Correction filter use in finite-difference elastic modeling

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ABSTRACT

Correction filtering of the finite-difference elastic wavefield has been found to be a practical and efficient process. In a particular case shown, the cost of the beneficial effects was obtained by using a minimal convolution filter with an overall size of 3 by 3 points, and this resulted in a 80 percent increase in run times. Comparable results obtained by reducing sampling intervals required a one third reduction, which cost a 180 percent increase in run times. Further tests showed that the particular corrections filter set used was still quite effective when used on models with velocities 25% lower than the design velocities.

INTRODUCTION

The theory and practice of wavefield filters was introduced by the author in his PhD thesis (Manning, 2008). Each filter (of a set of filters) was designed to be convolved with the appropriate finite-difference calculations which represented partial differential equation terms of the wave equations. It was shown that when these corrections were applied, the wavefield extrapolation became far more accurate for a practical range of frequencies.

The limitation of this theory was that each region within a model required a unique set of filters, which depended on the velocity of the pressure and shear waves within the region. Another limitation of the correction filters tested was that they were usually quite large, and although they showed advantages over the simple technique of using finer sample rates, the advantages were not huge. Also, it was not clear how much damage was done when the filter edges operated on regions beyond those for which they were designed.

This paper developed after running finite-difference models for micro-seismic purposes. In some micro-seismic models the source and receivers are relatively near, and there are limited ranges of seismic velocities which need to be represented. The sampling rates could then be chosen for accurate modelling of these pressure wave velocities. The problem that then became obvious was that these sample rates were far from ideal for the lower velocity shear waves in the same regions, and they showed numerical dispersion that masked everything else once they arrived at a recording point.

Use of correction filters then proved very effective for reducing the numerical dispersion of the shear wave events to minimal levels. The main reason for this is that correction filters are designed separately and specifically for the local shear wave propagation. This is in contrast to the higher accuracy derivative calculations used (for example) in Levander (1988).

MODEL TESTING

Several models were run to obtain objective comparisons between corrected and uncorrected results. It was found that there was little difference between using the absolute minimum size of correction filter of 3 by 3 (since the filters are symmetrical zero-phase) and larger ones, so all tests used the small filters. The source was a 300 Hz zero phase Ricker wavelet on the symmetric (left) edge, with an explosive character but reduced energy in the horizontal directions. This resulted in source energy of both pressure and shear nature, but dependent on the propagation direction.

Two geological models were used for testing; the first with an almost constant velocity region of 4000 m/sec for Vp and 2500 m/sec for Vs, the second with an almost constant velocity region of 3000 m/sec for Vp and 1875 m/sec for Vs.

One set of finite-difference parameters sampled the geological model at intervals of 0.75 metres in X and Z, and time sampled at 0.0001 seconds through 900 steps. These parameters were used for ordinary second order calculations, and for corrected calculations. The corrected calculations required run times approximately 80% longer than the second order calculations.

The second set of parameters sampled the geology at 0.5 metres in X and Z, and at intervals of 0.000067 seconds through 1350 steps to reach the same total time as the first set. These parameters were used only for ordinary second order calculations, and executed in an elapsed time about 180% greater than the coarsely sampled models.

The first three Figures show the wave displacements after the last propagation step on the high velocity model. There is a plot for each of the propagations run on this model.

Figures 4 to 9 show vertical displacement seismograms obtained .through time at 300 metres depth and from 0 to 200 metres offset. There is a plot for each of the propagations run on both models.

RESULTS

The first six Figures give comparisons between the modelling improvements of using custom designed correction filters compared to the improvements of using finer sample rates. It is quite obvious that the corrected propagation snapshot in Figure 2 is higher quality than the finer sampled snapshot in Figure 3. The wavelets in Figure 3 are not quite as sharp, and do not have the zero-phase character of the wavelets in Figure 2. Figure 3 shows the first subtle signs of dispersion. The same conclusions may be reached by comparing the seismograms in Figures 5 and 6.

Figures 7, 8, and 9, display results from the lower velocities model. They allow comparisons between the finer sample rates as above, and correction with a filter set which is much less than optimum. Even so, similar conclusions may be reached when comparing the two cases in Figures 8 and 9. There is a little less obvious dispersion to be seen in Figure 8, even though the corrections used were not designed for this environment. The wavelets in Figure 8 are not really zero-phase, so extended propagation under these conditions would lead to problems.

CONCLUSIONS

There is no doubt that the use of optimum correction filters is a highly effective and efficient way to improve the results of finite-difference modelling. The author has reached this conclusion before, but not for the minimal version of the filters used here.

There is also a strong indication that a correction filter set may be effectively used for a range of velocities. This was shown for velocities that range lower than the design velocities.

FUTURE WORK

It may be feasible to relate velocity ranges and the corresponding accuracies of a given filter set.

REFERENCES

Levander, A. R., 1988, Fourth-order finite-difference P-SV seismograms: Geophysics, **53**, No. 11, 1425-1436.

Manning, P. M., 2008, Techniques to enhance the accuracy and efficiency of finite-difference modelling for the propagation of elastic waves: PhD thesis, The University of Calgary.

FIGURES

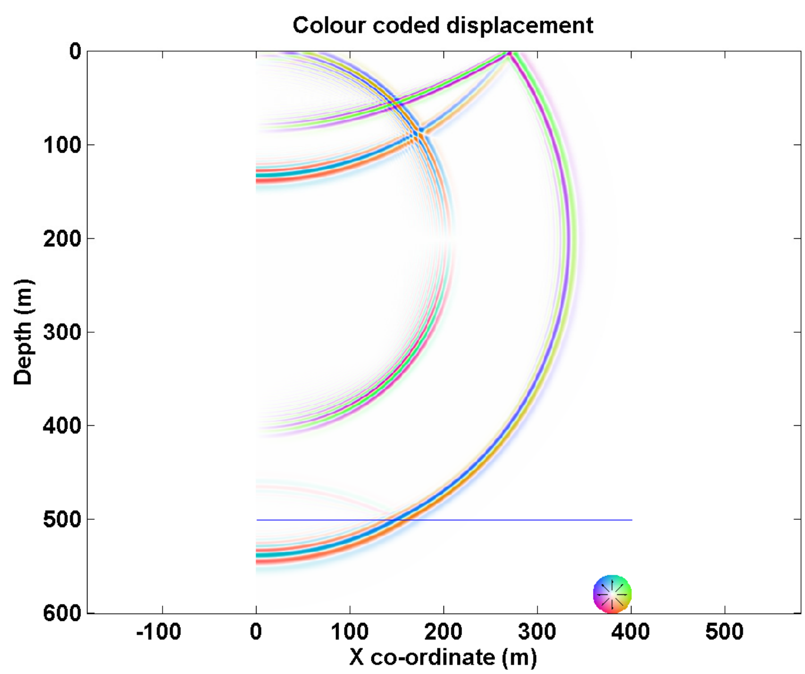

FIG. 1. Snapshot of uncorrected finite-difference wavefield propagation. Numerical dispersion may be seen as wave-fronts that are spread out and ringing.

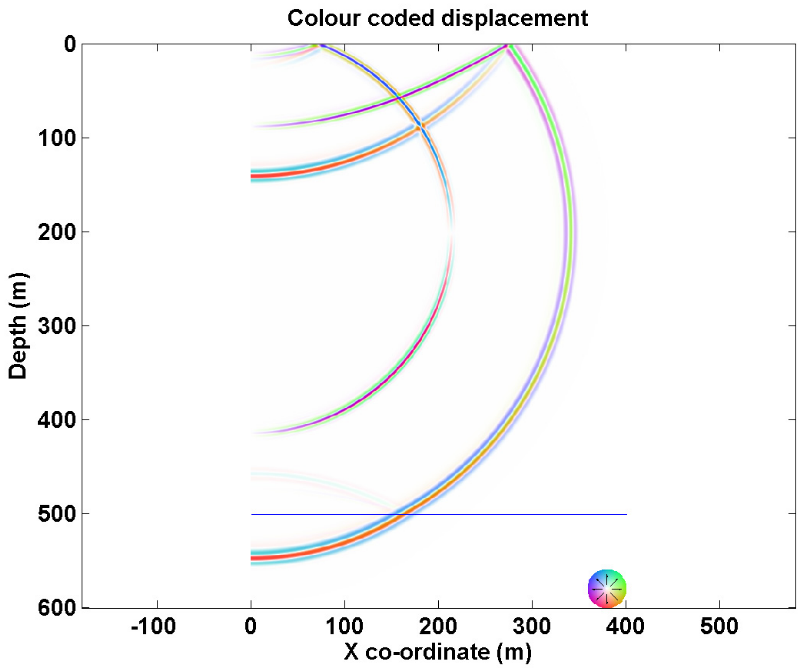

FIG. 2. Snapshot of corrected finite-difference wavefield propagation. The reduced dispersion of the wave-fronts shows them as having narrow width, and preservation of the initial zero phase character shows them as having a symmetric colour pattern.

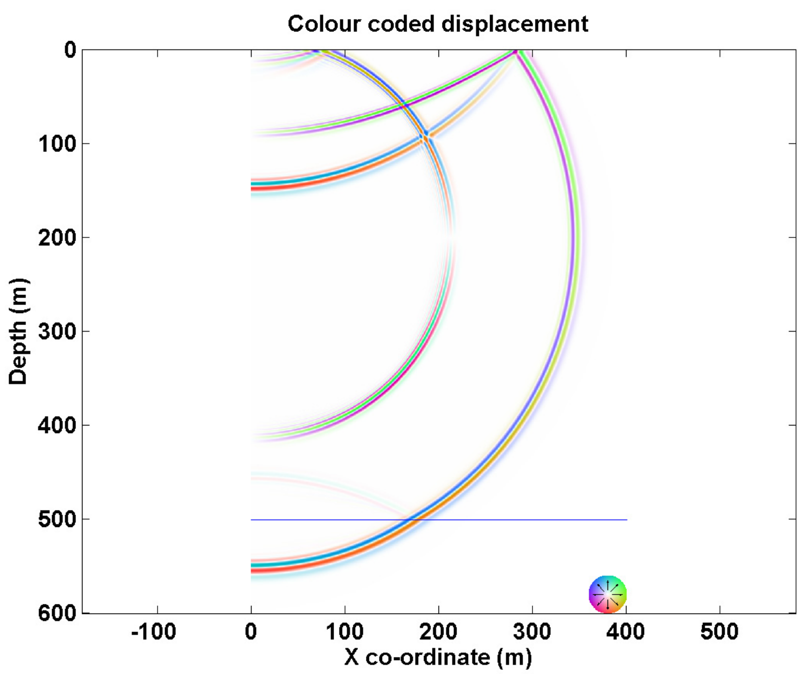

FIG. 3. Uncorrected finite-difference wavefield propagation with fine sampling. There is much less dispersion compared to Figure 1, but a little more than in Figure 2. The zero phase character is not well preserved.

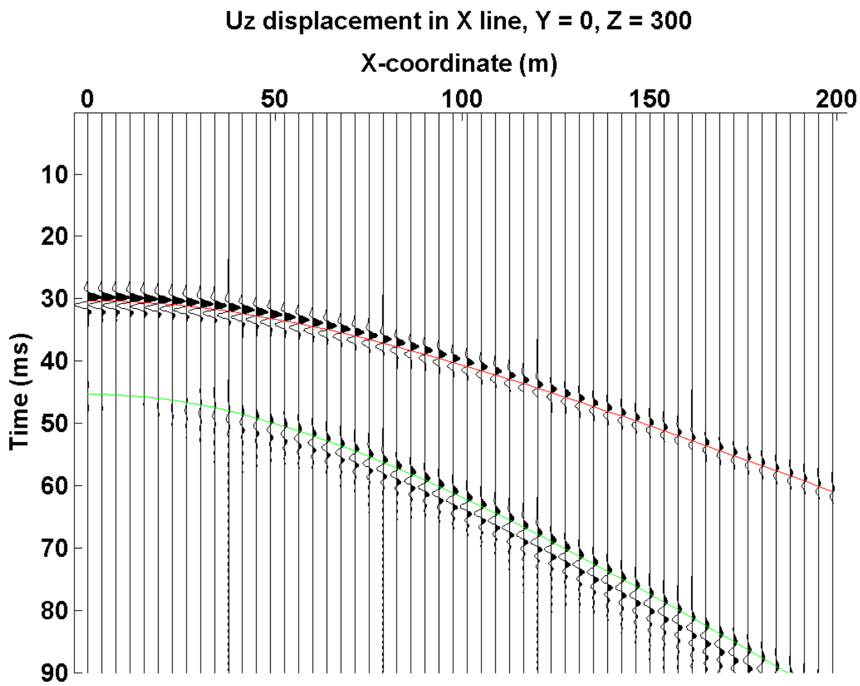

FIG. 4. Uncorrected finite-difference wavefield propagation presented as seismic traces. The pressure wave arrives earlier and has minimal dispersion. The shear wave arrives later, but has definite dispersion.

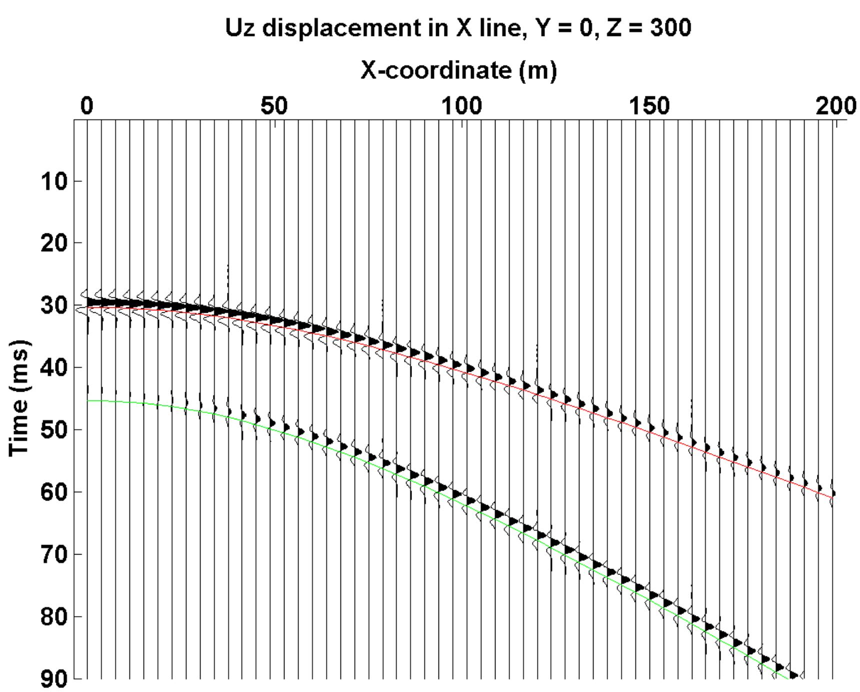

FIG. 5 Corrected finite-difference wavefield propagation using the exact velocities of the model. The wavelets are not dispersed and are almost exactly zero phase. Notice that the waves arrive earlier, as shown by comparison with the coloured moveout lines.

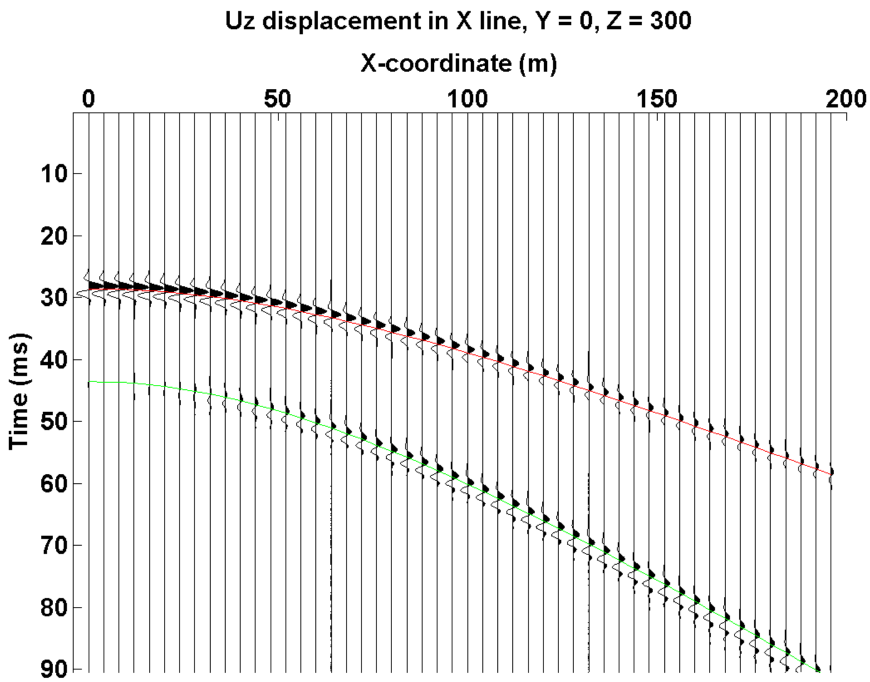

FIG. 6. Uncorrected finite-difference wavefield propagation with fine sampling. The wavelet dispersion is much less than in Figure 4, but is not reduced to the level seen in Figure 5.

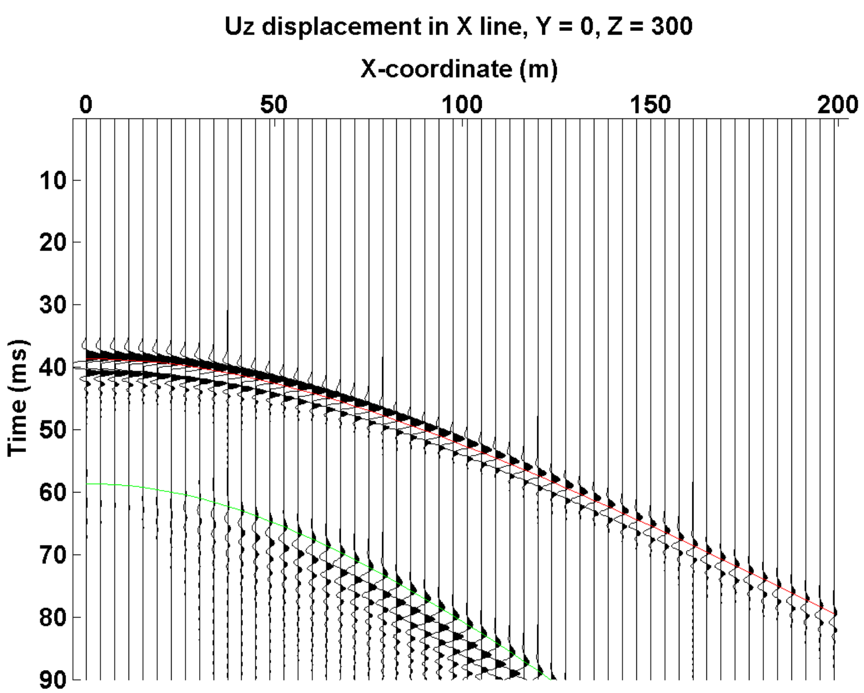

FIG. 7. Uncorrected finite-difference wavefield propagation in a 3000 m/sec medium. Dispersion is minimal on the pressure wave, but the shear wave has a very significant amount.

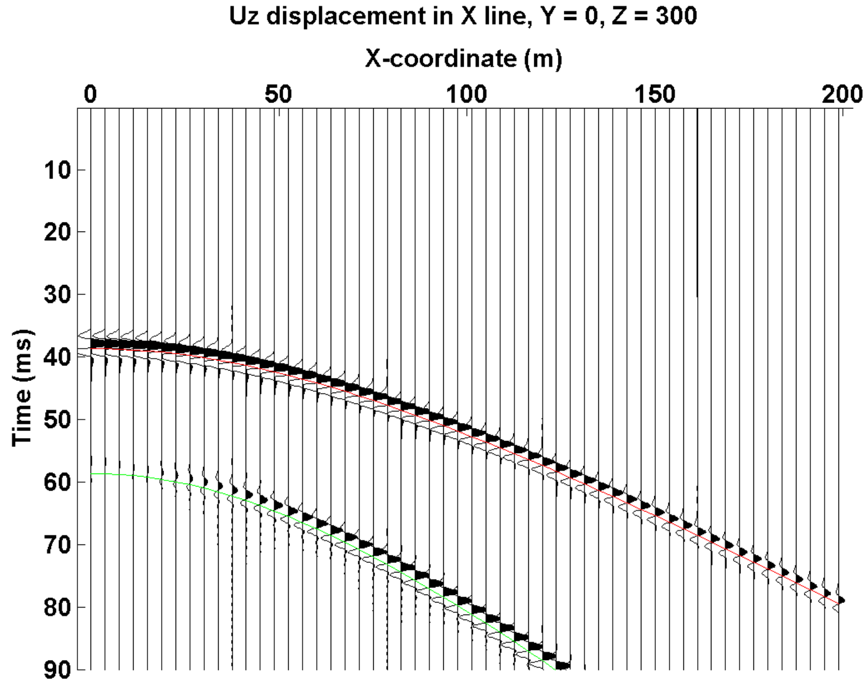

FIG. 8. Finite-difference wavefield propagation through a 3000 m/sec medium, but corrected as if it was a 4000 m/sec medium. The wavelets here have had most of the dispersion eliminated, but they do not have the clean zero-phase character of a very accurate correction, as in Figure 5.

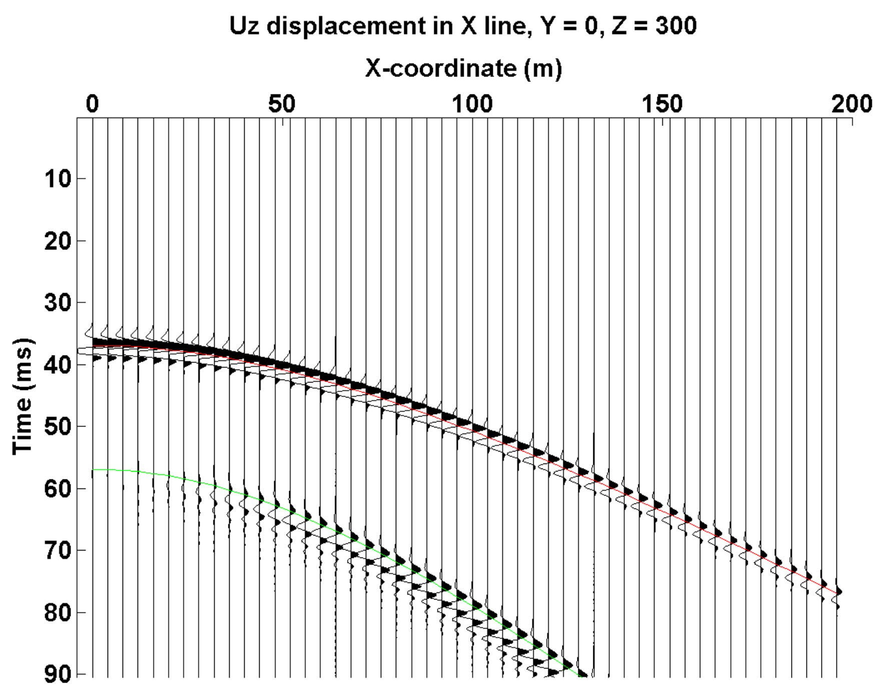

FIG. 9. Uncorrected finite-difference wavefield propagation in a 3000 m/sec medium, but with a fine sample rate The pressure wave is almost zero-phase, but the shear wave still has some dispersion.