Enhancing the subsurface image through advanced noise removal techniques in Up Down Deconvolution (UDD) for OBC data in Kutch Saurastra and Tapti Daman Block

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Keywords

Geophone noise attenuation, OBC, UDD, KS-TD Basin

Abstract

In shallow marine environments, hydrophone data often suffers from the presence of undesirable artifacts such as ghosts and reverberation. Instead of employing labor-intensive noise removal techniques, the application of Up-Down Deconvolution (UDD) in conjunction with the Ocean Bottom Cable (OBC) dual sensor acquisition technique offers a straightforward mathematical solution to effectively combine and attenuate these noise sources. However, a notable challenge in OBC surveys lies in the excessive ambient noise present in the geophone (Z) component.
This study provides a concise overview of the efficient noise attenuation steps that should be implemented on both geophone (Z) and hydrophone (P) data, both before applying UDD. By following these steps, optimal results can be achieved within the shortest possible timeframe.

Introduction

This study focuses on the Kutch Saurastra basin addressing the merging of two areas (Area A and Area B) acquired at different times with different survey geometries. Area A was acquired using cross spread shooting, while Area B employed parallel shooting. The location of the block is depicted in Figure 1. The bathymetry of Area A ranges from 15mto 50m for the shallow areas and 3m to 15m for the very shallow areas, while the bathymetry of Area B ranges from 25m to 45m. The varying bathymetry results in different levels of contamination from ambient noises throughout the areas. UDD, or up/ down deconvolution, is a signal processing technique used in seismic data processing to enhance the quality of the recorded seismic data. UDD works by deconvolving the upgoing wavefield recorded by a geophone or hydrophone from the downgoing wavefield. The deconvolution process essentially divides the recorded data by the impulse response of the earth, resulting in a waveform that ideally only contains the upgoing wavefield (Amundsen, 2001; Amundsen et al., 2001).

The common type of noises generally encountered with the hydrophone and geophone data in OBC survey are (S. Basu, et al.):

1. Spikes & noise bursts (Hydrophone & Geophone)
2. Scholte waves (Hydrophone & Geophone)
3. Trapped guided waves (Hydrophone & Geophone)
4. Bubble energy (Hydrophone & Geophone)
5. Shear Leakage (Geophone)
6. Direct Arrivals (Hydrophone & Geophone)
7. Multiple Energy (Hydrophone & Geophone)
8. Ghost Energy (Hydrophone & Geophone)

UDD leads to attenuation of events with opposite polarity in geophone and hydrophone. This eliminates Direct arrivals, Ghosts and Multiples. Hence, Direct Arrivals, Multiple energy and Ghosts should be preserved in input to UDD data.

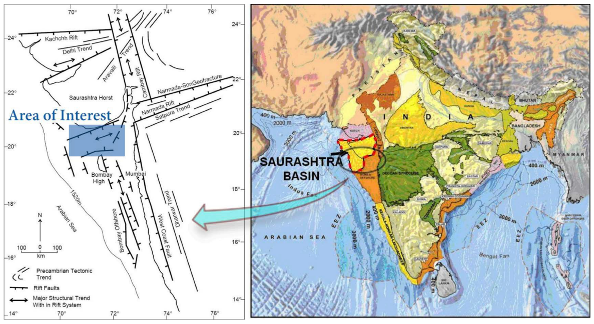

Figure1: Area map showing Area of Interest (Courtesy: DGH)

UDD is a resource intensive process as the data is converted in 3D tau-p domain and size gets 1000000 fold. Processing average-sized data with limited resources can result in significant time requirements, often stretching over several months to complete the task. By incorporating effective denoising techniques prior to applying Up-Down Deconvolution (UDD), numerous benefits can be achieved. These advantages encompass improved signal bandwidth, enhanced spatial and temporal resolution, better continuity of seismic events, and the preservation of valuable time and resources during subsequent post-processing stages. Therefore, this study aims at preparation of optimal and highly optimised input data for Up-Down Deconvolution (UDD).

Theory

This study utilised multiple noise attenuation steps to address the diverse types of noise present in Hydrophone and Geophone data. The selection of noise attenuation techniques was based on the specific characteristics of the noise and the desired signal. The noise and signal components, as illustrated in Figure 2, were effectively addressed through a series of domain-specific steps where noise and signal were well separated.

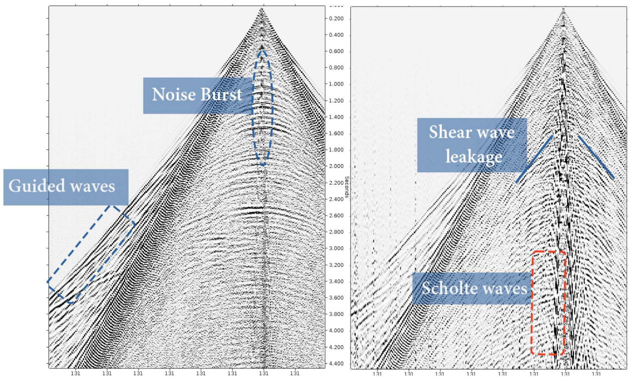

Figure2: Receiver gather of P component (left) and Z component (right) showing noise character.

Spikes or noise burst have anomalous amplitudes and their observed decay deviates from that of signal. In these cases seismic data can be transformed into frequency domain and a spatial median filter is applied. Characterized as frequency band that varies from median frequency, these are either scaled or replaced with interpolated band. Input data is sorted in shot domain and receiver domain. Incomplete removal of these noise components can significantly compromise the effectiveness of deconvolution techniques, including UDD, and other subsequent processes. Attenuation is applied using varying spatial widths in inline and crossline direction, testing for noises in different frequencies, using amplitude to define and attenuate and using various time windows to define temporal continuity.

Bubble energy was effectively eliminated using conventional debubbling methods, employing the far-field signature extracted from the shot gather. Scholte waves propagate along the interface and hence, experience high degree of attenuation and has very low velocity. As shown by red dot in Figure3 they are high amplitude, low velocity events. These are non uniform coherent noises which can be estimated in bands at each trace location using frequency- space (f-x) domain fan filters and a least square optimisation scheme (Zhao Zhang, et al.). Typically fan filters work in f-k domain and for this data is first transformed from x-t to f-x and then to f-k. Due to irregular trace spacing this second Fourier transform can break down and therefore instead of transforming data, filter is transformed from f-k to f-x domain. The process of transforming the filter involves mapping the frequency- wavenumber coordinates to frequency- offset coordinates. Therefore using velocity, frequency and number of traces as parameter attenuation of bands of scholte waves in iterations on shot gather. The signal was preserved using f-x infinite impulse response filters which deploys a spatial low- pass filter with a cut off wavenumber. In this case study, additional noise sources such as guided waves were mitigated within the UDD process itself by converting the data to the Radon domain and implementing a 3D tau-p mute. Removal of all above noises were done for both P and Z component as evident by Figure3 where noise elimination process has yielded excellent results, effectively mitigating unwanted noise from the data.

After the successful removal of random and coherent noises, shear leakage in the Z component of data is targeted. These occur mostly due to poor coupling at sea floor in OBC survey. UDD aims to remove the source wavelet from the seismic data, and the presence of shear noise can distort the estimated wavelet and affect the deconvolution results. In 3C seismic data records, the horizontal components

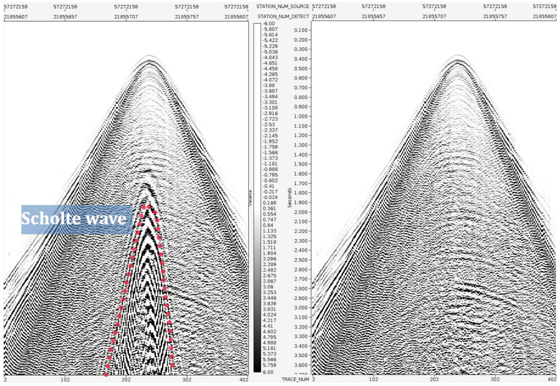

Figure3: Shot gather before (left) and after (right) Noise attenuation in P Component.

(X and Y) are utilised to estimate and subtract the shear component from the vertical component (Z). In cases where only horizontal components are recorded dueto logistical constraints and limited shear wave sensitivity, removing the shear wave component became quite challenging. These shear noise appear random in shot domain and in receiver domain it appears coherent to semi coherent as evident in Figure4. In most materials, including rocks and soils, the shear velocity is typically lower than the primary velocity. This is because shear waves require the deformation of the material and the resistance to shearing motion, which tends to be slower compared to the compression and expansion of particles that primary waves cause. Hence, in receiver domain theyhave higher moveout than primaries which can be observed in Figure4.

De-noising was therefore applied in receiver domain. F-x domain dip filter, median filters and an additional 3D tau-p domain filter was used to model this shear leakage and adaptively subtract from data. Firstly,Tau- p domain is utilised which is a resource intensive process. Input P and Z gathers are primarily interpolated and then converted to 3D Tau-p domain parameterising the number of traces, slowness, frequency and window sizes. These properties can be readily utilised in 3D Tau-p domain. (Stoffa, P.L, et al.) A velocity mute is applied modelling lower velocity shear noise. The far offset shear noise are modelled in this domain and for modelling of remaining noise f-x domain filters were used. Flowchart for this process is shown in figure5.

Figure6 shows the input and output after removal of Bubble noise, Anomalous noise, Scholte noise and Shear leakage.

By selectively modelling noise, this technique effectively enhances the signal-to-noise ratio, resulting in improved clarity of desired seismic events. Traces are dropped depending on the requirements. The study data was brought back to original grid spacing. Removal of shear leakage has been successfully achieved, resulting in a significant reduction in unwanted noise. This data is used as input to UDD. Figure 7 presents two UDD outputs, illustrating the impact of shear noise on the input data. The left image shows the result when shear noise was present in the input, while the right image demonstrates the improved outcome achieved when shear noise was effectively attenuated before applying UDD.

Stack of input P component, Z component and UDD output can be seen in Figure8. The combination of noise attenuation techniques and UDD has proven highly effective in preserving the major horizons on the stack and retaining the hyperbolic events on the gather (Figure 6&7). This success has been instrumental in the overall achievement of our project. Spectrum for input P and Z component and output after UDD is shown in Figure9. After the application of UDD, data sets exhibited spectral enhancement with reduced notches for ghosts and multiples in the spectrum improving flatness. This reduction in notches indicates a more uniform distribution of energy across the frequency spectrum, resulting in a balanced spectral response.

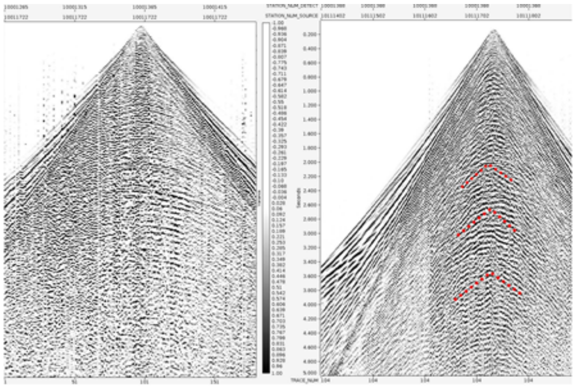

Figure4: Shear Leakage in Shot domain (left) and Receiver domain (right)

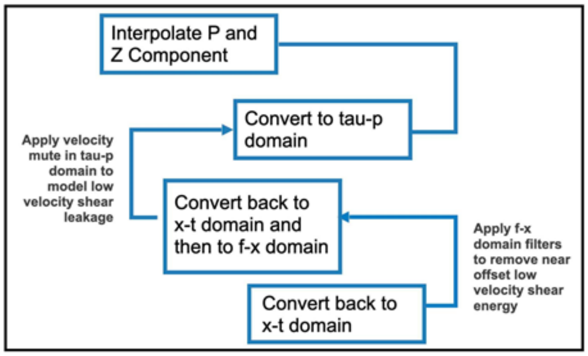

Figure5: Shear Leakage removal workflow

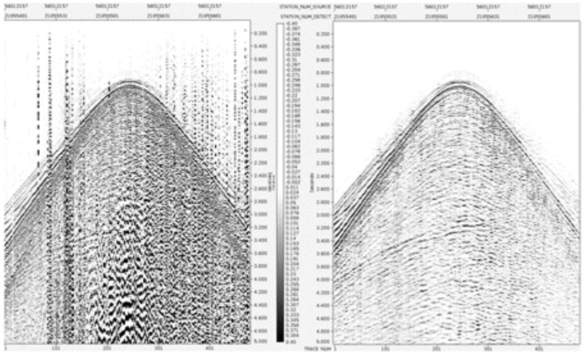

Figure6: Shot gather before (left) and after (right) Noise attenuation in Z Component

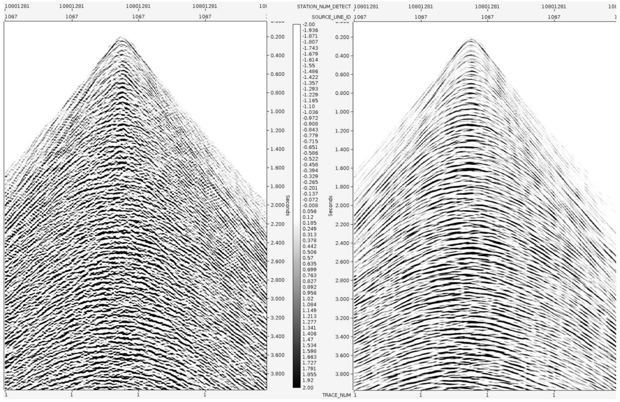

Figure7: UDD applied Receiver gather without (left) and with (right) shear noise attenuation before UDD in Z Component

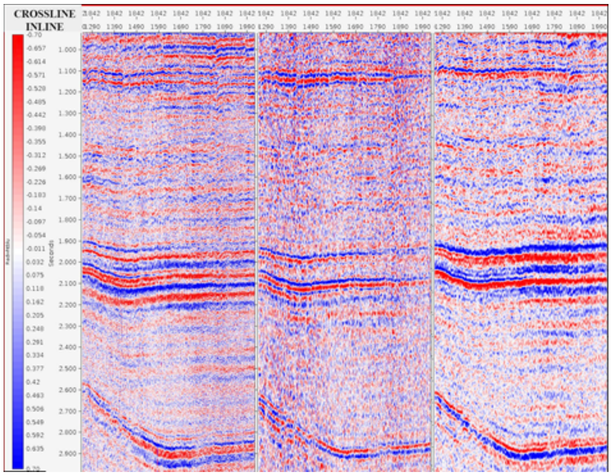

Figure8: P component (left), Z component (middle) and UDD (right) stack

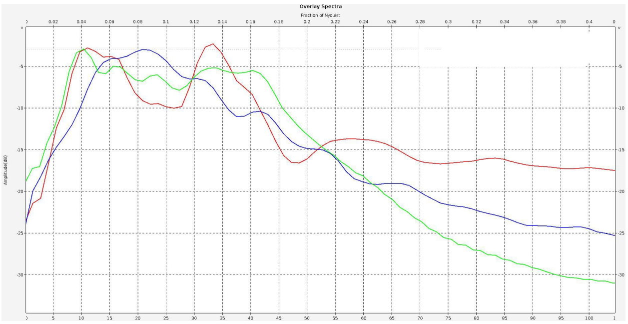

Figure9: Amplitude spectrum for Input P component (red), Z component (blue) and UDD output (green) stack

Results

UDD, combined with a 3D tau-p mute, effectively attenuates noises in the seismic data. Additionally, wavelet shaping enhances the quality of the signal. The application of UDD (Up-Down Deconvolution) proved successful in removing linear noise components, such as reverberations and surface waves, resulting in clean seismic image. The deconvolution process led to enhancement of resolution and improvement of interpretation of subsurface features. The stack (Figure8) demonstrates improved structural continuity, indicating a more coherent and connected representation of the subsurface features. The

implementation of weighted least square Radon filtering showed promising results in attenuating coherent noise and suppressing unwanted events contributing to a clearer and more focused seismic image. Curvelet filtering, with its ability to capture localised and anisotropic features, effectively attenuated noise while preserving the essential seismic signals. 3D Tau-p domain noise attenuation played a significant role in the study, targeting shear noise components in the transformed domain. The issue of shear leakage, which refers to the contamination of Z-component seismic data with shear wave energy, was addressed. Through the utilisation of advanced processing techniques, including shear leakage removal algorithms, the impact of shear leakage on the final seismic image was minimised. This resulted in a more accurate representation of the subsurface features and improved interpretation.
After UDD noise attenuation was further done to attenuate any remnant noise.

Following Noise Attenuation steps were also applied in other domains

1. Radon filtering and Multi panel frequency interpolation in offset domain.

Following steps were applied Post stacking
1. Horizon based filtering
2. Amplitude conditioning
3. Radon demultiple.

The combined implementation of these processes has resulted in a remarkable enhancement of data quality, as evidenced by the comparison between the Raw and Final PSTM stack in Figure 10. The intermediate sequences between Daman, Mahuva, and Panna have been significantly resolved, exhibiting improved continuity of stratigraphy. Additionally, the attenuation of near-surface reverberations has been effectively achieved, leading to a much cleaner and clearer representation of the subsurface.

Figure 11 provides a comparative analysis that highlights the superior effectiveness of UDD combined with proper noise elimination in removing linear noise components, such as reverberations and surface waves, when compared to PZ summation.The deconvolution process employed in UDD offers enhanced precision in targeting and eliminating these noise sources, leading to a seismic image that is significantly cleaner and exhibits improved resolution and interpretation capabilities.

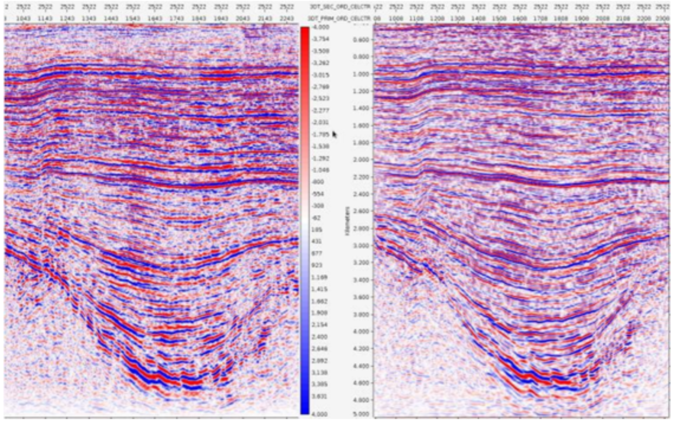

Figure10: Raw(left) vs Final(right) stack

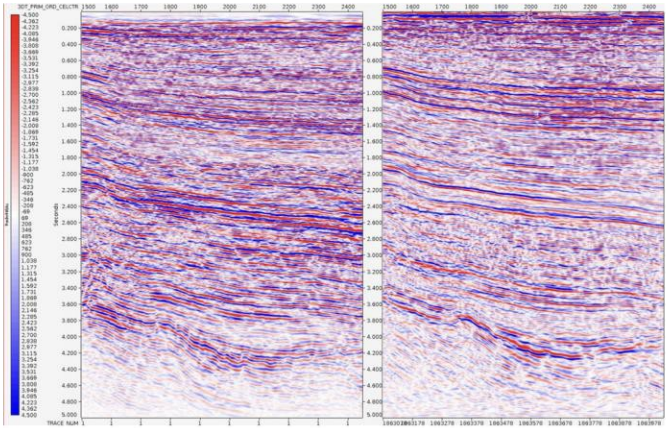

Figure11: CRAM scaled to time output (left) vs UDD PSTM output (right) stack

Conclusions

In conclusion, a comprehensive study on noise attenuation techniques applied to OBC (Ocean Bottom Cable) seismic data before application of UDD is presented. The objective was to enhance the quality and interpretability of the data by reducing the impact of various types of noise.

This study reviewed several noise attenuation methods, including UDD (Up-Down Deconvolution), weighted least square Radon, curvelet filtering, 3D tau-p and coherent noise attenuation techniques. Each technique was described in detail, highlighting its application, usability and response.

Furthermore, the specific challenges associated with OBC data, such as the presence of guided waves, Scholte waves, and complex noise patterns are discussed. It highlighted the importance of addressing these challenges to improve the seismic image quality and reliability. Based on the analysis and evaluation of the different noise attenuation techniques, it was observed that a combination of methods often yielded the best results. Additionally, emphasis was provided on the significance of proper noise characterisation, adaptive filtering, and the utilisation of domain-specific algorithms, such as 3D tau-p domain filtering in OBC seismic data processing. Overall, utilisation of advance attenuation techniques for OBC seismic data was done. The presented methods provide valuable tools for improving data quality, enhancing subsurface imaging, and facilitating accurate interpretation in challenging marine environments. Further research and experimentation can build upon these findings to refine and develop more advanced noise attenuation techniques for OBC seismic data in the future.

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