Elastic finite-difference modeling for testing acquisition and processing methods

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Summary

We have modified research-oriented 2D finite-difference code to allow convenient production of realistic model shot records on desktop computers. The modeled data are shot records acquired at the surface of simulated 2D geological models which contain two main components: a broad background layered cross-section, and a number of anomalous zones representing hydrocarbon targets or near-surface weathering pockets. The resulting shot records must be processed to suppress noise and to find surface consistent statics in order to enhance signal enough to image the subsurface structure. The models can be used to test the efficacy of PP and PS processing, and to investigate the effects of trace density, shot intervals, and missed shots on the accuracy and fidelity of migrated images of reservoir targets.

Introduction

The finite-difference (FD) modeling uses the staggered-grid technique developed most notably by Virieux(1986). Manning (2008) gave some further developments of finite-difference theory, and wrote research-styled MATLAB software implementing his ideas. We have adapted those programs for practical and general use. Among features introduced were: smooth interpolations of the geological interfaces, better plots of the input geology files for quality control, smoothing of the gridded data to improve stability, automatic cycling through a series of source points, output of the trace data directly to SEGY formatted files, as well as simplification of input files.

Input geology models

The first feature of the geology model is that it is represented with geometry and values of Vp, Vs, and density in a text file that is saved with a particular file name (with extension .geo). A unique base name for each model is used for both the input geology file and the output SEGY files. This ensures that the output traces can be tied later to the particular model conditions which produced them.

The second feature is that most of the geology is given in broad strokes (averaged). Layer cake geology is usually sufficient for this, but this ensures that wave-fronts (or raypaths) approach the critical areas at realistic angles. Most of the model shown in Figure 1 is parameterized in this way.

The third feature is that most anomalous zones are defined by 'boxes' (actually polygons) with properties that override the general background parameters. Examples of these boxes are shown in Figure 1: the weathering pockets just below the surface shown in dark blue, and the reservoir zone at a depth of 500 metres.

Modeling surface-wave noise caused by velocity/density anomalies

The example in Figures 1 and 2 is presented to show the effects of near-surface velocity and/or density anomalies on the overall appearance of seismograms acquired in land surveys. The dark-blue boxes at zero depth on Figure 1 represent low-velocity overburden lenses. The common-shot gather of

Figure 2 shows strong surface waves that are scattered by these lenses. The scattered surface waves produce complicated and overlapping noise cones which severely obscure reflections from deeper interfaces. Even more complex surface-wave patterns can be produced to test processing schemes used to attenuate the source-related noise prior to statics corrections and migration for imaging the deeper reflectors.
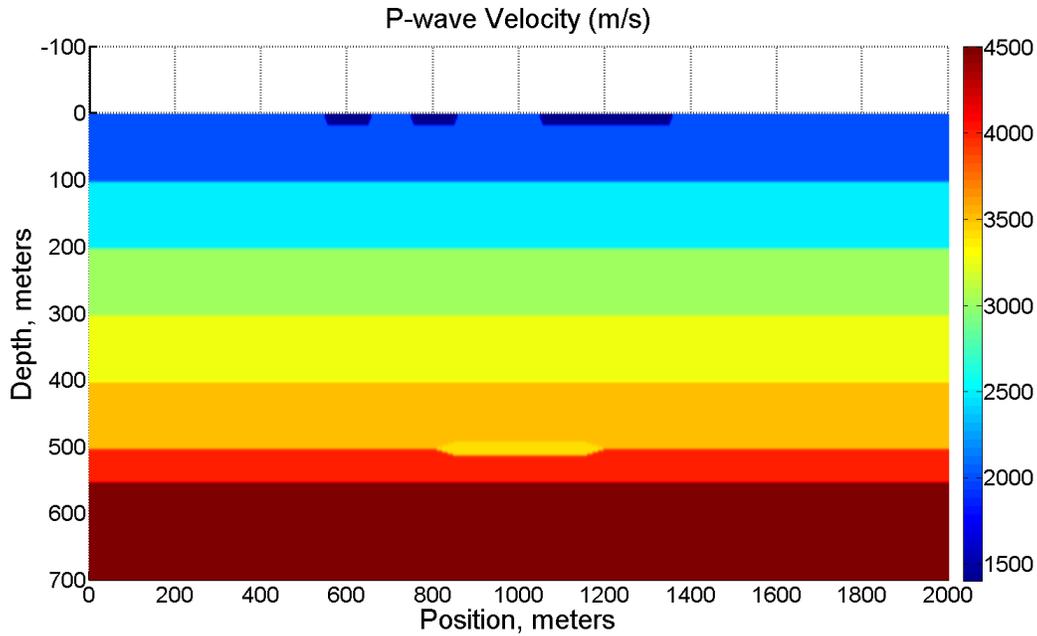

Figure 1: A geology model with three weathering pockets near the source point at 1000 m.
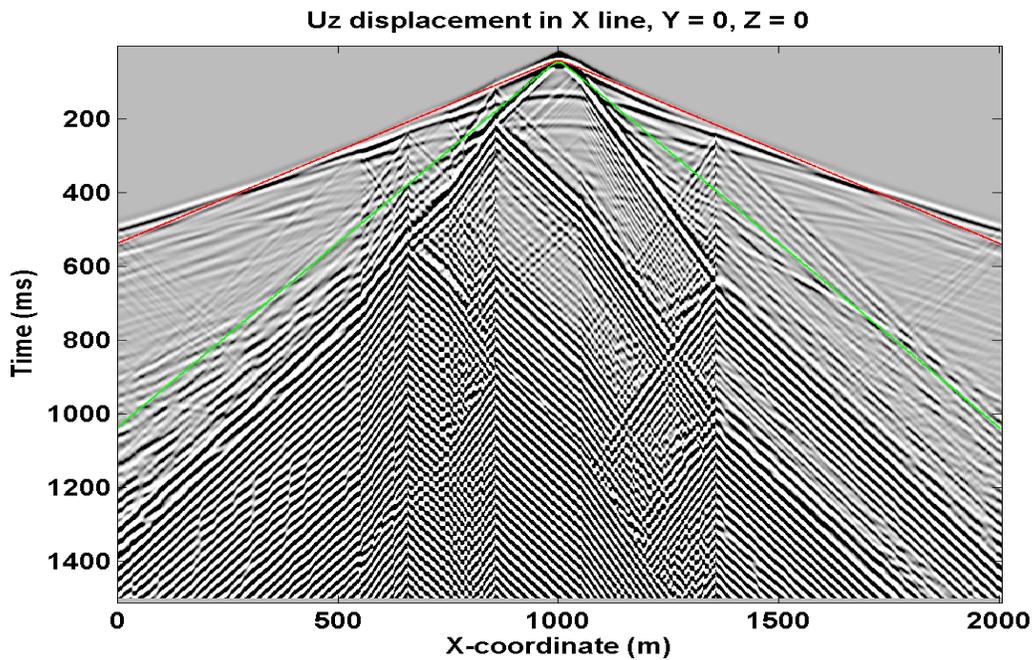

Figure 2: Common shot gather of traces from the model of Figure 4. The surface-wave noise cones originating from the velocity anomalies at the surface build up to high amplitudes.

The surface-wave noise modeled on Figure 2 is not entirely consistent with real data because it is in-line, whereas in real data, scattered noise can approach from any azimuth. However, the buildup of real surface waves from all directions is partially compensated for by the reduced drop-off of the waves in two dimensions, leaving a similar cone of noise near the source point.

A time lapse example

Figure 3 shows the geology models for a time lapse example (each multi-shot model of 100,000 traces takes about 15 hours on a desktop PC). The models include an overburden and a weathered layer with very low P and S velocities and varying thicknesses. The common source gathers of the vertical and radial seismograms displayed on Figures 4 and 5 are very complicated, and coherent reflections have been completely obscured by surface wave reverberations and scattering within the low-velocity overburden. Visually, the baseline data and the monitor data appear to be identical. However, the normalized plots of the differences between the monitor and baseline seismograms clearly show an anomaly caused by the altered properties of the target zone.
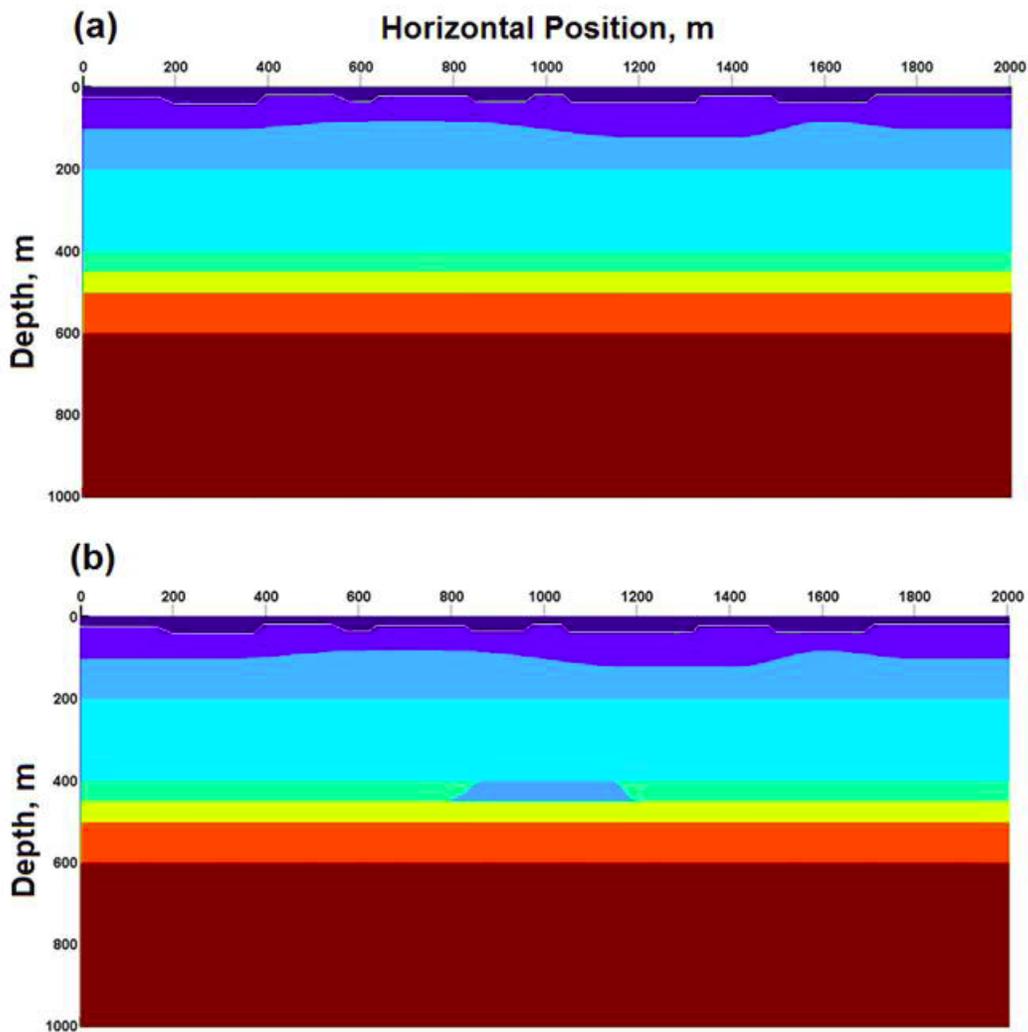

Figure 3: (a) geology model for a baseline survey; (b) geology model for a subsequent monitor survey. The properties of the target zone in the centre of the model has zero contrast with its host layer in the baseline survey; but has about a 10% decrease in velocities and 4% decrease in density in the monitor survey.
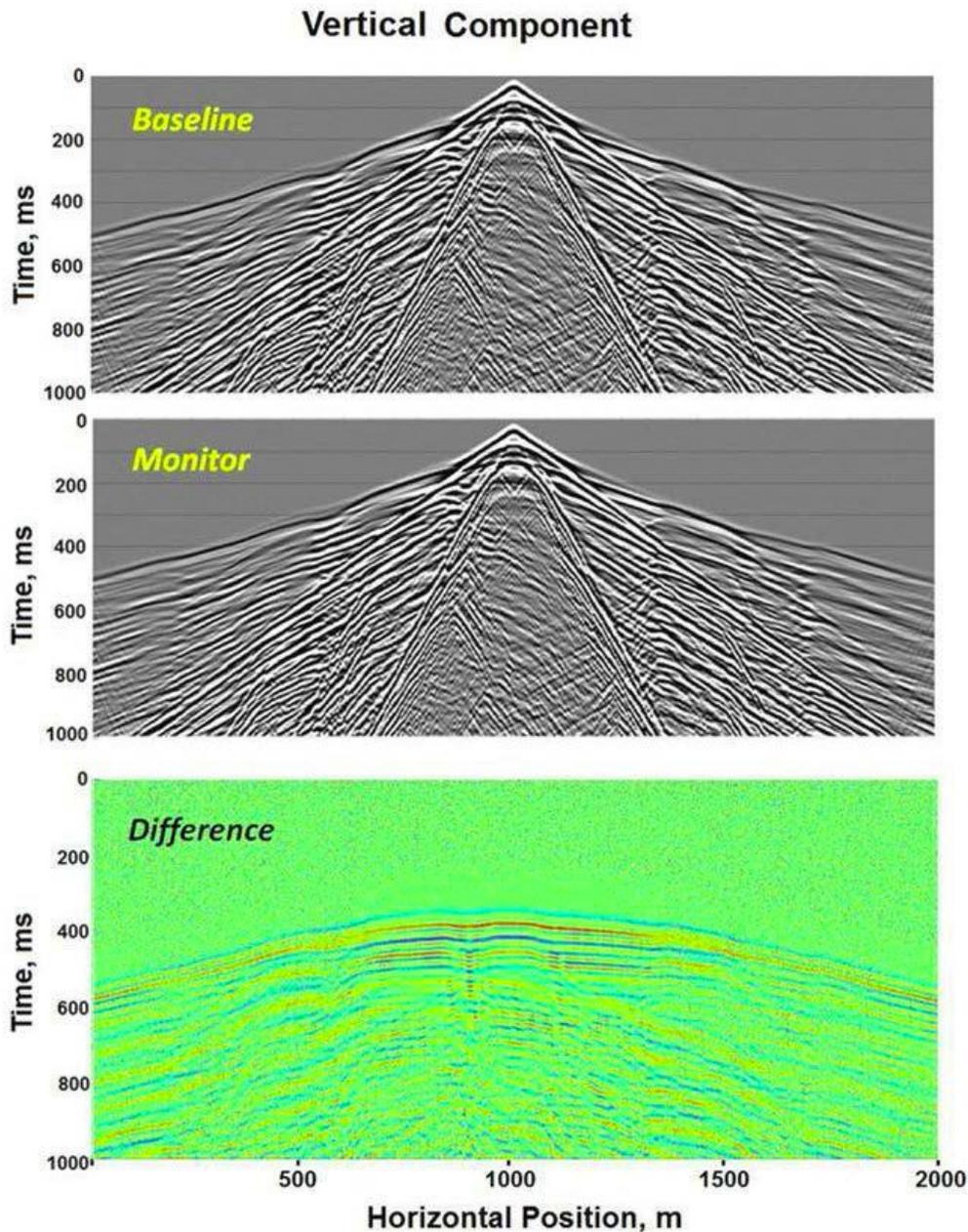
Vertical Component

Figure 4: The vertical component data for fixed source gathers over the models of Figure 3. The grid size is 0.20m, the time step is 0.25ms, and the number of time steps is 4000. Dominant frequency of source wavelet is 30Hz.

Discussion

Complete modeled datasets consist of multiple shot records acquired at evenly spaced points on the surface of a geology model. The source-related noise is usually different for each shot, and to remove it requires a flexible and adaptive scheme. The statics caused by the shallow anomalies and overburdens with varying thickness are surface consistent, a property made use of by the more sophisticated static analysis programs. Thus, many of the significant problems faced by seismic data processors can be simulated by the FD modeling. The effectiveness of particular processing flows can be judged on how well resulting migrated images represent the (known) subsurface geology. FD modeling can also be done as a pre-survey planning step, generating synthetic datasets that may be useful for validating proposed seismic acquisition strategies in a particular geological environment.
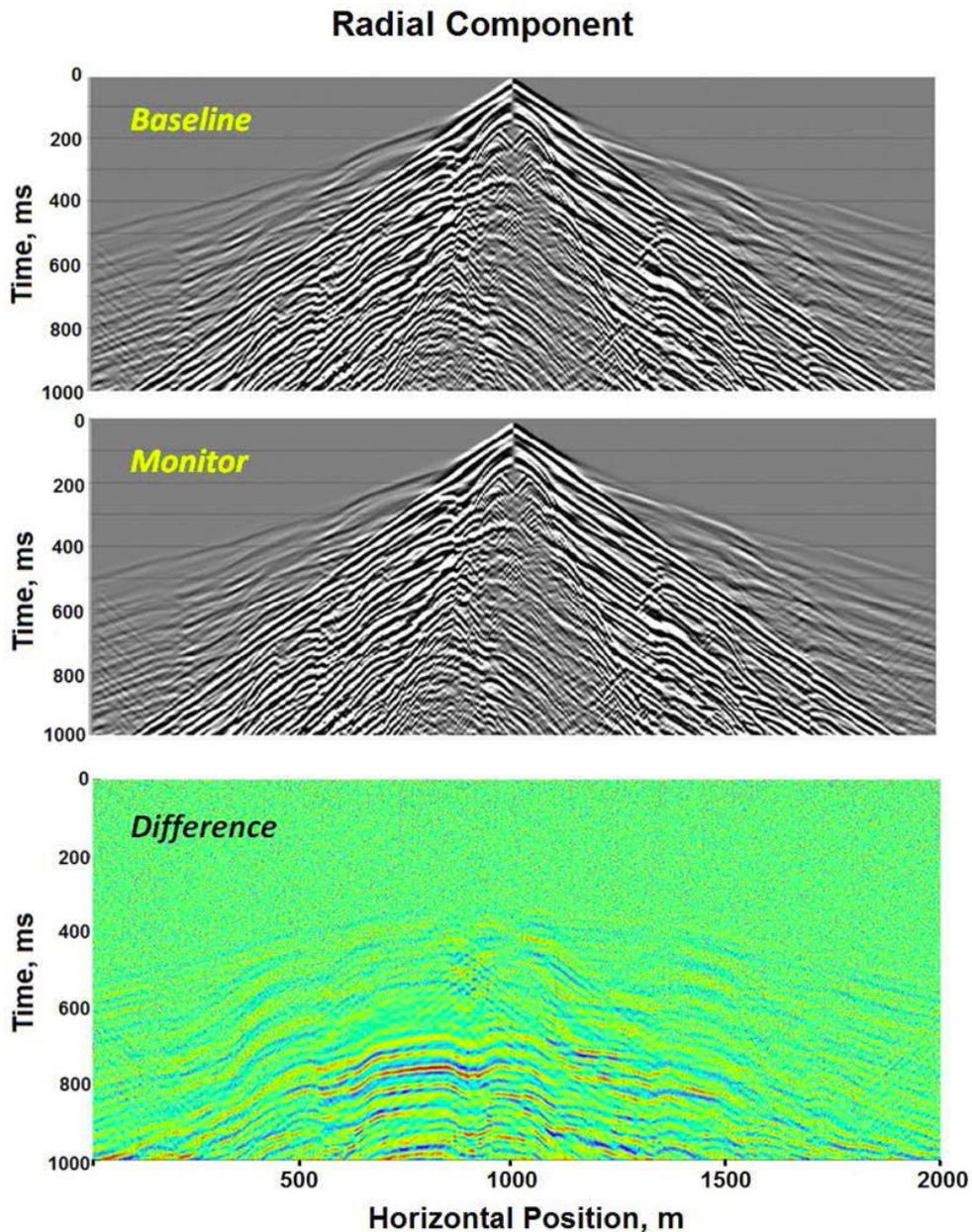
Radial Component

Figure 5: The radial component data for a fixed source gather over the models of Figure 3.

Conclusions

The modelling shown here will quantify acquisition and processing signal to noise limitations.

Acknowledgements

References

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.

Virieux, J., 1986, P-SV wave propagation in heterogeneous media: velocity-stress finite-difference method: Geophysics, **51**, 889-901.