BICORR—a new ProMAX module for data correlation analysis

David C. Henley and Arnim B. Haase

ABSTRACT

An accompanying chapter in this report introduces the use of the cross-bicorrelation function for correlation analysis of time series data. The function has been implemented in ProMAX and can be useful for analyzing both model data and seismic field data. The function is briefly described, and its parameters discussed. Suggestions regarding displays of the output and use of the function in diagnostic processing flows are included.

INTRODUCTION

Much of the analysis of seismic data involves determining how various discrete events on seismic traces are related to each other. One of the most basic mathematical tools used for this purpose is the cross-correlation function and its Fourier transform, the cross-spectrum. Although it is statistically robust, one of the drawbacks of the cross-correlation function is that it is an "average" correlation over all the events in both the input time series; all individual event correlation details are lost. Furthermore, it is bandlimited by the mutual spectrum of the two input time series. A fundamental limitation of the cross-correlation function is that it is a second-order statistic and thus a function of only one variable, the time lag between the two input time series. Lu and Ikelle (2001) suggested the use of "higher order statistics" in the analysis of correlation between time series, specifically seismic traces, based on earlier work by Yung and Ikelle (1997). They identified a particular "third order cumulant" involving three input time series as having promise for the detailed analysis of time series correlations. When two of the three input series are identical, the third order cumulant they describe is known as the cross-bicorrelation, a function of two variables, both time lags, which maps simultaneously the correlations between events on the identical traces and between events on the dissimilar traces. It can be thought of as a function which exposes the details of both the autocorrelation and cross-correlation of a given input series with a second input series. For any two input series, therefore, there are two distinct, but related cross-bicorrelation functions, depending upon which input series is specified twice as input. The doubly designated input trace can be considered the "reference" trace against which both it and a second input trace are correlated simultaneously.

Because the individual peaks in the cross-bicorrelation function can often be identified with correlation of specific events on the input traces, the function can be useful in activities involving seismic event picking and can help resolve individual event correlations which are averaged together in the standard cross-correlation. The work by Lu and Ikelle (2001) illustrates the use of this function in seismic event analysis. Another, related function is also described, the normalized cross-bicorrelation function, in which the Fourier spectrum of the cross-bicorrelation is divided or "normalized" by the spectrum of the auto-bicorrelation. The inverse Fourier transform of the normalized spectrum then constitutes a "whitened" cross-bicorrelation in which the correlation peaks are sharper and better separated. The mathematical formulae for both the cross-bicorrelation function and its normalized form are given in a companion report chapter

(Henley and Haase, 2005), as well as in the original source material (Lu and Ikelle, 2001). They were originally programmed in Fortran by Haase, then incorporated into a ProMAX module by Henley.

The ProMAX module BICORR makes it easy to compute the cross-bicorrelation or auto-bicorrelation function for any two input seismic trace segments. Because the output of the function is a seismic trace gather, it can easily be manipulated using other standard seismic modules to produce further results. As described in Henley and Haase (2005), in addition to simply analyzing the display of the cross-bicorrelation function, the function or its transpose can be summed or “projected” to yield the autocorrelation or cross-correlation functions. Furthermore, the function can be re-mapped along a slant trajectory using the linear moveout function or the radial trace transform to alter the geometric relationships of its component peaks. Single profiles or curves can be extracted from the function or its transpose in order to “select” a particular correlation relationship, and the function can also be smoothed by trace mixing, running average, or other means before extracting a correlation curve.

BICORR—THE PROMAX MODULE

The ProMAX module BICORR is included with the 2005 CREWES software release; and although its documentation should be complete enough to enable the user to run it without problems, the module and its parameters will be described here as well, for completeness. BICORR is intended to be applied to ensembles of seismic traces, so input data must be in the form of ensembles with at least 2 traces each (unless the desire is to only compute auto-bicorrelation functions). Even a seismic section can be re-cast as an ensemble, however, by manipulations with the ProMAX functions TRACE HEADER MATH and INLINE SORT. BICORR selects input traces by absolute trace count within the current gather, but NOT by looking at the SEQNO trace header. In other words, it accepts an entire ensemble, whatever that may be, then selects two traces based on its own absolute trace count within the input ensemble. Below is a list of the input parameters required by BICORR:

- **Length of correlation window**—this parameter determines the length of the input trace segments that will be correlated against each other. This value, converted to samples, in turn determines the number of traces to be created for the output ensemble that constitutes the cross-bicorrelation function, as well as the length of the output correlations (twice the window length). The units of this parameter are ms. If the “normalize” option is chosen below, this parameter value is forced to a power of two less than or equal to the input value; so selecting a power of two as the input value can have some advantages. The default value is 256 ms.

- **Begin time of correlation window**—this parameter places the window at the starting position on both input traces desired by the user. Its units are ms, and the default value is 0 ms.

- **Trace number of the first trace**—this is the sequence number within the input ensemble of the first trace to be used in the function. It is an explicit trace count, NOT the value of the SEQNO trace header which may be present. Since the entire ensemble is present in memory, any trace number within the ensemble may be chosen, and it need not be smaller than the following parameter. The first trace is also the reference trace for the cross-bicorrelation function. The default value is 1.

- **Trace number of the second trace**—this is the sequence number within the input ensemble of the second trace chosen for the function. It is an explicit trace count, NOT the value of the SEQNO trace header which may be present. This parameter value need not be larger than the previous one…in fact it can be the same, in which case the auto-bicorrelation function is computed; or it can be smaller, in which case the cross-bicorrelation function computed is complementary to the one computed with the trace order reversed. The default value is 2.

- **Transpose switch**—when this parameter is set to one, the function which is written out is the transpose of the cross-bicorrelation function. This is useful when a particular correlation profile is to be extracted from the function, or when the function is to be summed or projected. Default value is 0.

- **Function normalize switch**—this switch parameter, when set to one, causes the normalized cross-bicorrelation function to be computed instead of the regular cross-bicorrelation. The default is 0.

- **Stability factor for spectral division**—because the normalization of the cross-bicorrelation function involves spectral division, this parameter determines the size of the constant to be added to all the elements of the divisor spectrum in order to avoid any division by zero. This factor is expressed as a decimal fraction of the peak amplitude of the divisor spectrum. The default is 0.001.

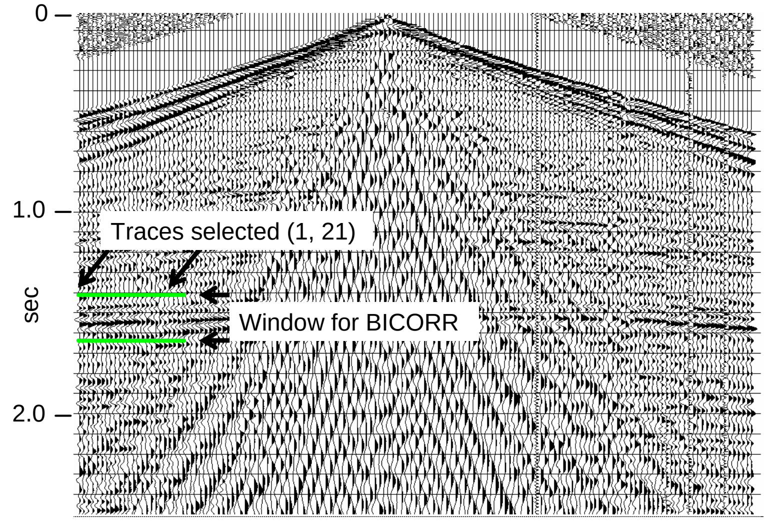
The cross-bicorrelation function is output as an ensemble, but only has a few rudimentary trace headers. In order to facilitate further processing using the function, it is useful to create a few of the more fundamental trace headers using TRACE HEADER MATH. One of the more useful headers to consider is OFFSET. With proper values in this header field, the traces can be stacked, mixed, tilted with linear moveout, or transformed to the radial trace domain, for example.

EXAMPLES

An accompanying chapter (Henley and Haase 2005) illustrates the use of BICORR on a simple synthetic model. Here, we demonstrate the function on actual seismic field data. Figure 1 shows the seismic trace ensemble that we used for the demonstration. In this gather, traces 1 and 21 were used to generate the cross-bicorrelation function.

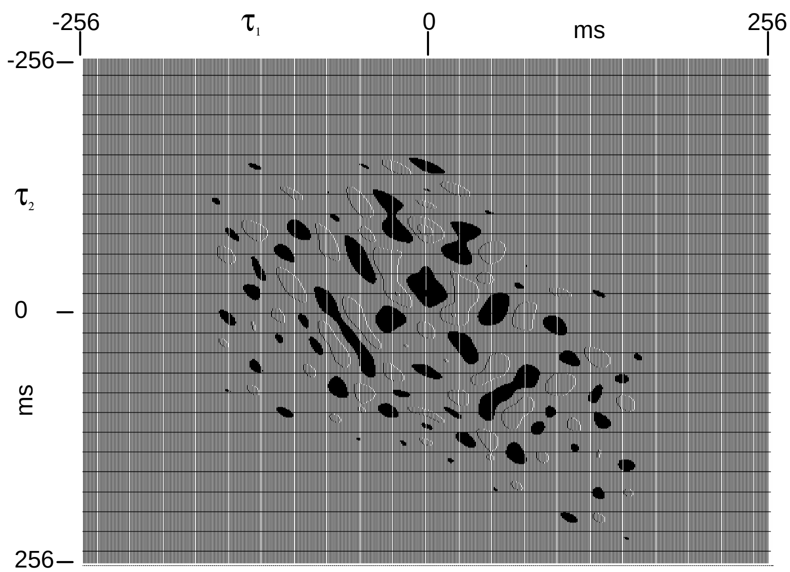
A note on terminology:

In what follows, the term “transpose” simply indicates that the cross-bicorrelation function displayed contains all the same values as the “regular” function, except that they have been reflected about the diagonal, and the τ_2 axis is now the left axis of the plot, while the τ_1 axis is the top axis, rather than vice versa.



Blackfoot shot gather showing trace segments selected for BICORR

FIG. 1. Shot gather from Blackfoot 2D 3C seismic survey used to demonstrate the ProMAX function BICORR.



Transpose cross-bicorrelation function for Blackfoot trace segments

FIG. 2. Cross-bicorrelation function for gated segments of traces 1 and 21 of the Blackfoot shot gather in Figure 1. Transpose means that the transpose switch in the ProMAX function is set to 1, so that summing the traces (projection) yields the cross-correlation of traces 1 and 21, rather than the autocorrelation of trace 1.

Figure 2 is a wiggle/var display of the cross-bicorrelation function generated by BICORR for 256 ms lengths of traces 1 and 21 of the ensemble in Figure 1. The start of each window was 1400 ms. Figures 3 and 4 show the same cross-bicorrelation function, but displayed using greyshade and color, respectively.

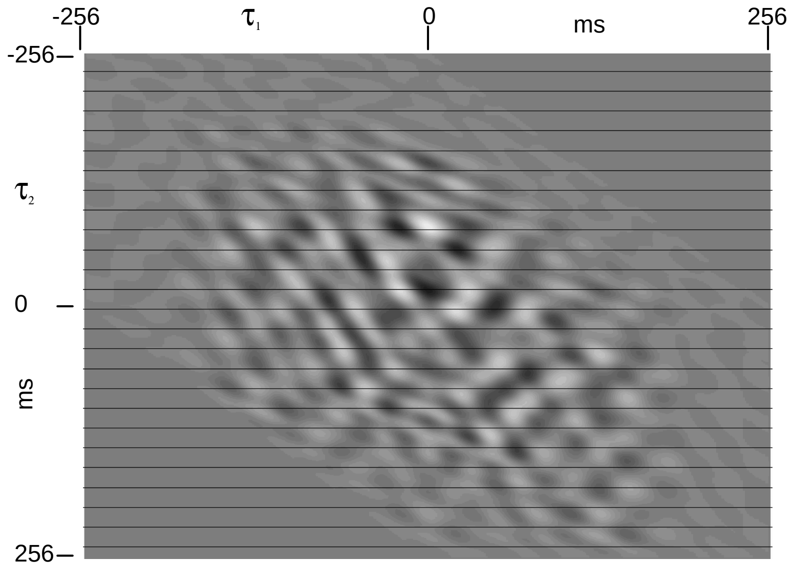


FIG. 3. Cross-bicorrelation function of Figure 2 displayed in greyshade format. Relative peak height is more apparent on this display.

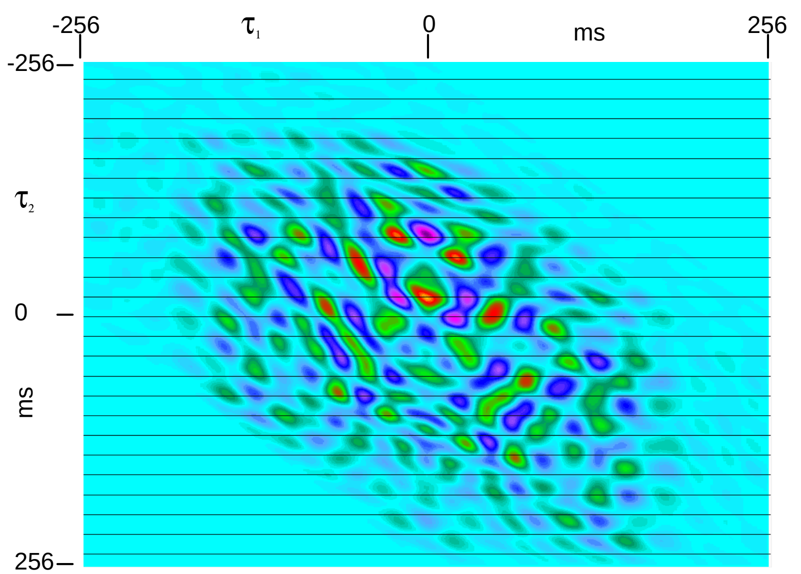


FIG. 4. Cross-bicorrelation function of Figure 2 displayed in colour contour format. Relative peak heights are even more readily seen than on the greyshade representation in Figure 3.

When the parameters specify the normalized cross-bicorrelation, the result is as shown in Figure 5, for a stability factor of 0.001. Note the much increased sharpness of the correlation peaks, but also the more coherent background noise correlations. Figure 6 is the result of summing the function in Figure 2 and replicating the trace for display. Each trace is now the cross-correlation of trace 1 with trace 21. Specifying the original function instead of the transpose, as in Figure 7, and summing it before replication results in the autocorrelation function of trace 1 (Figure 8). The same summation can be done for the normalized cross-bicorrelation function, and the result is a function (replicated and displayed in Figure 9) similar to the coherence function for traces 1 and 21.

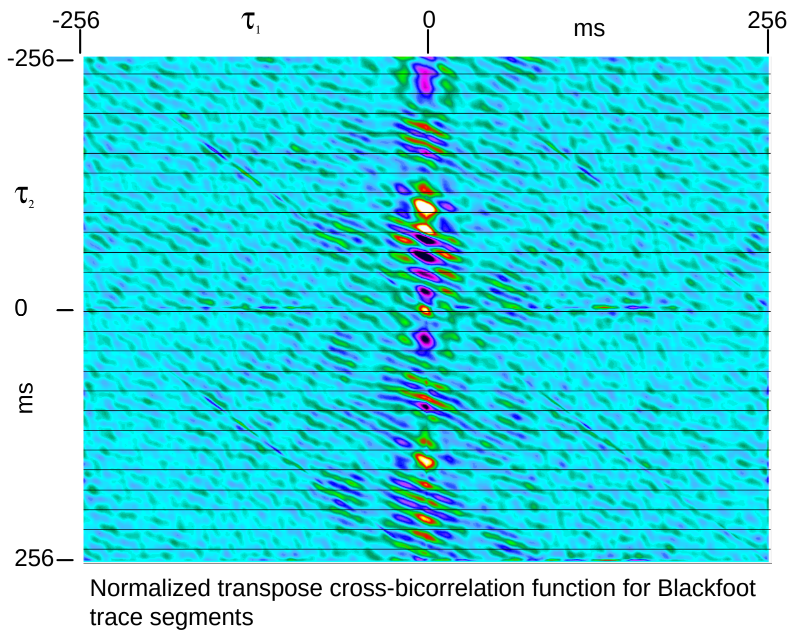
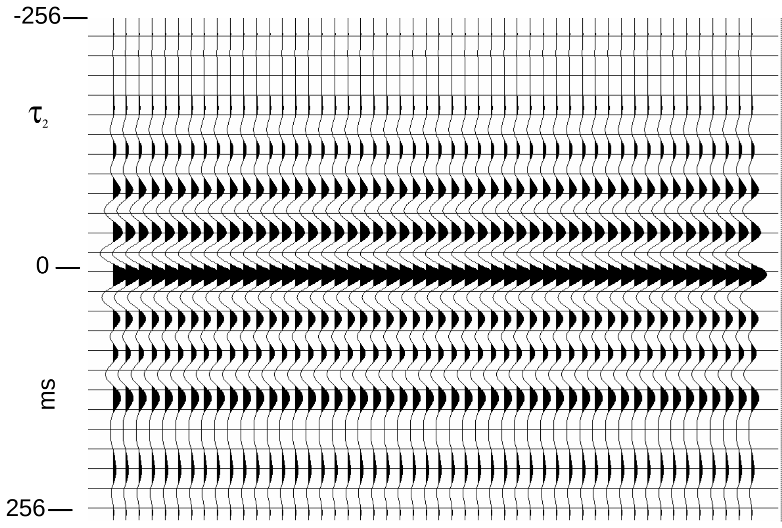
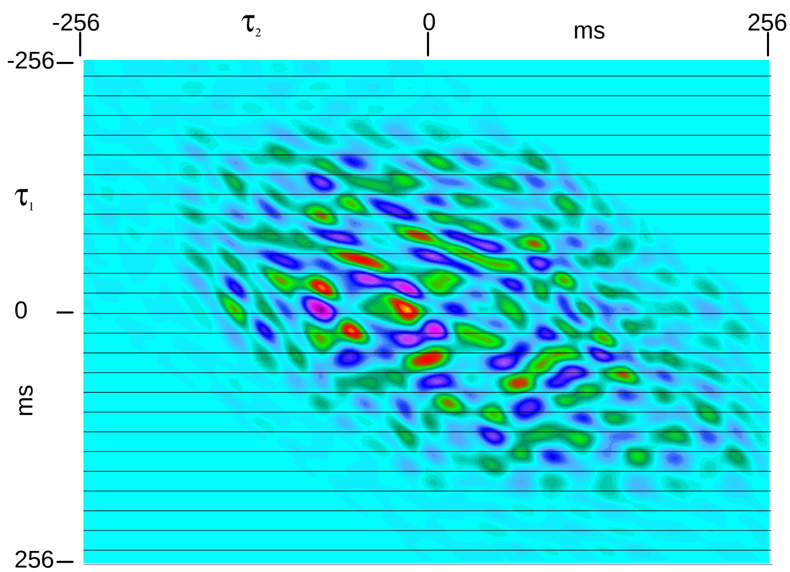


FIG. 5. Spectrally normalized cross-bicorrelation function for Blackfoot trace segments.



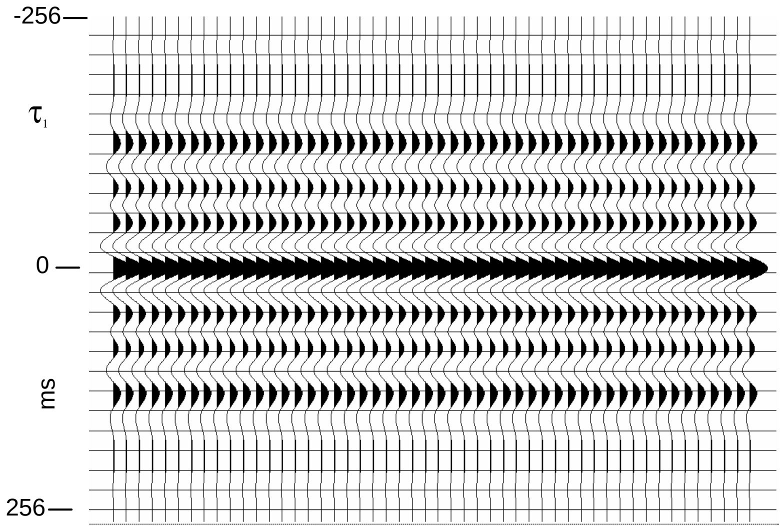
Cross-correlation function projected from transpose cross-bicorrelation in Figure 4

FIG. 6. Summation or "projection" of cross-bicorrelation function in Figure 4. This is the cross-correlation of input trace segments 1 and 21.



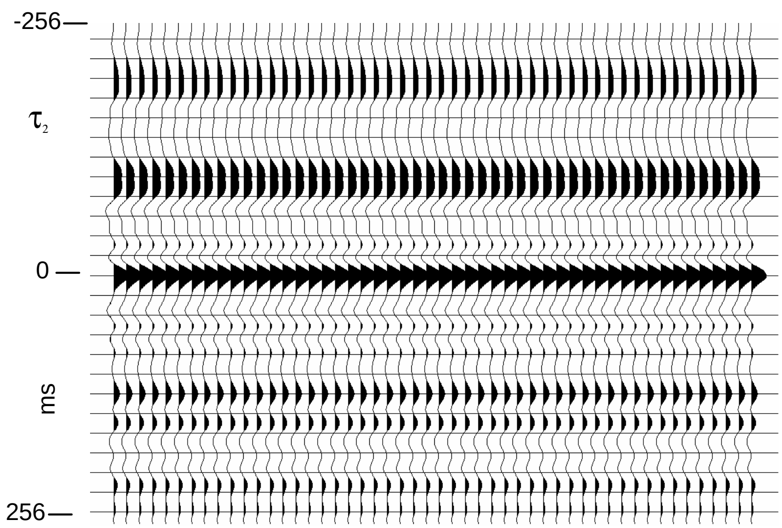
Regular cross-bicorrelation function for Blackfoot trace segments

FIG.7. Regular cross-bicorrelation function (no transpose) for Blackfoot trace segments 1 and 21.



Auto-correlation function projected from cross-bicorrelation in Figure 7.

FIG. 8. Summation or "projection" of the cross-bicorrelation function in Figure 7. This is the autocorrelation of trace segment 1 of the Blackfoot shot gather.



Cross-correlation function projected from normalized transpose cross-bicorrelation in Figure 5.

FIG. 9. Summation or "projection" of the cross-bicorrelation function in Figure 5. Note the improved resolution over Figure 8.

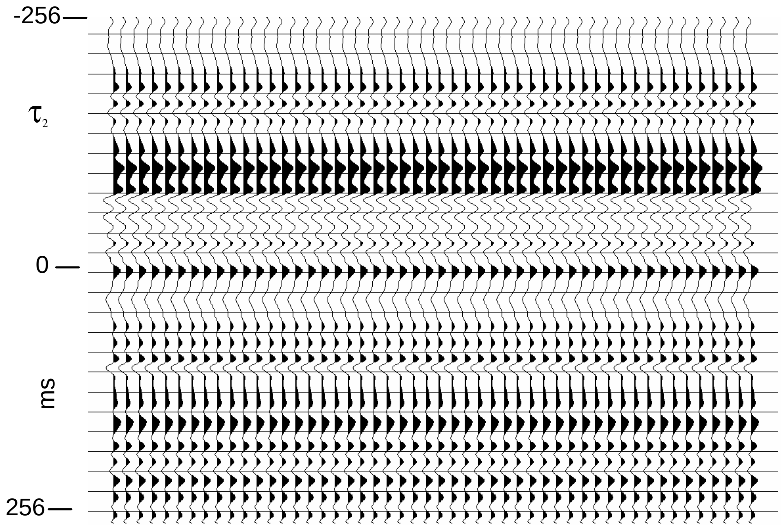
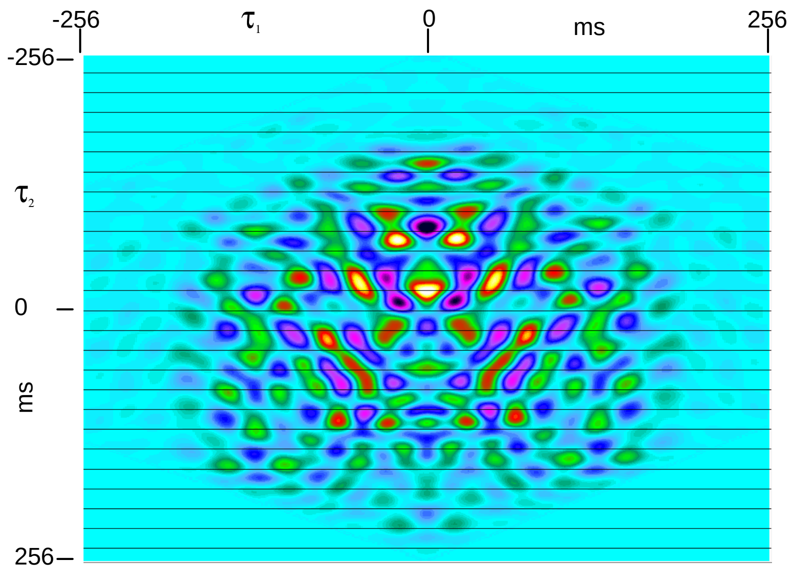


FIG. 10. Central profile extracted from the cross-bicorrelation function in Figure 5. Noise on this function is greater than that on Figure 9, where the summation has helped suppress subsidiary correlations.

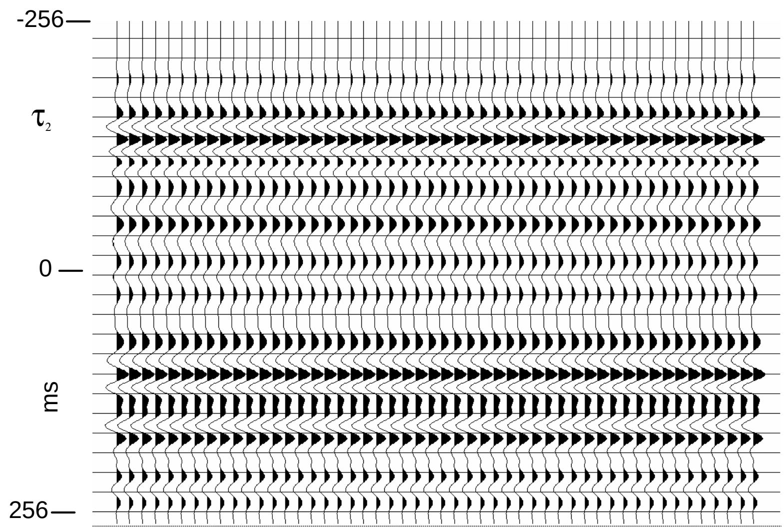
Figure 10 shows an example of extracting a single profile from the cross-bicorrelation function and replicating it, in this case the central correlation profile of the normalized cross-bicorrelation function. The most nearly comparable display is the summed function in Figure 9. The resolution of the images around the central peaks is similar, but the summed function seems to have smaller amplitudes away from the centre due to cancellation of the “noise” correlations in the summation. Another trick that can be used to attempt to improve correlation resolution is to remove the apparent slope of the cross-bicorrelation function by applying linear moveout (result in Figure 11). This provides a different relative orientation of the various correlation peaks in the function, so that the summation looks like Figure 12. Although the central correlation peaks are “thinner” in the tilt direction than in the originally plotted orthogonal time lag direction, their summation does not seem to be more highly resolved, probably because the realignment of the various peaks means that they overlap and interfere when summed.Selecting the central profile, as in Figure 13, however, restores the correlation resolution while reducing the influence from side lobes.

Remapping the normalized cross-bicorrelation function (Figure 5) results in Figure 14. Although the central peaks are apparently more highly resolved in this figure, the side lobe correlations are also obviously aligned, so that the projection shown in Figure 15 shows mostly side lobe energy. Selecting the central profile, as in Figure 16, however, restores the highly resolved central correlation. Comparison with Figure 10, on the other hand, shows that remapping the normalized cross-bicorrelation has no effect on the resolution of the central profile.



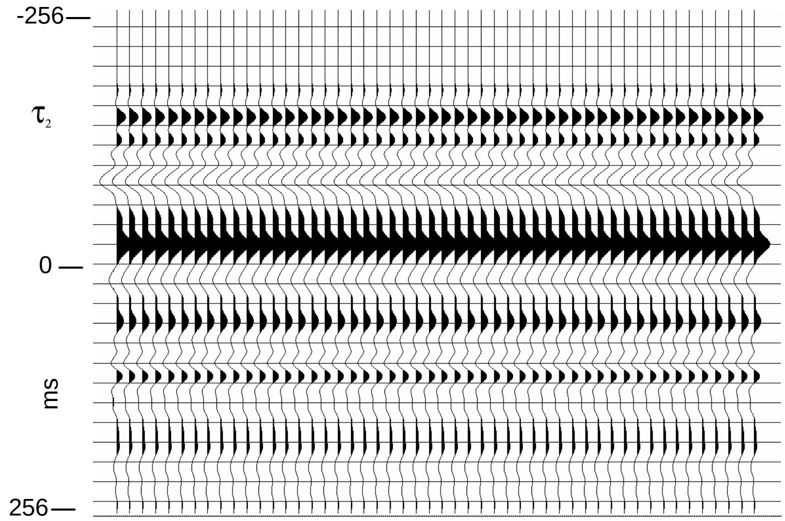
Remapped transpose cross-bicorrelation function for Blackfoot trace segments

FIG. 11. Cross-bicorrelation function remapped along a slope which aligns various subsidiary correlation peaks.



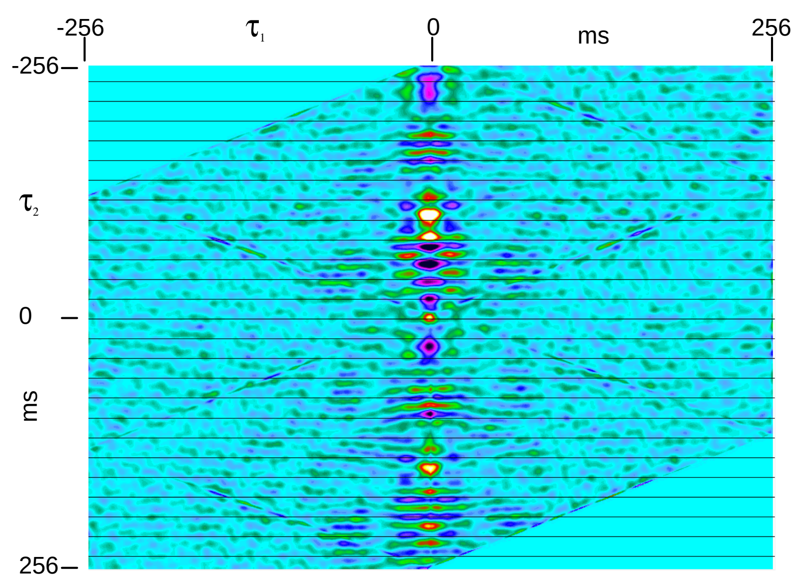
Projection of remapped transpose cross-bicorrelation in Figure 11.

FIG. 12. Summation or "projection" of remapped cross-bicorrelation function in Figure 11. Central correlations are much reduced by this projection.



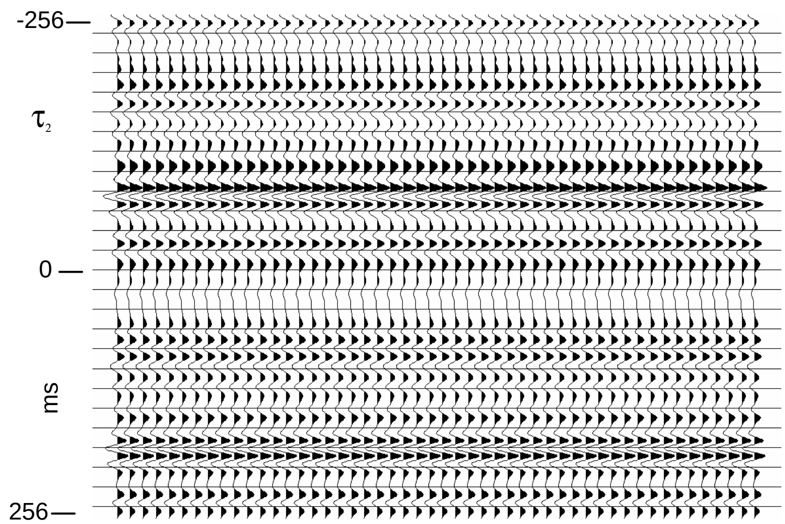
Central profile selected from remapped transpose cross-bicorrelation in Figure 11.

FIG. 13. Central profile selected from cross-bicorrelation function in Figure 11. This selection captures the principal correlations and greatly reduces the subsidiary correlations.



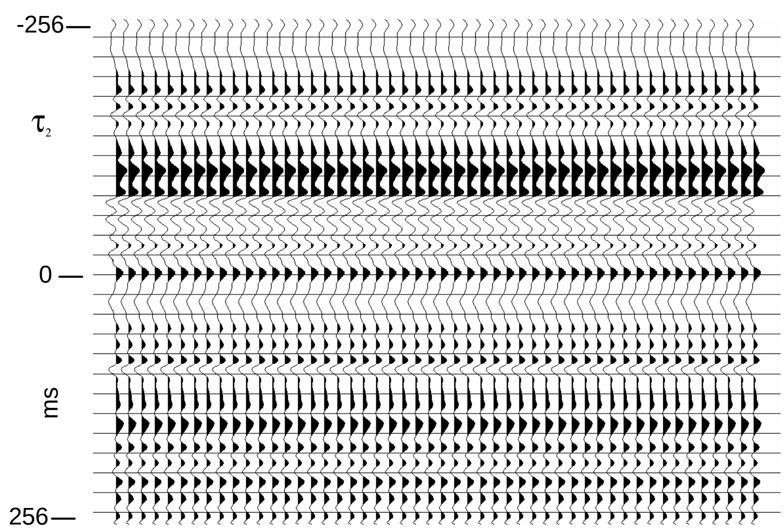
Remapped normalized transpose Cross-bicorrelation function for Blackfoot trace segments

FIG. 14. Normalized cross-bicorrelation function from Figure 5 as remapped along a slope parallel to the visible correlation noise.



Projection of remapped normalized transpose cross-bicorrelation in Figure 14.

FIG. 15. Projection of the remapped normalized cross-bicorrelation function in Figure 14. Although some of the principal correlations are enhanced, so is the background noise. The main correlation near $\tau_2 = 0$ is almost totally obscured, although visible on Figure 14.



Central profile selected from normalized remapped transpose cross-bicorrelation in Figure 14.

FIG. 16. Central profile selected from the remapped, normalized cross-bicorrelation function in Figure 14. The central correlation at zero is now visible, as well as the other principal correlations.

Simple diagnostic ProMAX processing using BICORR

We have described briefly above some of the kinds of analysis that can be used with the cross-bicorrelation function BICORR. Here, we will briefly describe the simple processing streams used to obtain these results, as well as those described in Henley and Haase (2005):

- To obtain the autocorrelation function from BICORR, default the transpose switch in BICORR to zero, follow the function with “CDP/Ensemble stack”. To replicate the trace for plotting, use “Reproduce Traces”.
- To obtain the cross-correlation function from BICORR, set the transpose switch in BICORR to one, follow with “CDP/Ensemble stack” and “Reproduce Traces”. *For most diagnostic purposes it is more useful to compute the transpose of the cross-bicorrelation function, than the original function.*
- To analyze slope within a cross-bicorrelation function in terms of linear moveout, use “Trace Header Math” after BICORR to set up the trace header OFFSET. Use an equation which sets the offset value of the central trace of the function to zero (offset = seqno*10 – 2560, for example). The velocity tool in “Trace Display” can then be used to find any apparent slope in the display.
- To remap the cross-bicorrelation function along a slope, first display the function as above, with OFFSET trace headers, then find the slope with the “Trace Display velocity tool. Rerun BICORR and “Trace Header Math”, followed by “Linear Moveout Correction”, in which the velocity value determined from the velocity tool is used as the moveout velocity.
- To select a specific profile from the cross-bicorrelation function, follow the BICORR function with an “IF”/”ENDIF” loop in which the “IF” selects a trace from the cross-bicorrelation function based on the trace header SEQNO. Inside the loop should be “Reproduce Traces” followed by “Trace Display”.
- To smooth the cross-bicorrelation function prior to selecting a specific profile, as described in Henley and Haase (2005), apply “Trace Mixing” after any “Linear Moveout Correction” and before the IF/ENDIF loop.

CONCLUSIONS

We have introduced a new module for ProMAX which is useful for detecting and analyzing the correlation between specific events on two input seismic traces. The module requires seismic trace ensembles as input and generates a new ensemble as output. The module can be combined with other ProMAX modules to produce various correlation diagnostics for the input traces selected.

ACKNOWLEDGEMENTS

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