Least-squares wave-equation migration of land data - synthetic results

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Summary

While least-squares Kirchhoff prestack time migration has provided excellent results in land data imaging of moderate structures, it can be limited in while handling complicated structures where multi-pathing may be important. In this study, we evaluate a least-squares PSPI (phase shift plus interpolation) depth migration for land data imaging. To accelerate convergence, we compute an approximate Hessian matrix to compensate for differences in subsurface illumination. Preliminary results on synthetic data illustrate several benefits of least-squares PSPI depth migration, including improving migration resolution and the reduction of migration artifacts. To reduce computation cost, we will focus on plane-wave least-squares PSPI depth migration in 2017.

Theory

In our research, PSPI one-way extrapolation operator is used for migration and demigration. Reference velocities at each depth level are chosen according to the complexity and lateral velocity variations of subsurface structures. To accelerate convergence of least-squares migration, approximate Hessian is calculated. In linear inversion, the Hessian matrix $\mathbf{H}$ can be expressed as

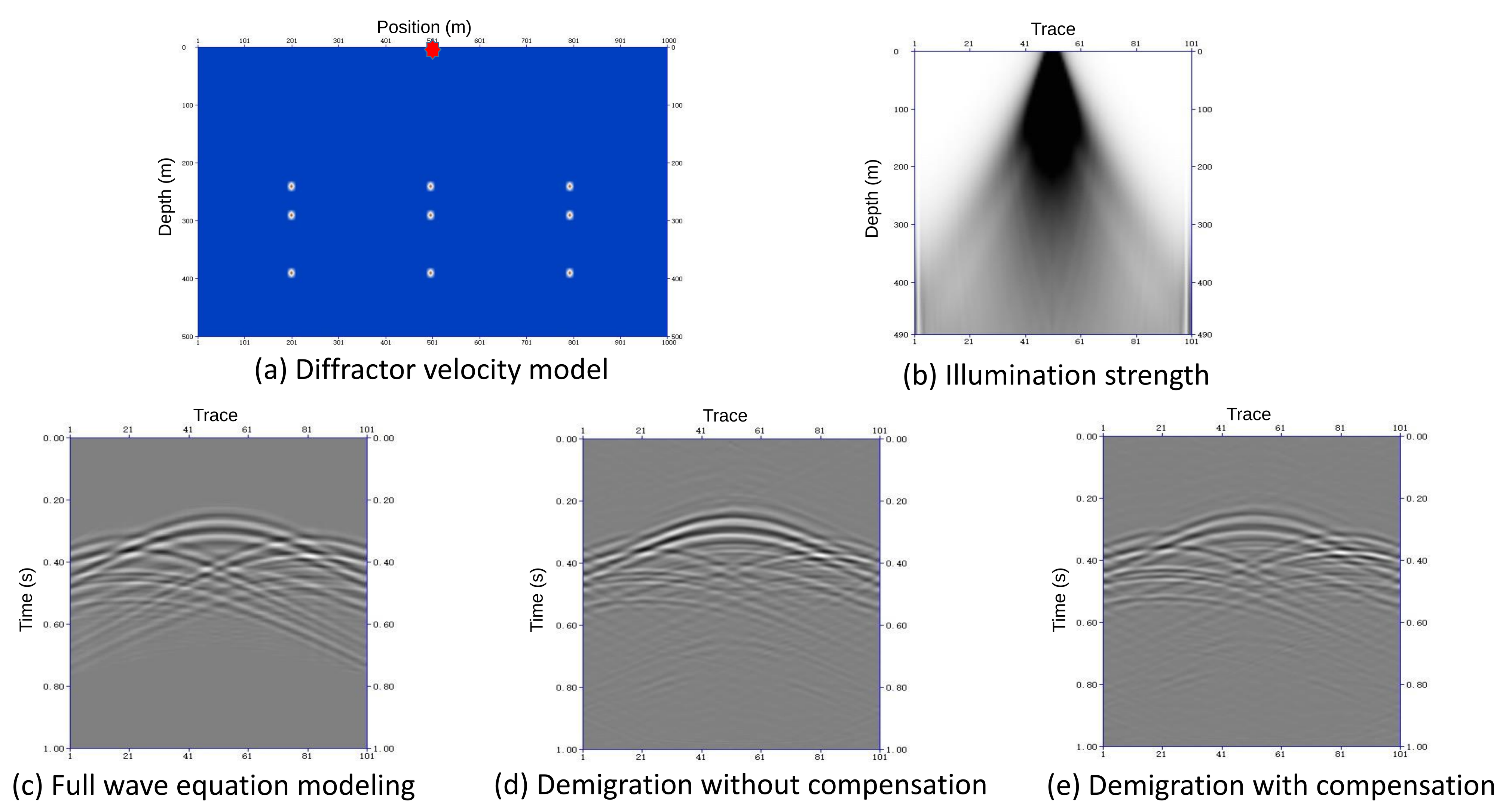
$$\mathbf{H}(\mathbf{x}_1,\mathbf{x}_2)=\mathbf{L}^{\mathrm{T}}\mathbf{L}=\mathrm{Re}\left\{\sum_{\omega}\omega^4\sum_{x_s}|f_s(\omega)|^2\mathbf{G}(\mathbf{x}_s,\mathbf{x}_1,\omega)\overline{\mathbf{G}}(\mathbf{x}_s,\mathbf{x}_2,\omega)\sum_{x_r}\mathbf{G}(\mathbf{x}_1,\mathbf{x}_r,\omega)\overline{\mathbf{G}}(\mathbf{x}_2,\mathbf{x}_r,\omega)\right\}$$

where $\mathbf{L}^{\mathrm{T}}$denotes the migration and $\mathbf{L}$ the demigration operators, ω the frequency and $f_s(\omega)$ the source waveform. $\mathbf{G}$ and $\overline{\mathbf{G}}$ represent the Green's function and its complex conjugate.

There are several different methods to approximate the Hessian matrix, the simplest of which is to approximate it by its diagonal, considered to be the illumination strength

$$\mathbf{H}(\mathbf{x})=\mathrm{Re}\left\{\sum_{\omega}\omega^4\sum_{x_s}|f_s(\omega)|^2|\mathbf{G}(\mathbf{x}_s,\mathbf{x},\omega)|^2\sum_{x_r}|\mathbf{G}(\mathbf{x},\mathbf{x}_r,\omega)|^2\right\}+\delta$$

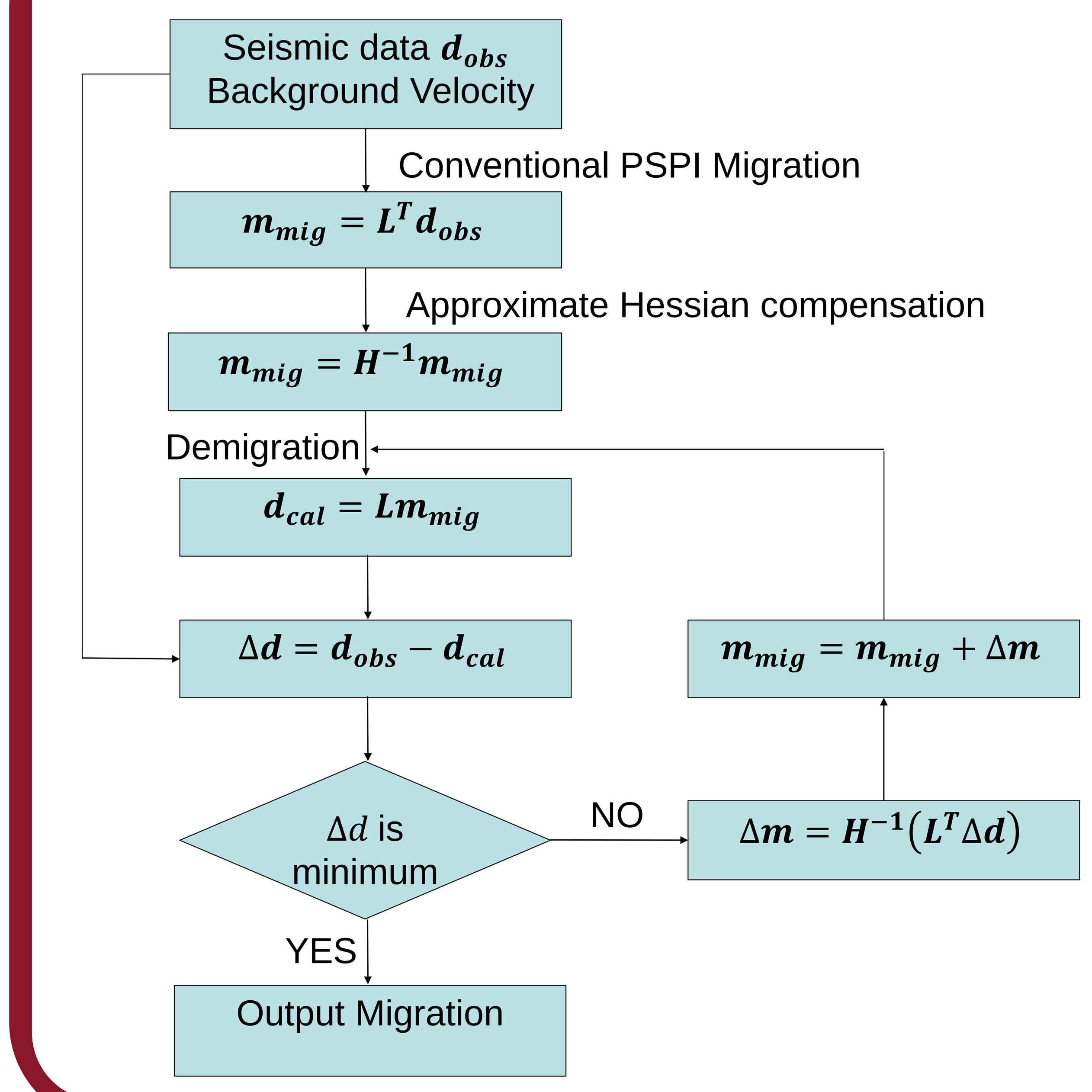
where δ is a damping factor to avoid dividing by zero. $\mathbf{H}$ (Figure 1) represents the illumination of the subsurface. The demigrated shot gather of a diffractor model with illumination compensation is much closer to the full wave equation modeling shot, compared with the one without illumination compensation.



(a) Diffractor velocity model
(b) Illumination strength
(c) Full wave equation modeling
(d) Demigration without compensation
(e) Demigration with compensation

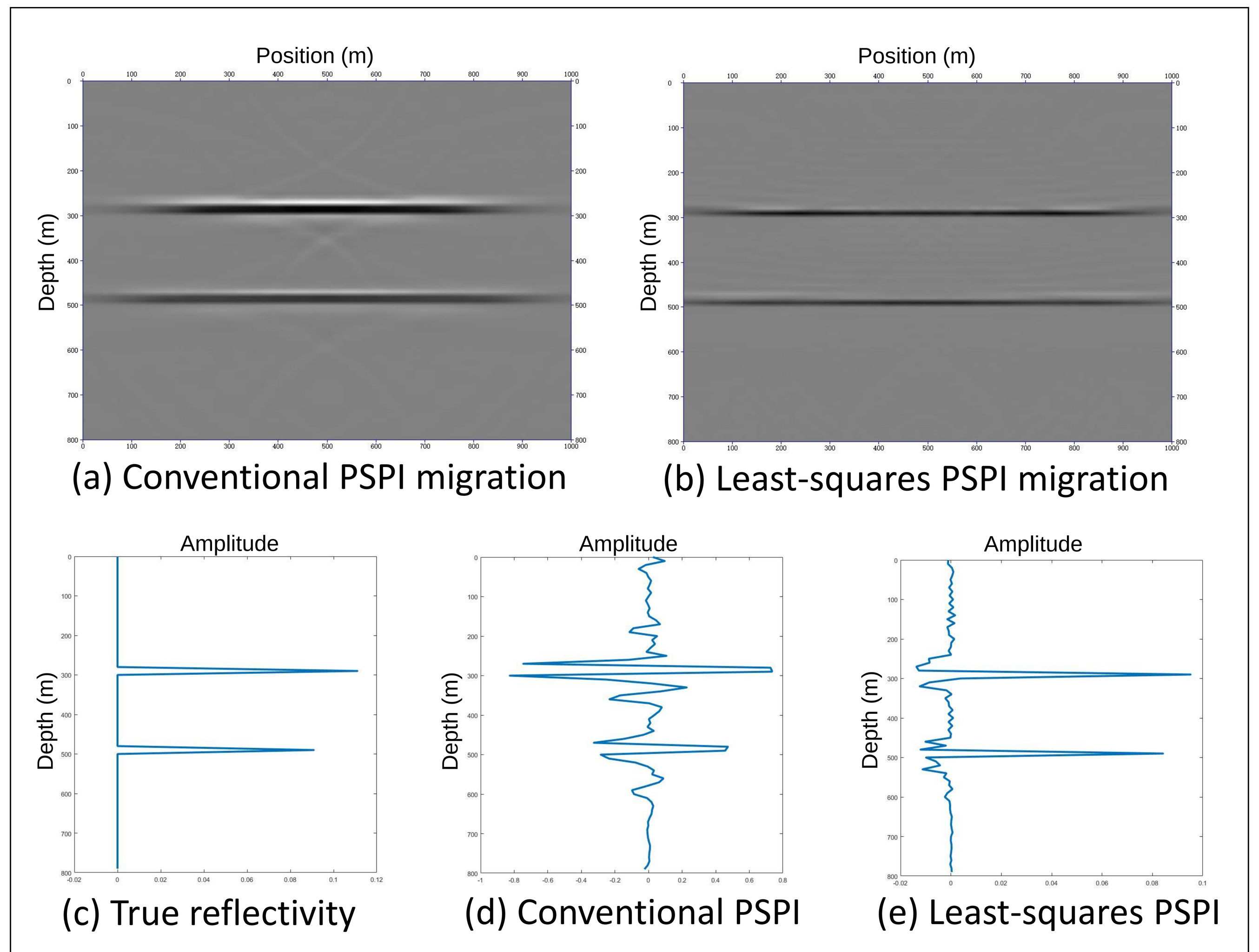
Figure 1. Illumination compensation as preconditioned operator for least-squares migration, the first demigration result with compensation is closer with full wave equation modeling result .

Workflow



Preliminary result

We compute a numerical test on a model with two horizontal layers (Figure 2) using conventional and this least-squares PSPI depth migration method. Note the improvement in vertical resolution and amplitude balancing towards the edges in the least-squares migration image.

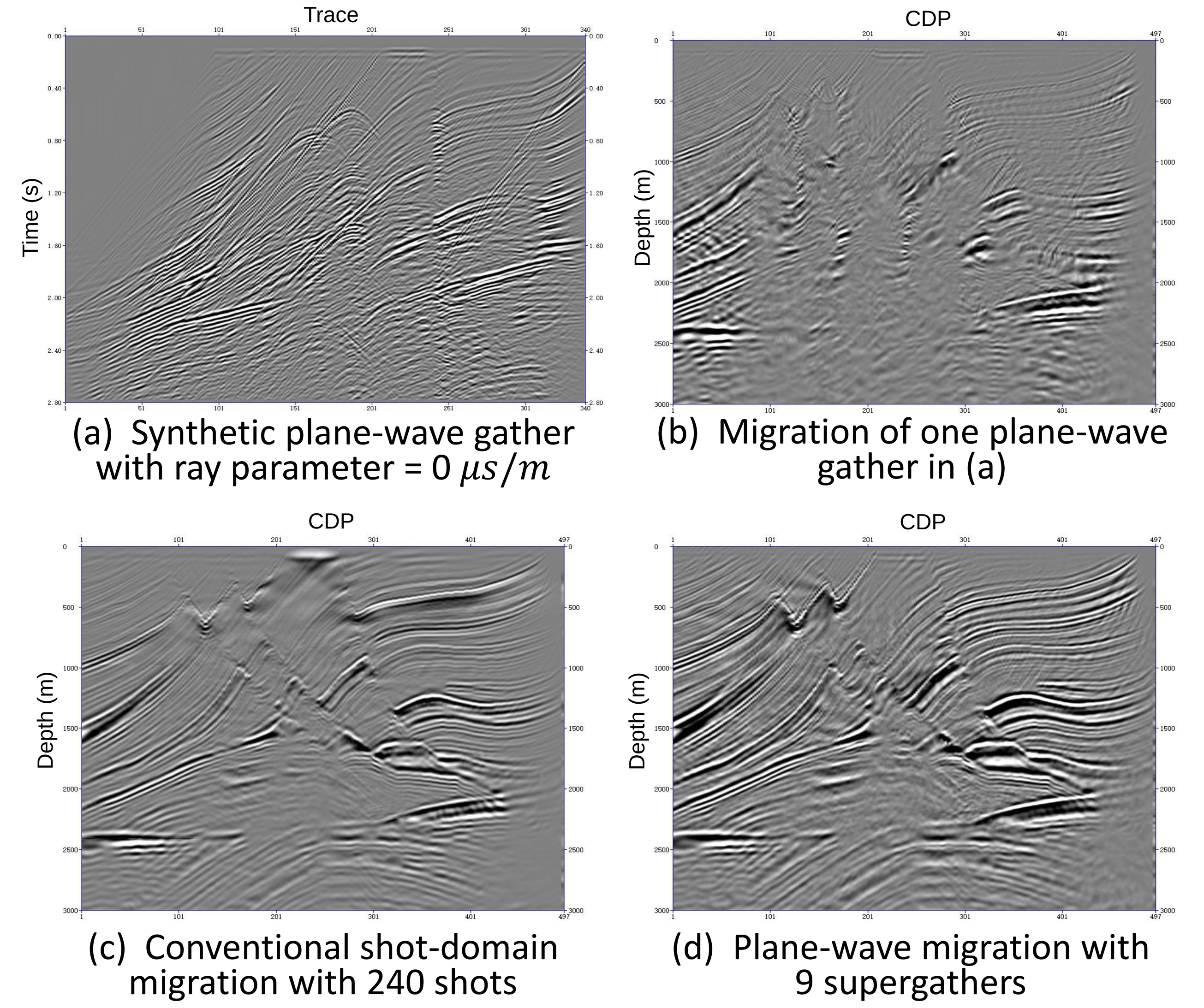


(a) Conventional PSPI migration
(b) Least-squares PSPI migration
(c) True reflectivity
(d) Conventional PSPI
(e) Least-squares PSPI

Figure 2. Numerical test of synthetic data. The single trace comparison (Figure c, d, e) indicate that migration resolution is improved by least-squares PSPI migration.

Future work plans

There are two challenges in least-squares migration of land data. The first challenge is the computation cost. A potential solution is to use plane-wave imaging. The migration results of the Marmousi model in Figure 3 shows a speed improvement by a factor of 7 over shot migration. The second challenge is data interpolation of irregularly sampled 3D land surveys. Here, we will investigate various implementations of 5D interpolation, including those using a 3D linear moveout high resolution Radon transform.



(a) Synthetic plane-wave gather with ray parameter = 0 $\mu s/m$
(b) Migration of one plane-wave gather in (a)
(c) Conventional shot-domain migration with 240 shots
(d) Plane-wave migration with 9 supergathers

Figure 3. Plane-wave migration of Marmousi model.

Conclusion

Preliminary synthetic results indicate that least-square PSPI migration produces high quality imaging results but at high computation cost. Our challenge is to improve the algorithm efficiency and reduce the number of iterations.

Acknowledgements

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References

Gazdag, J., and Sguazzero, P., 1984, Migration of seismic data by phase shift plus interpolation: Geophysics, 49, 124-131.

Kaplan, S. T., P. S. Routh, and M. D. Sacchi, 2010, Derivation of forward and adjoint operators for least-squares shot-profile split-step migration: Geophysics, 75, S225–S235.

Nemeth, T., C. Wu, and G. Schuster, 1999, Least-squares migration of incomplete reflection data: Geophysics, 64, 208–221.

Tang, Y., 2009, Target-oriented wave-equation least-squares migration with phase encoded hessian: Geophysics, 74, WCA95–WCA107.

Whitmore, N. D., 1995, An imaging hierarchy for common angle plane wave seismogram: Ph.D. thesis, University of Tulsa.

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