Microseismic Event Models from Finite-differencing with Corrections

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Summary

Finite-difference elastic modeling is suggested as a means for extracting the maximum amount of information from microseismic events. In particular, the models should employ the staggered-grid configuration, which can be readily initiated with any form of energy source, and can use specifically designed corrections to control dispersion. These benefits are explained and illustrated.

Introduction

Unlike most exploration and production seismic interpretation done currently, microseismic interpretation utilizes shear wave events as much as pressure wave events. In this respect it has more in common with global scale seismology than oilfield seismic work. The global seismology interpreters have had huge success with an analytic forward model driven by a double-couple energy source (see Figure 1a). The double-couple has proved to be an accurate description of shearing energy sources within the earth (earthquakes), and the forward analytic model of these sources, described in Aki and Richards (1980), has been very useful for projecting the ground motions recorded at the surface. Earthquakes usually cause events which are quite distinct in time, and the important predictions of the model were the position dependent time lag between the pressure and shear arrivals, as well as the polarity and relative amplitude of these arrivals.

Exploration and production (e&p) seismic industry has used forward models for many years to ensure that their interpretations were realistic. The most important use of these models has been to represent the many overlapping and interfering surface arrivals that result from a single source event, in order to see if real or potential reservoirs affect these arrivals, and in what way. The nature of the source event for these models may be described as an explosion (Figure 1b), which has pressure wave energy radiating uniformly in all directions. Sometimes finite-difference models have been used, but simpler models were also effective.

The ideal forward model for microseismic events combines the features employed by the global seismologists and the exploration and producing interpreters. The most natural choice for this is the finite-difference method described in the following section.

The staggered-grid finite-difference model (sgfd)

The general disadvantage of finite-difference models is the relatively high cost of building them. The advantages of the staggered-grid finite-difference models are:

- As with the seismologist's models, the sgfd method propagates the original pressure and shear pulses through all the features of the model. It also shows how the model will convert energy between the pressure and shear forms, which are real physical processes that occur in the earth.
- As with the e&p models, the sgfd method may be used within detailed layered or structural models to show how reflections tend to interfere with each other.
- Sgfd models may be readily initiated with any form of energy source. In particular, the seismologist's double-couple source may be directly translated into a sgfd source (Figure 1a), and the results are a close match for the analytical solution. The same source in a non staggered-grid model may be quite difficult. Other forms of sources may also be realistic, as discussed in the author's paper (Manning, 2010). The particular source used for the examples here is shown in Figure 1c.
- The sgfd method may be corrected for numerical dispersion, as described in the following section.

Corrections for numerical dispersion

The staggered-grid form of finite-difference modelling (stfd) is much more amenable to dispersion corrections than the non-staggered form. The most well-known paper on this subject is by Levander(1985), where fourth order derivative approximations were used instead of second order. The author (Manning,2008).presented a correction technique derived by different methods, and also discussed the general advantages of the staggered-grid in his thesis

Examples

The first example of a sgfd uncorrected model is shown in Figure 2. It simulates a microseismic event of the form in Figure 1c which has propagated through a homogeneous earth with a pressure wave velocity of 4000 m/sec., and a shear wave velocity of 2000 m/sec. The event is recorded 200 metres away, over an almost continuous range of 250 metres above and below the event elevation. The sample rates were chosen to minimize the dispersion of the pressure wave event, but the shear event displays considerable dispersion because of the lower shear wave velocity.

The second example in Figure 3 shows a microseismic layout identical to that in the first example, except that corrections have been applied. The corrections were applied using the author's techniques, which are very effective because they need target only those terms of the wave equation which propagate shear waves.

The third example in Figure 4 shows the wavefronts which have propagated from a source at the left plot edge, and in the centre of the narrow low velocity zone across the centre of the plot. The background has P and S velocities of 4000 and 2500 m/sec., and the narrow zone has velocities of 3000 and 1875 m/sec. The variety of head waves from, and reverberations within the thin layer show how complex the wavefields can become. An accurate interpretation of the wavefield shown here would require more closely spaced geophones than are usually used.

Conclusions

Staggered-grid finite-difference models are optimum for microseismic interpretations.

Dispersion corrections are necessary to enhance shear events.

Longer and more closely spaced geophone strings would improve interpretation accuracy.

Acknowledgements

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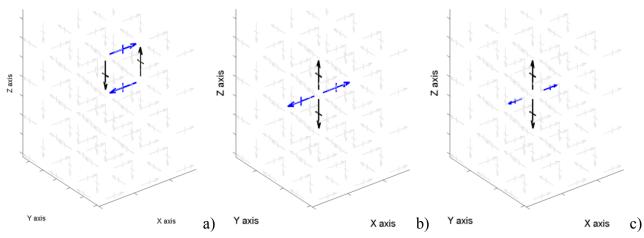
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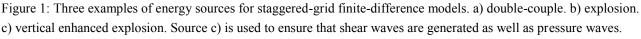
Levander, A. R., 1988, Fourth-order finite-difference P-SV seismograms: Geophysics, **53**, No. 11, 1425-1436.

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Manning, P. M., 2010, The volume couple as a source for microseismic events: Expanded abstract, GeoCanada2010, paper 816.

Figures

Figure 1: Three examples of energy sources for staggered-grid finite-difference models. a) double-couple. b) explosion. c) vertical enhanced explosion. Source c) is used to ensure that shear waves are generated as well as pressure waves.
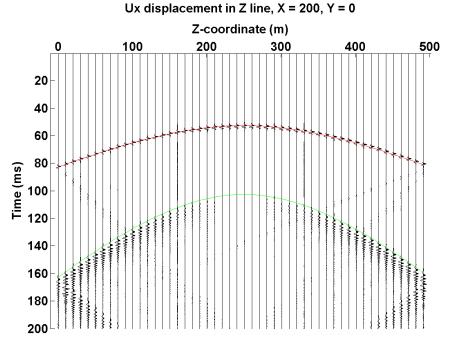

Figure 2: Model traces from a vertical enhanced explosion 200m. away. The pressure wave is good, but the shear wave has numerical dispersion.
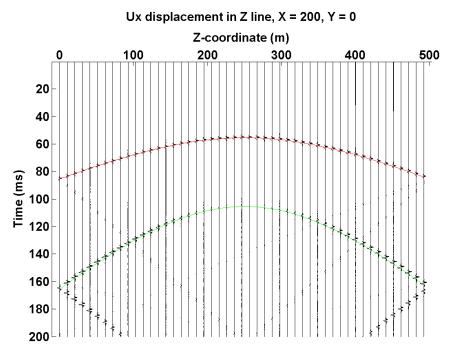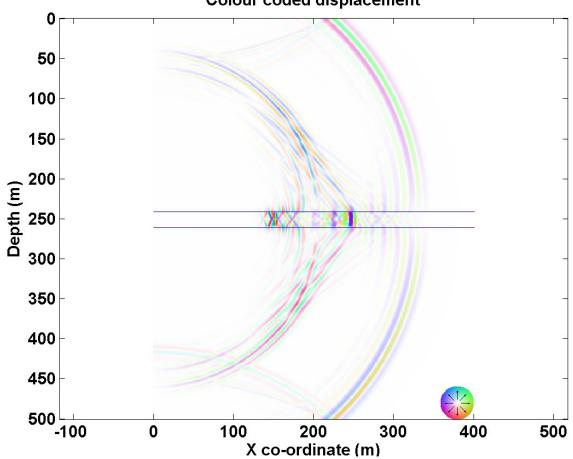
Figure 3: Traces from the same model used for Figure 2, but with dispersion corrections applied. Dispersion of the shear wave has been almost eliminated.

Figure 4: The wavefield model from a source at X = 0m., Z = 250m., within a low velocity thin bed. The complexity of this wavefield would be very difficult to interpret from the limited number of geophones usually deployed.