vertical resolution of the data and provides more reliable results for structural interpretation. It is to be emphasized that the superior results stem from the combination of the CRS technology with a *pre-stack* migration which is able to handle complex, non-hyperbolic move-out in the CDP gathers. The reflections at 1.4 sec and 2.8 sec are lost on the ZO CRS results but are confirmed by the PreSTM, however, the conventional result does not provide a comparable continuity. Similar structures have been observed on a 3D PreSTM in this area.

Depth velocity model building is currently under-way. First results for CO CRS stacked CDP gathers show better focused and less noise-contaminated semblance plots which provide a better input for picking.

Conclusions

In this case study the potential of the CO CRS technique for imaging complex data has been demonstrated for 2D over-thrust example with zones of high noise level and bad coupling. With respect to post-stack migrated ZO CRS and conventional PreSTM results, the pre-stack migrated CO CRS demonstrates far superior results in areas with very poor data and complex move-out. Here, the combination of the noise-reducing capability of the CRS together with the more precise pre-stack migration allows to image the complex data which cannot be handled by the other approaches.

Acknowledgement

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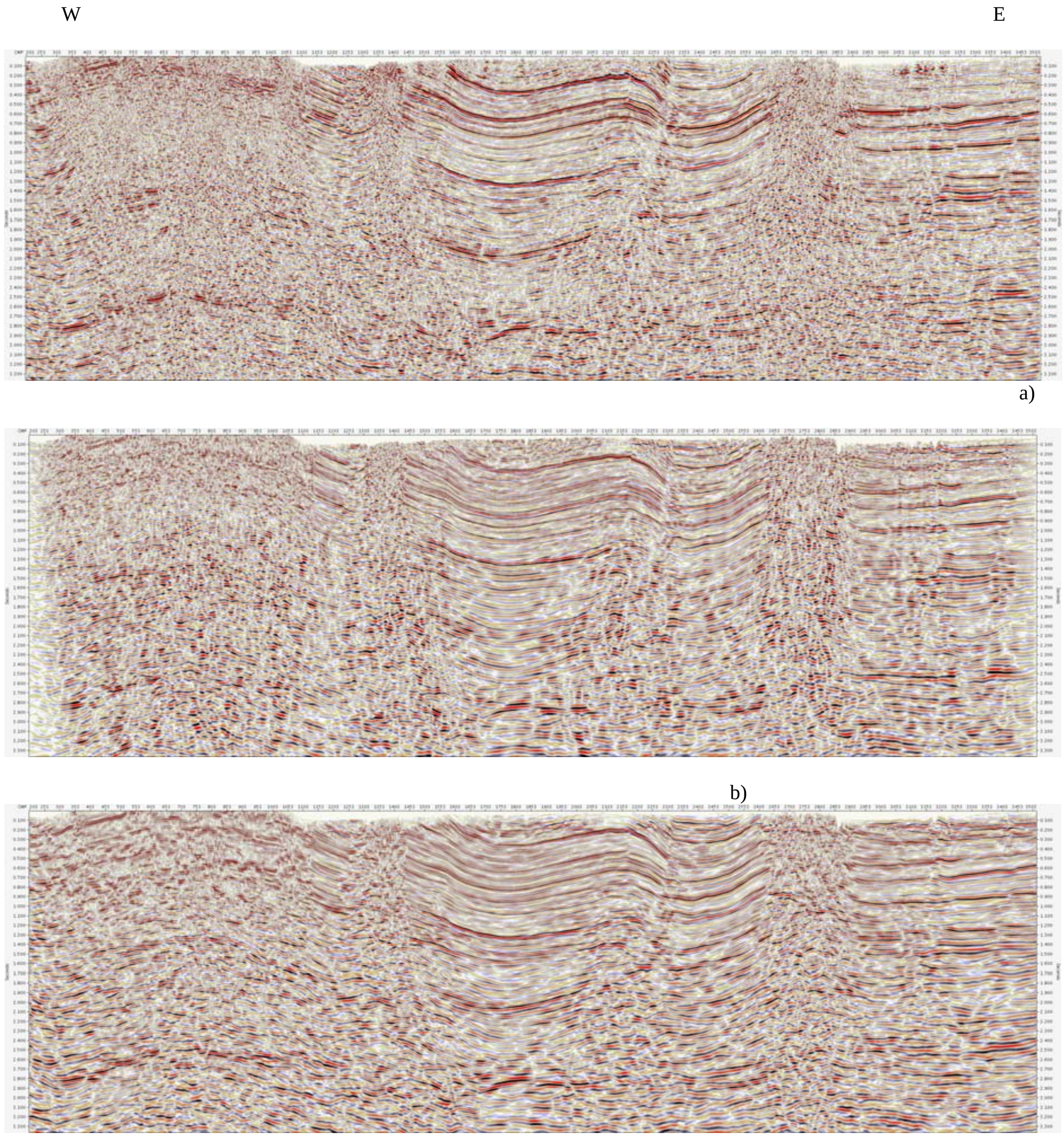

Figure 3: Comparison of time-migrated results: a) conventional PreSTM, b) PoSTM of ZO CRS, and c) PreSTM of CO CRS stack result. While both CRS techniques provide similar results in the Eastern part of the line, only the CO CRS is able to correctly image the complex Western area, showing strong noise reduction and improvement of event continuity.