1. Introduction

In this paper we apply Full Waveform Tomography (FWT) based on the Adjoint-Wavefield (AW) method to iteratively invert a 3-D geophysical velocity model for the South Island region, New Zealand (Eberhart-Phillips, 2010). The seismic wave fields were generated using numerical solution of the 3-D visco-elasticodynamic equations, and through the AW method, gradients of model parameters (compressional and shear wave velocity) were computed by implementing the cross-adjoint of forward and backward wavefields. The misfit is a frequency-dependent multi-taper travel-time difference using a period range 10 - 40 s. The main computational cost relates to the computation of the gradient of misfit function for each event (event kernel). We used L-BFGS/parabola fitting algorithms to obtain a model update. To verify the method’s performance, the synthetic seismograms were used to test the inversion algorithm.

2. Waveform segmentation using Pyflex and adjoint source construction/ misfit calculation using Pyadjoint

To set up the full waveform tomography problem, we solve the forward wave propagation problem using the Stress-Velocity formulation of 3D visco-elastic wave equations (Graeser, 1996) in the software em3dd. We then calculate the difference between the observed data recorded at seismic stations for different events and the simulated data from our forward simulation using an inverted source and a given velocity model. From the defined misfit function, we construct the Frechet derivatives based on seismic data inversion theory (Tarantola, 1984). We then consider the adjoint-wavefield method, which back-propagates the data to attract information of the medium structure. To construct the adjoint source for backward simulation, we implemented the multi-

3. Automated workflow and computational demand

Simulation domains of 352x352x160 km are derived from a detailed velocity model of a 3-D geophysical velocity model for the South Island region, New Zealand using 4km grid size (Figure 2a). The horizontal view of the initial VS profile at 4km depth includes 13 sources and 10 stations used for the first inversion stage (Figure 2b). For each simulation, the recorded time is 200s and step size is 1.06s. For each event, a forward and a backward (adjoint) simulations are performed to extract strain wavefields for kernel calculation. These strain wavefields store strain components for every single cell in the domain and for every 5 time steps. For total 13 events, the computation was divided to an automated parallel mode in Nerss’s supercomputer (Mau). In addition to the kernels calculation, the optimal step length calculation for model updating also uses multiple forward modeling and storage of gradients and models for at least 2 previous iterations to implement of L-BFGS method. One iteration of the inversion process approximately 200 core hours and occupies 4 terabyte nodes at a time.

4. Checkerboard test

To investigate the accuracy/ efficiency for the wave propagation solution and the inversion algorithm, a checkerboard test was implemented (Figure 3). The 3-D experimental set-up for the checkerboard test was shown in Figure 1b. We used a uniform grid of 10x10x1 events and 25 station; and the difference between the true and the initial models, is 10% (in log-scale). The source wavelet is the same with depth=8km, strike=54, dip=45, rake=90 and Mw=1.5. Data are filtered from 0.25-1.0Hz. After 10 iterations, the inverted model has been convergeing, showing a clear checkerboard model. Figure 3 shows the difference between the inverted and the initial VS (in log-scale) at 12km depth. The frequency-dependent phase differences between observed and synthetic data (misfit-reduce) decreases from 0.9% to 0.25 after 10 iterations and the number of windows picked increases along with the misfit reduction also presented in Figure 4c.

5. Broadband data inversion result

We used data from 13 Earthquake KFZ for true 100Hz and the synthetic data (red) generated from the initial model m00 according to the same event and station. Observed seismograms and synthetic seismograms were windowed by the Hanning window function. The variation of wave velocities (4 km) for each station was 1.2 km/s and the maxima window picked by PyFlex. Figure 5a shows the difference (at any depth) between the observed and estimated data (filtered through a bandwidth of 0.002-1.0 Hz) after 5 iterations (Figure 5). The good recovery of the checkerboard test using the presented FWT technique suggests the application for inversion of broadband data.

6. Future study

Since continuing inversion after iteration 10 using 13 events data does not improve the model significantly, we navigate the inversion further by adding more events (14 reference events). The further development of the method included the inverted model resolution area and increase the frequency content of the broadband data together with revising the centroid moment tensor solutions for the sources.