Processing for enhanced resolution to aid shallow hazard assessment: a case study in Brazil's Campos basin

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Abstract

The frequency content of seismic data from the shallower subsurface is usually substantially higher than that of data related to the deeper lying targets due to the presence of absorption. When processing conventional seismic data for shallow hazard assessment, the standard processing sequence and parameterization, do not provide high enough resolution to facilitate effective shallow hazard assessment. We show that through careful reconsideration of the processing sequence and parameterization, taking into account the difference in frequency content of the shallower data, a substantially higher resolution image can be obtained using conventional seismic data. The new processing sequence is illustrated with an example in the Campos basin offshore Brazil. For this data, at -20 dB, the bandwidth was effectively extended from 4 - 65 Hz to 3 - 165 Hz.

Introduction

High resolution processing for shallow hazard assessment (Lutz and Strijbos, 2009) aims to help with the identification of potential shallow geological hazards such as shallow gas (e.g. Ronen *et al*. 2012), near surface faults, sediment strength (e.g. Djikpesse *et al.* 2013), and water bottom anomalies. Such identification then allows for better planning when developing oil and gas fields and can help mitigate blowout risks due to the presence of shallow gas.

The Campos basin and its near surface overburden presents its own unique challenges and risks for drilling. A high resolution seismic is expected to help identify these risks and significantly reduce uncertainty associated with any potential geohazards encountered in the basin.

In this paper we highlight the specific processing steps that can make a difference to obtain enhanced resolution required for shallow hazard assessment, using conventional streamer seismic data. We show an example in the Brazilian Campos basin and compare images of the shallow subsurface obtained using conventional horizontal streamer data originally acquired and processed in 2000 and reprocessed in 2014 with the particular aim of obtaining enhanced resolution for shallow hazard assessment.

High resolution data pre-processing

When processing seismic data, the temporal sampling rate is often adjusted according to the frequency content of the data close to the target area. When the target is deeper, the frequency content of the data is typically lower than for shallower data, due to the absorption induced by the earth during wave propagation. Since the target for shallow hazard assessment is shallower, these data are expected to have higher frequencies than the data from the deeper lying targets. Therefore the original sampling rate of 2 ms was maintained and no resampling to 4ms was done, resulting in a Nyquist frequency of 250 Hz instead of 125 Hz.

When the target is deeper the velocity determination is often more focused on the deeper parts of the data, and relatively less attention is paid to the shallower parts of the data. Furthermore, the shallower reflections suffer more severely from move-out and/or migration stretch than the deeper ones, especially for the longer offsets. In the interest of time no attempt was made to refine the shallow velocity model to further optimize the migrated stack for the shallower parts by maximizing the usable offset range. Instead, the velocity model used to image the shallower subsurface was kept the same as the model

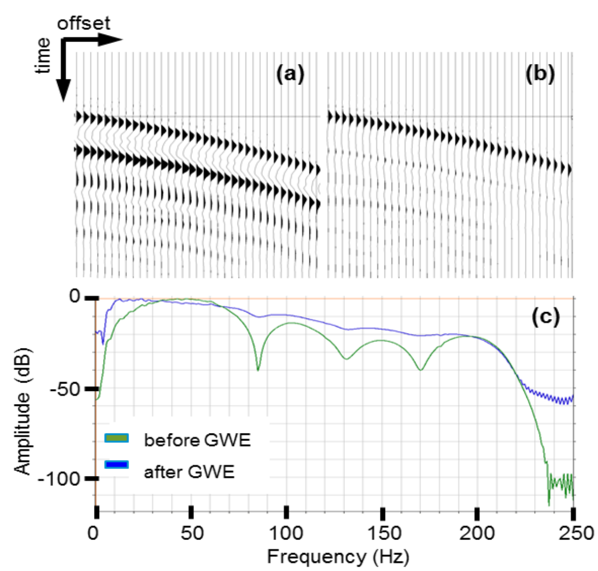

Figure 1. Several traces from a shot gather before GWE (a), after GWE (b) and amplitude spectra of a pre-migration stack before and after GWE (c).

used to image the deeper lying targets. To avoid any loss of resolution due to an imperfect velocity model, the offsets were limited to a maximum of 950 m.

Besides important processing steps such as noise attenuation, the main objective of shallow hazard studies is to expand the usable bandwidth as much as possible, thus enhancing resolution. Wang *et al.* (2013) introduced a Ghost Wavefield Elimination strategy (GWE) (i.e., de-ghosting) using a bootstrap approach in the τ-p domain to remove the source and receiver ghosts from the data. This iterative methodology derives the ghost delay-times from the data, thus being relatively insensitive to errors in either the shot or receiver depths. GWE can be applied to streamer data with either a constant or variable tow-depth (Bing *et al.* 2013). Since in this work the offsets were reduced to a maximum of 950 m, the S/N ratio in the τ-p domain was reduced when compared to using all available offsets. This challenged the applicability of GWE in the τ-p domain. Therefore we applied GWE using a bootstrap method in the f-x domain (Wang *et al.* 2012) instead of in the τ-p domain.

Figure 1 shows part of a shot gather as well as amplitude spectra of a stack before and after GWE. The source depth was 6 m while the receivers were towed at a depth of 9 m, inducing notches in the spectrum around 125 Hz and 83 Hz (calculated assuming vertical incidence and a water velocity of 1500 m/s). It was evident from Figure 1a and b that the source and receiver ghosts were being well removed by GWE and that the associated notches in the spectra were well attenuated as a result (Figure 1c). Indeed the low frequencies from 5-30 Hz were also well recovered.

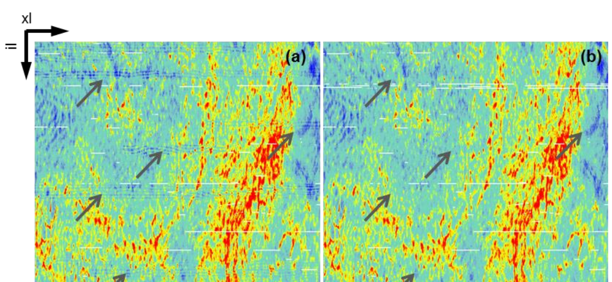

Figure 2. Amplitude map before (a) and after (b) acquisition footprint removal. The arrows indicate areas where the acquisition footprint is most visible before footprint removal.

Vishnoi *et al.* (2012) show how the variation of fold for short offsets from bin to bin or the lack of regularity of the offset and azimuth distribution can cause unwanted effects on the reflected signal. These variations can potentially mask important information about the geology and are often referred to as acquisition footprint. In order to remove any amplitude variations between shot sequences, between cables and between guns, a data driven approach was used to calculate an amplitude correction factor, based on the extraction of RMS amplitudes. Considering the objective was to remove the acquisition footprint in the shallow subsurface, the RMS amplitude correction factor was calculated using a shallow window following the water bottom.

Figure 2 shows amplitude maps of a window close to the water bottom before and after acquisition footprint removal. Clearly the footprint is largely removed while the amplitude variations due to the geological variations remain unaltered.

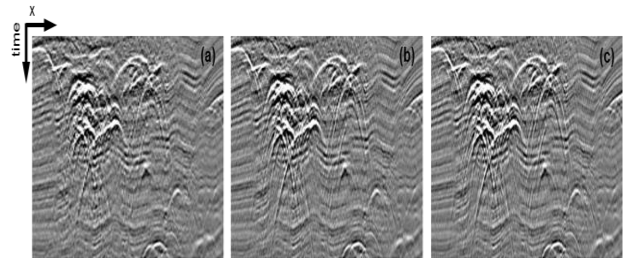

Figure 3. Shallow part of a 3D inline stack after trace-decimation and regularization to a 25m x 12.5m (a), 12.5m x 12.5m (b), and 6.25m x 12.5m (c) bin size.

The data was acquired with a 12.5 m receiver interval, a 50 m cross-line source separation, and a 100 m cable separation resulting in a subsurface grid of 6.25 m in the in-line and 25 m in the cross-line direction. In standard data processing for deeper lying targets, trace decimation is often used in order to reduce the volume of data and computation time. Such decimation is often justifiable in light of the reduced frequency content of the data for the deeper lying targets compared to the shallower subsurface. Avoiding this step and using all the data avoids the loss of any possible resolution. Further regularization to a cross-line bin size of 12.5 m instead of 25 m helps avoid aliasing of steeper dips.

Figure 3 shows a 3D inline stack after trace decimation to a conventional 25 m (a) and a 12.5 m (b) in-line bin size. Figure 3c shows the inline stack using the original 6.25 m in-line bin size, i.e. without any trace decimation. It is evident that trace decimation in the inline direction results in a loss of resolution, in particular for the diffraction tails. The presence of the high frequency diffractions obviously leads to further improved resolution after migration. Therefore we decided not to use any trace decimation and use all the data acquired in the field.

To further improve resolution, a depth sampling of 2m was chosen for the migration, instead of the typical 5m for standard processing. This benefits the imaging of the shallower data that contains higher frequency data than the data of the deeper-lying targets. The in-line and cross-line sampling intervals were kept at 6.25m and 12.5m, respectively.

To try and get as close as possible to a desired “white” spectrum, and thus maximum resolution, we applied a final post-migration shaping correction to the data. Such shaping correction was somewhat subjective and great care was taken not to introduce too much noise, thus affecting the S/N ratio. In order to achieve this we used a combination of wavelet shaping and random noise attenuation methods.

Figure 4 shows the amplitude spectrum of a 3D migrated stack before and after the spectral shaping correction. We see that the final result now approximates the desired white spectrum up to about 200Hz, thus indicating high resolution.

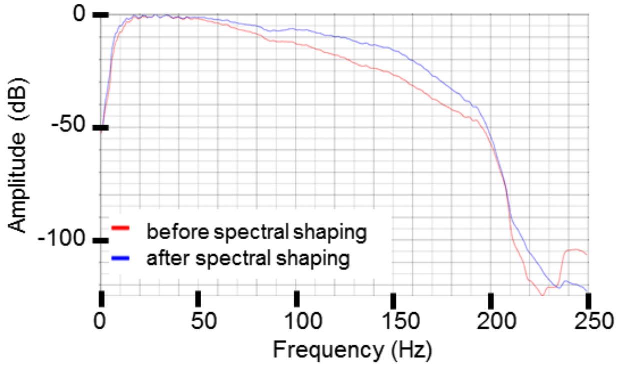

Figure 4. Amplitude spectrum before and after spectral shaping correction.

Conventional processing versus high resolution processing

In order to compare the difference between the high-resolution processing we described and conventional data processing, we processed a dataset acquired in 2000 with both processing sequences. For the high-resolution data processing we used the data-processing sequence outlined above. Both processing sequences included GWE and both datasets were Kirchhoff pre-stack depth migrated using the same TTI velocity model obtained through several iterations of high definition TTI non-linear slope tomography (e.g. Montel *et al.,* 2009).

Figure 5 shows 3D migrated stacks of the shallow subsurface from conventional (a) and high-resolution (b) data-processing. The overall resolution due to the high-resolution processing is substantially improved compared to the conventional processing. This can also be seen on the depth slices shown in Figure 6. The improved resolution is also evident when comparing the amplitude spectra of both images (Figure 7). At -20 dB the effective bandwidth is essentially improved from 4-65 Hz to 3-165 Hz.

Conclusions and discussion

We have showed that using a conventional dataset, a high-resolution image for the shallow subsurface can be obtained by adjusting the processing sequence and tailoring it to the higher frequency content of the shallower data compared to the data from the deeper lying targets. The key steps in the processing sequence that we highlighted are GWE, acquisition footprint removal, no trace decimation, a smaller subsurface grid (6.25 m x 12.5 m) as well as a smaller output migration depth sampling, and spectral shaping. Moreover, careful parameterization allowed a higher level of detail in the final image.

In the current work no attempt was made to refine the velocity model and tailor it to the shallow subsurface. As a result the offsets were limited to 950 m, partly in order to avoid loss of resolution due to inaccuracies in the velocity model. The maximum offset of the data acquired was much larger (4800 m). Therefore it remains to be seen how much more resolution could be obtained if an attempt was made to further refine the velocity model, therefore possibly allowing more offsets to be used to even further enhance resolution in the final image.

Acknowledgments

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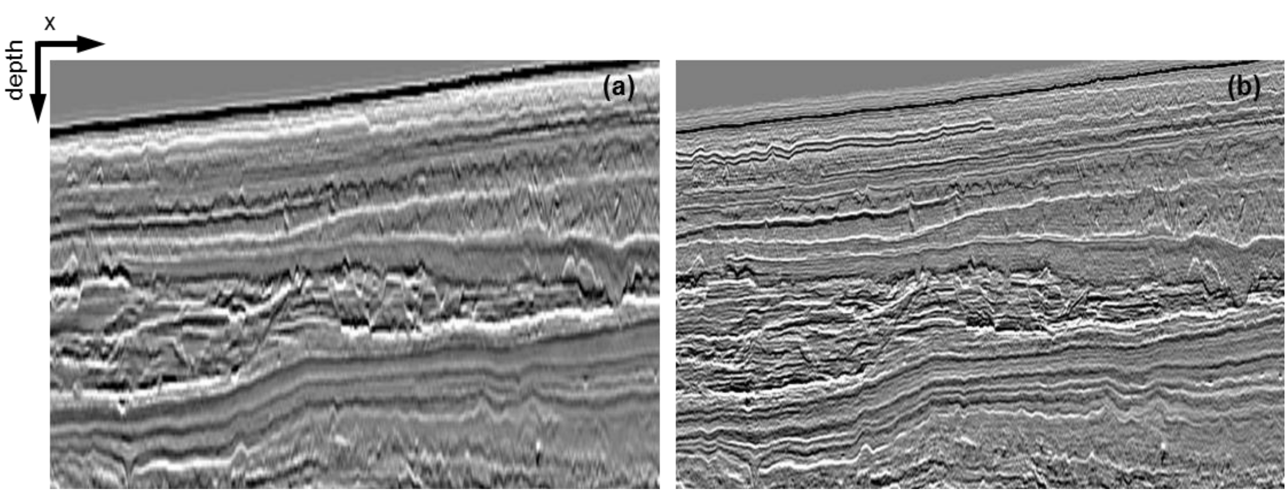

Figure 5. 3D migrated stacks obtained using conventional processing (a) and high resolution processing (b).

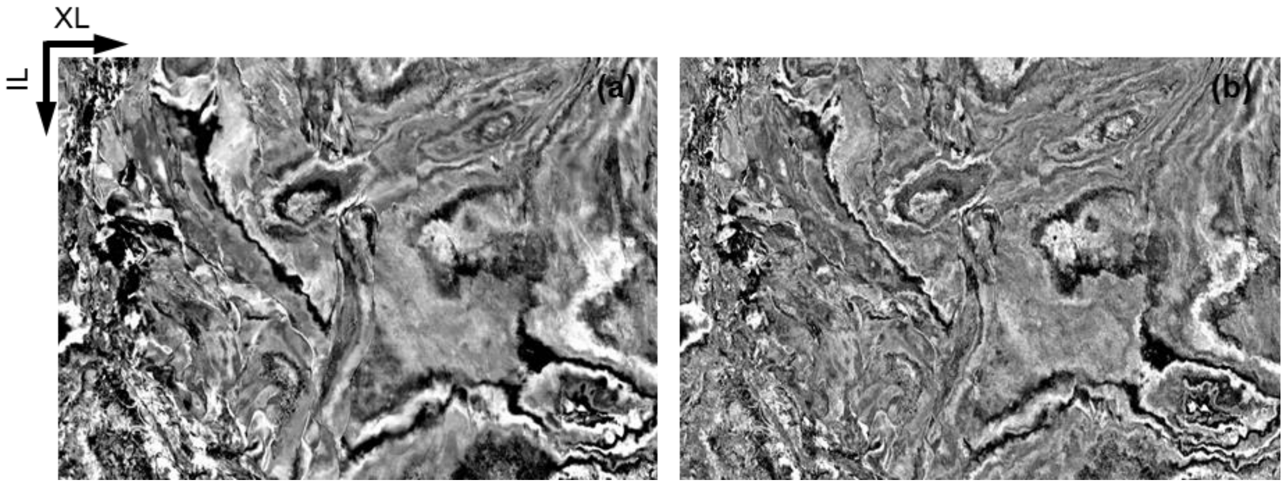

Figure 6: Depth slice taken at a few hundred meters below the water-bottom of the images obtained using conventional (a) and high-resolution data processing (b).

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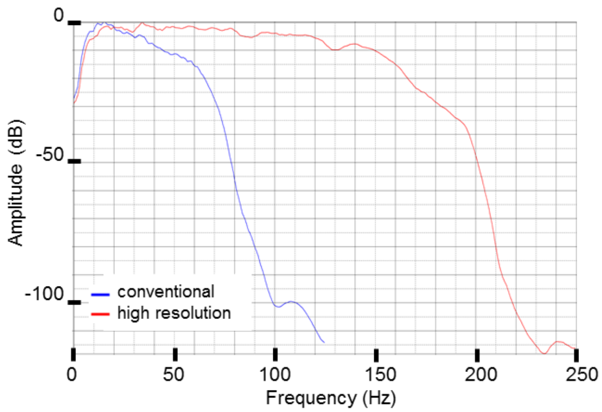

Figure 7. Amplitude spectra of images using conventional processing (Figure 5a) and high resolution processing (Figure 5b).