AVA Friendly Q Amplitude Compensation

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Summary

Q amplitude compensation is limited by the rapid growth of the exponential function of frequency used to apply the compensation. Signal to noise ratio limits the maximum useful boost on real data.

This paper will discuss how to handle the gain limit in a way consistent with amplitude vs. angle analysis AVA. It will be shown that a fixed maximum gain is not consistent with AVA.

We will also show a solution for another common issue with Q compensation for phase or amplitude in deep water. The problem is removing the travel time in the water column from the total travel time. Propagation of seismic frequencies through water shows almost no attenuation.

Introduction

The Q effect is a model which captures the effects of scattering and intrinsic attenuation on seismic energy. Phase compensation has been a standard part of seismic processing for decades (Trantham 1994). However, amplitude compensation on ghosted data was problematic and not used as often. With the advent of broadband acquisition and processing Q amplitude has become necessary in order to make up for the loss of high frequencies due to deghosting at conventional tow depths (<10 m).

Even though Q amplitude compensation does a reasonable job of restoring the high frequency bandwidth lost to deghosting, there is an issue due to the maximum gain limit imposed by many software packages. This gain limit is usually a constant specified in dB.

Because of the longer travel time on far offsets along a reflection, the far offsets will reach the gain limit at a lower frequency. This reduces the total area of the spectrum as a function of offset and attenuates peak amplitude vs. offset. This effect has the potential to mask the expected AVA effects.

A second issue then occurs if the data is migrated or normal moveout is applied. Stretch of the time domain wavelet shrinks the frequency domain wavelet. This reduces the cut off frequency as a function of frequency even more.

Theory

The amplitude compensation in the Q model is given by the following.

$$A_Q(f,T) = e^{\pi f T/Q} \qquad (1)$$

Where f is the frequency, T is the travel time in the sediments and Q is the constant used to describe the loss of high frequencies. This exponential can quickly exceed the signal to noise ratio of that data which means that lots of noise is emphasized. Noise is no aid to resolution.

A common way to limit this is to impose a maximum gain factor. The gain of Equation (1) in dB is given by the following.

$$g = \frac{20\pi}{\ln(10)}\frac{fT}{Q} \qquad (2)$$

If we specify a maximum value for the gain, then a maximum frequency for the correction is implied. Solving Equation (2) for this frequency we obtain the following.

$$f_{max} = g_{max}\frac{\ln(10)}{20\pi}\frac{Q}{T} \qquad (3)$$

As the sediment travel time T increases the maximum frequency decreases inversely. If this frequency falls within the seismic band the reduced bandwidth will affect the area under the wavelets spectrum. This will then affect the peak amplitude and distort AVA.

The maximum frequency will fall within the seismic band at some depth as T increases. So this effect is always a problem for at least some of the data. Therefore, we cannot use a constant maximum gain to limit the Q amplitude compensation and be consistent with AVA at all times.

One possible solution is to keep f_{max} fixed across a reflection. For example, use the zero offset maximum frequency for all offsets along a reflection. To accomplish this we only need to calculate the maximum frequency at zero offset and then hold it constant across the entire reflection. This is equivalent to allowing the maximum gain to increase with offset. From Equation (2) it can be seen that the maximum gain in dB with the maximum frequency held fixed will be proportional to the sediment travel time.

AVA analysis is often done on migrated gathers with reflections flattened across the offsets or on angle stacks which are constructed from these gathers. These data exhibit a stretch effect in the time domain equivalent to a squeeze effect in the frequency domain as follows:

$$f(\theta) = f(0)\cos(\theta) \qquad (4)$$

Where θ is the angle of incidence at the reflector. Because the data will continue to decay past the maximum frequency, the resulting residual Q effect will have a sharp frequency drop. Depending on how this interacts with the wavelet's amplitude spectrum an angle dependent amplitude distortion may result which makes stretch compensation difficult.

To obtain a constant maximum frequency we need to scale up the maximum frequency on the non-flattened gathers by $1/\cos(\theta)$. The squeeze effect in Equation (4) will then put all of the maximum frequencies at the same value.

So the algorithm consists of picking the maximum frequency at zero offset based on Equation (3) then scaling this up by $1/\cos(\theta)$ along a reflection. To implement these we need the sediment travel time T and the angle of incidence θ. Fortunately, we can obtain both of these quantities using an Equation from Dix (1955).

$$\frac{\sin(\theta)}{V_{int}} = \frac{x}{V_{NMO}^2(t_0)\sqrt{t_0^2 + \left(\frac{x}{V_{NMO}(t_0)}\right)^2}} \tag{5}$$

Where t_0 is the travel time of a reflection at zero offset, V_{int} is the interval velocity, x is the offset and V_{NMO} is the normal moveout velocity. This equation was derived using the assumptions of lateral velocity invariance and hyperbolic moveout, but allowing for curved rays. The angle of incidence and the interval velocity on the left hand side of Equation (5) can be evaluated at any time since this is the slowness and is a constant for a given ray path. Note: this is the same equation that is often used to calculate angle mutes (e.g. Walden 1991).

To get the water layer angle of incidence we can put in the water velocity for interval velocity as follows:

$$\sin(\theta_{water}) = \frac{xV_{water}}{V_{NMO}^2(t_0)\sqrt{t_0^2 + \left(\frac{x}{V_{NMO}(t_0)}\right)^2}} \tag{6}$$

Then using a trigonometric identity we can obtain the cosine of the water angle as follows:

$$\cos(\theta_{water}) = \sqrt{1 - \sin^2(\theta_{water})} \tag{7}$$

Now we can get the water layer travel time as follows:

$$t_{water}(x, t_0) = t_{0,water}/\cos(\theta_{water}) \tag{8}$$

Where $t_{0,water}$ is the zero offset water bottom time. This allows us to calculate the sediment travel time as follows:

$$T(x, t_0) = \sqrt{t_0^2 + \left(\frac{x}{V_{NMO}(t_0)}\right)^2} - t_{water}(x, t_0) \tag{9}$$

Next we need the angle of incidence at the reflector for stretch correction of the maximum frequency. Use Equation (5) evaluated at the reflector to obtain the following:

$$\sin(\theta(x, t_0)) = \frac{xV_{int}(t_0)}{V_{NMO}^2(t_0)\sqrt{t_0^2 + \left(\frac{x}{V_{NMO}(t_0)}\right)^2}} \tag{10}$$

We can then obtain the following.

$$\cos\big(\theta(x, t_0)\big) = \sqrt{1 - \sin^2(\theta(x, t_0))} \tag{11}$$

We now have all of the elements for an AVA friendly Q amplitude compensation. The algorithm is as follows:

1. Pick a window centered at $\boldsymbol{x}$ and $\boldsymbol{t}$.
2. Find the corresponding $\boldsymbol{t_0}$.
3. Calculate the sediment travel time using Equation **(9)**. This value is used in Equation **(1)** for Q compensation.
4. Calculate the maximum frequency at zero offset using Equation **(3)** with the zero offset sediment travel time.
5. Optionally: Boost this maximum frequency by dividing by the cosine using Equation **(11)**.

The above algorithm can be extended to flat gathers and angle stacks. These extensions will be discussed in the presentation.

Examples on model and real data will be shown.

Conclusions

Q amplitude compensation implemented with a constant gain limit are not consistent with AVA analysis. The resulting residual Q effect introduces an offset variation that is not consistent with normal wavelet behavior.

The minimum requirement for AVA analysis is that the maximum gain frequency be held constant on the non-flat gathers. The resulting cut off frequency will then be time variant, but constant across hyperbolic reflections. The cut off frequency is consistent across the gathers and can be treated as part of the wavelet. The maximum boost will then increase with angle of incidence.

Adding a stretch correction to the maximum frequency will make the cut off frequency consistent after migration or moveout correction. The cut off frequency is then dependent on t_0 only. The maximum boost will increase even more with angle of incidence.

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EDITED REFERENCES

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