Cleaning up first arrivals in the cross-spread domain

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Summary

Typically the first step in weathering statics correction is to pick the first-arrival times of the refracting energy. But first arrivals are often noisy, causing automatic pickers to produce poor results. I describe a novel method to remove random noise from the first arrivals by exploiting robust statistics and the "locally surface-consistent" property of cross-spreads. This can produce faster and better first-arrival picking, and thus more accurate weathering correction, at a lower cost.

Method

Picking the first-arrival – also called-first break – times of refracting energy is the initial step in weathering statics correction for land seismic (Cox, 1999, Chapter 5), and is mostly automated due to the massive amount of data in modern seismic surveys. Sometimes, though, it requires extensive and expensive human guidance and correction to ensure consistent results. A major cause of poor automatic picking is noise caused by wind, rain, traffic, pump jacks, powerlines, simultaneous shooting, and so on. This may become worse in the future due to the adoption of high-density mini vibe shooting and single-point receivers.

If random noise can be removed beforehand then automatic pickers will do a better job, resulting in faster throughput, reduced cost, and ultimately more accurate weathering correction. But this is a difficult task given that first arrivals can have short-wavelength statics between adjacent traces which we need to preserve, and that the noise is often severe, at times overwhelming the first arrival. Perhaps as a consequence, the literature on cleaning up first arrivals is surprisingly sparse given its importance (Dack, et al., 2014; Souza et al., 2017; Place et al., 2019).

Most modern 3D surveys are laid out along source and receiver lines, or as best as can be managed given local conditions. If we take all traces shot on a single source line and recorded on a single receiver line then we have a cross-spread gather. These gathers are well suited for many processing tasks (Vermeer, 2005). If we organize the traces from a single cross-spread onto a grid where one axis represents common source and the other axis represents common receiver (known as a surface diagram), then traces that are near each other on the grid are also near each other by every conceivable metric: source location, receiver location, midpoint location, absolute offset, inline and crossline offset, and (except at zero offset) azimuth. Here we will exploit the property that first-arrival times, when limited to a small local region of a cross-spread, are approximately surface consistent.

Suppose we have a single cross-spread gather, with the traces laid out on a grid representing common source on one axis and common receiver on the other. Also suppose we have a rough estimate of the first-arrival times (accurate to within, say, 100 ms), a function which is smoothly changing in space. A novel method to remove noise from first arrivals is as follows:

Divide the grid into small (e.g., 5 sources by 5 receivers) overlapping rectangular spatial tiles.

For each tile…
{
A: For each trace, extract a small (e.g., 400 ms) window of samples centered on the estimate of the first-arrival time.

B. Flatten the events in the windows by determining and applying surface-consistent source and receiver statics and a residual linear-moveout term. These corrections are independently determined for each tile.

C. Stack the flattened windows.

D: Place the stack back into the windows, undoing the flattening static that was applied to each trace in step B.

E: Insert the noise-attenuated windows back into the full traces, tapering the window boundaries so there is no abrupt change.
}

Once all tiles are processed, merge them together to reform the full cross-spread gather.

Step **B** is a tiny residual-statics problem (Cox, 1999, chapter 7). There are many ways this can be solved; see, for example, Taner et al. (1974) or Ronen and Claerbout (1985). Here I suggest a variation of "intertrace lag estimates" by Kirchheimer (1986). First, determine the time lag $t_{ij} – t_{pq}$ between every pair of traces within the tile, estimated using the standard cross-correlation technique, where the two subscripts represent source and receiver indices. Form the over-determined linear system of equations

$$t_{ij} - t_{pq} \;=\; S_i – S_p + R_j – R_q + (x_{ij} – x_{pq})\, M$$

where S_i is a source-consistent static shift, R_j is a receiver-consistent shift, x_{ij} is the trace offset, and M is a residual linear-moveout term. Due to the erratic nature of the time lags, this system is best solved using robust inversion (Ji, 2011) rather than least squares. The final static to flatten each trace (i,j) is $-S_i – R_j – (x_{ij} – x^*)\, M$, where x* is the offset of one of the central traces in the tile.

In step **C**, stacking the windows is also best done through robust statistics rather than the standard arithmetic mean (Elston, 2005), as the noise levels can vary erratically between traces. In step **D**, the scaling of the stack should be matched to the scaling of the original window data so as to minimize the difference between the original and filtered traces. When there is a serious misfit between an original and filtered trace, however, match filtering should not be done.

Results & Observations

Figure 1 shows part of a Vibroseis 3D shot record before and after cleaning up the first arrivals. The data is now far easier to pick -- in fact, the amount of noise suppression is surprising.

But the proposed method has some limitations. There are some regions where this method does poorly, particularly where a first-arriving refractor is very low amplitude compared to slower refractors. The method can also break down in the presence of geometry errors. This is disappointing, as first arrival picks are often used to identify geometry problems such as mispositioned sources and receivers. In addition this method requires that acquisition be carried out along source and receiver lines. Such acquisition is typical today, but more random acquisition designs may be popular in the future in certain regions.

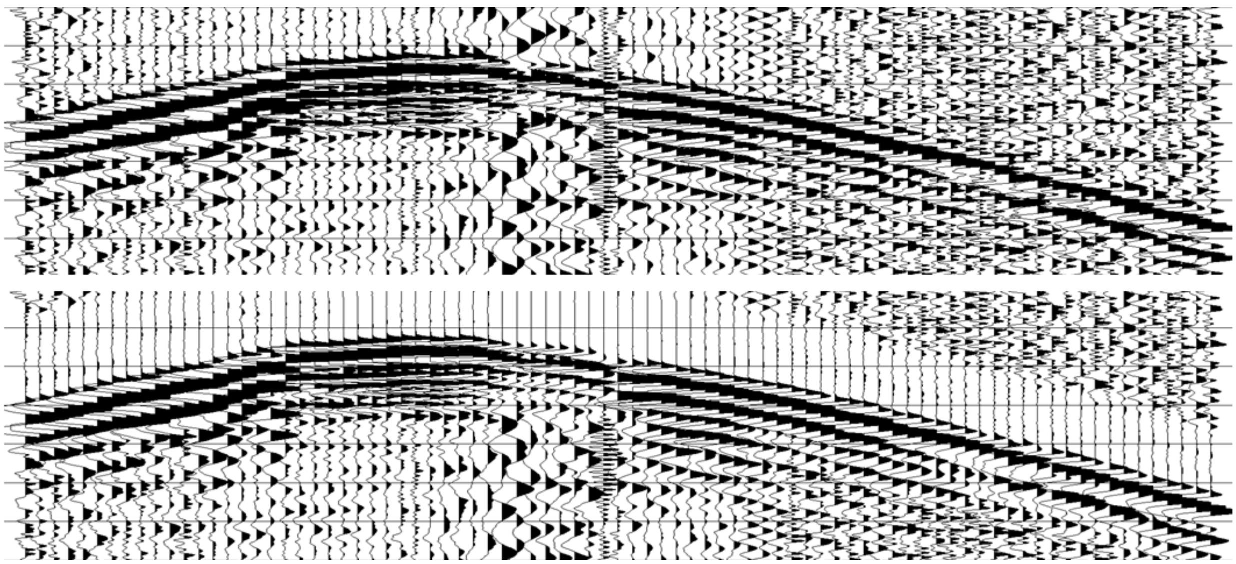

Figure 1: First arrivals before (above) and after (below) noise suppression. Data complements of Explor.

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