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Demultiple Techniques With Improved AVO Compliance

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Summary

Seismic data must be optimally processed for accurate reservoir characterization, and therefore each step of the processing sequence should be carefully designed and assessed for AVO compliance and primary preservation. In this paper, we focus on the demultiple process. This step is critical as it can be difficult to identify and separate primaries and multiples, especially in shallow water settings and at the low frequencies typical of broadband data. In this paper, we show 3 examples of using AVO information in the demultiple process. We discuss how AVO can help to derive primary models and how it can be incorporated into the cost functions of existing algorithms, such as the Radon transform or the adaptive subtraction. These algorithms can also be applied on migrated data, and we suggest that migrated multiple models are a powerful processing QC. We finish by showing a new AVO quality control via a pre-defined pre-stack classification method.

Introduction

The success of reservoir characterization methods relies on optimally processed seismic data, requiring each step of the processing sequence to be carefully designed and assessed for primary signal preservation and amplitude versus offset (AVO) compliance. In this paper, we focus on the demultiple step since it has significant potential for primary damage given that: (1) multiples are very energetic meaning that even small errors can damage the primaries; (2) it can be difficult to identify and separate primaries and multiples, especially in shallow water settings and at the low frequencies typical of broadband data. In this paper we present ways of improving the demultiple flow for primary preservation and how to directly incorporate the AVO preservation into the cost functions of existing demultiple algorithms, such as the Radon transform and a new adaptive subtraction scheme working on migrated primary and multiple models. We also propose a new quality control attribute which evaluates the AVO compliance of the data using a pre-stack classification method.

Improving primary preservation in demultiple by enforcing or preserving AVO compliance

We propose three ways of using AVO information to improve the demultiple flow for primary preservation. In two of these, we explicitly include an AVO cost-function in the algorithm. Also in two of the methods, primary and multiple models are analysed in the migrated domain. An additional advantage of this is that the imaged multiple model provides a useful uncertainty attribute when interpreting the final seismic gathers.

Method 1: Generating a primary model from AVO modelling to be used in the adaptive subtraction

Since multiples do not follow an AVO equation, AVO fitting or inversion can be a good multiple predictor, particularly where the moveout between primary and multiple is sufficiently large and when an acceptable velocity model is known. This property can be used to create a primary model for adaptive subtraction (Sablon et al. 2016). Following Johansen et al. (1995), each seismic event is modelled by a sum of a few orthogonal polynomials. The pre-stack data are modelled on an angle range much larger than the normal AVO validity, meaning the result is not interpretable in terms of AVO parameters. However, by extending the fit range, remaining multiple energy in the gathers is forced into the residual of the modelling.

Figure 1 shows the various steps needed to obtain an AVO-derived primary model. In this example, data are post-migration. Figure 1A shows an offset class (left) and a CDP gather with residual multiple (shown in red on the section). Figure 1B shows the residuals of a 2-term polynomial fit over a 5°-90° angle range. Notice how the large angle range in the pre-stack fitting forces a large part of the multiple into the residuals (blue box). This is the first version of the multiple model. We remove remaining primary energy from the fit residuals using a dip-separation filter (figure 1C). Figure 1D

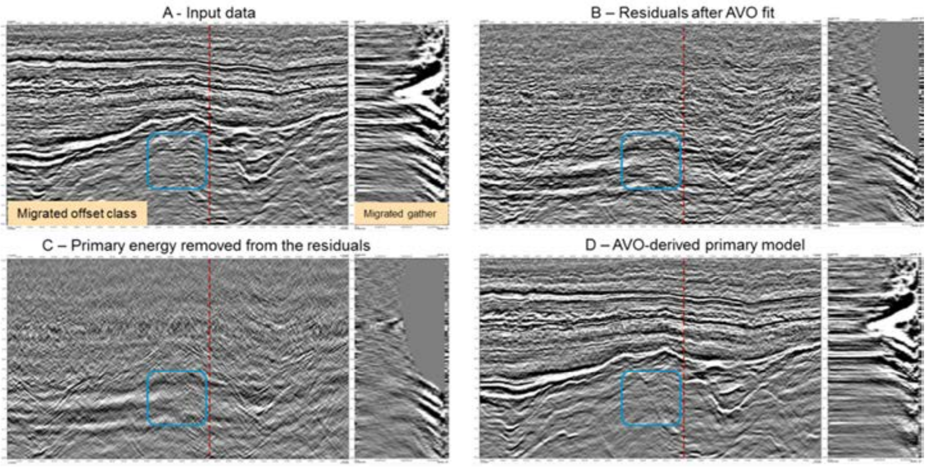

Figure 1: *Section of a migrated offset class(450m) – left- and CDP gather (location shown by the red line) for: A- Input data, B- Residuals after AVO fit, C- Residuals after pre-processing and D- Primary model derived using AVO information.*

shows the corresponding derived primary model which can then be used for primary preservation in a demultiple subtraction process. For the data example shown, this method works very well. It may struggle in shallow water and when the dip-separation between primary and multiple in the offset domain cannot be used as an additional criterion.

Method 2: Higher order Radon transform

An offset dependent amplitude cost function can be introduced into the Radon transform by combining the polynomial decomposition described above with the Radon transform (Xue et al., 2014). The two methods overcome their respective shortcomings. On the kinematic side, Radon honours the event trajectories, whereas a polynomial data fit does not. On the other hand, amplitude variations with offset are not included in the conventional Radon transform but are modelled by the polynomial decomposition. Figure 2 shows the impact of a higher term Radon compared to a conventional 1-term Radon (C and B respectively). The energy on the near offsets is better preserved after the 2-term Radon.

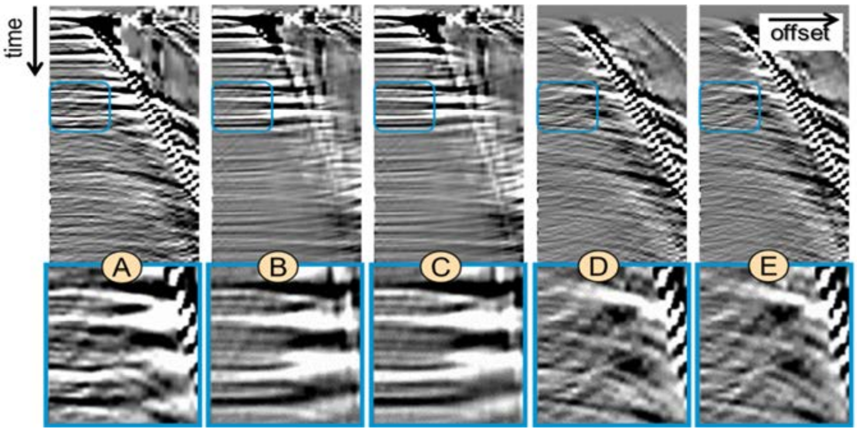

Figure 2: *CDP gather and zoom before demultiple (A), after 1-term (B) and 2-term radon (C) and the energy removed for 1-term (D) and 2-term radon (E).*

AVO models and NRMSE (Normalised RMS residuals Envelope) were then calculated (figure 3). NRMSE allows quantifying the relative AVO compliance of the data: low NRMSE (black) indicates good compliance. Figure 3 shows that the NRMSE is smaller overall for the higher order demultiple, indicating better AVO compliance. Similar to standard Radon, the higher order Radon is likely to struggle in situations where the moveout discrimination becomes too small.

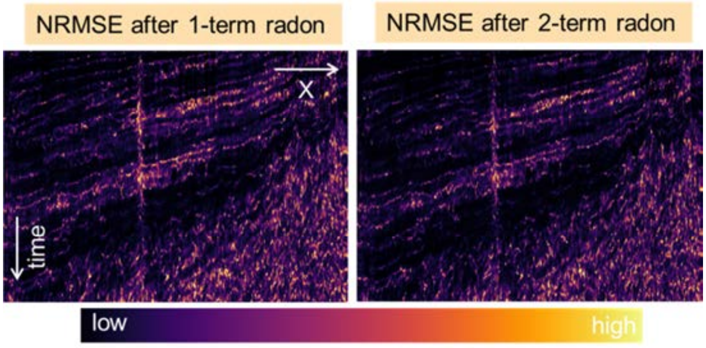

Figure 3: *NRMSE (envelope normalised sum of RMS residuals) obtained after AVO fit following a conventional 1-term Radon (left) and the proposed 2-term Radon (right).*

Method 3: AVO cost-function for primary leakage removal

Understanding the compliance of the data with AVO is crucial when interpreting reservoir characterization products. In order to QC and even repair possible primary damage during the pre-migration processing (i.e. demultiple & denoise) we propose a method using migrated primaries and noise models. In any case, we think it is advantageous to have an imaged multiple model, as it can serve as a QC product when interpreting the final processed gathers.

For each CDP gather and for each offset $\boldsymbol{i}$ of this gather we allow for the migrated primary estimate $\boldsymbol{p_i}$ to be repaired by adding back to it a (small) scaled version of the migrated multiple model $\boldsymbol{m_i}$ if this improves the AVO compliance:

$$p_i + c_i * m_i = R(0) + G * sin^2\theta_i$$

Solving this equation in the least-square sense gives a time and offset variant scalar c which can be used for QC, or which can be applied to recover primaries and remove residual multiples. Figure 4 shows the effect of this method on a single CDP gather. Figures 4A and 4B show the migrated data and migrated multiples. On this gather, primary leakage is clearly seen on the multiple volume (green arrow). Figure 4C shows the energy $\boldsymbol{c_i * m_i}$ to be added back for the data to better follow an AVO model. We can see that the algorithm identifies areas where primary leakage occurs. The energy can be added back to the data (Figure 4D) to improve the pre-stack continuity and the scalar values c can be used as an indicator of AVO uncertainty at this location.

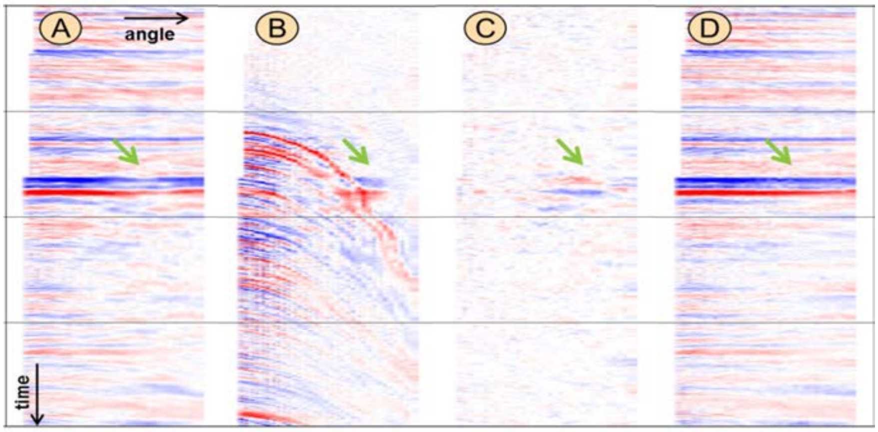

Figure 4: *Post-migration gather (A) and multiples (B). Primary leakage on the multiples is shown by a green arrow. (C) Energy to 'add back' to the data to improve the AVO compliance. (D) Data with primary leakage added back.*

QC of AVO compliance during the demultiple process via a classification scheme

Araman and Paternoster (2014) formalised a QC procedure to monitor the AVO suitability of the data throughout the processing sequence. Sablon et al. (2016) showed how to use pre-stack event continuity to assess the primary preservation of the demultiple process. This QC is based on the correlation between angle stacks and is very simple to implement and to interpret. It can be applied to data early in the processing sequence. However, it does not take into account amplitudes. On the other hand, relative pre-stack inversion has also been shown to be useful to assess the quality of the demultiple, i.e. for the low frequencies (Lacombe et al., 2017). This QC is more complex to implement, is more susceptible to other data issues such as wavelet stability and gather flatness, and may be more difficult to interpret.

With this in mind, we propose a new window-based QC which considers both pre-stack continuity and amplitude behaviour. Data are classified according to the correlation value between angle stacks and RMS behaviour with offset (figure 5). For the classification, we pre-define seven possible amplitude behaviours, of which two are good, and five indicate various data issues. CDPs where the correlation is low are classified as noise; in figure 5, correlation below 0.6 is considered as low and shown on the QC maps in white. For CDPs with high correlation, the horizon windowed RMS amplitude behaviour is classified according to its pre-stack trend and its observed anomaly (decreasing RMS black to grey and increasing RMS red to yellow). To be clear: we do not seek to group the RMS behaviour into the traditional AVO classification scheme; instead we are looking for a single monotonous trend (or possible deviations from it) to comply with AVO theory (colour coded in

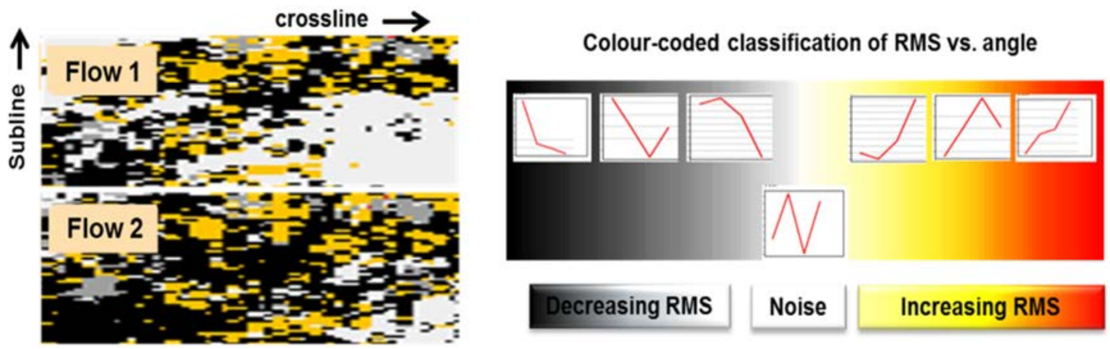

Figure 5: *Classification of RMS behavior with angle for two demultiple flows (left top and bottom). For each bin, the behaviour of the RMS as a function of angle is analyzed and colour coded. Lighter colours indicate an anomalous behaviour either of the nears or the fars, whereas a white colour indicates either that no trend can be found or that the correlation between the angle stacks is poor.*

our scheme as dark red or black). In figure 5, we show a small part of QC maps for this trend classification for two alternative demultiple flows. For the first flow, many locations are shown as noise (the map is white), meaning that either the correlation between angle stacks is low or that no trend defined in our classification is found on the data. For the second demultiple flow, most CDPs show a monotonous trend, implying that the AVO compliance is improved and that this demultiple algorithm is more suited for primary preservation and AVO.

Conclusion

We have highlighted the importance of the quality control of the demultiple step for primary preservation and ultimately for reservoir characterisation. We have proposed a new pre-stack data QC based jointly on correlation and AVO trend classification which allows a quick, easily interpretable way to assess the primary preservation early in the processing sequence. While using an AVO cost-function post-migration, we have also proposed an algorithm to locate areas affected by primary leakage during demultiple. AVO or pre-stack modelling can also be used during the demultiple process itself, either to derive a primary model or as a higher order cost function in the Radon transform. There is always potential for primary damage during processing but these QCs and algorithms provide additional support for processing decisions that reduce this risk.

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