Conventional imaging methods cause an offset-dependent stretch of the seismic wavelet, even with a correct velocity model and kinematically exact stacking or migration approaches. This stretch occurs either in the time domain during stacking or in the depth domain during pre-stack depth migration and deteriorates the resulting images. In contrast, data-driven imaging methods like Multifocusing or Common-Reflection-Surface stack do not suffer from such pulse stretch phenomena. Thus, the image quality is improved and areas with high offset/traveltime ratio in the pre-stack data no longer need to be muted to the usual extent. We discuss the origin of the pulse stretch phenomenon and the behavior of the stacking parameters in data-driven imaging methods in order to avoid the stretch.

Summary

Conventional imaging methods cause an offset-dependent stretch of the seismic wavelet, even with a correct velocity model and kinematically exact stacking or migration approaches. This stretch occurs either in the time domain during stacking or in the depth domain during pre-stack depth migration and deteriorates the resulting images. In contrast, data-driven imaging methods like Multifocusing or Common-Reflection-Surface stack do not suffer from such pulse stretch phenomena. Thus, the image quality is improved and areas with high offset/traveltime ratio in the pre-stack data no longer need to be muted to the usual extent. We discuss the origin of the pulse stretch phenomenon and the behavior of the stacking parameters in data-driven imaging methods in order to avoid the stretch.
Pulse stretch effects in the context of data-driven imaging methods

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Moveout-corrected CMP gathers

Below, the moveout-corrected CMP gathers are shown for the different functions of the stacking velocity. To emphasize the details, only the first reflection event is displayed. Obviously, the usual situation, increasing stacking velocity with increasing time (Figure 4), leads to the largest pulse stretch and would already require muting to preserve the wavelet. In case of a constant stacking velocity (Figure 5), the pulse stretch is less severe. However, it will still be significant for large offset to traveltime ratios. In contrast, the NMO correction with the stacking velocity approximation \( v \) constant ZO curvature (Figure 6) preserves the wavelet almost perfectly. The small expected compression of the wavelet can hardly be observed. The result for the velocity providing the best kinematic fit (corresponding to the red line in Figure 3d) looks just the same and is, thus, not displayed. Finally, the NMO correction was performed with the stacking velocities determined by the CRS stack (Figure 7). As expected, no pulse stretch can be observed and the result almost coincides with Figure 6.

Behavior of the kinematic wavefield attributes

In the following, we will reformulate the preceding sections in terms of the kinematic wavefield attributes of the CRS stack approach. Expressed in terms of midpoint coordinate \( x_p \) and half-offset \( h \), the second-order traveltime approximation reads

\[
\tau (x_p, h) \approx \tau_0 + \frac{2}{R_0} \sin \left( \frac{x_p}{R_0} \right) + \frac{R_0}{v_c} \left( x_p^2 + R_0^2 - 2 R_0 x_p \cos \frac{x_p}{R_0} \right) + \frac{R_0^2}{v_c^2} \left( x_p^2 + R_0^2 - 2 R_0 x_p \cos \frac{x_p}{R_0} \right)
\]

where \( v_c \) represents the near-surface velocity and \((x_p, \tau_0)\) is the considered ZO location. The CRS operator is parameterized by three kinematic wavefield attributes defined at the surface location \( x_p \), namely \( \alpha \), the emergence angle of the ray normal to the NIP (normal-incidence-point) wavefront, and \( R_0 \), the radius of the normal wavefront. These attributes are related to the local properties of a reflector segment in depth, namely its location, dip, and curvature, by means of two so-called eigenwave experiments (see, e.g., Jäger et al., 2001): in a first experiment, a point source is placed at the NIP and leads to the NIP wavefront that emerges at \( x_p \) with the radius of curvature \( R_{NIP} \). The second experiment is an exploding reflector experiment, the corresponding normal wavefront emerges with a radius of curvature \( R_{NIP} \). The common propagation direction of both wavefronts is given by \( \alpha \).

For the simple 1-D model considered above, all rays are vertical, and all normal wavefronts are plane, i.e., \( \alpha = 0 \) and \( R_{NIP} = \infty \) for all three events. Accordingly, the CRS operator reduces to

\[
\tau (x_p, h) = \tau_0 + \frac{2}{R_0} \sin \left( \frac{x_p}{R_0} \right) + \frac{R_0^2}{v_c^2} \left( x_p^2 + R_0^2 - 2 R_0 x_p \cos \frac{x_p}{R_0} \right)
\]

for any midpoint location \( x_p \). For the center of the wavelet, this represents the exact kinematic reflection responses of the three reflectors with \( R_{NIP} = \infty \), respectively. This is an alternative formulation of the CMP moveout formula (1). Reformulating Equation (4) in terms of \( R_{NIP} \) we readily observe that \( R_{NIP} \) remains constant along the wavelet, i.e., \( R_{NIP}(x_p) = R_{NIP}(x_p - \Delta x) \forall \Delta x \). Obviously, this is equivalent to the assumption of constant ZO curvature. Indeed, the NIP wavefront radius is preserved by means of the CRS (Figure 8) is almost constant for each event. Thus, this radius appears to be a more natural parameter for the traveltime curves.

Conclusions

We briefly reviewed the origin of the offset-dependent pulse stretch in conventional time domain processing with constant or smooth stacking velocity models. A stretch-free imaging with optimally recovered wavelet is not possible with such models, as the band-limited nature of data is ignored. We discussed an approximation of the stacking velocity variation along the wavelet that is well suited for the simulation of undistorted ZO sections. In contrast to the usually applied smooth stacking velocity models, the approach predicts a systematic velocity decrease with increasing traveltime along the wavelet. Thus, the limited bandwidth of the data is explicitly taken into account and wavelet distortions due to pulse stretch are avoided.

A comparison with CRS stack results for a 1-D model demonstrated that data-driven imaging methods automatically avoid the pulse stretch and introduce a systematic variation of the stacking velocity very similar to the predicted behavior. In other words, data-driven imaging methods performing generalized velocity analysis at every ZO location to be simulated implicitly consider the band-limited nature of seismic reflection data. Subsequent processes directly benefit from the input without pulse stretch.

Reformulated in terms of the kinematic CRS wavefield attributes, the variation of the stacking parameters along the wavelet vanishes. Thus, the radii of wavefront curvatures involved in the CRS stack approach provide a more appropriate parameterization of the reflection events. This is an important fact for applications that are based on picked traveltimes and CRS attributes, e.g., inversion (generalized Dix-type or tomographic, see related presentations below); samples picked out of phase do not lead to wrong attributes.

References


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Related presentations

P004 An integrated data-driven approach to seismic reflection imaging, Hertweck et al.
D17 CRS imaging of 3-D seismic data from the active continental margin offshore Costa Rica, Trappe et al.
D16 Residual static correction by means of kinematic wavefield attributes, Kooplin and Zwip
D27 Determination of velocity models from data-derived wavefront attributes, Duveneck
D31 3-D macro-velocity inversion by means of kinematic wavefield attributes, Höcht et al.