9th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2012"

P-273

# Removal of noises using Tau-P transformation - an indigenous tool for noise attenuation in shallow seismic data

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## *Summary*

*Seismic exploration is one of the most significant techniques for discovering the occurrence of oil and gas reservoirs. If the data is truthfully processed and interpreted, seismic data can provide a remarkably good subsurface image for trustworthy geologic interpretations of the accurate subsurface geology. Drilling activities are extremely expensive and accurate estimation of an area's subsurface geological features can increase the likelihoods of striking an economically recoverable reserve reducing the probabilities of wasting money and effort on a nonproductive findings.*

*To acquire the meaningful seismic data in shallow water in particular; disastrous effects of direct, guided, refracted and surface waves as dominant noises tend to obscure the high-resolution seismic reflection signals. These different components of source-generated noise may completely mask shallow reflections at many locations on the earth. Conventional processing methods have limited approaches to achieve a separation of signal and noise in X-T domain. By transforming the data from the X-T domain to other domains such as the frequency-wavenumber (F-K) domain or the time-slowness (tau-P) domain, those noises can be separated more effectively from the meaningful signal to produce the best subsurface precise images minimizing artifacts. This present paper corresponds to processing of shallow seismic data, more precisely, using improved methods of tau-P transformation and other processes to remove unwanted noises from meaningful reflection signals to produce the unambiguous processed output for amenable interpretations of the subsurface complexities.*

## Introduction

Wide-ranging processing techniques to remove noises from seismic signals are commonly developed based upon the characteristics of the noises. In other words, all of these noises are embedded concurrently with the reflection signals that indicate subsurface features. Thus, the noise and reflection signals tend to overlap when the survey data is displayed in X-T domain and this overlap can mask primary reflection signals and make it complicated or unfeasible to identify patterns which inferences about clear- cut subsurface geology. The effects of these noises on 3D seismic data include corrupting wavelet estimation for deconvolution and model-based wavelets, distorting signal amplitude characteristics, degrading static solutions, contaminating low fold 3D stack, and creating migration artifact in the final processed output misleading the interpretations.

Many methods seek to achieve a separation of signal and noise by transforming the data from the X-T domain to other domains, such as the frequency-wavenumber (F-K) domain or the time-slowness (tau-P), as there are less overlap between the signal and noise data. Once the data is transformed, various filters are applied to the transformed data in such a way that noises are separated from primary reflection signals and, thereby to eliminate as much of the noise as possible ensuing enhancement of primary reflection signals. The data then is inverse transformed back into the offset-time domain for onward processing.

For 3D seismic data, which has irregular-offset sampling, ground roll loses its linearity and changes apparent velocity with the direction of wavefront propagation. For this reason, conventional field arrays, f-k filters, notch filters, and linear Radon Transform methods have limited success to eliminate such noises. We propose using an effective tau-p method to suppress 3D source noise which can be

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very effective at attenuating these kinds of dominant noises contaminating the seismic reflections.

This study is an effort to remove the source-generated different noises in 3D End-on shallow seismic data using tau-p domain processing and also to ascertain its excellent efficacy to obtain the noise-free primary reflection signals.

## Processing Approach

High-resolution shallow seismic data recorded in the time-domain at many locations are plagued by the devastating effects of direct, refracted, guided, and surface waves. Techniques to remove such dominant noises are in general developed based upon the characteristics of the noises. Ground roll, for example, appears as low-velocity, low-frequency and high-amplitude dispersive waves which are sprinkled in fan-shaped zones at near offsets about the source. Conventional processing methods may lead to the mis-processing of source-generated noise specially guided waves causing the unintentional removal of important shallow reflections.

Several widespread processing practices transform the data into a new domain, perform some kind of operation to eliminate these noises and then the inverse method is used to reverse the transform. The purpose of this study is to process the 3D End-on shallow seismic data in tau-p domain where signal can be more easily be separated from those significant noises and filtered or muted out.

It is often easier to understand noise types and design a filter with the data transformed into the tau-p domain. Moreover, deconvolution in tau-p domain rather than T-X domain is preferred as it is very much effective to remove shot-generated shallow reverberations. Consequently after applying deconvolution in tau-p domain, a suitable tau-p mute filter is designed and applied to data to enhance the seismic signals by removing those critical noises.

## Application of Tau-P transform for signal enhancement

The tau-p transform is an indigenous processing tool and a legitimate attempt to preserve the wavefield uniqueness of the seismic data as it provides an increased separation between different seismic waves i.e., multiples, ground-roll, P and S waves amongst others. One realistic benefit of working in the tau-p domain is that we can study the different wave modes as function of their corresponding slowness values (p=1/v), where v represents the propagation velocity.

The tau-p transform is a special case of radon transform where the data are decomposed as a series of straight lines which map to points in the tau-p domain. The Hyperbolic events in shot gathers map to elliptical curves in tau-p. This technique also used to be referred to as slant-stacking since to produce the input data may be stacked along a series of straight lines in tau-p domain. This tau-p processing scheme is directed to improved methods for processing seismic data to remove unwanted noise from meaningful reflection signals and for more truthfully determining the stacking velocity function for a set of seismic data.

This application is becoming beneficial prior to predictive deconvolution for multiple suppression since this performs more accurately in the tau-p domain. The tau-p transform may also be used to optimally isolate and filter guided waves, refractions and types of interference. Filtering in the tau-p domain which resulted in the effective attenuation of source-generated noise is usually more expensive than in the F-K domain, but can produce better quality results. Figure-1 shows the Comparison of Deconvolution output on Gather both in T-X & Tau-p domain and it clearly signifies that the deconvolution in tau-p domain has produced much better results in removal of strapping reverberations of shallow multiples.

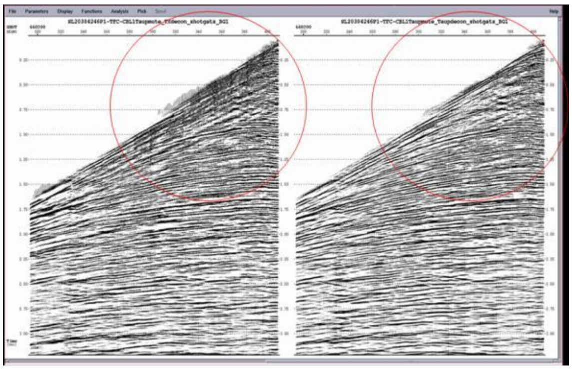


Figure – 1: Comparison of T-X (Left) & Tau-p (Right) Deconvolution on Gather.

Subsequently, their stack responses are also compared and the comparison alongwith the frequency spectrums are also shown in Figure-2 which illustrates that Tau-p deconvolution stack definitely produced better clarity compared to T-X deconvolution stack in bringing out the reflection events more prominently reducing robust reverberation noises.

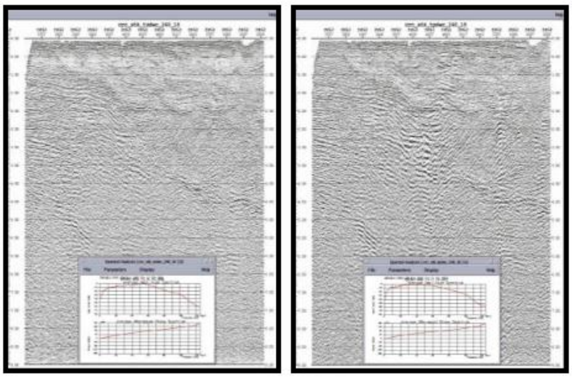


Figure – 2 : Comparison of stack response of T-X Deconvolution (Left) & Tau-p Deconvolution (Right) alongwith their spectrums.

After application of deconvolution in tau-p domain, Tau-p filtering/muting can be used to attenuate noise by dividing the Tau-p transform into pass and reject zones. Moreover, straight lines representing tight source-generated noise also map into points at greater p values in the tau-p domain. These properties form the basis for designing tau-p filters that pass signal and reject noise in all common geometry domains.

The method of tau-p transforms, however, is more effective at filtering all multiples, including those recorded at near offsets. When the data is not subjected to NMO correction, signals for multiple reflection events, including those recorded at near traces, will transform into regions of greater slownesses than those for primary signals. They then will be filtered out along with other noise at greater slownesses.

Inaccurate definition of tau-p mute may lead to the misprocessing and misinterpretation of source-generated noise as reflection or the unintended removal of true reflections. Careful muting of direct, refracted, guided and surface waves (collectively referred as source-generated noise) is the key factor for successful imaging of the shallow subsurface. The dominance of source-generated noise (i.e., first break and guided waves) represented by the near-horizontal events about zero slowness p. The several tau-p mutes are tested & applied on decon gather in tau-p domain and then the tau-p mute is optimized by comparing their stack responses. That unmuted data is then transformed back into offset-time space and is subtracted from the original data. This subtraction process removes the multiple reflections from the gather, leaving the primary reflection signals easier to process further.

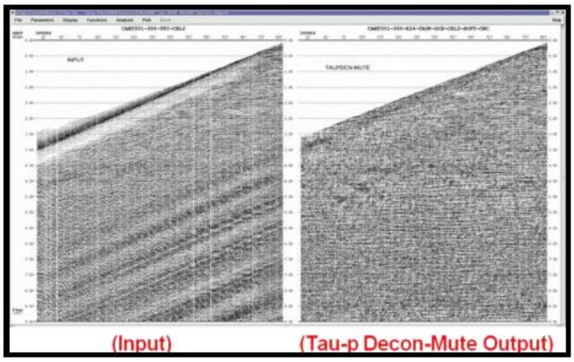


Figure – 3: Application of Tau-p Deconvolution & Tau-p Mute (on Gather).

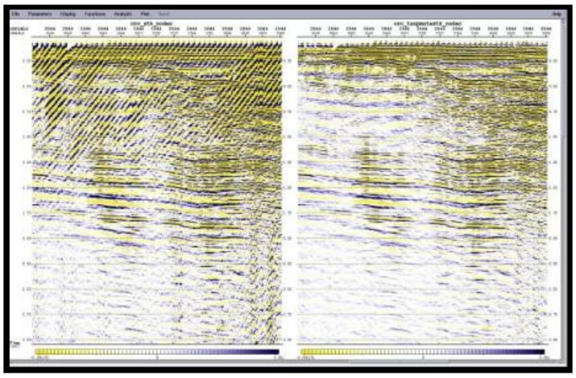


Figure – 4: Comparison of Stack before (Left) & after noise removal (Right) in Tau-p domain.

Finally, inverse hyperbolic transformation yields shot gather dominated by reflections. In tests of the combined tau-p processing scheme on a shot gather, significant improvements in the quality of reflections in the pre-stacked data and on a fully processed section are produced. The comparisons of gather before and after application of tau-p deconvolution & tau-p mute is shown in Figure-3. Furthermore, the comparison of stack generated before and after noise removal in Tau-p domain is shown in Figure-4 indicating significant enhancements in the S/N ratio.

On the tau-p filtered output, the enhanced signal content is inverse transformed from the time-slowness domain back to the offset-time domain. The signal amplitude for the enhanced signal content is thus restored. The processed and filtered data may then be subjected to further processing by which inferences about the subsurface geology of the survey area may be inferred.

## Additional Noise Attenuation prior to PSTM

After application of tau-p filtering, shot gathers are inversed to T-X domain and trace decimation is performed. Consequently, spatial anti-alias filter (K-filter) was applied for removing the effect of linear noise caused by spatial aliasing due to trace decimation of gathers by designing FK-polygon in tau-p decon & tau-p mute applied shot gather. Tau-p decon & tau-p mute applied shot gather and corresponding FK spectra is shown in Figure-5 which shows the presence of linear noise caused by spatial aliasing and the K-filtered output along with noise removed FK spectra is shown in Figure-6. After application of spatial anti-alias filter on the decimated gather, offset regularization was performed to get uniform fold and regularized offset gather throughout full volume in such a way that the near offset and farthest offset are not disgustingly over or under fold.

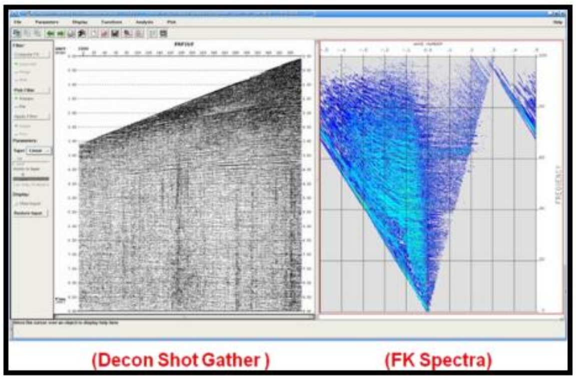


Figure – 5: Tau-p decon & Tau-p mute applied Shot Gather & corresponding FK Spectra.

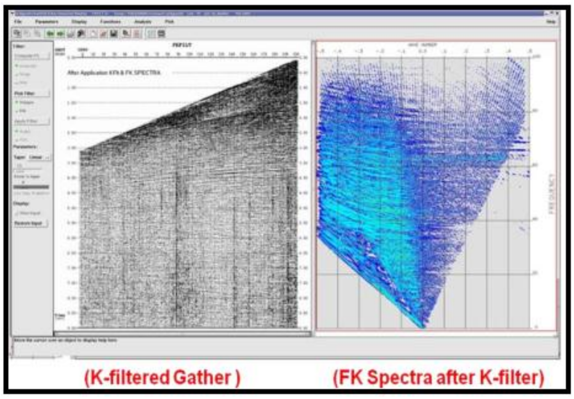


Figure – 6: K-filtered Shot Gather & corresponding FK Spectra.

For Random Noise Attenuation in common offset mode, 3D FXY Spatial Prediction Filtering (FXY) is applied which designs and applies a 3D spatial prediction filter and passes the filtered data to downstream modules for further processing. The results produced are superior to those obtained with standard two dimensional prediction filters. After the offset regularization of full 3D volume in specified regular interval, 3D FXY Spatial Prediction Filtering was applied in common offset domain in each offset class after splitting the data and then additional noise suppression were performed in T-F transform for further signal enhancement.

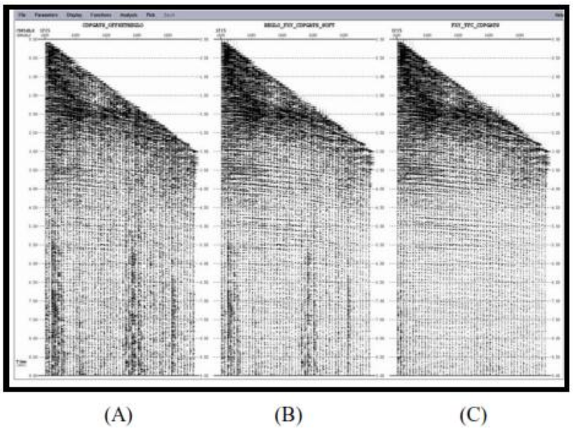
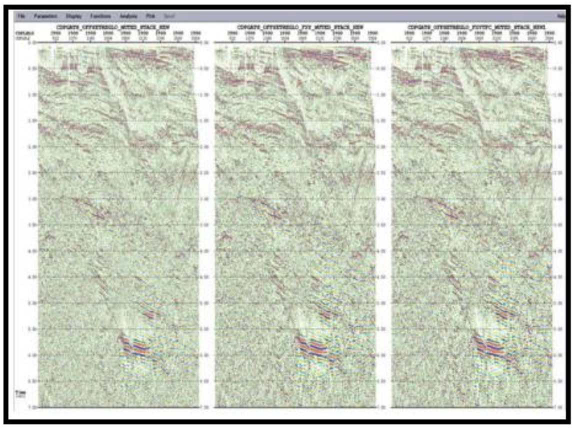


Figure – 7: Comparison of CDP Gather A) After K filtered & Offset regularised; B) After FXY in common offset mode & C) After FXY plus noise suppression in T-F domain.

Comparison of gathers is shown in Figure-7 as well as their stack responses are also compared in Figure-8 in three different phases i.e., A) After K-filtered & Offset regularised; B) After FXY in common offset mode & C)

After FXY plus noise suppression in T-F domain. Time Slices at 6000ms of full volume CDP Stack are also compared before and after application of RNA (FXY) plus noise suppression in T-F domain in Figure-9. It is evident from all these comparisons, noises are significantly attenuated to enhance the signal to noise ratio.



(A) (B) (C)

Figure – 8: Comparison of CDP Stack A) After K filtered & Offset regularised; B) After FXY in common offset mode & C) After FXY plus noise suppression in T-F domain.

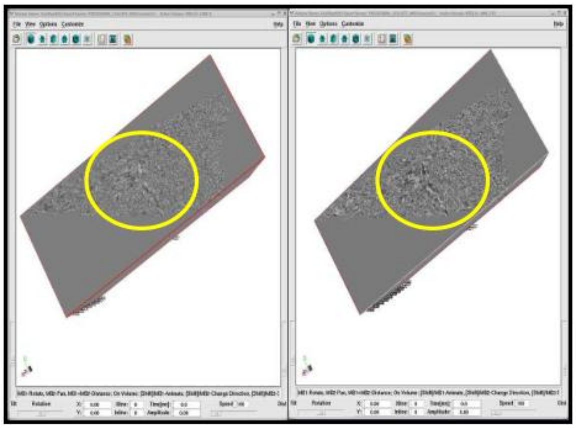


Figure – 9: Time Slice at 6000ms before (Left) and after FXY plus noise suppression in T-F domain (Right) in common offset.

Subsequently, after all-encompassing removal of noises towards appropriate conditioning of CDP gathers, these noise free conditioned gathers were used as input for pre-stack time migration for precise subsurface imaging. Using the final RMS velocity volume shown in Figure-10, PSTM is done and the PSTM output for a representative inline extracted from the processed 3D seismic volume is shown in Figure-11 depicting clear-cut subsurface features.

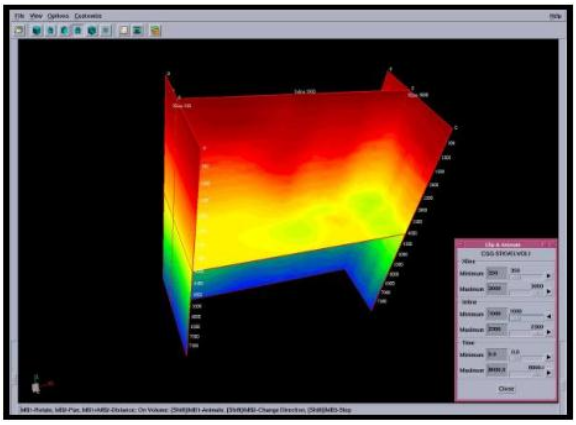


Figure – 10: Final RMS Velocity Volume used for PSTM.

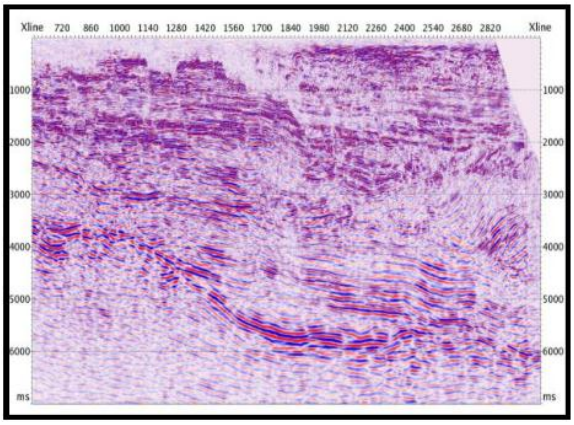


Figure – 11: Final PSTM Stack for a representative inline extracted from the processed 3D seismic volume.

## Conclusions

Ultimately, many methods strive for achieving a separation of signal and dominant noise by transforming the data from the X-T domain to other domains, but reflection events on the tau-p processed stacked section were found to illuminate the primary reflection events very meticulously than those on the conventionally processed section in other domain.

The different components of source-generated predominant noise may completely mask shallow reflections but removal of these critical noises using tau-p transformation in shallow seismic data can be very much effective in producing the best subsurface precise images diminishing artifacts that can mislead the truthful interpretation of the subsurface intricacies. Deconvolution and other cleaning tool are also found very much effective to remove shot-generated shallow reverberations in tau-p domain and in turn producing superior quality processed output for onward trustworthy interpretation.

To conclude, the decomposition of high-resolution seismic data into reflections and source-generated noise is a critical processing step that can be performed more efficiently and effectively in the tau-p domain than in the t-x domain. The suggested tau-p processing strategy is worthwhile for improving the quality of seismic images of the shallow subsurface. Eventually, the increased accuracy and proficiency of this process enhances the accuracy of surveying underground geological features and, therefore, the probability of accurately finding the occurrence of oil and gas reservoirs.

## References

Binzhong Zhou, and Stewart A. Greenhalgh, 1994, “Linear and parabolic tau-p transforms revisited” Geophysics; Volume 59, Issue. 7; pp. 1133-1149.

Greg Turner, 1990, “Aliasing in the tau-p transform and the removal of spatially aliased coherent noise”, Geophysics, Volume 55, Issue 11, pp. 1496.

Mary E. Kappus, Alistair J. Harding, and John A. Orcutt, 1990, “A comparison of tau-p transform methods”, Geophysics, Volume 55, Issue 9, pp. 1202.

## Acknowledgements

The authors are grateful to Shri V. Rangachari, ED-BM, KG-PG Basin for his recommendation and permission to publish this paper. The authors wish to express their sincere gratitude to Shri B. S. N. Murthy, GM (GP) & HGS, Dr. R. C. Iyer, GM (GP) & Head RCC for their active supervision, encouragement and treasured suggestions during the entire work. Earnest thanks are also due to Shri K. V. Krishnan, DGM (GP) for his extended guidance, support and suggestions during this project.

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