Non-conventional seismic differencing in time-lapse II

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Abstract

Conventional seismic differencing relies on a number of assumptions which may not always represent reality. Error associated with the use of conventional imaging algorithms, and error due to source/receiver coupling variations are assumed to be small relative to the seismic response of fluid transport in a reservoir for which source/receiver positioning must be the same between surveys in time-lapse. The result is that conventional differencing involves simple match filtering followed by subtraction where the interpretable product is an image of the change in fluid location superimposed upon some background noise level. In reality, however, errors are often very large. We observe that though errors might be large, and with the exception of source/receiver location repeatability, coupling variation and system errors result in differences in seismic amplitude and not necessarily seismic phase.

With this observation we develop four non-conventional seismic differencing algorithms: 1) Cross-correlation differencing (CCD), 2) Pseudo cross-correlation differencing (PCCD), 3) Conventional imaging condition differencing (CICD) and 4) Imaging condition differencing (ICD). The CCD and PCCD algorithm uses cross-correlation and gaussian function to create filtering operator later multiplied by conventional difference and migrated in time and frequency domain, respectively. The CCD proves to be computationally costly, whereas PCCD improves computational cost and resolution. As both algorithms are dependent on the user to move from filtering operator creation to non-conventional differencing to migration, we develop CICD algorithm as a pilot algorithm to ICD. CICD is based on the pre-stack depth migration and conventional differencing. It performs wavefield extrapolation and conventional differencing at the imaging condition. As CICD proves to be robust, we develop ICD that is also based on pre-stack depth migration but performs non-conventional differencing (PCCD) at imaging condition. ICD algorithm fully eliminates dependance on the user, improves resolution and computational cost.

Theory

CCD

Step I: Calculate cross-correlation Matrix	→	**Step II:** Calculate cross-correlation	→	**Step III:** Gaussian filtering	→	**Step IV:** Invert cross-correlation	→	**Step V:** Filter cross-correlation	→	**Step VI:** Conventional difference filtering

CCD algorithm takes shot gathers of baseline and monitor surveys and filters them using cross-correlation and Gaussian function to notched out zero lag in time domain. This result is then scalar multiplied by the inverse operator to undo cross-correlation operation, then scalar multiplied by conventional seismic difference to produced filtered seismic difference. Computational cost of CCD is $O(M^5N^5 + 3MN + MNlog(MN))$ for *mxn* baseline and monitor survey matrices.

PCCD

Step I: Fourier transform data	→	**Step II:** Calculate pseudo cross-correlation	→	**Step III:** Gaussian filtering	→	**Step IV:** Convolution	→	**Step V:** Invert pseudo cross-correlation	→	**Step VI:** Inverse Fourier transform	→	**Step VII:** Conventional difference filtering

As CCD is computationally expensive we develop the same algorithm in frequency domain and call it PCCD. The inputs of this algorithm are Fourier transformed baseline and monitor surveys. PCCD uses pseudo cross-correlation, that is cross-correlation in frequency domain, and Gaussian filter to notch out zero lag through convolution. The result is inverse Fourier transformed back to time domain and scalar multiplied y conventional seismic difference to produce filtered seismic difference. Computational cost of PCCD $O(M^2N^2 + 2MN + 5MNlogMN)$ for *mxn* baseline and monitor survey matrices.

CICD

Step I: Fourier transform data	→	**Step II:** Wavefield extrapolation	→	**Step III:** Conventional differencing

As both CCD and PCCD algorithms depend on user to move from filtering to migration, we develop CICD method as a pilot to ICD method. It takes in the shot gathers of baseline and monitor surveys, Fourier transforms them, then extrapolates wavefields and conventionally differences data at every depth step within the pre-stack depth migration. Computational cost of CICD is $O(MN + MNNlog(MN))$ for *mxn* baseline and monitor survey matrices.

ICD

Step I: Fourier transform data	→	**Step II:** Wavefield extrapolation	→	**Step III:** PCCD

ICD method takes in the shot gathers of baseline and monitor surveys, Fourier transforms them, then extrapolates wavefields and PCCD filters data at every depth step within the pre-stack depth migration. Computational cost of ICD $O(M^2N^2 + 2MN + 6MNlogMN)$ for *mxn* baseline and monitor survey matrices.

Examples

Salt Models

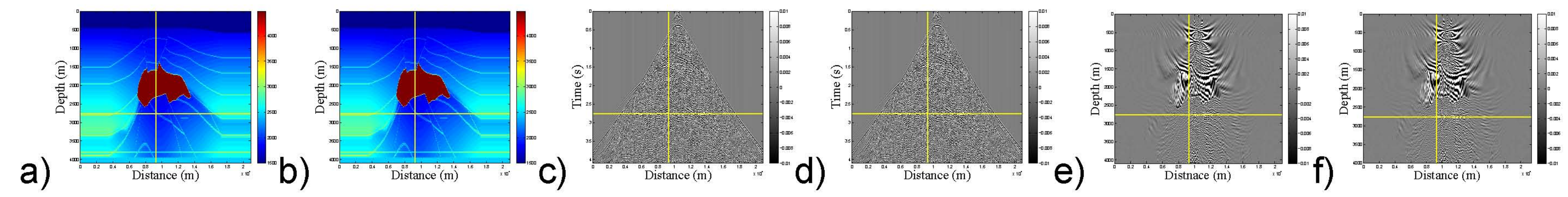

Figure: EAGE/SEG salt models: a) original velocity model, b) authors modified original model by inserting a small reflector in the sub-salt region to accommodate time-lapse analysis, c) shot gather of the original model, d) shot gather of the modified model, e) migrated original model and f) migrated modified model. Note yellow cross-arrows to indicated the location of inserted reflector as the only difference between the original and manipulated models.

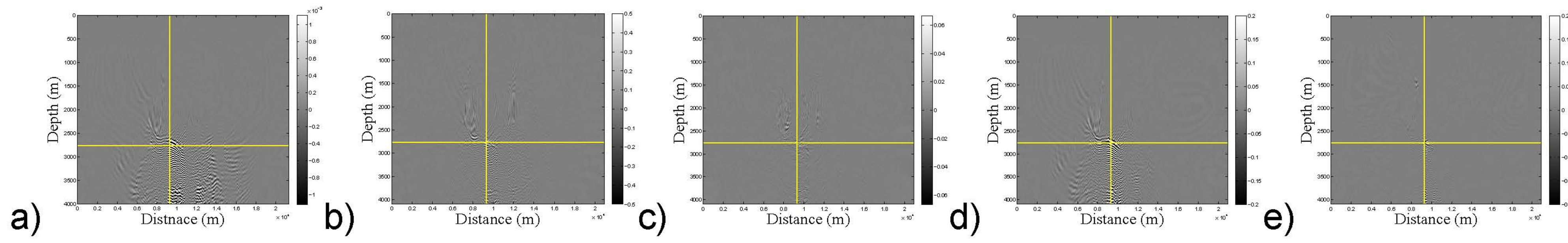

Figure: Differencing algorithms: a) CD, b) CCD, c) PCCD, d) CICD and e) ICD. Note not much difference between CD and CICD models. On the other hand note significant imaging improvements in differencing after non-conventional algorithms CCD, PCCD and ICD. The three non-conventional differencing models show higher resolution by focusing the location of the inserted reflector when compared to two conventional differencing results. Note yellow cross-arrows to indicated the location of inserted reflector.

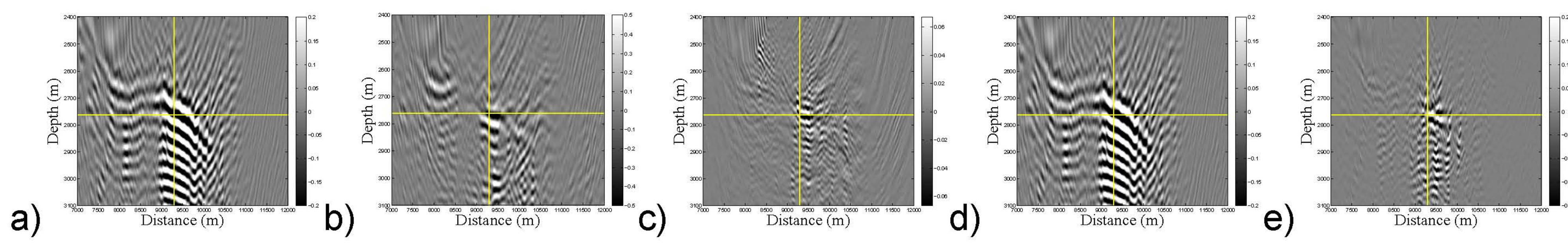

Figure: Differencing models zoomed in: a) CD, b) CCD, c) PCCD, d) CICD and e) ICD. Note yellow cross-arrows to indicated the location of inserted reflector.

Waterflood Models

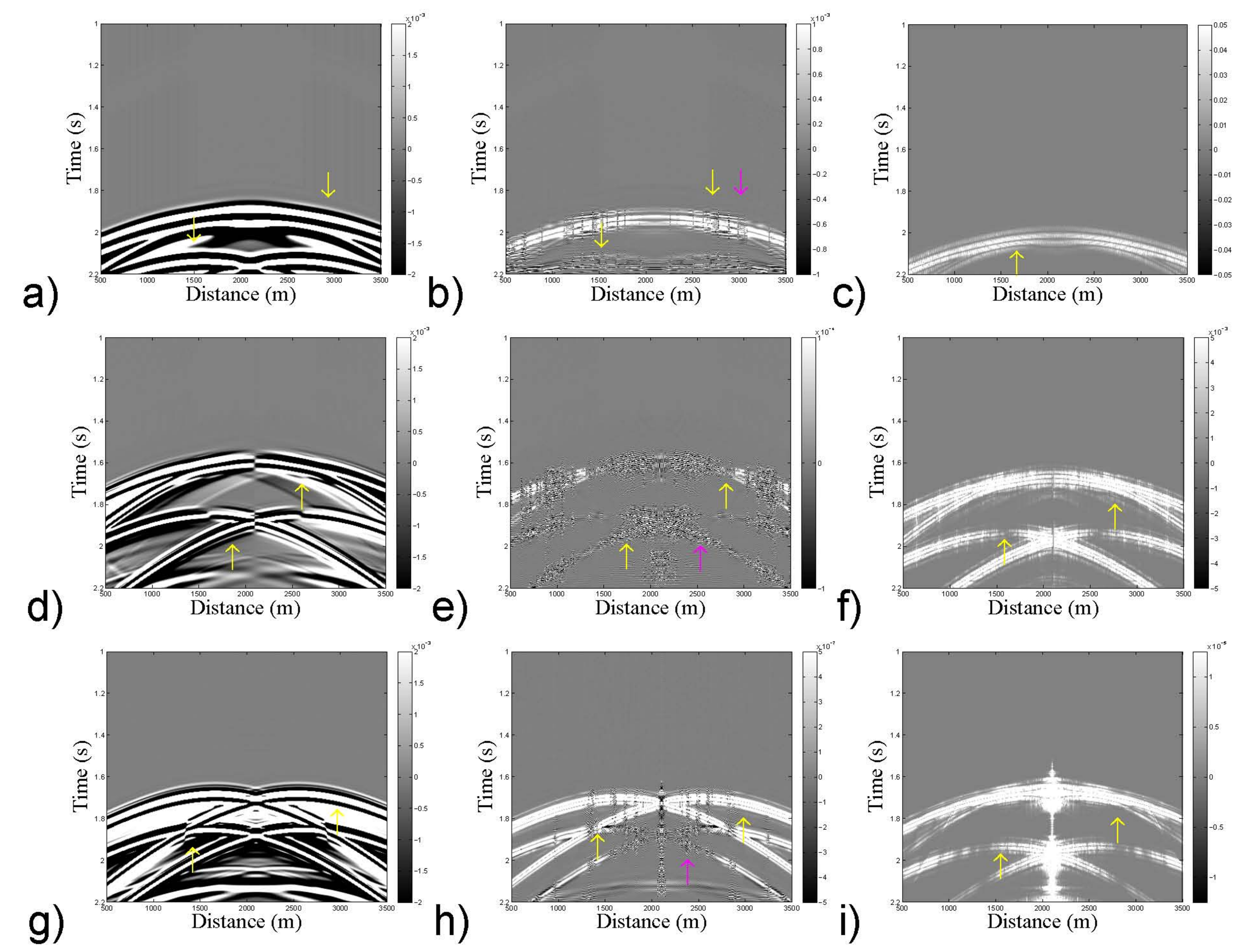

Figure: 3C-3D shot gather differencing: a) x-component CD of day 1 and 28, b) x-component CCD filtering of day 1 and 28, c) x-component PCCD filtering of day 1 and 28, d) y-component CD of day 1 and 28, e) y-component CCD filtering of day 1 and 28, f) y-component PCCD filtering of day 1 and 28, g) z-component conventional differencing of day 1 and 28, h) z-component CCD filtering of day 1 and 28 and i) z-component CCD filtering of day 1 and 28. The yellow and magenta arrows denote waterfronts and numerical artifacts, respectively. Note waterfronts imaging significantly highlighted on CCD and PCCD filtered models when compared to CD models.

Conclusions

The CCD, PCCD and ICD algorithms prove to be valuable alternative tools in seismic differencing and time-lapse analyses. They are able to highlight differences on seismic time-lapse models and eliminate unnecessary information in its vicinity. The computational cost and user dependance vary from algorithm to algorithm.