B003 Stacking velocity analysis with CRS Stack attributes

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Abstract

The Common-Reflection-Surface (CRS) Stack has been established over the past years as an alternative to standard data-driven imaging techniques. The CRS Stack not only yields high-quality stack sections from multi-coverage reflection pre-stack data but also provides—as by-product to the stacked section—important wavefield attributes. With the knowledge of the near-surface velocity only, these attributes can be extracted from the stacking parameters which constitute the Common-Reflection-Surface stacking operator. The wavefield attributes are of use for a multitude of seismic applications. These include among others the computation of the geometrical spreading factor, the determination of the projected Fresnel zone, or the inversion to obtain a velocity model. The stacking velocity can also be expressed in terms of these wavefield attributes and is determined in a reliable way with the CRS Stack.

Introduction

The CRS Stack has been introduced to simulate zero-offset (ZO) sections from 2-D seismic reflection pre-stack data (Müller et al., 1998), where sources and receivers are supposed to be located on a straight line (the seismic line) on the measurement surface. We want to refer to this approach in the following as the ZO CRS Stack. Meanwhile, there exists another 2-D CRS approach to construct any finite-offset section from pre-stack data (Zhang et al., 2001). The ZO CRS operator is derived by means of paraxial ray theory and has a three-parameter description. If the near-surface velocity in the vicinity of a coincident source/receiver location is known, the three stacking parameters determined by means of a coherency analysis directly from the data (Jäger et al., 2001) are related to important wavefield attributes. These attributes are the wavefront curvatures of two hypothetical waves at the coincident source/receiver location and their common propagation direction (emergence angle) at this point. In this way the stacking parameters obtain a "physical" meaning: as the description of the ZO CRS stacking operator is based on the assumption of curved reflector segments in the subsurface, one can deduce information about the reflectors' positions, dips, and curvatures from the wavefield attributes. Thus, the CRS stack approach implies a generalization of the well-known CMP stack and velocity analysis. Instead of only one wavefield attribute—the stacking velocity—the CRS stack provides an entire set of wavefield attributes.

In case of varying elevations along the seismic line, the parameterization of the ZO CRS stacking operator has to be corrected to obtain wavefield attributes with a well-defined geometrical meaning. Therefore, we firstly introduce the modified ZO CRS stacking operator where the parameters include the influence of a smoothly curved topography. Recently, a ZO CRS operator has been derived to extract the correct wavefield attributes even for complex topography along the seismic line.

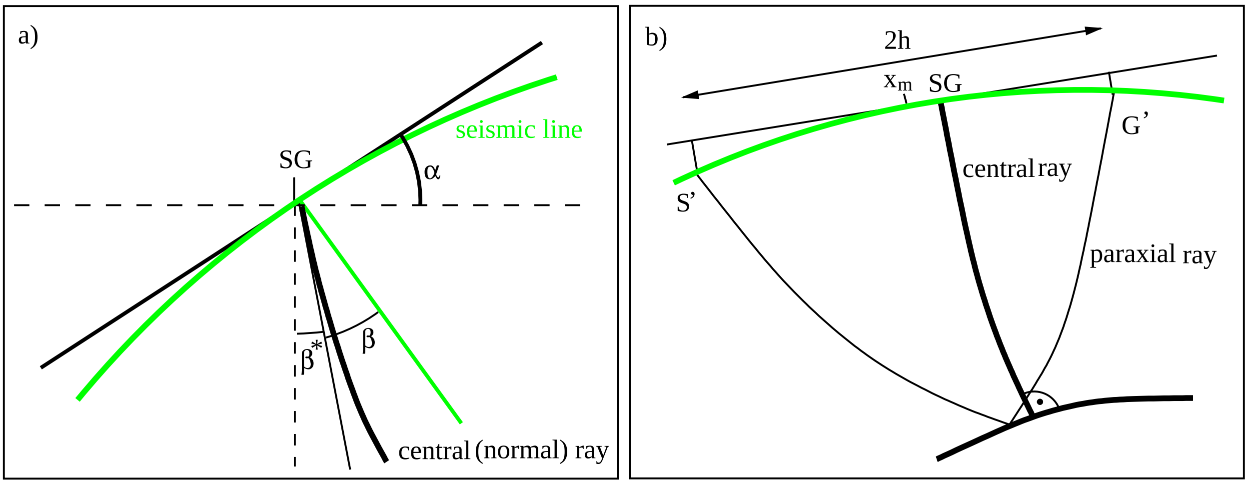

Figure 1: a): The seismic line has in the vicinity of SG the curvature K_S which is indicated by the circular arc. α is the local dip of the seismic line, β is the angle between the central ray and the normal to the seismic line at SG, and β^* is the angle between the central ray and the vertical line through SG. b): Definition of source and receiver coordinates of a paraxial ray for a curved measurement line with respect to SG.

The data-derived wavefield attributes can be related to the stacking velocity and other important seismic attributes as, for instance, the geometrical spreading factor or the projected first Fresnel zone (see, e.g., Vieth, 2001). We explain how the stacking velocities are obtained for reflection events from picked CRS attributes on a real data example.

Zero-offset CRS Stack for a curved measurement line

For the ZO case, the three stacking parameters of the CRS stacking operator for 2-D media can be related to wavefield attributes, if the near-surface velocity in the vicinity of the coincident source/receiver (in the following denoted by SG) location is available. Theses attributes are associated with the two so-called hypothetical eigenwaves which are the normal-incidence-point (NIP) wave and normal (N) wave (Hubral, 1983) propagating along the ZO (normal) ray. The wavefield attributes are given by the emergence angle β of the eigenwaves and the wavefront curvatures K_{NIP} and K_N, respectively, determined at SG. If sources and receivers are located on a curved measurement line, the influence of the topography on the data-derived attributes have to be taken into account to properly evaluate β, K_{NIP}, and K_N. If we denote the uncorrected values of the three wavefield attributes derived from the data, i.e. the values based on the assumption of a straight measurement line, by β^*, K^*_{NIP}, and K^*_N then the correct values β, K_{NIP}, and K_N are given by the following relations:

$$\beta^* = \beta - \alpha \, , \tag{1}$$

$$K^*_{NIP} \cos^2\beta^* = K_{NIP} \cos^2\beta - K_S \cos\beta \, , \tag{2}$$

$$K^*_N \cos^2\beta^* = K_N \cos^2\beta - K_S \cos\beta \, , \tag{3}$$

where α denotes the dip and K_S the local curvature of the seismic line at SG (see Figure 1a). Both parameters are assumed to be known. Please note, K_S is positive if the curved measurement line falls below its tangent at the SG. Substituting these relations in the ZO CRS stacking operator (as given, e.g., by Mann et al., 1999) yields

$$t^2 = \left(t_0 + 2\,\frac{\sin\beta}{v}\,x_m\right)^2 + \frac{2\,t_0}{v_0}\left(K_N \cos^2\beta - K_S\cos\beta\right)x_m^2 + \frac{2\,t_0}{v_0}\left(K_{NIP}\cos^2\beta - K_S\cos\beta\right)h^2 \, , \tag{4}$$

where t_0 is the ZO traveltime along the central ray and v denotes the near-surface velocity at SG. The offset $2h$ and midpoint x_m refer to the projections of all shot-receiver pairs in direction of the surface normal at SG onto the tangent at this point (see Figure 1b).

High-resolution stacking velocity

The ZO CRS approach uses a traveltime formula like equation (4) as stacking operator. This formula defines a surface in the multi-coverage pre-stack volume. By variation of the parameters the operator is fit to the reflection event in the vicinity of a ZO sample. An accompanying coherence analysis determines the parameters that yield the best fit operator. To simulate the amplitude at the ZO sample, the amplitudes along the operator are summed up and assigned to respective ZO sample. The result of this procedure is that the ZO sample carries the following information: a stack value (summed amplitude), the parameter values, and a coherency value. Of course, the location of actual reflection events in the ZO section is unknown. Therefore, the procedure described above is applied to a grid of ZO samples. This yields a simulated ZO section, a coherence section, and the CRS attribute sections. By means of the CRS attributes one can easily derive a stacking velocity section. In case of a smoothly varying measurement surface, the stacking velocity is expressed by

$$v_{stack}^2 = \frac{2\,v_0}{t_0\,\left(K_{NIP}\cos^2\beta - K_S\cos\beta\right)}\,. \tag{5}$$

In addition, sections for the geometrical spreading factor and the projected first Fresnel zone can be calculated with the determined attributes.

To identify actual reflection events, one can consider the coherence and stack sections as well as the in general met continuity of the parameters along these events. As much more traces are used during the coherency analysis and for the stack compared to, e.g., the NMO/DMO/stack, the CRS attributes are much more stable and reliable than the stacking velocity obtained from conventional velocity analysis. The picking, for instance, of the stacking velocity in the section is simplified with the help of the high-quality coherency section which helps to identify reflection events. Note that every ZO sample carries a stacking velocity value which leads to a high horizontal and vertical resolution of the stacking velocity section. In Figure 2, we show an example of picked stacking velocities associated with a reflection event in the simulated ZO section obtained by the ZO CRS Stack.

Conclusions

We have introduced a new analytic moveout formula for a curved measurement surface which may find application in a variety of seismic problems. Furthermore, we presented how the CRS Stack can be used for velocity analysis. The stacking velocity can be calculated via CRS attributes obtained as a ”by-product” to the simulated ZO section. The picking of stacking velocities is guided by a high-quality coherency section which improves the reliability of the picking procedure.

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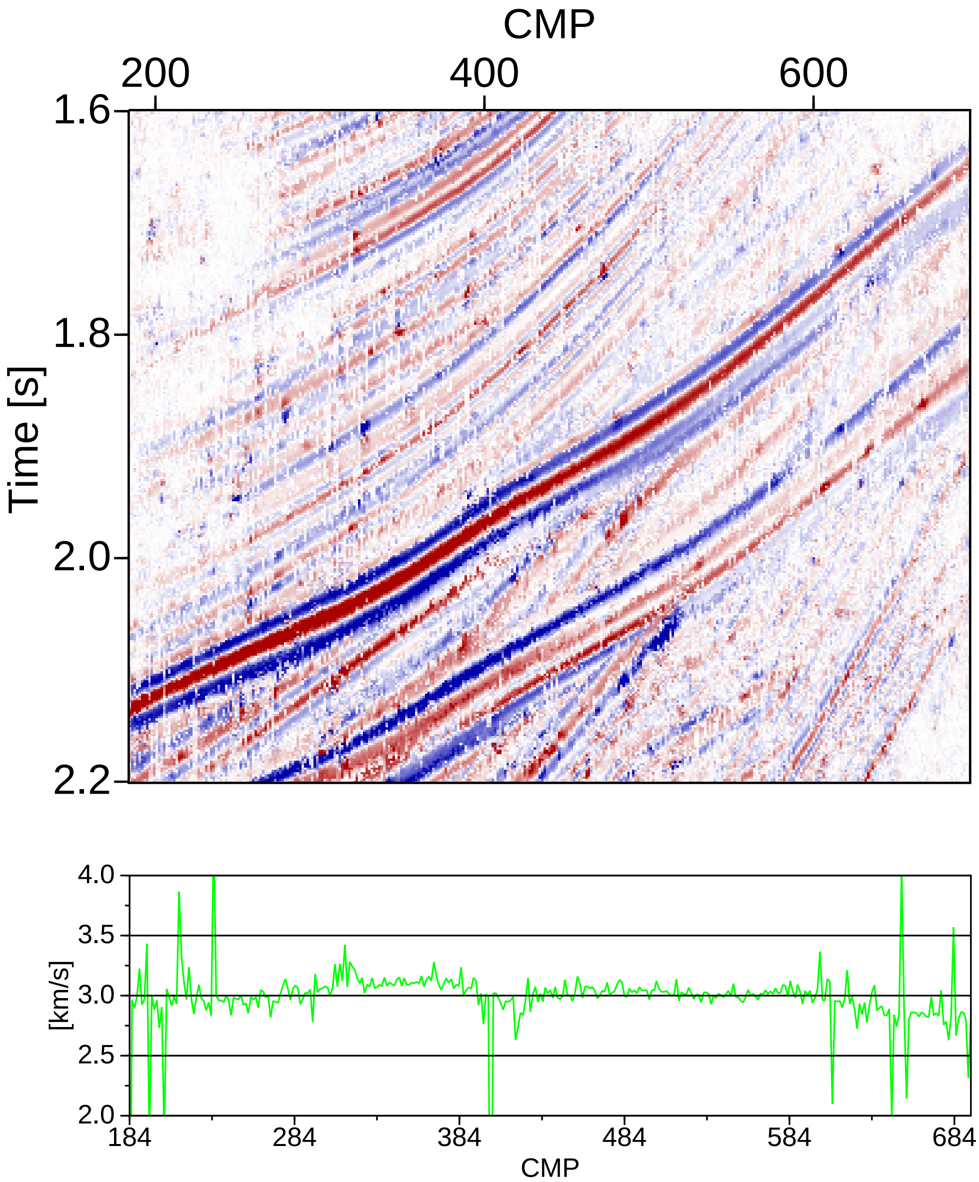

Figure 2: Upper part: subset of CRS stacked ZO section. Lower part: stacking velocities along the strong event crossing the ZO section shown in the upper part.

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