A Novel 3-D De-multiple Workflow for Shallow Water Environments - a Case Study from the Brage field, North Sea

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SUMMARY

In shallow water environments, near surface reflectivity information is poorly recorded with 3-D towed streamer acquisition geometries. Therefore, the missing information must be reconstructed in the data prior to the de-multiple step. For this purpose, assumptions are typically made on shallow reflectivities and velocities. In the presented workflow, we use full waveform inversion and imaging with multiples, in order to extract the required information from the data acquired with dual-sensor towed streamer system. Then multiple models are generated by wavefield extrapolation. A comparison is shown on real data from North Sea, where the de-multiple processing is run once using a priori information on shallow multiple generators and then through the new workflow, which demonstrates that the extra information recovered has a significant impact on the effectiveness of the de-multiple process.

Introduction

We present a case study over the Brage field, North Sea, where a 3-D dual sensor towed streamer survey is acquired for structural imaging purposes. One of the main challenges in processing the data resides in removing prominent surface related multiples generated by various shallow interfaces including the seabed. However, due to the shallow water environments, the lack of recorded near-offset primary information does not allow the use of 3-D data-driven methods, such as 3-D SRME (Moore and Bisley, 2006). Therefore model-based de-multiple method have been successfully implemented by making assumptions on shallow reflectivities and velocities (Barnes *et al*, 2014). Whilst the information may be reasonable for the seabed when it is gently varying across the survey, it is at best over-simplified or distorted, if not lacking, for other shallow multiple generators.

In order to extend the effectiveness of the method while making most parameters data-driven, we propose a 3-D workflow suited to data recorded with dual-sensor streamer systems which will provide the shallow information, i.e. multiple generators, with accurate depth, reflectivity and seismic velocity information. The workflow starts from raw data and the final output are pre-processed data after de-multiple, typically input to advanced depth imaging workflows.

The key methods which are combined are: wavefield extrapolation, full waveform inversion (FWI) and imaging with multiples, the latter making use of up- and down-going wavefields available from dual-sensor recordings. The three methods may be used again for final imaging of data after the de-multiple stage. However we will mainly focus on the multiple modelling aspects in this paper.

Methodology

3-D wavefield extrapolation for multiple modelling requires both velocity information as well as a reflectivity model for the near surface overburden that contains the main multiple generators (Brittan *et al*, 2011). This information is commonly modelled for the water layer by using bathymetry information, water velocity measurements and an estimate of the seabed reflectivity. In order to extend the range of multiple generators, as well as improve the accuracy of the information and derive it from the data in a 3-D manner, we combine advanced imaging tools such as full waveform inversion and imaging with multiples, which can be used at a very early stage of the data processing. It will respectively provide a detailed velocity model (Crawley *et al*, 2010) and a high-resolution seismic image of the shallow overburden.

Full waveform inversion uses the raw pressure records and a starting velocity model. The extent and accuracy of the velocity update will not be discussed here; however, using modern broadband long offsets streamer data which is rich in low frequency and full waveform inversion will allow to produce a detailed interval velocity model of the subsurface in the shallow depths range where standard tomography tools are less effective due to a lack of offsets.

For common 3-D marine streamer acquisition geometries, near-offset coverage is insufficient to estimate reflectivity from primary reflections in the very shallow water environments. Therefore imaging with multiples (Whitmore *et al*, 2010), also known as separated wavefield imaging (SWIM), will extend the near surface illumination and reflectivity information, given the availability of up- and down-going pressure wavefields with dual-sensor recordings (Carlson *et al*, 2007), which are both necessary for applying the deconvolution imaging condition at the specular reflection points of free surface multiples.

In our case, the reflectivity data are fed back as an earth model in order to generate free surface related multiple. Indeed, the multiple model is obtained by re-injecting the recorded data containing primaries and multiples through the earth model by 3-D wavefield extrapolation which is controlled by a velocity model (Figure 1).

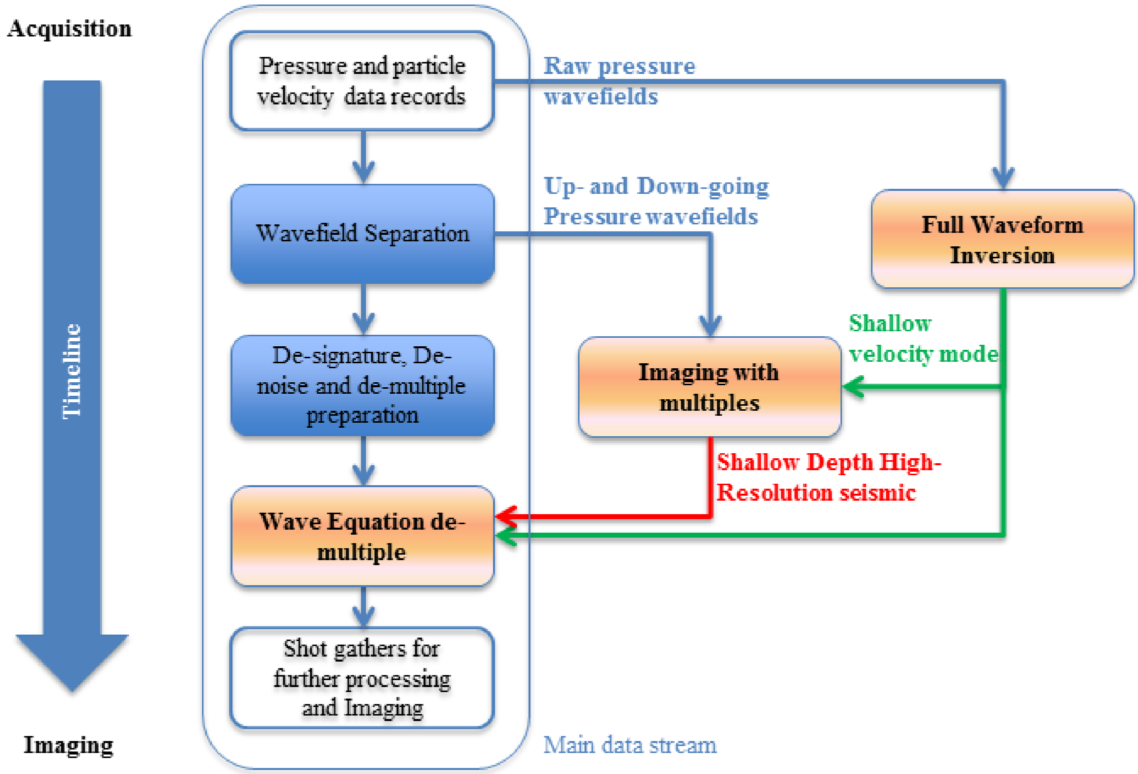

Figure 1 *Workflow diagram for processing of dual-sensor streamer data from raw stage up to the main de-multiple stage. The left column represents the main data flow and critical path affecting turn-around. The extra steps for extracting the information for multiple modelling by wavefield extrapolation can be run in parallel of the main data pre-conditioning steps.*

The velocity model updated by full waveform inversion will ensure the imaging with multiples is effective in the same range of depths. The same velocity model is used again for the wavefield extrapolation step for multiple model generation.

Data example

At the Brage field, the very shallow overburden is affected by a low velocity channel and thin layers of varying velocities (Figure 2). Therefore, in addition to the strong water-bottom reflection, shallow multiple generators introduce significant multiple contamination at the deeper reservoir level.

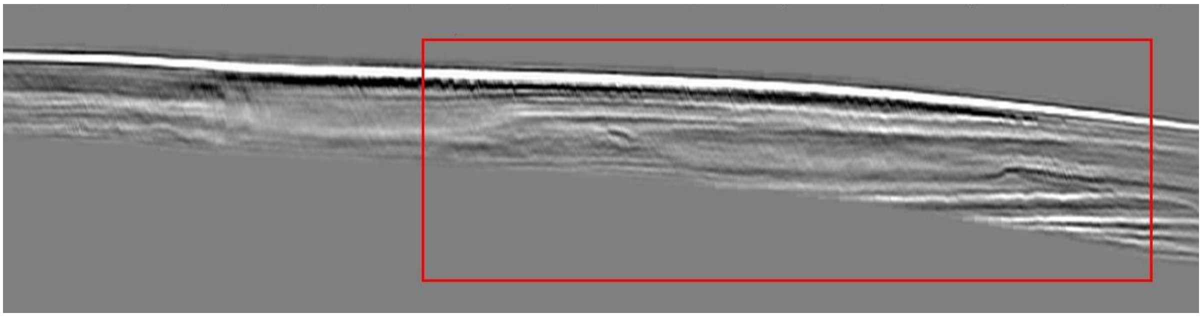

Figure 2 *Examples of seismic data using imaging with multiples. The red box indicates the multiple generators which have an impact on the stack results shown on figure 3. This high-resolution picture reveals many reflectors just below seabed with laterally varying reflectivity. The complete data are obtained as a dense 3-D cube extending to the actual receiver positions covered during the acquisition.*

The reference de-multiple flow is making use of *a priori* information. Indeed the reflectivity model only comprises a single synthetic reflection representing the seabed and the velocity model is given only by a constant value, the average measured water velocity. Therefore the wavefield extrapolation method produces a multiple model which gives good attenuation of water-bottom multiples but leaves significant cross-cutting events in the data.

With the extra near-surface reflectivity information recovered from imaging with multiples, the multiple model for the extended workflow contains more real prominent multiples for which the modelled amplitudes better matches the real recorded data. The least-square adaptive subtraction demonstrates the benefit of the more comprehensive model by removing more multiples while some primary reflectors appear clearer on the stack images after the de-multiple step (Figure 3).

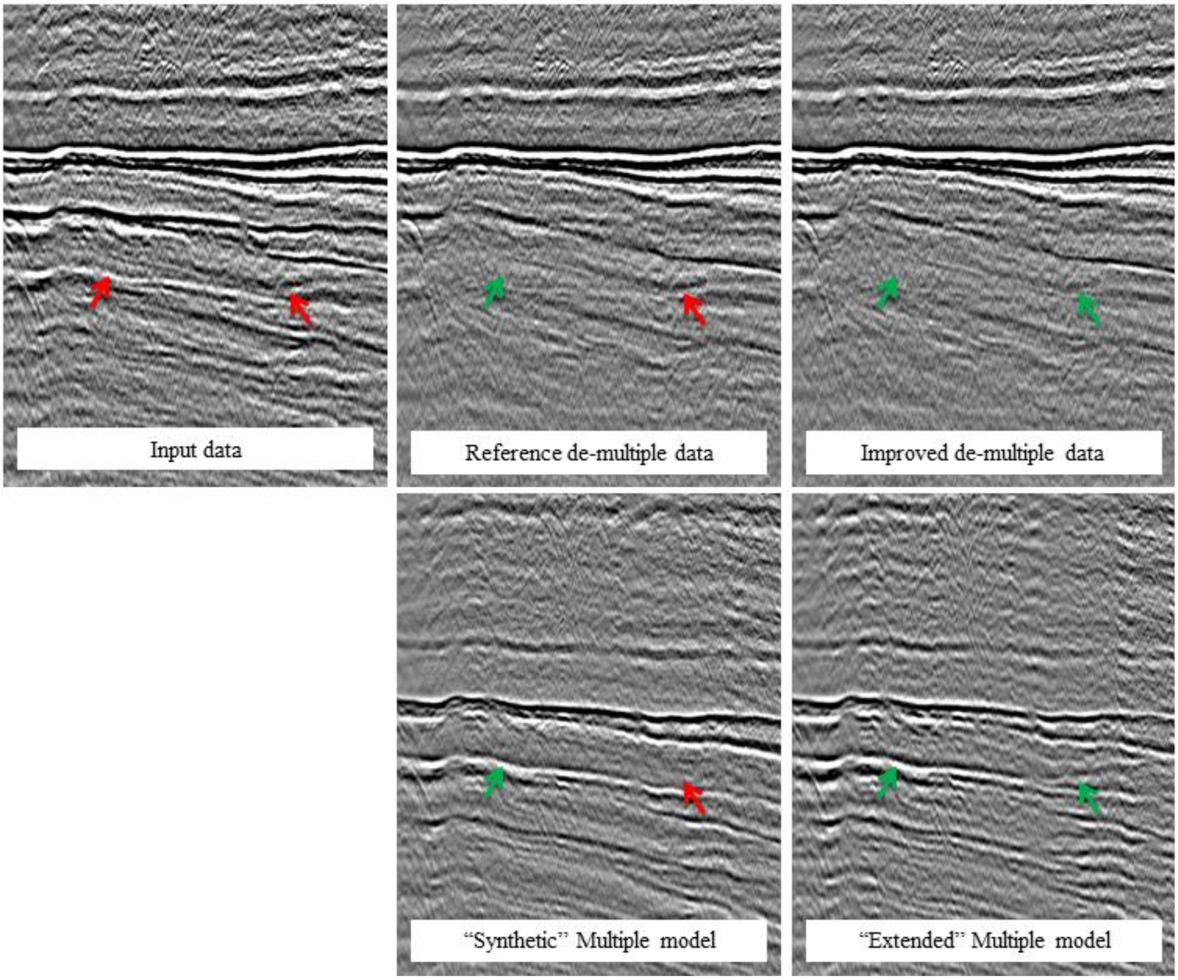

Figure 3 *2D NMO stack displays of data and multiple models. Red arrows indicate multiples in the data, or lack of- in the multiple model. Green arrows indicate good multiple attenuation in the data or good multiple modelling.*

The section on Figure 3 represents a deep reservoir interval starting below a very strong reflection. The synthetic multiple model is obtained by using a priori information. The extended multiple model is obtained with the new workflow. The reference de-multiple shows very good attenuation of water-layer related multiples, as for the improved de-multiple. The improved flow also removes other surface related multiples of shallow generator whose amplitude is higher than underlying primaries. The better de-multiple reveals weak interface of geological interest, in this case with an obvious dip difference with multiples.

Conclusions

We have demonstrated that advanced imaging methods, applied to data acquired with modern dual-sensor tower streamer system, can be combined with wavefield extrapolation de-multiple method in order to extend its range of application. We observe on the example dataset that the same de-multiple step becomes more effective by including more accurate information about the true reflectivity of the near surface. Moreover, we emphasize that the modelling parameters for multiple generation are now derived from the same recorded data as used for the main processing workflow.

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