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Migration Velocity Analysis with Maximum Stack Image Power

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SUMMARY

Waveform inversion can be implemented in either data domain or in image domain, which is usually called migration velocity analysis. As a data-domain approach, classic waveform inversion attempts to find a velocity model that minimizes the misfit between the real data and the simulated data. This kind of inversion has little success for the past decades. We believe that one of the reasons is the unknown wave equations, which is used to simulate the wavefields. Therefore, an effective waveform inversion should emphasize on the events' traveltime or phase information and downplay the role of amplitude information. Based on the criteria that images must be geometrically coherent after migration, we propose an image-domain approach. When the velocity is correct, the events at CIGs have maximum stack power for redundant shots. This approach uses RTM as the migration engine.

Our optimization problem is therefore correspondingly defined as a semblance-like objective function, which is constrained by RTM's forward and backward two-way scalar wave equations. The gradient of the objective function is derived by adjoint state technique.

Introduction

Waveform inversion can be implemented in either data domain, which compares the differences between the real data and the simulated data (Tarantola, 2005), or in image domain, which checks the coherency of the events in the CIGs (Common Image Gathers) (Chavent and Jacewitz, 1995). As a data-domain approach, classic waveform inversion has little success in the field data experiments. We think that one of the reasons is the unknown wave equations. It is very possible that waves propagate with different kinds of wave equations at different locations. Fortunately, although these wave equations generate different amplitudes, their eikonal equations are more or less the same. This suggests that traveltime is more reliable than amplitude. Therefore, an effective waveform inversion should emphasize on the events' traveltime or phase information and downplay the role of amplitude information. We propose an image-domain approach that is based on the criteria that seismic data must be geometrically coherent after prestack depth migration. When the velocity is correct, the events at CIGs should have maximum stack power for redundant shots. Here we choose RTM as the migration engine. Our optimization problem is therefore defined as an image-domain semblance-like objective function, which is constrained by RTM's forward and backward two-way scalar wave equations. The gradient of the objective function is derived by adjoint state technique.

Method

The objective function for stack power of the images is defined as

$$\max_{v} H(p,q,v) = \max_{v} \frac{1}{2}\langle R, R\rangle \tag{1}$$

where R is a stacked migration image:

$$R(p,q,v) = \sum_{n=1}^{N} R_n = \sum_{n=1}^{N} \langle p_n, q_n \rangle_t \tag{2}$$

The wavefields p_n satisfy the scalar wave equation

$$\ell(v)\, p_n = \left(\frac{1}{v^2}\frac{\partial^2}{\partial t^2} - \Delta \right) p_n = S(x,y,z,t) \tag{3}$$

where $S(x,y,z,t)$ is a source function. The wavefields q_n are the solutions of the adjoint equation (Tarantola, 2005)

$$\ell(v)^T q_n = \left(\frac{1}{v^2}\frac{\partial^2}{\partial t^2} - \Delta \right) q_n = D(x,y,z,t) \tag{4}$$

Here $D(x,y,z,t)$ is the observed data. Unlike equation (3), which is an initial-condition problem, equation (4) is a finial-condition problem. After application of Lagrange multiplier technique, besides the original equations (3) and (4), two extra adjoint equations are obtained:

$$\ell(v)\overline{p_n} = \left(\frac{1}{v^2}\frac{\partial^2}{\partial t^2} - \Delta \right)\overline{p_n} = -p_n \bullet R \tag{5}$$

$$\ell(v)^T \overline{q_n} = \left(\frac{1}{v^2}\frac{\partial^2}{\partial t^2} - \Delta \right)\overline{q_n} = -q_n \bullet R \tag{6}$$

Equations (3) and (5), (4) and (6) represent demigration processes, which build all the transmission waves and their reflected waves. Therefore, if p_n and q_n are transmission waves, $\overline{p}_n$ and $\overline{q}_n$ will be the reflected waves ignited by incident waves p_n and q_n, respectively.

And the gradient can be represented as:

$$\nabla_v H = \sum_n \left[\left\langle -\frac{1}{v^2}\frac{\partial^2 p_n}{\partial t^2}, \overline{q_n} \right\rangle_t + \left\langle -\frac{1}{v^2}\frac{\partial^2 \overline{p_n}}{\partial t^2}, q_n \right\rangle_t \right] \quad (7)$$

Example

We test our algorithm with a 3D two-layer model. One sphere anomaly is embedded in the top homogeneous medium. The velocity in the sphere anomaly is 10% decrease (1800m/s) from its background velocity (2000m/s). Figure 1a) is the RTM result with the true velocity model. Figure 1b) is the RTM result without the sphere anomaly. Figure 1d) is the velocity perturbation after five nonlinear iterations. It shows the inversion goes in the right direction.

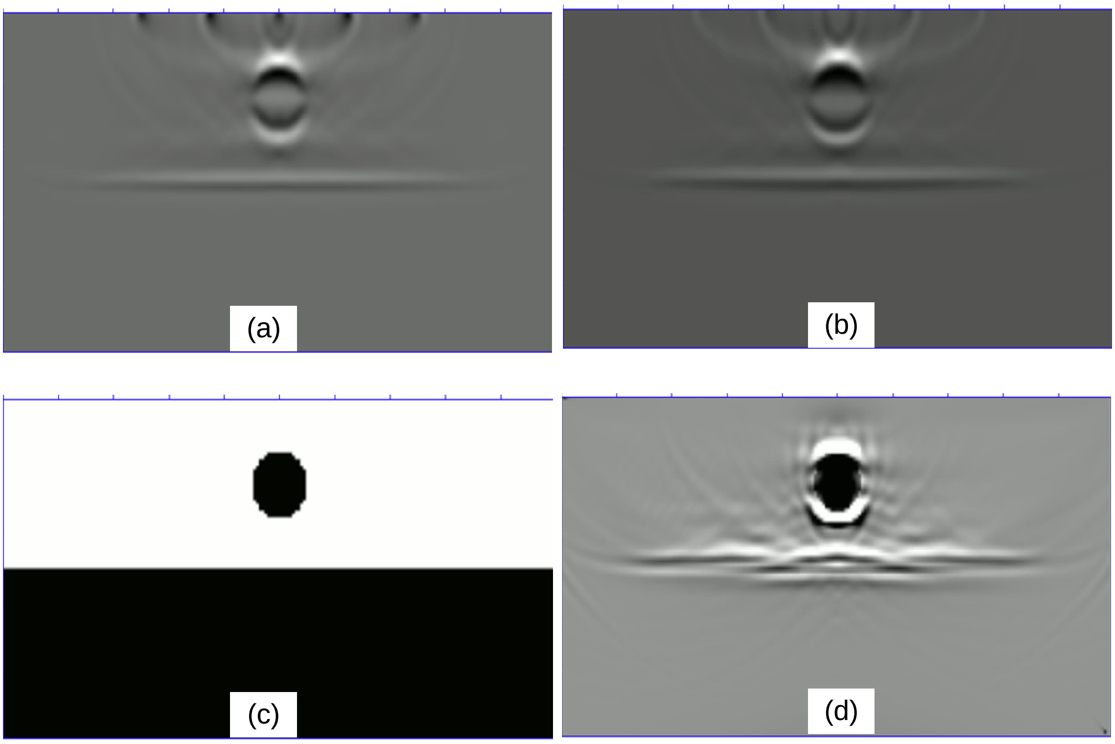

Figure 1: *(a) is the RTM result with the correct velocity (c). (b) is the RTM result with the background velocity. (c) is the true velocity. (d) is the final velocity perturbation.*

Conclusions

The objective function for classic waveform inversion will definitely hurt than help inversions. We propose an image-domain objective function that is relying on event coherency (traveltime). It works by maximizing the stack power in CIGs. Therefore it has the effect of emphasizing more on the reliable traveltime information and downplaying the role of unreliable amplitudes. Although it may converge slower than classic waveform inversion, it should be more adequate for field data experiments.

References

Chavent, G. and C.A., Jacewitz, 1995. Determination of background velocities by multiple migration fitting, Geophysics, 60(2): 476-490.

Tarantola, A., 2005. Inverse problem theory and methods for model parameter estimation, SIAM.