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

Ines Veile and Jürgen Mann

Geophysical Institute, University of Karlsruhe (TH)
Wave Inversion Technology (WIT)

Salvador, Bahia, Brazil, August 26th, 2009

Overview

Motivation

CRS-based limited-aperture migration

Alternative approach

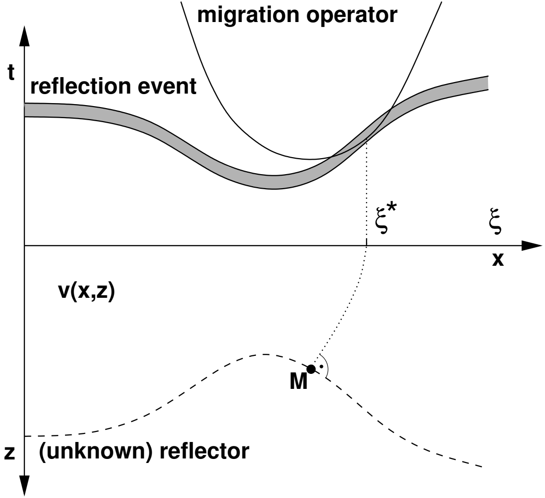
Synthetic data

Real land data

Conclusions

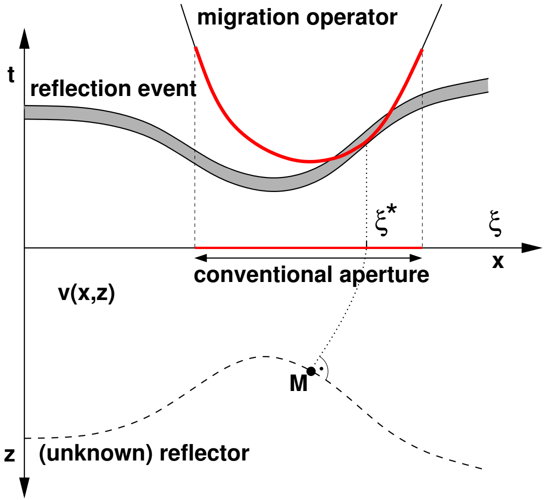
Motivation

Motivation



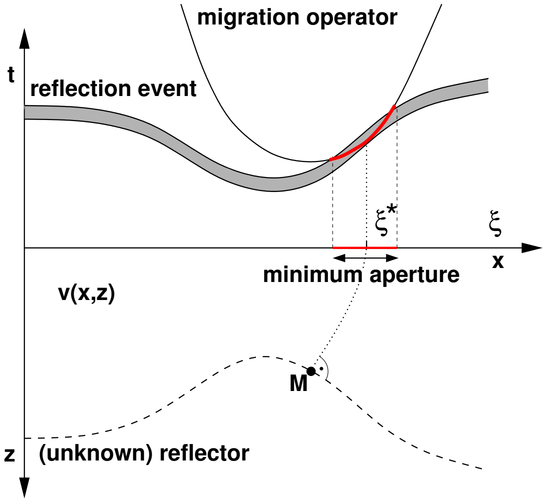
Jäger (2005)

Motivation



Jäger (2005)

Motivation



Jäger (2005)

Motivation

Limited aperture = optimum aperture

Motivation

Limited aperture = optimum aperture

- 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
- size of aperture
  ➥ projected Fresnel zone

both as functions of offset

CRS-based limited-aperture migration

CRS-based limited-aperture migration

CRS attributes (here: 2D)

I. Veile and J. Mann

CRS-based limited-aperture migration

CRS attributes (here: 2D)

- emergence angle α ➥ dip of reflection event

CRS-based limited-aperture migration

CRS attributes (here: 2D)

- emergence angle α ➥ dip of reflection event
- radius of NIP wavefront R_{NIP}

CRS-based limited-aperture migration

CRS attributes (here: 2D)

- emergence angle α ➥ dip of reflection event
- radius of NIP wavefront R_{NIP}
- radius of normal wavefront R_{N}

CRS-based limited-aperture migration

CRS attributes (here: 2D)

- emergence angle α ➥ dip of reflection event
- radius of NIP wavefront R_{NIP}
- radius of normal wavefront R_{N}

Derived properties

CRS-based limited-aperture migration

CRS attributes (here: 2D)

- emergence angle α ➥ dip of reflection event
- radius of NIP wavefront R_{NIP}
- radius of normal wavefront R_{N}

Derived properties

- projected ZO Fresnel zone

$$\frac{W_{\mathrm{F}}}{2} = \frac{1}{\cos\alpha}\sqrt{\frac{v_0\,T}{2\left|\frac{1}{R_{\mathrm{N}}} - \frac{1}{R_{\mathrm{NIP}}}\right|}}$$

CRS-based limited-aperture migration

CRS attributes (here: 2D)

- emergence angle α ➥ dip of reflection event
- radius of NIP wavefront R_{NIP}
- radius of normal wavefront R_{N}

Derived properties

- projected ZO Fresnel zone

$$\frac{W_{\mathrm{F}}}{2} = \frac{1}{\cos\alpha}\sqrt{\frac{v_0\,T}{2\left|\frac{1}{R_{\mathrm{N}}} - \frac{1}{R_{\mathrm{NIP}}}\right|}}$$

- projection of CRP trajectory

$$x_{\mathrm{m}}(h) = x_0 + r_{\mathrm{T}}\left(\sqrt{\frac{h^2}{r_{\mathrm{T}}^2} + 1} - 1\right) \quad \text{with} \quad r_{\mathrm{T}} = \frac{R_{\mathrm{NIP}}}{2\sin\alpha}$$

CRS-based limited-aperture migration

CRS-based limited-aperture migration

Available so far

CRS-based limited-aperture migration

Available so far

- size of aperture for offset zero

CRS-based limited-aperture migration

Available so far

- size of aperture for offset zero
- extrapolation of stationary point to finite offset

CRS-based limited-aperture migration

Available so far

- size of aperture for offset zero
- extrapolation of stationary point to finite offset

Still missing

CRS-based limited-aperture migration

Available so far

- size of aperture for offset zero
- extrapolation of stationary point to finite offset

Still missing

- extrapolation of projected Fresnel zone
  ➥ less critical

CRS-based limited-aperture migration

Available so far

- size of aperture for offset zero
- extrapolation of stationary point to finite offset

Still missing

- extrapolation of projected Fresnel zone
  ➥ less critical
- stationary point not yet related to migrated image point ➥ crucial!

CRS-based limited-aperture migration

Available so far

- size of aperture for offset zero
- extrapolation of stationary point to finite offset

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 $\overset{!}{=}$ reflection event dip

Alternative approach

Alternative approach

Problems with tangency criterion

Alternative approach

Problems with tangency criterion

- reflection event dip not available/reliable at all locations

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)

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

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

Alternative approach

Kirchhoff migration

Alternative approach

Kirchhoff migration

- migrates energy from stationary point to image point

Alternative approach

Kirchhoff migration

- migrates energy from stationary point to image point
- is a linear process

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)

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

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

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

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

Alternative approach

Determination of stationary point

Alternative approach

Determination of stationary point

- stationary point characterized by trace location

Alternative approach

Determination of stationary point

- stationary point characterized by trace location
  ➥ trace location serves as migration weight

Alternative approach

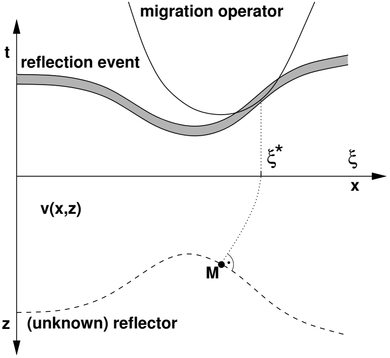
Determination of stationary point

- stationary point characterized by trace location
  ➥ trace location serves as migration weight
- ratio of migration results represents locations of stationary points

Alternative approach

Determination of stationary point

- stationary point characterized by trace location
  ➥ trace location serves as migration weight
- ratio of migration results represents locations of stationary points



Alternative approach

Determination of stationary point

- stationary point characterized by trace location
  ➥ trace location serves as migration weight
- ratio of migration results represents locations of stationary points

Advantages in this context

Alternative approach

Determination of stationary point

- stationary point characterized by trace location
  ➥ trace location serves as migration weight
- ratio of migration results represents locations of stationary points

Advantages in this context

- only required for offset zero

Alternative approach

Determination of stationary point

- stationary point characterized by trace location
  ➥ trace location serves as migration weight
- ratio of migration results represents locations of stationary points

Advantages in this context

- only required for offset zero
  ➥ poststack vector diffraction stack is sufficient

Alternative approach

Determination of stationary point

- stationary point characterized by trace location
  ➥ trace location serves as migration weight
- ratio of migration results represents locations of stationary points

Advantages in this context

- only required for offset zero
  ➥ poststack vector diffraction stack is sufficient
- based on CRS-stacked section with high S/N ratio

Alternative approach

Determination of stationary point

- stationary point characterized by trace location
  ➥ trace location serves as migration weight
- ratio of migration results represents locations of stationary points

Advantages in this context

- only required for offset zero
  ➥ poststack vector diffraction stack is sufficient
- based on CRS-stacked section with high S/N ratio

General problem

Alternative approach

Determination of stationary point

- stationary point characterized by trace location
  ➥ trace location serves as migration weight
- ratio of migration results represents locations of stationary points

Advantages in this context

- only required for offset zero
  ➥ poststack vector diffraction stack is sufficient
- based on CRS-stacked section with high S/N ratio

General problem

- not all image points are associated with actual stationary points

Alternative approach

Determination of stationary point

- stationary point characterized by trace location
  ➥ trace location serves as migration weight
- ratio of migration results represents locations of stationary points

Advantages in this context

- only required for offset zero
  ➥ poststack vector diffraction stack is sufficient
- based on CRS-stacked section with high S/N ratio

General problem

- not all image points are associated with actual stationary points
  ➥ criterion required for identification

Simple synthetic model

Model properties:

Simple synthetic model

Model properties:

- two horizontal reflectors

Simple synthetic model

Model properties:

- two horizontal reflectors
- homogeneous background model

Simple synthetic model

Model properties:

- two horizontal reflectors
- homogeneous background model

Consequences:

Simple synthetic model

Model properties:

- two horizontal reflectors
- homogeneous background model

Consequences:

- no GFTs required

Simple synthetic model

Model properties:

- two horizontal reflectors
- homogeneous background model

Consequences:

- no GFTs required
- picking in depth domain trivial

Simple synthetic model

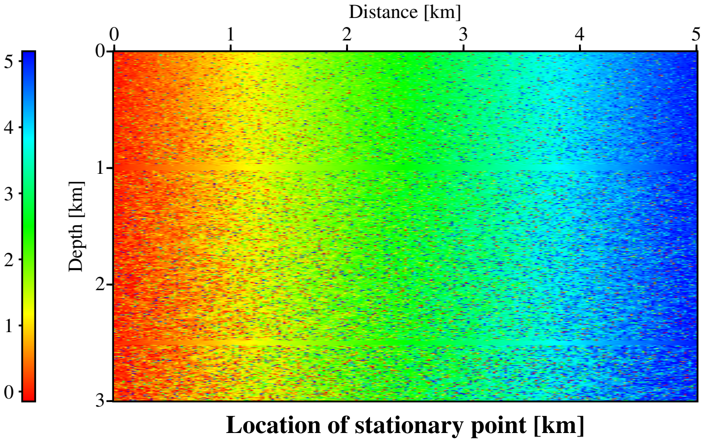
Model properties:

- two horizontal reflectors
- homogeneous background model

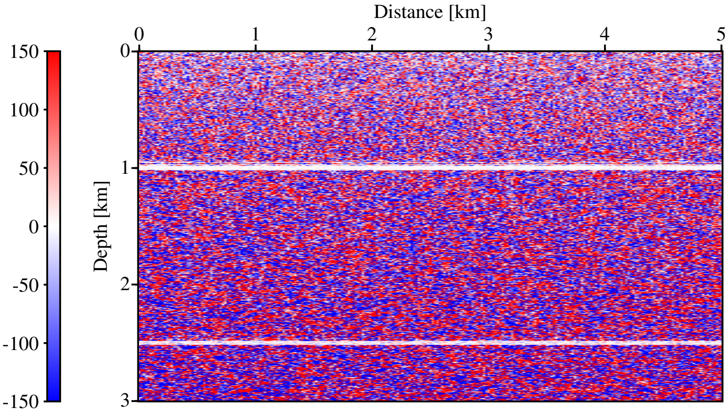
Consequences:

- no GFTs required
- picking in depth domain trivial
- stationary point expected to coincide with depth image point

Location of stationary point

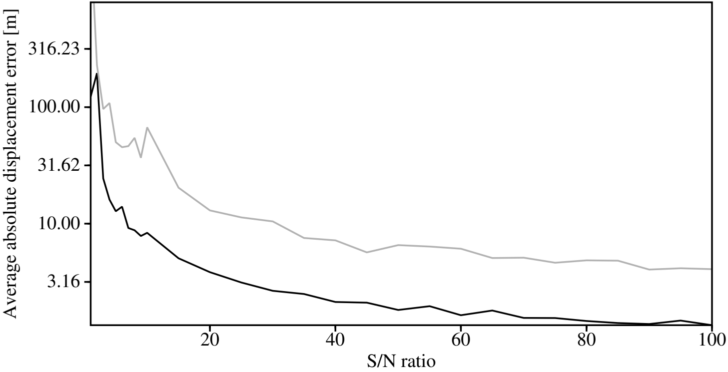


Displacement of stationary point



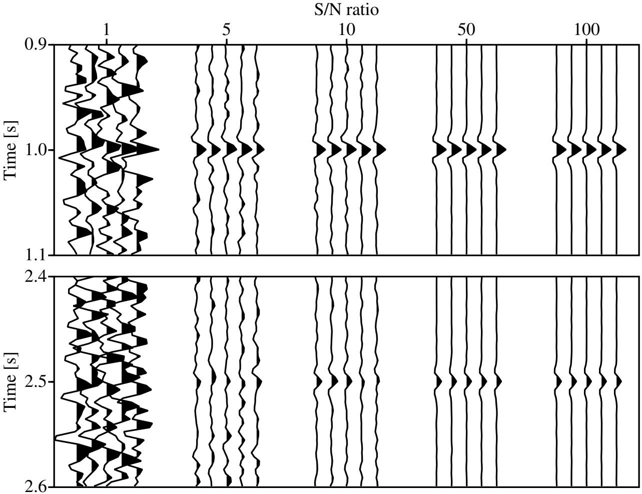
Displacement of stationary point [m]

Displacement error [m] as function of noise level

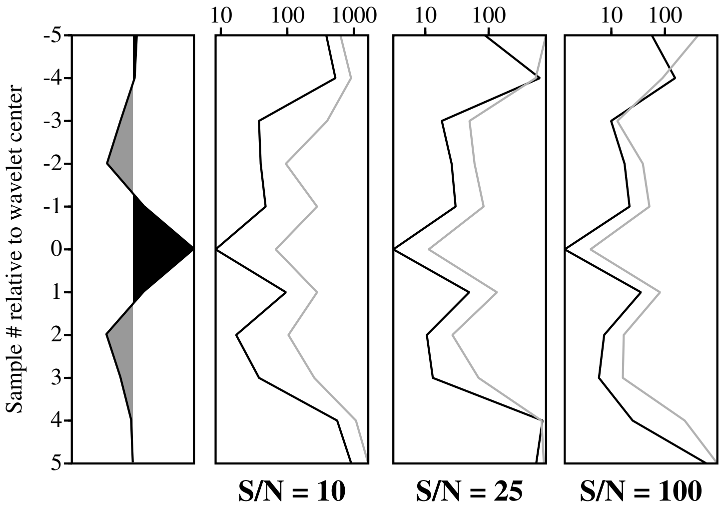


black: first event, gray: second event

Traces as function of noise level



Displacement error [m] along wavelet



Observations

Observations

- Double diffraction stack in principle applicable

Observations

- Double diffraction stack in principle applicable
- Problems to be addressed:

Observations

- Double diffraction stack in principle applicable
- Problems to be addressed:
    - instability for zero-crossings of wavelet

Observations

- Double diffraction stack in principle applicable
- Problems to be addressed:
  - instability for zero-crossings of wavelet
  - background migration noise

Observations

- 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

Observations

- 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

Acquisition parameters:

- fixed split-spread layout

Real land data

Acquisition parameters:

- fixed split-spread layout
- total line length $\approx 12\,\text{km}$

Real land data

Acquisition parameters:

- fixed split-spread layout
- total line length $\approx 12\,\text{km}$
- shot and receiver spacing $50\,\text{m}$

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

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:

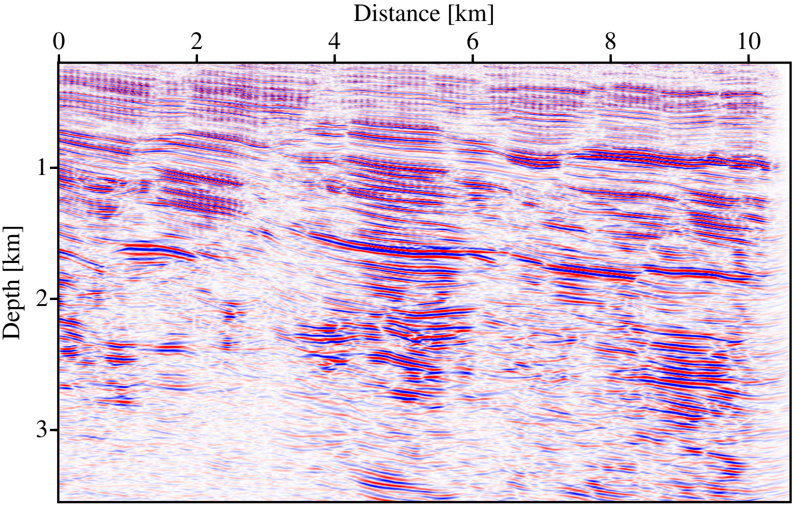
- fixed split-spread layout
- total line length $\approx$ 12 km
- shot and receiver spacing 50 m
- temporal sampling rate 2 ms
- linear upsweep of 10 s from 12 to 100 Hz
- standard preprocessing

Real land data

Acquisition parameters:

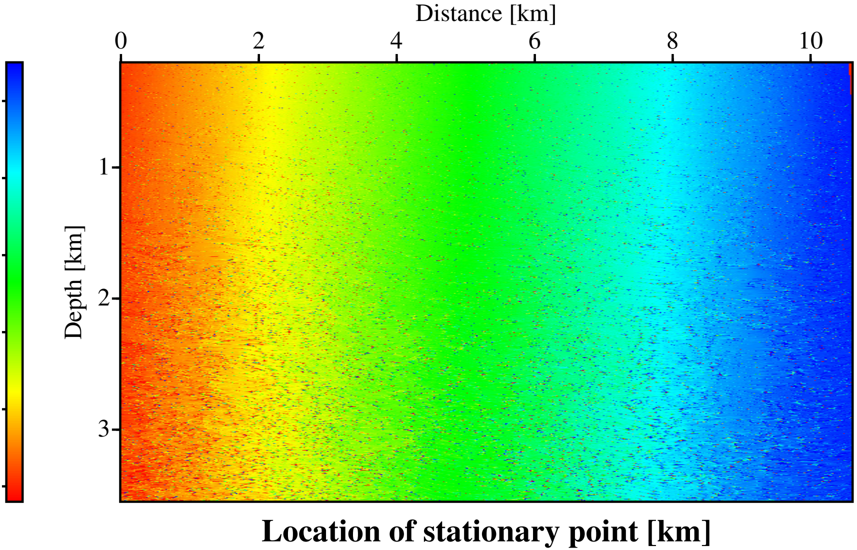
- fixed split-spread layout
- total line length $\approx$ 12 km
- shot and receiver spacing 50 m
- temporal sampling rate 2 ms
- linear upsweep of 10 s from 12 to 100 Hz
- standard preprocessing
- see, e. g., Hertweck et al. (2004)

Conventional depth migration

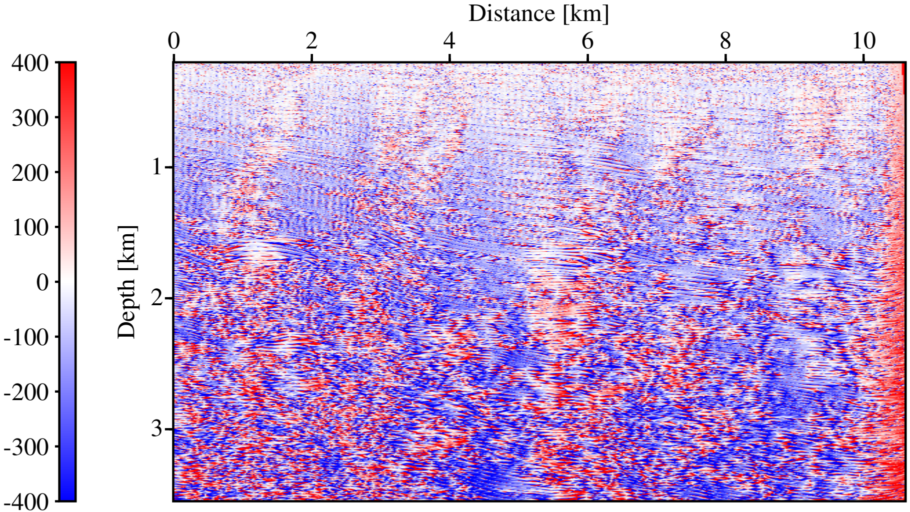


Migrated section

Location of stationary point

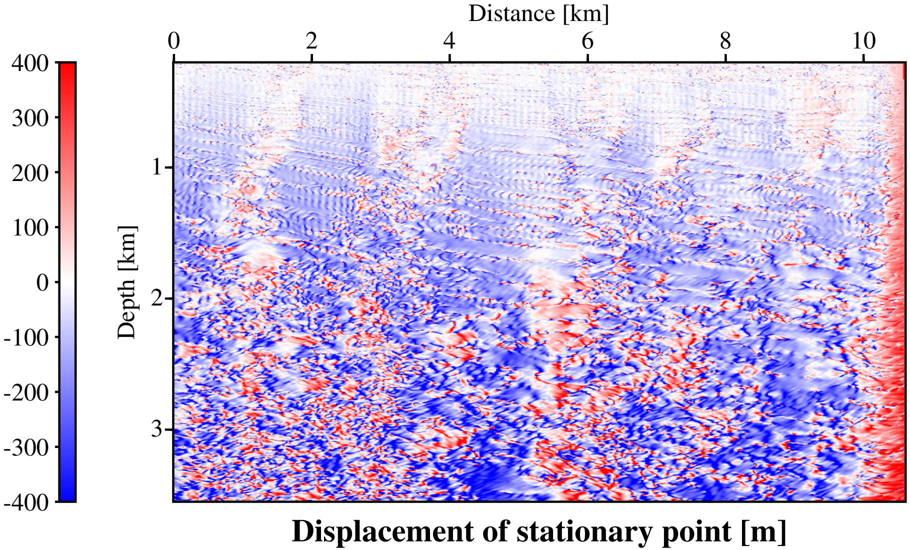


Displacement of stationary point

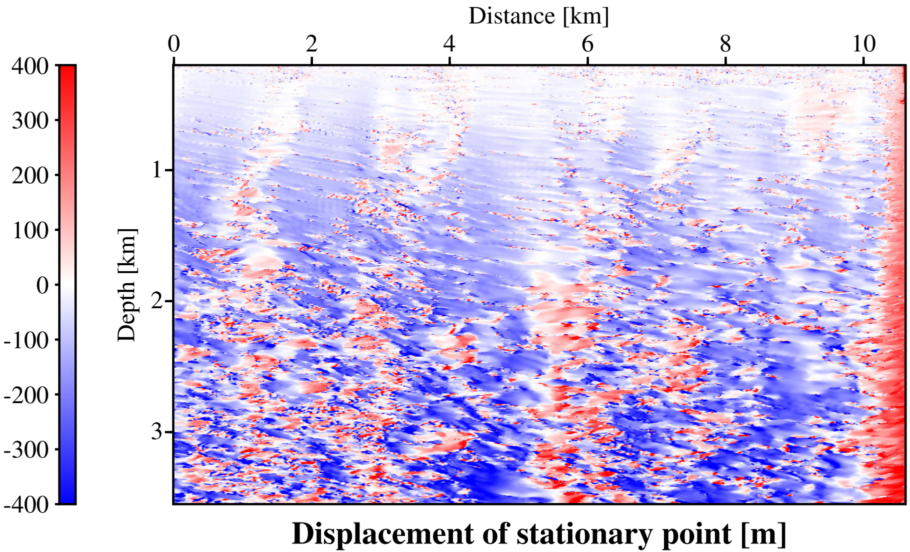


Displacement of stationary point [m]

Displacement based on trace envelopes

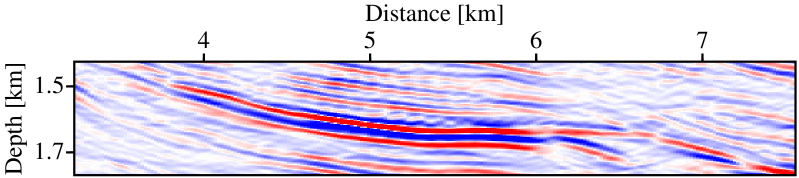


Displacement after event-consistent smoothing

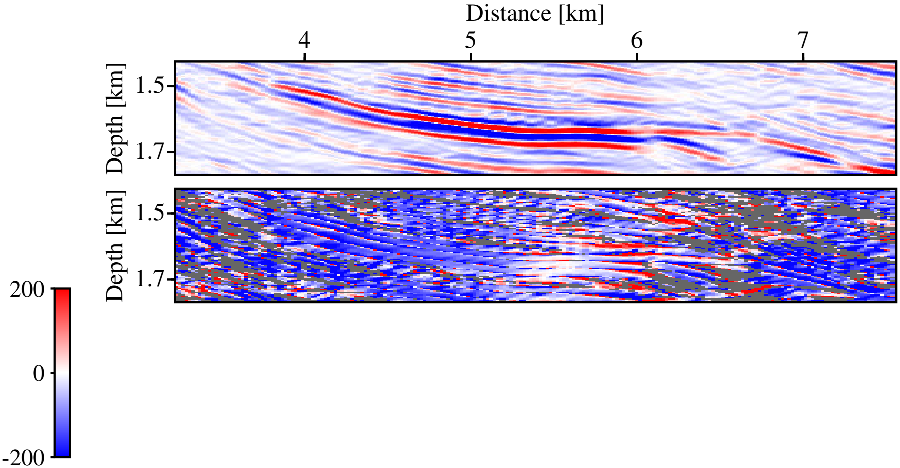


Displacement [m] after event-consistent smoothing

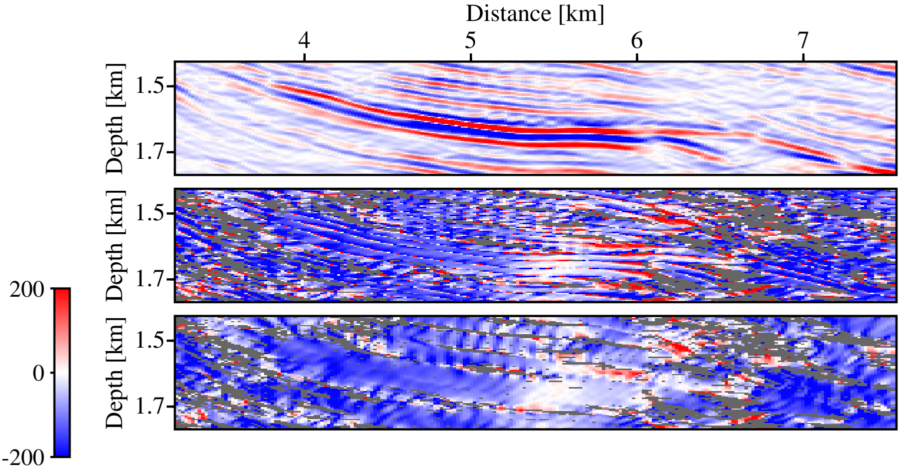
Displacement [m] after event-consistent smoothing



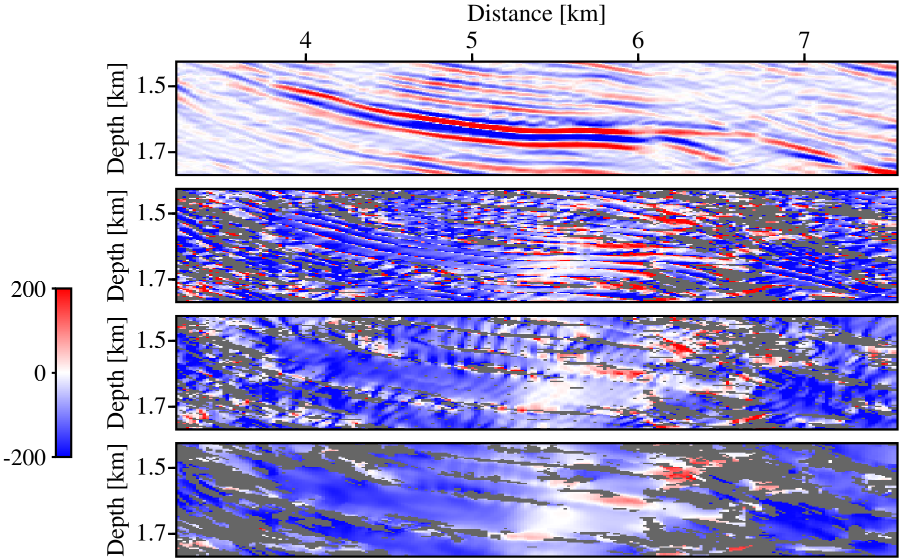
Displacement [m] after event-consistent smoothing



Displacement [m] after event-consistent smoothing



Displacement [m] after event-consistent smoothing



Workflow to calculate stationary points

Workflow to calculate stationary points

- Weight input data with trace location

Workflow to calculate stationary points

- Weight input data with trace location
- Perform double diffraction stack

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!

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

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

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

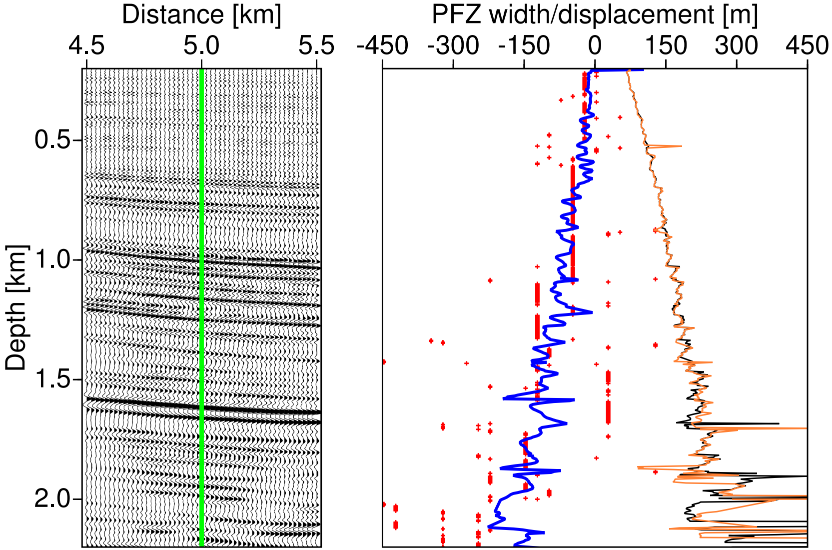
Workflow to calculate stationary points

- 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"

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

Dip-based strategy vs. double diffraction stack



Stationary point displacement DB, DDS. PFZ width DB, DDS.

Conclusions & Outlook

Conclusions & Outlook

- Double diffraction stack results more plausible

Conclusions & Outlook

- Double diffraction stack results more plausible
- Dip-based errors tolerable due to near-1D data.
  Might not hold for more complex structures!

Conclusions & Outlook

- Double diffraction stack results more plausible
- Dip-based errors tolerable due to near-1D data. Might not hold for more complex structures!
- However:
  large aperture required to capture steep events

Conclusions & Outlook

- Double diffraction stack results more plausible
- Dip-based errors tolerable due to near-1D data. Might not hold for more complex structures!
- However:
  large aperture required to capture steep events
  - ➥ operator aliasing might affect stationary points

Conclusions & Outlook

- Double diffraction stack results more plausible
- Dip-based errors tolerable due to near-1D data. Might not hold for more complex structures!
- 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)

Conclusions & Outlook

- Double diffraction stack results more plausible
- Dip-based errors tolerable due to near-1D data. Might not hold for more complex structures!
- 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?