An optimized workflow for coherent noise attenuation in time-lapse processing

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Introduction

Time-lapse processing (4D seismic) has become an important reservoir monitoring tool in the oil and gas industry. 4D differences between seismic surveys can be linked with changes in pressure and saturation within the reservoir and the injection regions. This can provide key information on how to improve reservoir productivity and helps in reducing risks and uncertainties in infill drilling.

The role of time-lapse seismic processing is to compensate for non-repeatability of the acquisition as much as possible in order to produce the best possible 4D signal (Calvert, 2005). Coherent noise attenuation constitutes a great part in seismic processing and especially in time-lapse processing where the 4D subtraction of vintages leads to noise from both datasets appearing in the difference image. In a marine environment, surface related and interbed multiples have to be attenuated before imaging. Methods such as Surface-Related-Multiple-Elimination (SRME) (Verschuur and Berkhout, 1997) (Lin et al., 2005), and Radon transforms (Hugonnet et al., 2009) are commonly used to tackle this kind of noise. Least-squares adaptive subtraction has been the industry standard in the framework of SRME. In the time-lapse processing paradigm, a method has recently been proposed to simultaneously adapt multiple models in such a way that 4D differences are optimized (Zabihi et al., 2012). We build on this idea by developing a seismic processing workflow which is optimized for 4D signal enhancement in a more generalized manner, at a lower cost and with minimal impact on turnaround.

Method

In the implementation of Zabihi et al., 2012, for every processed vintage, the data (Primary + Multiple) and the SRME model are both migrated, and the simultaneous adaptive subtraction of all vintages takes place in the image domain. From a practical point of view, this approach adds the cost of one extra migration per processed vintage. It also increases the risk of migrating aliased events in the data or the multiple models which may introduce artefacts in the final image. However, the most limiting feature of this implementation is its inability to directly tolerate further processing of the data after the multiple modelling and until the subtraction is performed post imaging. For example, applying a pre-imaging Radon de-multiple would be unachievable for obvious reasons, and this could degrade the overall effectiveness of the method.

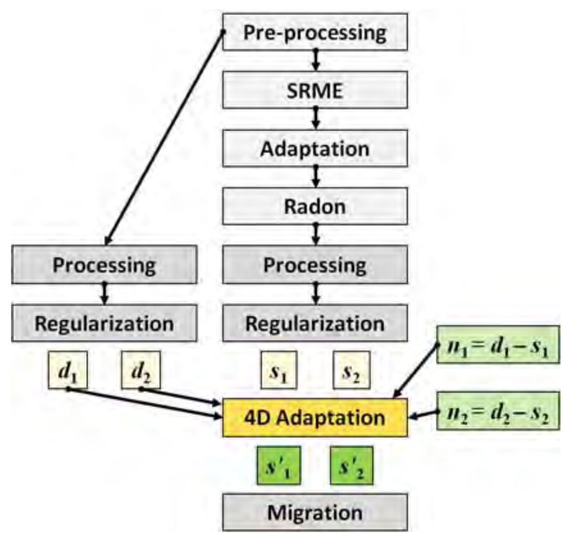

Figure 1 *The proposed workflow for two vintages*

Our proposed workflow, Figure 1, utilizes the same idea in a more effective implementation. We leave unchanged the way conventional 4D processing is applied to the data, but we add a single extra simultaneous coherent noise adaptation and subtraction step for all processed vintages. The seismic data is processed for each vintage in the usual sense where as many noise attenuation processes can be applied as required.

Prior to the imaging step, for every acquisition vintage, i, the signal model, s_i, is directly subtracted from the original data before noise attenuation, d_i, to give a noise model, n_i.

$$n_i = d_i - s_i \tag{1}$$

Note that n_i contains all the conventional noise from the data. This includes surface related multiples, internal multiples, and possibly any kind of coherent and predictable noise. Also note that the noise model for each vintage has already been adapted independently to its corresponding dataset, this can either be in an explicit manner as in the SRME case or in an implicit manner as in the Radon or deconvolution case. Following the idea of Zabihi et al., 2012, we minimize a cost function, E, to derive filters, f_i, that simultaneously reshape the noise models for all vintages, where the 4D differences between vintages act as regularization constraints. The minimisation equation is given below:

$$E = \sum_{i=1}^{N} \left\| d_i - f_i * n_i \right\| + \lambda \sum_{i=1}^{N-1} \sum_{j \neq i}^{N} \left\| \left(d_i - d_j \right) - \left(f_i * n_i - f_j * n_j \right) \right\| \qquad (2)$$

where N is the number of processed vintages and λ is a weighting parameter that controls the ratio between noise model matching and 4D differences. It is important to note that f_i are no longer considered matching filters that harshly adapt SRME models to data, which can differ significantly in amplitude and character, they are now treated as mild shaping filters that readjust the noise models to fit the data while honouring the repeatability of different vintages. The newly estimated signal models are now given by

$$s_i^{'} = d_i - f_i * n_i \qquad (3)$$

These signal models, $s_i^{'}$, are now passed to the migration phase for the final image to be formed.

As data from the different acquisition vintages may have different geometrical aspects, such as fold or acquisition azimuth, all vintages must be synchronized before the simultaneous subtraction step can be performed. This can be achieved via 5D regularization which is now widely used. The domain in which the adaptive subtraction is performed can be freely chosen. The common channel domain is frequently used for SRME multiple subtraction with high rates of success. This domain also proved to be successful for our implementation.

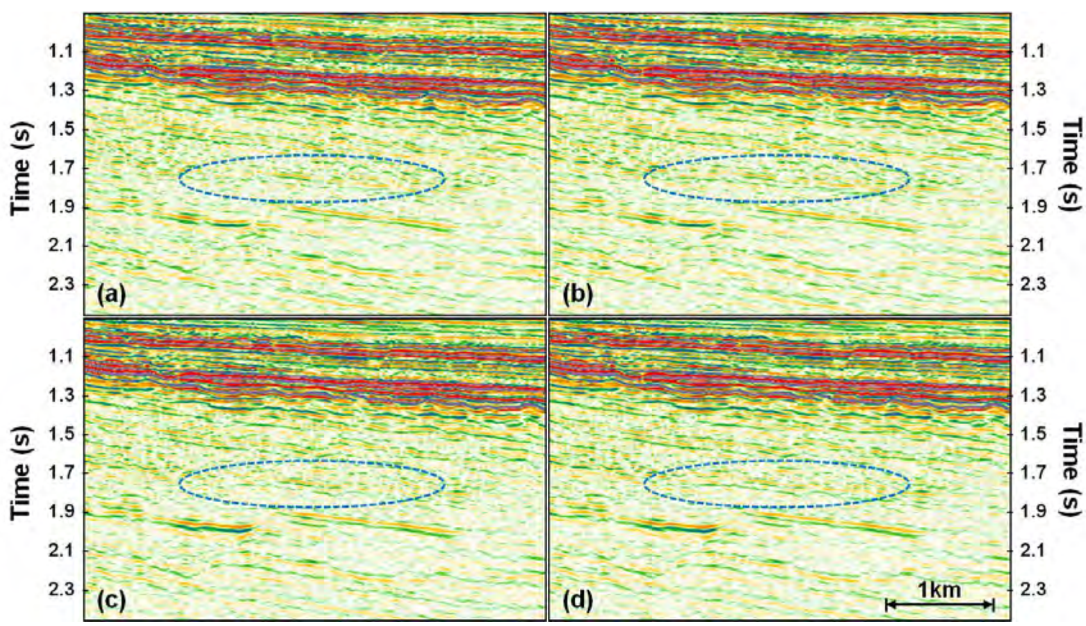

***Figure 2** Final migration stacks of two processed vintages from the Schiehallion oilfield. (a) The 1996 data with conventional processing. (b) The 1996 data with the extra simultaneous adaption step. (c) The 2004 data with conventional processing. (d) The 2004 data with the extra simultaneous adaption step. Note that the circled event is healed by the extra adaptation step.*

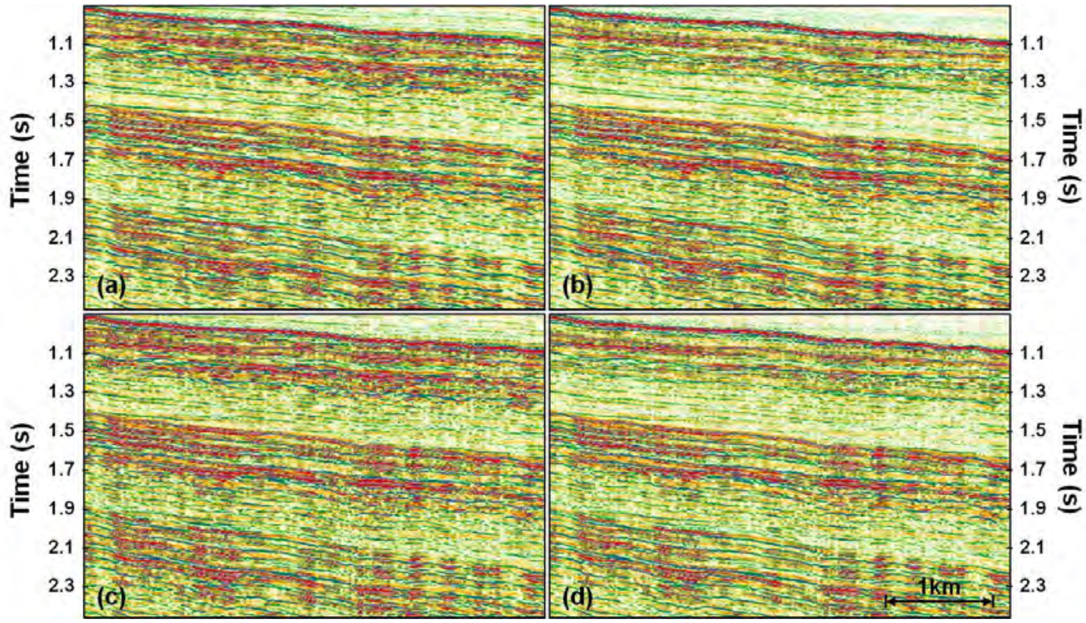

Figure 3 *Near offset pre-imaging data of the two processed vintages. (a) The 1996 total data. (b) The 1996 noise model. (c) The 2004 total data. (d) The 2004 noise model.*

Real Data Example

We use two vintages acquired over the Schiehallion oilfield in 1996 and 2004 to test our proposed workflow. The processing sequence involved both SRME and pre-imaging Radon demultiple steps. Routine time-lapse friendly seismic processing, such as tidal statics correction, designature and swell noise attenuation is applied to the data. The simultaneous adaptive subtraction of the noise models from the two vintages is performed in the common channel domain just before the imaging phase. As mentioned before, adaptation parameters are required to be mild. In this run, we use 800ms windows with a spatial extent of 100 traces. Kirchhoff depth migration has been used as the final imaging tool and then stretched to time. For comparison purposes, the same data without the extra simultaneous adaptation has also been migrated.

Figure 2 shows the final migration results for the two vintages with and without the extra adaptation step applied and Figure 3 shows the pre-imaging data and noise models that has been input to the extra adaptation step. The migrations with the extra 4D adaptation are more continuous and coherent.

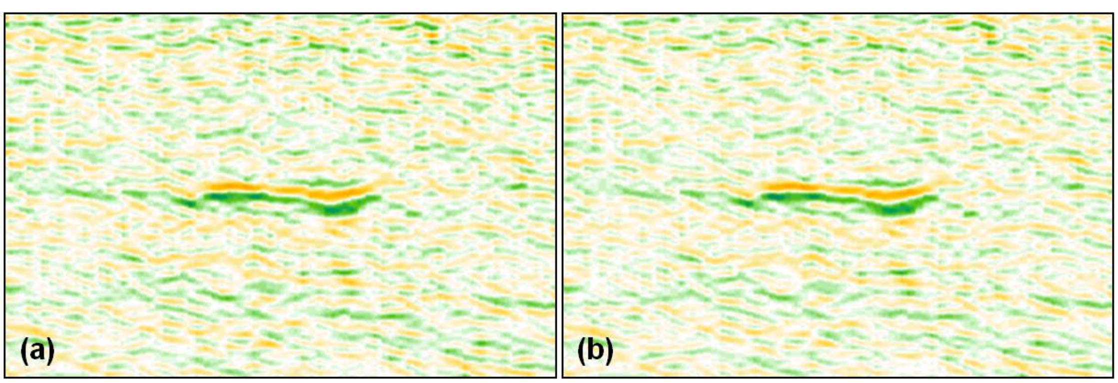

Figure 4 *Zoomed 4D difference sections of the final migration stacks of the two processed vintages of the Schiehallion dataset. (a) With conventional processing. (b) With the extra simultaneous adaption step. Overall, the section with the extra adaption step is cleaner while the 4D signal is not harmed.*

The extra adaptation step optimises the 4D signal, but can compromise the 3D signal seen on the individual vintages, when compared with the version without the additional 4D adaptation. This can be beneficial for time-lapse processing as it significantly improves the 4D S/N, resulting in greater standout of the 4D signal. This can be seen in Figure 4 where the result of the proposed workflow gives an overall quieter section without harming the actual 4D signal. Figure 5 displays NRMS maps of the difference section for conventional and simultaneous adaption. The lower average NRMS value demonstrates the consistent improvement using this proposed technique.

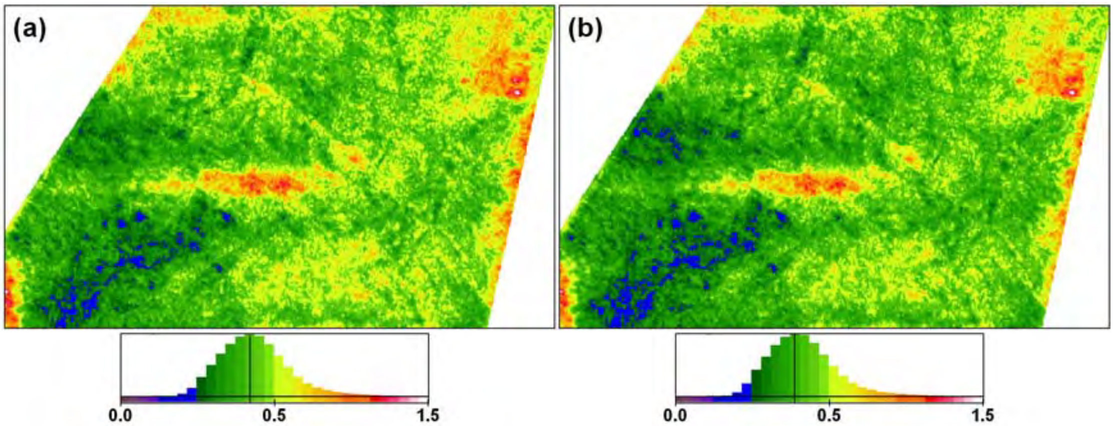

Figure 5 *NRMS maps difference sections of the final migration stacks of the two processed vintages of the Schiehallion datasets. (a) With conventional processing. (b) With the extra simultaneous adaption step. The map with the extra adaption step is quieter.*

Conclusions

A new workflow utilising the method presented in Zabihi et al., 2012, is developed. The proposed workflow overcomes the limitations of the original implementation with a significantly easier and hence faster flow and generalizing the approach to include coherent noise and not just surface related multiples. It also requires minimal changes to conventional workflows where best practices have been developed over years of experience. The new implementation has been successfully applied to the full Schiehallion dataset with significant improvement in the final 4D product.

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