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Time-lapse FWI of VSP data using the FD-injection method

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Summary

FWI suffers from severe computation costs, it requires many times of forward modeling of the whole domain of the model. Time-lapse inversion may require at least twice the effort of FWI with parallel strategy (PRS). More advanced time-lapse strategies will further increase the computation burden. In addition, these time-lapse strategies will eventually introduce artifacts into the time-lapse result due to different convergence between baseline and monitor models. In the monitoring of CO2 injection and storage, VSP acquisition has been widely employed. In this work, we use the FD-injection method for time-lapse FWI of VSP data, which can provide better target-oriented inversion of velocity change with reduced computation cost..

Method

The FD-injection method (Robertsson and Chapman, 2000) has been proposed to calculate seismograms after model alternations in a local domain. Borisov et al. (2015) has proposed to use this method for target-oriented time-lapse full waveform inversion for seismic data with surface acquisition geometry. In Fig 1, on the left side is a baseline model, there's a wedge-shaped reservoir in it. On the right side is a monitor model, there's a velocity change in reservoir. In both subfigures, the red circles represent the sources, Si and Vi are the injection surface and subvolume, Ve is an FD submesh for the second simulation and Se acts like an absorbing boundary.

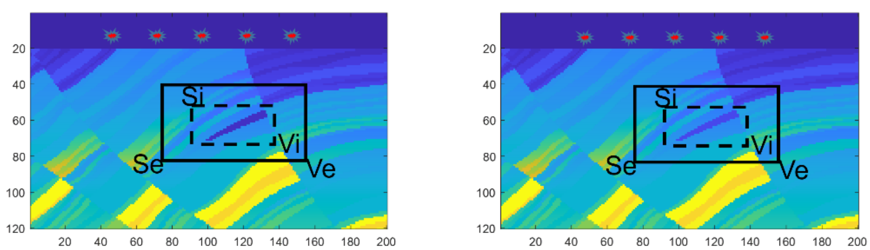

Figure 1. Baseline model (left) and monitor model (right).

The workflow is as follows. First, we pre-calculate the whole domain wavefield in the baseline model and store the wavefield along the injection surface Si as "effective sources" for the second modeling. If the model is not changed, the wavefield propagates in Vi will be perfectly reconstructed, and wavefield in Ve will be zero. When the model is changed, some energy inside Vi will leak out into the Ve domain, and this part of energy is the difference between the baseline and monitor model. In a VSP acquisition geometry, the receiver array is usually located close to the CO2 injection area, we can directly use the difference of acquired data in a time-lapse survey as the observed data to invert monitor model.

In a non-staggered acoustic case, the wave equation is expressed as

$$\frac{\partial^2 p}{\partial t^2} = \alpha^2 \nabla^2 p$$

In the simulation of baseline model, we store the pressure wavefield *p* whose FD stencils interact with the injection surface Si. While in the simulation of monitor model, first we update the wavefield in the Ve. Then we inject stored wavefield along Si as "effective sources" to correct wavefield. As last we repeat these two steps for the next time step. The correction step can be expressed as (van Manen et al., 2020).

$$p_{i,j}^{n+1} = 2p_{i,j}^{n} - p_{i,j}^{n-1} + \frac{\alpha^2 \Delta t^2}{(\Delta x)^2} \sum_{i'=-I}^{I} c_{i'} p_{i+i',j}^{n} + \frac{\alpha^2 \Delta t^2}{(\Delta y)^2} \sum_{j'=-J}^{J} c_{j'} p_{i,j+j'}^{n}$$

where *c* represent the coefficient in FD scheme.

Results and Conclusions

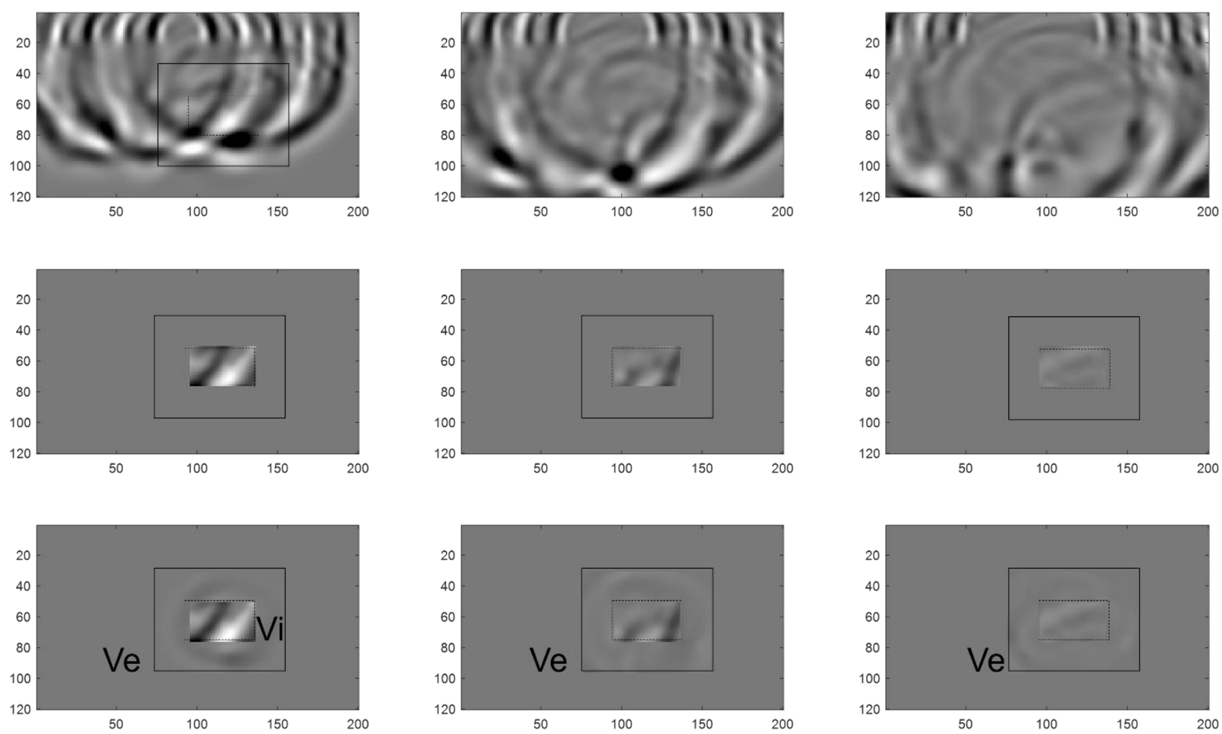

Figure 2. Snapshots of wavefield at 0.5 ms, 0.6 ms and 0.7 ms (from left to right column): pressure in baseline model by direct modelling (first row), reconstructed pressure in baseline model by FD-injection method (second row), reconstructed pressure in monitor model by FD-injection method (third row).

In this work, we use a part of modified Marmousi model with dimension 120 by 200. The grid size is 10 m. In the wedge-shaped area, there is a 150 m/s change in the monitor model. 5 sources are evenly deployed at the surface and 50 receivers are located vertically between the left boundary Vi and Ve. In Figure 2, we present the snapshots of wavefield at 0.5 ms, 0.6 ms and 0.7 ms. Using the FD-injection method, we reconstruct the wavefield in the target area in both baseline and monitor models. In the second row of Figure 2, we can see outside of Vi domain, the energy of pressure is zero, while in the third row, due to velocity change, there is energy leaks out, which represents the data difference of time-lapse survey.

Then we use the data difference as the observed data to invert monitor model. In Figure 3, we present the time-lapse result, which is obtained by subtracting baseline model from monitor model. From this result, we can see this method can well identify the velocity change area and recover the velocity change value.

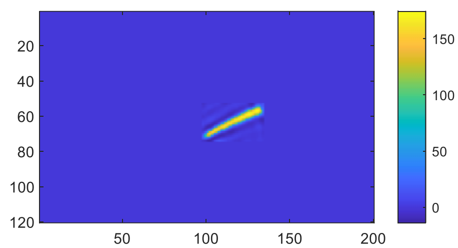

Figure 3. Time-lapse result.

Acknowledgements

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