A simplified 2D common reflection surface stack

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Summary

While multidimensional zero-offset stacking, namely common-reflection-surface (CRS) stack, offers seismic stack with high signal to noise ratio, the procedure based on local coherence analyses along many trial surfaces can be tedious, time-consuming, and expensive. In this abstract, we derive a simplified CRS (SCRS) formula as a first order approximation to the original multi-parameter approximation of the travel time; and reduce the number of parameters to be estimated from three to two. Out of these two parameters, we extract the local slope of velocity structure by using a model-based technique, and estimate the remaining parameter, CRS stacking velocity, by scanning for the best fit. This way, the procedure becomes a one parameter optimization process whose cost is comparable to that of the conventional velocity analysis.

Introduction

The CRS stack forms CRS super gathers by incorporating neighboring common-mid-point (CMP) gathers and uses all pre-stack multi-coverage reflection data information in the first Fresnel zone. Consequently, by summing up more coherent energy from the data, CRS stack method generates simulated zero-offset section with higher signal-to-noise ratio (Mann et al. 1999). Figure 1, shows a comparison of the stacking areas of conventional CMP stack (thick green line) and CRS stack operator (green area).

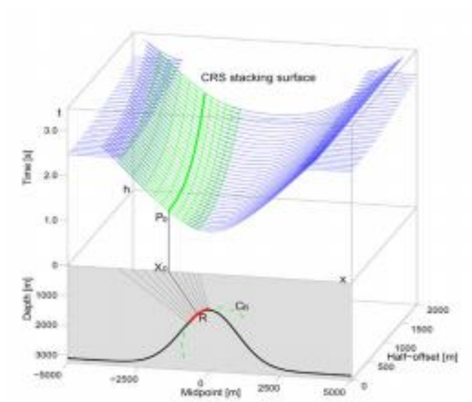


Figure 1. The CRS stacking gather (green area) comparing to CMP stacking gather (the thick green line) (after Muller, 1999).

The common reflection surface travel time formula in inhomogeneous media can be derived by means of normal (N) wave and normal incident point (NIP) wave, and the 2D CRS stacking operator can be expressed by three wave field attributes which can be obtained by computing the Taylor series expansion of the squared travel time formula and retaining only the terms up to the second-order (Heilmann, 2007):

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

where h is the half-offset; $x_m - x_0$ is the midpoint displacement with respect to the considered CMP position x_m and the zero-offset ray at surface position x_0; t_0 corresponds to the zero-offset two-way travel time; α is the emergence angle of the zero-offset ray, R_N is the radius of curvature of the normal wave; R_{NIP} is the radius of the normal incidence point wave; and v_0 is the near-surface velocity. Figure 2 shows that (a) if the NIP wave front at the observation point x_0 propagates downwards, it will focus at point NIP and then propagate back to the surface, such that the arriving wave front at the observation point x_0 coincides with the initial wave front; (b) if the Normal wave at the observation point x_0 propagates downwards, it will hit the second reflector simultaneously in all points within Fresnel zone and then bounces back to the surface with the same wave front (e.g. Mann et. al. 1999).

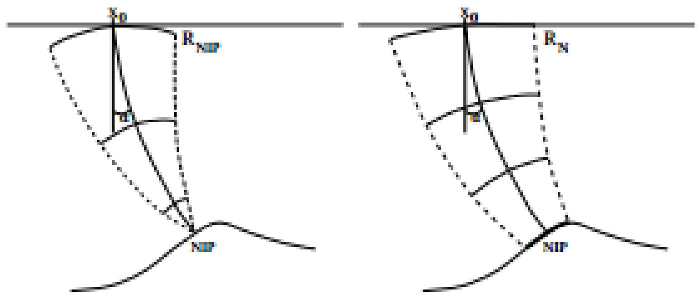


Figure 2: Illustration showing the propagating of (a) NIP wave and (b) Normal wave.

The stack based on equation (1) is an optimization problem that involves three parameters α, R_N and R_{NIP}. Although there exist multi-parameters optimization techniques, they are very time consuming due to local coherence analyses along many trial surfaces and how to speed up this process is an undergoing research project (e.g. Waldeland et. al., 2018). In this paper, we present a simplified CRS method by modifying the original formula by a first order approximation. With combination of velocity structure from picked velocity, the processing of CRS stack becomes a one parameter optimization problem and the computational cost of processing becomes comparable to that for the conventional velocity analysis.

Method description

Equation (1) is applied to the multiple CMP gathers and it should also be applicable to a single CMP gather. Let $x_m - x_0 = 0$, and for a flat reflector, this equation becomes

$$t^2(h) = t_0^2 + \frac{2t_0 h^2 cos^2\alpha}{v_0 R_{NIP}} \quad (2)$$

Because in this case, equation (1) should be equal to conventional NMO equation and therefore,

$$\frac{2t_0 cos^2\alpha}{v_0 R_{NIP}} = \frac{4}{V_{NMO}^2} \quad (3)$$

Substituting equation (3) into equation (1) yields

$$t^2(x_m, h) = \left[t_0 + \frac{2\sin(\alpha)(x_m - x_0)}{v_0}\right]^2 + \frac{4h^2}{V_{NMO}^2} + \frac{2t_0 cos^2\alpha}{v_0}\frac{(x_m - x_0)^2}{R_N} \quad (4)$$

Considering a small reflection element that can be approximated by a small reflection line with small local curvature, then R_N should be very large and we may drop the last term to have

$$t^2(x_m, h) = \left[t_0 + \frac{2\sin(\alpha)(x_m - x_0)}{v_0}\right]^2 + \frac{4h^2}{V_{crs}^2} \quad (5)$$

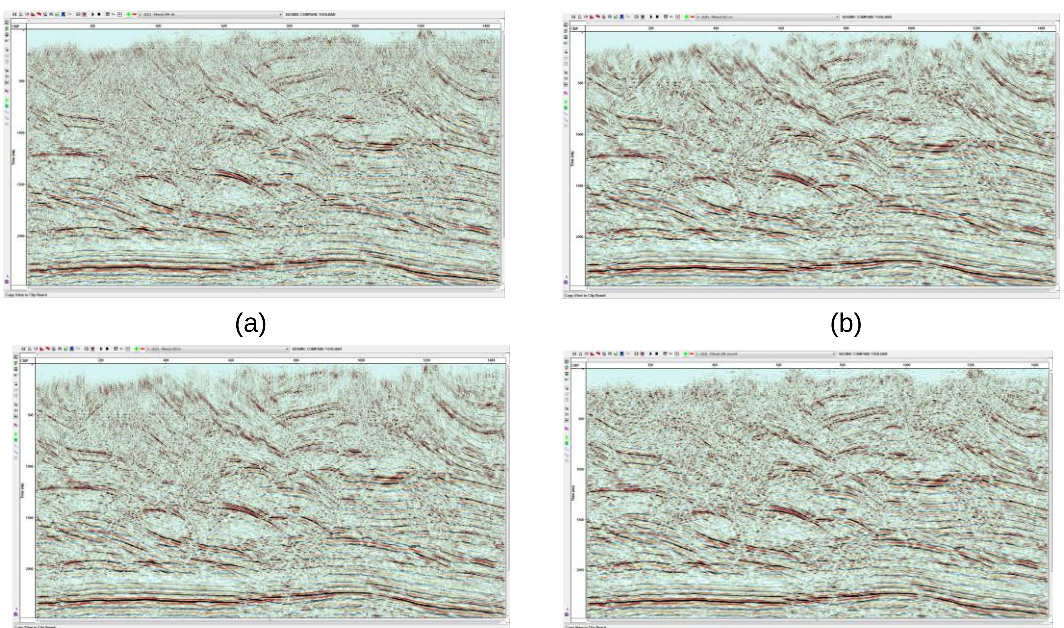
In equation (5), v_{crs} replaces, v_{NMO} to partially compensate for dropping last term; and the term $\sin(\alpha)/v_0$ corresponds to the ray parameter that can be estimated by using a model-based angle search on the input CMP stacked data. The v_{crs} search is a semblance based search that is the same as NMO velocity search. The original CRS requires all parameters to be defined at each time sample. To speed up the process, we propose to search the parameters α and v_{crs} only at velocity control points and then interpolate for the other samples.

The summary of simplified CRS processing is as follows: first, use the input velocity model that is obtained via NMO velocity analysis to define control points. Then, find the optimal angles at the control points and search for optimal v_{crs} that gives the maximum coherence at the control points. Finally, interpolate the angles α and velocities v_{crs} at all time samples. The quality of the results will depend significantly on the consistency, density and quality of the initial NMO velocity picking.

Example

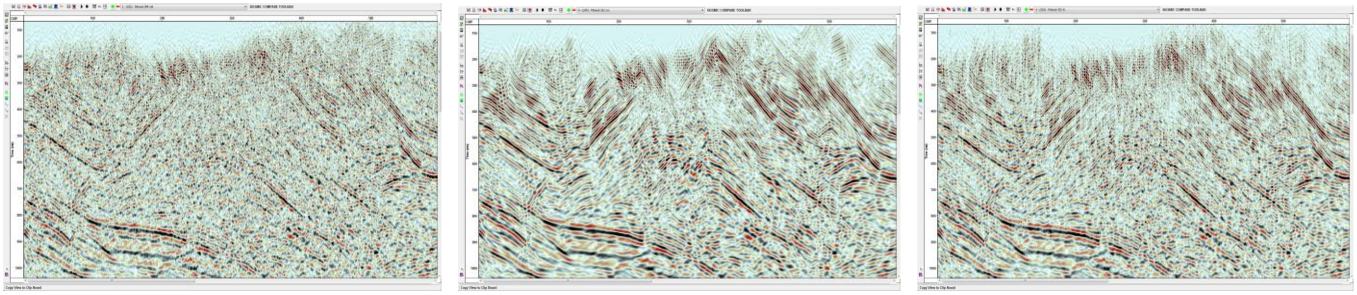
Figure 3 shows the results of SCRS and CMP stacking of a 2D data set. To have a fair comparison, the same frequency band pass filter is applied to both data sets. In the figure 3, (a) is the CMP stack; (b) is the SCRS stack, (c) is the CMP stack with f-x denoise, and (d) is the result of applying five trace moving average to the CMP stack. The denoise techniques were applied on CMP stack to get a fair comparison. Compared to CMP with f-x denoise, the signal in SCRS is smoother and more continuous. CMP stack with five trace moving average appears laterally smeared, especially in the shallow part of the section.

Figure 4 and Figure 5 show close-up views of the upper left and upper right parts of the original image for the input, SCRS and f-x denoised results.



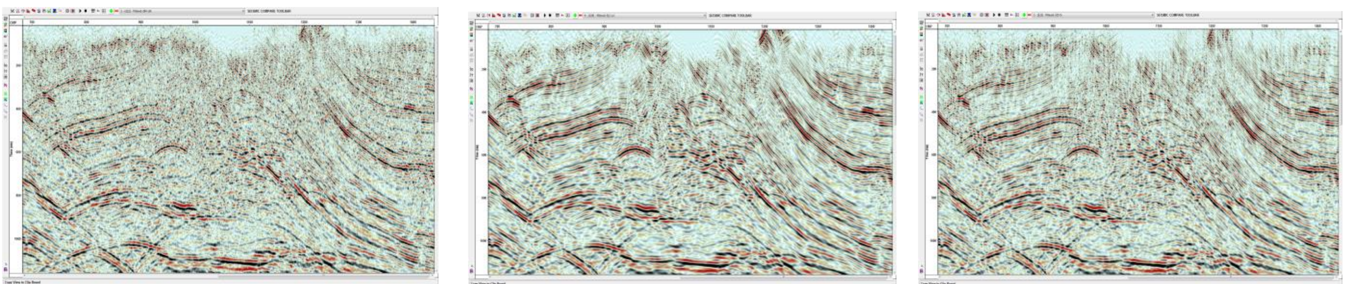
(a) (b) (c) (d)

Figure 3. (a) The CMP stack, (b) the SCRS stack, (c) the CMP stack with f-x denoise, and (d) the CMP stack with five trace moving average.



(a) (b) (c)

Figure 4. The upper left part of the plots in Figure 3 for (a) the CMP stack, (b) the SCRS stack, and (c) the CMP stack with f-x denoise.



(a) (b) (c)

Figure 5. The upper right part of the plots in Figure 3 for (a) the CMP stack, (b) the SCRS stack, and (c) the CMP stack with f-x denoise.

Discussions and conclusions

We presented a simplified CRS method that may produce zero offset stack with relatively higher signal to noise ratio for a moderate geological structure at a cost comparable to that of conventional CMP stacking as a result of significant cost reduction for the search parameters. The SCRS formula is a first order approximation of the original CRS travel time approximation for subsurface that consist of moderate sized geological structure. Searching parameters used for SCRS at picked velocity control points may not only speed up the process but also make the processing stable due to relatively strong energy in the data at these points. The method relies on the quality of the original NMO velocity picking, a procedure that is routinely used in the seismic data processing, which can assure the quality of the generated SCRS stack.

Acknowledgements

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