HANDLING THE CONFLICTING DIP PROBLEM IN THE CRS/i-CRS METHODS

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ABSTRACT

Most current implementations of the CRS operator suffer from the occurrence of conflicting dip situations in the acquired data. To address this properly we apply the idea of the CDS. We use the i-CRS operator that can be related to the CRS operator, and show, that conflicting dips can be resolved well in multi-parameter processing. The results are promising and reveal a lot of potential for further applications. This is shown by a diffraction separation technique applied to field data obtained in the Levantine Basin.

INTRODUCTION

The Common Reflection Surface (CRS, Müller, 1999; Jäger et al., 2001; Mann, 2002) and implicit Common Reflection Surface (i-CRS, Vanelle et al., 2010; Schwarz, 2011) stack increase the signal-to-noise ratio significantly and their attributes can be used for further applications like diffraction separation (Dell and Gajewski, 2011) and prestack data enhancement (Baykulov and Gajewski, 2009). However currently the handling of conflicting dips with the CRS operator (Mann, 2001) is not reliable and often leads to suppression of the less dominant events. Soleimani et al. (2009) suggested the Common Diffraction Surface (CDS) stack to account for this problems. However they used a simplified version of the CRS operator and it can not be used for most further CRS attribute based methods.

We describe the concept of the CDS and extend it to the CRS and i-CRS methods. We apply it to a synthetic and a field data set and discuss occurring issues. Additionally we perform a CRS attribute based diffraction separation.

COMMON REFLECTION SURFACE STACK

The CRS stack is a multi-parameter stacking technique, that considers neighboring midpoints as well as the offset while the Common Midpoint (CMP) method uses only offsets. Therefore more traces are stacked and the signal-to-noise ratio is improved significantly.

The CRS operator consists of three wave-field attributes which are related to two hypothetical one-way experiments as shown in figure 1. The resulting two waves are described by the angle of the emergence α of the ZO ray and the corresponding radii of curvature, R_N for the normal (N) wave and R_{NIP} for the normal-incidence-point (NIP) wave (Hubral, 1983). The normal wave is generated by an exploding reflector model around the normal-incidence-point. The normal-incidence-point wave is generated by a point source at the normal-incidence-point for a specific reflector.

The CRS formula in its hyperbolic expression is given by:

$$t^2(x_m, h) = \left(t_0 + \frac{2\sin\alpha}{v_0}\Delta x_m\right)^2 + \frac{2t_0\cos^2\alpha}{v_0}\left(\frac{\Delta x_m^2}{R_N} + \frac{h^2}{R_{NIP}}\right) \quad (1)$$

where $\Delta x_m = x_m - x_0$ is the midpoint displacement, h the half-offset, t_0 the two-way traveltime (TWT) of the zero-offset (ZO) ray and v_0 the near surface velocity.

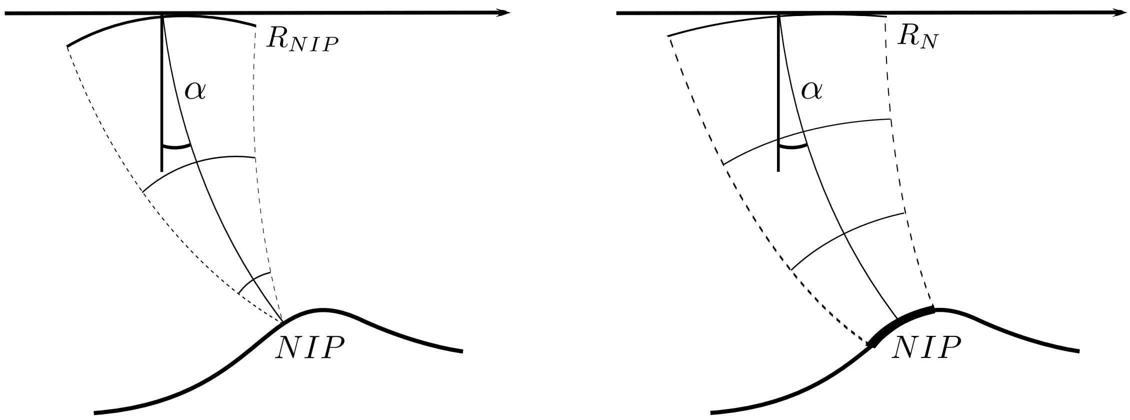

Figure 1: Two hypothetical experiments: The normal-incidence-point wave is shown on the left side with its radius of curvature R_{NIP} and angle of emergence α. The normal wave with the radius of curvature R_N, is caused by an exploding reflector experiment (right).

IMPLICIT COMMON REFLECTION SURFACE STACK

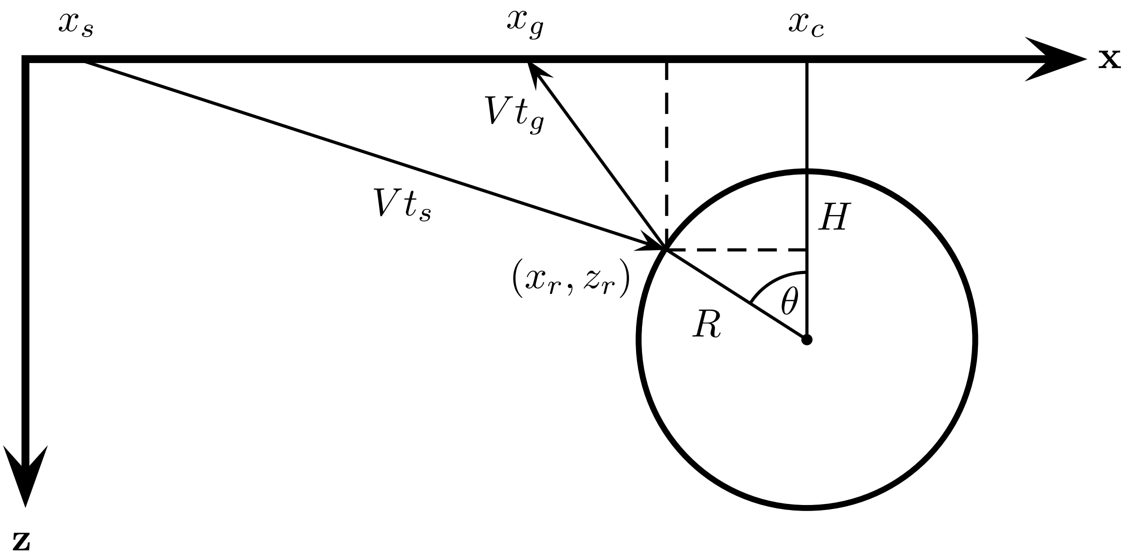

Figure 2: Deviation of the i-CRS operator modified after Schwarz (2011).

The i-CRS operator is another multi-parameter stacking technique derived by a model based approach. It assumes a locally circular reflector as shown in figure 2. It depends on three parameters of the circle (x_c, H and R) as well as the background velocity V and reads

$$\begin{aligned} t_s &= \frac{1}{V}\sqrt{(\Delta x_m - h - \Delta x_c - R\sin\theta)^2 + (H - R\cos\theta)^2} \\ t_g &= \frac{1}{V}\sqrt{(\Delta x_m + h - \Delta x_c - R\sin\theta)^2 + (H - R\cos\theta)^2} \\ t &= t_s + t_g \end{aligned} \tag{2}$$

where Δx_m is the midpoint displacement, h the half-offset, θ the reflection point angle on the circle and Δx_c the displacement of the circle. Additionally the reflection angle θ on the circle has to be calculated. It depends on the traveltimes t_s and t_g

$$\tan\theta = \tan\theta_0 + \frac{h}{H}\frac{t_s - t_g}{t_s + t_g} \tag{3}$$

and can be solved in an iterative fashion with the first assumption of an zero offset ray, where the dependence on t_s and t_g vanishes

$$\tan\theta_0 = \frac{\Delta x_m - \Delta x_c}{H}. \tag{4}$$

Schwarz (2011) showed, that a few iterations are already sufficient.

COMMON DIFFRACTION SURFACE STACK

Soleimani et al. (2009) proposed a strategy to solve the conflicting dip problem of the CRS operator. They search multiple operators for one sample where each operator has a fixed angle of emergence α. This ensures that events that stem from different directions are accounted for individually. If two events are located at the same t_0 and originate from the same direction, the events still can not be separated. However, this does usually only occur when a diffraction and reflection apex coincide.

In order to reduce the required computation time Soleimani et al. (2009) do not search for R_{NIP} and R_N but for a combined parameter $R_{CDS} = R_N = R_{NIP}$. Since R_N is equal to R_{NIP} for diffractions they call their method Common Diffraction Surface Stack (CDS). In fact it is not only a surface stack in midpoint and offset direction but a volume stack were the third dimension is the angle of emergence. The operator for a particular value of α reads

$$t^2(\alpha, x_m, h) = \left(t_0 + \frac{2\sin\alpha}{v_0}(\Delta x_m)\right)^2 + \frac{2t_0\cos^2\alpha}{v_0 R_{CDS}}\left(\Delta x_m^2 + h^2\right). \tag{5}$$

During the attribute search only the parameter R_{CDS} is unknown. The angle of emergence α is fixed, where a range of different α-values is considered, i. e., for each value of α a specific operator based on equation 5 is determined. It should be noticed that this approximation is not valid for reflections since R_N and R_{NIP} are different in this case.

EXTENSION TO CRS AND I-CRS

The CDS stack is not very well suited for reflections. The CRS method on the other hand is well suited but suffers from the conflicting dip problem so it is a natural choice to extend the CDS idea to the CRS method. The optimization is more time consuming in this case since the operator does not only depend on one unknown parameter but two. Fortunately the operators for each angle can be calculated individually which makes it easy and efficient to parallelize. Therefore each operator can be optimized on a different CPU which makes it less time consuming. Furthermore the standard CRS requires a three parameter optimization while here, only R_N and R_{NIP} are required since α is fixed.

The principal concept to separate operators for a sample by a single parameter can be extended to any kind of stacking operator. The CRS is a simple choice since the angle of emergence α is well suited for that purpose. In principal one could also separate by curvatures but this is less reliable.

Since the i-CRS operator is better suited for diffractions and equally well for reflections compared to the CRS operator (Schwarz et al., 2012) and the i-CRS attributes can be converted to CRS attributes (Schwarz, 2011) we use the i-CRS operator here. In the next sections we apply the above described method to synthetic and field data.

SIGSBEE2A

For the application to synthetic data we consider the Sigsbee2a data-set which describes a geological setting in the deep water Gulf of Mexico including a large salt body of complex shape. This leads to a variety of interference of the reflected and scattered wave fields resulting in a huge amount of conflicting dip situations. Furthermore the model contains some faults and several point diffractors located in the deeper parts of the model adding more such situations.

Figure 3 shows the CRS stack using the suggested conflicting dip handling by Mann (2001). Some of the conflicting dip situations can be resolved, especially in the salt free area on the left side and at areas where the wave-fields have similar amplitudes. In areas where the amplitudes differ significantly most smaller events are truncated by the most dominant event. This is not the case in figure 4 where we used the proposed method with the i-CRS operator. The conflicting dips are very well resolved up to the point where even diffractions caused by velocity stair-steps in the modeling process can be imaged. Intersecting events cause visible positive and negative interference. Furthermore the order of amplitudes is a magnitude higher since more contributing energy is stacked. The coherence section in figure 5 appears very smooth and consistent with few truncations and noise. The stripe pattern is caused by the discrete sampling of α. In the next section we consider a field data example.

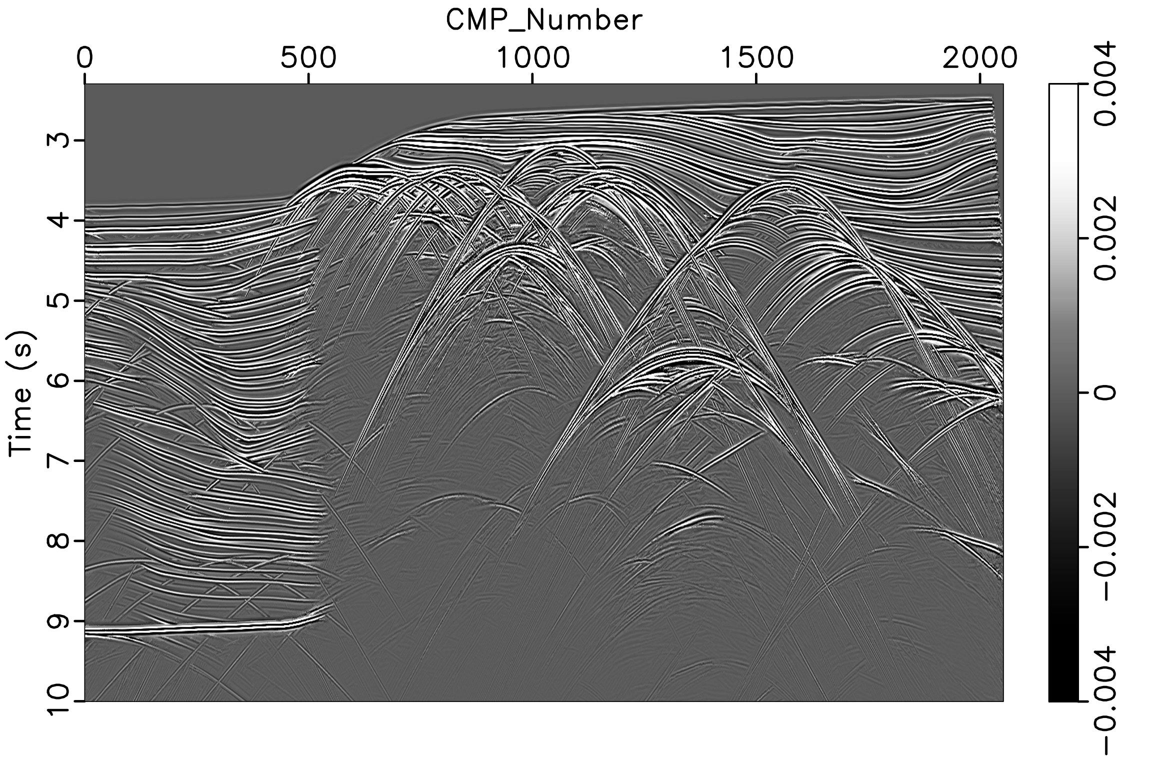

Figure 3: Sigsbee2a i-CRS stack obtained using the conflicting dip handling of Mann (2001).

FIELD-DATA EXAMPLE

The field-data was acquired in the Levantine Basin in the Mediterranean Sea. The subsurface contains salt roller and several fault systems providing a high amount of diffractions. Figure 6 displays the stack using the i-CRS operator and no conflicting dip handling. The diffractions caused by the salt roller are visible while most diffractions from the faults are masked by other events. This is not the case in figure 7 where we used the proposed method. Similar to the Sigsbee2a example the method suffers from a signal stretch but is able to image the former missing diffractions well. The stacked energy is significantly higher. An application of the CRS attributes based diffraction separation (Dell and Gajewski, 2011) on this data set is shown in figure 8 where diffractions are well separated except for parts of the seafloor and the salt bottom. The apex position is often truncated since the horizontal reflections are more prominent than the diffractions and the operator for angles close to zero mostly fitted the reflections. Since diffractions usually back-scatter less energy then reflections the amplitudes in the diffraction separated stack are smaller. The next section provides a solution to the signal stretch problem.

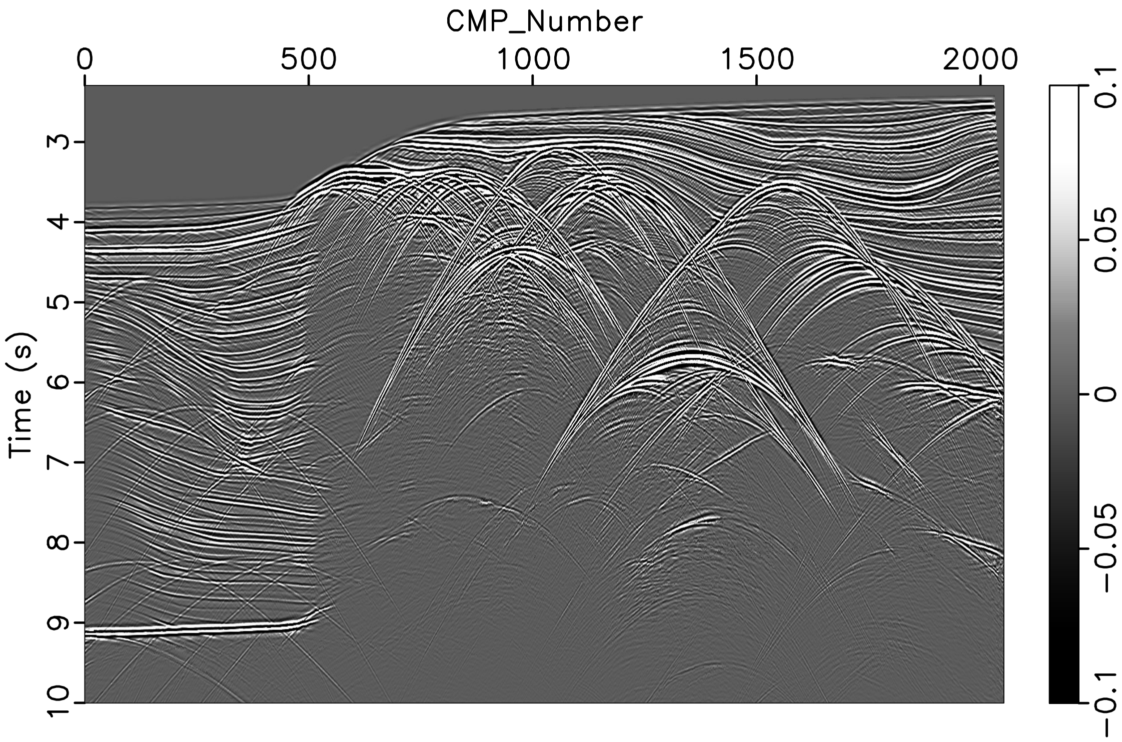

Figure 4: Sigsbee2a i-CRS stack using the new conflicting dip handling.

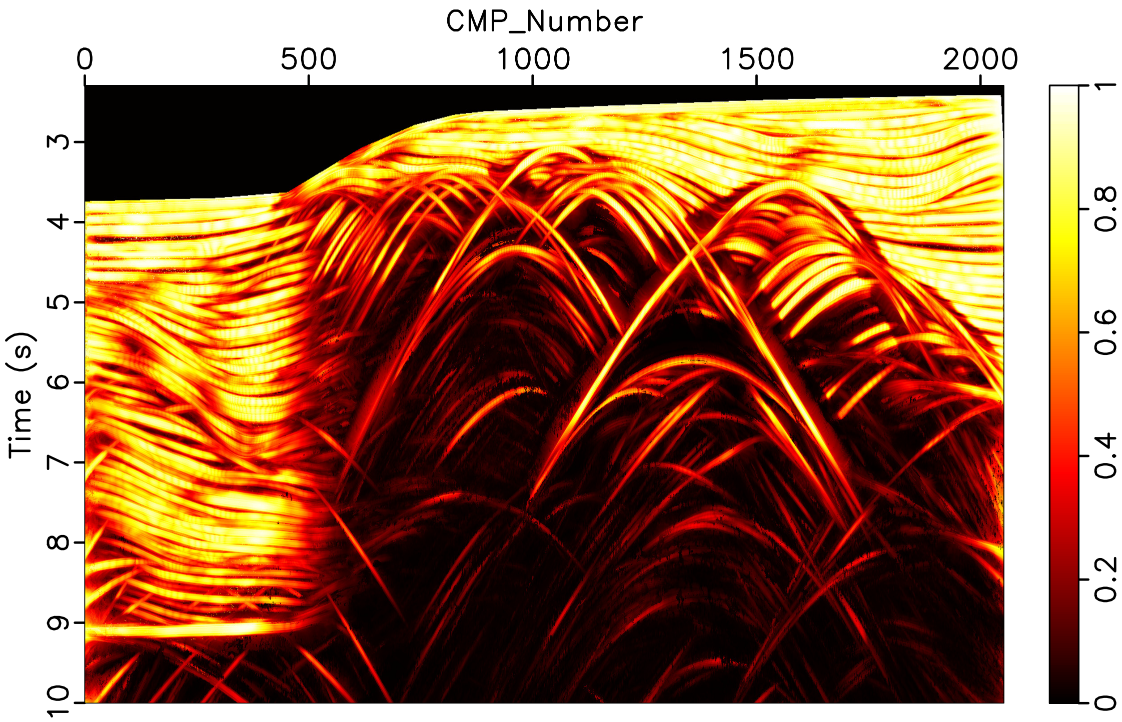

Figure 5: Sigsbee2a coherence section obtained by the highest coherence contribution out of all operators per sample. The stripe pattern is caused by the discrete α sampling.

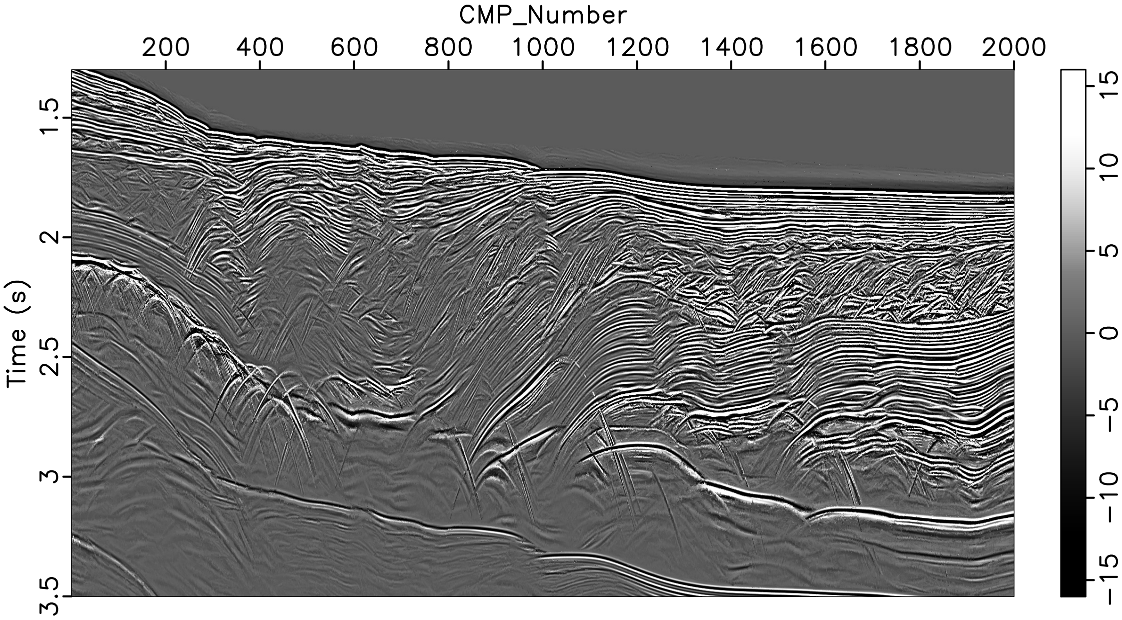

Figure 6: Stack obtained with the i-CRS operator not considering conflicting dips.

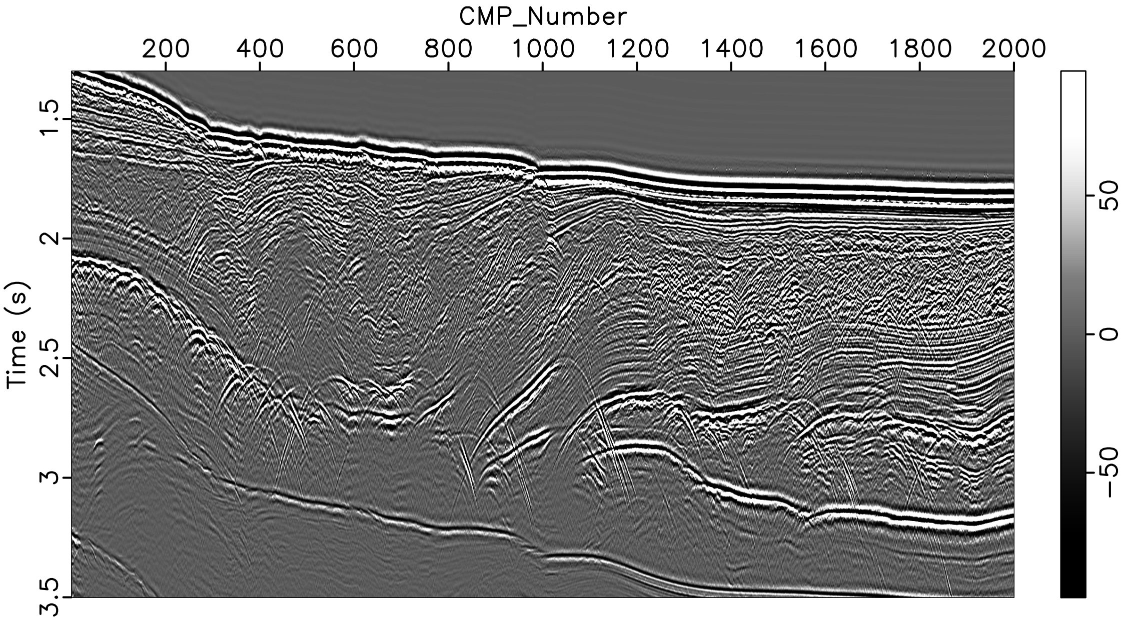

Figure 7: Stack obtained with the i-CRS operator considering conflicting dips with the new approach.

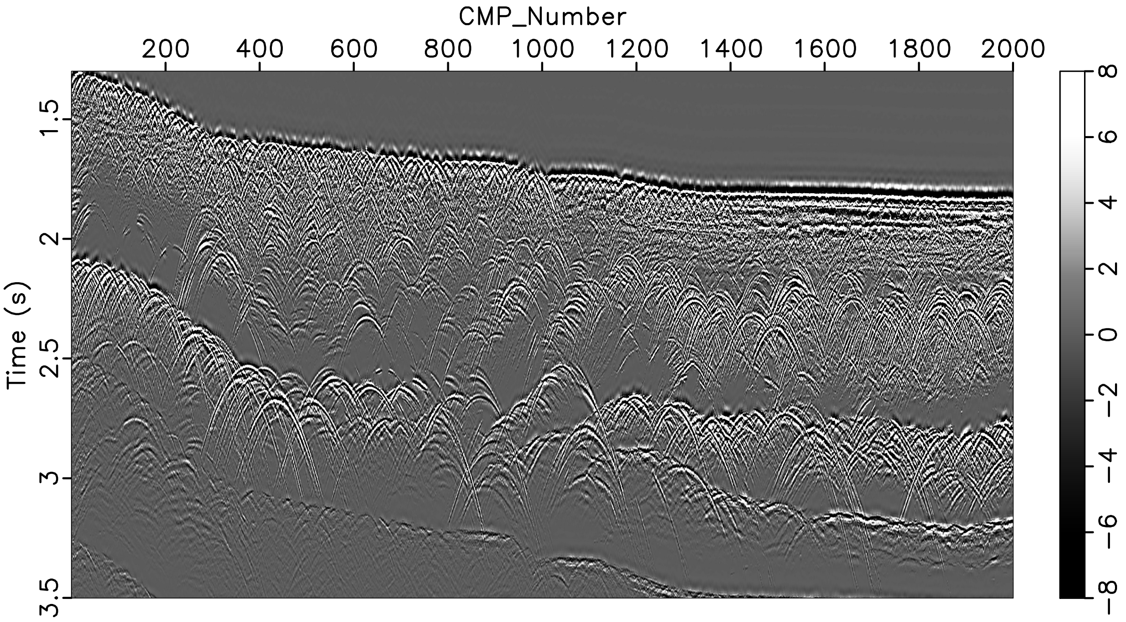

Figure 8: Diffraction separation considering conflicting dips. Most diffractions can be successfully separated. However residuals are left at the seafloor, the bottom of salt and the respective multiples.

SIGNAL STRETCH

The signal stretch especially visible at the sea floor of the field data set in figure 7 is an important issue for further applications. The stretch can also be observed in the parameter sections. Therefore a better parameter determination can solve this problem. Walda and Gajewski (2014) propose a global optimization scheme using a genetic algorithm. Limiting the parameter space of the optimization to an interval of possible α values instead of the full range allows the consideration of multiple operators using separate intervals. The width of the interval close to values of $0°$ should be smaller since a superposition of reflected and diffracted energy is more likely in this case. An application is shown in figure 9. The poor quality is caused by a very low number of iterations applied to a very small population. However we do not observe a signal stretch.

CONCLUSION

We extended the CDS stack idea to the CRS and i-CRS method and showed that the conflicting dips can be imaged very well. In the synthetic examples even diffractions caused by stair stepping from the modeling process in the Sigsbee2a data set were imaged. Furthermore the diffractions are enhanced which is a further advantage, especially in the diffraction separation process which works very well with the new conflicting dip approach.

Since the current implementation uses a discrete angle description the individual coherence sections can be used to evaluate directions of certain events. This will be used in the future to create illumination maps. Moreover, the coherence is consistent and smooth with very little truncations.

While the method shows good results regarding the treatment of conflicting dips and their incorporation into further processing steps we also face some drawbacks. First we have to deal with a higher computational effort since more operators per sample have to be determined. Fortunately a discrete description of α reduces the dimension of the optimization by one. The most prominent problem is a significant signal stretch. This problem can be solved by using a better optimization scheme combined with a better angle fragmentation distribution.

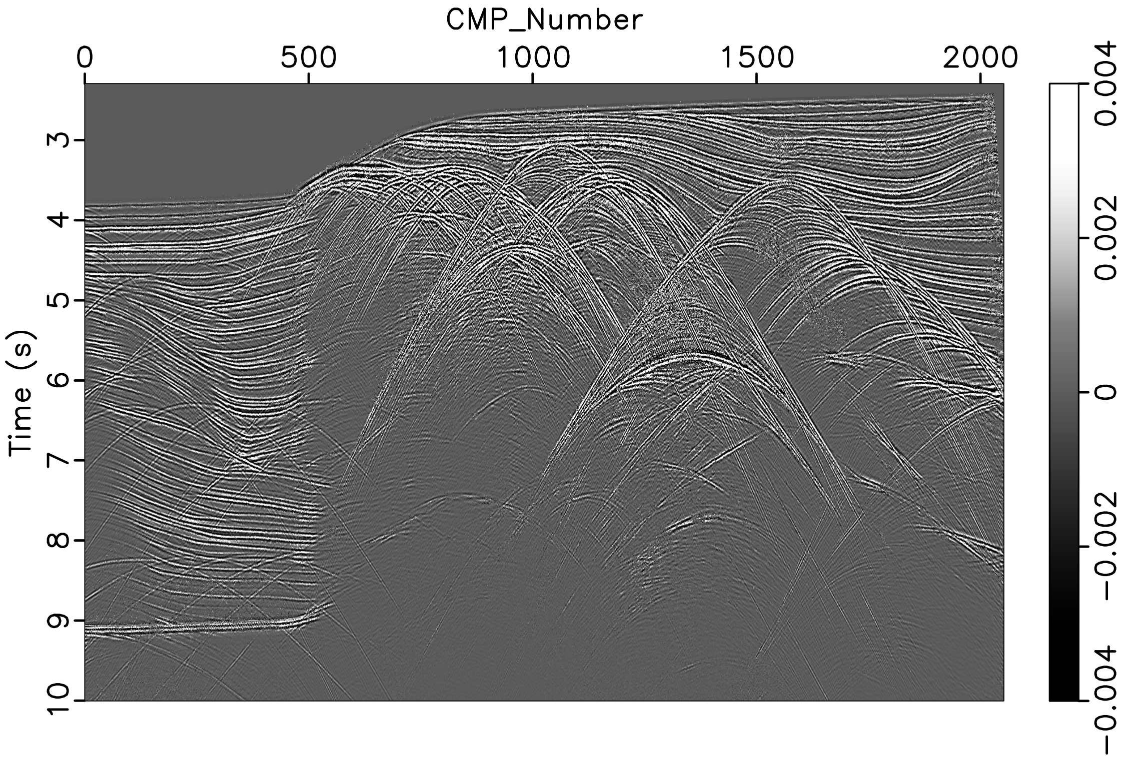

Figure 9: Sigsbee2a stack obtained with the CRS operator using a pure genetic algorithm optimization.

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REFERENCES

Baykulov, M. and Gajewski, D. (2009). Prestack seismic data enhancement with partial common-reflection-surface (crs) stack. *Geophysics*, 74(3):V49–V58.

Dell, S. and Gajewski, D. (2011). Common-reflection-surface-based workflow for diffraction imaging. *Geophysics*, 76(5):S187.

Hubral, P. (1983). Computing true amplitude reflections in a laterally inhomogeneous earth. *Geophysics*, 48:1051–1062.

Jäger, R., Mann, J., Höcht, G., and Hubral, P. (2001). Common-reflection-surface stack: Image and attributes. *Geophysics*, 66:97–109.

Mann, J. (2001). Common-reflection-surface stack and conflicting dips. *71st Annual Internat. Mtg., Soc. Expl. Geophys*, Extended Abstracts:Session SP 5.3.

Mann, J. (2002). *Extensions and Applications of the Common-Reflection-Surface Stack Method*. PhD thesis, Logos Verlag, Berlin.

Müller, T. (1999). *The Common Reflection Surface Stack Method: Seismic Imaging without explicit knowledge of the velocity model*. PhD thesis, University of Karlsruhe.

Schwarz, B. (2011). A new nonhyperbolic multi-parameter stacking operator. Master's thesis, University of Hamburg.

Schwarz, B., Vanelle, C., Gajewski, D., and Kashtan, B. (2012). i-CRS: Application of a new multi-parameter stacking approach to complex media. Society of Exploration Geophysicists.

Soleimani, M., Piruz, I., Mann, J., and Hubral, P. (2009). Solving the problem of conflicting dips in common reflection surface (crs) stack. *1st International Petroleum Conference & Exhibition*, EAGE, expanded abstracts, A39.

Vanelle, C., Kashtan, B., Dell, S., and Gajewski, D. (2010). A new stacking operator for curved subsurface structures. SEG 80th Annual Meeting, Expanded Abstracts.

Walda, J. and Gajewski, D. (2014). *Global optimization of the CRS operator using a genetic algorithm*, page to be filled. WIT Report. WIT Consortium.