Multicomponent internal multiple prediction analysis with elastic Stolt-migration, time-stretching, best-fitting

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Abstract

Identifying lower-higher-lower relationship is essential to inverse scattering series internal multiple prediction, which is more difficult for multicomponent predictions due to the wave-mode conversion of P- and S-waves. The elastic inverse scattering series algorithm delineated the scheme of constructing the satisfied combinations to predict the multicomponent internal multiples. However, it requires the appropriate inputs, for both P- and S-components, that all sub-events sorted into related pseudo-depths which is a monotonic function of the actual depth. The inappropriate inputs may misunderstand the wave-model conversion and disorder the lower-higher-lower relationship of sub-events. Unfortunately, the monotonic condition is broken between the pseudo-depth in an elastic-isotropic-homogeneous background and actual depth because the wave-mode conversion is only handled at the surface layer. In this paper, we propose several methods to search the best approximation of the exact solution.

1.5D formulation in variant domains

Multicomponent prediction algorithm in (k,z) domain:

$$b_3^{ij}(k_g,\omega) = -\int_{-\infty}^{+\infty} \mathrm{d}z_1 e^{\mathrm{i}(\nu^m+\nu^i)z_1} b_1^{im}(k_g,z_1) \int_{-\infty}^{z_1-\epsilon} \mathrm{d}z_2 e^{-\mathrm{i}(\nu^n+\nu^m)z_2} b_1^{mn}(k_g,z_2) \times \int_{z_2+\epsilon}^{+\infty} \mathrm{d}z_3 e^{\mathrm{i}(\nu^j+\nu^n)z_3} b_1^{nj}(k_g,z_3) \quad (1)$$

where, input is obtained by $b_1^{ij}(k_g,z) = \mathrm{i}2\nu^j D^{ij}(k_g,z)$, $\{i,j\} \in \{P,SV\}$. Matson (1997) indicated that $D^{ij}(k_g,z)$ is images of P-P and P-SV reflections using elastic Stolt-migration (ETM) with two constant background velocities.

Prediction in (p,z) domain:

$$b_3^{ij}(p_g,\omega) = -\int_{-\infty}^{+\infty} \mathrm{d}z_1 e^{\mathrm{i}(\nu^m+\nu^i)z_1} b_1^{im}(p_g,z_1) \int_{-\infty}^{z_1-\epsilon} \mathrm{d}z_2 e^{-\mathrm{i}(\nu^n+\nu^m)z_2} b_1^{mn}(p_g,z_2) \times \int_{z_2+\epsilon}^{+\infty} \mathrm{d}z_3 e^{\mathrm{i}(\nu^j+\nu^n)z_3} b_1^{nj}(p_g,z_3) \quad (2)$$

Here, the inputs are similar to equation 1, but they are mapping in the horizontal slowness instead of wavenumber. To implement the multicomponent prediction in plane-wave domain, the monotonic condition of vertical travel time and pseudo-depth must also be satisfied. Instead of stretching the inputs in vertical traveltime axis, prediction with modified integral limits, while the weighted traditional plane-wave data are inputs, can produce the same result. Its mathematical formula is written as,

$$b_3^{ij}(p_g,\omega) = -\int_{-\infty}^{+\infty} \mathrm{d}\tau_1^{im} e^{\mathrm{i}\omega\tau_1^{im}} b_1^{im}(p_g,\tau_1^{im}) \int_{-\infty}^{\Upsilon(\tau_1^{im}|\tau_2^{mn})-\epsilon} \mathrm{d}\tau_2^{mn} e^{-\mathrm{i}\omega\tau_2^{mn}} b_1^{mn}(p_g,\tau_2^{mn}) \times \int_{\Upsilon(\tau_2^{mn}|\tau_3^{nj})}^{+\infty} \mathrm{d}\tau_3^{nj} e^{\mathrm{i}\omega\tau_3^{nj}} b_1^{nj}(p_g,\tau_3^{nj}) \quad (3)$$

with time-stretching integral limit,

$$\Upsilon(\tau_2^{mn}|\tau_1^{nj}) = \begin{cases} \tau_2^{mn}, & j=m; \\ \frac{\alpha+\beta}{2\beta}\tau_2^{mn}, & j=S \;\&\; m=P; \\ \frac{2\beta}{\alpha+\beta}\tau_2^{mn}, & j=P \;\&\; m=S; \end{cases} \quad (4)$$

or with best-fitting integral limit,

$$\Gamma(\tau_2^{mn}|\tau_1^{nj}) = \frac{v^{mn}(p_g,\tau_2^{mn})}{v^{nj}(p_g,\tau_1^{nj})}\tau_2^{mn} \quad (5)$$

Inputs preparation with different methods

The elastic Stolt-migration was performed by re-griding Fourier transformed data into vertical-wavenumber domain. The angular frequency in function of vertical wavenumber with wavenumber/horizontal-slowness are plotted in Figure 1 and 2.

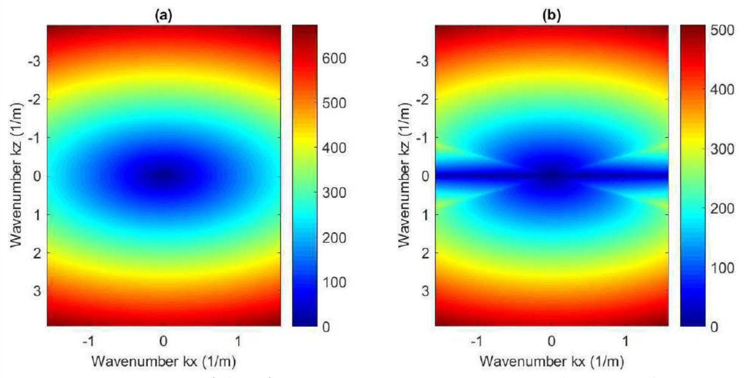

FIG. 1 $\omega(k_z)$ in wavenumber k.

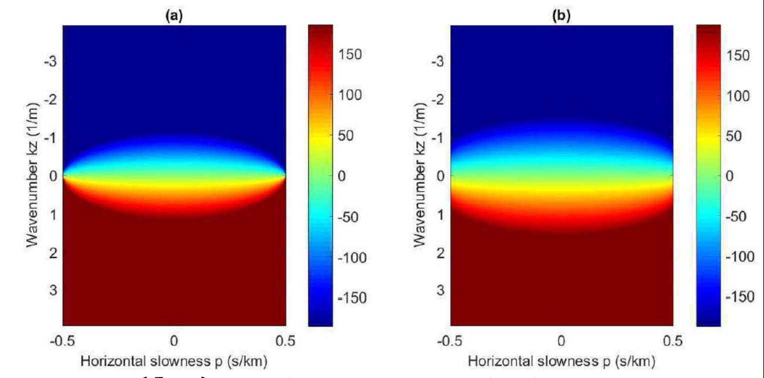

FIG. 2 $\omega(k_z)$ in horizontal slowness p.

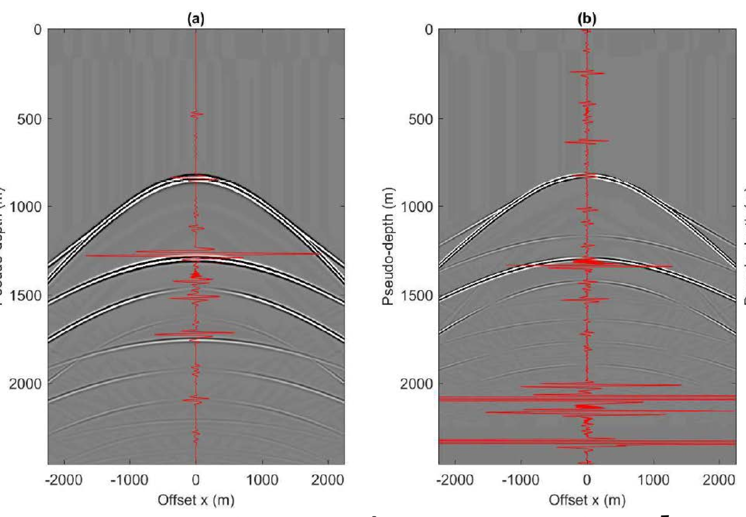

FIG. 3 Migrated traces using k.

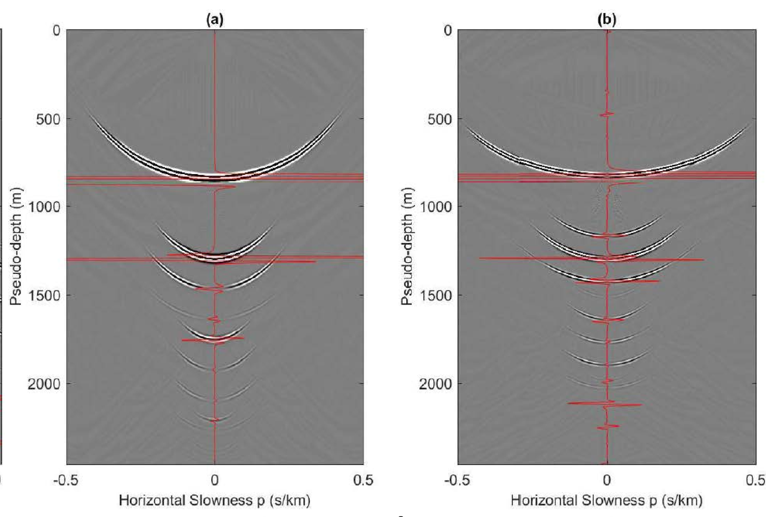

FIG. 4 Migrated traces using p.

The final migrated traces of a shot profile are overlaying plotted in Figure 3 (using wavenumber) and 4 (using horizontal slowness) with stretched data in (x, z) and (p, z) domains. With the elastic Stolt-migration, the inputs of pseudo-depth domain prediction are obtained and shown in Figure 5 and 6, related to wavenumber and horizontal-slowness respectively. Different levels of aliasing can be found in (k, z) and (p, z) domains, which are fatal drawbacks in prediction because a series of fake lower-higher-lower combinations are generated.

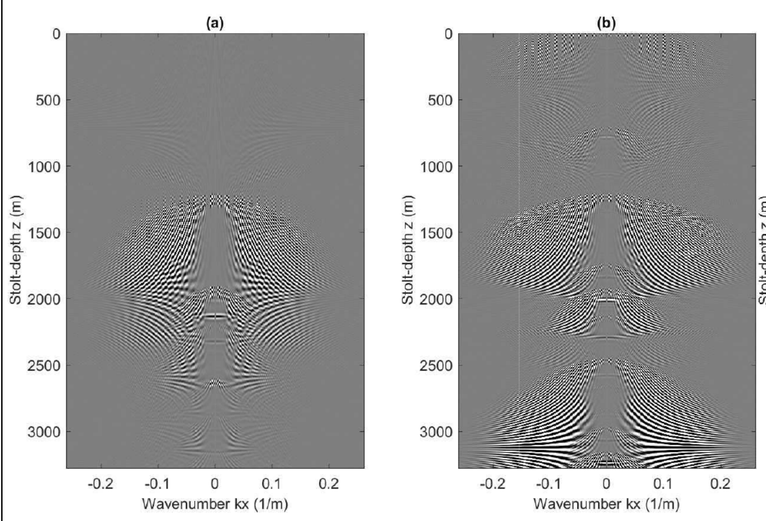

FIG. 5 Inputs for (k,z) domain.

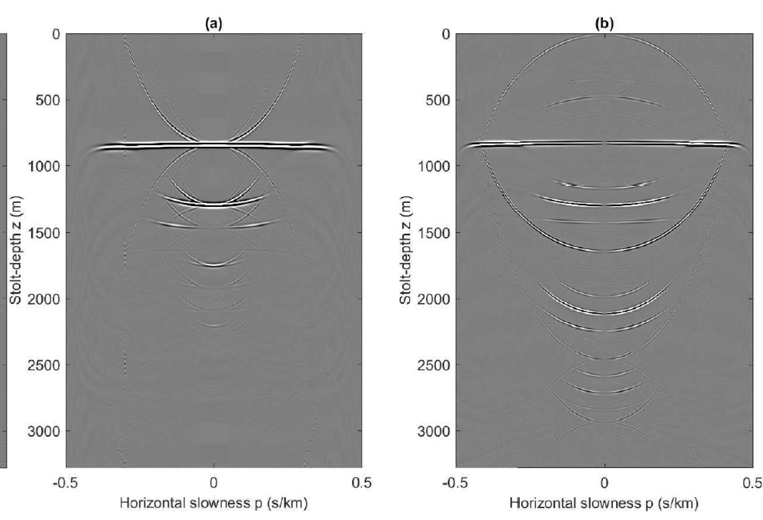

FIG. 6 Inputs for (p,z) domain.

For plane wave domain algorithm with modified integral limits, the inputs are weighted $\tau-p$ transformed data, shown in Figure 7. With time-stretching method, equation 4 will be used to select combinations met lower-higher-lower criteria. With best-fitting approach, it requires a best-fitting velocity model which is computed using high resolution hyperbolic radon transform (Figure 8). And the velocity model is plotted in Figure 9 and its matching is also drawn in Figure 10.

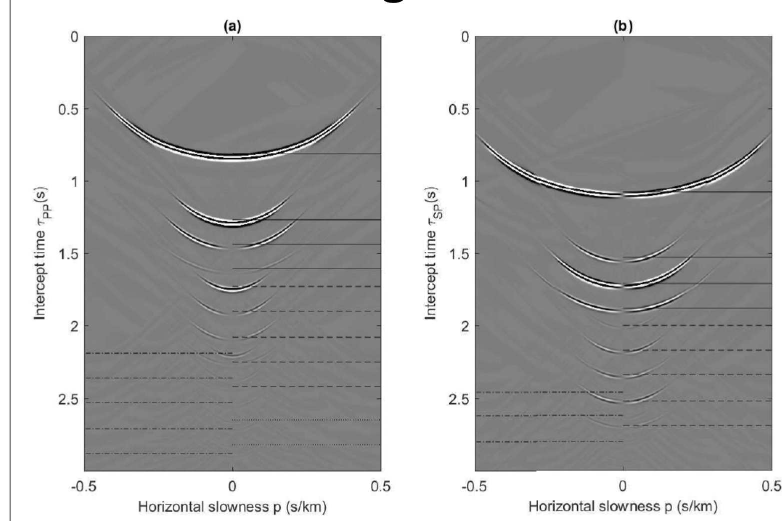

FIG. 7 Inputs for (p,τ) domain.

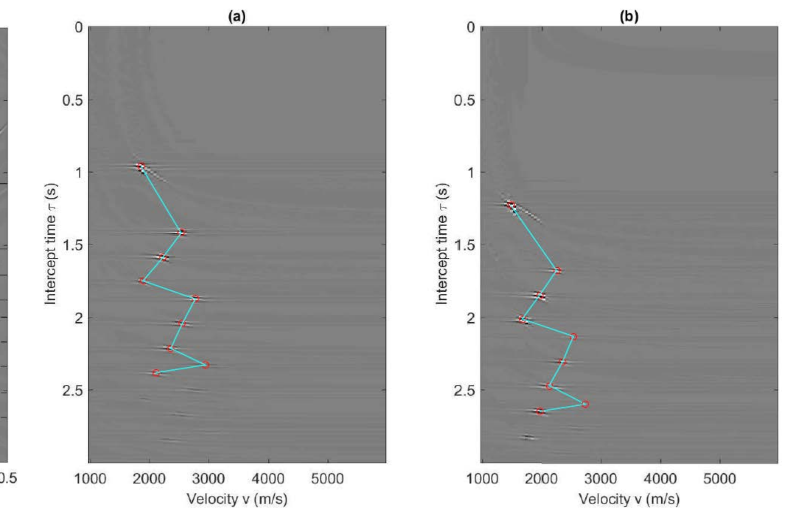

FIG. 8 Hyperbolic radon panel.

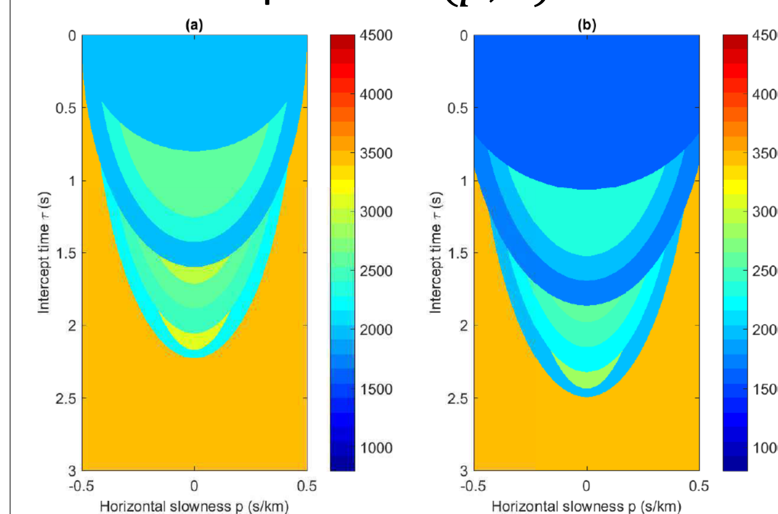

FIG. 9 Best-fitting velocity model.

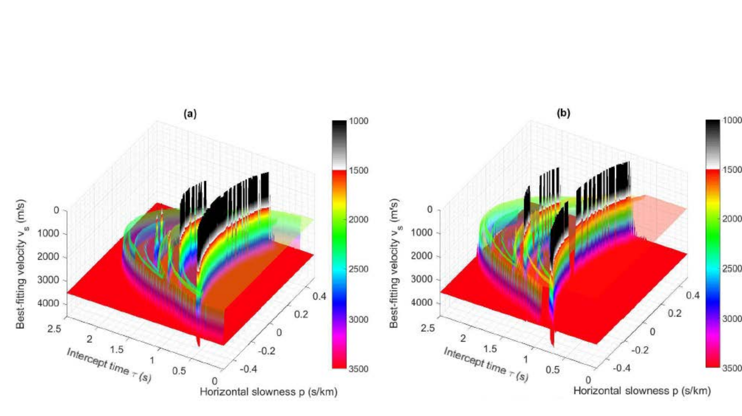

FIG. 10 Velocity matching.

IM Predictions

Implementing prediction with inputs in Figure 5 and 6 is pointless since the aliasing. Therefore, predictions were only performed in (p,τ) domain with variant modified integral limits (Eq. 4 and 5).

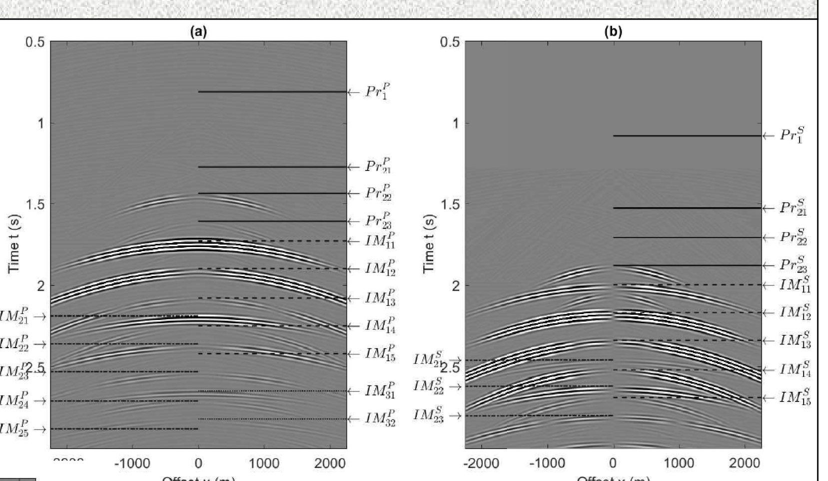

FIG. 11 (Top) Prediction with time-stretching only, $\epsilon = 96ms$.

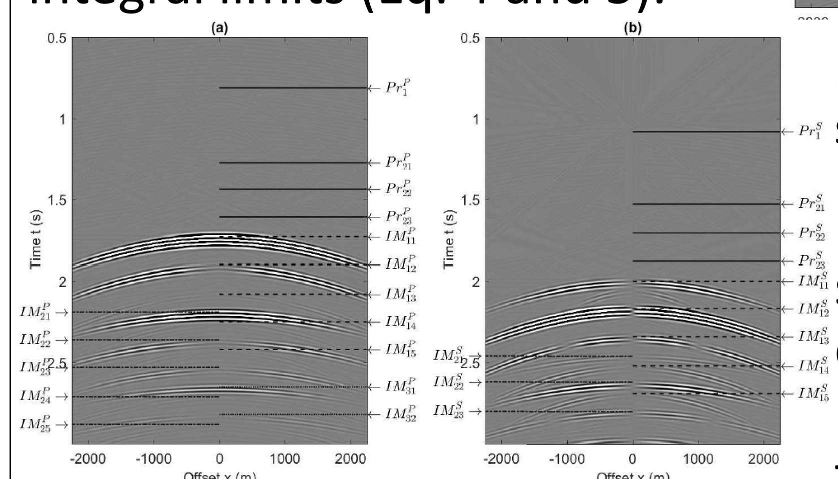

FIG. 12 (Left) Prediction with best-fitting only, $\epsilon = 200ms$.

Figure 11 indicates time-stretching method failed to eliminate primary events. Figure 12 shows the best-fitting requires a large ϵ.

However, the cross-validate condition given by best fitting and time-stretching produced a clean predicted result while allowing a small constant search parameter ϵ.

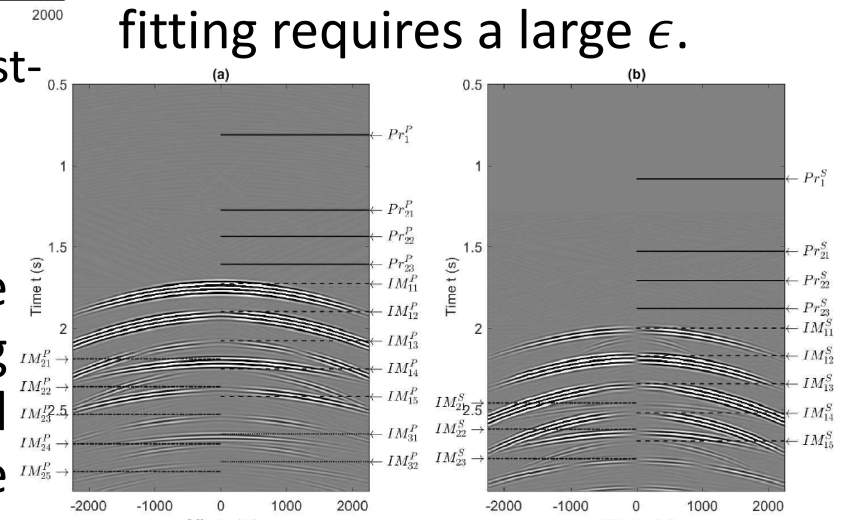

FIG. 13 (Below) Prediction with time-stretching & best-fitting, $\epsilon = 96ms$.

Acknowledgements

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