DSR wave-equation migration for steep and overturned events.

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Summary

Wavefield-continuation migration algorithms deal nicely with complex velocity models, but have the disadvantage that they are typically implemented to perform only downward continuation. Energy in the wavefield that turns to 90° or more with respect to the vertical is lost. The result is that steep events may be lost from the image. We describe a method of coordinate rotation that enables steep events to be imaged by changing in a simple way from downward continuation to diagonal continuation. The sum of two or three such migrations produces an image with good imaging of steep and shallow dips.

Introduction

Migration methods based on downward continuation have the advantage that they are affordable with current computer power, and are more accurate than Kirchhoff methods where velocities are complex and multiple arrivals important. They have the disadvantage that they are based on the one-way wave equation, and thus dip-limited.

A number of workarounds exist. Most recently Sava and Fomel (2004) and Brandsberg-Dahl and Etgen (2003) use malleable coordinates that follow traced rays. The latter do a beam migration along individual rays, and merge the image, while the former migrate all the beams together by using non-orthogonal coordinates.

A simpler-looking alternative to ray-based coordinates is tilted coordinates. Shan and Biondi (2004) use a tilted coordinate system for plane-wave migration. Zhang and McMechan (1997) use a horizontal extrapolator on post-stack data to similar effect. Etgen and Brandsberg-Dahl (2002) also mention tilted coordinates.

Claerbout (1985, pp. 272-275) and Hale (1992) save evanescent waves for a second pass, upwards instead of down. Two-pass methods are applicable for poststack data and rely on the data only turning over once, though that is probably reasonable in a large number of cases. Alternatively, more passes could be performed.

Biondi and Shan (2002) use reverse-time migration to image overturned events. Reverse-time migration should naturally handle all dips and velocities, but is still expensive for today's computers.

To devise a practical and computationally efficient method, we join the second group, and rotate the coordinate system of the migration by rotating the velocity model by a constant angle. The data are now effectively acquired on a slope. We use a prestack double-square root (DSR) migration to migrate the data as if from topography, in a manner akin to Reshef (1991), and rotate the resulting image back. The image is still dip-limited, but we have control over which range of dips is imaged, and we can sum two or three images together in order to produce an image with a wide range of dips.

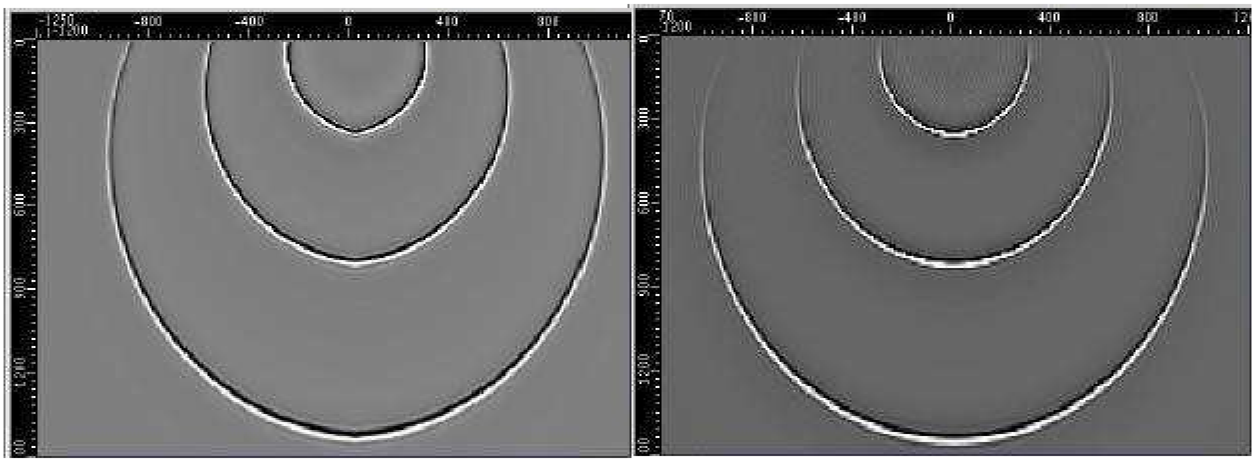
Theory

We take the relatively simple step of rotating the velocity model by some angle θ (45° in the examples in this paper). This means that the recording surface is no longer at depth $z=0$, but along the line $z=x\cos(\theta)$. This can be viewed as migration from topography. Following the method of Moshe Reshef (1991), we begin the migration with an empty wavefield and insert each trace when the current wavefield depth crosses the surface location where it was recorded. For prestack data, and depending on the particular migration algorithm being employed, care may be required to apply only the source or receiver term as appropriate.

Examples

Figure 1 depicts the problem with impulse responses. Figure 1a shows a migration impulse response in a linearly increasing velocity, computed with Kirchhoff migration. Figure 1b shows the same impulse response computed using a DSR migration. The linear gradient induces overturning waves, which are not properly imaged by the migration. They show up, though faint and somewhat misplaced.

Figures 2 give a synthetic example of the proposed solution. Figure 2a is post-stack migration of a synthetic data set (Lavaud and Duquet, 2001), with a number of increasingly steep events, and large velocity contrasts between them. The steepest of these is imaged only very faintly. Figure 2b shows the velocity model, tilted 45°, and 2c shows the image obtained from that model. Figure 2d is the sum of the two migrations; all events are well imaged.



(a) (b)

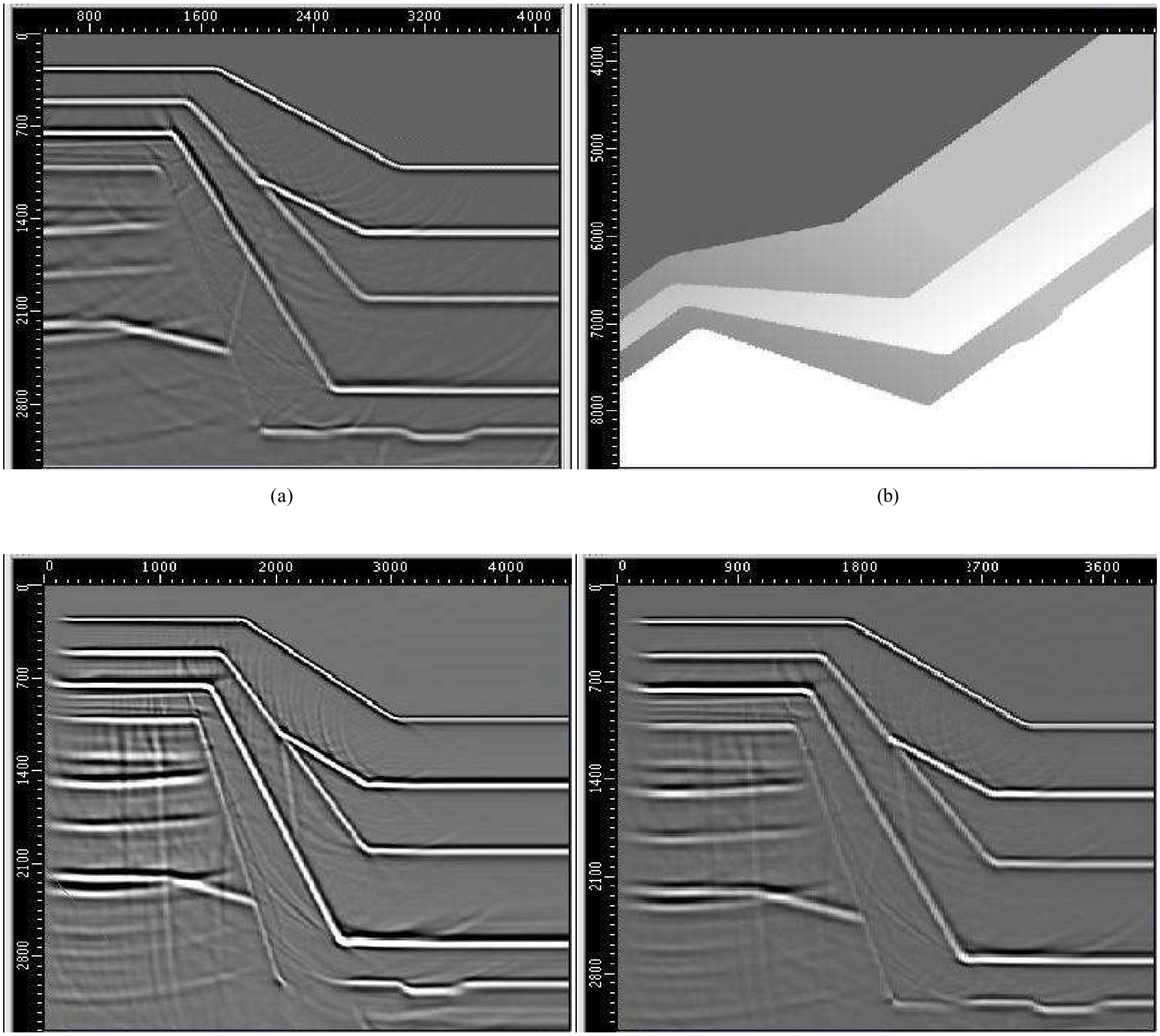
Figure 1: Impulse responses depicting dip limitation of migration based on downward continuation. (a) Kirchhoff migration impulse response in a vertical velocity gradient. (b) Impulse response generated with a downward-continuation migration.

Gulf of Mexico data example

Figures 3 illustrates a real data example, provided by Fugro Multi Client Services. Figure 3a depicts a DSR migration performed with sediment velocity, in the normal top-down fashion. The top salt is clearly visible but the sides are not (nor do they appear with subsequent salt flood, not shown). Figure 3b shows the same migration with tilted migrations added to it. The image is somewhat noisy and some frequency has been lost, but possible salt flank events appear. The sediment events do not quite truncate against the apparent flanks, but this is probably because the flank events are not imaged from outside the salt as initially expected, but through it. Adding salt will likely push the flank event further out to meet the sediments. A tilted salt flood migration is the next step in this example, and will be presented in talk with other imaging results.

Conclusions

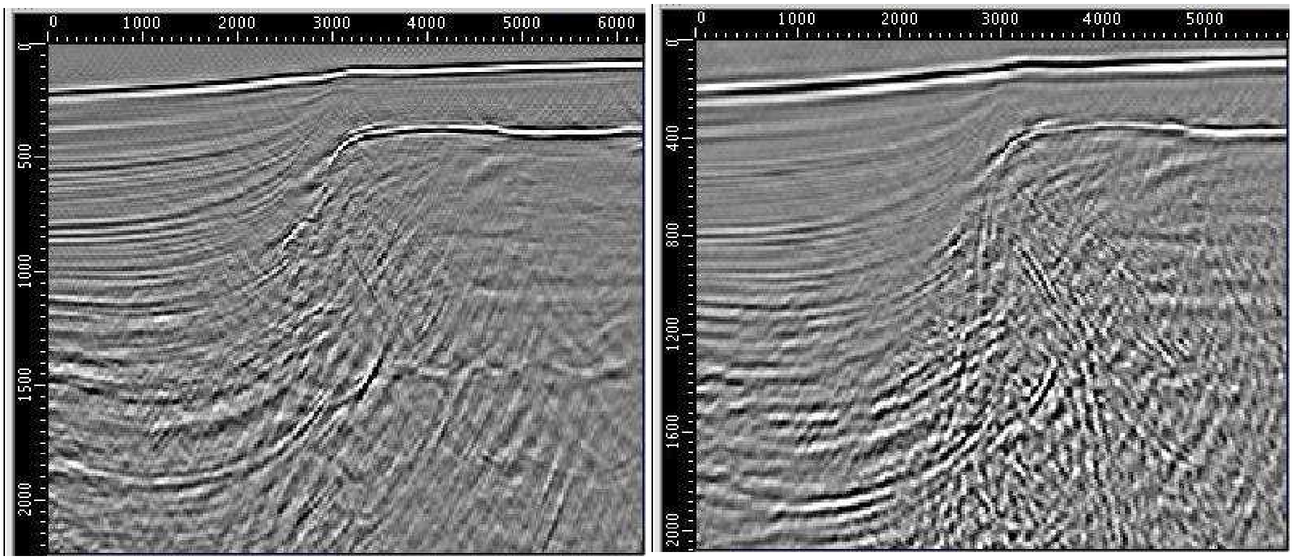
In recent years, numerous ways of overcoming dip limitations in one-way wave equation migration have appeared. In this paper we attempt to formulate one that is easily implemented without any data preprocessing and computationally feasible for routine use. We rotate the velocity model by a fixed angle, and migrate the data as though from topography. The effect is an image with the same angle range, but different bounds, as a normal downward continuation migration. The sum of two or three such images gives an image with a broad angular band, though some additional art will be required to combine them seamlessly.



(a) (b)

(c) (d)

Figure 2: Sections depicting common-azimuth migration in tilted coordinates. (a) A “normal” common-azimuth migration from a flat surface. (b) Velocity model tilted 45°. (c) Migration from 45 ° topography images the steep event. (d) The composite image shows all dips.



(a) (b)

Figure 3: Sections depicting common-azimuth migration in tilted coordinates. (a) A “normal” common-azimuth migration from a flat surface. (b) Sum of 2 migrations at different angles.

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