Internal multiple prediction and subtraction: VSP, pre-and post-stack seismic data examples

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ABSTRACT

A land dataset has been donated to CREWES due to a significant issue with internal multiples. This dataset includes well logs, a VSP and 3D seismic data. Synthetic modeling and tie to the 3D data demonstrate that internal multiple problems are present. A synthetic data test shows that inverse scattering series internal multiple attenuation can be used to remove some of the internal multiple energy. The learnings from this synthetic study are applied to both the VSP and 3D data. Extension to these data has proved to be challenging, though it is difficult to quantify results, and there are still learnings from the analysis. While there are minimal assumptions for the inverse scattering method, it is possible that that of low noise has been violated in this data set. Despite these difficulties there are locations throughout the 2D crossline test where there appear to be improvements in coherency, though this is largely a qualitative observation.

INTRODUCTION

Several conclusions were made from the synthetic modeling and prediction analysis companion paper (Iverson et al., 2018b). The synthetic modeling displayed the potential for significant internal multiples. The inverse scattering series internal multiple attenuation method is utilized (Weglein et al., 1997). This method was able to attenuate internal multiples and improve the synthetic dataset, most notably deeper in the section (Iverson et al., 2018b). Due to the modeling displaying the internal multiple problem and the success of the inverse scattering internal multiple attenuation on the synthetics, this method is applied to the real datasets. This report will outline the results for the VSP, stacked seismic data and the pre-stack data.

VSP DATA

The VSP was recorded with 43 three component geophones with a geophone spacing of 49.34ft. The geophone array was moved six times to give the final dimensions of the survey with a top depth of 55ft and a bottom depth of 11304.52 ft from KB. A Vibrioses source with a linear 16 second sweep from 2-140 Hz with 0.5 sec cosine tapers and two sweeps per vibe point. This had a 6 second recording length at 1ms sample rate (Figure 1).

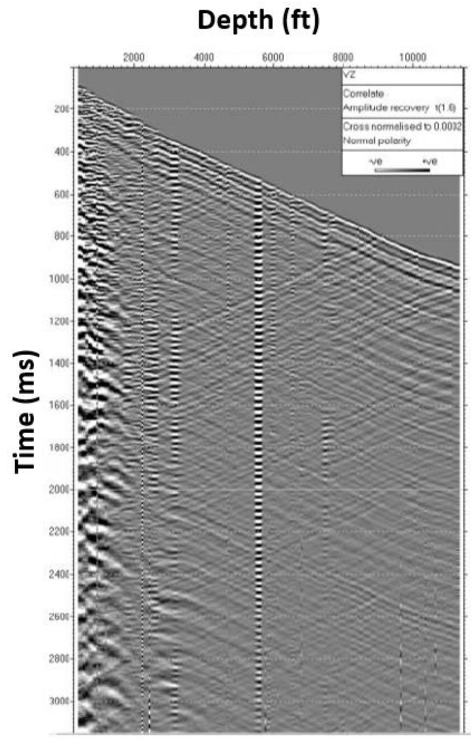

FIG. 1. Recorded VSP with upgoing and downgoing wave, displaying the image from a processing report

The data quality in general is acceptable with clear upgoing and downgoing wavefields and distinct multiples on the downgoing waves. At shallow depths the data begins to degrade as the noise level increases. This is thought to be due to poor geophone coupling in the shallow portion of the well. There are a few ringy traces present throughout the data.

VSP processing

The VSP was processed internally at CREWES by Raul Cova. This was completed on the vertical component of the geophone. The first break was picked to flatten the data. Next the upgoing and downgoing wavefields need to be separated. This is done by flatting the data on the direct arrival and using a trace median filter to remove the upgoing energy giving a result where only the downgoing wavefield remains. The downgoing wavefield is subtracted from the original VSP to leave only the upgoing wavefield. The upgoing wavefield is the desired output to be used for internal multiple attenuation analysis. Note, no deconvolution is applied to this dataset to minimize any impacts this may have on the multiples, as the deconvolution operator may remove some of the multiple energy. The result is displayed and compared to the Synthetic VSP (Figure 2) (Iverson et al. 2018b).

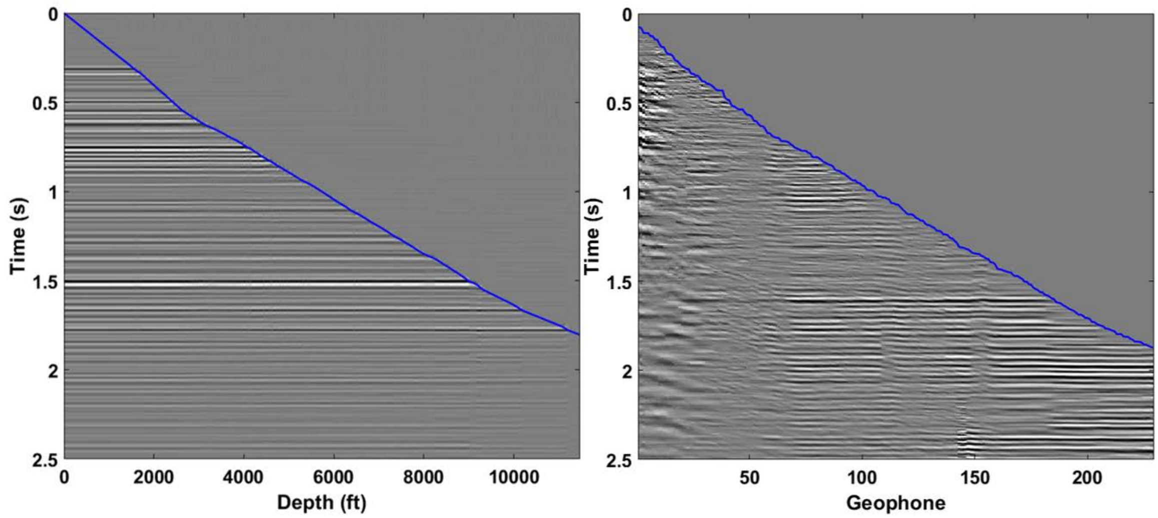

FIG. 2. (Left) Synthetic VSP upgoing wave (Right) Recorded VSP with upgoing wave

First the outside corridor stack and the full stack are compared (Figure 3). It would be preferred to use the zero depth trace or a smaller stack from the shallower depth geophones, however due to the previously noted noise issues this is not possible. It was shown with synthetic data that the full stack which includes primaries and multiples is a reasonable approximation to the zero depth trace (Iverson et al., 2018b).

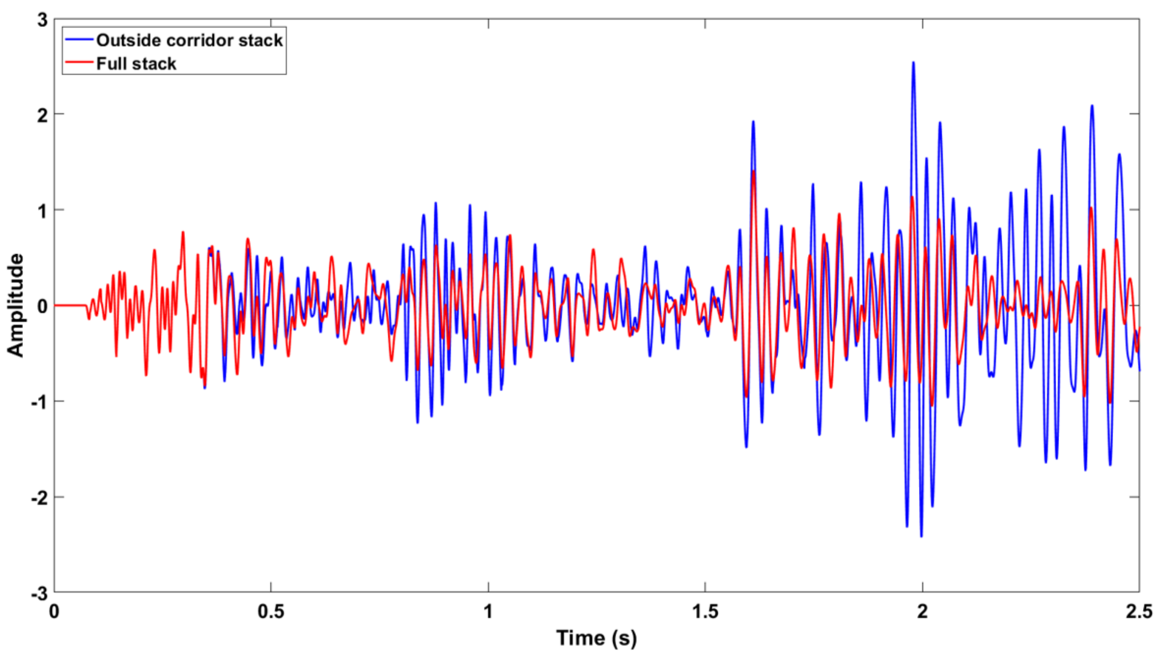

FIG. 3. Full stack (Primaries and multiples) and outside corridor stack (primaries only)

There are significant differences between the two stacks, some of this variation is due internal multiples present in the data. As time increases the amplitudes of the two traces begin to diverge. It is proposed that some of this may be due to additional amplitude gain being required for the full stack. At this stage it is unclear to what extent the difference between the two is due to multiples and understanding this is key as the multiple trace is created by subtracting the two. An additional time power gain is applied to the full stack and this brings the amplitudes to a comparable value with the full stack (Figure 4). It was seen in the synthetic case that amplitude differences existed between the two, but it was not as significant as seen in Figure 2. With the additional time power scaling there is still a significant difference in the two stacks deeper in the VSP which may be due to multiples. As it is unsure which is correct the original version without the additional time power gain is used. There was a shallow section missing in the logs which may also contribute to the internal multiples. This comparison displayed in Figure 4 was displayed to show there is uncertainty in the multiples trace.

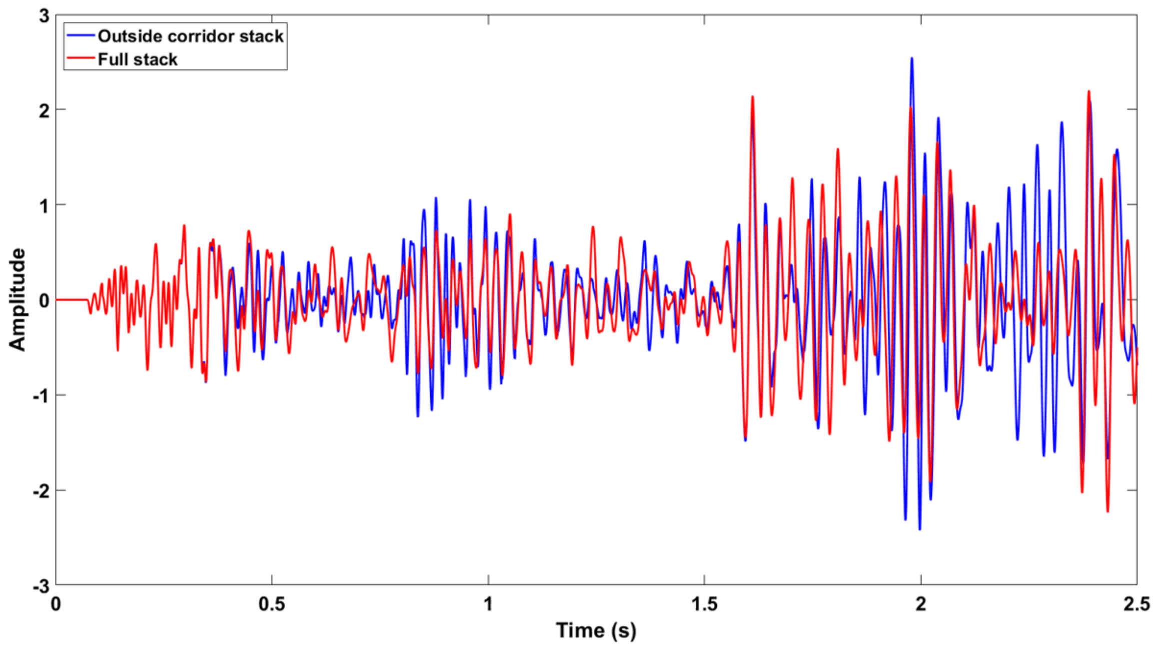

FIG. 4. Comparing full stack (Primaries and multiples) to outside corridor stack (primaries only)

Displayed is the frequency spectrum of the two stacks from the VSP the peak frequency is approximately 30 Hz (Figure 5). The spectrum has significant notching and variation in amplitude through the bandwidth.

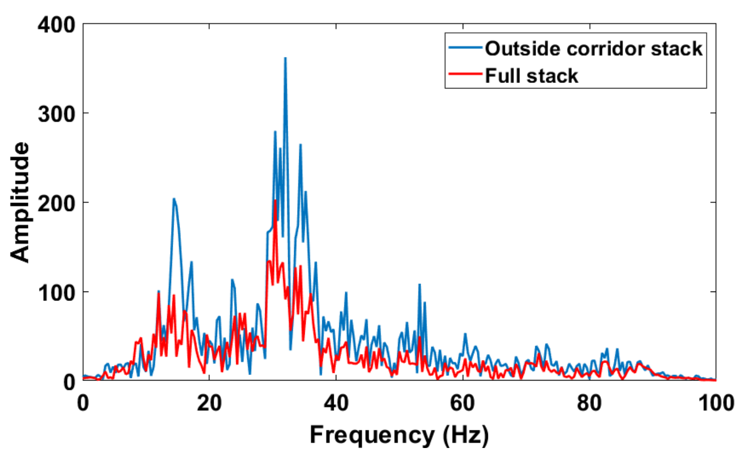

FIG. 5. Frequency content differences between full stack (Primaries and multiples) to outside corridor stack (primaries only)

VSP internal multiple prediction

The full stack is used in the internal multiple prediction algorithm using the inverse scattering series (Weglein et al., 1997). This is compared to the multiples trace created by subtracting the outside corridor stack and the zero depth trace (Figure 6). The prediction success is highly variable throughout the multiple trace. At certain locations the predicted amplitudes match well but there are other portions of the trace with a poor match to the multiples estimate with either the amplitudes or the polarity being incorrect. This variation from a reasonable to poor estimate occurs over a short period of time. Since this is recorded data there are valid concerns if the difference between the full stack and corridor stack is entirely due to multiples, given the noise present in the data.

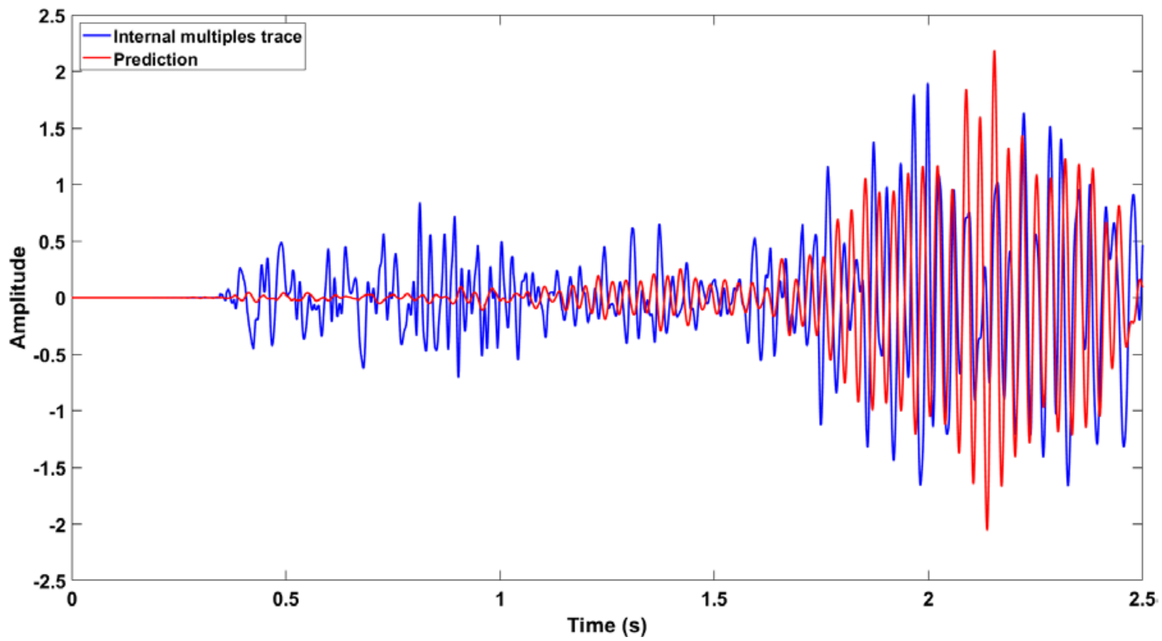

FIG. 6. Internal multiple prediction and internal multiples trace

The 2D adapative subtraction method is used to see if improvements to the prediction can be made. Due to the concerns with the amplitudes and how quickly the mismatch can vary in time uplift may be found with the 2D adaptive subtraction (Iverson et al., 2018c; Keating et al, 2015). Displayed is the 2D downward generator space after stacking (Figure 7).

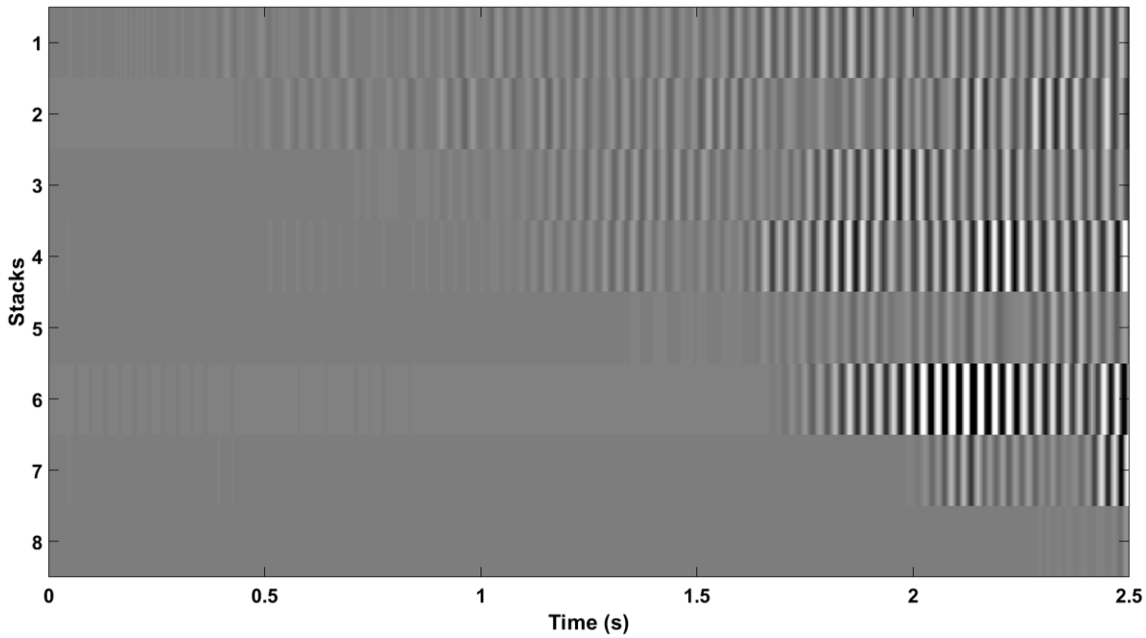

FIG. 7. Downward generator space after stacking for 2D adaptive subtraction

The 2D adaptive subtraction result is compared to the internal multiples trace (Figure 8). There appears to be an improved match to the internal multiples trace.

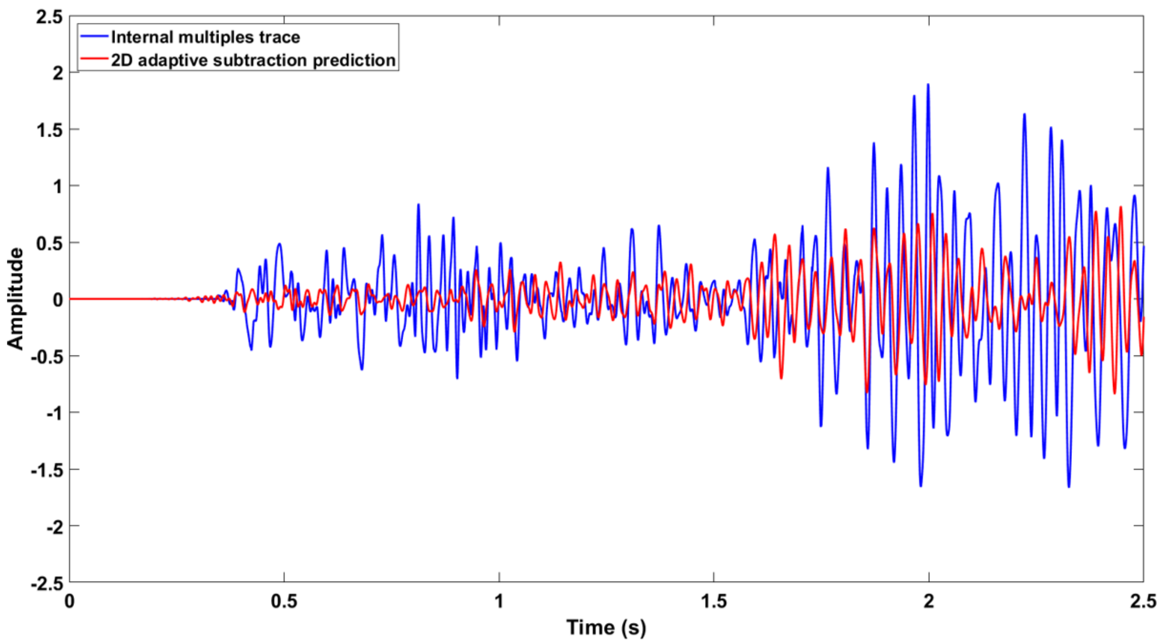

FIG. 8. Internal multiple prediction with 2D adaptive subtraction and internal multiples trace

The outside corridor stack is compared to both the full stack and the multiple attenuated full stack (Figure 9). For the recorded VSP the result is more variable relative to the synthetic case. For the pure synthetic case a decrease in internal multiples was displayed throughout the trace after multiple attenuation (Iverson et al., 2018b). In the recorded data there are locations with improvements, but this has become increasingly subjective.

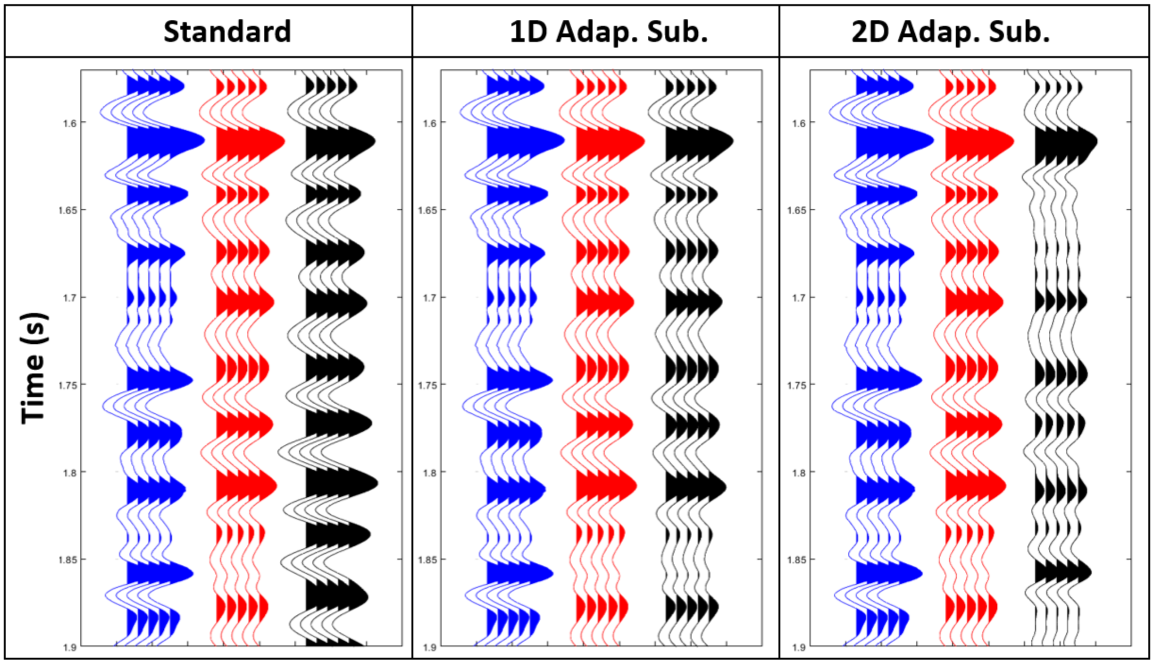

FIG. 9. Outside corridor stack (primaries) in blue, zero depth trace (primaries and multiples) in red and zero depth trace after internal multiple attenuation in black for (Left) b3 subtraction (Middle) 1D adaptive subtraction (Right) 2D adaptive subtraction

STACKED DATA

Next the post stack seismic data is analyzed. This has been processed through to prestack time migration with steps including denoising, amplitude scaling, velocity analysis, deconvolution and 5D interpolation. Information of which processing steps were applied is known, but with minimal details on parameters. Though PSTM stacked data may not be an ideal stage in the processing sequence to apply internal multiple attenuation the method is attempted as the final step. This is done to determine the applicability to fully processed data. If successful on fully processed data, this method to attenuate internal multiples can be easily applied to any data volume without requiring reprocessing.

Well tie

The well is tied to the seismic data to compare with the synthetic modeling and testing and is completed using Hampson-Russell software (Figure 10). To tie the well the checkshot was used from the VSP which applied a slight stretch and a bulk shift. Also shown is the cross correlation of the synthetic seismic to the data.

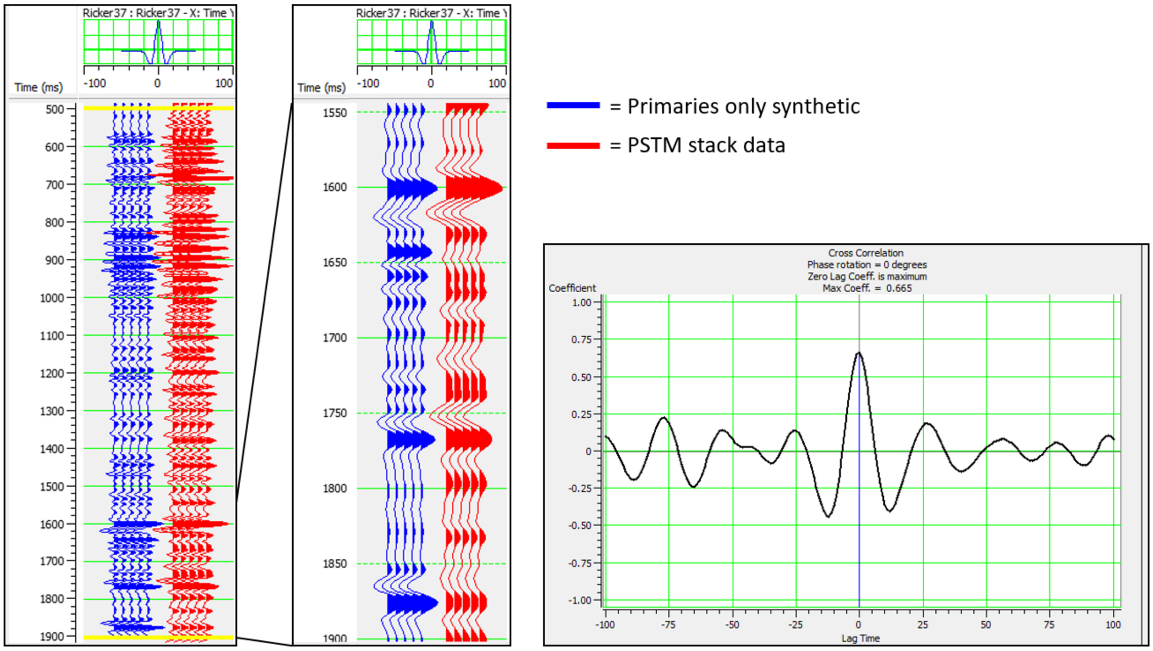

FIG. 10. Well tie to 3D PSTM stacked data and cross correlation

The stacked seismic data is compared to the VSP and the synthetic VSP (Figure 11). This is initially done deeper in the section as it was shown from the synthetic modeling there was success attenuating these high amplitude internal multiples. Both the corridor stack and the zero depth trace tie the stacked reflection data. What is of significance is how the synthetic zero depth trace displays a good match to the seismic at depth. Confirming the internal multiple issue with the data as there is an improved qualitative match to the data at locations with significant internal multiples. Due to the similarity between the synthetic with multiples and the stacked trace this also gives confidence that inverse scatter series method may be able to assist in this issue as it was successful on the synthetic VSP example (Iverson et al., 2018b).

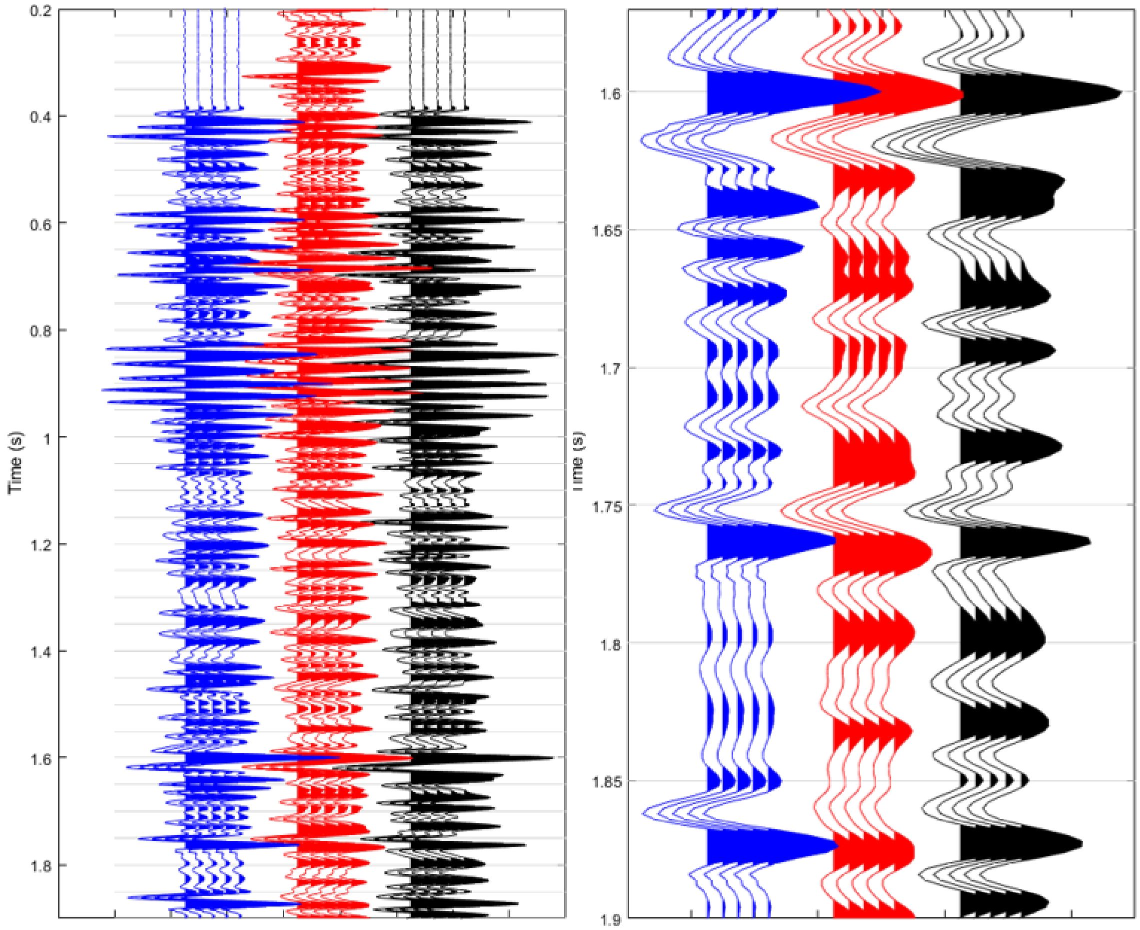

FIG. 11. Outside corridor stack (blue) trace from 3D PSTM Stack (red) and zero depth trace (black)

The primaries only outside corridor stack is compared to the stacked data (Figure 12). This overall shows a reasonable tie with some amplitude mismatches. There appears to be a temporal drift between the two that is more noticeable in the shallow portion of the well. This is possibly due to the frequency content differences between the tool recording the sonic log data that was used to create the synthetic VSP and the seismic data.

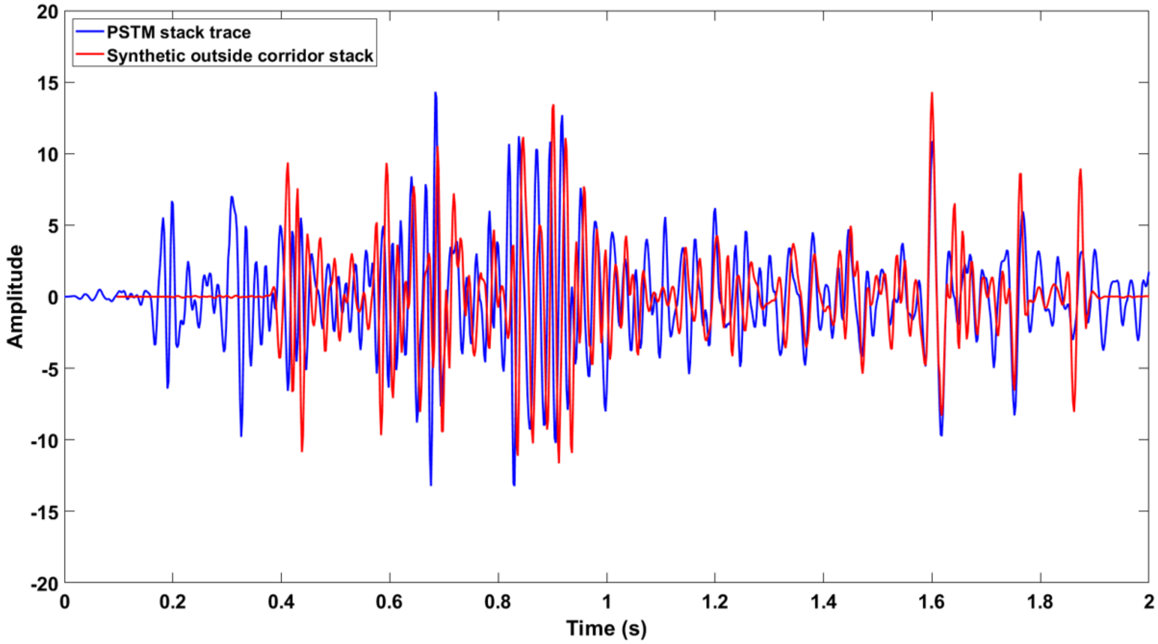

FIG. 12. Synthetic outside corridor stack (Primaries) and trace from 3D PSTM Stack

The synthetic outside corridor stack with primaries and internal multiples is compared to the stacked data is displayed (Figure 13). The two traces show similar character with some amplitude variations through the trace. Note deeper in the section around 1.8 seconds the improved amplitude match, relative the primaries only trace.

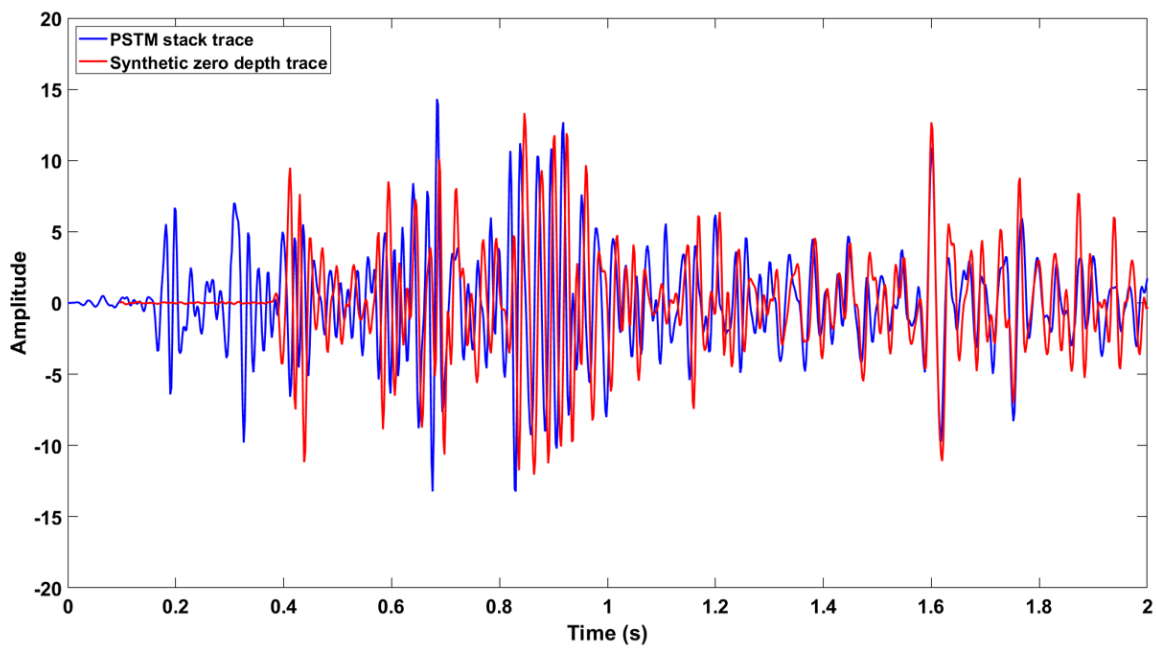

FIG. 13. Synthetic zero depth trace (Primaries and multiples) and trace from 3D PSTM Stack

Displayed is the frequency spectrum of the single PSTM stacked trace (Figure 14). This shows central frequency around 37 Hz and a broader range of frequencies than the VSP.

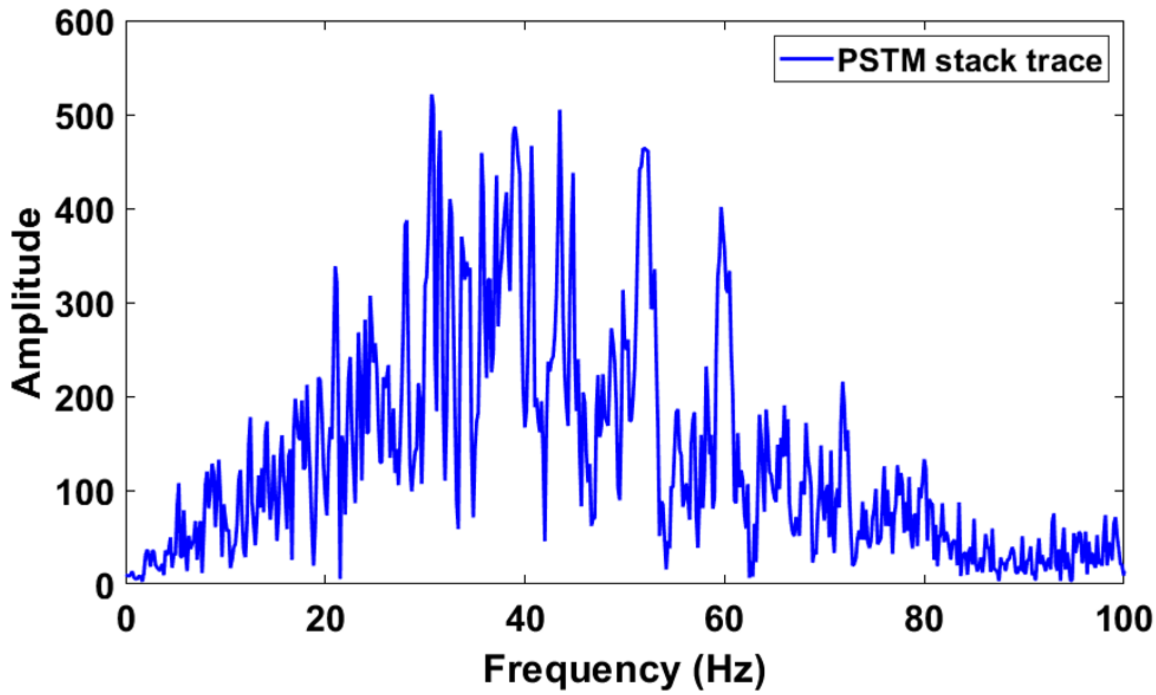

FIG. 14. Frequency spectrum of PSTM Stack

Internal multiple prediction on stacked data

The stacked data trace is used in the inverse scattering series internal multiple prediction algorithm (Weglein et al., 1997). This was completed with an epsilon value of 15. The prediction is displayed and overlain with the input trace (Figure 15). Applying the method to the stacked data becomes more difficult to verify the success of the algorithm. With a VSP there is the ability to generate the various corridor stacks. With the stacked data there is not this same reference trace.

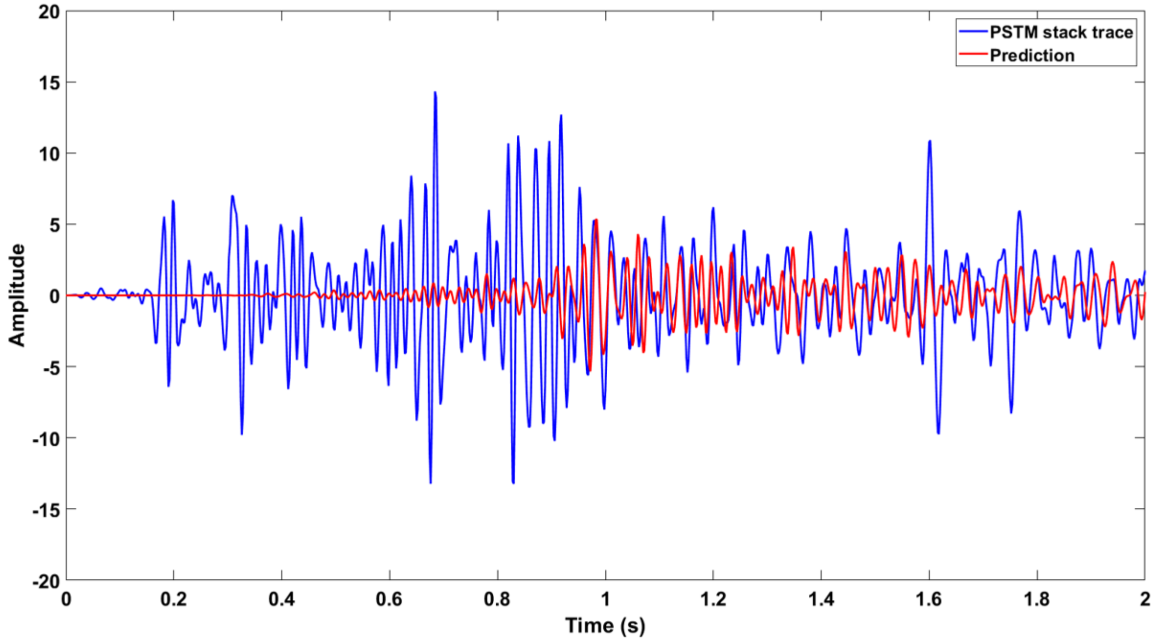

FIG. 15. Internal multiple prediction and trace from 3D PSTM Stack

Displayed is the 2D Downward generator space for the prediction after stacking (Figure 16). Again, even after stacking as the 2D generator space is viewed the resulting prediction in this space is complex.

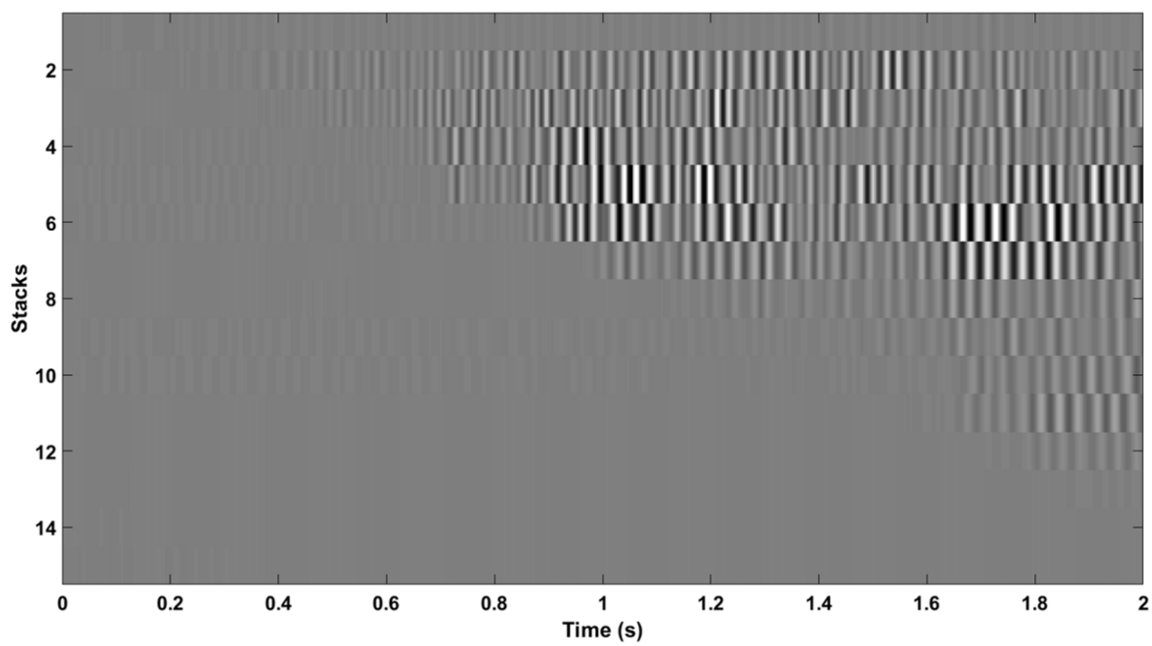

FIG. 16. Downward generator space after stacking for 2D adaptive subtraction

The outside corridor stack from the synthetic VSP and recorded VSP can be used to assist judging the success of the algorithm. This is compared to the primaries only synthetic to see if the attenuated trace is better tied to the synthetic with no multiples (Figure 17). The results from the stack are also difficult to determine the success of the method in attenuating multiples. There are locations where that it has improved but it may have also been detrimental in some locations. The results are also highly sensitive to the stack size used in the 2D adaptive subtraction. It was shown that there is significant similarity between the synthetic zero depth trace which contained primaries and multiple and the tie to the PSTM stack trace. There were encouraging results from this initial synthetic test as it appeared to display the ability to attenuate multiples with the inverse scattering series method for this dataset. With the decreased success on the real data this may display just how critical some of the amplitude differences between the synthetic input trace and the PSTM trace to the algorithm.

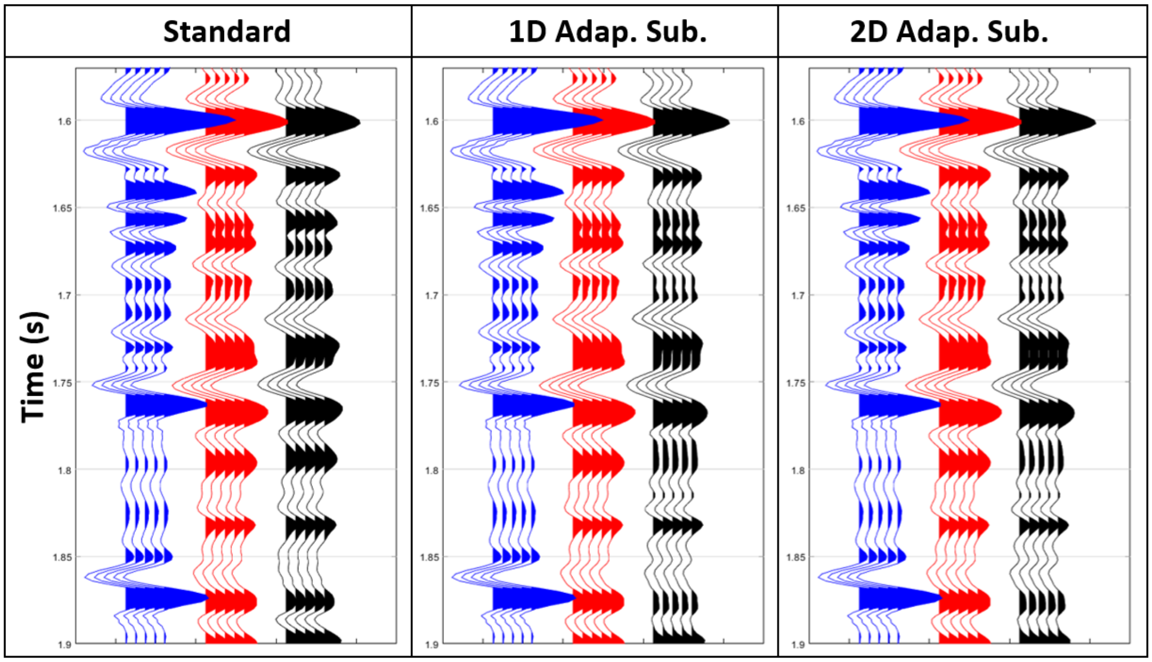

FIG. 17. Outside corridor stack (primaries) in blue, PSTM trace (primaries and multiples) in red and PSTM trace after internal multiple attenuation in black for (Left) b3 subtraction (Middle) 1D adaptive subtraction (Right) 2D adaptive subtraction

Crossline prediction

The internal multiple prediction method was then applied to a crossline from the data to compare the result on a 2D crossline (Figure 18). Due to the relatively flat geology of the data the resulting internal multiples also have minimal dip. This is where the amplitudes of the events and how the multiples are attenuated from the data becomes critical.

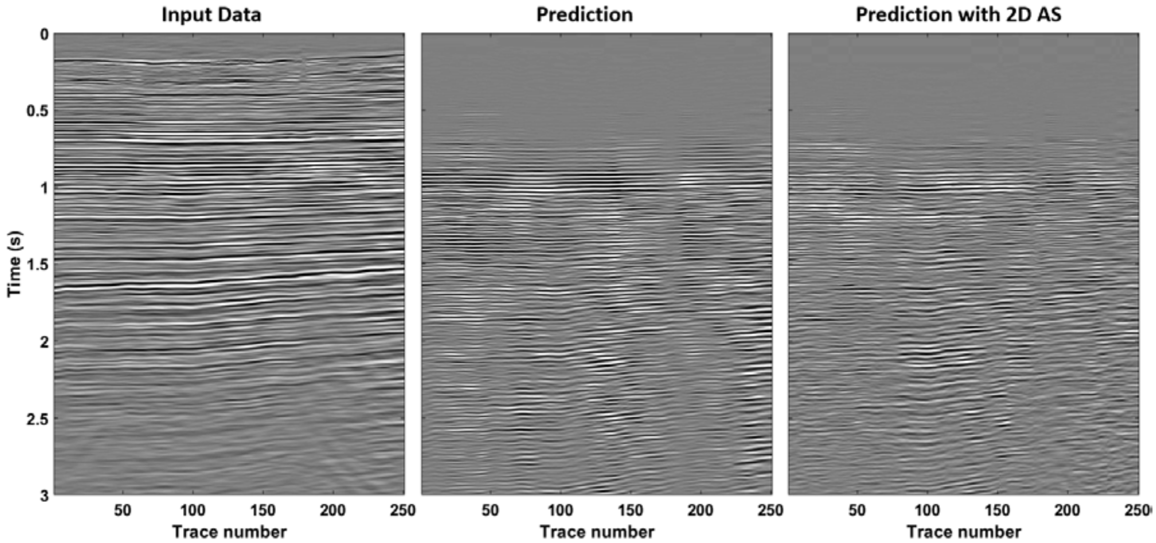

FIG. 18. Crossline displaying 3D PSTM stack data (Left) input data, (Middle) internal multiple prediction and (Right) internal multiple prediction with 2D adaptive subtraction

Displayed is the result of attenuating the internal multiples with the 2D adaptive subtraction in the downward generator space (Figure 19). The results display minimal variation between the two but there are some small changes in coherency through the crossline.

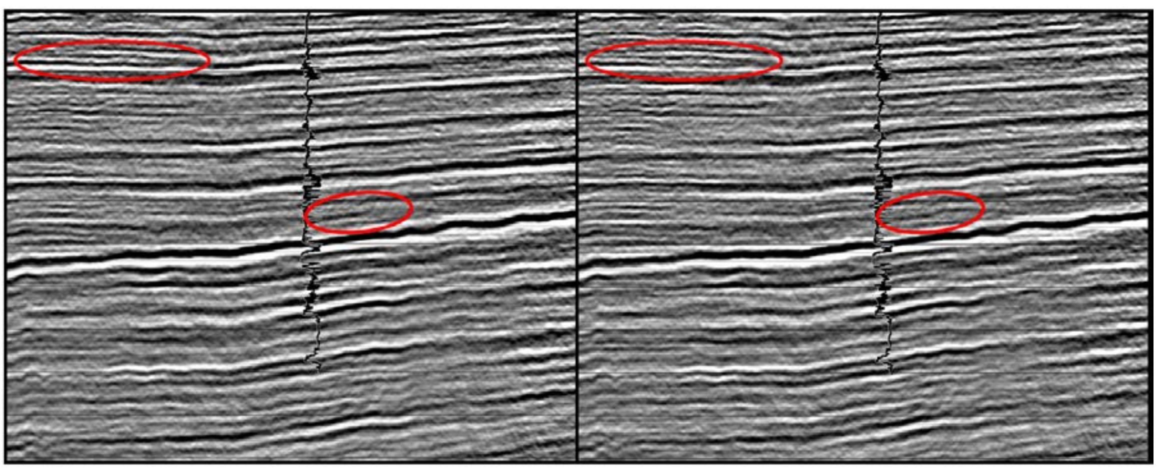

FIG. 19. (Left) Crossline through PSTM stack.(Right) Crossline through PSTM stack after internal multiple attenuation, with red ovals highlighting significant areas of change due to internal multiple attenuation.

The well tie is compared after the internal multiple attenuation (Figure 20). Comparing the cross correlation pre and post multiple attenuation the results show a negligible change in the tie. Due to the minimal quantitative differences a qualitative comparison is needed to see if there are improvements in space.

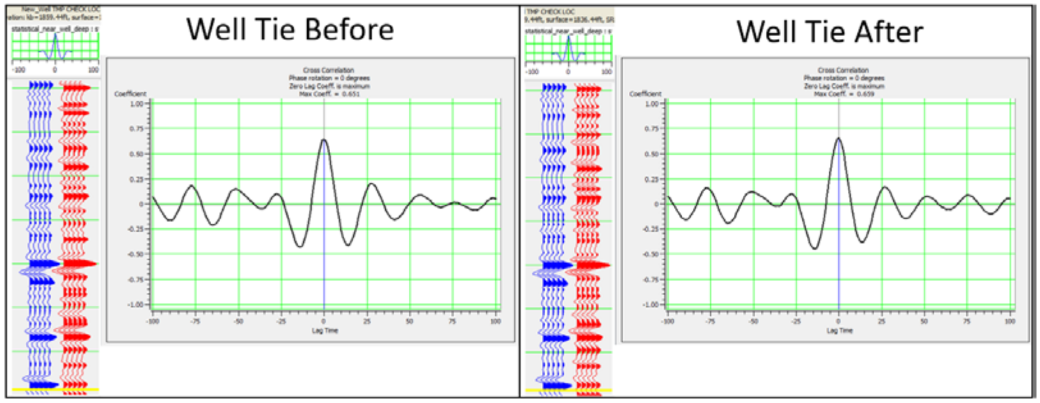

FIG. 20. Well tie cross correlation (Left) Before and (Right) after internal multiple attenuation

Processing impact on stack results

Though the stack ties the zero depth trace synthetic reasonably well there are still differences between the two. The internal multiple attenuation results from the synthetic testing were encouraging but this has not been seen in the real data. The question that is raised is the possibility of additional processing that may assist in the prediction of internal multiples. The method assumes that the only events that remain in the data are primaries and internal multiples. It requires that these are both part of the input data as they will be used to predict events and the multiples must also be present for the subtraction. Has the migration or other processing steps altered the multiples in the data. If there is noise or other events in the data that is not primaries or internal multiples these events will be used by the algorithm to predict the relevant internal multiples.

PRESTACK DATA

The final dataset to be tested is the prestack data. There are three datasets which were made available to test the method on. The pre-interpolation, post interpolation and the migrated data. Displayed is the pre-interpolation data (Figure 21). This has irregular sampling which can impact the method as (Iverson et al., 2018a).

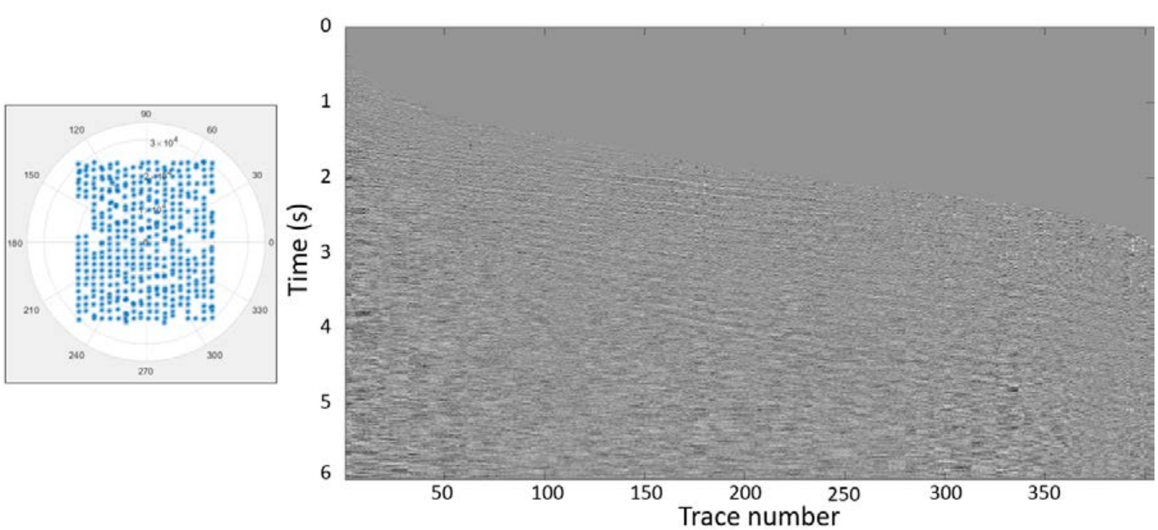

FIG. 21. (Left) CMP acquisition distribution (Right) seismic gather before 5D interpolation

After interpolation the dataset is now regularized and there is a significant improvement to the signal present in the data (Figure 22). This will aid in the algorithm using these events and the increased signal to noise to produce and improved result. The regular sampling also assists the algorithm (Iverson et al., 2018a)

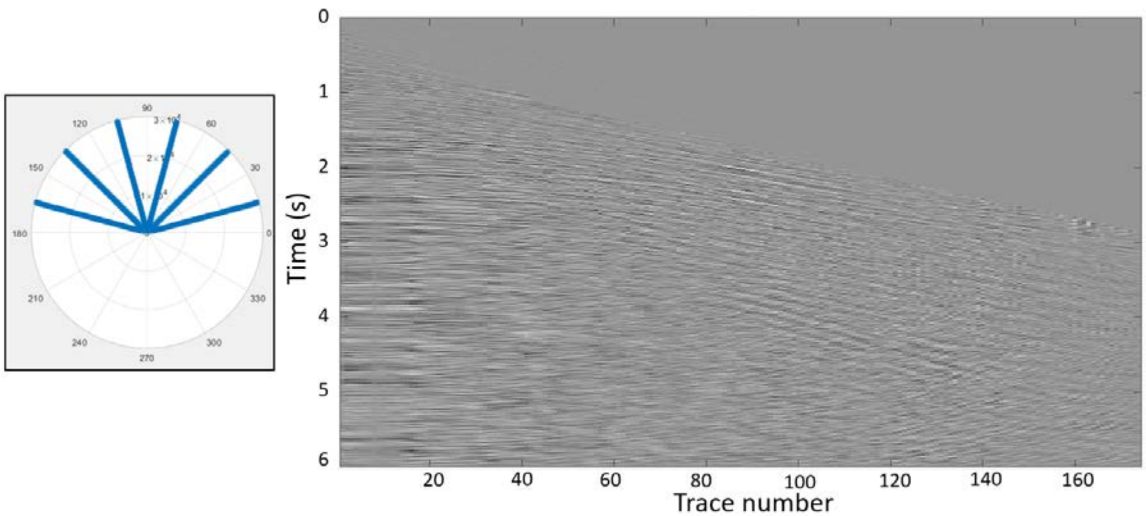

FIG. 22. (Left) CMP acquisition distribution (Right) seismic gather after 5D interpolation

Time offset internal multiple prediction

The time offset version of the internal multiple prediction algorithm is used on the prestack data (Figure 23) (Innanen., 2015; Iverson et al., 2018a). Displayed is the input and prediction of the internal multiples (Figure 20). There are numerous distinct events that can be seen in the prediction. There also appears to be linear events that have been predicted which can be seen in the input data. The prestack data may require further processing prior to the application of the internal multiple prediction algorithm.

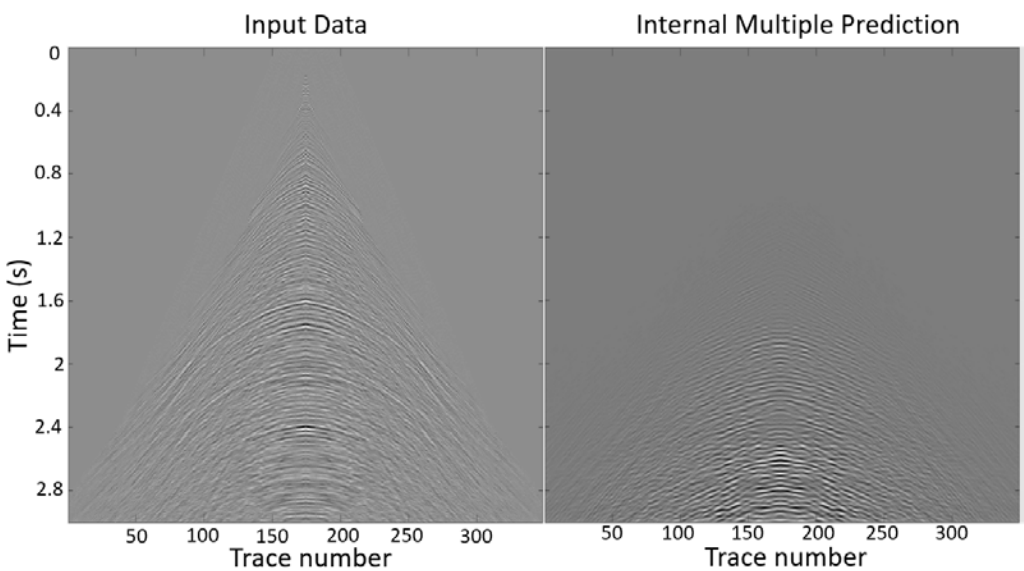

FIG. 23. (Left) seismic gather after 5D interpolation (Right) Time offset internal multiple prediction of seismic gather after 5D interpolation

CONCLUSIONS

A continuing goal of CREWES is to successfully apply the inverse scattering series internal multiple attenuation to land data. These real data tests of the method have been more difficult to determine their success. The majority of the real data cases displayed locations with improvements due to the attenuation of multiples with other locations where it has possibly been detrimental. This potentially demonstrations how critical preserving amplitudes through processing can be to assist these data driven methods. Success was seen on the synthetics with similar character, so the next steps are to determine how to achieve this success with real data. This will be addressed by determining what stage of processing and what pre-processing can assist the internal multiple attenuation algorithm.

ACKNOWLEDGMENTS

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REFERENCES

Innanen, K. A., 2015, Time domain internal multiple prediction, CREWES Annual Report, 27.

Iverson, A., Innanen, K. A., and Trad, D., 2018a, Internal multiple prediction in the offset-time domain: Response to irregular spatial sampling, SEG Technical Program Expanded Abstracts 2018, pp 4538-4542.

Iverson, A., Innanen, K. A., Trad, D., and Rauch-Davies, M., 2018b, 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., 2018c, Internal multiple prediction with higher order terms and a new subtraction domain, CREWES Annual Report, 30.

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.

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.