Full Waveform Tomography with Consideration for Large Topography Variations

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Summary

For inverting land seismic data, it sometimes requires to handle large topography variations in the full waveform tomographic imaging. This may not be a trivial issue, since the forward modeling using a finite difference approach may produce inaccurate results if the topography variations are too large and the surface numerical conditions are no longer valid. To solve the problem, we design a variable grid mesh system for acoustic finite-difference modeling that addresses two concerns at the same time, that is, topography variations and finer grids required for lower velocity medium. The grid system remains constant laterally, but the grid size increases downward. In such a system, topography shall be sufficiently sampled with sophisticated boundary conditions, and the high velocity area in the deeper part is not oversampled, ensuring efficient computation. Along topography, we apply boundary conditions in multiple directions so that ensures wavefield continuity across lateral grids. In inversion, we convert the variable grids to a regular and uniform grid system so that sensitivities are uniformly weighted. We tested with foothill synthetic model for forward modeling and also for waveform inversion.

Introduction

For near-surface velocity structure imaging and also for subsurface velocity model building that includes surface topography, topographic variations must be considered in both forward finite-difference modeling and tomographic inversion. Once the near-surface area is included in the waveform tomography, it actually introduces issues not only just surface topography, but also fine gridding requirements for low velocity zone near the surface. According to the stability requirements in the finite-difference algorithm, grid mesh must be sufficient small to sample low velocity zone. Unlike in the subsurface, velocity in the near-surface area may vary from 350 m/s to 6500 m/s, with general situation that the velocity in the top area is low, and in the deep area is high .

If we apply an uniform grid to satisfy the grid requirement in the top area, then the computation with an uniform fine grid system is going to be very costly. The mesh system that we design in this study shall solve this problem along with topography consideration by using a variable grid system. This tomography approach is applicable for both near-surface imaging and also for subsurface imaging that includes the near-surface area.

Staggered Finite-Difference Modeling with Topography

How to accurately satisfy the traction-free boundary conditions on a general topographic surface is an important and difficult issue for finite difference seismic wave simulation. With staircase approximation to irregular surfaces, Ohminato & Chouet (1997) simulated 3D seismic wave propagation using the second-order accurate staggered finite difference scheme, which needs 25 grid points per wavelength due to the topography and the numerical dispersion error. Robertsson (1996) and Pitarka & Irikura (1996) implemented the staircase approximation of the irregular surface in the forth-order accurate staggered finite-difference scheme. The point per wavelength requirement is reduced to around 15. Zhang & Chen (2006) proposed a collocated-grid finite-difference that can use a curvilinear grid to avoid the artificial scatterings. But for very large topography variations, a separate grid generation software will be required to generate the curvilinear grid. In this paper, we propose two techniques to enhance the grid representation of the topography using nonuniform Cartesian grid, which could reduce the points per wavelength to the same level as the dispersion error requirement and meanwhile, the grid could be easily automatically generated for rough topography during tomography iterations.

For acoustic wave, the free surface boundary condition requires the pressure to be zero at the surface, which implies that the pressure is anti-symmetric and the velocity vector is symmetric with respect to the surface. In finite-difference method, these zero/symmetric/anti-symmetric conditions should be implemented along both x and z direction for rough topography.

In traditional treatments, the topography is discretized by the Cartesian grid (Figure 1a), which requires at least 15 points per wavelength to accurately simulate the topographic effect. To better sample the topography while using larger horizontal grid size, we use a nonuniform grid approach (Pitarka 1999) in which the vertical grid is smaller in the topographic region but larger at greater depth, and also the topography is represented by nearest either pressure location or vertical velocity location instead of only located to the pressure location (Figure 1b). We could observe that the topography is better represented by the nonuniform grid in Figure 1b. Since both velocity and stress could be symmetrically or anti-symmetrically imaged with respect to the free surface, we could also improve the grid representation by adopting diagonal imaging to reduce the staircase error.

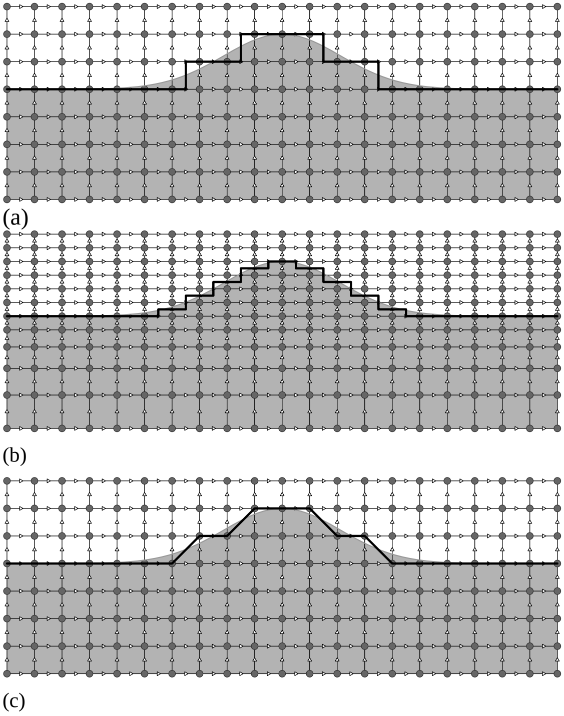

Figure 1: (a) Traditional Cartesian grid discretization of the topography. (b) Nonuniform grid discretization of the topography, the topography is located to nearest either pressure or vertical velocity to enhence the resolution. (c) Cartesian grid discretization of the topography but with diagonal stress/velocity imaging.

For acoustic wave modeling, the output field is usually the pressure component. Due to the zero-pressure condition at the free surface, the output amplitude is sensitive to the distance of the output location to the free surface. In our implementation, we correct this distance effect by dividing the amplitude by the distance. Numerical tests validate that this correction is important to fit the field data.

To validate the acoustic finite-difference modeling, we generate synthetic shot gather on the foothill model (Figure 2) using different free surface treatments. Figure 3a is the synthetic gather using the traditional Cartesian grid without the amplitude correction. The gather exhibits amplitude jumps along the surface due to the discretization of the topography and the location of the output. Figure 3b and 3c show the synthetic gather using the nonuniform grid and diagonal imaging techniques respectively. The amplitude is corrected by the distance to the free surface. We can see the improvement of Figure 3b and 3c over Figure 3a. In these numerical tests, the horizontal grid spacing is 30m, and the maximum frequency of the source time function is 18.75Hz, thus the points per wavelength is around 7.

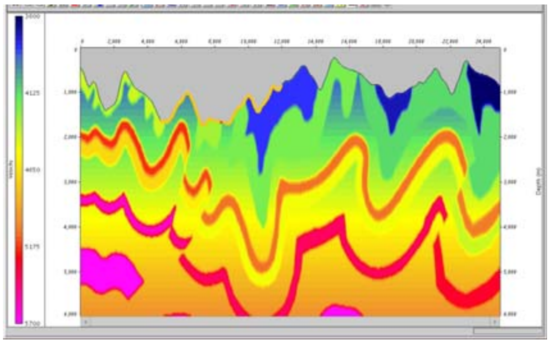

Figure 2: Topographic toothill model with the geometry of shot and receivers for the synthetics comparison.

Waveform Tomography Test on Foothill Model

We shall test the forward modeling and inversion using foothill velocity model, which includes significant topography variations and also velocity variations. This test includes 278 shots, and 480 channels per shot. We calculated true data using the new finite-difference method that we developed in this study.

The velocity model in Figure 4 shall be used as a starting model. The near-surface area is resolved from the first arrival traveltime tomography. And we added a smooth velocity field in the subsurface.

After 100 iterations by using the program with parallel computation implementation, it produces the following velocity image in Figure 5 with small RMS misfit in inversion.

Figure 6 and 7 shows the overlaid waveforms between synthetics (red) and input data (black) from the initial model and the final model.

Conclusions

We implement a waveform tomography approach with variable grid mesh system that can help address the issue of large topography variations and also the computation speed for a near-surface velocity model with large velocity range. Synthetics test with foothill model seems promising.

Acknowledgements

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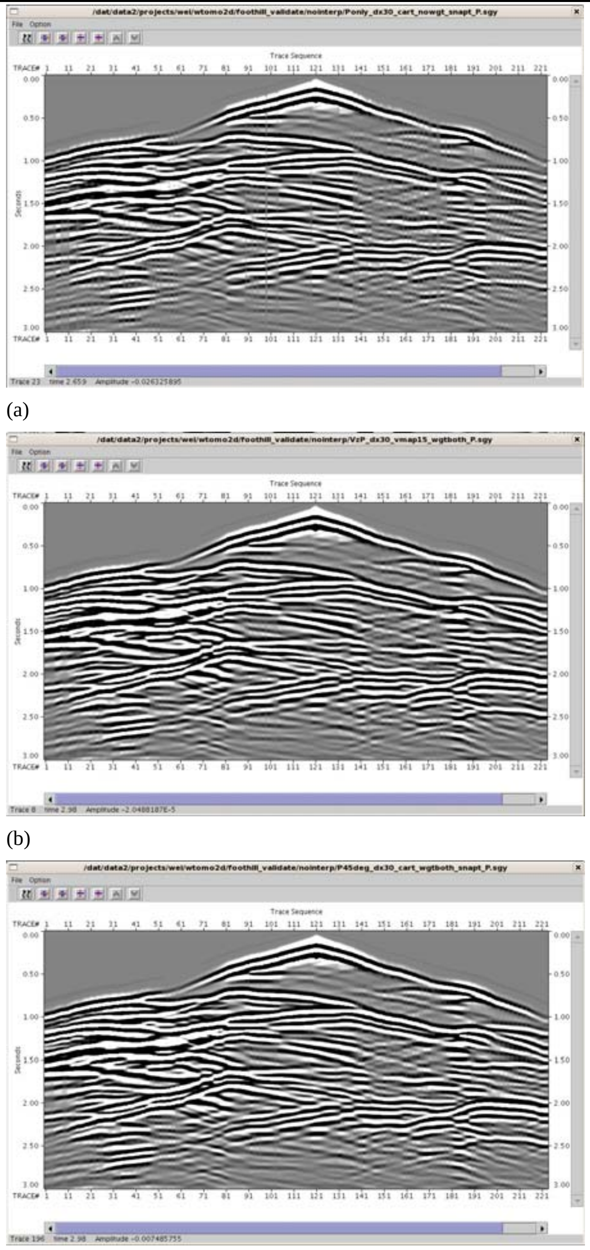

(a)

(b)

(c)

Figure 3: Synthetic shot gather using (a) Traditional Cartesian grid discretization without correction of pressure amplitude; (b) Nonuniform grid discretization with amplitude correction; (c) Cartesian grid discretization with diagonal imaging and amplitude correction.

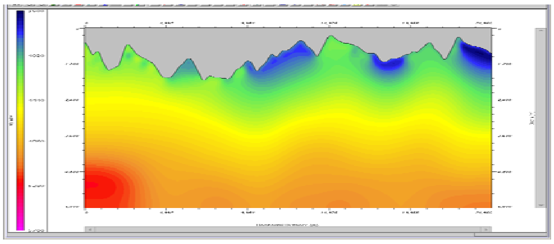

Figure 4: Initial velocity model

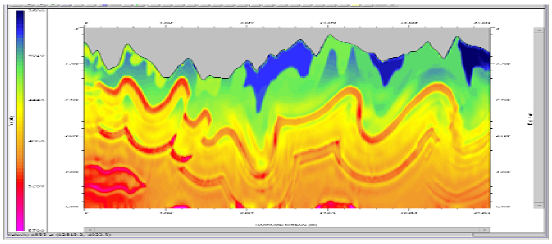

Figure 5: Waveform tomography result after 100 iterations

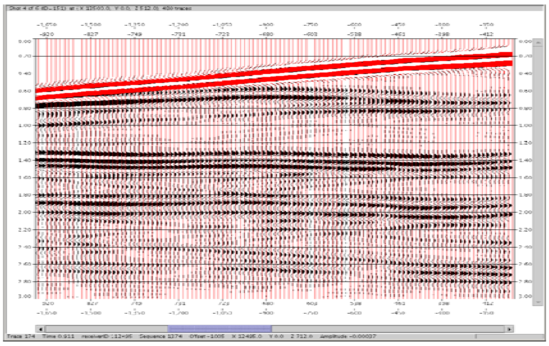

Figure 6: Synthetics using the initial model (red) and input data (black).

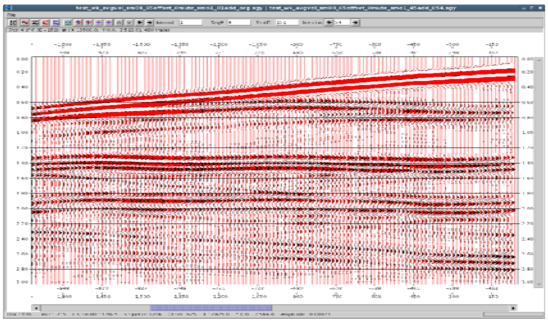

Figure 7: Synthetics using the final model (red) after 99 iterations and input data (black).

EDITED REFERENCES

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