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Short Note

How variable velocity dip moveout improves post-stack migration

Patrick Blondel[1]

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INTRODUCTION

Nowadays, a standard industrial seismic processing almost always involves the constant-velocity dip moveout correction. Two main features make the process attractive. First, the computational cost is low compared to prestack migration in both two-dimensional and three-dimensional processings. Secondly, because constant-velocity dip moveout is "independent of velocity", it may come before velocity analysis, removing the effects of dip (Forel and Gardner, 1988).

However, the hypothesis of constant velocity is somewhat inconsistent with the concept of velocity analysis which results in the construction of a depth-variable velocity model. Recently, several methods for depth-variable velocity dip moveout (Godfrey, 1992; Artley, 1992; Meinardus and Schleicher, 1993) undeniably improved the zero-offset stack section. However, one can wonder if they clearly improve the result of the post-stack migrated section.

In this paper I show that the depth-variable velocity dip moveout strongly differs from the constant-velocity dip moveout not by the shape of the operator (although the operator is squeezed horizontally when the velocity increases with depth (Hale, 1983; Artley, 1992)) but by the amplitude distribution along the operator. In the second section, a synthetic data example shows how the processing flow NMO-$v(z)$ DMO-post-stack migration is comparable to pre-stack migration.

[1]**email:** not available

SOME AMPLITUDE ISSUES

Jakubowicz (1990) gave an elegant formulation of (f, k) dip moveout where a finite number of dips are processed separately and stacked according to equation (1),

$$P_{\mathrm{DMO}} = \sum_i \Delta D_i \; P_{D_i}, \tag{1}$$

where P_{D_i} is the wavefield, NMO-corrected for a single dip D_i, and ΔD_i is the width of the dip-range surrounding D_i. Obviously, if the dip sampling is irregular, the dip-decomposed wavefields stack with a different weight. Beasley (1988) derived an amplitude scheme for Kirchhoff dip moveout from Jakubowicz's weighting by using the following practical approximation:

$$\Delta D_i \approx \frac{\partial^2 t_0}{\partial x^2} \Delta x. \tag{2}$$

To the first order, the amplitude along the dip moveout operator is proportional to its time curvature. This approximation is close to the amplitude scheme mathematically derived by Black *et al.* (1993) from (f, k) dip moveout (Blondel, 1993). Thus, Jacubowicz's dip moveout by dip-decomposition, Black's Kirchhoff dip moveout, and (f, k) dip moveout have a very similar amplitude distribution.

In the general case of depth-variable velocity, there is no analytic expression of the amplitude along the operator but the dip-decomposition method gives us a qualitative idea. Indeed, the operator of variable-velocity dip moveout may be build point by point for a range of dips regularly sampled. Then, a region where the points are close to each other allows a significant stack of the dipping segments of the operator, and thus corresponds to an area of high amplitude. Figure **??** shows an impulse response of dip moveout in a time-variable velocity model whose profile is represented in Figure **??**.

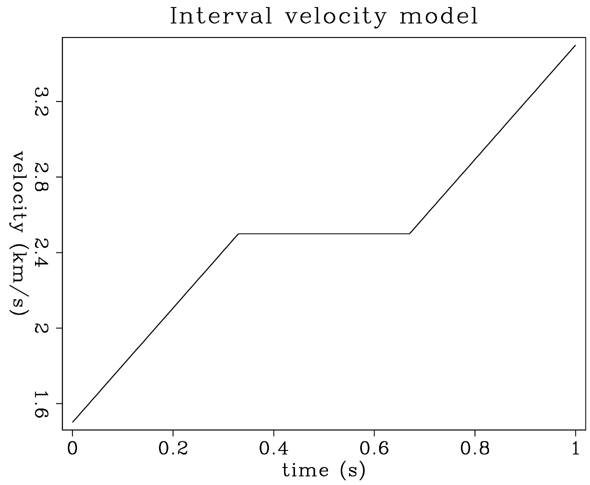

Figure 1: Interval velocity model. patrick2-vel [ER]

Artley's (1992) $v(z)$ dip moveout method which produced Figure **??**, requires a non-linear inversion of a 4×4 system of equations for each time, offset, and dip we

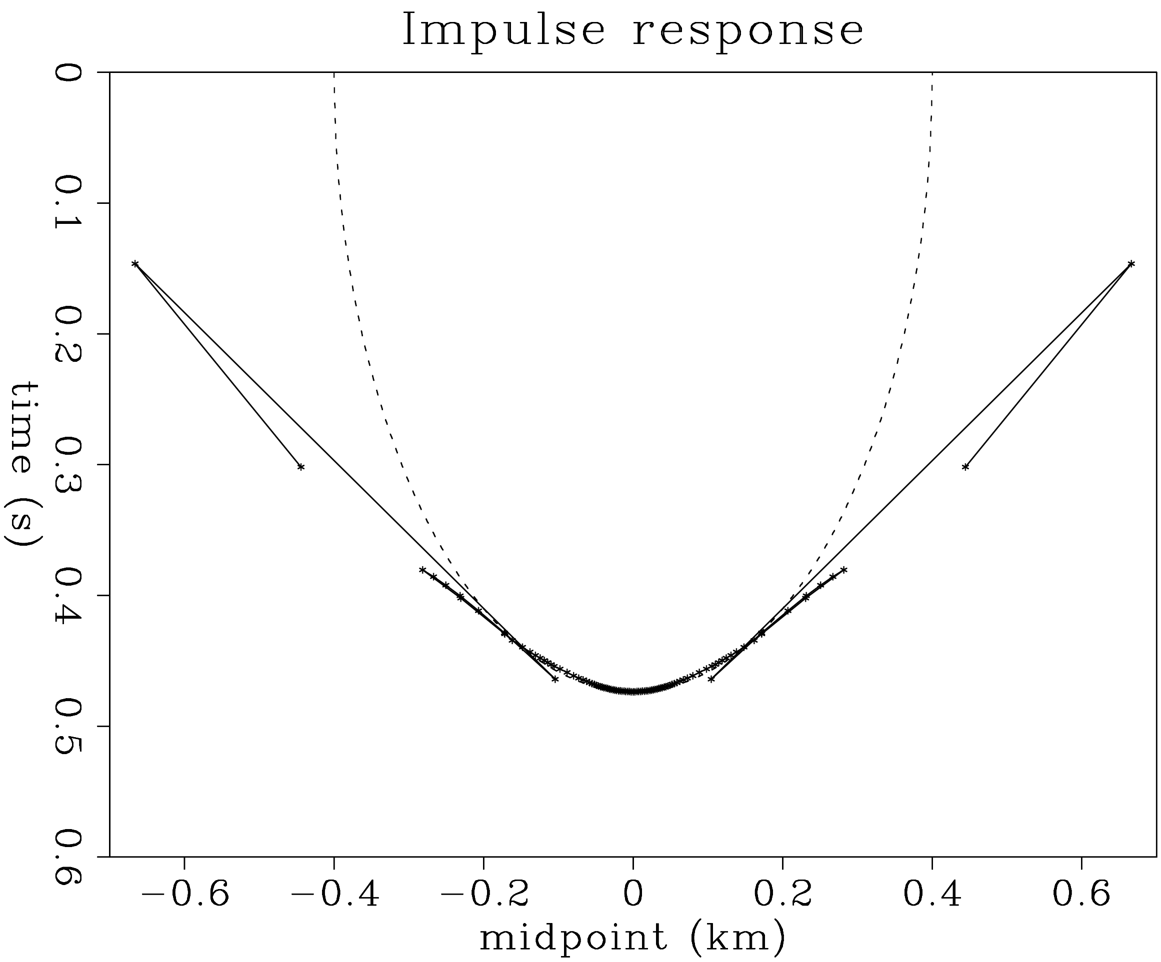

Figure 2: Impulse response of $v(z)$ 2-D DMO for an offset of .8 km and a total two-way traveltime of 1. s. The stars along the operator correspond to a uniform sampling of dips. The denser are the points, the higher is the amplitude of the operator. The dashed line represents the elliptic support of the constant-velocity DMO impulse response for the same offset and traveltime. Both the solid and dashed lines have a similar shape in the region of high amplitudes, differing only by the triplications along the solid line. The unrealistic points beyond the offset show that there is a problem of convergence of the $v(z)$ DMO algorithm for steep dips. patrick2-imprs [ER]

consider. Though it is a time consuming process, it provides us with amplitude information. First, the triplication of the impulse response have a low energy for this velocity model (a troff in the velocity profile would show a high amplitude triplication). Secondly, the amplitude varies a lot along the operator, starting high at gentle dips, decreasing, and increasing again just before a triplication.

The shape of a $v(z)$ DMO operator differs from the constant-velocity DMO operator essentially by a number of triplications along its branches (Figure **??**). However, since these triplications are generally low-amplitude, the shape is not the most discriminative feature of the operator. The amplitude variations along the operator strongly depend on the velocity model, and therefore play the important role in the dip moveout correction.

COMPARISON WITH CONSTANT-VELOCITY DIP MOVEOUT

There is no doubt that replacing the constant-velocity dip moveout step by a variable-velocity dip moveout step improves the zero-offset section after stack. However, the final result of a standard processing flow is the post-stack migrated section. Thus, the idea of comparing the pre-stack migrated section to the post-stack migrated sections with and without the constant velocity assumption is natural. David Lumley provided the synthetic data example that appears in the next three figures. The synthetic model includes four diffractors at various depth and midpoint positions, two horizontal events, and a 45-degree dipping event, overlaid by a strong constant RMS-velocity gradient ($V_{\mathrm{RMS}}^{(\mathrm{km/s})} = 1.5+2.\tau^{(\mathrm{s})}$). The processing flow involving a constant-velocity dip moveout step is displayed in Figure **??**. The three deepest diffractors are unfocused whereas the shallow diffractor is focused but low-amplitude. The horizontal reflectors are well imaged but the dipping event has lower amplitude than expected though it is not mispositioned. As shown in Figure **??**, the variable-velocity step corrects for these inaccuracies and yields a post-stack migrated section hardly differentiable from the pre-stack migration (Figure **??**).

The similarity between the pre-stack migration and the post-stack migration after depth-variable velocity dip moveout is not surprising because the two processing are equivalent when there is no lateral velocity variation. However, the clear improvement with respect the a standard processing makes the variable-velocity dip moveout a very useful tool.

CONCLUSION

The main difference between constant-velocity and variable-velocity dip moveout is not much the shape of the operator but the amplitude distribution. Because this distribution highly depends on the velocity model, the variable-velocity dip moveout considerably improves the post-stack migration. However, the drawback is the high

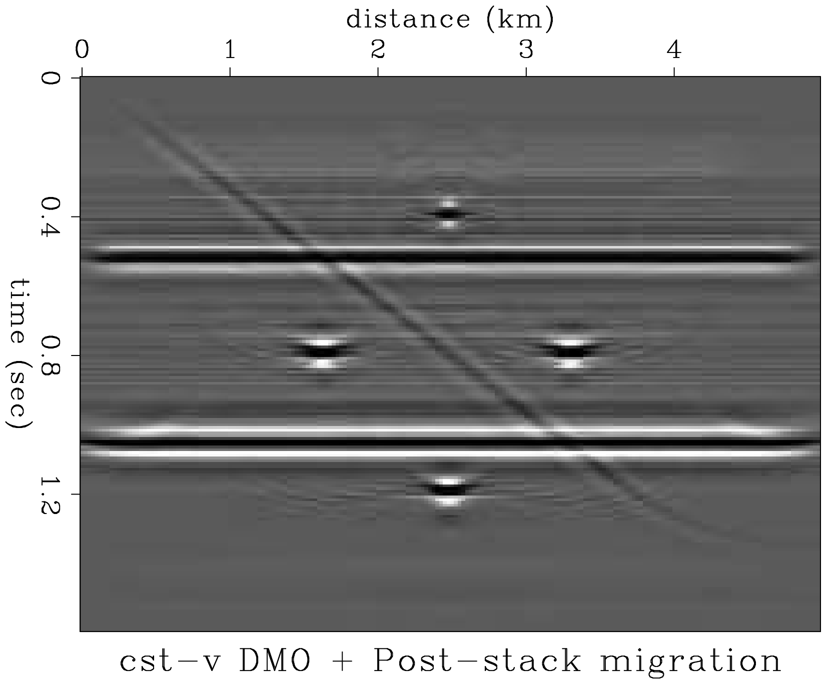

Figure 3: Post-stack migrated section after NMO, constant-velocity DMO and stack. The deepest diffractors are unfocused and the dipping event is low-amplitude. patrick2-cvmig [ER]

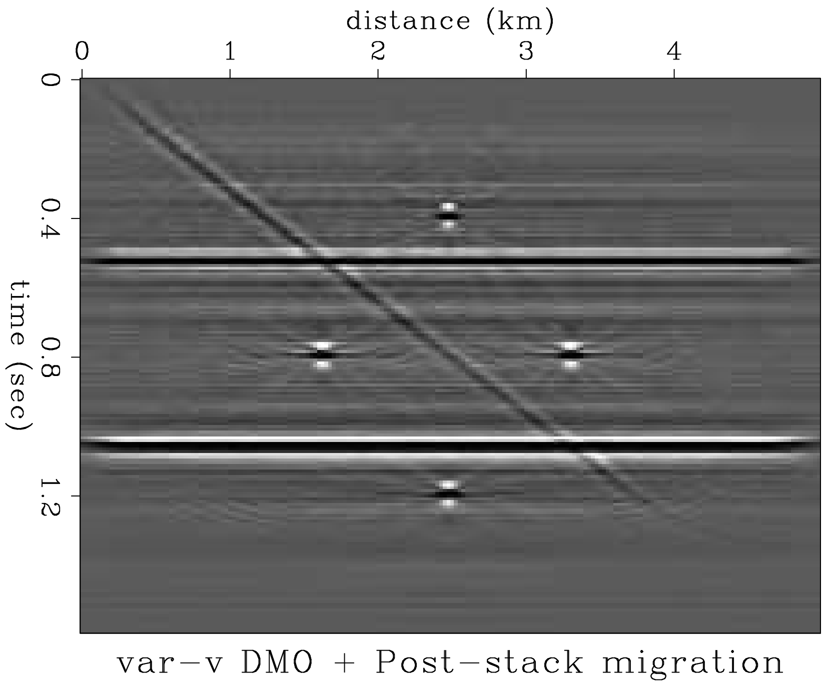

Figure 4: Post-stack migrated section after NMO, variable-velocity DMO and stack. The diffractors and the dipping event are well image. patrick2-vvmig [ER]

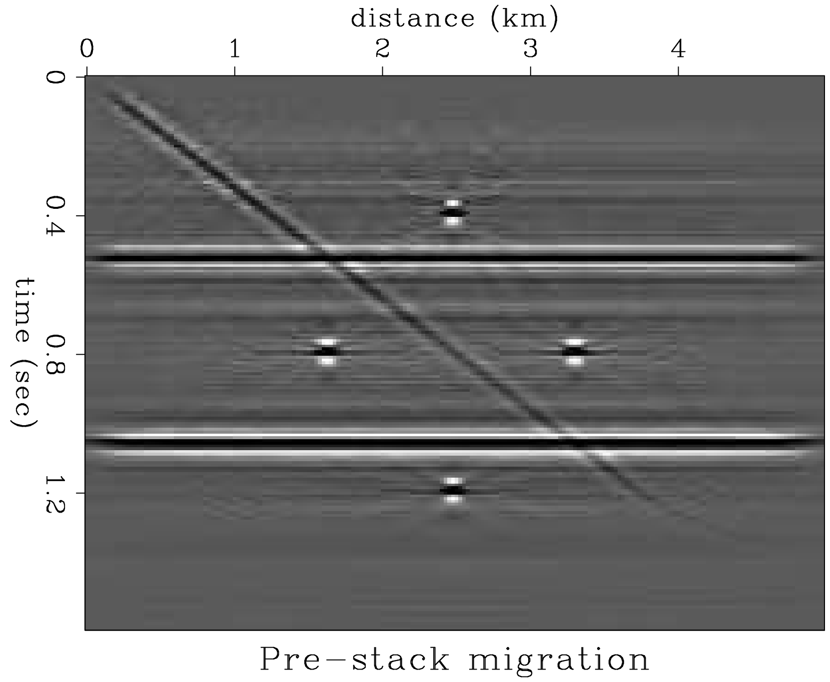

Figure 5: Pre-stack migration. Click on the following button to see a movie of the three previous pictures. patrick2-psmig [ER]

computational cost. For example, Artley's method is more costly than a pre-stack migration, because the algorithm does much more than computing the zero-offset traveltime: it performs a ray-based pre-stack migration and uses the computed zero-offset traveltime to apply the dip moveout correction. Because Meinardus or Artley's algorithms are based on the dip-decomposition idea, it is possible to reduce the computational cost by cutting down the number of dips to process.

In order to improve the quality of the processing, one must pay a computational cost. In the majority of the practical cases, constant velocity dip moveout will give the best trade-off between the quality of the processing and the computational efficiency, especially if it runs on parallel machines.

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