Factors affecting spatial resolution

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In the literature true-amplitude prestack migration formulas have been derived for *single-fold* 3-D datasets with two spatial coordinates ξ_1 and ξ_2, and traveltime t or frequency f as the third coordinate. ξ_1 and ξ_2 describe the shot/receiver configuration, e.g. $\mathbf{x_s} = (X, Y, 0)$ and $\mathbf{x_r} = (\xi_1, \xi_2, 0)$ describe a 3-D common shot gather, and $\mathbf{x_s} = (\xi_1, Y, 0)$ and $\mathbf{x_r} = (X, \xi_2, 0)$ describe a cross-spread.

Beylkin et al. (1985) describe a change of variables from (f, ξ_1, ξ_2) to (k_x, k_y, k_z) as follows:

$$\mathbf{k} = f\,\nabla_x \phi(\mathbf{x}, \xi), \qquad (1)$$

in which $\mathbf{k} = (k_x, k_y, k_z)$ is the wavenumber vector in the migration domain, whereas $\phi(\mathbf{x}, \xi)$ is the traveltime surface of a diffractor $\mathbf{x} = (x, y, z)$ in the subsurface associated with shot/receiver pairs described by ξ. $\nabla_x \phi(\mathbf{x}, \xi)$ represents the derivative of $\phi(\mathbf{x}, \xi)$ with respect to the output point $\mathbf{x}$.

Eq. 1 determines the region of coverage D_x in the spatial wavenumber domain (the 3D spatial bandwidth obtained by migration). Beylkin et al. (1985) state: "*the description of D_x is, in fact, the estimate of spatial resolution*." The larger the region of coverage in $\mathbf{k}$, the better the *potential* resolution.

If D_x is well covered by the seismic data set, the maximum wavenumbers that follow from Eq. 1 are a good measure of resolution and $R = 1/2k_{max}$ may be used as a measure of the minimum resolvable distance. For a 2D common-offset section in a medium with constant velocity v, it follows that

$$R_x = \frac{v}{4 f_{max} \sin\theta \cos i}, \qquad (2)$$

where θ is the maximum illuminated dip angle, and i is the angle of incidence to that dip angle. It follows that the best resolution occurs for zero-offset ($i = 0$).

Resolution can also be analysed by migrating the traveltime surface of a single diffractor in $(0, 0, z)$ in a constant-velocity medium, followed by measurement of the width of the resulting spatial wavelet. Fig. 1 displays the result of such an exercise applied to various 2D common-offset gathers with varying line lengths.

More interesting is to investigate the behavior of the spatial wavelet for 3D input data. Fig. 2 allows a comparison of the potential resolution of the basic subsets of common 3D geometries. The spatial wavelets are shown for the zero-offset gather, some common offset gathers, the cross-spread, and the 3D common-shot gather, all for the *same square common midpoint area* of 1000 x 1000 m, with the diffractor in the center of that area at 500 m depth. For ease of comparison, the wavelets are not shown in an areal sense, only the wavelets for the x-coordinate are shown.

The best potential resolution is obtained for the zero-offset gather, whereas the common-shot gather produces the worst result.

Reference

Beylkin, G., Oristaglio, M., and Miller, D., 1985, Spatial resolution of migration algorithms: *in* Berkhout, A.J., Ridder, J., and van der Waals, L.F., Eds., Proceedings of the 14th Internat. Symp. on Acoust. Imag., 155-167.

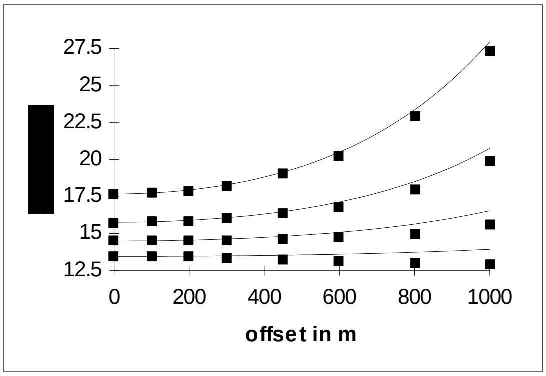

Fig. 1. Widths of spatial wavelets as a function of offset for line lengths 1000 (top), 1300, 1700 and 2500 m. The drawn curves correspond to Eq. 2, calibrated at zero offset.

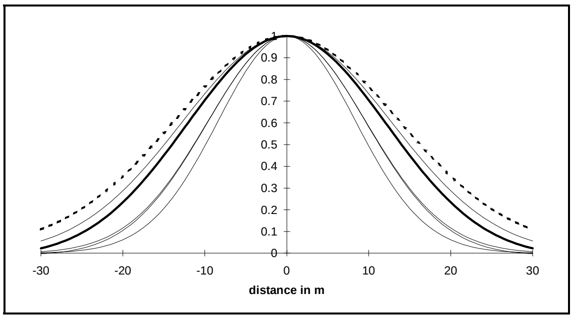

Fig. 2 Spatial wavelets for various single-fold 3D data sets. Drawn thin curves are for common-offset gathers, with the narrowest wavelet for zero offset, the next two (nearly coinciding) for 600 m inline and 1000 m crossline common-offset gathers, and the widest for 1000 m inline. The heavy curve represents a cross-spread, and the dotted curve a 3D common-shot gather.