Picking and fitting first-break times on Gabor transforms of uncorrelated Vibroseis signals

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ABSTRACT

Estimates of the bulk dispersive velocities of an earth volume can be obtained from the Gabor transforms of uncorrelated Vibroseis signals recorded in VSP surveys. The transforms provide time-frequency displays on which first-break times can be picked automatically. Analysis of these times gives directly measured estimates of the frequency-dependent velocity of the bulk rock volume through which the seismic waves have propagated.

METHOD AND RESULTS

Examination of Gabor transforms of uncorrelated Vibroseis signals recorded at different offsets and depths suggests that the first-break times can be matched using a function characterized by only five or six parameters. A least-squares nonlinear regression technique with a relatively simple nonlinear function can be used to smoothly fit the picked times.

Automatic first-break time picking based on modified energy ratios (MER) works well when signal-to-noise ratios (SNRs) are high. After removing any outlier picks caused by noise in the transforms, the remaining picks are fitted by applying the MATLAB utility **nlinfit** with a simple function that includes a linear component plus a smaller nonlinear component.

Figure 1 displays the Gabor transform of the Vibroseis sweep used in the VSP survey. The first-break times for the transformed sweep have a linear frequency dependence. According to the definition of the programmed sweep,

$$t_s(f) = T/(f_{max} - f_{min}) \cdot f \quad , \qquad (1)$$

f_{min} = 2Hz, f_{max} = 150Hz, and sweep duration T = 20 sec.

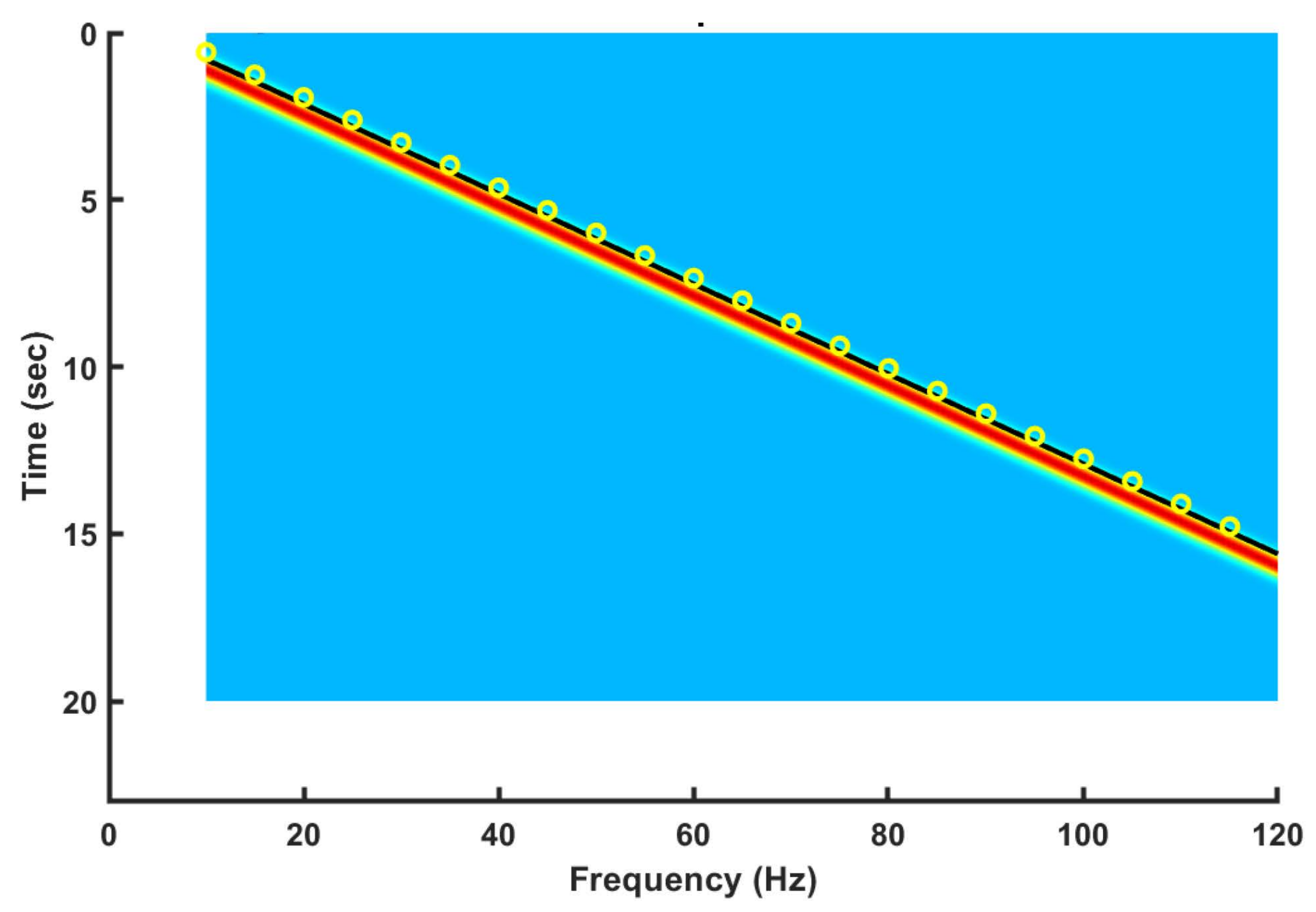

Fig. 1: Gabor transform of the survey Vibroseis sweep. Yellow circles are automatically picked first-break times. The black line plots times calculated according to Equation 1.

For the Gabor transforms of uncorrelated signals at two different depths (Figures 2 and 5), the first-break times excepting outliers follow smooth trajectories that have an assumed time-frequency dependence defined by

$$t_m(f) = (\,a_1 \cdot f + a_2) + b_1 \cdot \exp(-b_2 \cdot ((f + b_3)\text{^}2)) + b_4 \quad . \qquad (2)$$

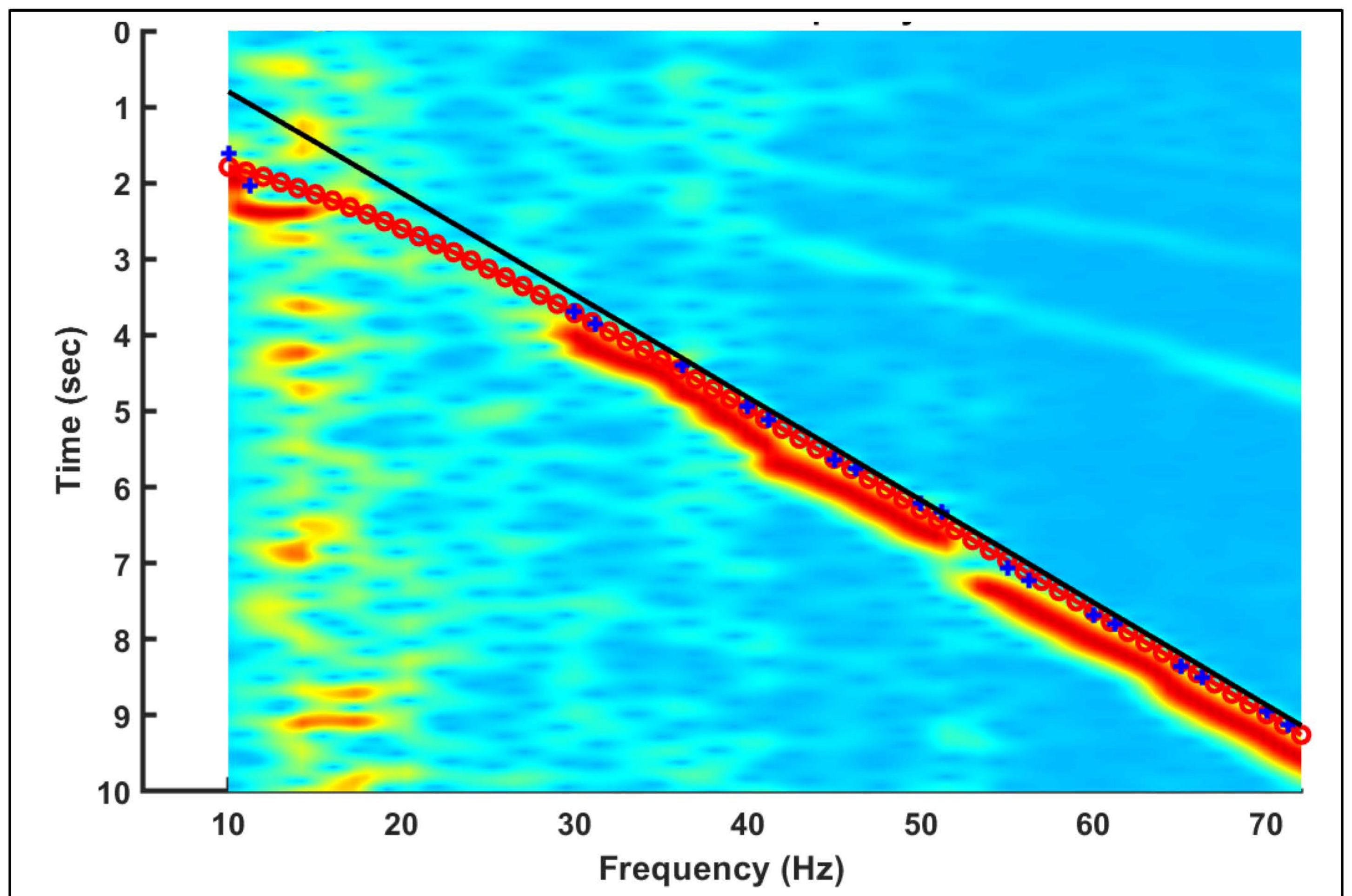

Fig. 2: Gabor transform of the uncorrelated signal from a receiver at depth = 1m. Blue crosses are automatically picked first-break times with outliers eliminated. The black line plots the times calculated according to Equation 1. Red circles are the interpolated times calculated according to Equation 2 after using **nlinfit** to find optimized values for the parameters b_i.

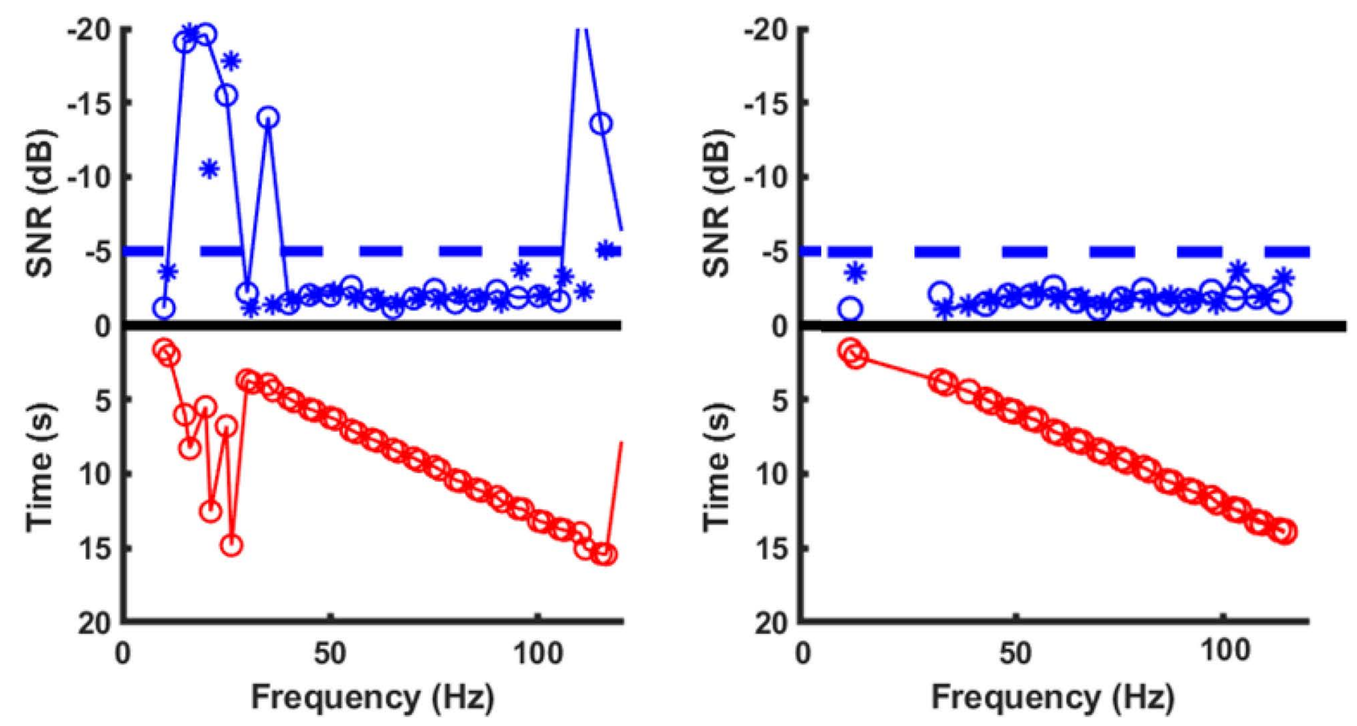

Fig. 3: Left: SNRs (blue) and automatic time picks (red) for the Gabor transform shown on Figure 2. Low SNR values and outlier times are associated with noisy transform values at frequencies between 12Hz and 32Hz. Right: SNRs and automatically picked times with outliers eliminated.

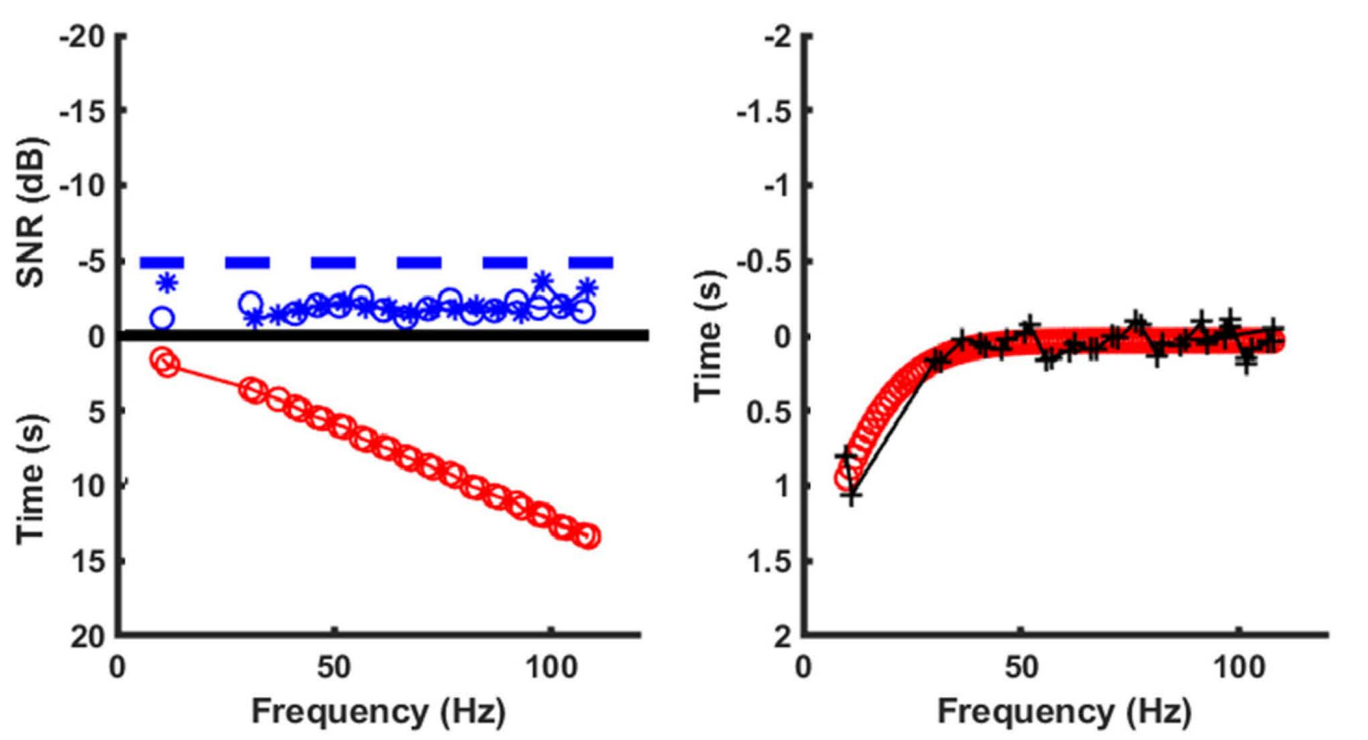

Fig. 4: Left: SNRs (blue) and automatic time picks (red) without outliers for the Gabor transform on Figure 2. Right: Black crosses are noisy residual times obtained by subtracting linear values at corresponding frequencies from the picked times; red are smoothed and interpolated values after fitting the noisy residual times using the nonlinear term in Equation 2 with **nlinfit**.

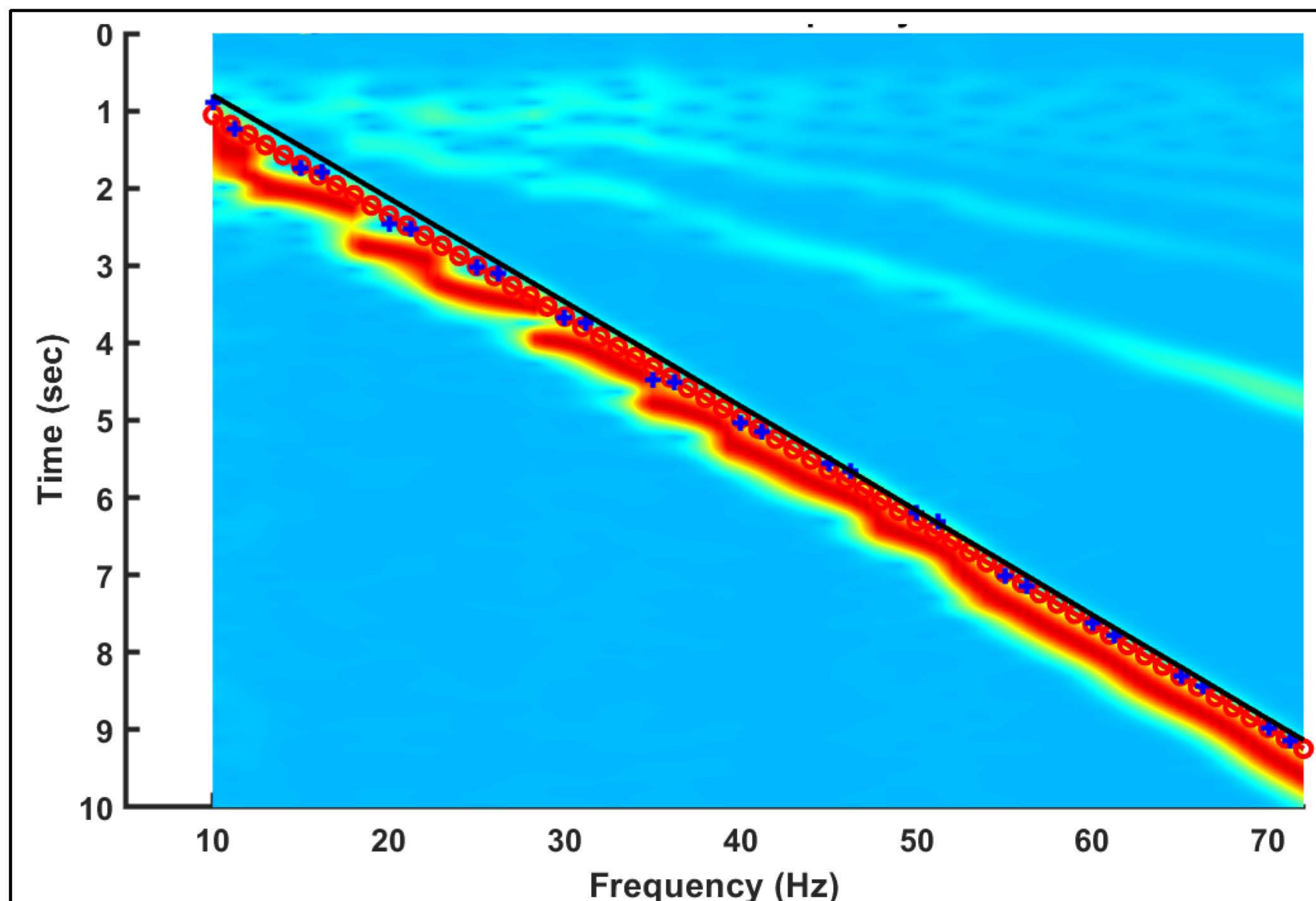

Fig. 5. Gabor transform of the uncorrelated signal from a receiver at depth = 97m. Blue crosses are automatically picked first-break times. Red circles are the times calculated according to Equation 2.

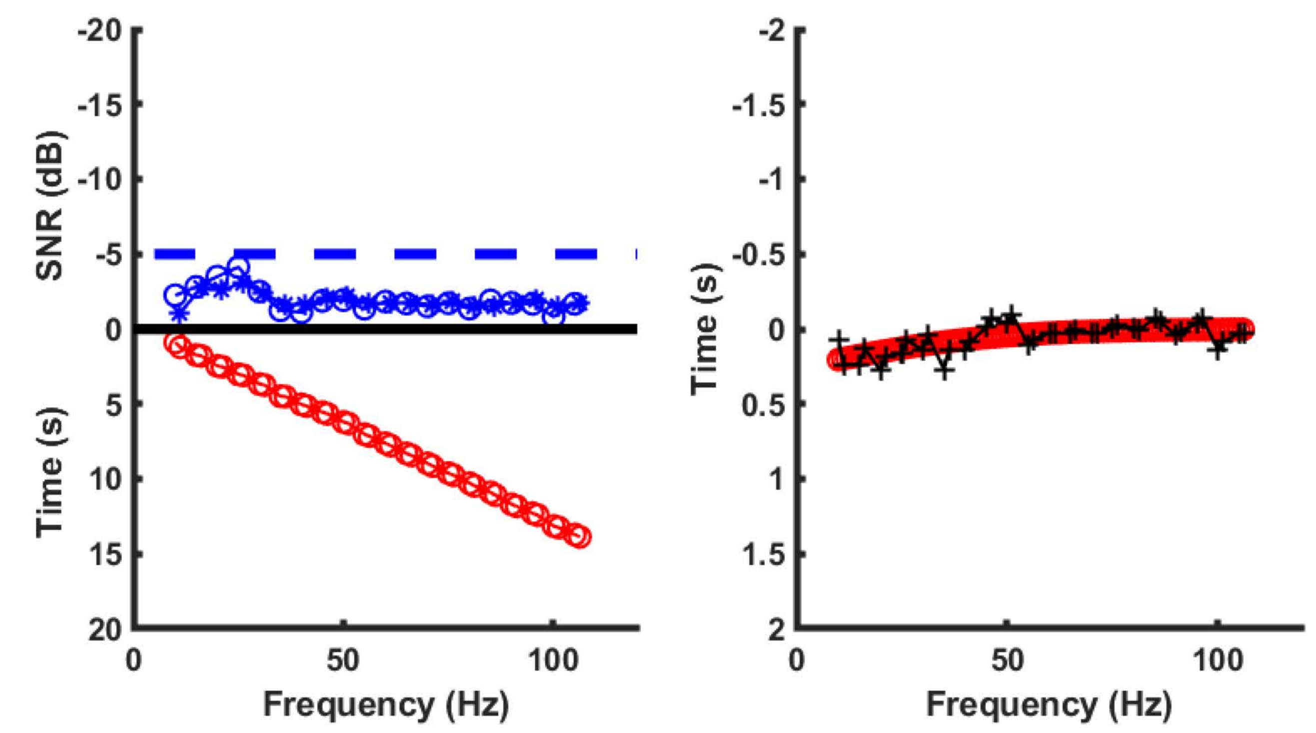

Fig. 6. Left: SNRs and automatic time picks for the Gabor transform shown on Figure 7. Right: Black crosses are noisy residual times; red are smoothed and interpolated values after fitting the noisy residual times using the modified Gaussian function with **nlinfit**.

DISCUSSION AND CONCLUSION

After outlier values are eliminated, automatically picked first-break times on Gabor transforms of uncorrelated signals from VSP surveys can be matched with a relatively simple function defined by Equation 2. The linear term involving the coefficients $[a_1 \;\; a_2]$ are known from Equation 1 with the slope $a_1 = T/(f_{max} - f_{min})$ and the intercept a_2 = 0. The nonlinear term with coefficients $[b_1 \;\; b_2 \;\; b_3 \;\; b_4]$ is a modified Gaussian function.

Residual times obtained by subtracting the linear values at corresponding frequencies from the picked times, the are well fitted using the nonlinear term with the MATLAB utility **nlinfit** to find optimal values of the coefficients $[b_1 \;\; b_2 \;\; b_3 \;\; b_4]$. The optimized coefficients are then used to interpolate and smoothly fill any gaps in the picked times caused by outliers. The sum of interpolated linear and nonlinear components (plotted as red circles on Figure 2 and 5) are well fitted (in the least-squares sense) to the apparent time-frequency dependence observed on the Gabor transforms.

ACKNOWLEDGEMENT

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