Model Preconditioning Based Global Optimization: Application to Prestack Migration Velocity Analysis

Somanath Misra*
University of Alberta, Edmonton, AB
smisra@phys.ualberta.ca

and

Mauricio Sacchi
University of Alberta, Edmonton, AB, Canada

Summary

Very Fast simulated Annealing with model preconditioning operators is used to optimize for the interval velocities. The cost function to be minimized is based on the assumption that depth migrated sections for the adjacent shot gathers show lateral consistency in waveforms. A harmonic cost function, also referred to as the migration misfit criterion (MMC) that estimates the lateral variability in the depth migrated sections of adjacent shot gathers is used for the optimization scheme. Global optimization scheme with model preconditioning operators that enforce smoothness in the lateral direction and edge preservation smoothness in the vertical direction is used. The use of model preconditioning operators has resulted in faster convergence and more importantly, has allowed the algorithm to operate on the entire model space providing better resolution in the estimation of velocities.

Introduction

Accurate depth images of prestack seismic data requires a good estimation of the macro or the background velocity. In the image domain, the prestack migration velocity analysis is done by two important techniques, (a) focussing analysis (Yilmaz and Chambers, 1984) and (b) residual wavefront curvature analysis (Al-Yahya, 1989). The later technique is also referred to as the migration moveout (MMO) analysis. Such techniques require velocity picking and depth corrections at each iterations of the optimization. Also it is observed that such techniques provide poor results in structurally complex geological areas (Jervis et al., 1993). In this paper, we present a scheme for migration velocity analysis based on the migration misfit criterion to obtain a higher resolution velocity structure. We use Very Fast Simulated Annealing (VFSA) with the model preconditioning operators to minimize the cost function (MMC). The main idea is that when the estimated velocity is accurate, the lateral variability of the depth migrated sections from the adjacent shot gathers is minimum (Jervis at al. 1996). We adopt the approach of optimizing with VFSA through the model preconditioning operators (Misra and Sacchi, 2007). We apply two model preconditioning operators, smoothing operator in the lateral direction and edge preserving operators in the vertical direction, during each VFSA iterations. The edge preserving operators are similar to the ones proposed by

AlBinHassan et al. (2006). We test the algorithm on a simple problem with 2 pairs of shot gathers. The results show that the algorithm can estimate the velocity within reasonable accuracy.

Method

Very Fast Simulated Annealing is a global optimization technique which allows a faster temperature schedule compared to the classical simulated annealing schemes. However, when the model dimension increases, the convergence rate of any global optimization schemes suffers drastically. In the migration velocity analysis, the dimension of the model space is often quite large. In order to avoid the slow rate of convergence due to the high model dimension, we propose to introduce the model preconditioning based global optimization (VFSA) to optimize over the entire velocity grid. We observe that the approach has resulted in estimating relatively well resolved velocity structure. The following cost function (Varela et al., 1998) was used for optimization in the model preconditioning global optimization scheme.

$$J = -\frac{1}{Ns}\sum_{i=1}^{Ns}\frac{2\left\langle d_{i,1}^{m}(x,z), d_{i,2}^{m}(x,z)\right\rangle}{\left\langle d_{i,1}^{m}(x,z), d_{i,1}^{m}(x,z)\right\rangle + \left\langle d_{i,2}^{m}(x,z), d_{i,2}^{m}(x,z)\right\rangle} \qquad (1)$$

Where Ns represents the number of shot pairs, $d_{i,1}^{m}$ and $d_{i,2}^{m}$ are the depth migrated sections for the shot 1 and shot 2 in the i^{th} shot pair.

Synthetic Data Examples

Data: The data consist of 4 shot gathers in pairs. The two pairs of shot gathers are 300 m apart and the shot gathers within each pair are 100 m apart. The data are generated by using the second order acoustic finite-difference modeling scheme. Automatic gain control is applied to the data. External mute is applied to remove the direct arrivals. Also, the data generated from the finite-difference algorithm are filtered with a pass-band of 1 Hz to 40 Hz. A total of 101 receiver locations are used in each shot gather. The receiver locations are 20 m apart. The offset range is 100m to 2000 m. The four shot gathers are shown in Figure 1.

Model: The model space consists of velocity values at the grid points that are 10 m apart in both horizontal and vertical directions. The grid size is 301 by 301 which covers a length of 3000 m in the horizntal direction and a depth of 3000 m. The model search space is bounded within an upper and lower bound of ± 750 m/sec with respect to the true velocity values at the grid locations. The velocity model shows lateral velocity gradient.

Figure 2 (a) shows the true velocity model. Figure 2 (b) shows the initial guess model. The initial guess model is chosen randomly within the upper and lower bounds as mentioned before. Figure 2 (c) shows the estimated velocity model. A total of 400 VFSA iterations were performed to obtain the estimated velocity model. Since, the cost function is evaluated two times at a particular temperature, a total of 800 forward model evaluations are performed to obtain the estimated velocity model. It is observed that the model preconditioning based VFSA scheme estimates the velocity model within a reasonable accuracy. Figure 3 shows the depth migrated sections for the four pairs of shot gathers. The left panel shows the depth migrated section obtained by using the true velocity. The middle panel shows the depth migrated section obtianed by using the initial guess velocity model. It is noticed that the initial guess velocity model is not close to the true velocity model in terms of the measure of the migration misfit. The right panel shows the depth migrated section obtained from the estimated velocity model. The figure shows that the reflectors are correctly positioned in depth when the shot gathers are depth migrated with the estimated velocity. Figure 4 shows the cost function evaluated at each VFSA iteration. The '*' indicates the desired value of the cost function obtained by evaluating the cost function using the true velocity model.

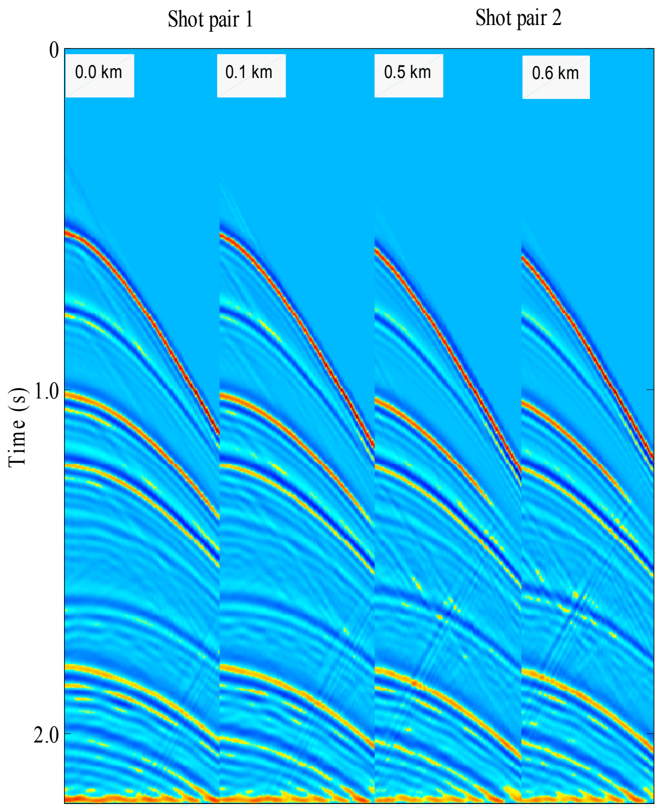

Figure 1: The four shot gathers (2 pairs). The shot locations are mentioned in the box.

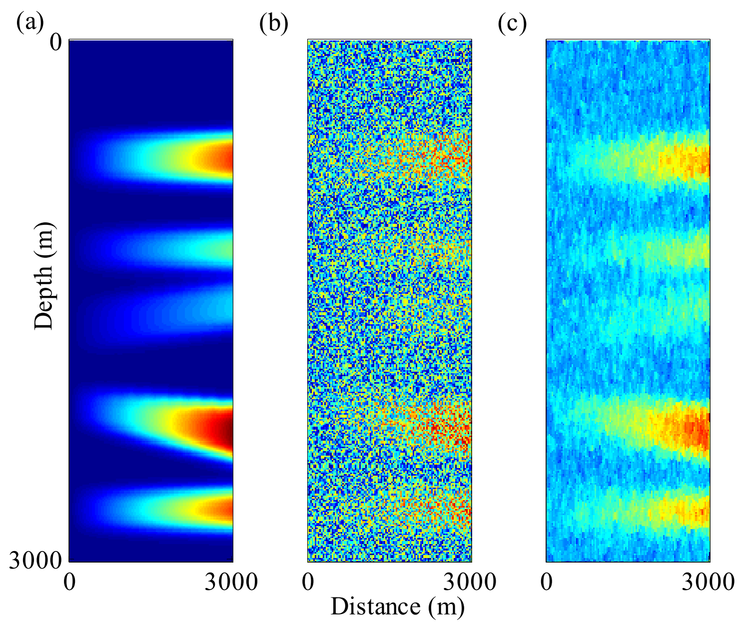

Figure 2: (a) True velocity model (b) Initial guess velocity model (c) Estimated velocity model.

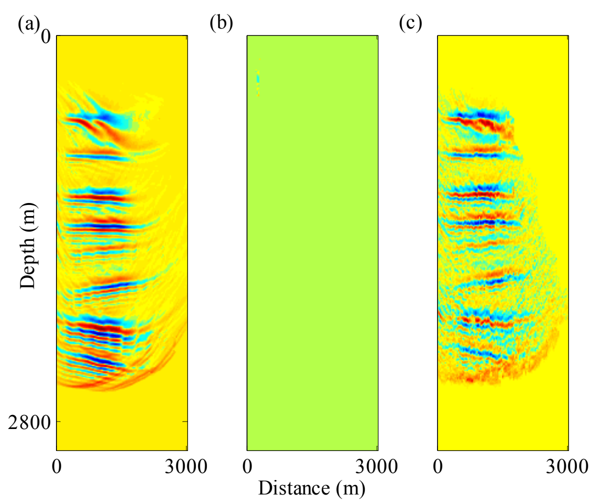

Figure 3: (a) True velocity migration (b) Initial guess velocity migration (c) Estimated velocity migration.

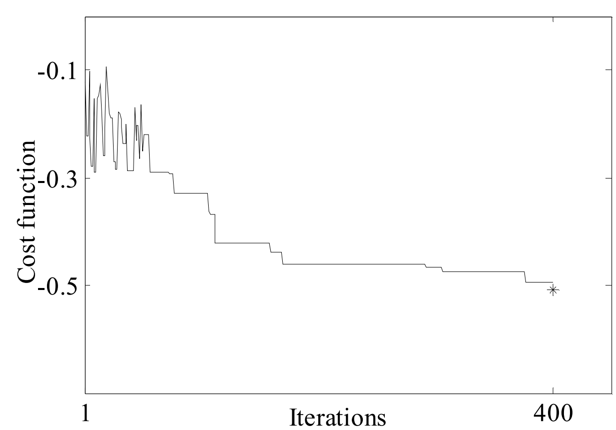

Figure 4: Lowering of the cost function evaluated at each iteration. The * indicates the desired cost function value obtained by the true velocity migration.

Conclusions

We propose a method to estimate prestack migration velocity with model perconditioning based very fast simulated annealing scheme. The proposed algorithm optimizes for the velocity values at the entire grid locations. Two model preconditioning operators (lateral smoothing operator and vertical edge preserving smoothing operator) are used to precondition the model space for a favorable solution consistent with the *a priori* information. We tested the algorithm on 2 pairs of shot gathers and observe that the algorithm estimates the migration velocity within a reasonable accuracy.

References

AlBinHassan, N.M., Y. Luo, and M.N. Al-Faraj, 2006, 3D edge-preserving smoothing and applications, Geophysics, 71, P5-P11.

Al-Yahya, K., 1989, Velocity analysis by iterative profile migration, Geophysics, 54, 718-729.

Jervis, M., Stoffa, P.L., and Sen, M.K., 1993, 2-D migration velocity estimation using a genetic algorithm, Geophys. Res. Letters., 20, 1495-1498.

Jervis, M., Sen, M. K., and Stoffa, P.L., 1996, Prestack migration velocity estimation using nonlinear methods, Geophysics, 60, 138-150.

Misra, S. and Sacchi, M.D., 2007, Non-linear one dimensionalprestack seismic inversion with edge-preserving-smoothing filter, 69th EAGE conference and exhibition, London, UK.

Varela, L., Stoffa, P.L., and Sen, M.K., 1998, Background velocity estimation using non-linear optimization for reflection tomography and migration misfit, Geophysical Prospecting, 1998, 46, 51-78.

Yilmaz, O., and Chambers, R., 1984, Migration velocity analysis by wavefield extrapolation, Geophysics, 49, 1664-1674.