Enhancing Land Surface Multiple Attenuation by Hybrid Event Matching

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Abstract

We present a case study workflow for prestack prediction and attenuation of surface multiples from a survey located in the Middle East. The proposed approach is applicable to any land survey where surface and near-surface multiples generated from reflection and trapped refraction events propagate along the field data records. The workflow employs event splitting strategy to independently match the surface-related multiple estimation (SRME) to the field data. The event separation targets better attenuation of strong linear dipping multiples that has been inaccurately predicted by the surface related multiples estimation method.

First, we apply 5D interpolation to improve the near-offset coverage and overall survey data spatial sampling, increasing spatial coverage for better near-surface multiple prediction response. The 5D interpolation process also acts as an effective random noise attenuation algorithm. Next, we predict the surface multiples using a 3D SRME prediction algorithm.

Predicted events are divided into reflection-based and refraction-based generated multiples. The former model follows a typical least-squares matching aimed to attenuate the reflection-generated surface-related multiples, while the latter is used as prior model inside a dip-based prediction-error filtering (PEF) scheme. Matched models are merged and followed by a mild least-squares matching workflow to attenuate the estimated surface multiples.

The new workflow effectively attenuates poorly predicted surface-related multiples, improving the overall seismic response after imaging, and enhancing correlation with borehole information.

Introduction

Free-surface-related multiple contamination is often regarded as a secondary concern when compared with internal multiple interference (El-Emam et al., 2005; El-Emam et al., 2011; Ras et al., 2012; Wu et al., 2011). Apparent velocity discrimination and relatively strong absorption, due to double propagation through highly heterogeneous and unconsolidated formations, are weighted when deciding to address this noise later in the processing flow. Observed surface and near-surface-related reverberations are stronger at post-critical incidence angles, mainly trapped between weathering and the first compact formations. This coherent noise appears as linear events with relatively low-velocity propagation.

The most common attenuation approach is the application of apparent velocity discrimination filtering after prestack imaging (El-Emam et al., 2001). Addressing surface multiples after imaging negatively affect processing applied prior prestack imaging, such as data-driven internal multiple prediction algorithms. These methods assume that no surface and near-surface multiples are present in the seismic records. Leaving these events in the data during internal multiple prediction will generate artifacts in the model, impairing the effective removal of internal multiples from the field records. Moreover, observed trapped surface-related multiples appear as linear events after imaging, but part of its energy will manifest as crosstalk, affecting the quality of the final imaged gather. In such cases, it is recommended that surface and near-surface multiple contamination must be addressed before internal multiple attenuation and prestack imaging.

Current industry-standard 3D SRME generally performs well when predicting surface-related multiple reflections on onshore seismic data. On-the-fly interpolation (Moore and Dragoset, 2008) and surface-consistent (Wilkinson et al., 2014) implementations overcome the acquisition geometry and statics variations present in orthogonal surveys. Refracted trapped multiple events, however, are predicted with less fidelity than the reflection events, and a common least-squares matching approach is not able to correctly estimate the same class of multiples present in the field data.

We propose a hybrid workflow that splits and simultaneously matches reflection- and refraction-based surface and near-surface multiples predicted by 3D SRME. The poorly predicted refracted multiples are used as a prior model into a dip-based prediction-error filter (PEF) to obtain better models; whereas, the reflection-based events are matched using least-squares filtering. All models are merged into a least-squares simultaneous matching and attenuation workflow. This case study is applied on a 3D onshore survey in the Middle East, and overall results clearly show attenuation of the near-surface trapped reverberation, improving the overall image quality and its correlation with nearby well information.

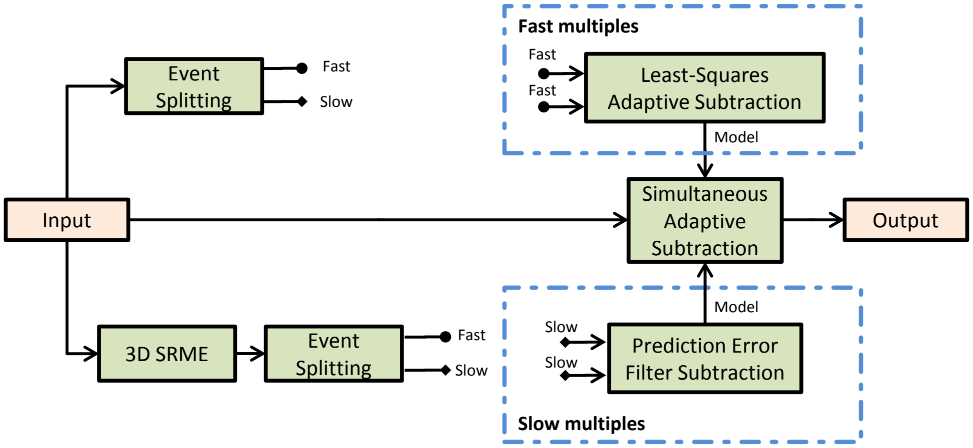

Figure 1 Flowchart of the hybrid adaptive subtraction workflow. Events from field data and predicted surface model are split into fast and low apparent velocity. Each event group is then matched using different approaches according to the model accuracy.

Method

Surface and near-surface reverberations are poorly predicted by 3D SRME due to acquisition sampling limitations. Advanced 5D regularization and interpolation schemes allied with on-the-fly interpolation can help overcome the spatial sampling limitation, but the required spatial sampling to accurately predict the linear moveout low apparent velocity pattern observed in this class of multiples imposes a hard constraint in terms of computational cost and storage footprint. On the other hand, reflection-based multiples are accurately predicted using the actual geometry and regularization present in the seismic survey.

Different corrections are required when dealing with a predicted surface multiple model that has two distinct characters. The diagram in Figure 1 shows the proposed approach to correctly match and attenuate all the surface-related reverberations present in the data.

Firstly, an initial moveout discrimination scheme is applied to isolate the low-velocity multiples from the field data and predicted surface multiple model. High-velocity events are, in general, accurately predicted by 3D SRME and pass through a least-squares filter process to match the predicted model to the field multiples. The resultant model in the low-velocity model is not as accurate as the high-velocity one, but it is still possible to visually verify the correlation between the predicted model and the field data. For such cases, a dip-dependent prediction error filter scheme (Spitz, 1999) is used to match the actual multiples. The output of both models is merged to the input data using a simultaneous least-squares subtraction process (Ala'i and Verschuur, 2003).

Results

The proposed workflow was applied in a single-sensor onshore seismic survey located in northern Kuwait. The survey area has a borehole centrally located and the full-fold area covers the oil/water contact at the Jurassic interval. Figure 2 shows a comparison between the field

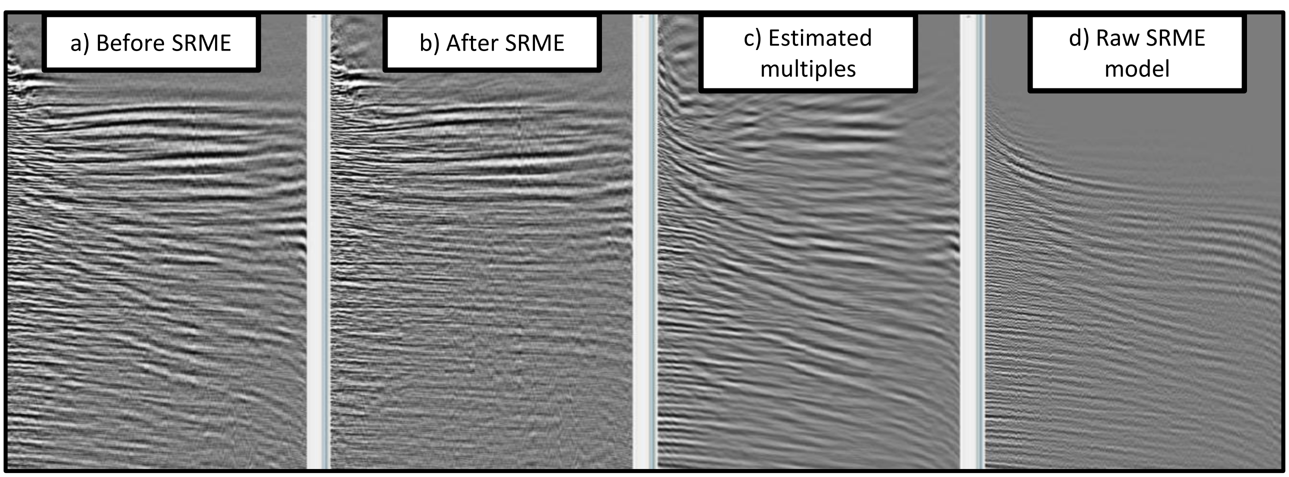

Figure 2 Common midpoint gathers of a) input, b) after surface-related multiple attenuation. The gathers in c) and d) show the final estimated surface multiples and the events predicted by 3D SRME. Linear events in the shallow part of gathers b) and c) are due transform approximations. They are localized over the mute/stretch zones and present no harm to the overall seismic data.

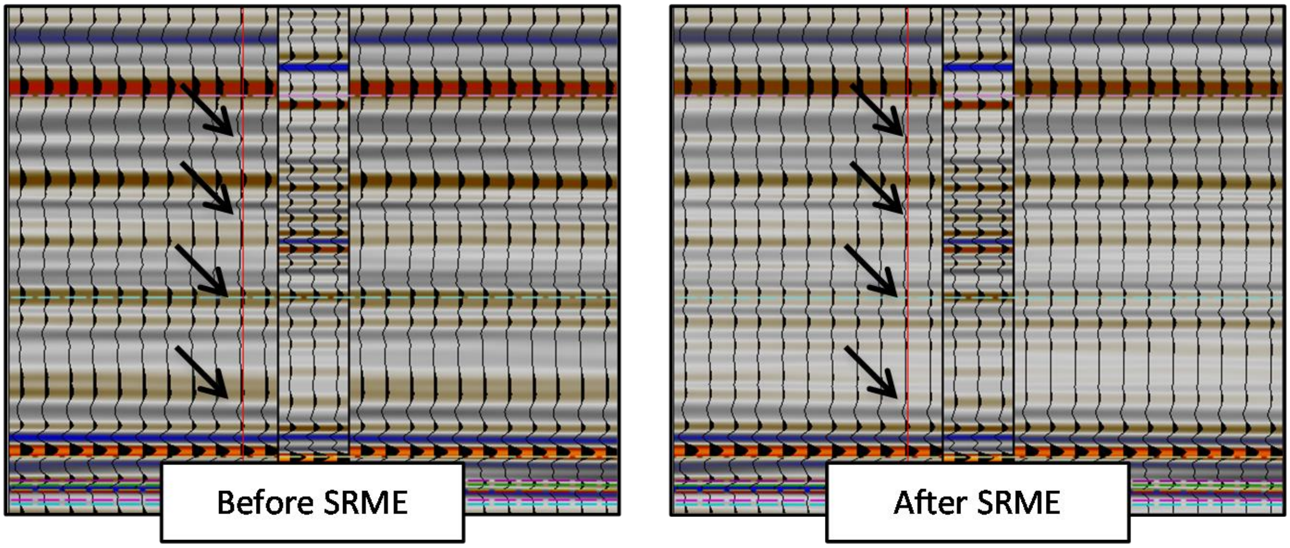

Figure 3 Seismic comparison between a pre-stack Kirchhoff migrated image and a synthetic trace derived from borehole measurements. The left image is before and the right one after surface multiple attenuation with hybrid adaptive subtraction workflow. Arrows point significant correlation improvement after the surface multiple attenuation workflow.

seismic data before and after the surface multiple attenuation, as well as the estimated multiples and the model predicted by the 3D SRME. It is possible to observe discrepancies between the predicted model and the field multiples, especially over the low-velocity reverberations. The proposed adaptive subtraction splits the events and performs a different matching for the fast- and low-velocity propagating events, and is able to match and subtract the surface-related multiples from the field data.

The seismic well-tie comparison after the prestack time Kirchhoff migration in Figure 3 shows the value of the surface multiple attenuation proposed in this work. Key events indicated by the arrows show the signal recovery and better lateral continuity. The better event matching between the borehole trace and the seismic image after surface multiple attenuation is also evident.

Conclusions

Multiple contamination is one of the major challenges for land data, whether surface or internal multiple related, where conventional methods based on periodicity and velocity or dip discrimination are suboptimal. This work showed a multiple attenuation workflow that employs a 3D, true-azimuth prediction of surface multiples allied with a hybrid adaptive matching approach. The proposed workflow was applied in a case study from the Middle East, where the final images showed significant improvement in vertical resolution, improving its correlation with borehole synthetic generated traces.

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