Multidimensional moveout estimation

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SUMMARY

Moveout estimations in various domains and for different purposes differ mostly in the formulation of the equation. Our aim is to illustrate the gain in stability and consistency of an estimated parameter field by moveout equations that simultaneously introduces and parametrizes orthogonal dimensions in the estimation process. We expand or make use of existing formulas to analyze the impact of a multidimensional estimation on the quality of the moveout parameter field.

INTRODUCTION

Moveout correction plays an important role in various seismic imaging applications. For unmigrated prestack data, a moveout correction is mostly applied to determine a stacking velocity field from CMP gathers. This stacking velocity field serves for various purposes, such as NMO correction, simulation of a zero-offset (ZO) section and Dix-inversion. For migrated data, residual moveout correction analyzes common-image gathers (CIG) to quantify the alignment of the migrated horizons in offset direction or the focusing in angle domain. The estimated residuals allow to improve the focusing of the stack and serve as input for an update of the velocity model.

Usually, the input (CMP or CIG) gathers are processed independently. Because this may lead to an unstable and fluctuating parameter field (jittering), the parameter field is regularized a posterior by filtering or smoothing algorithms. In this respect, event consistent smoothing (Klüver and Mann, 2005) is an interesting technique but considers a regularization after estimation. An straightforward approach to regularize the parameter field during estimation is to to mix several gathers, i .e . to use supergathers or superbins. Here, the aim is to stabilize the parameter field by increasing the number of traces and to force a lateral consistency of the parameter field. However, often these superbins are constructed without additional correction terms, which supposes horizontal invariance of the moveout.

Our aim is based on the principle of supergathers, where we want to emphasize two major issues:

1. account for the lateral variation by additional correction terms, and
2. regularize the parameters during the estimation process.

Because the use of supergathers introduces one or more additional dimensions, the first point states that we have to extend the moveout equation to these dimensions. Furthermore, additional parameters are required to describe the a-priory unknown moveout in the extra dimensions. This description is for instance encountered in the framework of the common-reflection-surface (CRS) and multifocusing (MF) techniques (Jäger et al., 2001; Berkovitch et al., 1994) The second point states that we should make use of the complete extended moveout equation and apply a simultaneous search of all parameters. A separate estimation of the parameters is often conditioned by the computational expense. Here, we want to demonstrate the gain in stability and reliability by a simultaneous estimation in spite of the computational expense.

FORMALISM

The moveout is used to describe the kinematics of a reflection event in time or depth domain. In other words, it parametrizes the time or depth delay from a reference point of the event or horizon. Therefore, most analyzing schemes make use of an analytical formula with one or more parameters. We will restrict to a moveout formula that is designed for the offset domain. Let us illustrate the general idea by the following simple parabolic moveout equation in offset domain:

$$\Delta\tau(h) = \tau - \tau_o = c\,h^2, \quad \text{with} \quad \tau_o = \tau(h=0). \tag{1}$$

Here, h denotes the offset, τ_o denotes the reference point at zero offset and the parameter c quantifies the moveout. In equation (1), we assume symmetry of the moveout with respect to zero offset.

Introducing neighboring gathers, let us choose a simple extension by a first order approximation in the additional dimensions:

$$\Delta\tau(h, \Delta x_i) = c\,h^2 + a_i\,\Delta x_i, \tag{2}$$

Here, Δx_i denotes the deviation of neighboring gathers in dimension i where the additional parameter a_i describes the dip of the reflection event. In this manner, the moveout curve (eq. 1) extends to a (hyper)surface (eq. (2)). Choosing $a_i = 0$ corresponds to a mix of gathers (superbins) and assumes no lateral variation of the reflection events or horizons. A separate estimation firstly determines the moveout in offset by eq. (1) prior to the estimation of the parameters a_i in the orthogonal dimensions.

Equations (1) and its extension (2) are simplified versions of the general formalism where a moveout equation $f(h)$ extends to $f(h, \Delta x_i)$ by introducing extra dimensions. In the following we demonstrate the impact on the estimated parameter field that describes the moveout in offset direction using a) the single gather approach formalized by eq. (1) and b) its extended versions using supergathers.

APPLICATIONS

Residual moveout correction

A standard approach for residual moveout correction is based on eq. (1) which represents the paraxial form of the residual wavefront-curvature equation presented by Al-Yahya (1989). In this scheme each CIG gather is analyzed separately. For our purpose, we expand eq. (1) to eq. (2) and parametrize the lateral variation of a migrated horizon by the local dip in inline and crossline. This approach allows us to include neighboring gathers in the estimation scheme.

To demonstrate the impact we applied the standard scheme using single gathers and the multidimensional approach using eq. (2) on a synthetic 2D data set migrated with an incorrect velocity model. The estimation of the moveout in offset described by the parameter c was performed for every sample of the depth image at ZO using automatic picking and semblance as coherency criterion. Using the multidimensional formula (2) we applied a simultaneous estimation of the parameters c and a. The parameter c was limited by a maximum moveout of $\pm$ 1000 m at maximum offset. For the multidimensional approach we allowed a maximum dip of $\pm$ 40 degrees and included 11 CIGs in the midpoint aperture.

Figure 1 shows the estimated depth delay at maximum offset defined by c for the two schemes. One can observe that the multidimensional approach shows much less fluctuations and provides an implicit smoothing of the parameter c. Figure 2 shows the corresponding stack sections using only single CIG gathers as input for both approaches.

2D Common-reflection-surface stack

For demonstration we use a simplified version of the hyperbolic ZO-CRS formula for 2D. Therefore, we restrict to a first-order approximation in cross-gather (CMP) direction:

$$t^2(\Delta x_m, h) = (t_0 + 2\, p_x\, \Delta x_m)^2 + \frac{h^2}{v_s^2}. \tag{3}$$

Here, h denotes the offset, Δx_m the midpoint of a data trace relative to a investigated trace at zero-offset. The parameters are given by the stacking velocity v_s and the horizontal slowness component p_x of a reflection event.

By means of eq. (3) we investigate the results of three different schemes:
a) standard NMO approach: each CMP gather is analyzed independently. In this approach, Δx_m=0 and the parameter p_x has no influence.
b) standard NMO approach as described in a) followed by a smoothing algorithm.
c) superbin approach: neighboring CMP gather are mixed to incorporate more traces in the estimation of the stacking velocity. This approach is equivalent to setting p_x=0. For the application we used three neighboring CMP gathers.
d) multidimensional approach: simultaneous estimation of all parameters in equation (3) incorporating all dimensions. Here, the aperture in midpoint direction comprehends 11 CMP gathers.

We applied these scheme on a real data set using an automatic picking procedure. This means the moveout is estimated for each sample of the ZO section where a velocity value is defined by the maximum semblance in the data along the corresponding moveout. We investigated the results on a diffraction branch with a slope of $\sim 40°$. Figure 3 shows the estimated stacking velocity fields obtained by the various approaches. The velocity field estimated by a standard NMO scheme (Fig. 3a) shows strong fluctuations which could be attenuated by a subsequent smoothing procedure (Fig. 3b). Figure 3c displays the result of the superbin approach. Although, the resulting velocity field shows less fluctuations than the standard approach it looses the steep dipping diffraction pattern because a lateral variation is not taken into account. Figure 3d shows the stacking velocity field using eq. (3) without any restrictions. Here, the resulting velocity field reflects the structure of the reflection and diffraction patterns.

Figure 4 displays the CMP stacks corresponding to the stacking velocity fields shown in Figure 3. All stacks were obtained using single CMP gathers as input (standard CMP stack) and were produced with the same algorithm. Although the quality of the stacking velocity field does not necessarily reflect upon the quality of the stack, we also observe a positive impact of the multidimensional approach in this case.

CONCLUSIONS

Using cross gather information in the moveout estimation with an adequate correction term provides an implicit smoothing of the parameters along the reflection events or migrated horizons. Thereby, we increase the amount of reliable parameters and avoid fluctuations along events or horizons. This property is of benefit for a subsequent smoothing algorithm which might still be necessary to remove outliers and produce a consistent parameter field between the events. However, the computational cost is much higher compared to a standard processing.

ACKNOWLEDGMENTS

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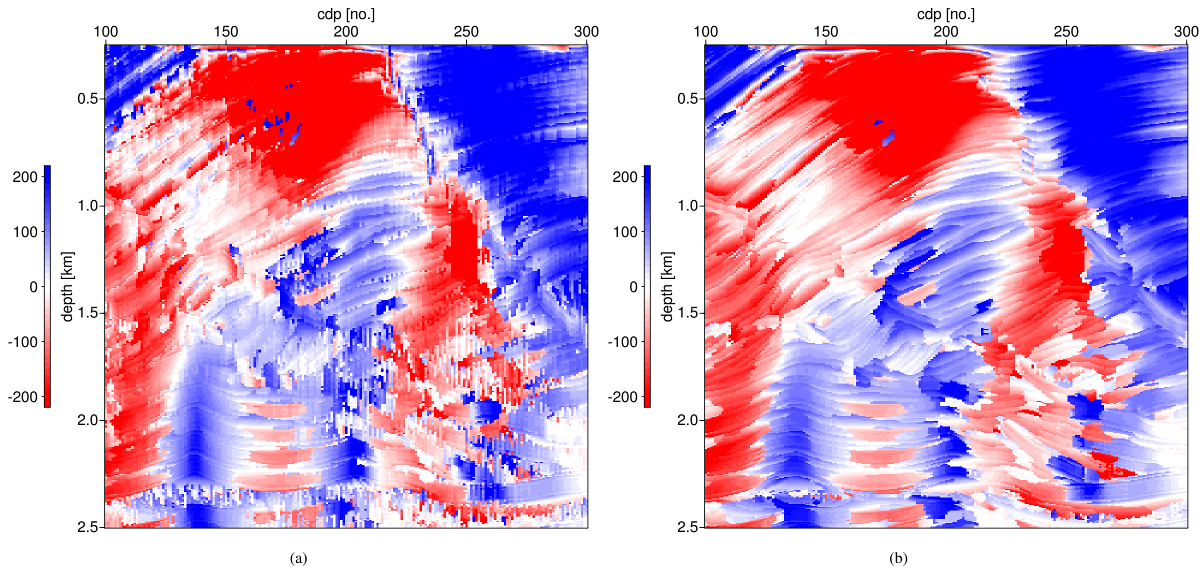

Figure 1: estimated moveout at offset 3700 m obtained by (a) standard and (b) multidimensional approach.

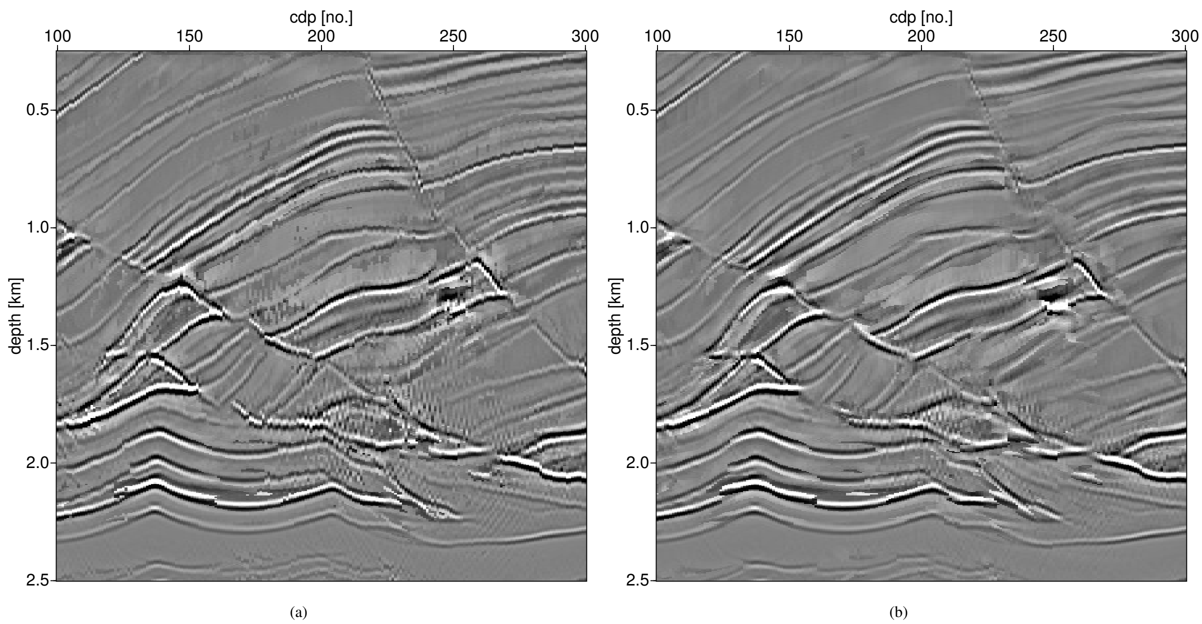

Figure 2: single CIG gather stacks using the parameters of the standard (a) and multidimensional (b) approach.

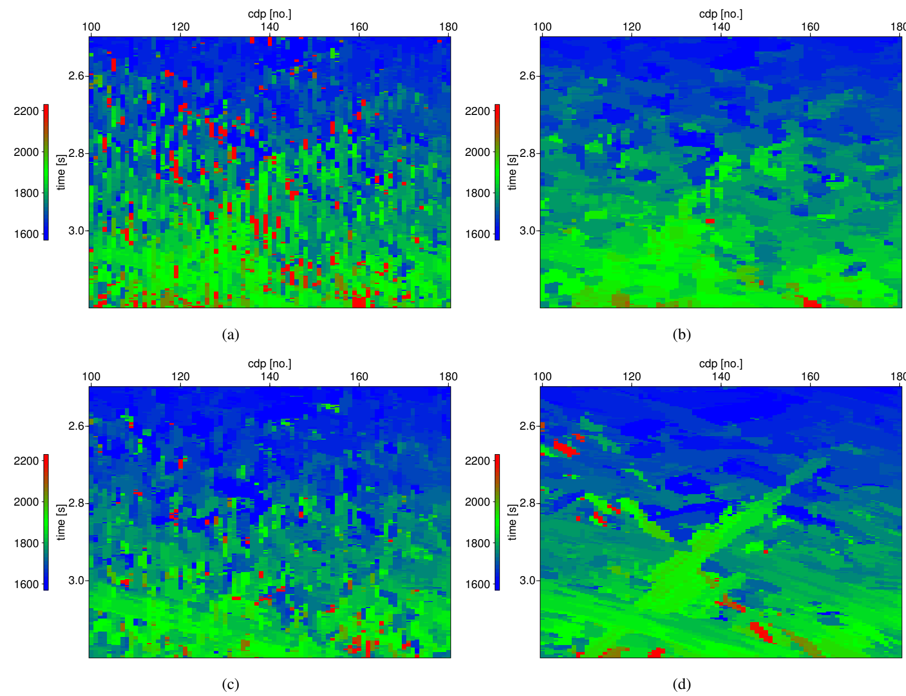

Figure 3: estimated stacking velocity from (a) individual CMP gathers, (b) smoothed field of (a), (c) superbin approach, (d) simultaneous estimation.

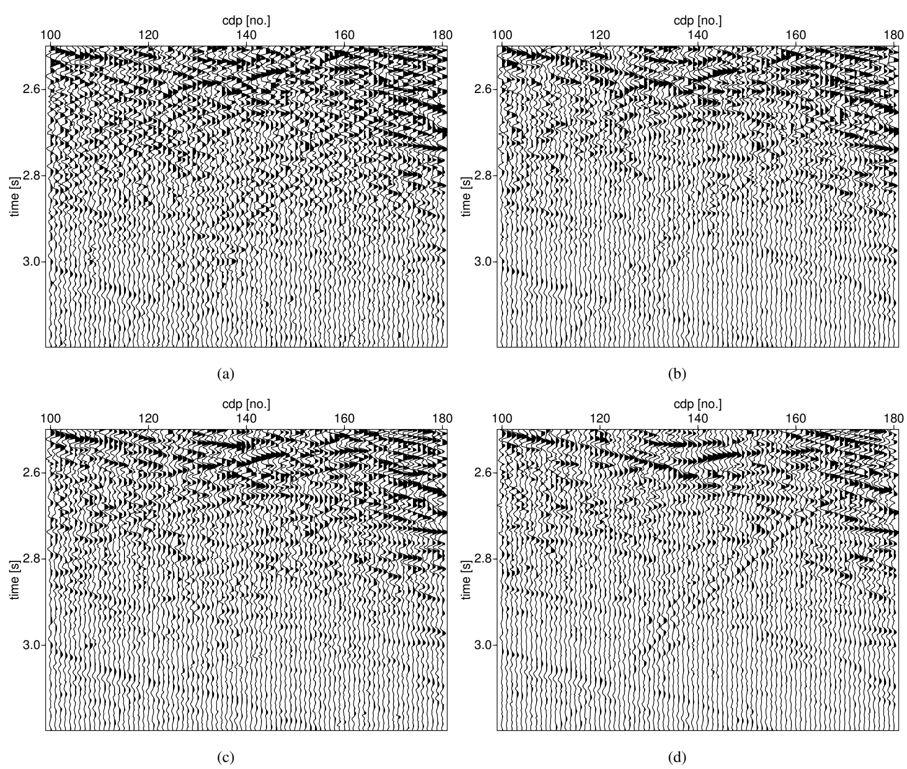

Figure 4: CMP stacks using the stacking velocity fields shown in Figure 3.

EDITED REFERENCES

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