WS11-A01

Auxiliary Media - A Generalized View on Stacking

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SUMMARY

Stacking still plays a fundamental role in seismic data processing. While the summation helps to decrease data redundancy and leads to a first interpretable time image with a high signal-to-noise ratio, the estimated stacking parameters form the foundation of many important subsequent processing steps, including depth imaging. Current multi-parameter stacking techniques aim to include higher order terms in the traveltime moveout surface. Without increasing the number of parameters, this goal is commonly achieved by assuming a certain reflector geometry and straight raypaths. In the presence of heterogeneity, as a consequence, moveout is described in an auxiliary medium. Although modern methods are usually based on the same set of parameters, we show that they can be divided into two types of approximations, one assuming an effective medium, the other describing the optical analogue in a medium of constant near-surface velocity. Based on ideas of de Bazelaire and Höcht, we provide a simple but general recipe to transform operators from the effective to the optical medium. As an example, we investigate the optical representation of a nonhyperbolic effective medium operator currently in use. In addition, we clarify the unique role of the multifocusing method and point out distinct advantages of both approaches.

Introduction

Extending ideas of de Bazelaire (1988), the common reflection surface (CRS) stack takes neighboring CMP gathers into account. It is based on three surface-related kinematic wavefield attributes, which are closely linked to first- and second-order derivatives of the traveltime near the reference ray. In addition to the well-known parabolic and hyperbolic formulae (e.g. Jäger et al., 2001), several higher-order approximations exist, which all depend on the very same set of parameters.

In this work, we argue that without increasing the number of parameters, all non-parabolic approximations are based on the concept of straight rays, and consequently describe moveout in an auxiliary medium of constant velocity. Depending on the incorporation of parameters, the actual subsurface model is either replaced by a medium with effective properties or the method describes traveltime differences for the optical analogue in a medium of constant near-surface velocity. Based on suggestions by de Bazelaire (1988) and Höcht et al. (1999), we establish a connection between both domains and provide a general recipe with which all effective medium operators can be transformed to their surface-based optical representations. Following this recipe, we introduce a transformed version of the implicit CRS (i-CRS) approach by Schwarz et al. (2012), which, like the hyperbolic CRS operator, is based on an effective medium. The multifocusing method (MF, Gelchinsky et al., 1999) in contrast, being closely related to de Bazelaire's shifted hyperbola, has properties of an optical approach, confirmed by the fact that both, multifocusing and the transformed i-CRS operator, turn out to perform equivalently for synthetic examples.

CRS attributes and geometrical optics

In the classical CMP stack, the summation operator is a hyperbolic expression, which is only exact for a planar reflector and a constant velocity overburden. For the inhomogeneous case, the actual model is replaced by an effective medium with constant velocity v_{NMO} (see, e.g., Jäger et al., 2001). De Bazelaire (1988) suggested an alternative strategy to account for heterogeneity by utilizing simple concepts of geometrical optics. In his approach, not the velocity changes, but the center of coordinates. Since this corresponds to the application of a shift in time rather than in velocity, de Bazelaire's shifted hyperbola, which depends only on the velocity near the surface, can be considered a macro-model independent time imaging method. De Bazelaire's shifted reference t_p is the zero-offset time in the optical image space of constant near-surface velocity v_0. It can be formulated in terms of the radius of curvature R_{NIP} of the fundamental NIP wavefront, which leads to an appealing geometrical interpretation (Höcht et al., 1999). Due to coefficient comparisons, so-called osculating equations can be gained. These connect the effective to the surface-based attributes. Inspired by the work of Höcht et al. (1999), we suggest the following recipe to transform effective-medium-based traveltime operators to the optical image space:

$$t_{shift} = t_{eff}(t_0 = t_p) + t_0 - t_p \quad , \tag{1}$$

where t_0 is the zero-offset traveltime and $t_p = 2R_{NIP}/v_0$. We have applied this strategy to the recently introduced implicit CRS (Schwarz et al., 2012), which is a nonhyperbolic effective medium operator. As a result we get a shifted double-square-root expression, which behaves just like multifocusing, as will be shown in the following section.

Synthetic examples

Our synthetic examples consider the diffraction case in a constant vertical velocity gradient medium $v =$ 2000 m/s$+\gamma z$, with γ ranging from 0 for the homogeneous case to 1.5 s^{-1}, representing strong vertical inhomogeneity. Figure 1 shows the achieved semblance values of multifocusing and both, conventional i-CRS and its optical representation as a function of the distance from the apex and the strength of the gradient. Multifocusing (Figure 1(c)) provides a good description for moderate and small gradients. However, it shows a rapidly decreasing performance for stronger gradients and larger distances to the apex. The conventional i-CRS operator, in turn, despite being parameterized with the same attributes

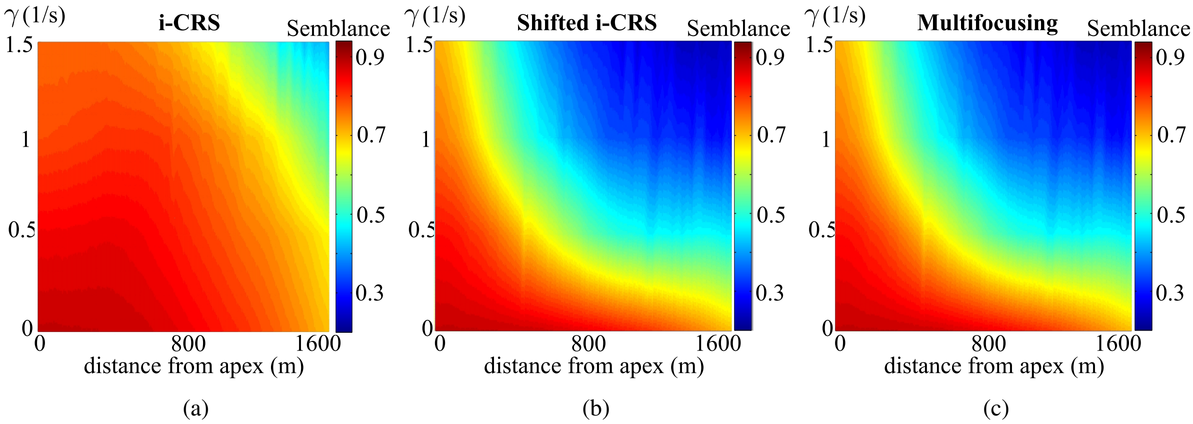

Figure 1 *Semblance distributions for i-CRS (a), the shifted i-CRS expression (b), and multifocusing (c) as a function of lateral distance to the diffractor and the vertical gradient strength* γ*.*

and having the same double-square-root shape, turns out to be less affected by heterogeneity. The shifted version of the i-CRS approximation reveals exactly the same semblance distribution as multifocusing, indicating that time-shift-based parameterizations are less suited to account for inhomogeneity than their effective medium counterparts (compare Figure 1(a) and 1(b)).

Conclusions

We found that current multiparameter stacking techniques can be divided into two groups of approximations, one assuming an effective medium, the other dealing with projections in the optical image space. While the hyperbolic CRS operator is closely related to the NMO hyperbola, which substitutes the actual subsurface model by a medium of a constant effective velocity, the multifocusing method reveals a strong link to the shifted hyperbola by de Bazelaire, which is an optical approach. The implicit CRS, like hyperbolic CRS, is an effective medium operator. Based on ideas of de Bazelaire and Höcht et al., we have presented a general recipe that allows for a simple transformation from the effective medium to optical image space. Synthetic examples reveal that the effective-medium-based conventional i-CRS operator is only mildly affected by overburden heterogeneity, whereas the shifted counterpart shows considerably decreased quality for higher gradients. Multifocusing, being a native optical image space approach, shows the exact same behavior for the considered gradient examples.

Acknowledgements

We thank the Applied Seismics Group Hamburg for continuous discussions. This work was partly supported by the sponsors of the Wave Inversion Technology (WIT) Consortium and the project 'Imaging steep structures with diffractions' (BMU 0325363C).

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