Internal multiple prediction and subtraction: well log synthetic

Andrew Iverson, Kris Innanen and Daniel Trad

ABSTRACT

Internal multiples can be a significant issue in the processing and interpretation of seismic data. The inverse scattering series internal multiple attenuation algorithm is used to predict and attenuate internal multiples. The algorithm has displayed success, especially in cases with separation between the primary and internal multiple events. A land dataset with a significant internal multiple problem has been donated to CREWES. The focus of this report is on synthetic tests created from the donated well logs prior to analysis of the donated seismic data. Several objectives are examined here, including confirmation of the multiple issue through modeling, and assessment of the applicability of the method to predict and attenuate internal multiples in this case. It is shown that a careful implementation of the method using 2D adaptive subtraction successfully attenuates internal multiples, even where there is significant overlap between primary and multiple energy.

INTRODUCTION

A data set including an extensive well log suite, VSP and 3D seismic was donated to CREWES due to the presence of significant internal multiples in the data. To predict and attenuate internal multiples the inverse scattering series internal multiple prediction is utilized (Weglein et al., 1997). Prior to the prediction analysis on the recorded data, synthetics from the well logs will be generated to both confirm the issue of internal multiples and to test the inverse scattering series internal multiple prediction algorithm for its applicability to this dataset. There is a companion report which will demonstrate the prediction on the recorded datasets provided (Iverson et al., 2018a). The modelling utilizes the sonic and density logs sampled at 0.5ft intervals with an approximate length of 11000ft (Figure 1). The logs in the near surface are missing so the values are extrapolated to the surface. The single additional layer to the surface was chosen over a possibly more complex model so the dataset will use only measured values.

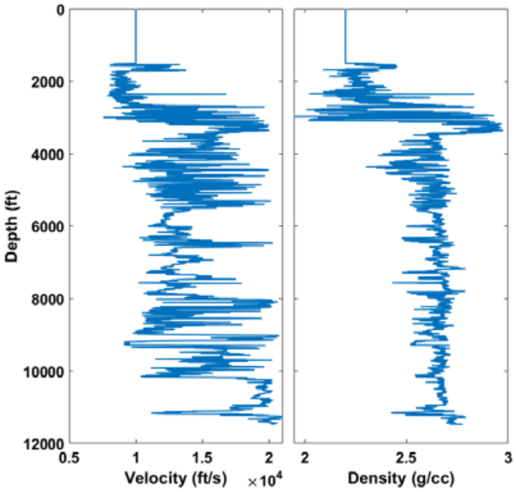

FIG. 1. (Left) Sonic log (Right) Density log to be used in creating synthetic VSP

SYNTHETIC DATA MODELING

Synthetic modeling will allow for the comparison to the recorded seismic data with both primaries only and primaries and internal multiples synthetics. Two different synthetics are generated to model both the VSP and the reflection seismic data due to frequency content variations between the data sets. The central frequency of the VSP is approximately 30 Hz where the PSTM data is 37 Hz (Iverson et al., 2018a). The process of creating the synthetic VSP and the analysis will be outlined for the 30Hz case and the results will be displayed for both frequency content synthetics.

Synthetic modeling algorithm

The method to generate synthetic seismic will use layer propagator matrices. This is done using the function vspq from the CREWES MATLAB toolbox (Margrave, 2014). The method allows for fast calculations of a trace that includes all orders of internal multiples by creating propagator matrices depending on the number of layers. This can calculate various synthetic outputs including primaries only, primaries and internal multiples, surface multiples and other combinations (Margrave, 2014). The function from the toolbox is used to calculate a VSP which includes only primaries and internal multiples. An assumption of the internal multiple prediction algorithm is a dataset with only primaries and internal multiples. This tool also has the option to include Q in the computation for attenuation and changes to the wavelet. For this study Q is not included.

Synthetic VSP

The synthetic VSP was created using the following parameters. A zero phase 30 Hz Ricker wavelet was used as the source, the desired output is the displacement spectrum, sampled at 0.002ms with a record length of 6 seconds. Though the well depth is only 11000ft and the well bottom travel time is approximately 2 seconds the rest of the multiple train is also recorded. The data which was originally sampled at 0.5ft intervals was resampled to 5ft intervals to decrease the number of layers for the computation and the geophones were inserted at every layer (5 ft). The resulting synthetic VSP is displayed with the recorded VSP for a qualitative comparison (Figure 2).

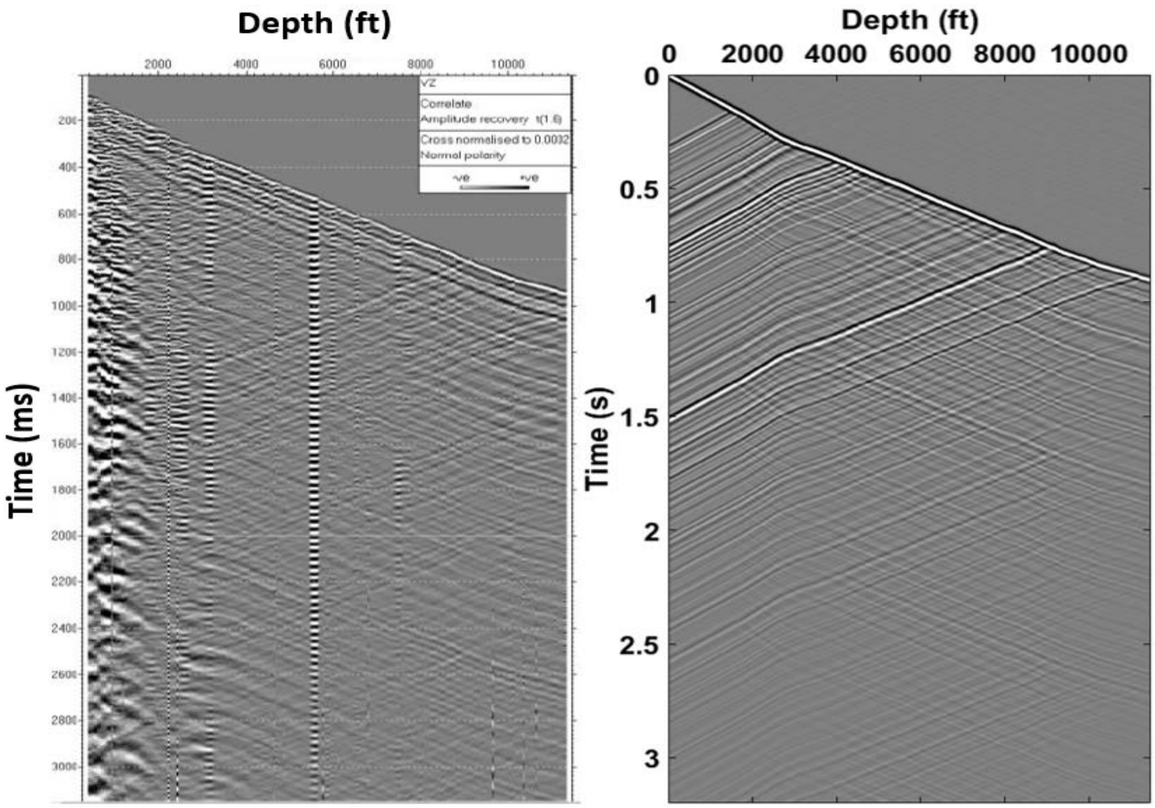

FIG. 2. (Left) Recorded VSP with up and downgoing waves, (Right) Synthetic VSP with up and downgoing waves

The only processing step required for the synthetic VSP is to flatten the data, so the corridor stacks can be generated. Once internal multiples are included in the modeling the travel times no longer obey a simple travel time relationship. That is due to short path internal multiples causing dispersion in the wavefront altering the arrival time of the direct wave. To overcome this the flattening of the data was completed by combing both first break picking and using the exact calculated travel times (Figure 3).

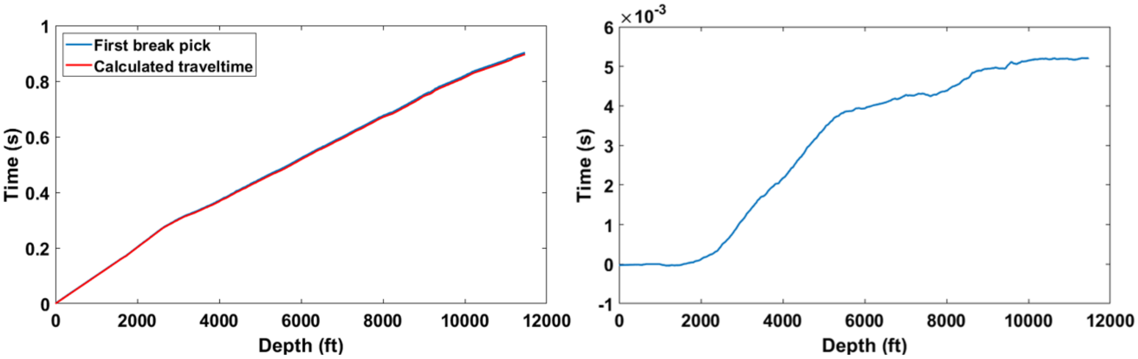

FIG. 3. (Left) calculated one way travel time and picked one way travel time (Right) Smoothed difference between the two one way travel times

By using this combination of a first break pick and the calculated travel time an accurate first break is calculated, and the result is flat VSP (Figure 4). This is critical because if the VSP is not properly flattened this will cause errors in the calculation of the corridor stacks.

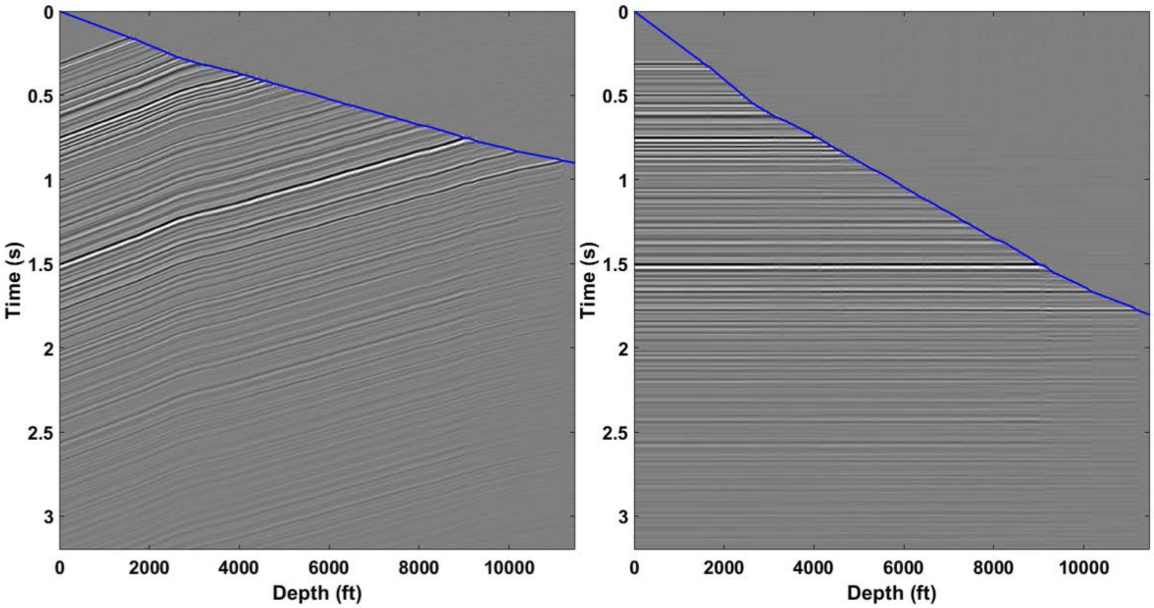

FIG. 4. (Left) Synthetic VSP with first break pick displayed in blue with upgoing events (Right) flattened synthetic VSP with first break pick displayed in blue with upgoing events

Displayed is the final flattened upgoing VSP (Figure 5). There are three traces that will created and used in the internal multiple prediction analysis, the outside corridor stack, full stack and zero depth trace.

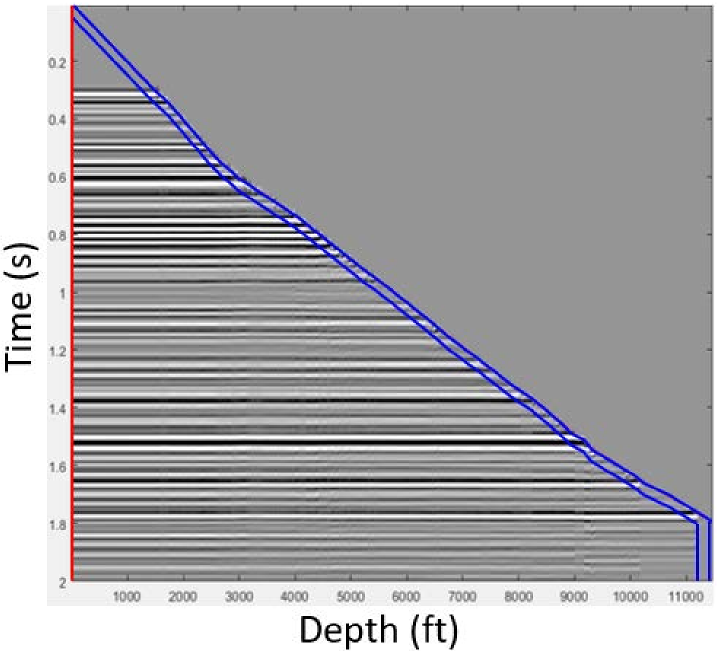

FIG. 5. Flattened synthetic VSP displaying outside corridor stack (primaries) in blue and zero depth trace (primaries and multiples) in red.

The outside corridor stack is created by stacking the outside 25 traces. These events represent the reflected seismic waves that have traveled a short distance before being recorded by the geophone. The reflected waves are recorded directly after the first arrival of the downgoing source wavefront. The resultant stack approximates a primaries only trace, though it should be noted that there will be some short path internal multiples included. For the purposes of this project this will be referred to as the primaries only trace. The second trace is the zero depth trace, this is identical to a geophone on the surface and would be the same as a standard reflection survey. This trace will have both primaries and internal multiples as would be recorded on the surface. The last trace to be analyzed is the full corridor stack which is a stack of all the data to again give an estimate of the primaries and internal multiples trace. For the noise free synthetic the full stack is not as necessary as we can use the single zero depth trace. In practice when there is noise present in the data the full stack can assist in removing noise to result in an approximation of the primaries and multiples trace. The critical comparison to be made is between the outside corridor stack and the zero depth trace (Figure 6). The difference of these two traces gives an estimate of the internal multiple trace as recorded on the surface. This assists in determining the severity of the internal multiples in the trace and at what time in the seismic record they have the potential to be detrimental.

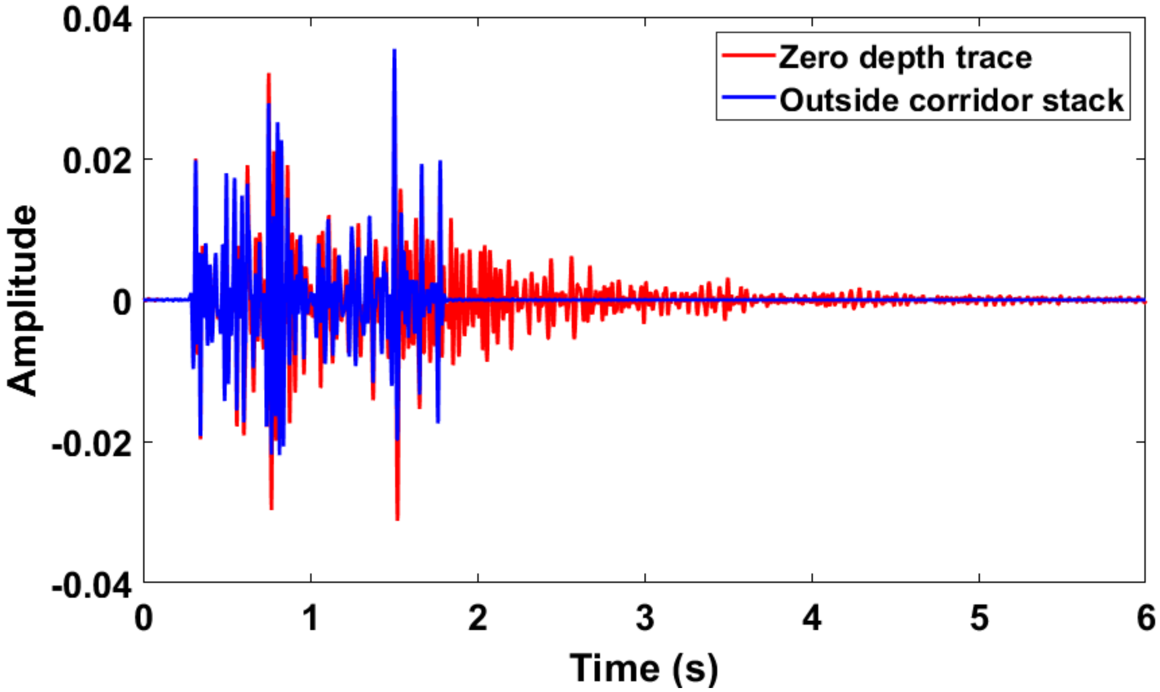

FIG. 6. Outside corridor stack (primaries) in blue and zero depth trace (primaries and multiples) in red, note after approximately 1.9 seconds the well log ends.

The outside corridor stack ends at approximately 1.9 seconds which corresponds to where the well log data ends. After this there are no longer any primaries and the subsequent data is all internal multiples. The same plot is made but restricted to this time limit (Figure 7). At these earlier times there are no multiples which are isolated from a primary. The resulting primaries and internal multiples trace has similar character to the primaries only but with drastically different amplitudes due to the internal multiples. This overlapping primary and multiple energy can make it difficult when attempting to estimate the amplitudes of the multiples for subtraction during the adaptive subtraction step.

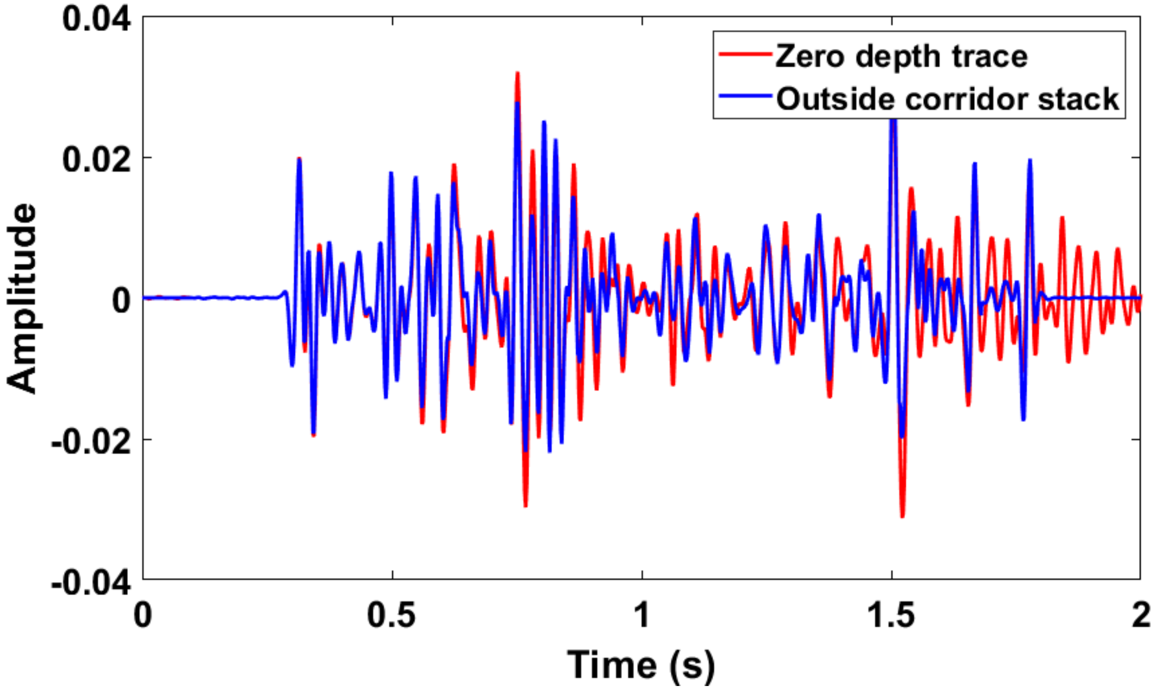

FIG. 7. Outside corridor stack (primaries) and zero depth trace (primaries and multiples).

Next the full stack and zero depth trace are compared (Figure 8). These are both approximations of a primaries and internal multiples with some differences. Ideally the zero depth trace is used but this may not be possible due to noise. It is shown that some multiples that are not properly estimated with the full stack, but it is a reasonable estimate to use if the zero depth trace is not feasible.

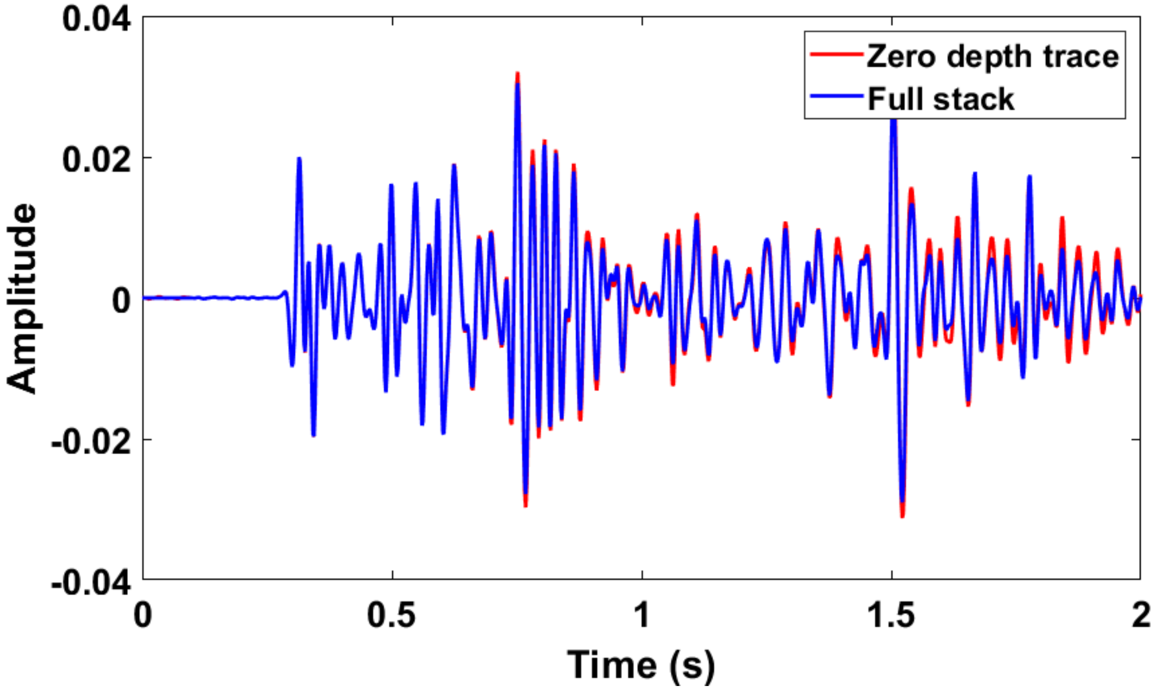

FIG. 8. Full stack (primaries and multiples) and zero depth trace (primaries and multiples)

INTERNAL MULTIPLE PREDICTION

The prediction is carried out on the zero depth trace using the frequency domain version of the algorithm with an epsilon value of 15. For the given sampling rate and frequency content this epsilon value should prevent artifacts in the prediction. The results are displayed in the downward generator space (Figure 9). This downward generator space is used to carry out the adaptive subtraction (Iverson et al., 2018b; Keating et al., 2015). The generator space displays the complexity of the prediction when the input synthetic is also complex with numerous primaries and multiples which also overlap. The 2D downward generator space does not have isolated multiples as seen on simpler synthetics (Iverson et al., 2018b). This also displays how all the predicted internal multiples reside in the upper right half of the space noted by the blue line along the diagonal.

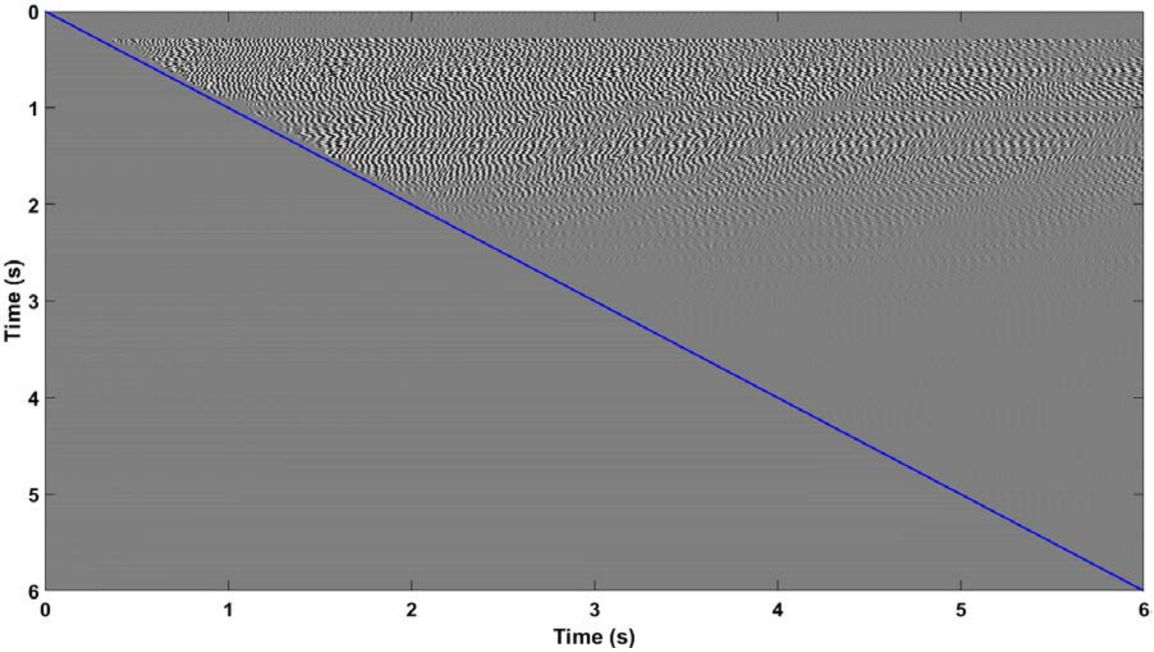

FIG. 9. The 2D Downward generator space for the zero depth trace prediction

To create the 1D prediction the 2D space is summed over the downward generator direction (rows). The 1D prediction is compared to the input zero depth trace which contains primaries and internal multiples (Figure 10).

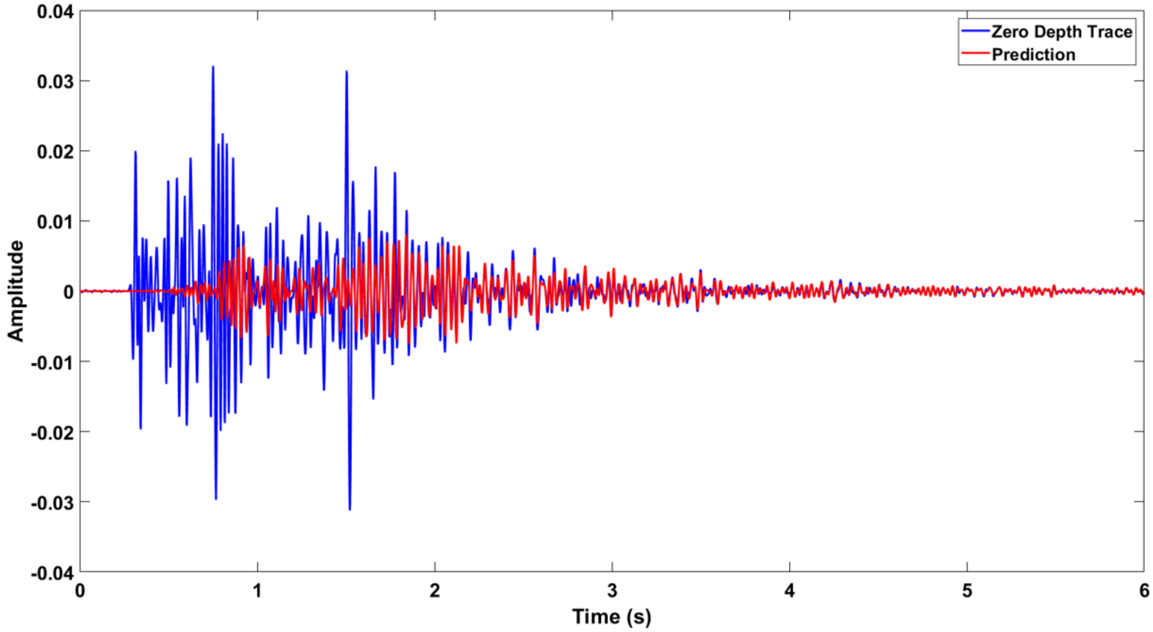

FIG. 10. Zero depth trace compared to the 1D internal multiple prediction

To determine the success of the prediction the multiples trace is created by subtracting the zero depth trace and the outside corridor stack and compared to the prediction (Figure 11). Overall the algorithm has been able to predict the internal multiples with some issues in the amplitudes of the predictions. The largest errors occur early in the trace until approximately 0.6 seconds. After this the predicted trace shares similar character to the multiple trace.

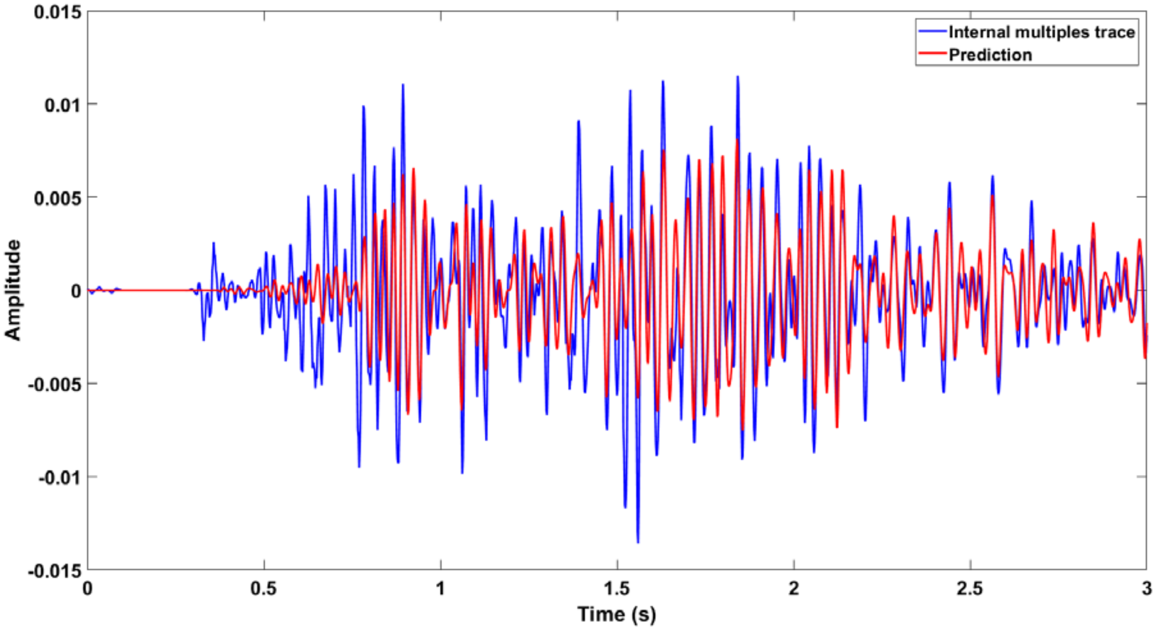

FIG. 11. Internal multiples trace in red and internal multiple prediction in blue.

The accuracy of the prediction is also quantified by evaluating the rolling average of the absolute value of the trace (Figure 12). This is completed on both the internal multiples trace and the subtraction of the internal multiples trace and the prediction. Note the absolute value of the difference will only reduce to zero if the multiple is predicted exactly. If the multiple is significantly overpredicted or incorrectly predicted in terms of polarity the plot will be higher than the baseline multiple trace. This metric is used so that locations of significant error will be displayed by crossover in this diagram. If the multiple is slightly under or overpredicted this will display as a reduction in the value. This raises the question of what successful multiple attenuation is. Often there is the concern of damaging primary energy when removing multiples. If a multiple is underpredicted than it is thought to have been partially attenuated. If the multiple is overpredicted than there are concerns that you are damaging primaries. This raises the question if it is more detrimental to have under attenuated multiples which may still obscure the primaries or overpredicted multiples and remove some primary energy. If there are concerns about damaging primaries, then the multiple prediction can simply be scaled back so that all events are underpredicted.

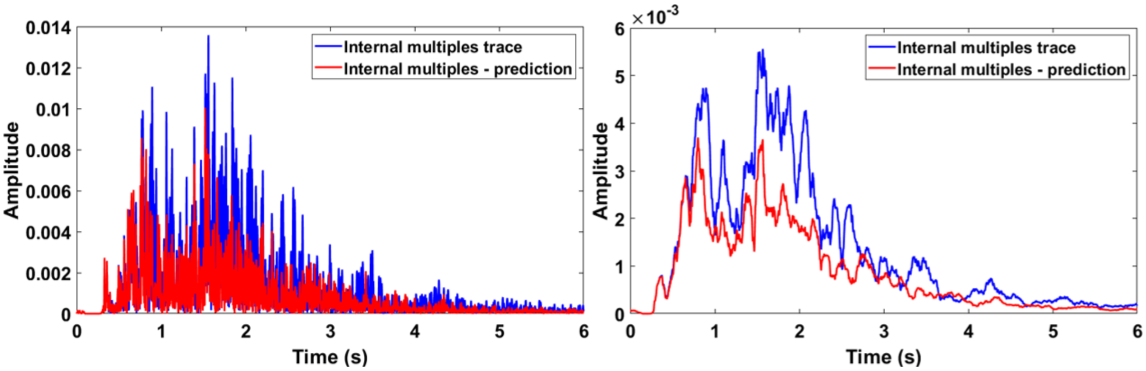

FIG. 12. (Left) Multiples trace in red and internal multiple prediction in blue taken as absolute value of the multiples trace and difference with the multiples trace (Right) a 50 point moving average window is used to smooth the traces.

The amount of multiple energy is shown to have decreased except for a few locations where the value is slightly higher. The prediction algorithm appears capable of successfully attenuating some of the internal multiples in the data.

Next the 2D adaptive subtraction is applied to the downward generator space. Though the adaptive subtraction is designed to vary slowly in the vertical direction it has been found helpful to reduce the number of traces in this direction through stacking (Figure 13). This will have two benefits, the first is to minimize overprediction by reducing the number of traces that can be combined to fit the data. The other is to reduce computational time as there are fewer filter coefficients to be calculated.

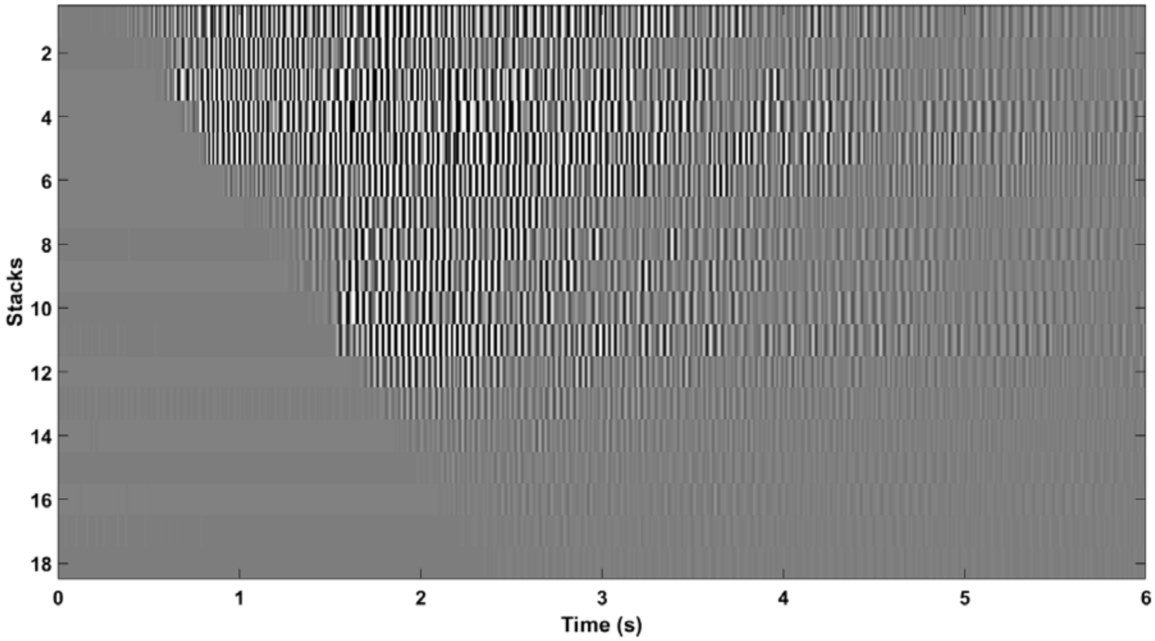

FIG. 13. Displaying the 2D downward generator space for the synthetic VSP after stacking

The result of the 2D adaptive subtraction is compared to the multiple trace (Figure 14). Again, there is a reasonable prediction to the internal multiple trace with the bulk of the mismatch occurring early in in the trace. It is difficult to see the uplift due to the 2D adaptive subtraction as there are still amplitude mismatches between the predicted result and the multiples.

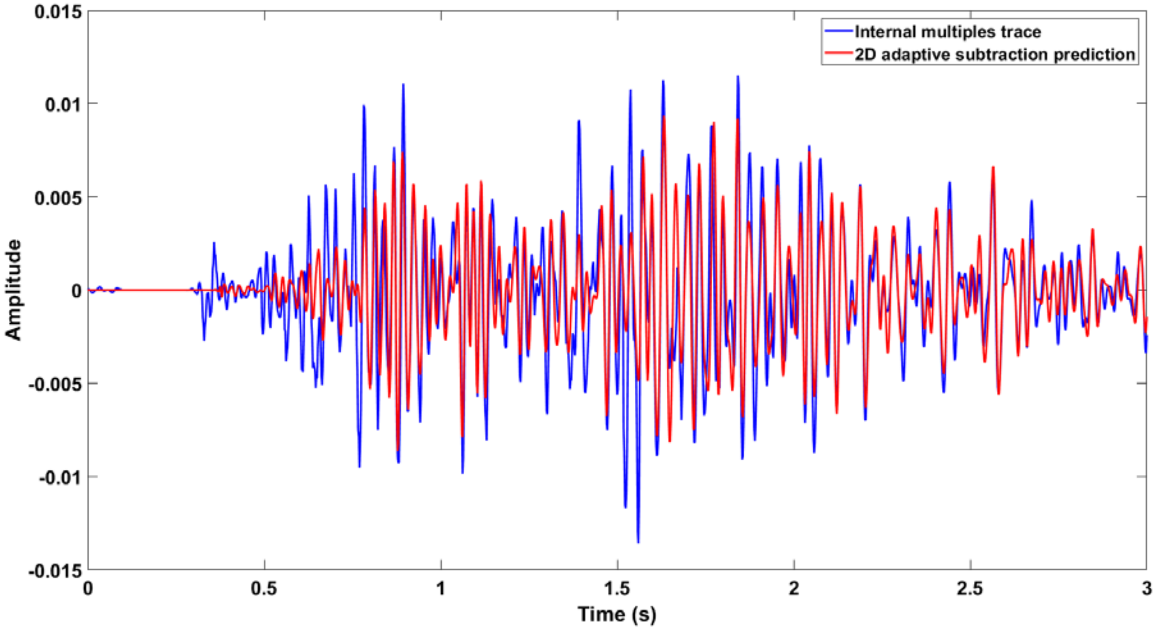

FIG. 14. Multiples trace and internal multiple prediction from 2D adaptive subtraction.

The numerical plots are created to compare the prediction and prediction with 2D adaptive subtraction (Figure 15). In both cases the multiple energy has been diminished.

The 2D adaptive subtraction has improved the prediction at mostly later times in the trace with some locations throughout where it has been slightly detrimental. Note that there are no primaries to obscure the prediction after approximately 1.9 seconds. This may have assisted the adaptive subtraction as there are some locations with isolated internal multiples. This may not be possible for recorded data cases as there will continually be primary energy.

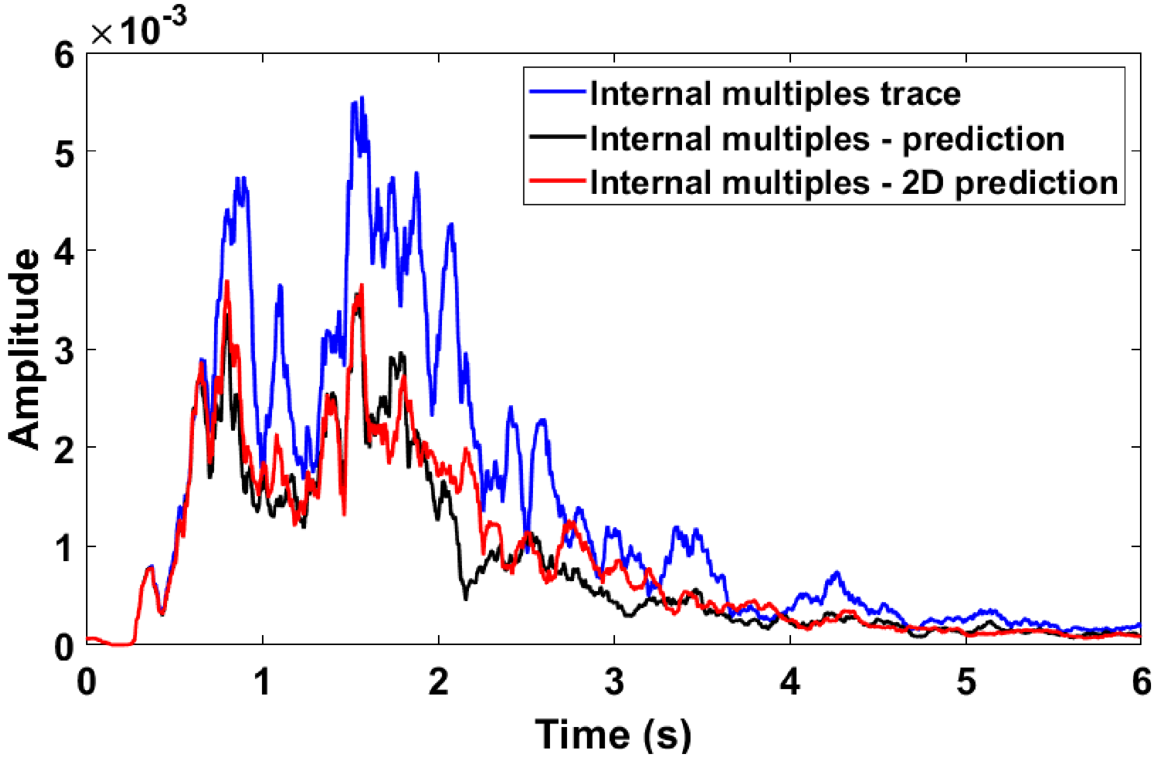

FIG. 15. Absolute value of multiple trace, and difference with the two predictions with rolling average window of 50.

Finally, this is compared qualitatively by looking at the three representative traces in a more conventional wiggle plot (Figure 16). These include the outside corridor stack which is the primaries only trace and goal to return to after internal multiple attenuation. The zero depth trace which is the input into the algorithm and includes primaries and internal multiples, and finally the result of attenuating internal multiples applying the prediction to the zero depth trace.

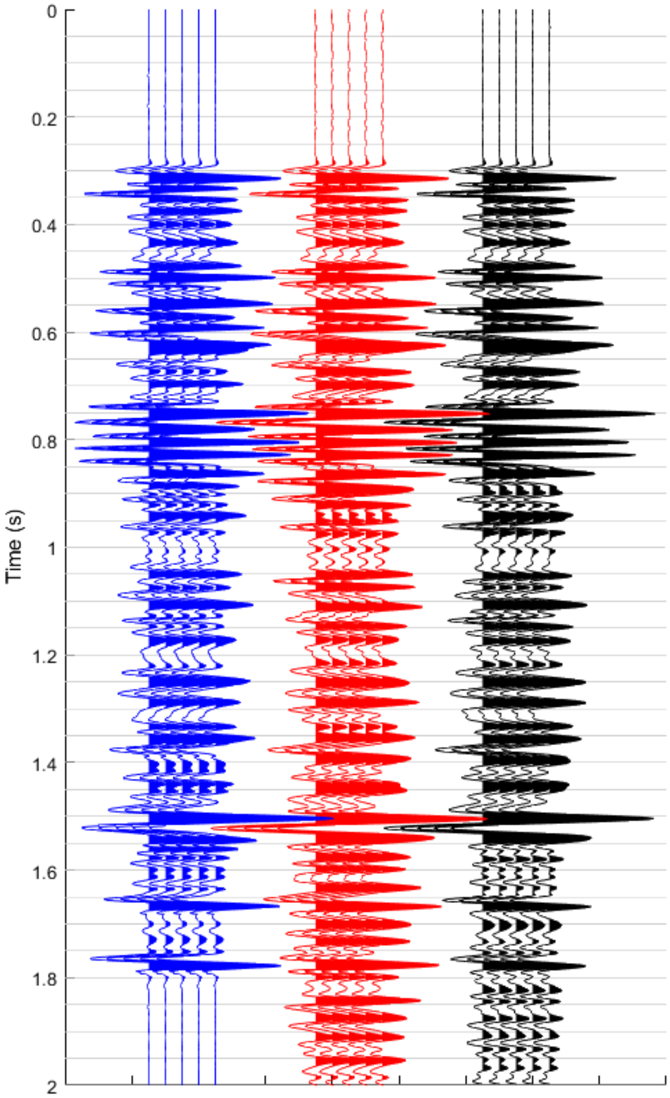

FIG. 16. outside corridor stack (primaries) in blue, zero depth trace (primaries and multiples) in red and zero depth trace after internal multiple attenuation in black.

The result is analyzed near the base of the trace where the initial internal multiple modeling shows significant internal multiples (Figure 17). For all images in the figure the blue and red traces remain constant, only the black trace changes as noted. All versions have done a remarkable job of taking the input trace which was significantly contaminated with multiples at this level and return the traces to a state where it resembles the primaries only trace. There are several locations with polarity reversals and events previously obscured events can now be imaged.

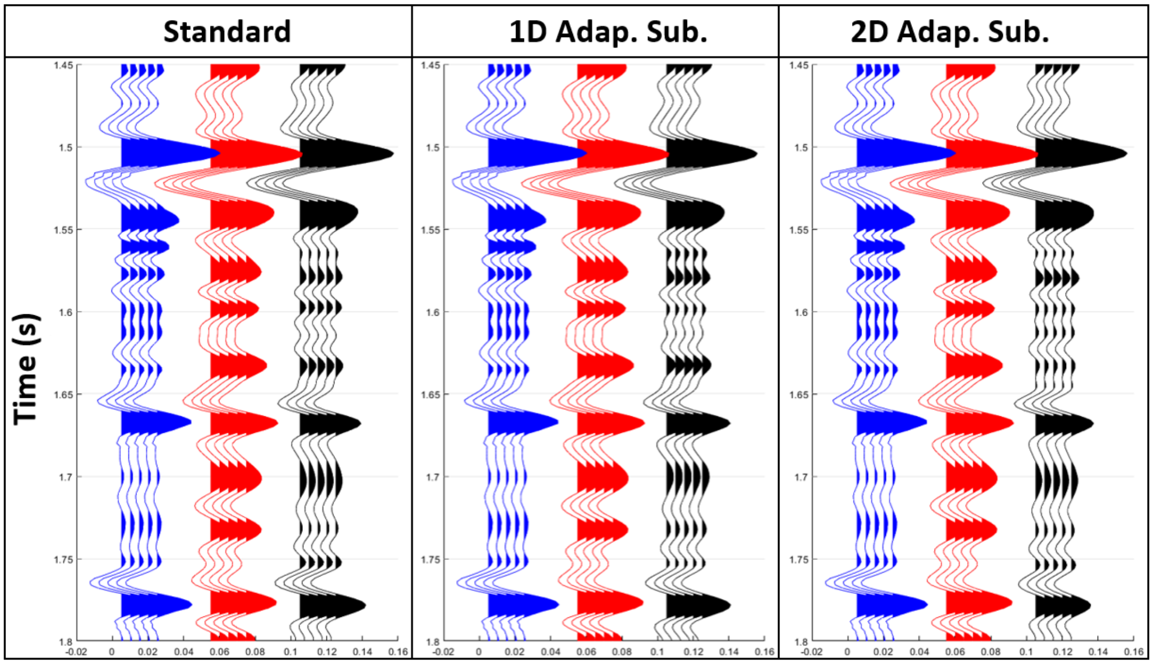

FIG. 17. Outside corridor stack (primaries) in blue, zero depth trace (primaries and multiples) in red and zero depth trace after internal multiple attenuation in black for (Left) b3 subtraction (Middle) 1D adaptive subtraction (Right) 2D adaptive subtraction

Displayed is the result of following all the previously outlined steps but with a 37Hz Ricker wavelet (Figure 18). This was done due to frequency differences between the recorded VSP and stacked data. A significant improvement is seen on the trace with an enhanced similarity between the primaries only trace and the result of attenuating the multiple contaminated trace.

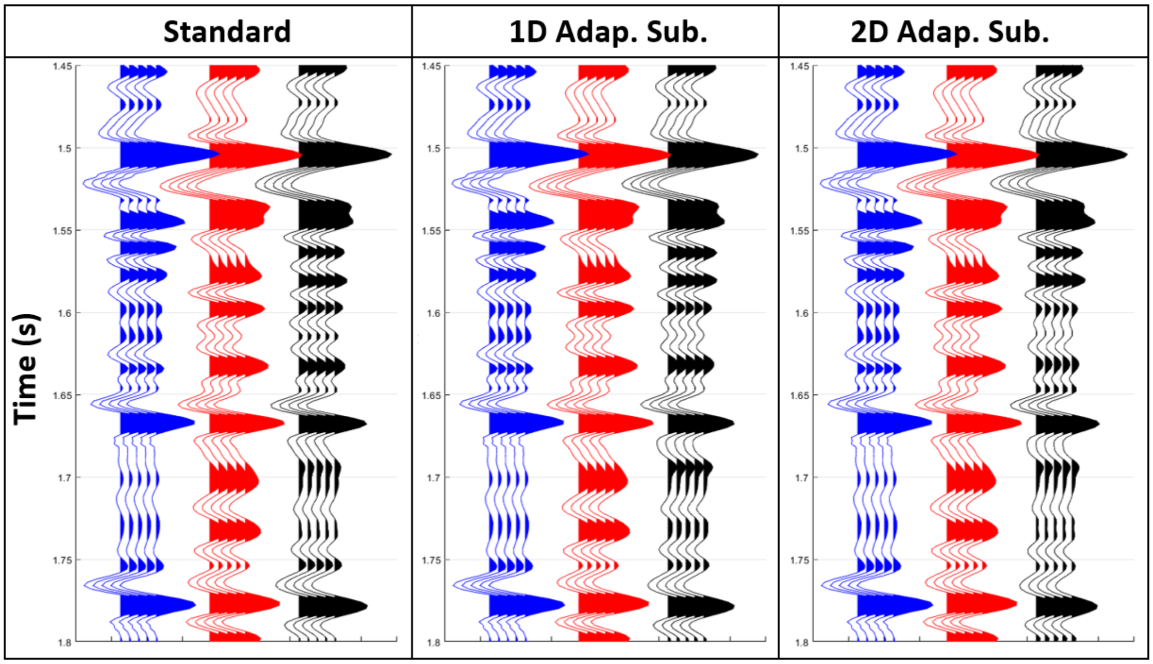

FIG. 18. Using 37 Hz Ricker wavelet displaying outside corridor stack (primaries) in blue, zero depth trace (primaries and multiples) in red and zero depth trace after internal multiple attenuation in black for (Left) b3 subtraction (Middle) 1D adaptive subtraction (Right) 2D adaptive subtraction

CONCLUSIONS

There were two main goals for this synthetic test. The first was to see how the algorithm preformed on a significantly complex synthetic and to determine if the method is applicable for the real data case. The results display it can succeed in this complex scenario. The direct subtraction and the adaptive subtraction versions all displayed improvements due to multiple attenuation. This success gives confidence moving forward to apply the inverse scattering series internal multiple prediction method to the recorded data.

ACKNOWLEDGMENTS

The authors would like to thank the sponsors of CREWES for the support of this work and Devon for the donated data and permission to publish. This work was also funded NSERC through the grant CRDPJ 461179-13. Andrew Iverson would also like to thank NSERC and SEG for their support.

REFERENCES

Keating, S., Sun, J., Pan, P., and Innanen, K. A., 2015, Nonstationary l1 adaptive subtraction with application to internal multiple attenuation, CREWES Annual Report, 27.

Iverson, A., Innanen, K. A., Trad, D., and Rauch-Davies, M., 2018a, Internal multiple prediction and subtraction: VSP, pre-and post-stack seismic data examples, CREWES Annual Report, 30.

Iverson, A., Keating, S., Innanen, K. A., and Trad, D., 2018b, Internal multiple prediction with higher order terms and a new subtraction domain, CREWES Annual Report, 30.

Margrave, G. F., and Daley, P. F., 2014. VSP modelling in 1D with Q and buried source, CREWES Annual Report, 26.

Weglein, A. B., Gasparotto, F. A., Carvalho, P. M., and Stolt, R. H., 1997, An inverse-scattering series method for attenuating multiples in seismic reflection data, Geophysics, 62(6), 1975–1989.