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Noise Attenuation and Pre-conditioning of seismic data for time and depth imaging in deep water environment- East Coast of India

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Summary

Seismic data preconditioning in deep water survey is very essential process prior to time / depth migration with reference to strong multiples masking deeper primaries and cost of deep water drilling. The paper starts with an analysis of background noise with the help of RMS amplitude map in water column. Then a processing flow is outlined to precondition the deep water seismic data which would be used for the purpose of time and depth migration. The proposed flow includes – attenuation of swell noise / object strike noise with f-x projection filter, near-offset surface related multiples by 2D / 3D SRME, far-offset multiples with high resolution Radon and diffracted multiples by frequency based multiple attenuation technique. An advanced 3D SRME technique is also shown in this paper which works well in complex situations. Major hindrance encountered in deep water imaging. Attenuation of diffracted multiples, along with primary multiples, is highly challenging but essential process. However, total elimination of these noises is not practically possible as de-noise, de-multiple process effect the S/N ratio. A flow diagram showing the basic steps for noise analysis and attenuation is depicted in Figure 1.

Introduction

Raw seismic data are often dominated by coherent and incoherent noises. Ghost, reverberation, multiples, etc. are categorized as coherent noise, while swell noise, spikes due to production equipment, etc. are defined as incoherent noise.

In this paper, noises encountered in deep water environment of east coast of India are discussed along with their removal / attenuation techniques.

Krishna Godavari basin along the east coast of India has been proven as one of the most promising petroliferous basin of India. The whole basin is filled with thick pile of sediments from Permian to recent age. In the tertiary rapid sedimentation occurred, particularly in the Miocene age. The shallow sediments have numerous gas pockets, lowly compacted sediments with varying reflectivity and gas hydrate. This set up generates strong free surface multiples of various order as well as diffracted multiples. The weather condition in east coast of India often generates high swell even in deeper water and strong variable current causes high feathering of streamers.

The main focus will be on multiples suppression and swell noise attenuation which accounts for

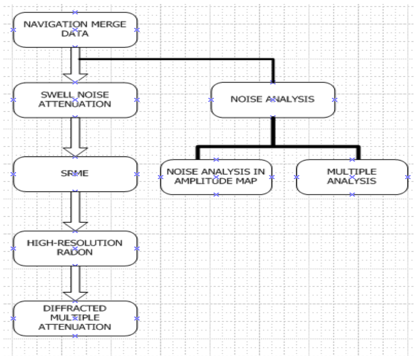

Figure 1: Flow Diagram of basic steps used for noise and multiple attenuation.

Noise Analysis

The background noise encountered during the survey is shown in Figure 2. The RMS amplitude is calculated for all streamers in water column. The amplitude spectrum in Figure 2 shows high amplitudes at low frequency due to swell in sea. Object strike noise caused by floating debris striking the streamers / birds / acoustic pods is displayed in Figure 3.

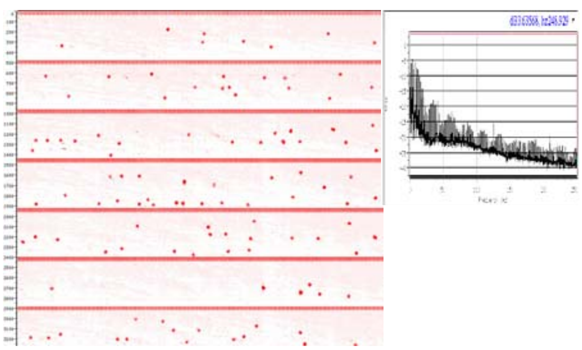

Figure: 2 Background noise in RMS amplitude Map

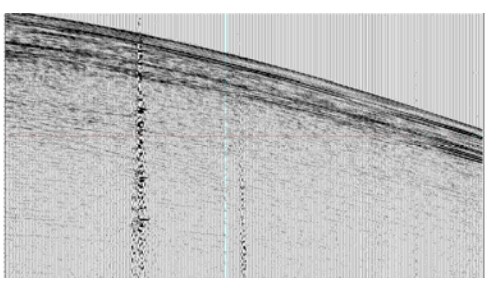

Figure: 3 Object strike noise

Methodology

Swell Noise Attenuation

Swell noise, which is characterized by low frequency and high amplitude, is a significant hurdle to seismic exploration in the marine environment. Weather is one of the main cause for swell noise generation. In swell noise attenuation process, the low frequency & high amplitude random noises are attenuated through the projective filter (Guillaume Cambois, 1995) which ensures better preservation of signal as shown in Figures 4 and 5.

The amplitude spectrum in Figure 5(c) shows the removed noises after application with this process are having low frequency and high amplitude which are the characteristics of swell noise.

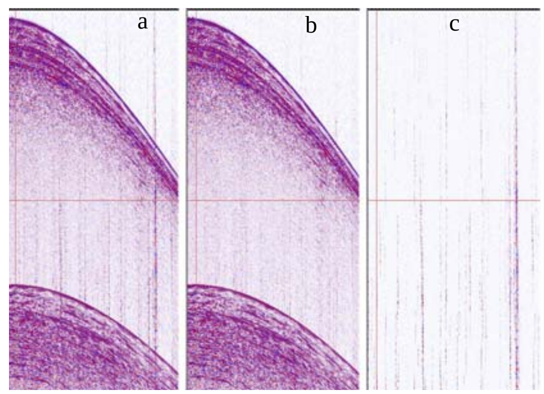

Figure 4: (a) Input SP for swell, (b) SP after swell noise attenuation and (c) Difference section.

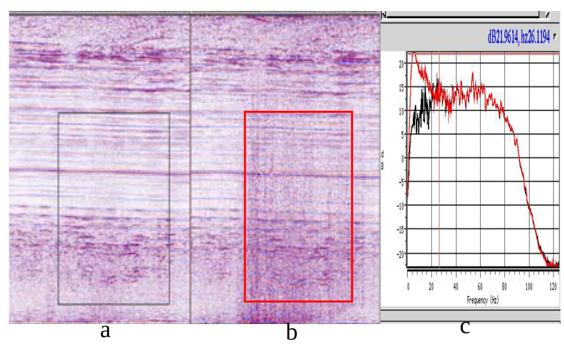

Figure 5: (a) Stack before swell noise attenuation, (b) Stack after swell noise attenuation and (c) Spectral analysis

Surface Related Multiple Elimination (SRME)

This method predicts and attenuates surface related multiples (events that experience a reflection on the free surface) from the marine seismic data, without any knowledge of interfaces and velocities. Essentially each shot must be spatially convolved with a receiver at the same location and vice versa. Finer sampling or very good interpolation is required so that the source and receiver are on the same grid. Data at zero or near offset improves the prediction of multiple model.

The methods use different mathematical formulations but are essentially identical for free surface multiples are as follows –

- Wave theory is honoured, and the subsurface is not required. The SRME methods (Verschuur 1992) are not sensitive to errors in the water-bottom picks.
- A "wavelet" is still required. The wavelets extracted from the data itself or use adaptive subtraction to achieve result Figure 6. The result of such a process is shown in Figures 7 and 8.

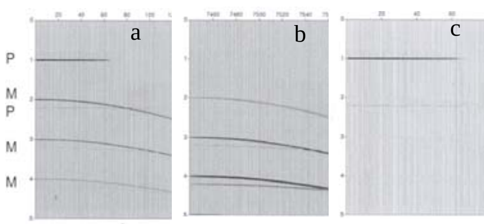

Figure 6: (a) Input data, (b) Multiple Model and (c) Adaptive subtraction

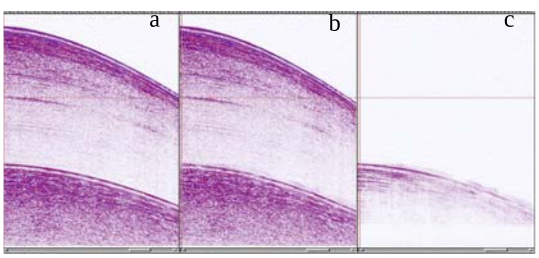

Figure 7: (a) SP before 2DSRME, (b) SP after 2DSRME; and (c) Difference

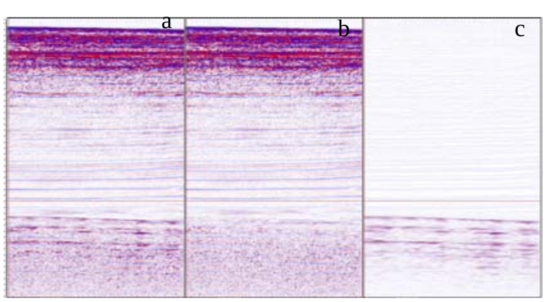

Figure 8: Stack section (a) before, (b) after 2D SRME and (c) their differences.

Out of the spectrums, shown in Figure 9, there is a decrease in the amplitude within the multiple zone (blue colored curve) only and others are remain unchanged. This clearly indicates that the SRME attenuated the multiples within the multiple zone only and has not touched any signal from the other zones. This is also validated by the stack sections presented in the Figures 8 and 12.

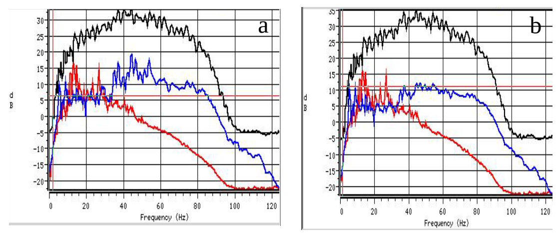

Figure 9: Frequency spectrum (a) before and (b) after 2D SRME at three different depth levels. Black represents shallower section, red represents above multiple zone and blue represents within multiple zone.

Figures 10 and 11 display the cross-correlation of predicted multiple models with the seismic data in 2D and advanced 3D SRME respectively. These Figures show that the multiples are better predicted for all offsets in advanced 3D SRME, whereas, 2D SRME could predict multiples in near offsets only. In case of the dataset affected by strong feathering and undulating water bottom, 3D SRME should be the right tool. With an advance 3D SRME, which is azimuth comprehending and has better interpolation techniques, the multiples are better predicted in all offsets range. The comparison stacks for 2D SRME and advanced 3D SRME are depicted in Figure 12.

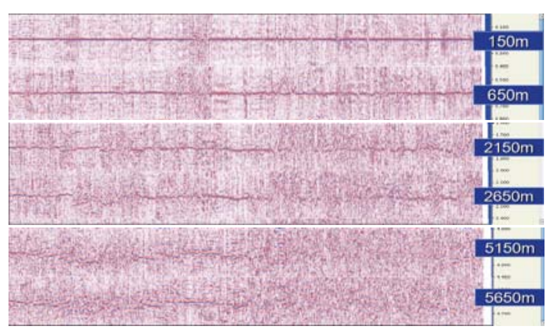

Figure 10: Predicted error map with 2D SRME

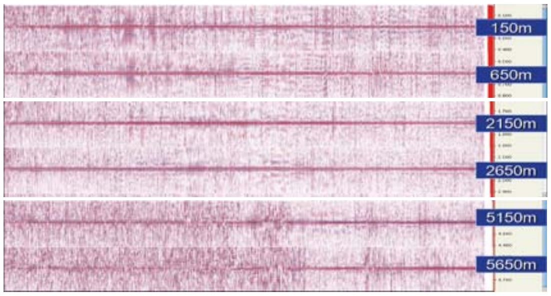

Figure 11: Predicted error map with advanced 3D SRME.

High-Resolution Radon Anti-Multiple

Velocity based methods such as Parabolic Radon is used as a de-multiple tool in deep water. This method fails to differentiate between primary and multiple at near offset due to small move-out between the two.

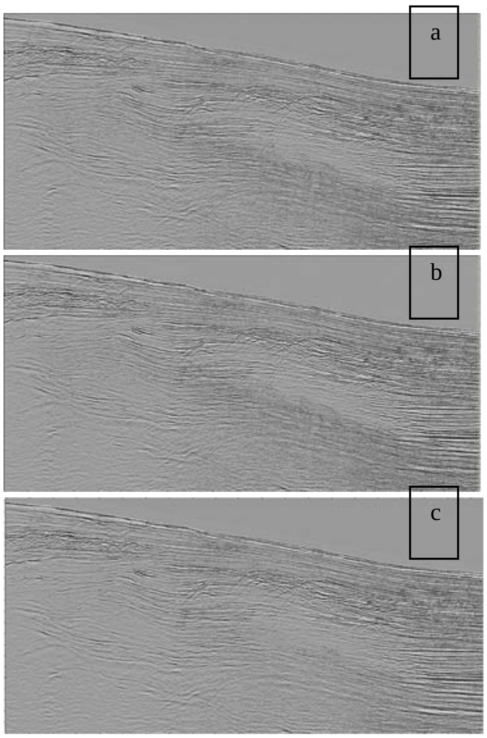

Figure 12: (a) Input stack, (b) 2D SRME output (c) Advanced 3D SRME.

In the high-resolution RADON de-multiple method, a model of primary and multiple events are computed. This computation is based on data decomposition into user-defined parabolas and performed using a high-resolution, de-aliased least squares method in the frequency-space (f-x) domain for each frequency within the band. Event corresponding to parabolas with a greater curvature than a user defined threshold is considered to be multiples (refer Figure 13). Event corresponding to parabolas smaller than this threshold is considered to be primary events. Figure 13 explains the primary, multiple and parameter definitions used in RADON process. The effectiveness of this RADON method for removing multiples is displayed Figure 14 with the help of the CMP gathers and the F-K spectrums.

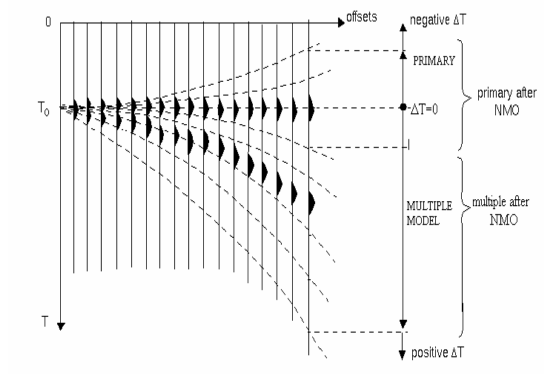

Figure 13: The RADON parameter definitions.

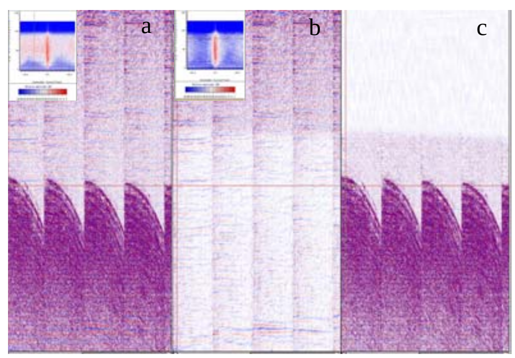

Figure14: (a) CDP gathers before High resolution Radon, (b) CDP gathers after High Resolution Radon and (c) Difference

However diffracted multiples remain in data after 2D SRME and High Resolution Radon. For this reason a next level of multiple attenuation is added.

Diffracted Multiple Attenuation

In the data where the apex of multiples is shifted from zero offset towards mid offset, high resolution Radon fails to attenuate those. There are two methods to attenuate these type of apex shifted multiples.

First one is based on the modeling of the apex shifted multiples and adaptive subtraction of this multiple model from the seismic data (Stewart, Jones and Hardy, 2007). This is done with the help of some modified variant of Radon de-multiple technique.

The second one is based on the frequency discrimination between the diffracted multiples and the signals at a particular depth. The first approach is more accurate but very expensive process in terms of CPU time.

The results of the diffracted multiples attenuation with the help of second approach are shown in Figure 15.

Conclusions

The processing of the deep water seismic data are always challenging in terms of the attenuation of multiples and noises related to sea conditions. With the presence of residual multiple energy and the noise in the data,

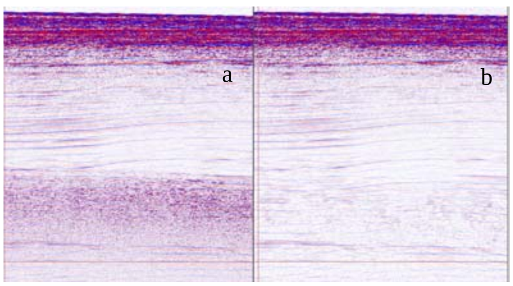

Figure 15: Stack sections (a) before and (b) after diffracted multiple attenuation.

1. Velocity model estimation becomes difficult and erroneous.
2. Migration artifacts like swings may degrade the output.

Before the data goes into pre-stack time or depth migration, care should be taken to eliminate these noises / multiples, as they contaminate the migration results. From this study we conclude the following –

- Swell noises are better attenuated by f-x projective filter,
- 2D SRME takes care of multiples at near offset while advanced 3D SRME is effective for all offsets.
- High Resolution Radon and diffracted multiple attenuation is more effective for residual hyperbolic multiples and diffracted multiples respectively.

Unlike West coast of Indian deep water, east coast data demands a robust denoise and demultiple workflow with amplitude preservation. This enhances the exploration success of tertiary AVO friendly gas plays and multiples masked tertiary and Mesozoic oil plays.

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