# PARTIAL 3D CRS STACK

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## ABSTRACT

*The 3D CRS stack method is usually used to simulate a ZO volume of seismic data. The quality of the generated stacks is in general better than of conventional NMO/DMO stack due to increased signal-to-noise ratio. Poststack time/depth migrated CRS stack volumes outline more details than the conventionally migrated section. However, there is need for improvement of prestack data quality using the CRS stack. We extended the CRS method to enhance the S/N ratio of prestack data by generating 3D CRS supergathers. Obtained gathers can be used to generate prestack migrated data with the CRS quality. Trace interpolation/regularisation is another application of this technique. We suggest to use stable and robust partial CRS summation for the regularisation of traces.*

## INTRODUCTION

The quality and regularity of 3D seismic data may vary depending on the parameters of acquisition and the geological situation in study area. Quite often the S/N ratio of seismic data must be enhanced to be able to perform reliable processing, e.g., stacking velocity analysis, velocity model building and other processes. Regularly spaced traces are necessary for many processing schemes as well. Regularisation of seismograms and filling the gaps in case of missing data is usually performed using different binning and interpolation techniques (see, e.g., Yilmaz, 2001; Fomel, 2003).

The CRS stack method (e.g., Müller, 1999; Jäger et al., 2001; Mann, 2002) being intensively developed in last years, provides kinematic wavefield attributes that can be used for many processing tasks, including prestack data enhancement and regularisation. Enhancement of prestack data using partial CRS stack was already successfully implemented for 2D by Baykulov and Gajewski (2008, 2009). Gierse et al. (2008) showed the possibilities to enhance velocity analysis and to fill data gaps by CRS techniques. Höcht et al. (2009) developed the operator-oriented CRS interpolation scheme for 3D data.

In this work we describe the method of enhancing the quality and regularity of 3D seismic data using the partial 3D CRS stack method. Improvement of the S/N ratio as well as trace regularisation can be obtained by a simple and robust partial summation algorithm. The partial CRS operator is calculated based on the kinematic wavefield attributes estimated during the automatic CRS search, i.e., to improve the prestack data the results of conventional CRS stack are used.

We show the results of the partial 3D CRS stack on two synthetic examples, and apply the method to a real 3D dataset.

## THEORY

3D CRS stack operates in time domain using a second-order approximation of the reflection traveltimes. A detailed description of the theory and implementation of the 3D ZO CRS stack can be found in the literature, e.g., by Bergler et al. (2002) or Müller (2007). The stacking operator for the ZO trace is given by a hyperbolic second-order traveltime approximation:

$$t_{hyp}^2 = (t_0 + \mathbf{w} \cdot \mathbf{m})^2 + \frac{2t_0}{v_0}\Big(\mathbf{m}^{\mathrm{T}}\mathbf{N}\mathbf{m} + \mathbf{h}^{\mathrm{T}}\mathbf{M}\mathbf{h}\Big), \tag{1}$$

where $t_0$ is ZO two-way traveltime, $v_0$ is surface velocity, vector $\mathbf{w}$ contains 2 components of emergence angle (azimuth and dip), matrix $\mathbf{M}$ contains 3 attributes of the normal-incidence-point (NIP) wave, matrix $\mathbf{N}$ contains 3 attributes of the normal (N) wave, $\mathbf{m}$ and $\mathbf{h}$ are midpoint and source-receiver offset vectors, respectively.

Partial 3D CRS stack uses the stacking parameters estimated for each CMP position and calculates the stacking operator for every sample in the output domain. The workflow is similar to that applied in the 2D case by Baykulov and Gajewski (2009), and consists of the following steps:

1. Automatic 3D CRS parameter search as applied by Müller (2007) is performed. As a result of this process, 8 kinematic wavefiled attributes are estimated for each CMP position and every ZO time sample of input data.
2. The output domain for 3D CRS supergather is defined. The current implementation assumes two options:
   a) The output domain is the same as for the input data, i.e., the generated supergather traces have the same locations as the input traces.
   b) The output domain is regularised and completely pre-defined by the user.
3. For each specified trace and for each time sample in the output domain, an automatic search for the corresponding $t_0$ traveltime is performed. The algorithm for the $t_0$ search is based on best-fit approximation of reflection traveltime, and is similar to the 2D method described by Baykulov and Gajewski (2009). The basics of the method is that the $t_0$ time for considered sample of the output seismogram is found, which provides minimum misfit between the calculated CRS operator and the observed reflection traveltime in the input data.
4. The best-fit $t_0$ time and the corresponding CRS attributes are taken to compute the partial CRS stacking surface that is a part of the 3D CRS stacking operator. This surface is constrained by apertures in both offset and midpoint dimensions which can be chosen independently. After that, a weighted summation of all amplitudes along the partial CRS stacking surface is performed.

By summation of many traces to generate one output sample, the amplitudes of random noise are attenuated, increasing the S/N ratio of the resulting seismograms. Moreover, the CRS stacking operator and, therefore, the partial CRS stacking surface may be calculated for every specified trace within the CRS aperture. Therefore, the method can be used for regularisation purposes.

## RESULTS

The proposed method of partial CRS stacking was tested on synthetic 2D and 3D datasets, and applied to real 3D data.

The first synthetic data were generated using a 2D layered model with different interval velocities in each layer (see Figure 1). Random Gaussian noise with S/N = 20 was added to the seismograms after modelling.

Because of strong amplitude difference between the first and second reflection, the latter one is hidden by noise and almost not visible in the seismograms (see Figure 2(a)). Figure 2(b) shows the partially stacked CRS supergather for the same location. It is obvious that the S/N ratio was increased, and the second (deeper) reflection became visible at 1.75 s $t_0$ two-way traveltime (TWT).

Figure 3(a) shows the same noisy CMP gather as presented in Figure 2(a), but several traces were randomly eliminated from the data, simulating nonregularities in seismic acquisition. Partial CRS stack ( Figure 3(b)) successfully reconstructed the amplitudes of missing traces using the information from

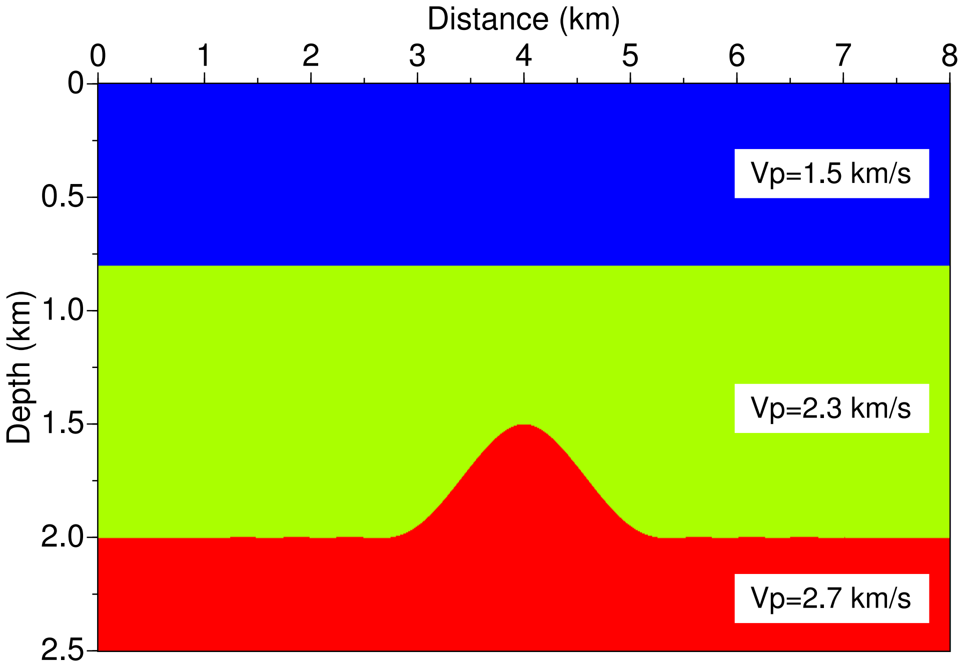
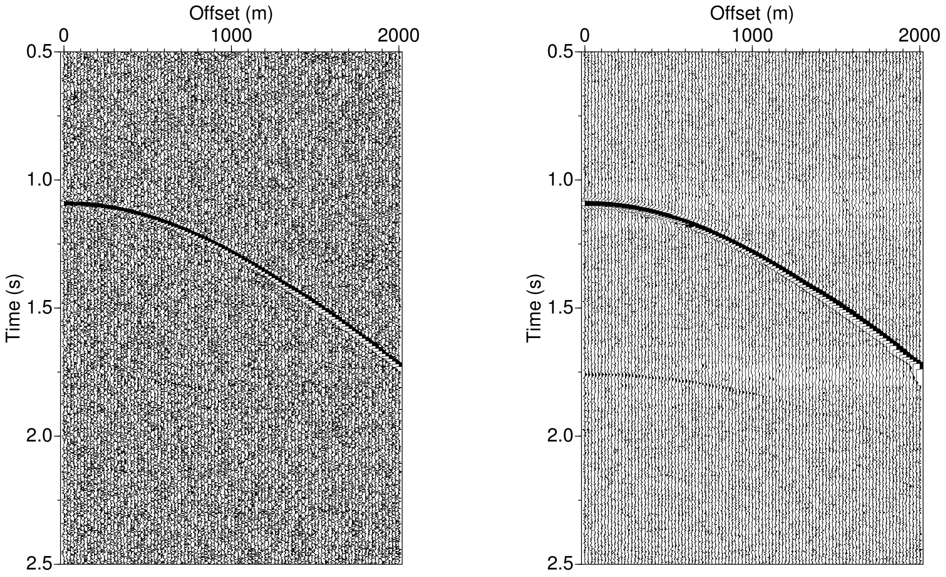


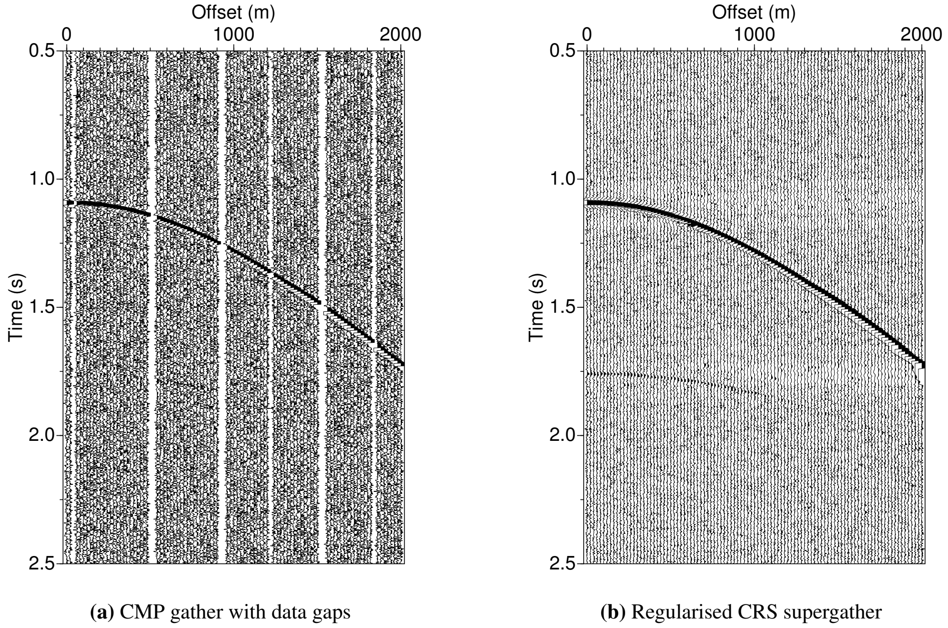
**Figure 1:** Synthetic 2D model containing three layers with different interval velocities.



**(a)** CMP gather

**(b)** CRS supergather

**Figure 2:** Synthetic 2D data. Strong random noise presents in the CMP gather (a), the deeper reflection at 1.75–2 s TWT is almost not visible. The CRS supergather (b) shows increased S/N ratio, the deeper reflection is visible and can be used for reliable velocity analysis.



**(a)** CMP gather with data gaps

**(b)** Regularised CRS supergather

**Figure 3:** Synthetic 2D data. Several traces were eliminated from the CMP gather (a) to simulate data gaps (missing shots). In the CRS supergather (b) the missing traces are reconstructed.

neighbouring CMPs. Like in the previous example, the S/N ratio and the visibility of deeper reflection was increased.

The second dataset was generated using a simple 3D synthetic model that consists of four horizontal layers with different interval velocities increasing from 2 km/s at the surface to 5.5 km/s at deeper levels. Random Gaussian noise with S/N=20 was added to the generated seismograms, so that most of reflections are hardly visible (Figure 4(a)). After estimation of CRS parameters and generating 3D CRS supergathers, the S/N ratio was significantly increased, and three reflections at traveltimes of about 1.8 s, 3.4 s and 4.4 s became visible (Figure 4(b)).

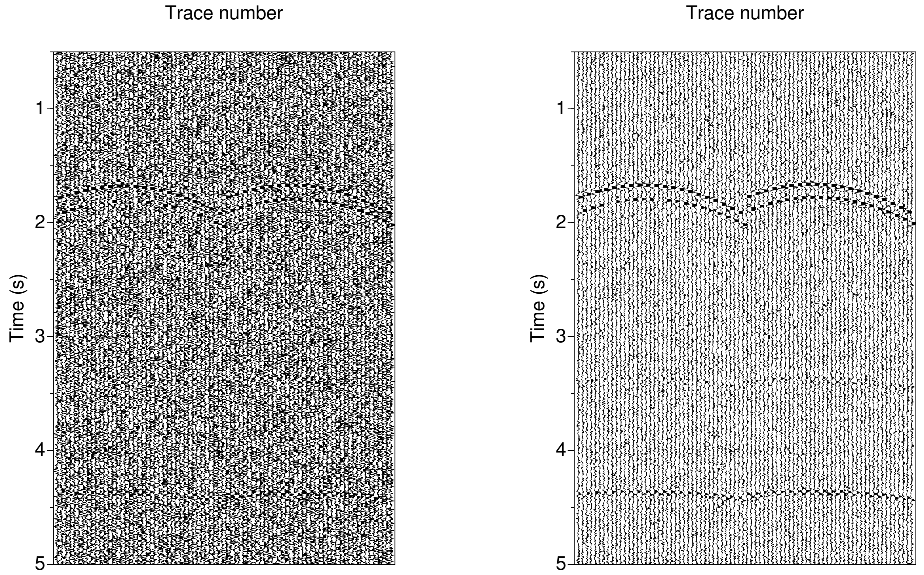
The third example consists of a 3D land dataset (courtesy of Addax Petroleum Services Ltd, Geneva) for challenging area. The data were shot in 1997 with a bin size of 25*25 m and a nominal stacking fold of 36. Source line interval was 200 m, and source/receiver point interval was 50 m with maximum source-receiver offset of about 3000 m. Since the traces have different azimuthal distribution, they are located irregularly on a 2D TWT-offset plane in Figure 5(a). Here we performed both partial summation and regularisation of traces using the CRS stack. The resulting 3D CRS supergather is shown in Figure 5(b). Due to the regularity of traces in the 2D plane and increased S/N ratio, many coherent events became visible, which could hardly be observed in the input data.

## DISCUSSION

Regularisation of 3D seismic data is a challenging task. Seismic traces have varying azimuthal distributions, which complicates and limits regularisation possibilities. The regularisation should be performed not at every position, but only in chosen azimuth directions. For a stable and reliable 3D CRS regularisation either the output domain must be completely pre-defined by the user, or a sophisticated algorithm should be developed which takes the azimuthal distribution of traces into account.

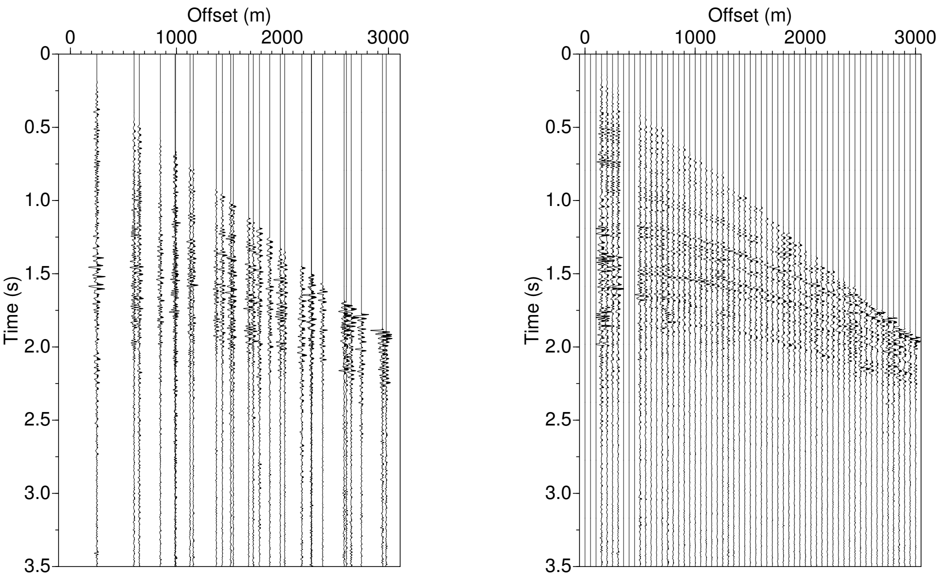
For the proposed method of seismic data enhancement and regularisation the CRS parameters must be carefully estimated. Depending on the reliability of the estimation algorithm, the quality of the partial CRS stack may vary. Therefore, all methods for improvements of CRS parameter search are worth to apply for producing reliable and stable parameters for the partial 3D CRS stack.

The partial 3D CRS stack operates with second order hyperbolic traveltime formula that has it limi-



**(a)** Input data **(b)** Partial 3D CRS stack

**Figure 4:** Synthetic 3D data with noise. In the original data (a) only the strongest reflection at 1.8 s TWT is visible. The generated 3D CRS supergather (b) shows three reflections at different time levels (1.8, 3.4 and 4.4 s TWT), the S/N ratio is increased.



**(a)** CMP gather **(b)** CRS supergather

**Figure 5:** Real 3D data. Original CMP gather (a) has several traces spaced irregularly in the 2D TWT-offset plane. Reflections are hardly visible. The partial 3D CRS stack provided CRS supergather (b) with regular traces, where coherent reflections can be identified. Data gaps between 0–100 m and 300–500 m offset are too large, for filling these areas larger apertures may be used.

tations in geologically complex areas as salt plugs and various unconformities. Just as the CRS stack in general, the partial CRS stack needs properly chosen apertures in both offset and midpoint direction.

## CONCLUSION AND OUTLOOK

The presented results indicate the potential of the CRS stack method for prestack data enhancement and regularisation in 3D. The generated CRS supergather have higher S/N ratio and improved coherence of reflection events than the original data. Enhanced prestack gathers can be used in different processing schemes, e.g., velocity analysis, prestack time/depth migrations, which is a subject for further investigations.

Current implementation assumes only one reflection dip at the same time, conflicting dip situations are not considered. The program, however, can be easily extended to take conflicting dips into account, when reliable CRS parameters for every conflicting dip event are provided.

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