Time lapse processing of OBC vs. streamer data in a Campos Basin deep water field

José Cláuver de Aguiar Junior and Marcos Sebastião dos Santos, PETROBRAS, Brazil
Simon Wolfarth and Jean-Luc Formento, CGGVeritas, Brazil
Anne Rollet, CGGVeritas, France

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Abstract

Time lapse seismic has matured a lot in the past years. The repetition in positioning for new acquisitions, followed by a rigorous parallel processing, has become the norm for time lapse studies. However, when we decide to perform a 4D processing using two surveys with very different acquisition configurations, like towed streamer and OBC, repeatability does not exist and a parallel processing can hardly been applied.

Previous studies involving these configurations in a shallow water environment showed that reliable 4D signal could be obtained, even if those fundamentals in time lapse acquisition and processing were not met.

The purpose of our study was to assess if reliable 4D signal could still be recovered when towed streamer and OBC data are compared, but this time in a deep water environment.

Introduction

The seismic surveys processed here are located over an oil field in Campos Basin, offshore Brazil. Reservoir is composed of upper cretaceous turbiditic sands presenting an average porosity of 27%, saturated by light oil of 29^o API. Water depth in the area varies from 300 to 1100 meters, as can be seen in figure 1.

In 1999, a 3D survey was acquired by towed streamers with reservoir characterization purposes and, in 2005, an OBC survey was acquired as base for future time lapse OBC studies. Having two vintages separated by more than 5 years, time during which production was carried on, CGGVeritas was contracted to undertake a time lapse project in order to verify if any meaningful 4D anomaly could be mapped and correlated to changes in reservoir.

Due to the nature of the differences between towed streamer and OBC vintages, minimizing the differences in positioning between these surveys and applying the same processing sequence to both ones is simply impossible. The alternative left was to focus on processing the signal to the best of its ability in a 3D sense, delaying cross-equalization to the post-stack domain.

This paper summarizes the most important steps of processing flow, shows evolution of 4D QC attributes during the project and presents some final results.

Acquisition and pre-stack processing

Acquisition and QC

Several past studies demonstrated that the accurate repetition of acquisition geometry is a key to obtain high quality results in time lapse processing. In this current case, to repeat source and receiver positions was obviously not the purpose of the 2005 OBC acquisition. However, once this reservoir has an excellent acoustic response, already known from previous works, we decided to take advantage of the existence of two 3D surveys over the field and try to extract some meaningful 4D signal from these legacy data, whose only similarities are sail-lines direction and bin size.

The decision to proceed with processing was based also on significant results obtained in the past by hybrid projects involving OBC and streamer surveys, even knowing that those projects were located in shallow water environment, where some simplifications not valid here were done.

The utilization of seismic surveys without any repeatability in acquisition not only led us to split the processing sequence in two distinct branches (figure 2), but also prevented us from computing any matching operator and the used 4D QC attributes (NRMS, RMS ratio and time-shifts) in the un-migrated space, as a consequence of the differences in ray paths. These extreme geometric differences resulted in different travel times and CMP locations in this space.

For this reason, all matching operators and 4D attributes were derived in the migrated domain, where traces are carried to similar positions and travel times. Thus, at selected major steps of the processing flow, pre-stack migrations were performed for both vintages with the only purpose of evaluating the processing in a 4D sense.

Pre-migration processing

De-multiple

- OBC vintage: PZ summation + Radon

The aim of the PZ summation for the OBC data was to remove the receiver ghost. In addition to de-ghosting, a peg-leg multiple attenuation was applied by performing a targeted gapped deconvolution using the accurate water depth estimates calculated in the cross-ghosting. PZ summation was then followed by high resolution Radon filter applied on 2D common receiver gathers.

- Towed streamer vintage: 2D SRME + Radon

The de-multiple sequence used to the streamer data consisted of 2D SRME followed by high resolution Radon filter applied on 2D CMP gathers.

Global matching

After de-multiple step, the two vintages were migrated and stacked in order to derive a global phase rotation and a global time shift to apply on the OBC data. After computation, these corrections were then applied on pre-stack non-migrated traces and 4D attributes were re-computed after a new migration. They were compared to the 4D attributes calculated with application of phase rotation and time shift in migrated domain, in order to confirm the advantage of a pre-migration correction, what indeed happened.

Amplitude correction

In order to compensate for spatial variations in amplitudes at receiver and source locations, surface consistent amplitude correction was applied to the OBC vintage, by computing average amplitude over a time window. The same type of processing was performed to the streamer data, but using a different time window in order to encompass the same primary events.

Regularization using irregular Fourier decomposition

For the OBC vintage, regularization was performed in common receiver domain, while for the towed streamer vintage, regularization was performed in offset domain.

Migration

The final 3D pre-stack time migration was performed using a Kirchhoff algorithm with a ray tracing option. For the OBC vintage, the migrated traces were extrapolated to mean sea level for travel time equalization with the streamer vintage. A procedure much more accurate than application of static corrections, which is acceptable when dealing with shallow water data.

Voronoi compensation was also applied to correct for amplitude distortions due to fold irregularities.

Post-stack cross-equalization

Final stacks were generated after residual move-out corrections followed by a second pass of high resolution Radon de-multiple, now on migrated CMP gathers.

The 4D difference cube obtained by straight subtraction of the two volumes was, not surprisingly, of poor quality, and 4D QC attributes present values slightly better than those of the previous step, but far from being good. In order to minimize 4D differences, post-stack global and local matchings were tested.

Global matching suite applied to OBC vintage 2005

The following single operators were derived and applied:

- RMS amplitude scalar
- Amplitude spectrum match filter
- Phase only match filter

Comparison between 4D attributes before and after this global equalization (figure 4) shows that no relevant improvements were achieved. This is explained by the great variability in phase and amplitude spectrum across the area that single operators cannot resolve.

Local matching suite applied to OBC vintage 2005

The following trace-by-trace operators were derived and applied:

- RMS amplitude scalar map
- Time-variant time shifts
- Phase only match filter
- Amplitude spectrum match filter

A large improvement in similarity can be noticed through the 4D attributes (figures 3 and 4) and at the stacked sections (figure 5). The local matching suite provided a final NMRS mean value of 0.4, still high when compared to more classical time-lapse projects, but encouraging if we consider the total lack of repeatability in our case. Amplitudes were significantly reduced above and below the reservoir in the difference section. It’s important to emphasize that this match workflow was done with great care and exhaustive tests, once local matching could provoke disastrous effect on 4D signal.

Figure 3 synthesizes the evolution of NRMS mean values along processing steps.

To validate these final results, the local matched final volumes were passed to the reservoir team who analyzed them and performed a comparison with synthetic seismic volumes generated from the reservoir petroelastic model. An example of this comparison is presented on figure 6, where one can see similarities between synthetic and real data in the south-western and central part of the field.

The complete 4D interpretation, as well as the evaluation of improvements in the reservoir model brought by this processing, is not the purpose of this paper.

Conclusions

Due to the differences in geometry of the towed streamer survey and the OBC survey used in this project, application of the same processing sequence to both data could not be done. In the same way, trace selection based on source and receiver positions (4D binning) was impossible. Each seismic dataset was therefore processed independently up to stack phase, with the exception of global phase and time-shift corrections applied before migration.

A post-stack cross-equalization flow, using local match operators, was applied in order to improve similarity. These local matchings were checked and validated by the reservoir team during the life of the project.

Preliminary interpretation showed encouraging results, indicating that useful information could be obtained from these 3D surveys in spite of the non-standard character of this project, in the time lapse technology point of view. Even in a deep water environment, where ray-path differences between streamer and OBC data become more critical and acquisition repeatability is virtually absent, it was valid to 4D process these legacy seismic data. The success of similar projects, however, is definitely not guaranteed. Results will be strongly dependent on the presence of favorable petrophysical properties at the reservoir.

Acknowledgement

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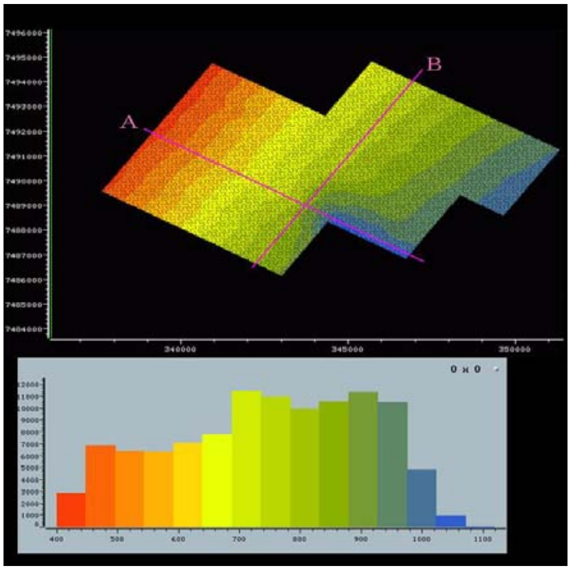

Figure 1: Water bottom topography under processing area in two-way travel time (ms) and color scale.

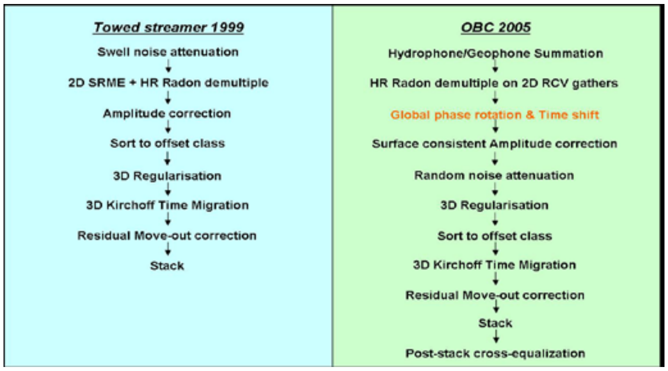

Figure 2: Simplified flow chart of key processing stpes

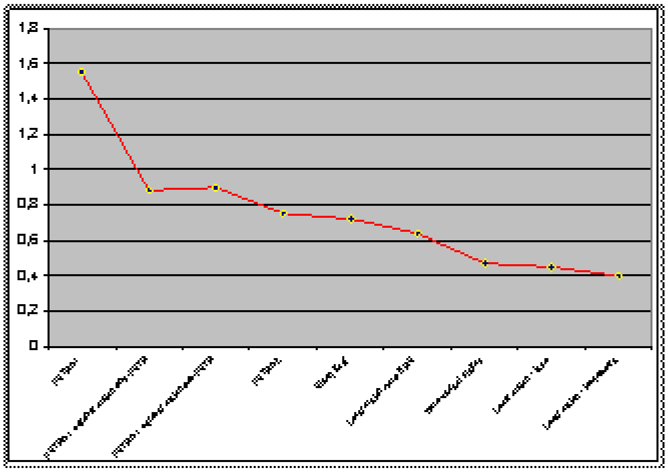

Figure 3. Evolution of NRMS mean value along processing key steps

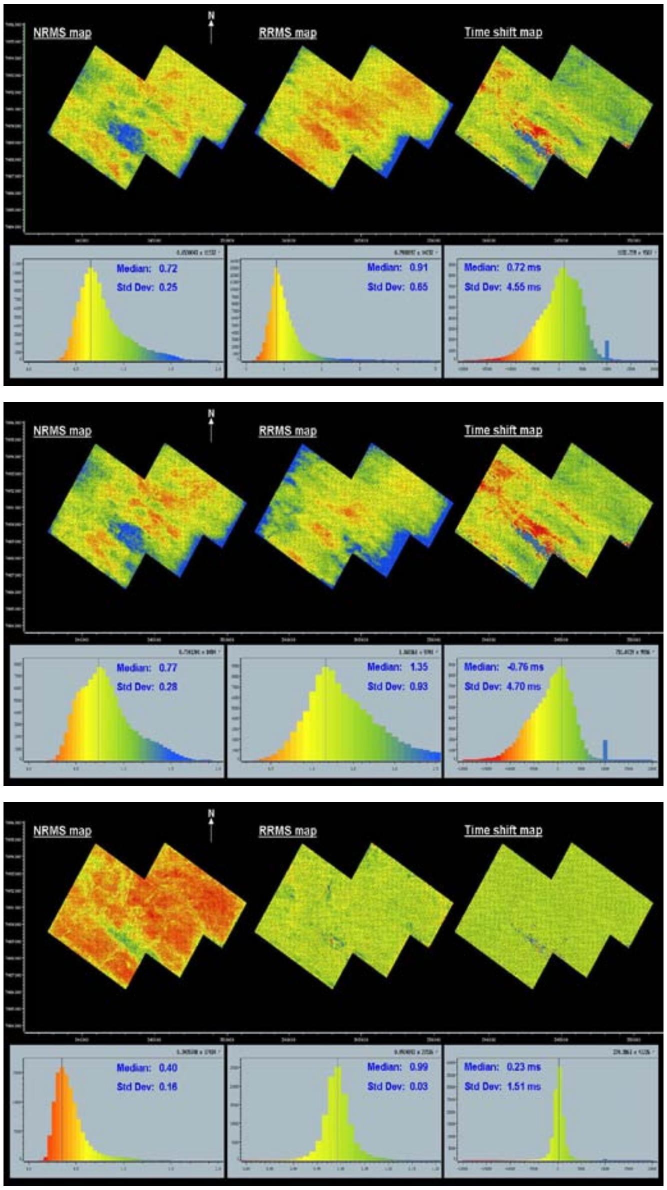

Figure 4: QC 4D attributes: NRMS, RMS ratio and time-shift. top) Reference full stack; middle) After global matching; bottom) After local matchings

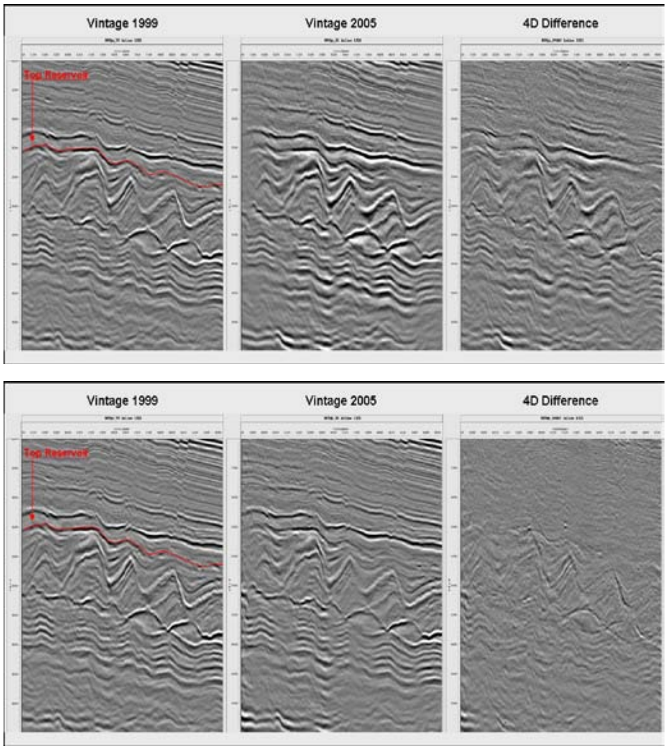

Figure 5: top) Reference stacked sections after final migration (1999, 2005 and difference); bottom) Same sections after application of the post-stack local matching suite on 2005 volume

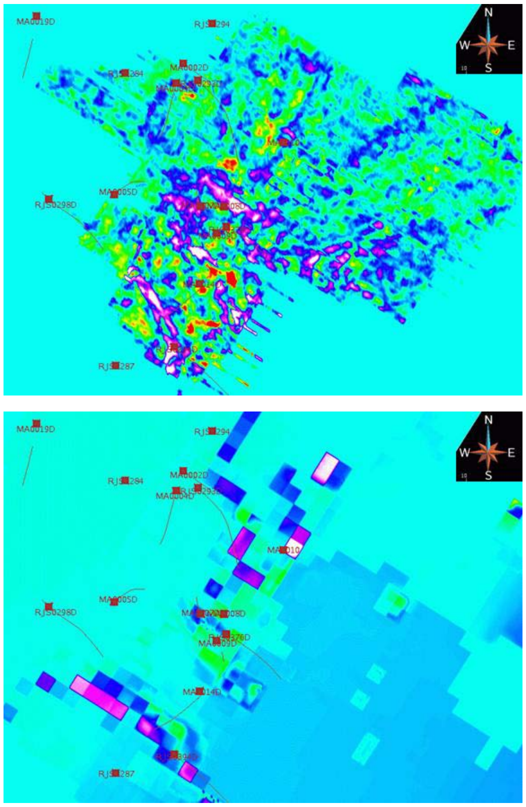

Figure 6: Difference amplitude maps at base reservoir over the southwestern part of the field. Real seismic data (top) and synthetic modeling (bottom). White and purple colors indicate lower acoustic impedances at the base of reservoir in 2005.