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A Model-based Approach to the Common-diffraction-surface Stack to Solving the Problem of Conflicting Dips - A Real Case

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SUMMARY

The Common-Reflection-Surface stack method parameterizes and stacks seismic reflection events in a generalized stacking velocity analysis. It considers a discrete number of events contributing to a given stack sample such that conflicting dip situations can be handled. The reliable detection of such situations is difficult and missed contributions to the stacked section cause artifacts in a subsequent poststack migration. As an alternative, the conflicting dip problem has been addressed by explicitly considering a virtually continuous range of dips with a simplified stacking operator in a process termed Common-Diffraction-Surface stack.

In analogy to the Common-Reflection-Surface stack, the Common-Diffraction-Surface stack has been implemented and successfully applied in a data-driven manner based on coherence analysis in the prestack data. In view of the computational costs, we present a more efficient model-based approach to the Common-Diffraction-Surface stack designed to generate stack sections optimized to image discontinuities by poststack migration. This approach only requires a smooth macro-velocity model of minor accuracy. We present our results for the real data at the north of Iran and compare them to the CRS and data-driven CDS.

Introduction

The Common-Reflection-Surface (CRS) stack method follows the concept of the classical stacking velocity analysis, the local parameterization and stacking of reflection events by means of an analytic second-order approximation of the reflection traveltime (see, e. g., Mann et al., 1999). In its simplest implementation, the CRS stack determines only one optimum stacking operator for each zero-offset (ZO) sample to be simulated. Along this operator, we obtain the maximum coherence in the seismic reflection data. However, in the presence of curved reflectors or diffractors, various events might intersect each other and/or themselves, such that a single stacking operator per ZO sample is no longer appropriate. Thus, Mann (2001) proposed to allow for a small, discrete number of stacking operators for a particular ZO sample. The main difficulty in this approach is to identify conflicting dip situations and to decide how many contributions should be considered. This implies a tricky balancing between lacking contributions and potential artifacts due to the unwanted parameterization of spurious events.
Soleimani et al. (2009) proposed an adapted CRS strategy designed to obtain a stacked section as completely as possible by merging concepts of the dip move-out correction with the CRS approach: instead of only a discrete number of dips and, thus, stacking operators per sample, a virtually continuous range of dips is considered. To simplify this process and to emphasize diffraction events, this has been implemented with a CRS operator reduced to (hypothetical) diffraction events: this Common-Diffraction- Surface (CDS) stack approach has been successfully applied to complex land data (Soleimani et al., 2010). However, the approach is quite time consuming, as separate stacking operators have to be determined for each stacked sample to be simulated and each considered dip in a data-driven manner by means of coherence analysis in the prestack data.
Here, we propose a model-based approach to the CDS stack. We assume that a smooth macro-velocity model has already been determined in which the parameters of the CDS stacking operators can be easily forward-modeled. This is far more efficient than the data-driven approach and further emphasizes diffraction events.

Traveltime approximation

The CRS method is based on an analytical approximation of the reflection traveltime up to second order in terms of the half source/receiver offset h and the displacement of the source/receiver midpoint x_m with respect to the location x_0 of the stacked trace to be simulated. For the 2D case considered in this abstract, the hyperbolic CRS traveltime approximation can be expressed as

$$t^2(x_m,h) = \left[t_0 + \frac{2sin\alpha}{v_0}(x_m - x_0)\right]^2 + \frac{2t_0cos^2\alpha}{v_0}\left[\frac{(x_m-x_0)^2}{R_N} + \frac{h^2}{R_{NIP}}\right], \qquad (1)$$

with v_0 denoting the near-surface velocity. The stacking parameter α is the emergence angle of the normal ray, whereas R_N and R_{NIP} are the local radii of hypothetical wave fronts excited by an exploding reflector experiment or an exploding point source at the (unknown) reflection point of the normal ray, the Normal-Incidence-Point (NIP). All these properties are defined at the acquisition surface (x_0; z = 0).
For a true diffractor in the subsurface, an exploding point source experiment and an exploding reflector experiment naturally coincide such that $R_{NIP} \equiv R_N$. Thus, for diffraction events, the CRS traveltime equation (1) reduces to the CDS traveltime approximation

$$t^2(x_m,h) = \left[t_0 + \frac{2sin\alpha}{v_0}(x_m - x_0)\right]^2 + \frac{2t_0cos^2\alpha}{v_0R_{CDS}}\left[(x_m - x_0)^2 + h^2\right] \qquad (2)$$

with $R_{CDS} \equiv R_{NIP} \equiv R_N$. For reflection events, the CDS operator (2) is an inferior approximation compared to the full CRS operator (1) as $R_{NIP} \neq R_N$. Nevertheless, it still allows to approximate the event within a reasonably chosen aperture (Shahsavani et al., 2011). For the data-driven CDS stack, this simplified operator has been chosen for performance reasons. For the model-based CDS stack, this simplification is mandatory, as there is no structural information on reflector curvatures contained in the considered smooth macro-velocity model. Thus, a forward modeling of the lacking parameter R_N is not possible anyway.

Forward-modeling

The radius of the NIP wave occurring in the CDS operator (2) is associated with a hypothetical point source at the NIP. The local curvature of the corresponding wavefront is considered along the normal ray. Thus, the first step is to determine the potential normal ray by means of kinematic ray tracing. As we need this ray for a given surface location and a given emergence angle, the kinematic ray tracing is performed for the down-going ray. Kinematic ray tracing consists in the calculation of the characteristics of the Eikonal equation. We have chosen the particular system for which the variable along the ray is directly the traveltime, as we have to compute ray tracing results for a regular grid in ZO traveltime. The corresponding kinematic ray tracing system, in 2D a system of four coupled ordinary differential equations of first order, can be numerically integrated with the well known Runge-Kutta scheme of fourth order.
The determination of R_{NIP} requires dynamic ray tracing along the ray path. The 2D dynamic ray tracing system consists of two coupled ordinary differential equations of first order. For a given initial condition at a point of the ray, it allows to calculate the second partial derivative of traveltime normal to the ray for any point along the ray. For a point source initial condition at a NIP on the ray, this traveltime derivative yields the searched-for stacking parameter. However, it is highly inefficient to integrate the dynamic ray tracing system upwards along the ray, as this had to be performed separately for each considered point on the ray, i. e., hundreds or thousands of times along each ray. Instead, it is far more efficient to perform the dynamic ray tracing in parallel to the kinematic ray tracing along the down-going ray twice, for two mutually orthogonal initial conditions: one corresponds to a point source, the other to a plane wave source at the emergence point of the ray. With the two orthogonal solutions along the ray, we can directly compute the solution for any arbitrary initial condition at any point of the ray, indeed also in its reverse direction. Thus, the searched-for solution for a point source at the NIP is readily available for all potential NIPs along the ray.

Real data example

To allow for a direct comparison with the data-driven CDS method, proposed by Soleimani et al. (2009) we applied the model-based and data-driven CDS approach to the real data set located at the north east of Iran. This data set consist of a total of 497 shot gathers with 70 m shot interval and up to 96 receivers with a spacing of 36 m. Temporal sampling rate is 4 ms, offsets range from 0 to 3500 m.
A sequence of Common-Reflection-Surface (CRS) stack and Normal-Incidence-Point (NIP)-wave inversion has been applied to the data to obtain the smooth macro-velocity model (not shown), see Shahsavani et al. (2012) for details.
The kinematic and dynamic ray tracing has been performed for each Common-Mid- Point (CMP) bin at a lateral spacing of 18 m and a temporal step length of 0.4ms. Rays have been shot for an angle range of ±30° at 1° spacing. For the stacking process, the stacking parameter R_{CDS} is linearly interpolated in between the rays on a grid with 0.5° spacing. The midpoint aperture has a constant half-width of 300 m centered around the approximate CRP trajectory. The offset aperture ranges are from 100 m at 0.1 s to 3400 m at 7.5 s ZO traveltime. Semblance has been calculated within a time window of 56 ms.
Figure 1 shows the final result of the CRS stack. The reflection events show up with a high signal to-noise ratio and high continuity. However, many events are truncated and only appear in fragments where they intersect more dominant events. This leads to artifacts in a subsequent poststack migration, especially faults will be poorly imaged, as the corresponding edge diffractions are largely missing in the stacked section. In the data-driven CDS stacked section in Figure 2, these conflicting dip situations are fully resolved: the interference of intersecting events is properly simulated; many new steep events show up. It is clear that due to the more complete stack, this section is better suited as input for poststack migration. The stacked section shown in Figure 3 is quite similar to the corresponding result obtained with its data-driven counterpart. The main difference is the computational cost which is now more than two orders of magnitude lower for this data set. In table 1 the computation times for data-driven and model-based CDS stack are compared.

__Table 1__ Computation time for data-driven CDS stack and model-based CDS stack

Method	Computation time (hours)
Data-driven CDS stack	**669.56**
Model-based CDS stack	**3.92**

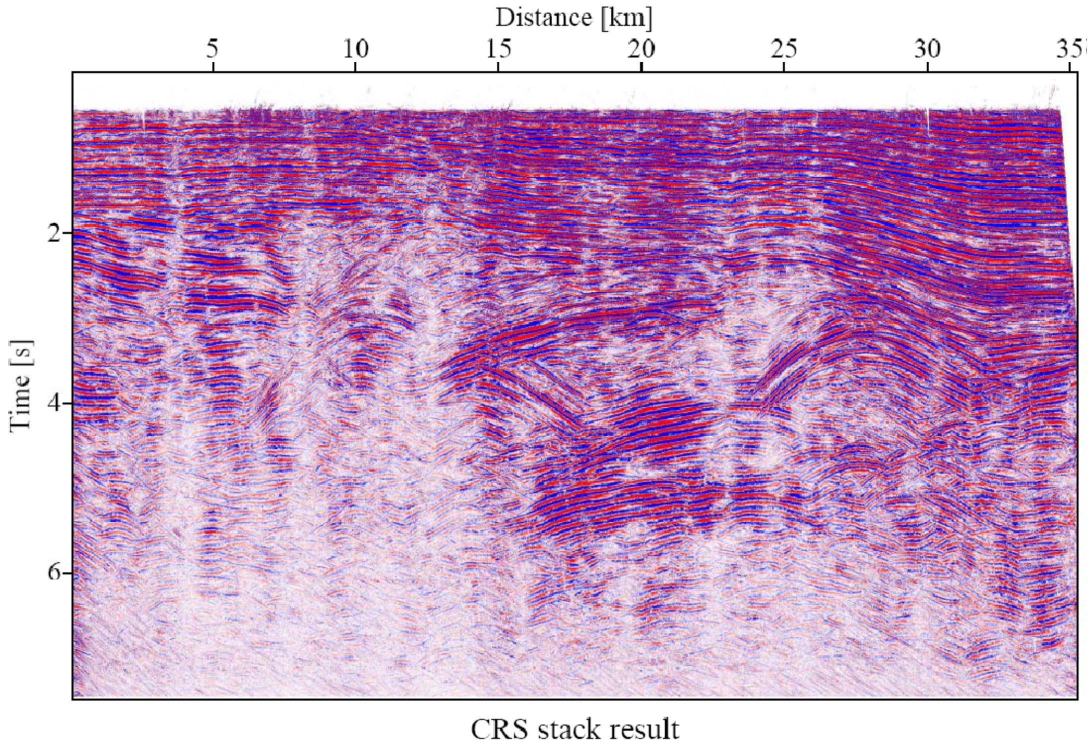

Figure 1 *Stack section obtained with the CRS approach*

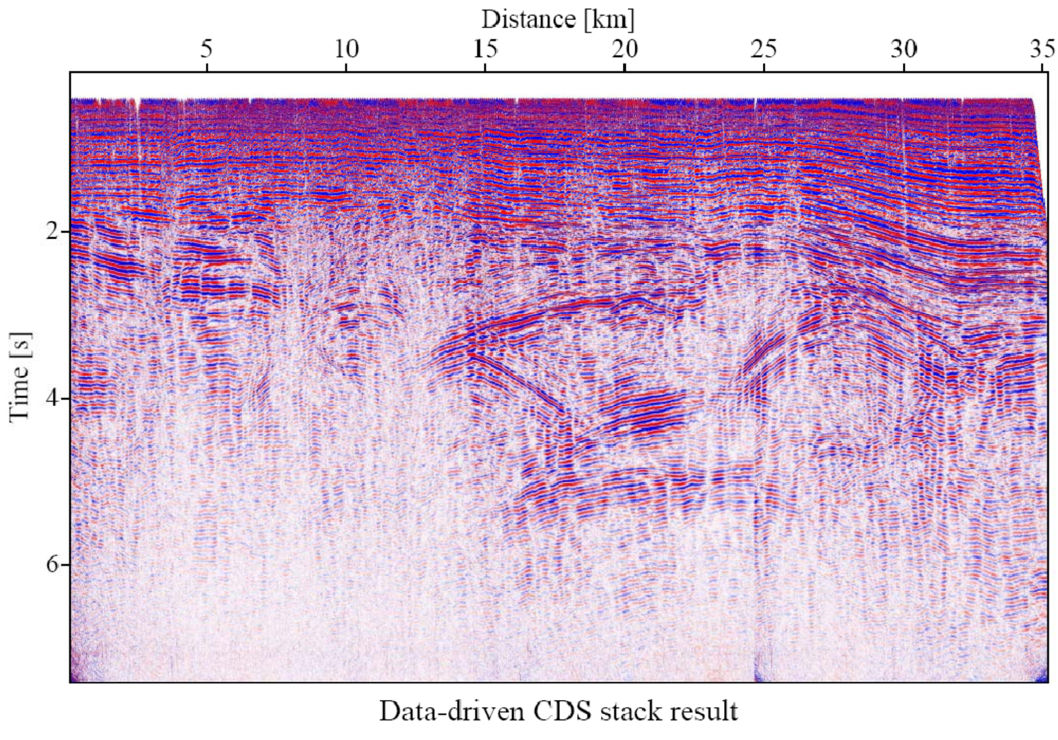

Figure 2 *Stack section obtained with the data-driven CDS stack approach*

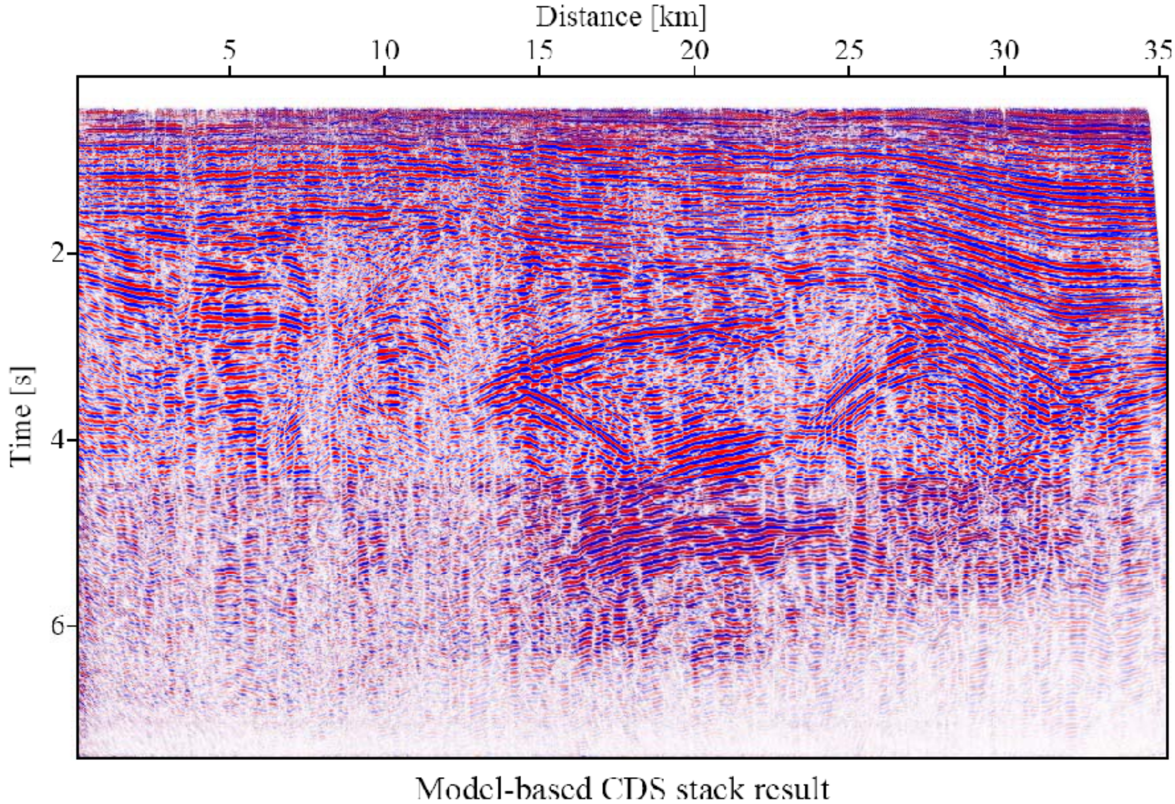

***Figure 3** Stack section obtained with the model-based approach*

Conclusions

We have implemented and applied a model-based approach to the CDS stack method. This method is intended to fully resolve the conflicting dip problem occurring in complex data and, thus, to allow to simulate a complete stacked section containing all mutually interfering reflection and/or diffraction events. The required macro-velocity model can be generated with any inversion method, including the sequential application of CRS stack and NIP-wave tomography. In contrast to the entirely data-driven CDS method, this model-based approach is far more efficient. The new approach yield even better result than the data driven approach with in a significant shorter computation time.

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