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Initial-model Construction for MVA Techniques

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SUMMARY

Migration is one of the main methods of imaging, and prior knowledge of the subsurface velocity is needed for its application. For iterative migration velocity analysis methods, good starting models are required. In this work, we compare two methods for the construction of initial models, being image-wave propagation and double path-integral migration. Both are able to generate an image migrated in time without an initial velocity model. We discuss the cost and benefit of each technique, as well as we evaluate the results before human intervention and interpretation.

Introduction

A major challenge both in the seismic exploration and in seismological investigations is the construction of the best undistorted image possible in depth from the acquired data. For this purpose, imaging methods are employed that rely on the knowledge of a subsurface velocity model. Most present-day model-building techniques are iterative procedures that improve a starting model based on intermediate results. Among these, most important are model-building methds based directly on migration itself, so-called migration velocity analysis (MVA). All of these techniques strongly depend on the quality of the starting model.

The basic techniques for constructing a starting model are the methods based on an analysis of the traveltime of seismic waves. Among the most commonly used methods are the Common-MidPoint (CMP) and Common Reflection Surface (CRS) stacks.

Both of these methods operate in the data-acquisition time domain. Thus, there is a need for transforming such a velocity model to the migration domain, be it in time or depth. This conversion is problematic in that it depends on the actual values of the velocity model to be converted (Hubral, 1977). Therefore, alternative velocity-analysis methods are desirable that work directly in the desired migration domain, so that there is no need for a conversion of the model domain.

Motivated by the importance of the subject, MVA methods have been proposed by many authors. Because of its conceptual clarity and simplicity, residual moveout (RMO) analysis has become a favorite tool for MVA. In recent years, many improvements have been proposed. However, few authors have studied the problem of how to construct the best possible starting model. Schleicher et al. (2008) and Schleicher and Costa (2009) proposed two MVA methods for time migration that can fill this gap. Both MVA methods purpose is to begin the analysis without the need to specify an initial velocity model that has already certain features of the searched model. Thus, they differ fundamentally from tomographic methods (Billette et al., 2003; Clapp et al., 2004) or full waveform inversion (FWI, see, e.g., Virieux and Operto, 2009), which require a good initial model to ensure convergence.

After an adequate time-depth conversion algorithm (Cameron et al., 2007, 2008; Iversen and Tygel, 2008), a high-quality time-migration initial model may even provide sufficient quality to serve for subsequent depth MVA or FWI methods.

Schleicher et al. (2008) and Schleicher and Costa (2009) tested their time-migration MVA methods on the synthetic Marmousoft dataset (Billette et al., 2003). These synthetic data were obtained by Born modeling in a smoothed version of the original Marmousi model. However, although the methods were applied to the same dataset, no comparison or combination was carried out.

In this work, we perform a comparison of both methods, both qualitatively and quantitatively, using the Marmousoft model, not only with respect to the quality of the resulting velocity model, but also to the human and computational effort required to achieve a certain quality. Another goal of our research is the setting of the parameters involved in the methods to optimize their performance, such as the measure of non-horizontality of the events in the common image gather (CIG) or the number of CIGs necessary for a successful analysis.

Theoretical Description

MVA by image-wave propagation of CIGs

Schleicher et al. (2008) started from the position of a horizontal reflector below a homogeneous medium with constant-velocity v_m as a function of vertical time τ, half-offset h, and migration velocity v, as derived by Al-Yahya (1989). It reads

$$\tau = \sqrt{\tau_0^2 + h^2(1/v_m^2 - 1/v^2)} \,, \tag{1}$$

where τ_0 is vertical time at zero offset, i.e., the true migrated position of the reflector image. They arrived at the image-wave equation for the continuation of a CIG,

$$\frac{\partial \tilde{p}}{\partial \tau} + \frac{v^3 \tau}{h^2} \frac{\partial \tilde{p}}{\partial v} = 0 \,. \tag{2}$$

Note that equation (2) does not depend on the medium velocity v_m nor the correct zero-offset vertical time τ_0 of the reflector. This equation was independently derived by Fomel (2003), who called it the kinematic RMO equation.

Schleicher and Biloti (2007) presented the equivalent of equation (1) for depth migration

$$z = \sqrt{\frac{v^2}{v_m^2} z_0^2 + \left(\frac{v^2}{v_m^2} - 1\right) h^2} \,, \tag{3}$$

where z_0 is the true depth of the supposedly horizontal reflector and z is the migrated pseudodepth.

Based on equation (3) and in analogy to the procedure in time, Schleicher et al. (2008) showed that the equation for continuation of the CIGs in depth can be written as

$$\frac{\partial p}{\partial z} + \frac{vz}{h^2 + z^2} \frac{\partial p}{\partial v} = 0 \,. \tag{4}$$

Because of the initial hypothesis of a horizontal reflector, equations (2) and (4) do not describe a dislocation of the image along the half-offset axis. The complete equation for dipping reflectors, which includes a derivative with respect to h, can be found in Fomel (2003). However, since the dislocation in the h direction is the smaller the closer the model is to the true one, equations (2) and (4) are sufficient for an iterative procedure (see also Al-Yahya, 1989).

MVA by double path-integral migration

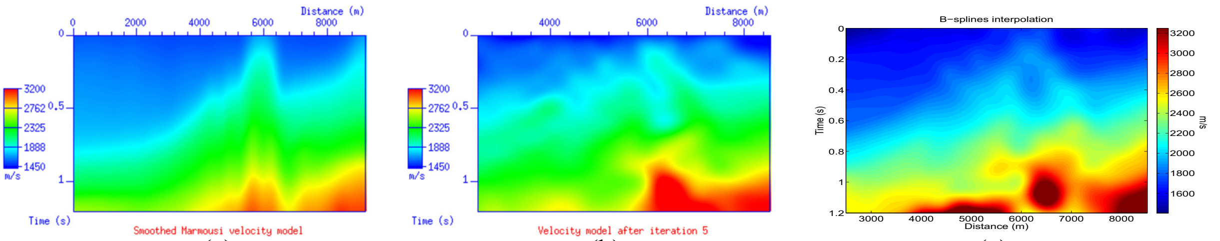
We compare the procedure and result of the above technique to the one of Schleicher and Costa (2009), which is based on the multipath-summation imaging process of Landa et al. (2006). Using their notation, the time-migration operator by multipath-summation can be written as

$$V_W(\mathbf{x}) = \int d\alpha \, w(\mathbf{x}, \alpha) \int d\xi \int dt \, U(t, \xi) \delta(t - t_d(\xi, \mathbf{x}; \alpha)) \,, \tag{5}$$

where V_W is the resulting time-migrated image at an image point with coordinates $\mathbf{x} = (x, \tau)$, x being the lateral distance, τ vertical time, $U(t, \xi)$ a seismic trace at coordinate ξ in the seismic data, $t_d(\xi, \mathbf{x}; \alpha)$ is a stacking surfaces corresponding to a set of possible velocity models that are parametrized using variable α and $w(\mathbf{x}, \alpha)$ is a weight function, which serves to attenuate contributions from unlikely trajectories and emphasize contributions from trajectories close to the optimal.

In the application of Schleicher and Costa (2009), α directly represented the migration velocity and the weight $w(\mathbf{x}, \alpha)$ was given by an exponential formula.

By means of Laplace's method and an asymptotic evaluation of the integral (5), Schleicher and Costa (2009) showed that the result of a multipath summation produces a migrated image, which is proportional to the migration with stationary velocity value. This analysis implies that the use of a slightly modified weight function, $\tilde{w}(\mathbf{x}, \alpha) = \alpha w(\mathbf{x}, \alpha)$ provides, at each point $\mathbf{x}$, a migration result that is proportional to the first one, the factor being the stationary value of the velocity migration at point $\mathbf{x}$. Thus, the ratio between the migration results provides this velocity value, allowing for the reconstruction of a velocity model for all points with a nonzero multipath-summation image.



(a) (b) (c)

Figure 1 *(a) Smoothed Marmousi velocity model; (b) Velocity model after five iterations of image-wave RMO correction (from Schleicher et al., 2008); (c) Velocity model extracted in the path-integral migration process (from Schleicher and Costa, 2009).*

Results

The process of time imaging needs a smooth velocity model. Both image-wave (Schleicher et al., 2008) and double path-integral (Schleicher and Costa, 2009) MVA methods provide such a smooth model. Since in the original works, both methods were tested for the Marmousoft model (time-converted version in Figure 1a), we can compare the results directly. Comparing the best velocity models obtained by image-wave and double path-integral MVA, we can see that both image-wave (Figure 1b) and double-multipath MVA (Figure 1c) recovered good images in the sedimentary parts of the model but failed below the geologically complex central part due to the limitations of time migration.

While there is a notable difference between these velocity models, it is not easy to see the differences in the resulting migrated image of each technique with its corresponding velocity model (Figure 2). This illustrates the ambiguity in the determination of a starting model for iterative methods. Further investigations will need to decide which of the models is better suited for this purpose.

In additional tests, we tried to automate the image-wave MVA method, which, in its original form, requires a certain amount of human interference. Figure 3 shows two migrated images obtained after fully automated execution of 5 iterations, based on using maximum semblance picking criterion for reflector flatness. For Figure 3b, the obtained semblances were smoothed before picking. We see that the images are equivalent to the ones obtained in the original works, with only slight differences. The overall processing time for the automated procedure reduced from the order of days to the order of hours.

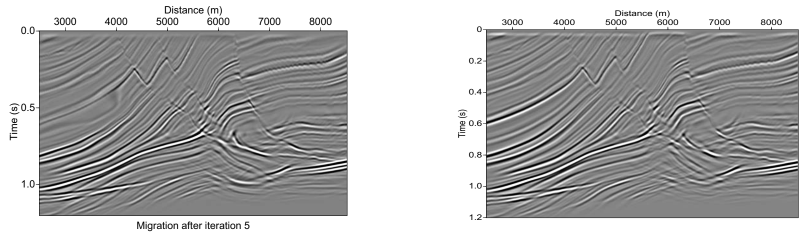
The tests suggest that the double path-integral MVA can immediately provide an initial velocity model of the same quality as obtained by image-wave MVA after several iterations. However, automation of the latter process still leads to competitive processing time.

Further tests will be executed to evaluate the dependence of the methods on the respective parameters like number of grid points, smoothing criteria, interpolation method, number of CIGs for velocity analysis, distance between CIGs for velocity analysis, different regularization and many others.

Finally, we will investigate whether the velocity model generated by double path-integral can be further improved by image-wave migration, forming then a fully automated hybrid method.

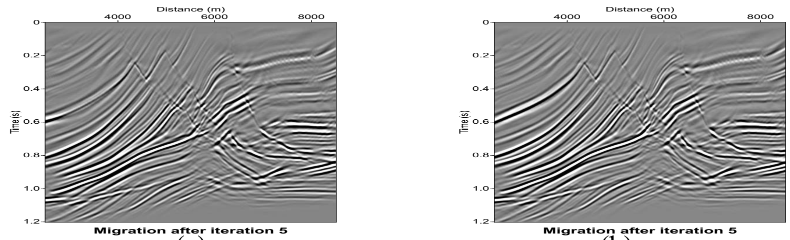
Conclusions

We have compared the quality of the velocity models obtained from image-wave (Schleicher et al., 2008) and multipath MVA (Schleicher and Costa, 2009). Our evaluation demonstrates that both methods are equivalent regarding the final result, i.e., the time-migrated image. However, for them to be qualitatively compatible, the original velocity continuation method requires manual velocity picking, thus needing more human effort to reach the desired result. To reduce this effort, an effective automatic velocity picking has been developed/implemented which was able to produce migrated images of the same quality.



(a) (b)

Figure 2 *Migrated image obtained by (a) image-wave propagation (from Schleicher et al., 2008) and (b) by path-integral imaging process (from Schleicher and Costa, 2009).*



(a) (b)

Figure 3 *Migrated image obtained by image-wave propagation using autopicking with (a) maximum semblance (b) smoothed semblance.*

We remind that the velocity continuation method starts its processing from a constant velocity (e.g., water velocity), while path-integral imaging allows to extract a velocity model without a-priori information. This suggests intuitively that the velocity model generated by path-integral imaging can be used as an initial model in velocity continuation.

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