Tomographic inversion with CRS attributes: data extraction and preconditioning

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Overview

Introduction

Velocity determination with 3D CRS attributes

Attribute preconditioning and extraction

Synthetic data example

Conclusions

Acknowledgments
Introduction

Construction of a background/migration velocity model is one of the key aims of seismic imaging schemes.

- Problems with conventional reflection tomography: identifying and picking events in the prestack data
- 3D velocity models for depth imaging
- Tomographic approach based on CRS stack results
- Advantages:
  - picking in simulated ZO volume of high S/N ratio
  - pick locations independent of each other
  - very few picks required
NIP waves and velocities

CRS attributes $M_h$ and $p_\xi$ at $(t_0, \xi)$ describe second-order traveltime approximation of emerging NIP wave.
NIP waves and velocities

In consistent velocity models, NIP waves focus at zero traveltime.
Tomography with CRS attributes

Find a velocity model in which all considered NIP waves, described by kinematic wavefield attributes, are correctly modeled.

For tomographic inversion in 3D, one azimuth $\phi$ of $M_h$ is required: $M_\phi$.

For multi-azimuth data the full Matrix $M_h$ is to be preferred.
3D tomography with CRS attributes

Data and model components

Data:
\((\tau, M_{11}, M_{12}, M_{22}, p_{\xi_x}, p_{\xi_y}, \xi_x, \xi_y)_i\)

\(\tau = t_0/2\)

Model:
\((x, y, z, e_x, e_y)_i, v_{jkl}\)

\(v_{jkl}: B\text{-spline coefficients}\)
Inversion procedure

- nonlinear least-squares problem:
  - iterative solution, local linearization
  - $\tau, p_{\xi_x}, p_{\xi_y}, \xi_x, \xi_y$
    from kinematic ray tracing
  - $M_h = DB^{-1}$ from dynamic ray-tracing:
    $T = \begin{pmatrix} A & B \\ C & D \end{pmatrix}$
    propagator matrix in Cartesian coordinates
- model update $\Delta m$: least-squares solution of
  $F\Delta m = \Delta d$
- calculation of Fréchet derivatives (matrix $F$):
  ray perturbation theory
Regularization/additional constraints

Regularization:
- minimization of second derivatives of velocity (spatially dependent)

Additional constraints:
- $v(x, y, z)$ values at arbitrary locations $(x, y, z)$
- force velocity structure to follow local reflector structure
Synthetic example: forward modeled attributes

Model description:

- $9 \times 9 \times 9 = 729$ B-spline knots
- Horizontal spacing: 500 m
- Vertical spacing: 400 m
- 1008 NIP-locations used to model the input data
- Initial ray direction follows local velocity gradient
CO$_2$ CRS: Tomography
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NIP waves & velocities

CRS tomography

Inversion procedure

First example

Preconditioning...

Basics

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Motivation

CRS attributes have characteristic features:
- they should be constant along the wavelet
- they should vary smoothly along the event

However, in practice
- unphysical fluctuations
- outliers
- possibly not locally coherent

Thus
- event-consistent smoothing
- identification of valid pick locations
The event-aligned volume

time

2p₀

smoothing box

seismic event

midpoint x

midpoint y

x₀

y₀

t₀
Event-consistent smoothing

For each zero-offset sample and CRS-parameter

- align smoothing volume with reflection event using first traveltime derivatives
- reject samples below user-defined coherence threshold
- reject samples with dip difference beyond user-defined threshold
  - avoid mixing of events
- apply combined filter:
  - median filter ➡️ remove outliers
  - averaging ➡️ remove fluctuations
- assign result to zero-offset sample
Automated attribute extraction

For each selected trace

- search (next) coherence maximum
- get nearest maximum of stack envelope
- align volume with reflection event using first traveltime derivatives
- reject pick if user-defined percentage of all samples inside the volume
  - is below a given coherence threshold or
  - has a dip difference exceeding a given threshold
- or if amplitude is below a user-defined threshold
  - prefer high-energy events
- continue on selected trace
Synthetic data example

interval velocity [m/s] model at $y = 5000$ m
Synthetic data example

interval velocity [m/s] model at x = 5000 m
CRS-stacked volume

inline section at $y = 5000$ m
CRS-stacked volume

crossline section at $x = 5000$ m
Automatically picked ZO locations

$p$ and $M$ available for all picks
Inversion result (1)

reconstructed velocity [m/s] model at $y = 5000$ m
reconstructed velocity [m/s] model at $x = 5000$ m
Inversion result (2)

Reconstructed NIPs
Nearest true NIPs

full 3D view
Inversion result (2)

inline view at $4000 < y < 4300$ m
Inversion result (2)

![Graph showing reconstructed NIPs and nearest true NIPs with crossline view at 8000 < x < 8300 m]
Conclusions

- 3D tomographic inversion based on CRS attributes
- Advantages:
  - very few picks are required
  - automated smoothing of attributes
  - automated picking in ZO volume
  - no assumptions about reflector continuity
  - smooth velocity model (ideal for ray tracing)
- Limitations:
  - smooth velocity description must be valid
  - limited lateral variation within CRS apertures (approximately hyperbolic traveltimes)
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