Event-consistent smoothing in generalized high-density velocity analysis

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Introduction

Conventional stacking velocity analysis:

- (semi-)interactive, interpretative velocity picking
- coarse picks on selected key events, only
- human interaction required
- low temporal and spatial resolution
- pulse stretch deteriorates stack result

Thus desirable:

- automated approach
- more appropriate parameterization
- maximum resolution
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Common-Reflection-Surface (CRS) stack

Generalization of conventional approach:

▷ second-order approximation of traveltime
▷ fully automated coherence-based application
▷ high-density analysis
▷ spatial stacking operator

▷ additional stacking parameters related to 1. and 2. traveltime derivatives
▷ geometrical interpretation
Common-Reflection-Surface (CRS) stack

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Geometrical interpretation of stacking parameters:

Emergence direction and curvatures of hypothetical wavefronts:

- exploding point source is normal-incidence-point (NIP) wave
- exploding reflector is normal (N) wave
Common-Reflection-Surface stack

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High-density analysis vs. smoothing

Stacking parameters are subject to

- fluctuations due to noise
- outliers due to failures to detect the relevant coherence maximum

Stacking parameters represent integral properties of the subsurface

- smooth variation along reflection events
- event-consistent smoothing along reflection events is justified!
High-density analysis vs. smoothing

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High-density analysis vs. smoothing

Bandwidth is limited. What happens along the wavelet?

- high-density stacking velocity
  - systematic variation along wavelet
  - smoothing reintroduces pulse stretch phenomenon
- CRS stacking parameters

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Pulse stretch phenomenon
Smooth model: stacking velocity vs. CRS parameters

Smoothing algorithm

Requirements:
- smoothing along reflection events justified ✔
- smoothing along wavelet justified
- remaining task: ensure event consistence

CRS stack provides:
- local shape of zero-offset reflection event ($\alpha$, $R_N$)
- approximation of projected Fresnel zone
- coherence values as measure of reliability
- this allows a simple and efficient smoothing algorithm
Smoothing algorithm

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For each zero-offset sample and each CRS parameter

- align smoothing window along reflection event using emergence angle $\alpha$ (optionally also $R_N$)
- reject samples below given coherence threshold ▶ use only reliable attributes
- reject samples with dip difference beyond threshold ▶ avoid mixing of intersecting events
- apply combined filter:
  - median filter ▶ remove outliers
  - averaging ▶ remove fluctuations
- assign result to zero-offset sample
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For each zero-offset sample and each CRS parameter

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Smoothing algorithm

Size of smoothing window:

- as small as possible, as large as required
- temporal extension $\leq$ wavelet length
- lateral extension $\ll$ projected Fresnel zone, either fixed or a fraction of approximate Fresnel zone given by CRS parameters

Smoothing in the 3D case:

- smoothing window is a small volume
- same selection criteria as in 2D
- combined filter has to be generalized for curvature matrices and slowness vectors
  - current research
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CRS stack section

Location [km]

Time [s]

1.0
1.5
2.0
2.5
3.0
3.5
0 2 4 6 8 10

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Coherence

Emergence angle [°]

NIP wave radius [km]

Coherence-based mask applied
(for visualization, only)
Schematic example

Coherence

Emergence angle [°]

NIP wave radius [km]

Smoothing window aligned with reflection event
Schematic example

Select all samples in window
Schematic example

Apply coherence threshold and dip difference threshold
Schematic example

Smoothing:

- Sort remaining samples by magnitude
Schematic example

Smoothing:

- Sort remaining samples by magnitude
- Average given fraction of samples around median
Schematic example

Coherence

Emergence angle [°]

NIP wave radius [km]

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Schematic example

Coherence
Emergence angle [°]
NIP wave radius [km]

Repeated for all location smoothed attribute sections
Real data example

CRS parameter sections (detail)

Emergence angle [°]  NIP wave radius [m]

Original parameters as obtained by CRS stack (no coherence mask applied)
Real data example

CRS parameter sections (detail)

Emergence angle [°]  NIP wave radius [m]

Original parameters as obtained by CRS stack (coherence mask applied for display, only)
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Emergence angle [°]  NIP wave radius [m]

Smoothed parameters
(coherence mask applied for display, only)
Real data examples

CRS stack sections (detail I)

Stack with original vs. stack with smoothed parameters
Real data examples

CRS stack sections (detail II)

Stack with original vs. stack with smoothed parameters
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- based on CRS stacking parameters and coherence
- removes outliers
- removes fluctuations
- preserves kinematic properties of reflection events
- avoids mixing of intersecting events
- improved quality of stacked section
- more physical CRS stacking parameter sections for various applications like macromodel determination etc.
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Related presentations

Session SP 4, Thursday morning:

**SP 4.4** A seismic reflection imaging workflow based on the common-reflection-surface (CRS) stack: theoretical background and case study

**SP 4.5** CRS imaging and tomography versus PreSDM: a case history in overthrust geology

**SP 4.6** CRS stack and redatuming for rugged surface topography: a synthetic data example

**SP 4.8** 3D focusing operator estimation using sparse data