Shaping the Vibroseis first arrival

Stewart Trickett
Juniper Bay Software

Summary

Vibroseis first arrivals are often ringy and noisy, making it difficult to pick a consistent feature for weathering correction. Even when a consistent feature is picked, it's not clear where the true first-arrival time is relative to it. I describe a novel shaping filter that removes the ringyness and focuses the first-arrival energy into a single strong peak, making it less likely to be submerged by noise. Further, this peak is at the true first-arrival time. The result is better picks and more accurate weathering statics.

Method

Correcting for time delays caused by low-velocity near-surface weathered layers is one of the oldest steps in land seismic processing (Dobrin, 1941; Cox, 1999). The usual approach is:

- Pick the first-arrival times of the seismic data.
- Interpret a weathering model from these times.
- Apply statics based on this model, in effect turning the near surface into a constant-velocity layer.

Here we seek to improve the first step for Vibroseis data by applying a shaping filter beforehand. But what do we mean by the first-arrival time of a trace? The most fundamental definition is:

> *Def 1: The least time it takes for seismic energy to travel from source to receiver.*

For impulsive sources, this is commonly interpreted as:

> *Def 2: The time of the initial onset of source energy.*

The Vibroseis seismic wavelet is made up of, at a minimum, a convolution of the following (Figure 1):

- Klauder wavelet (Baeten and Ziolkowski, 1990)
- Far-field differential operator (Aki and Richards, 2002, §4.2.1)
- Q attenuation response (Aki and Richards, 2002, §5.5)
- Geophone response (Hons et al., 2008)

We assume that the SEG polarity standard (Landrum et al., 1994) has been followed. The last three items are minimum phase, but the Klauder wavelet is zero phase, having an energy onset many seconds before its time zero. This makes Definition 2 unworkable for Vibroseis data. In response, processors often apply an all-pass shaping filter that converts the Klauder wavelet to minimum phase (Ristow and Jurczyk, 1975), giving:

> *Def 3: The time of the initial onset of source energy after converting the Klauder wavelet to minimum phase.*

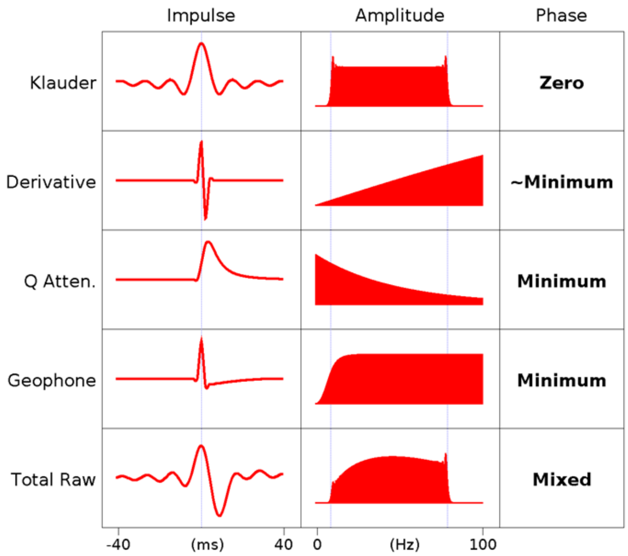

Figure 1 The components making up a raw first-arrival wavelet. The 10-80 Hz sweep band is indicated with light lines.

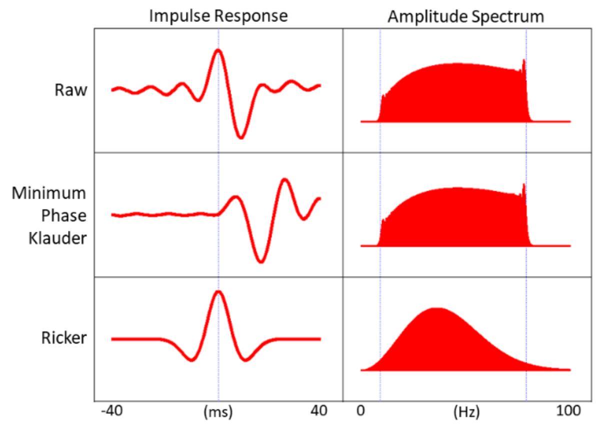

Figure 2 The modelled seismic wavelets for the raw data, the raw data with the Klauder wavelet converted to minimum phase, and the proposed Ricker wavelet.

This is only partially successful. The difficulty of converting a band-limited wavelet with a sharp-edged amplitude spectrum to minimum phase means that ringyness is often still present. Further, the onset of energy is gradual, making it difficult to detect on noisy traces.

I propose a different definition:

> *Def 4: The time of the earliest signal peak when the seismic wavelet's initial peak is at its time zero.*

The idea is to shape the known seismic wavelet to one which is:

- Zero phase.
- Compact and simply shaped. Notably it's not ringy.
- Has almost all of its energy contained within the sweep frequency band.
- Has a single strong positive peak at time zero, but no other peaks.

Here I use a zero-phase Ricker wavelet (Hosken, 1988) although other wavelets are possible. A Ricker wavelet has one parameter – the peak frequency f_p – which I recommend setting to about 45% of the maximum sweep frequency.

The proposed method replaces the seismic wavelet with a Ricker wavelet as follows:

> *Multiply the frequency response of the raw trace by the frequency response of a Ricker wavelet and divide by the frequency response of the modeled raw wavelet (with prewhitening to avoid dividing by small values).*

Figure 2 shows the modeled seismic wavelets for the raw data, the raw data with the Klauder wavelet converted to minimum phase, and the proposed Ricker wavelet.

The amount of Q attenuation that the first arrival has suffered is typically unknown. One solution is to assume a fixed reasonable rate of attenuation for all arrivals – setting Q to 50, for example. Although this will rarely be correct for any trace, it works surprizingly well, the main effect of an incorrect Q being a slight shift in arrival time. A better solution, though, is to measure the rate of attenuation. Hatherly (1986) describes one method for doing this.

Changes to the automatic picking algorithm are needed:

- Peaks should be picked.
- Tests such as energy ratio (Coppens, 1985) should be centered about .75 / f_p before each candidate peak.
- Once a peak has been selected as indicating the first arrival, no adjustment should be made to its time.

Results

Tests are carried out on real Vibroseis data with an 8-115 Hz 20 s linear sweep. Three versions are compared:

RAW Unfiltered
MP Klauder wavelet shaped to minimum phase
RIC Seismic wavelet shaped to a Ricker wavelet

Figure 3 shows some RAW early first arrivals displaying considerable ringyness. The MP and RIC data are far less ringy. In all three data sets, the first arrivals look remarkably like their estimated wavelets in Figure 2.

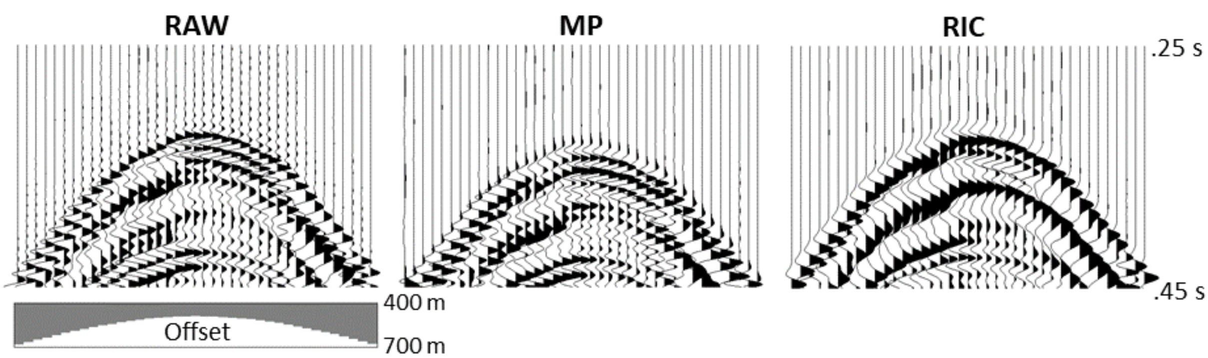

Figure 3 First arrivals at early times showing ringyness in the RAW and MP data sets. The RIC dataset has only slight ringyness.

Figure 4 shows some first arrivals at deeper times suffering from strong noise. The bottom display is the same as the top but with the picks shown. Only the RIC picks do not cycle skip.

Figure 5 shows the pick times for a single shot record, flattened using a linear-moveout function. Both the RAW and MP picks show clear signs of cycle skipping, while the RIC picks do not.

In theory the proposed shaping filter lets us pick the true first-arrival time, an advancement over past methods. It's difficult, however, to prove this in practice. But the method demonstrably delivers more *consistent* picks by reducing ringyness and being more resistant to noise.

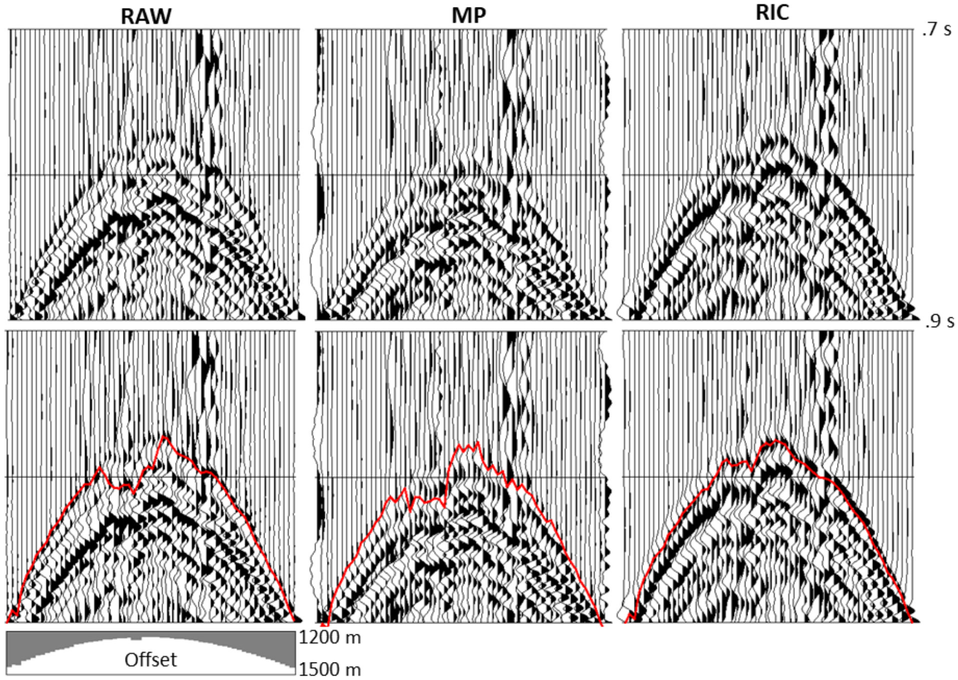

Figure 4 First arrivals at later times. The bottom display is the same as the top, but with the picks shown in red. The RAW and MP datasets have cycle skipped, while the RIC has not.

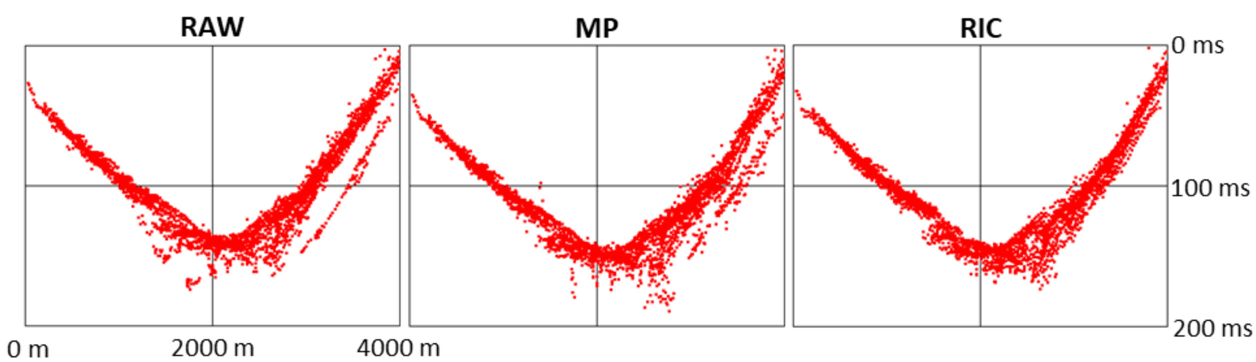

Figure 5 First arrival times for a single shot flattened using a linear-moveout function.The x axis represents offset. The RAW and MP picks show signs of cycle skipping beyond 3000 m, while the RIC picks do not.

Acknowledgements

Thanks to Absolute Imaging Inc. for the use of their facilities, and to Samo Cilensek, Dave Bloxham, Dennis Quinn, and Jack Bouska for their help and feedback.

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