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A Global-scale AVO-based Pre-stack QC Workflow - An Ultra-dense Dataset in Tunisia

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SUMMARY

Throughout a processing sequence, data AVO must be preserved in order to perform AVO analysis on the final dataset which will be used for reservoir characterization. We therefore need an efficient AVO-based pre-stack QC which assesses the impact of a processing step on the AVO.
In this paper we introduce a pre-stack data QC method based on AVO which can be applied to all types of 3D datasets. It consists firstly of data reduction of the pre-stack data through angle stacks. Then a robust AVO model is extracted using dip-consistent macro-binned AVO fitting. Finally, a comparison of the robust AVO model to the seismic data is performed using quantitative attributes such as the correlation and NRMS (normalized root-mean-square) of the data and the model. The main strength of this method lies in its efficient applicability to large amounts of data, without well control. This is demonstrated via application of the method to an ultra-dense land dataset from Tunisia.

Introduction

The seismic industry trend is to increase the amount of acquired data to obtain more information. This extra information can come from wide azimuth acquisition, increased sampling rate, denser acquisition, and so on. Compared to conventional datasets, these denser datasets allow geophysicists to improve the resolution and the image quality of deeper and more complex hydrocarbon reservoirs. Reservoir characterization, a crucial step before drilling, relies mainly on the amplitude and phase stability of the wavelet, which is commonly evaluated by amplitude versus offset (AVO) analysis. Consequently, the ability to assess the AVO behavior throughout processing (Coleou *et al*., 2013) on the full area of interest is required. Indeed, the AVO trend could be incorrectly modified or damaged especially during noise reduction, demultiple or amplitude corrections. Therefore, it must be monitored at critical steps (Araman & Paternoster, 2014). However, an extra QC that demands a careful diagnosis on the whole survey pre-stack can be costly. This is particularly true with big datasets with high fold. A simple and efficient pre-stack AVO-based QC workflow is hereafter presented together with results obtained on an ultra-dense land dataset.

The dataset and processing sequence

The dataset used in this paper is an ultra-dense broadband land survey, as presented by Seeni *et al*. (2009). The survey area is located in the Jebel Grouz Tunisian field. The processing sequence applied is the following: migration (referred as RAW hereafter), residual move-out correction (RMO), residual multiple attenuation (MA), footprint attenuation and coherence enhancement (merged in one step FK_COH) and finally trim statics.

The bin size of our dataset is 15m x 15m, with a nominal fold of 4100. With such a large fold, pre-stack analysis and QC of the data is difficult and potentially time-consuming. Moreover, as there is no log data we are unable to QC the processing with wavelet QC and mini-inversions around wells. The methodology for pre-stack QC will therefore have to rely on seismic data only; it must also be adapted to deal with the ultra-dense data.

Global scale quantitative QC

In a first step, we define a flow which allows a global and time-efficient QC of the data at each processing step. This flow is based on the comparison of real data with a data-based AVO model as described by Coleou *et al*. (2013). The original flow has been modified so that the AVO fitting performed on the data shows better spatial continuity.

Derivation of a robust AVO model by data fitting

AVO describes how the amplitude changes as a function of incidence angle. As the dataset presented here has large fold, 4100 traces per bin, for an easier and faster data manipulation, angle stacks are computed. Then an AVO analysis is performed on the four angle stacks (8º, 20º, 28º and 36º for near, mid, far and ultra-far stacks respectively).The two-term Shuey approximation of the Aki-Richards (1980) equations is used. The reflection coefficient R is defined as a function of the incidence angle θ, the intercept A and the gradient B, $R(\theta) = A + B \sin^2 \theta$ (1)

In the following, we assume that equation (1) is valid for the angle range used here. For angles larger than 30 degrees this could be questioned; however, the AVO model used here will only be used for comparison with the data, and there is no risk of matching a non-linear amplitude behavior to a linear data model.

AVO fitting is commonly done gather by gather. In order to increase the spatial consistency and reduce noise, we implemented a 3D stabilization of the AVO model. We perform dip-consistent macro-binning and use traces from the central bin and its neighboring bins. Rather than working on a time-slice we take into account the structural dip to align events across the macro-bin. Intercept and gradient sections with and without macro-binning stabilization are displayed in Figure 1. The use of structurally consistent macro-binning improves event continuity on intercept and gradient especially in the shallow part, where random noise is well attenuated. An alternative method of noise reduction based on spatial co-filtering of the intercept and gradient as described by Whitcombe *et al*. (2004) was also tested; in this case, it did not improve upon the results shown in Figure 1.

Once only consistent signal remains in the intercept and gradient, an AVO pre-stack model is computed, following equation (1)**.** The model can then be compared to the seismic data in order to assess the AVO behavior and to quantify the improvement or degradation between processing steps.

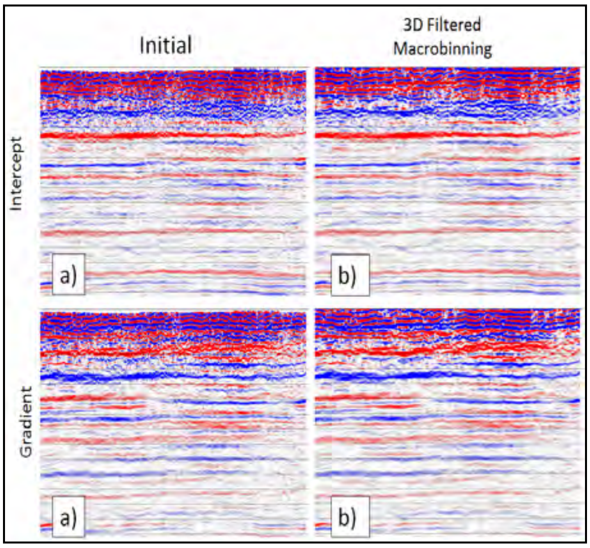

Figure 1 *Example of intercept and gradient sections from 0 to 750ms with a) conventional AVO fit and b) dip-consistent macro-binned AVO fit.*

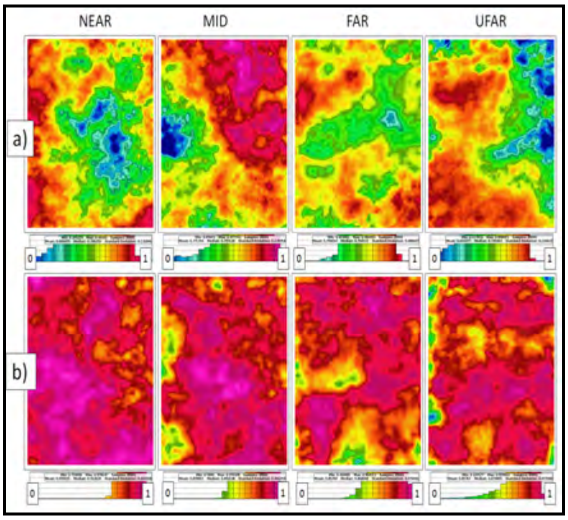

Figure 2 *Cross-correlation maps between seismic and AVO model for the four angle stacks, computed in a time window around a horizon at 1570ms: (a) after migration and (b) at the end of post-processing.*

Similarity measurement between seismic and AVO model

To measure the similarity between the seismic and the AVO model, QC attributes are generated after each processing step. The QC attributes used here were defined by Coleou *et al*. (2013): cross-correlation at zero lag (CC), NRMS, quality and anomaly indicators. In a first step, maps of cross-correlation between the data and the AVO model are analyzed for the four angle stacks (Figure 2). The cross-correlation is calculated over a time-gate around a horizon centered on the reservoir, for two processing steps: after migration and at the last stage of the processing sequence. From the maps, the cross-correlation median value for the whole survey of the mid stack after migration is 10% higher than the other stacks. After post-processing, the cross-correlation median value has increased for all stacks between 15 and 20% and the areas with poor correlation have been improved (blue areas in Figure 2). The median is then more homogeneous across the stacks at the end of processing. Histograms of the median values of such attributes are well suited to follow the evolution of data quality through the processing. Figure 3 shows the cross-correlation median values of the full area through all the steps of post-processing for four angle stacks (near, mid, far and ultra-far) computed in a time window along three horizons. Damaging steps can now easily be spotted when looking at ΔCC, the difference between two consecutive processing steps of the CC median value. Such instances are highlighted on the right hand side of Figure 3 in red ellipses. Although the negative ΔCC values are not large (less than 5%), the main damaging steps are the multiple attenuations (green boxes) at shallow level on mid stack and the trim statics (light blue) at the deeper and intermediate levels on the far stack. Nevertheless, the multiple attenuation has greatly improved the matching with the AVO model on the far angle stack at shallow and intermediate levels.

A single QC attribute is never enough to fully express the quality of the data. In order to further investigate primary preservation other attributes could be used such as NRMS: this would show amplitude changes and thus loss of primary energy. In our case, the behavior of the NRMS was found to be similar to the cross-correlation.

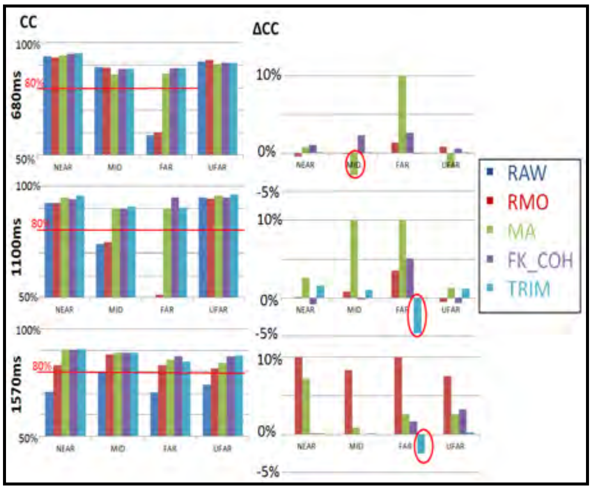

Figure 3 *Histograms of the median cross-correlation per angle stack per processing step (left column). On the right, the difference between two steps (ΔCC) for each angle stack. Red ellipses are highlighting a potential.*

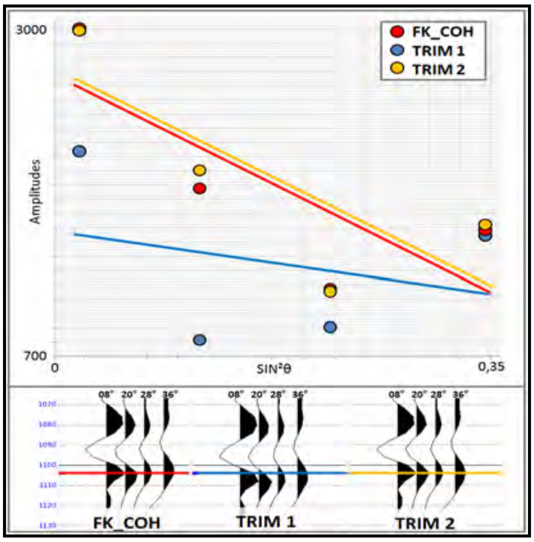

Figure 4 *Three angle gathers with their respective amplitude vs. angle plots at 1104ms. From left to right: after FK_COH (red), after trim statics (blue), after trim statics modified (orange).Orange and red values are almost superimposed for near, far and ufar.*

Local scale quantitative QC

Our global QC allows us to quickly check which processing steps have a negative impact on AVO consistency. When issues are identified at global level, further investigations are needed locally for a better understanding of the cause of the issue (we call this “diagnostic QC”). The diagnostic QC can take various forms. As explained in Araman and Paternoster (2014), it can focus on pre-stack consistency, stability of the wavelet or gather alignment, depending on the processing step to be investigated.

In our case, a local AVO analysis of pre-stack gathers is enough to diagnose the issue of the trim-statics highlighted by our global QC. Figure 4 shows the AVO curve obtained for a single gather at fixed time. Amplitude before trim-statics is in red, and after in blue. The application of trim statics has clearly changed the AVO trend in our data. The change of trend is due to a time-shift of the maximum peaks across angles around this particular horizon. By applying an alternative trim statics method, this problem is overcome and the AVO trend is preserved (orange in Figure 4). Looking at this figure, we can also notice that the linear fit assumption (equation (1)) used to create the AVO model may not be valid for the ultra-far angles (36 degrees). However, we are still able to spot damage to the AVO trend with this method.

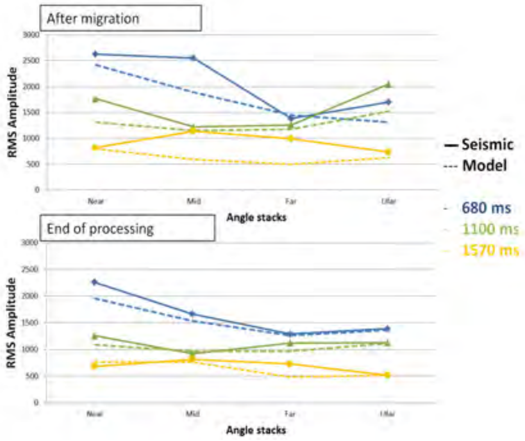

Figure 5 *Median RMS amplitude versus offset (four angle stacks) at three horizons.*

Discussion: Other QCs to look at

As already discussed, more than one QC is needed to assess the quality of the pre-stack data. We can also investigate wavelet stability through phase and spectral content with the dominant frequency attribute, depending on the process to QC. In our case, pre-stack alignment measurement (time-shift) was also a good indicator. Also, the AVO trend can be analyzed as on Figure 5. Here, RMS amplitude is plotted as a function of angle after migration and after post-processing on the three horizons presented above. We notice that globally the seismic amplitude and the models are in closer agreement after post-processing and it ensures then that the final dataset is consistent with an AVO model. By correlating all the QCs mentioned above, interpretation of the results allows the geophysicist to determine whether a processing step is damaging the AVO behavior. However, as this AVO-based QC might not validate alone whether a process has fully preserved the signal, more traditional QCs must also be considered to guarantee the complete signal preservation.

Conclusions

We have introduced a way to build a reliable AVO model of the processed dataset, based on a robust extraction of the intercept and gradient volumes from the seismic data. A 3D structurally consistent macro-binning method is applied to keep only spatially consistent AVO information. From the comparison between the modelled AVO and the seismic data we compute a variety of global attributes (cross-correlation, NRMS etc.) which are used to validate the processing with regards to pre-stack data quality at each processing step. Applying this flow to an ultra-dense datas*et al*lowed us to detect and subsequently correct for processing anomalies. Contrary to AVO QC performed in a limited area around a well, the strength of this global approach, applicable to all types of 3D datasets (marine, land), is to provide robust mechanisms over the whole survey area. This ensures that the full final seismic data will be reliable for elastic inversion and reservoir characterization.

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