Tomographic inversion with CRS attributes: data extraction and preconditioning

Tilman Klüver and Jürgen Mann
Geophysical Institute
University of Karlsruhe
Germany

09/22/2006

Summary

The Common-Reflection-Surface (CRS) stack method provides kinematic wavefield information in a highly-automated way from seismic reflection data. Together with a tomographic inversion scheme based on this information a fast and robust imaging workflow can be established. In order to be of use in the inversion the kinematic wavefield information has to be appropriately preconditioned and extracted.

In this abstract we briefly review the basics of the CRS stack and the related inversion. The main topic is the presentation of simple and robust strategies to remove outliers as well as fluctuations from the wavefield attributes and to extract reliable attributes suited for the inversion process.

CRS stack

The CRS method is based on a second-order approximation of the kinematic reflection response of a reflector segment in depth. The CRS operator approximates the traveltimes along paraxial rays in the vicinity of a zero-offset (ZO) central ray emerging at a given midpoint location. An explicit formulation of the 3D CRS operator can, e.g., be found in Bergler et al. (2002). In the 3D case, the operator depends on a total number of eight independent attributes: two components of the horizontal slowness vector and six independent components of matrices containing second traveltime derivatives with respect to the midpoint and offset coordinates, respectively.

Similar to conventional stacking velocity analysis, these parameters are determined by means of coherence analysis. This results in a 3D volume for each of these parameters. Assuming the near-surface velocity to be known, these eight stacking parameters can be related to so-called kinematic wavefield attributes. These are the azimuthal direction and emergence angle of the ZO central ray as well as the curvature matrices of two hypothetical wavefronts of the so-called normal (N) and normal-incidence-point (NIP) wave.

Tomographic inversion

The normal-wavefront is related to the exploding reflector experiment. This experiment is not further explained here, because it is not used in the tomographic inversion. The NIP-wavefront is related to a point source placed on the reflector at the normal-incidence-point of the ZO central ray. The NIP-wavefront reaches the acquisition surface after the one-way traveltime in the azimuthal direction with well-defined emergence angle and curvature.

For a given set of initial depth locations (normal-incidence points) and a given initial velocity model the kinematic attributes are forward calculated. The misfit between these forward modelled attributes and the ones extracted from the seismic reflection data is then iteratively minimised in the least-squares sense using a local linearisation around the current model parameters.

Finally one obtains a smooth macro-velocity model which best explains the kinematic wavefield attributes extracted from the data.

Data extraction and preconditioning

During the CRS stack, the optimum stacking operator is determined independently for each sample in the ZO volume. In this way, the NMO stretch effect is avoided. However, the sample-by-sample determination of the stacking parameters might lead to non-physical fluctuations in the obtained attribute values. Due to several facts, a stable determination of attributes might not be possible for every ZO location. In order not to distort further processing it is necessary to remove these unwanted fluctuations. In contrast to stacking velocity determined in a conventional way, the spatial traveltime derivatives used to parameterise the CRS stacking operator remain locally constant along the wavelet. Additionally, as long as paraxial ray theory is applicable, these spatial traveltime derivatives should vary smoothly along a reflection event. These two observations justify the application of an event-consistent smoothing algorithm:

for each zero offset sample and CRS parameter

- align a smoothing window with the reflection event using first traveltime derivatives
- inside this window, reject samples below user-defined coherence threshold
- reject samples with dip difference beyond a user-defined threshold with respect to the central sample
- apply a combined filter: a median filter to remove outliers and averaging around the median to remove fluctuations
- assign the result to the corresponding ZO central sample

For each smoothed attribute value, only samples on the same reflection event are considered. There is no mixing of intersecting events. This means that conflicting dip situations can be considered in a natural way and do not lead to wrong results. The combination of a mean and median filter turned out to be a simple and robust strategy to remove outliers and fluctuations from the kinematic wavefield attribute volumes. The size of the smoothing window should not exceed the temporal length of the wavelet. In the spatial dimension, its width covers several neighbouring midpoint locations.

So far we have preconditioned the data. For the actual inversion process we need a strategy to identify and extract wavefield attributes associated with actual reflection events. Note that the attributes show a random behaviour at other locations.

In order to distinguish between valuable information and noise, we apply a coherence-based automatic picking strategy using the same aligned window as applied in the smoothing process. The coherence gives a direct measure of the reliability of the kinematic wavefield attributes. In other words, the coherence is a direct measure how well the CRS stacking operator fits the prestack data. However, only using coherence as a reliability criterion in selecting picks can be misleading as one might also select picks related to correlated noise, which can have quite high coherence values. Therefore, we consider additional criteria. Our automated picking algorithm is formulated in the following way:

for each trace

- search the coherence maximum on the selected trace and go to the nearest maximum of the stack envelope
- align a window with the reflection event using first traveltime derivatives
- check if a user-defined percentage of all samples inside the window has coherence values higher than a given threshold and a dip difference with respect to the central sample below a given threshold
- optionally, check if the amplitude exceeds a user-defined threshold
- continue on the selected trace until a user-defined maximum number of picks on this trace is reached.

Thus, valid picks are not only selected according to their coherence value. Taking into account information from neighbouring samples on the same reflection event allows to check if the pick location under consideration is actually part of a locally coherent reflection event.

Conclusion

The presented strategies to smooth and extract wavefield attributes from CRS results are prerequisites for a successful and highly automated application of a CRS-based imaging workflow. Thus, all necessary tools for the CRS processing of real data related to CO_2 sequestration as well as hydrocarbon and geothermal exploration are now available.

References

S. Bergler, P. Hubral, P. Marchetti, A. Cristini, and G. Cardone, 2002, 3D Common-Reflection-Surface stack and kinematic wavefield attributes. The Leading Edge, 21(10):1010-1015.

T. Hertweck, J. Mann, T. Klüver, 2005, Event-consistent smoothing in the context of the CRS stack method, Journal of Seismic Exploration, 14(2-3):197-215

T. Klüver, J. Mann, 2005, Event-consistent smoothing and automated picking in CRS-based seismic imaging, Society of Exploration Geophysicists, Technical Program Expanded Abstracts, pages 1894-1897