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Adaptive Limitation of the Migration Operator Aperture

M. Alerini* (SINTEF Petroleum Research) & B. Ursin (University of Trondheim)

SUMMARY

In Kirchhoff based migration, the relevant information is located at the specular reflection point along the migration operator. Limiting the migration operator around this specular point not only increases the speed of the process but also improves greatly the quality of the migration results by suppressing important aliasing artifacts. The aperture of the migration operator is connected to the notion of Fresnel zone and therefore depends on the position on the image domain. We present here an original way of determining this aperture for seismic prestack depth migration in angle domain assuming the geological dip is known. Our approach has several advantages compared to previously proposed ones: it is easy to implement in an already existing code, it is easy to use, it can take into account local errors in the estimated geological dips and it is possible to consider multi-oriented dips as in discontinuities.

Introduction

Kirchhoff migration is based on a continuous integral ranging from minus infinity to plus infinity. The necessary discretization and truncation of this integral introduces noise in the migrated image. This noise can be attenuated by limiting the migration operator aperture around the specular point. This is a well-known problem and different attempts have been proposed to solve it. There are numerous publications on this topic nowadays and we can cite among other Sun (1998), Hua and McMechan (2001), Baina et al. (2003), Brandsberg-Dahl et al. (2003), Lüth et al. (2005) or Buske et al. (2006).
Two points are important: the location of the specular reflection point along the migration operator and the size of the aperture of this operator. The specular point can be determined by several approaches: maximum of focusing of the energy (Baina et al., 2003, Brandsberg-Dahl et al., 2003), use of the slopes at sources and receivers (Nguyen et al., 2002), interpretation of a previously migrated image (Schleicher et al., 1997) or interpolation of map migration of locally coherent events (Alerini et al., 2007) for instance.
The aperture of the migration operator should allow constructive interferences, or contain the first Fresnel zone (Schleicher et al., 1997, Sun, 1998). We propose here a new criterion to limit the migration operator aperture. The main idea is to find an expression of the traveltime difference between the migrated ray and the specular ray as a function of the difference of angle between the migrated and geological dip directions. Our approach has several advantages compared to others: it is extremely easy to implement in an existing migration code and to use. In particular it does not require any extra ray tracing but simply a few more quantities to be integrated along the ray. In addition, it can take into account errors on the geological dips and the multi-orientation of some regions as faults. The migration operator is still limited in the region of constructive interferences around the specular ray but, we will work only on local quantities at the image point in depth.
We show first the derivation of our criterion and then show its validity on a synthetic dataset.

Methodology

The main idea of our approach is first to relate the difference between the geological dip and the migrated dip to a traveltime difference and then to relate this traveltime difference to the migration operator aperture. As we want to keep only the migration operator region which allows constructive interferences when summing delayed signals, we can write the criterion

$$|\Delta T| \le \frac{T_P}{k}, \tag{1}$$

where ΔT is the traveltime difference, T_p is the source wavelet duration and k a tuning parameter. Typically, for monochromatic waves on phase at their sources k=2 and Tp is the inverse of the frequency. As we will see in the following, our problem is slightly different but we will keep criterion (1) as a guide line.
Finding the traveltime difference due to a perturbation in the geological dip is more complicated. Indeed, although paraxial ray theory can provide the difference of traveltime between two one-way rays for a different initial shooting angle (Farra, 1999), the migration operator is computed on the two-way ray pair. We thus have to find an angle difference between the one-way rays given a difference between the geological dip and the two-way migrated ray. This can be found by reminding some concepts of the angle migration process.
Seismic prestack depth migration in angle domain performs a summation over the migrated dips from sources and receivers

$$\nu^m = \nu^s + \nu^r, \tag{2}$$

for which the difference is kept constant (Ursin, 2004)

$$\nu^d = \nu^s - \nu^r. \tag{3}$$

In addition, we can write that the migrated dip is the sum of the specular dip and a perturbation

$$\nu^m = \nu_\varphi + \Delta\nu^m. \tag{4}$$

We can do the same with the dips from the source and the receiver

$$\begin{cases} \nu^s = \nu_\varphi^s + \Delta\nu^s \\ \nu^r = \nu_\varphi^r + \Delta\nu^r \end{cases}, \tag{5}$$

where the geological dip is the sum of the dips along the specular directions from the source and the receiver

$$\nu_\varphi = \nu_\varphi^s + \nu_\varphi^r. \tag{6}$$

Since the dip difference, ν^d, in equation (2) is constant, it follows that $\Delta\nu^s = \Delta\nu^r$ which we denote $\Delta\nu$. Then we have $\Delta\nu^m = 2\Delta\nu$. The dip perturbations are all in the plane defined by ν^s and ν^r. The new migration dip can then be written as

$$\nu^m = \nu_\varphi + 2\Delta\nu^m. \tag{7}$$

Knowing the geological dip, equation (6) can give us the angle difference between the one-way ray branches (specular and migrated) without computing the specular ray.
It is now possible to use the second order expression of the traveltime difference for a perturbation of the initial slowness vector given by Farra (1999)

$$\Delta T = \mathbf{q}_0 \cdot (\mathbf{\Pi}_1 \mathbf{Q} \Delta\mathbf{p}) + \frac{1}{2}(\mathbf{\Pi}_2 \mathbf{Q} + \mathbf{P})\Delta\mathbf{p} \cdot (\mathbf{\Pi}_1 \mathbf{Q} \Delta\mathbf{p}), \tag{8}$$

where $\mathbf{\Pi}_1$ and $\mathbf{\Pi}_2$ are projection matrices and $\mathbf{P}$ and $\mathbf{Q}$ are parts of the propagator matrix. $\mathbf{q}_0$ is the slowness vector at surface pointing upward and $\Delta\mathbf{p}$ is the slowness perturbation at the image point. All those quantities can be computed by paraxial ray tracing.
Equation (8) leads to a problem: indeed, nearly horizontal rays can have a huge traveltime difference even for very small angle perturbation. This means that using directly equation (8) will prevent contributions from horizontal rays and basically our migration operator will be smaller at large offsets. To correct this in a heuristic way we will compute the traveltime difference not at the acquisition surface but along the tangent to the specular wavefront when this one reaches the acquisition surface. This is equivalent to the Young's experiment (Hecht, 1987) where the signals are in phase along this surface and the interferences are observed at the image point along the migrated reflector.
We can now apply equation (8) on the rays toward the source and toward the receiver and combine the criteria on both rays in a single expression. We weight the condition (1) by the ratio of one-ray traveltime compared to the two-traveltime and obtain

$$\left|\Delta T^i\right| \le \frac{T_\varphi^i}{T_\varphi}\frac{T_P}{k}, \tag{9}$$

With i=s,r, $T_\varphi = T_\varphi^s + T_\varphi^r$ is the two-way specular traveltime and T_φ^i are the two one-way specular traveltimes. We simply have thus to multiply the migration kernel by 1 if condition (9) is satisfied and by 0 if it not (with some smooth tapers).

Numerical examples

We validate our approach on a synthetic data example which is a smooth variation of the Marmousi model. We use here estimated model and structural dip field (Alerini et al, 2007). Sources and receivers are regularly spaced every 25m. The data are computed by a 2.5D ray+Born algorithm and the source is a Dirac delta function filtered between 10Hz and 40Hz. For the limitation of the migration operator, we use T_p=1/25s and k=2.8 (Sheriff, 1991).
Both migrated stacks (figure 1) are similar, at least in regions were the dip could have been properly estimated. No artifacts are obvious on the stack without any limitation of the migration operator. Common image gathers show better the advantage of our method. Indeed, they contain clearly much less noise with our approach than without any limitation of the migration operator (figure 2).

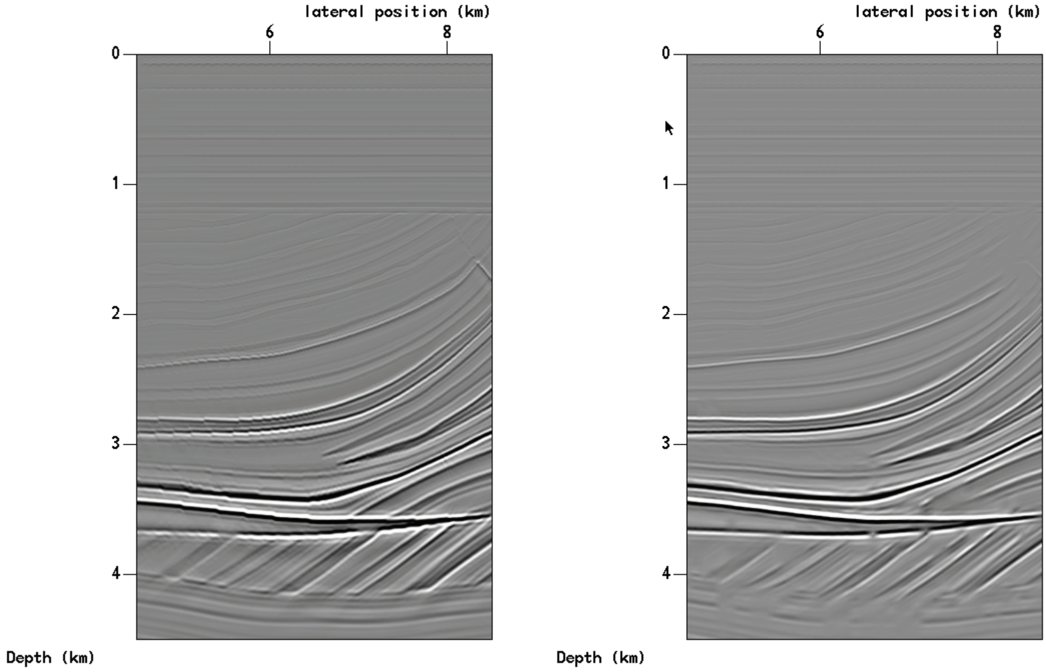

Figure 1: Migrated stacks. (left) without and (right) with limitation of the migration operator.

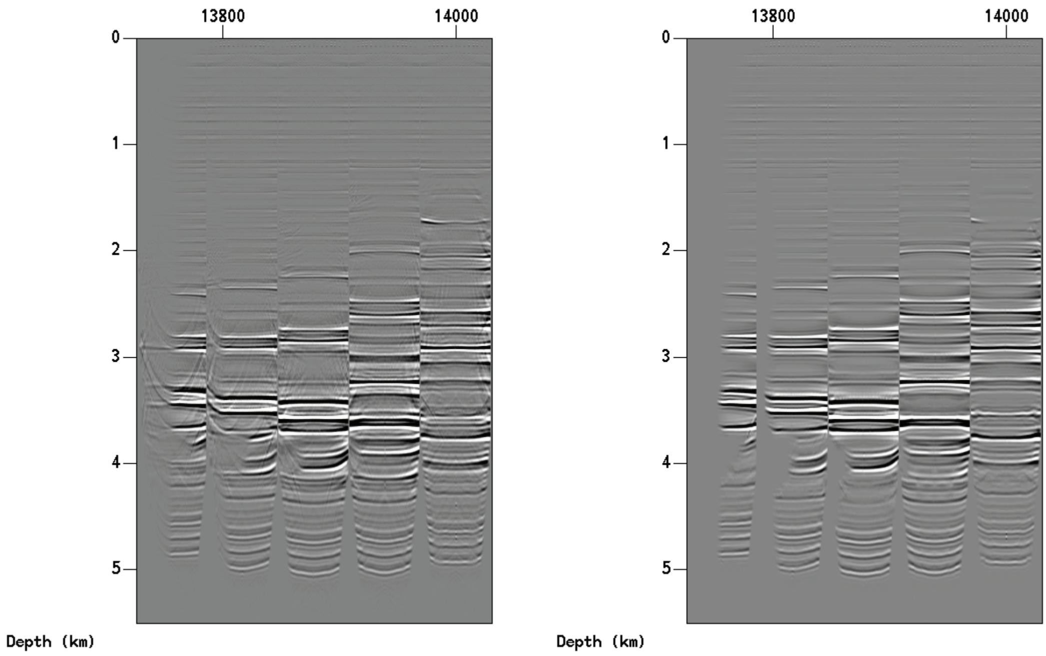

Figure 2: Common image gathers in angle domain at lateral positions 4.5, 5.5, 6.5, 7.5, 8.5km. (left) without and (right) with limitation of the migration operator. The coherent noise disappears with our approach.

Conclusion

We have presented here a new approach to compute locally the migration operator size. Compared to other approaches it has the advantages of being easy to implement in an existing code, easy to use, can take into account local errors on the geological dip together with possible multi orientation.

On synthetic data examples we have validated our approach which reduce remove nicely artifacts. This in particular can provide common image gathers which can be post-processed in an easier way.

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References

Alerini, M., M. Riede, and B. Ursin, 2007, Limited-aperture migration by sterotomography output: Presented at the 69th Ann. Internat. Mtg., Eur. Ass. Geosc. Eng.

Baina, R., S. Nguyen, M. Noble, and G. Lambar´e, 2003, Optimal anti-aliasing for ray-based kirchhoff depth migration: Presented at the 73rd annual meeting, Soc. Expl. Geophys.

Brandsberg-Dahl, S., M. de Hoop, and B. Ursin, 2003a, Focusing in dip and AVA compensation on scattering angle/azimuth common image gathers: Geophysics, **68**, 232–254.

Buske, S., M. Heigel, and S. Lueth, 2006, Fresnel-volume-migration of single-component of seismic data: Presented at the 68th Ann. Internat. Mtg., Eur. Ass. Geosc. Eng.

Farra, V., 1999, Computation fo second-order traveltime perturbation by Hamiltonian ray theory: Geophys. J. Int., **136**, 205–217.

Hecht, E., 1987, Optics: Addison-Wesley Publishing Company, Inc., 2nd edition.

Hua, B.-L. and A. McMechan, 2001, Parsimonious 2-D postack depth migration: Geophysics, **66**, 1497–1503.

Lüth, S., S. Buske, R. Giese, and A. Goertz, 2005, Fresnel volume migration of multicomponent data: Geophysics, **70**, S121–S129.

Nguyen, S., M. Noble, P. Thierry, and R. Baina, 2002, Ray-based anti aliasing for depth migration: Presented at the 64th Ann. Internat. Mtg., Eur. Ass. Geosc. Eng.

Schleicher, J., P. Hubral, M. Tygel, and M. S. Jaya, 1997, Minimum aperture and Fresnel zones in migration and demigration: Geophysics, **62**, 183–194.

Sheriff, R. E., 1991, Encyclopedic dictionary of applied geophysics: Society of exploration geophysicists, 3rd edition.

Sun, J., 1998, On the limited aperture migration in two dimensions: Geophysics, **63**, 984–994.

Ursin, B., 2004, Parameter inversion and angle migration in anisotropic elastic media: Geophysics, **69**, 1125–1142.