Double diffraction stack for an alternative strategy for CRS-based limited-aperture Kirchhoff depth migration

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Overview

Motivation

CRS-based limited-aperture migration

Alternative approach

Synthetic data

Real land data

Conclusions
Motivation

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Jäger (2005)
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Conclusions
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Conclusions
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Limited aperture = optimum aperture
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- minimized unwanted contributions
- optimum S/N ratio
Motivation

Limited aperture = optimum aperture
  ▶ minimized unwanted contributions
    ➡ optimum S/N ratio
  ▶ less summations required
    ➡ increased performance
Motivation

Limited aperture = optimum aperture

- minimized unwanted contributions
  - optimum S/N ratio
- less summations required
  - increased performance
- reduced migration artifacts, no operator aliasing
Motivation

Limited aperture = optimum aperture

- minimized unwanted contributions
  ⇒ optimum S/N ratio
- less summations required
  ⇒ increased performance
- reduced migration artifacts, no operator aliasing
- smallest aperture allowing true-amplitude processing
Motivation

Required properties for limited aperture
Motivation

Required properties for limited aperture

- location of aperture
  ➤ stationary point
Motivation

Required properties for limited aperture

- location of aperture
  - stationary point
- size of aperture
  - projected Fresnel zone
Motivation

Required properties for limited aperture

- location of aperture
  - stationary point
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both as functions of offset
CRS-based limited-aperture migration

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CRS-based approach
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Conclusions
CRS-based limited-aperture migration

CRS attributes (here: 2D)
CRS-based limited-aperture migration

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- emergence angle $\alpha$ ➞ dip of reflection event
CRS-based limited-aperture migration

CRS attributes (here: 2D)

- emergence angle $\alpha \Rightarrow$ dip of reflection event
- radius of NIP wavefront $R_{\text{NIP}}$
CRS-based limited-aperture migration

CRS attributes (here: 2D)

- emergence angle $\alpha \Leftrightarrow$ dip of reflection event
- radius of NIP wavefront $R_{\text{NIP}}$
- radius of normal wavefront $R_N$

\[ W_{\text{F}}^2 = \cos \alpha \left( 1 + \left| \frac{R_N - 1}{R_{\text{NIP}}} \right| \right) \]

\[ x_m(h) = x_0 + R_{\text{NIP}} \frac{\sqrt{h^2 + 1} - 1}{\sin \alpha} \]

Motivation
CRS-based approach
Alternative approach
Synthetic data
Real land data
Conclusions
CRS-based limited-aperture migration

CRS attributes (here: 2D)

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Derived properties
**CRS-based limited-aperture migration**

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- emergence angle $\alpha \Rightarrow$ dip of reflection event
- radius of NIP wavefront $R_{\text{NIP}}$
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**Derived properties**
- projected ZO Fresnel zone

\[
\frac{W_F}{2} = \frac{1}{\cos \alpha} \sqrt{\frac{v_0 T}{2\left|\frac{1}{R_N} - \frac{1}{R_{\text{NIP}}}\right|}}
\]
CRS-based limited-aperture migration

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- projection of CRP trajectory

\[
x_m(h) = x_0 + r_T \left(\sqrt{\frac{h^2}{r_T^2}} + 1 - 1\right)
\]

with

\[
r_T = \frac{R_{\text{NIP}}}{2 \sin \alpha}
\]
CRS-based limited-aperture migration

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CRS-based approach

Alternative approach

Synthetic data

Real land data

Conclusions
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Available so far
CRS-based limited-aperture migration

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- size of aperture for offset zero
CRS-based limited-aperture migration

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- size of aperture for offset zero
- extrapolation of stationary point to finite offset
CRS-based limited-aperture migration

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Still missing
CRS-based limited-aperture migration

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  - less critical
CRS-based limited-aperture migration

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- extrapolation of projected Fresnel zone ➔ less critical
- stationary point not yet related to migrated image point ➔ crucial!
CRS-based limited-aperture migration

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- size of aperture for offset zero
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Still missing
- extrapolation of projected Fresnel zone ➞ less critical
- stationary point not yet related to migrated image point ➞ crucial!

current solution:
application of tangency criterion for offset zero
migration operator dip $\uparrow$ reflection event dip
Alternative approach

Problems with tangency criterion
▶ reflection event dip not available/reliable at all locations
▶ migration operator dip has to be calculated numerically from GFTs (depth migration)
¯ determination of the stationary point not sufficiently solved
alternative approach will be tested:
vector diffraction stack i.e. multiple application of Kirchhoff migration with different weight functions (e.g., Tygel; 1993)
Alternative approach

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DD stack for
CRS-based
limited-aperture
Kirchhoff depth
migration
I. Veile and J. Mann

Alternative approach

Kirchhoff migration
▶ migrates energy from stationary point to image point
▶ is a linear process
also migrates any superimposed information (with slow lateral variation)

General idea
▶ migrate with unit weight
▶ migrate with superimposed information
ratio of migration results recovers superimposed information at migrated location
Alternative approach

Kirchhoff migration
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- stationary point characterized by trace location
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General problem
- not all image points are associated with actual stationary points
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General problem

- not all image points are associated with actual stationary points
  ➤ criterion required for identification
Simple synthetic model

Model properties:

- Two horizontal reflectors
- Homogeneous background model

Consequences:
- No GFTs required
- Picking in depth domain trivial
- Stationary point expected to coincide with depth image point
Simple synthetic model

Model properties:

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Location of stationary point
Displacement of stationary point

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CRS-based approach
Alternative approach
Synthetic data
Real land data
Conclusions
Displacement error [m] as function of noise level

black: first event, gray: second event
Traces as function of noise level

![Graph showing traces as a function of noise level.](image-url)
Displacement error [m] along wavelet

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Alternative approach

Synthetic data

Real land data

Conclusions
Observations
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- Double diffraction stack in principle applicable
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- Problems to be addressed:
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  - instability for zero-crossings of wavelet
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  - results only reliable and meaningful along reflection events
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- Double diffraction stack in principle applicable
- Problems to be addressed:
  - instability for zero-crossings of wavelet
  - background migration noise
  - results only reliable and meaningful along reflection events
    ➞ (automated) identification required
Real land data

Acquisition parameters:
Real land data

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- fixed split-spread layout
Real land data

Acquisition parameters:
- fixed split-spread layout
- total line length $\approx 12$ km
Real land data

Acquisition parameters:
- fixed split-spread layout
- total line length $\approx 12$ km
- shot and receiver spacing 50 m
Real land data

Acquisition parameters:

- fixed split-spread layout
- total line length \( \approx 12 \text{ km} \)
- shot and receiver spacing 50 m
- temporal sampling rate 2 ms
Real land data

Acquisition parameters:
- fixed split-spread layout
- total line length \( \approx 12 \text{ km} \)
- shot and receiver spacing 50 m
- temporal sampling rate 2 ms
- linear upsweep of 10 s from 12 to 100 Hz
Real land data

Acquisition parameters:
- fixed split-spread layout
- total line length \(\approx 12\) km
- shot and receiver spacing 50 m
- temporal sampling rate 2 ms
- linear upsweep of 10 s from 12 to 100 Hz
- standard preprocessing
Real land data

Acquisition parameters:

- fixed split-spread layout
- total line length $\approx 12$ km
- shot and receiver spacing 50 m
- temporal sampling rate 2 ms
- linear upsweep of 10 s from 12 to 100 Hz
- standard preprocessing
- see, e.g., Hertweck et al. (2004)
Conventional depth migration
Displacement of stationary point

Depth [km] 0 2 4 6 8 10

Distance [km]

Displacement of stationary point [m]

-400 -300 -200 -100 0 100 200 300 400

Distance of stationary point [m]
Displacement based on trace envelopes
Displacement after event-consistent smoothing
<table>
<thead>
<tr>
<th>Distance [km]</th>
<th>Depth [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1.5</td>
</tr>
<tr>
<td>5</td>
<td>1.7</td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>
Displacement [m] after event-consistent smoothing
Displacement [m] after event-consistent smoothing
Displacement [m] after event-consistent smoothing

![Image of displacement after event-consistent smoothing](image-url)
Displacement [m] after event-consistent smoothing
Workflow to calculate stationary points

- Weight input data with trace location
- Perform double diffraction stack
- Calculate envelopes of analytic signal
- No more zero-crossing problems!
- Calculate ratio of double diffraction stack results
- Perform partial “CRS stack” in depth domain
- Identification of events
- Provides subset of “wavefield attributes”
- Perform event-consistent smoothing
- Attenuates migration noise
Workflow to calculate stationary points

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  ▶ provides subset of “wavefield attributes”
- perform event-consistent smoothing
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Dip-based strategy vs. double diffraction stack

Stationary point displacement DB, DDS. PFZ width DB, DDS.
Conclusions & Outlook
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- Dip-based errors tolerable due to near-1D data. Might not hold for more complex structures!
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- However: large aperture required to capture steep events
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    ➣ operator aliasing might affect stationary points
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    - introduces artifacts in limited-aperture migration (although not subject to operator aliasing itself)
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- However:
  - large aperture required to capture steep events
    - operator aliasing might affect stationary points
    - introduces artifacts in limited-aperture migration (although not subject to operator aliasing itself)
    - anti-aliasing filter useful during double diffraction stack?
DD stack for CRS-based limited-aperture Kirchhoff depth migration

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