Detection and characterization of anelastic AVF with the Gabor transform

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Abstract

Amplitude variation with frequency (AVF) inversion can be used to estimate Q given anelastic frequency-dependent reflection coefficients. While AVF signal is generally analyzed event-by-event, traces are usually populated with many events at different arrival times. This creates the need to perform time-frequency analysis in order to isolate the reflectivity from a single event. We choose the Gabor transform as the instrument for our analysis and use it to estimate frequency-dependent reflectivities from synthetic traces. These reflectivities are then inverted to obtain accurate Q estimates. In order to test limits of this method, we also tested its performance under increasing noise levels, as well as with a reflection from a second interface that is close to the interface in which we are interested.

Estimating R(ω)

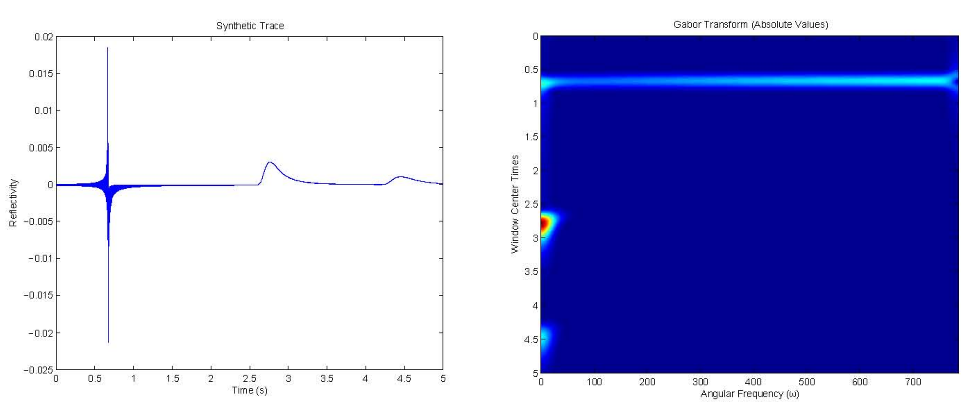

Figure : 1. Trace from our velocity and Q model and its corresponding Gabor transform. (a) The signal we are analyzing arrives at around 0.7 s, while additional signals at $\sim$ 2.8 and 3.5 s are included to ensure we are only analyzing part of the signal. (b) Absolute value of the Gabor transform of the trace shown in (a).

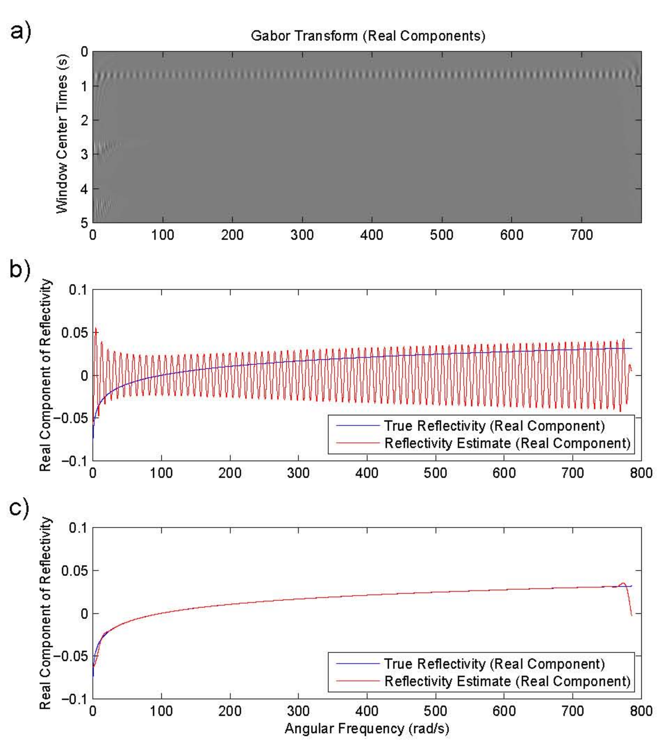

Figure : 2. Removal of phase effects in the real component of the signal. The oscillations of the real component of the Gabor transform with frequency in (a) cause an oscillatory Re reflectivity estimate in (b). (c) Multiplying the Re reflectivity estimate by $e^{-it_a\omega}$ removes these effects.

Series expansion of R(ω) for Inversion

We expand R(ω) for a wavefield arriving at normal incidence as

$$R(\omega) = \left(\frac{1}{4}a_c - \frac{1}{2}F(\omega)a_Q\right) + \left(\frac{1}{8}a_c^2 + \frac{1}{4}F^2(\omega)a_Q^2\right) + ... \quad (1)$$

where

$$a_c = 1 - \frac{c_0^2}{c^2}, \quad a_Q = \frac{1}{Q}, \quad (2)$$

and

$$F(\omega) = \frac{i}{2} - \frac{1}{\pi}log\left(\frac{\omega}{\omega_r}\right). \quad (3)$$

Close Reflectors

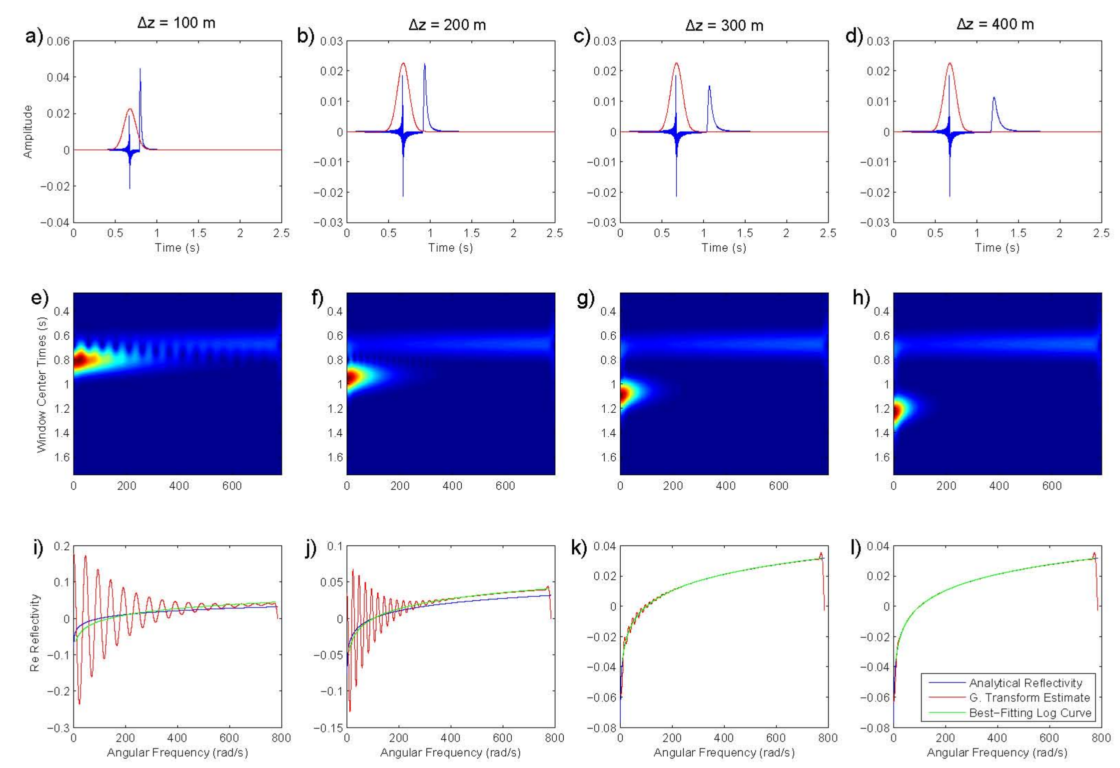

Figure : 3. Analysis using our standard Gaussian window size for closer reflectors. (a-d) show traces for two reflectors separated by distances of 100, 200, 300, and 400 m. In red is the size of the Gaussian window used in our Gabor transforms for this analysis. (e-h) show the Gabor transforms and (i-l) show the R(ω) estimates, and their best-fit curves, for the traces above them.

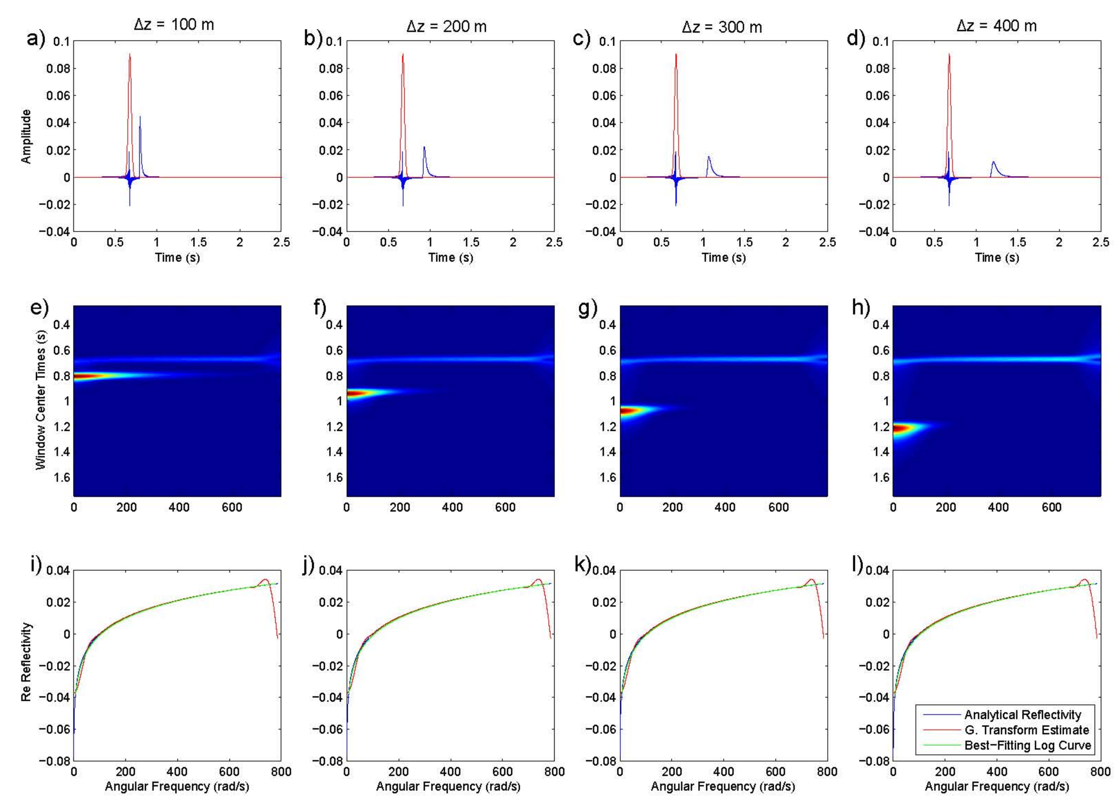

Figure : 4. Analysis using windows a quarter the size as used in Figure 3.

Q Estimates

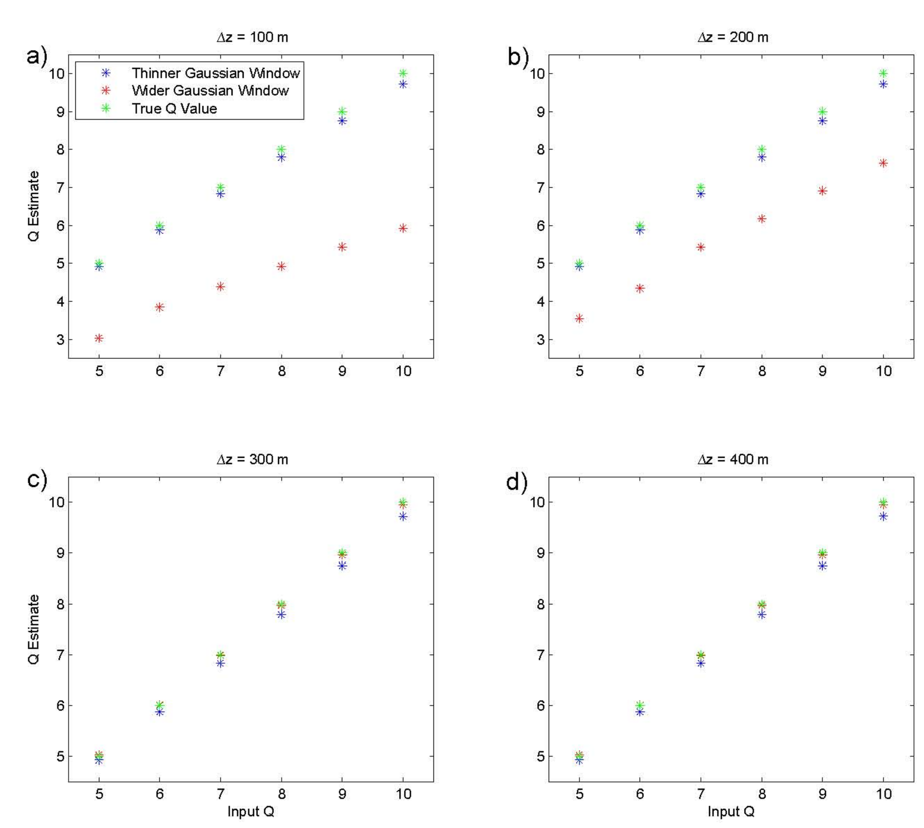

Figure : 5. Q estimates for close reflectors. (a & b) Using a thinner window produced more accurate Q estimates for the very close reflectors. (c & d) Using a wider window produced slightly more accurate Q estimates for the farther reflectors.

Added Noise

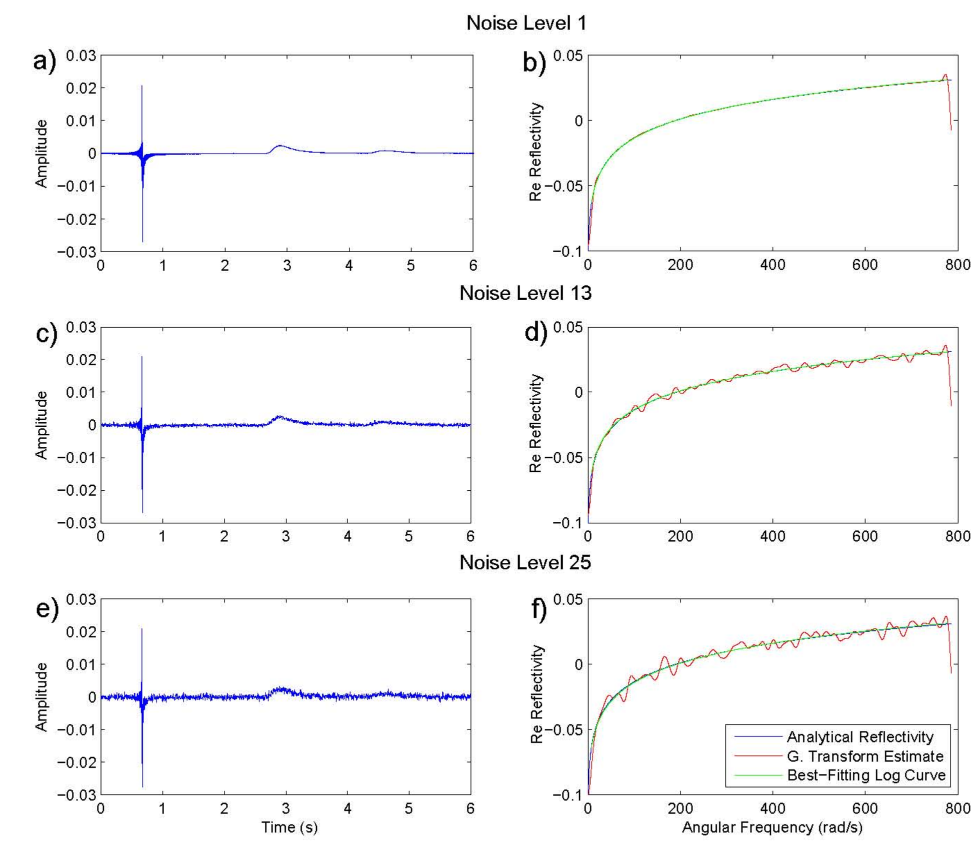

Figure : 6. Noisy traces and their respective reflectivity estimates. (a), (c), and (e) Synthetic traces with increasing levels of white noise added. (b), (d), and (f) Real R(ω) estimates, and their best-fit curves, using eq. 1, plotted against the true reflectivity.

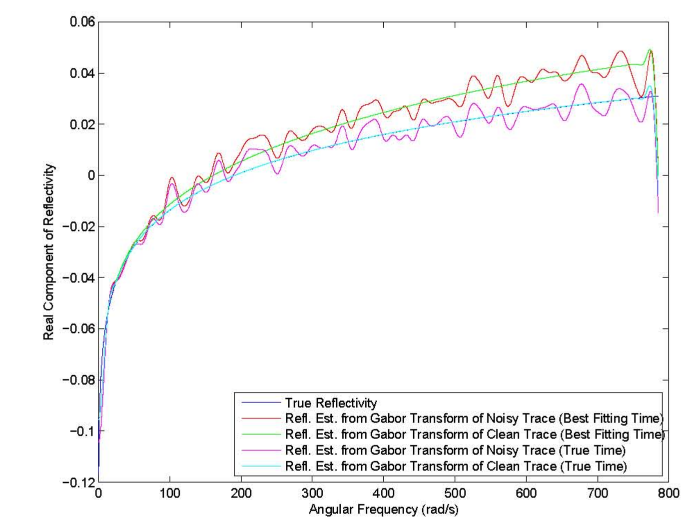

Figure : 7. Wrong t_a estimate due to noise. Due to the noise, t_a was misestimated, resulting in a noisy R(ω) curve with the wrong slope (shown in red), and if a clean trace is processed using the same best-fitting time found for the noisy trace, it will not match the true reflectivity (green vs. dark blue). If the same noisy trace is processed using the correct t_a (shown in magenta), it better fits the true reflectivity. Using the clean trace with the correct time is shown for comparison (cyan).

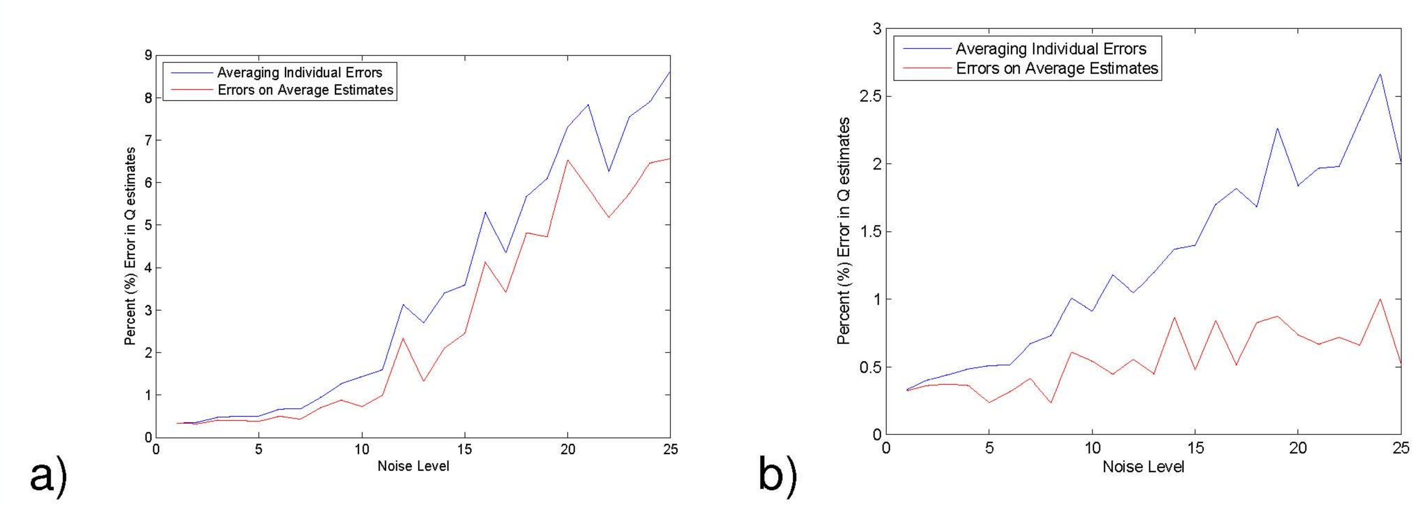

Figure : 8. (a) Percent errors in Q estimates using noisy data. In blue are the average percent errors in Q estimates for 25 increasing levels of noise. In red are the percent errors in the Q estimates when averaging the same Q estimates across 10 noisy traces. (b) The same test was performed as in (a), but t_a was fixed to the correct value.

Conclusions

- AVF analysis can successfully estimate Q in synthetics using the Gabor transform.
- Signal that is close in time to the event being analyzed can worsen the estimate, but smaller window sizes can help with this.
- There is some instability in the current algorithm due to phase effects; the introduction of a low frequency component in the R(ω) estimate can greatly influence the inferred Q value.