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Research Paper

Application of Predictive Deconvolution for Enhancing Resolution in 2D Marine Seismic Data Processing

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ABSTRACT

In marine seismic data, short period multiples are a persistent issue that frequently obscure primary reflections and diminish the clarity of subsurface images. To suppress these undesirable events, predictive deconvolution is sometimes used, but its success depends on choosing proper parameters, which are usually kept constant throughout the seismic line. In this work, we propose a zone-based, adaptive method for predictive deconvolution that adapts the prediction gap and operator duration to variations in the dataset and frequency content. This method enhances the management of lateral geological variations and produces more consistent results.

The technique is implemented prior to velocity analysis and stacking, which enables more precise moveout corrections and cleaner collections. We assess its performance by utilising a combination of spectral and structural indicators, such as bandwidth expansion, RMS amplitude consistency, semblance sharpening, and reflector continuity. The results of our 2D marine dataset demonstrate significant improvements, including a 25% increase in bandwidth resolution and visibility of primary events, particularly in shallow zones that are impacted by strong reverberations. In summary, this adaptive predictive deconvolution approach works well for improving seismic resolution and can be expanded to 3D data or combined with machine learning in the future.

Keywords: Predictive Deconvolution, Marine Seismic Processing, Multiple Suppression, Resolution Enhancement, Adaptive Filtering

INTRODUCTION

In marine seismic data, the existence of short period multiples decreasing the clarity event of seismic images. These multiples mainly cover primary reflections, leading to structural misidentification (Güney et al., 2019). Predictive deconvolution is a proven technique for reducing this problem by focus on periodic energy patterns associated with short-period reverberations (Peacock & Treitel, 1969). The technique works with the predictable of multiples to generate an inverse filter that suppresses coherent noise while maintaining primary. Its practical application involves comprehensive parameter testing despite its theoretical simplicity. The estimation of operator length and prediction gap must be adapted to the data and relevant to acquisition geometry and subsurface complexity (Dondurur, 2018). This study examines the application of predictive deconvolution on a 2D marine dataset in terms of industrystandard workflows and systematic parameter testing.

Marine seismic data mainly demonstrate robust water-bottom reverberations due to of the high acoustic impedance contrast between seawater and the underlying sediments. These reverberations can be particularly persistent in shallow marine environments, where short-path multiples overlap with primary waves (Wei, 2003). This overlap complicates both velocity analysis and stacking quality. Conventional filtering methods may inadequately attenuate such energy while maintaining important signal information. Predictive deconvolution provides a targeted technique by utilizing statistical predictability in the autocorrelation domain. This turns it suitable for pre-stack conditioning before velocity picking or amplitude analysis. It is increasingly essential in surveys where primary-to-multiple ratios are low and signal fidelity is critical (Yilmaz, 2001). Although predictive deconvolution is not a new technique, its implementation remains in processing workflows, particularly with advancing acquisition methods and high-frequency recording devices. Improvements in digital recording and broader bandwidth increased both the prospects and difficulties related to its application. Higher resolution data demand precise wavelet estimates and clearer differentiation of signal and noise in the frequency domain. Furthermore, this is complicated by the lateral variations in lithology and variable seabed topography, which affect multiple behaviors (Verschuur, 2006). Therefore, predictive deconvolution must be performed dynamically, using parameters that adapt to variations in water depth and reflector continuity. Our research solves these problems by implementing zone-based deconvolution techniques into the seismic data.

This research aims to establish a connection between theoretical understanding and field-based application, thereby generating insights that are directly applicable to the routine processing of marine seismic data. Using a real 2D marine data, our approach concentrates on data-driven parameter selection and performance through post-deconvolution analysis. The results enhance not only a specific dataset but also inform best practices for future research in similar geological settings. In the final analysis, this study proves the importance of predictive deconvolution as an important tool for enhancing the interpretability and resolution of seismic data in complex marine environments (Zhu & Wang, 2018).

MATERIALS & METHODS

Data

The data in this study was acquired using a single-streamer marine configuration. Acquisition parameters included a 25-meter shot interval, 25-meter receiver interval, 96 channels, and a 2 ms sampling rate. The total line length approximately 2681 meters, with a maximum record length of 5 seconds. The water depth ranged 200 meters. Data were recorded using a conventional airgun array with a peak frequency around 40 Hz and a usable bandwidth of 3–125 Hz. This setup follows best practices in marine acquisition design (Güney et al., 2019; Wang et al., 2013), providing sufficient spatial and temporal resolution for multiple attenuation.

Preprocessing Step

This study adopted a marine seismic data processing workflow. The preprocessing step before deconvolution comprised the following steps:

1. Geometry Setup

The first critical step in marine seismic data processing is the accurate definition of acquisition geometry. Geometry setting involves assigning spatial coordinates to each trace by integrating shot and receiver positions based on navigation data (SPS Files). Geometry errors can affect to incorrect trace positioning, resulting in stacking artifacts and velocity analysis inconsistencies. This step also includes the application of datum corrections. A correct geometry ensures spatial coherence of reflectors across gathers for accurate moveout correction, stacking, and migration.

2. Trace Editing

Trace editing is performed to remove dead traces or high amplitude noise that could decrease the quality of the final stack. This process involves both automated and manual methods to identify traces with zero amplitude, clipped signals, or phase reversals. Maintaining only high-quality, coherent traces improves the stability of predictive filtering and enhances the reliability of semblance-based velocity picking.

3. Amplitude Recovery

Due to geometrical spreading and energy loss from spherical divergence, the amplitude of reflected seismic energy decreases with increasing travel time. Amplitude recovery is applied to compensate for this decay and to restore relative amplitude fidelity, which is essential for accurate deconvolution and AVO (amplitude variation with offset) studies. This process include energy balancing across shot gathers to correct for variations in source strength or coupling. The recovered amplitudes contribute to a more uniform signal level across time and offset, improving filter stability in predictive deconvolution. Consistent amplitude behavior across traces is a key prerequisite for effective multiple attenuation.

4. Noise Attenuation

Noise attenuation targets coherent and incoherent noise that may interfere with primary signal content and decrease the performance of deconvolution and migration. Effective noise attenuation enhances the signal-to-noise ratio (SNR), providing a cleaner input for predictive deconvolution and improving the reliability of wavelet estimation.

Predictive Deconvolution Workflow

Predictive deconvolution as a pre-stack process aimed to compressed the seismic wavelet and attenuating short-period multiples, particularly those caused by water-bottom reverberations. The predictive deconvolution comprised the following steps:

1. Autocorrelation Analysis

The process begins with the estimation of the autocorrelation analysis for each trace. This step identifies the periodicity in the signal, which corresponds to multiples (e.g., water bottom reverberations). Autocorrelation helps estimate the dominant multiple period which inform the selections of prediction gap.

2. Define Predictive Deconvolution Parameter

Operator length and prediction gap are the two principal parameters and their selection must reflect the dominant period of the multiples and the bandwidth of the data. Operator lengths parameter test ranges from 120, 160, 180, 200 and 240 ms, while prediction gap parameter test ranges from 8, 16, 24 and 36 ms for shallow marine data. These parameters are iteratively tested on selective shot gathers to observe their impact on wavelet sharpness, multiple suppression and amplitude stability.

3. Apply Predictive Deconvolution Filter Trace-by-Trace

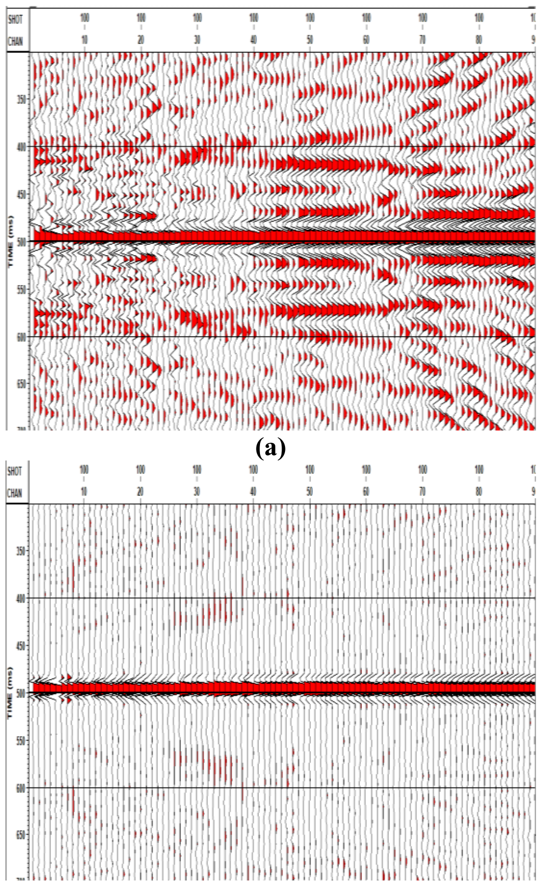
A least-squares solution based on Wiener-Hopf formulation is used to compute the deconvolution filter that minimizes the energy of coherent events (short period multiples) in the marine data (Samson and West, 1995; Robinson, 1975). This filter applied trace-by-trace, effectively whitening the seismic signal and enhancing temporal resolution. The output is a convolutional filter applied in the time domain. Implement the filter across each trace within define time window gate (200 – 3500 ms). This step compresses wavelet and suppresses multiples in pre-stack data.

Parameter optimization by a combination of spectral balancing and reflector enhancement. The criteria for optimal parameter selection included maximum coherence of primary events, minimal residual multiples, and stable amplitude. In addition to visual QC and frequency bandwidth spectrum were used to assess

improvements quantitatively (Carneiro et al., 2017).
Maintaining a consistent processing framework and isolated the predictive deconvolution stage, we ensured that the observed improvements in resolution and noise suppression could be directly attributed to parameter changes. This strict control over processing parameter allowed for rigorous evaluation under realistic field conditions. In line with previous deconvolution studies (Zhu and Wang, 2018; Romauli et al., 2016), our study shows the importance of adaptive and data-driven filtering in marine seismic data. The workflow demonstrated here contributes to advancing predictive deconvolution as a precision tool for shallow water seismic processing.

RESULT

The application of adaptive predictive deconvolution resulted in a significant enhancement in multiple suppression, temporal resolution, and reflector continuity through the 2D marine data. In shallow parts characterized by strong bottom reverberations, the technique successfully suppressed short-period multiple noise and enhanced primary reflectivity. The optimum operator configuration, determined through iterative testing, produced stacked sections with sharper wavelets and enhanced primary events.
Figure 1 displays the difference between the autocorrelation analysis before and after predictive deconvolution was applied. Before deconvolution, autocorrelation shows clear periodic side lobes, which are a sign of strong short-period reverberations that are usually seen with water-bottom multiples. These side lobes are almost the same distance apart, which shows that the multiple energy is predictable and coherent. After deconvolution autocorrelation, on the other hand, shows a sharper central peak with much smaller side lobes. This is because the wavelet is more compact and the predictable energy components have been effectively attenuated. This change in the autocorrelation function is a direct result of the predictive error filter's ability to remove coherent, periodic energy while keeping the random characteristics of primary reflections. The autocorrelation peak getting narrower means that the time resolution is improved and there is less interference from multiples. This change is very important for making velocity analysis more accurate and for ensuring the stacking and migration stages that come after it more reliable. The decreased possible wavelet overlap that comes from less side lobe energy also means that there is less of a chance of this occurring, which can make it difficult to understand in shallow parts.

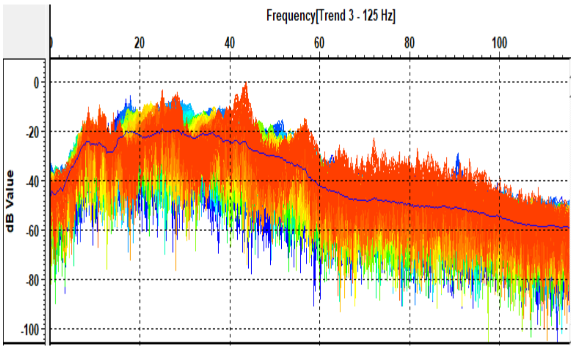


(a)

(b)

Figure 1. Autocorrelation analysis (a) before and (b) after predictive deconvolution

Frequency spectrum revealed an expanded broader bandwidth after deconvolution, particularly within the 5–100 Hz range. Reflector terminations that were previously indistinguishable due to overlapping energy were distinctly resolvable, which improve geological interpretation. The quantitative results correspond with qualitative observations, confirming the method's effectiveness.



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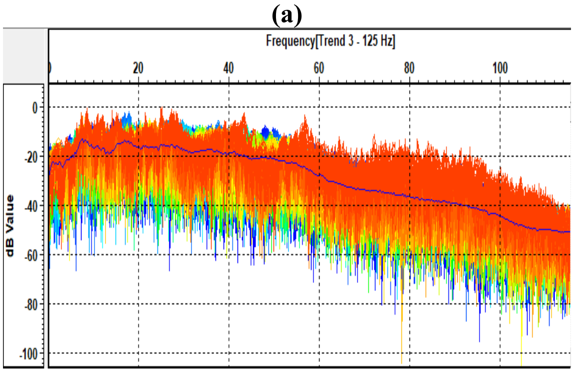
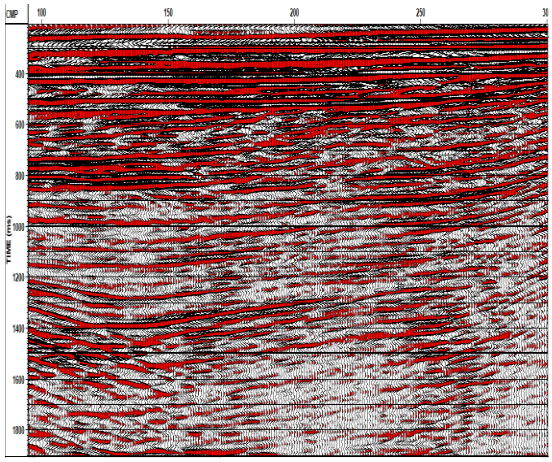


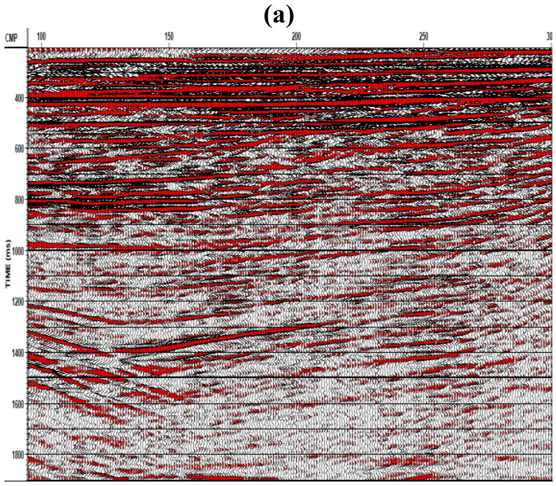
(b)

Figure 2. Comparison amplitude spectrum analysis (a) before and (b) after predictive deconvolution

Comparisons of the amplitude spectrum before and after deconvolution in Figure 2 demonstrated a substantial decrease in low-frequency multiple energy, particularly below 20 Hz. After deconvolution spectrum analysis displayed more higher frequency content, signifying effective reverberation attenuation. In deeper parts, while primary energy predominated, residual long-period multiples remained present but were considerably diminished. Enhancements in semblance coherence plots validated improved circumstances for velocity analysis, particularly advantageous for NMO correction and stacking precision. In all studies, the optimal values preserved primary event amplitude fidelity while suppress multiple. These results show the balance between noise reduction and signal data by correct predictive deconvolution parameter.



(a)



(b)

Figure 3. Comparison stack section (a) before and (b) after predictive deconvolution

Figure 3 shows a comparison of seismic stack sections from 2D line, showing the effect after predictive deconvolution on image quality. The left panel displays the stack section before deconvolution process, whereas the right panel displays the same section after adaptive predictive deconvolution process. Before deconvolution stack, water-bottom multiples and reverberations present as high-amplitude, sub-horizontal noise events, especially beneath the seafloor reflection, masking deeper primary reflections and diminishing continuity between reflectors. After deconvolution section has much improved reflector continuity, sharper wavelet characteristics, and enhanced resolution of deeper features. The attenuation of short-period multiples results better seismic image, allowing the clear identification of stratigraphic layers and fault geometry. Reflectors previously cover by coherent noise are now identifiable, particularly in shallow to mid-depth intervals (0.3–1.8 s TWT). The signal-to-noise ratio has improved, facilitating more accurate horizon tracking and structural analysis. These enhancements confirm the successful application of adaptive predictive deconvolution in reducing multiple interference and improving the vertical resolution of marine seismic data.

DISCUSSION

The improvements show that predictive deconvolution works in real data. Detailed parameter testing is a key finding that enabled the adaptation of the method to the complex wavelet behaviors found in marine data. Predictive deconvolution has been around for a long time, but it only works well when the parameters are set to fit the data. This makes even more important to have proficient geophysical judgment when choosing operator lengths and prediction lags. It was necessary to use both statistical analysis and visual QC to make sure that the parameters were appropriate. Additionally, the research emphasizes the workflows that can be considered common and generally applicable. Customization, especially through zonal adaptation, led to much better results.

The noise suppression-signal preservation compromise is crucial. Aggressive deconvolution settings can over-whiten or distort reflectivity, especially in key frequency ranges. Our results show that it is possible and crucial to carefully control, especially when working with data from different water depths and types of rocks. We found a compromise that kept the geology valid by looking at the RMS amplitude and spectral features. These evaluations not only helped with deconvolution, but also helped with the next phases in processing, such as stacking and migration. The clear improvement in how easy it is to understand shows how useful these kinds of comparison studies are. When it comes to choosing parameters, a data-informed approach is better than a template-based one.

The zonal technique used in this study is a big step forward in the use of predictive deconvolution. In marine environments, traditional processing generally presume that the line is uniform, which is not usually the case in real life. We set the deconvolution parameters to fit the data.

Adding predictive deconvolution to the larger processing sequence also affects how interpretation workflows work. Better continuity and less noise make structure mapping and attribute analysis more reliable. This is especially important for analyzing faults and characterizing reservoirs in complicated environments. The strategy described here helps to make horizon selection and amplitude variation with offset (AVO) experiments better. By dealing with reverberation effects early on, the geophysical analysis that occurs later is stronger. The accuracy of the processed data is closely related to how well the interpretation works. So, predictive deconvolution is not just a filtering step; it is also an important part of the seismic processing step.

Finally, our study improve knowledge about the best ways to handle marine data. As gathering technologies get better and the need for higher resolution data grows, processing methods must also change. When used dynamically, predictive deconvolution addresses these changing needs by improving resolution without damaging the integrity of the data. Our study provides a framework for finding this balance and shows how important it is to process data in a way that takes its context into account. Future study could look into how to combine this with machine learning to make parameter adjustment and zone classification automatic. These kinds of improvements would make workflows even smoother and make the most of data. This work gives a strong base for these kinds of new ideas in the future.

CONCLUSION

This study shows that predictive deconvolution implemented using adaptive parameterization approach, significantly improves the temporal resolution and image clarity of 2D marine seismic data. By adjusting operator length and prediction lag according to spectral attributes, the approach effectively reduces short-period water-bottom multiples and compresses the seismic wavelet while maintaining amplitude quality. The implementation of this technique before velocity analysis enhances stack quality and provides a more dependable velocity model and migration result. The beneficial effect of the approach is confirmed through an extensive integration of spectrum, amplitude, and structural quality control evaluations, demonstrating quantitative enhancements across all tested areas.

The enhanced spectral bandwidth, continuity of reflectors, and less coherent noise enable superior delineation of subsurface structures, especially in shallow parts where reverberation energy poses significant challenges. Faults, stratigraphic terminations, and thin beds—frequently covered by multiples in standard processing—become much visible following adaptive deconvolution. The capacity to adapt the filter according to geological variation also mitigates overcorrection in complex areas, maintaining geological accuracy and signal quality. These results show the necessity of implementing adaptive techniques into conventional deconvolution operations, particularly in progressively complex and high-resolution acquisition conditions.

The proposed workflow provides a solid framework for future innovation. The methodology is easily extensible to 3D surveys and can benefit from the inclusion of machine learning for automatic parameter optimization and zonation. Furthermore, real-time or onboard implementation may become possible with current developments in seismic computing technology. As marine seismic processing advances towards more adaptive, high-resolution, and interpretation-focused methodologies, predictive deconvolution augmented by geological insight and adaptive design continues to be an essential instrument. This study confirms its ongoing significance and provides the way for its enhancement and extension in future geophysical applications.

Declaration by Authors

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REFERENCES

1. Carneiro, R. N. C., Leite, L. W. B., Vieira, W. W. S., & Rufino, C. S. (2017). Predictive deconvolution of multiple free surface in marine seismic data. 15th International Congress of the Brazilian Geophysical Society & EXPOGEF. https://doi.org/10.1190/sbgf2017-117
2. Dondurur, D. (2018). Acquisition and Processing of Marine Seismic Data. Elsevier Science Publishing Co.
3. Güney, R., Karslı, H., & Dondurur, D. (2019). Optimum parameter selection in offset-dependent predictive deconvolution: testing on multichannel marine seismic data. Marine Geophysical Research, 40(4), 601–617. https://doi.org/10.1007/s11001-019-09390-w
4. Peacock, K. L., & Treitel, S. (1969). Predictive deconvolution: theory and practice. Geophysics, 34(2), 155–169. https://doi.org/10.1190/1.1440001
5. Romauli, A., Manik, H. M., & Subarsyah. (2016). Penerapan dekonvolusi spiking dan dekonvolusi prediktif pada data seismik multichannel 2D di Laut Flores. Jurnal Teknologi Perikanan dan Kelautan, 7(2), 153–162. https://doi.org/10.24319/jtpk.7.153-162
6. Verschuur, D. J. (2006). Seismic Multiple Removal Techniques: Past, Present and Future. EAGE Publications.
7. Wei, C. S. (2003). Suppression of water bottom multiples in shallow seismic data by predictive deconvolution. University of New

Brunswick. Retrieved from https://unbscholar.lib.unb.ca/items/588ecf1e-1efa-4aa1-bdb8-35965bd1e9d3

8. Yilmaz, Ö. (2001). Seismic Data Analysis: Processing, Inversion, and Interpretation of Seismic Data. Society of Exploration Geophysicists.
9. Zhu, S., & Wang, B. (2018). Application of adaptive predictive deconvolution in marine seismic data. Indonesian Journal of Electrical Engineering and Computer Science, 12(9), 6827–6832. http://doi.org/10.11591/ijeecs.v12.i9.pp6827-6832
10. Samson, C., & West, G. F. (1995). Dereverberation of marine reflection seismic data by a spatial combination of predictive deconvolution and velocity filtering. Marine Geophysical Research, 17(1), 1–15. https://doi.org/10.1007/BF01268048

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