Waveform inversion of multicomponent blended data with polarization filters

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ABSTRACT

We present a new algorithm for directly imaging blended data via waveform inversion. The algorithm makes use of the directional information contained within muticomponent blended data by introducing polarization filters at each iteration. We show that with the introduction of these polarization filters, the waveform inversion results contain significantly fewer artifacts than those obtained with conventional waveform inversion of blended data.

INTRODUCTION

The main challenge associated with waveform inversion of blended data is the artifacts that appear due to the cross talk between sources. The current state of the art is to regularize the inversion by imposing constraints that smooth along the structure present in the inverted model parameters (Tang et al., 2009; Xue et al., 2014). While this technique is effective at suppressing the spurious artifacts, it compromises resolution in the earth model.

To overcome this issue, we present a modified waveform inversion algorithm that makes use of the directional information contained in the multicomponent data that are generally acquired during simultaneous source surveys with ocean-bottom node receivers. We incorporate this additional information into the waveform inversion by introducing polarization filters at each iteration. We estimate these filters and then apply them to the blended data to give approximate deblended data. We then compute the waveform inversion gradient on these approximately deblended data which provides gradients with much fewer artifacts and therefore better model updates. In a linearized waveform inversion example for acoustic multicomponent blended data, we show that the inverted model resulting from this algorithm has significantly fewer artifacts.

THEORY

The conventional objective function for waveform inversion of blended data can be written as follows:

$$J(\mathbf{m}) = \frac{1}{2}||\widetilde{\mathbf{f}}(\mathbf{m}) - \widetilde{\mathbf{d}}||_2^2, \tag{1}$$

where $\mathbf{m}$ is an earth model (e.g., velocity model), $\widetilde{\mathbf{f}}$ is the non-linear blended wave equation modeling operator and $\widetilde{\mathbf{d}}$ is the recorded blended data. The minimization of equation 1 results in an optimal $\mathbf{m}$ such that the synthetically modeled blended data $\widetilde{\mathbf{f}}(\mathbf{m})$ fits the true recorded data in the least-squares sense. Waveform inversion of multicomponent blended data with polarization filters minimizes the following modified blended waveform inversion objective function:

$$J(\mathbf{m}) = \frac{1}{2}||\mathbf{f}(\mathbf{m}) - \mathbf{P}\widetilde{\mathbf{d}}||_2^2, \tag{2}$$

where $\mathbf{m}$ is again an earth model, $\mathbf{f}$ is an independent modeling operator, $\widetilde{\mathbf{d}}$ is multicomponent blended data and $\mathbf{P}$ contains polarization filters.

These polarization filters are estimated from the independently modeled data (as a result of $\mathbf{f}(\mathbf{m})$) and then are used in order to deblend the data by minimizing the following objective function:

$$J(\mathbf{d}_1, \mathbf{d}_2) = \frac{1}{2}||\mathbf{d}_1 + \mathbf{d}_2 - \widetilde{\mathbf{d}}||_2^2 + \frac{1}{2}||\mathbf{P}_2(\mathbf{d}_1 - \widetilde{\mathbf{d}})||_2^2 + \frac{1}{2}||\mathbf{P}_1(\mathbf{d}_2 - \widetilde{\mathbf{d}})||_2^2, \tag{3}$$

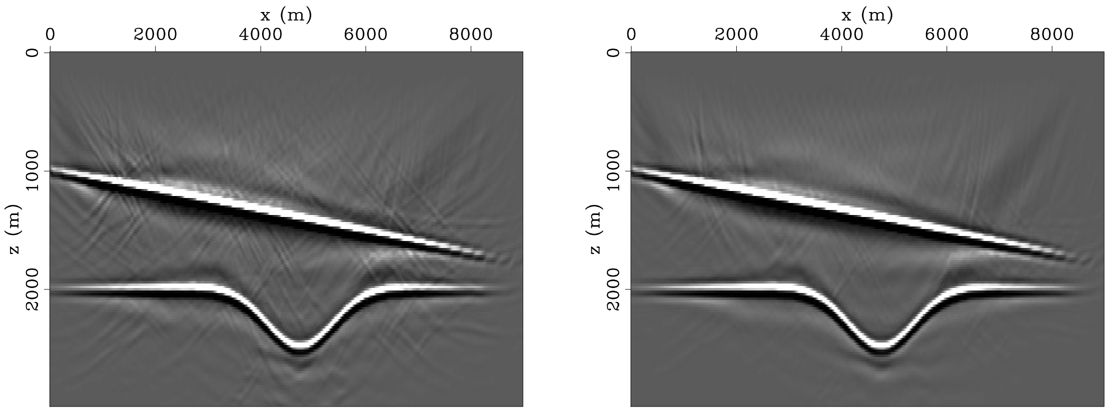
where $\mathbf{d}_1$ and $\mathbf{d}_2$ are the deblended data and $\mathbf{P}_1$ and $\mathbf{P}_2$ are the polarization filters estimated from the independently modeled data. Note that minimizing equation 3 is equivalent to $\mathbf{P}\widetilde{\mathbf{d}}$. Once the data are approximately deblended via the minimization of this objective function, they are then used to compute the waveform inversion gradient and subsequently update the model. This process of deblending and imaging at each iteration is repeated until convergence.

RESULTS

We tested the algorithm for a linearized waveform inversion problem with synthetic multicomponent acoustic blended data generated from a dipping reflector and syncline model. The results after four iterations of conventional blended linearized waveform inversion and waveform inversion with polarization filters are shown in Figures 1a and 1b respectively. Note that the result of waveform inversion with polarization filters has a significant reduction in artifacts.

CONCLUSION AND FUTURE WORK

We have shown that using the directional information contained in multicomponent blended data can improve imaging of blended data. Our waveform inversion of multicomponent blended data with polarization filters, that makes use of this directional information by filtering the blended data at each iteration, provided better waveform inversion results than conventional waveform inversion. In the future, we plan to apply this algorithm on multicomponent acoustic data acquired in the Mediterranean Sea by Kietta (Haumonté, 2016). Figure 2 shows the windowed direct arrival and



(a) (b)

Figure 1: Results after four iterations of (a) conventional linearized waveform inversion of multicomponent blended data and (b) linearized waveform inversion of multicomponent blended data with polarization filters. Note the significant reduction of artifacts in the inverted model obtained in panel (b) vs the model obtained in panel (a). [**CR**]

reflections of a single four component shot gather acquired during this survey. As these data are not blended, we will first blend them and then use these blended data as input to our modified waveform inversion algorithm. In addition to working with these data, we plan to extend our current numerical implementation to a fully elastic waveform inversion to apply our algorithm to blended multicomponent ocean-bottom node data.

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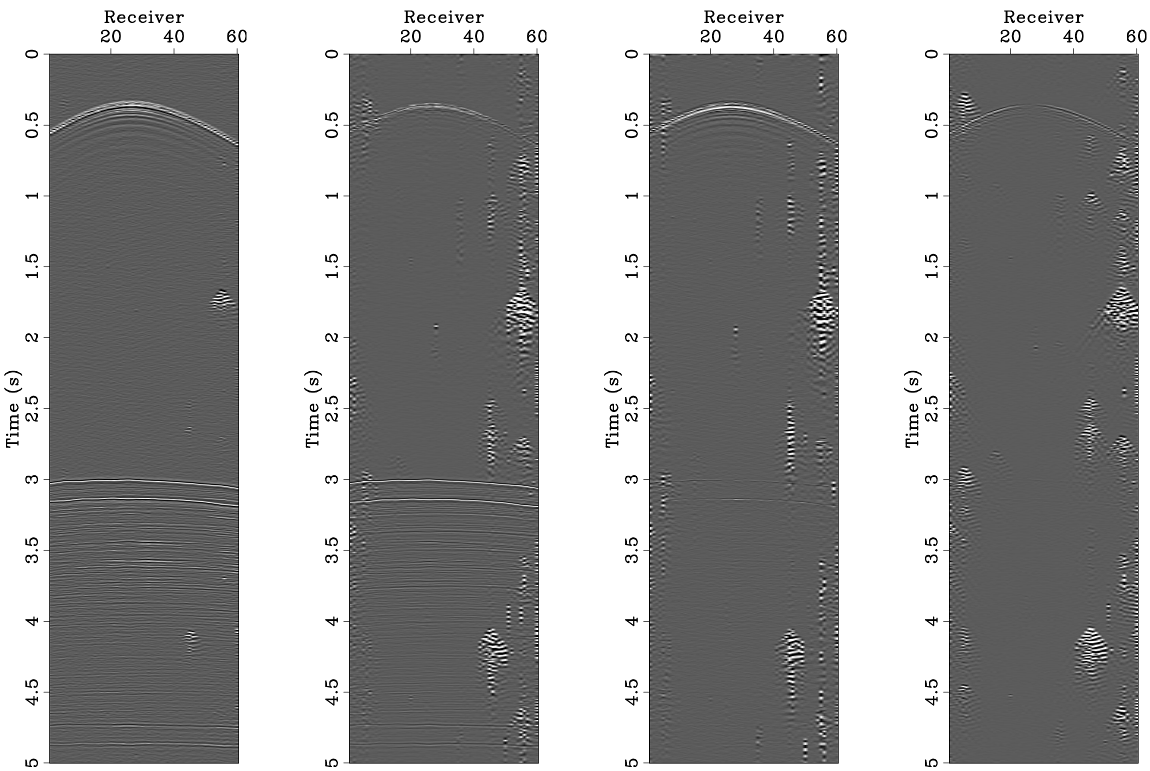

(a) (b) (c) (d)

Figure 2: A single multicomponent acoustic shot gather acquired in the Mediterranean sea by Kietta. (a) Hydrophone component, (b) vertical component, (c) crossline component and (d) inline component. [**CR**]