CRS-stack-based seismic imaging for land data – a case study from Saudi Arabia

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Outline

Introduction

Common-Reflection-Surface stack

Land-data processing

Topography handling
Residual static correction
Redatuming

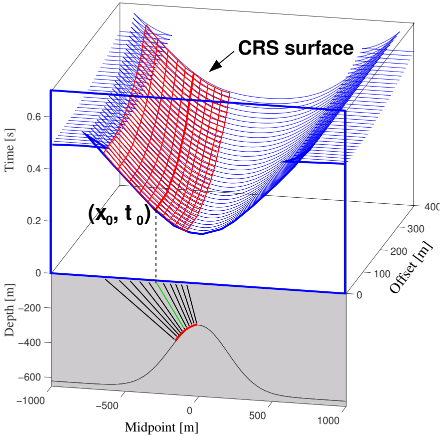
Real data example

Data set
CRS stack
Tomographic inversion
Depth migration

Conclusions

Common-Reflection-Surface stack

- Alternative to standard NMO/DMO/stack approach
- Principle:
  - Second-order approximation of reflection events
  - Coherence-based, high-density, multidimensional stacking parameter analysis



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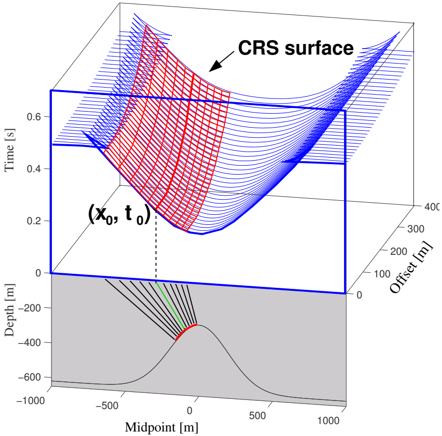

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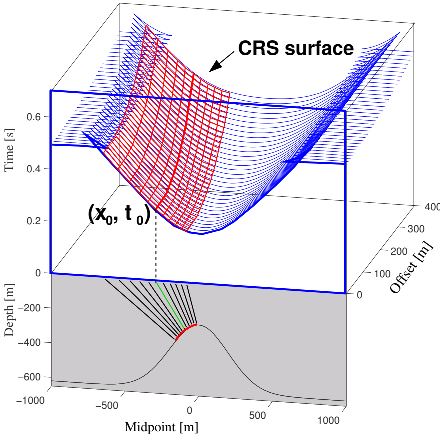

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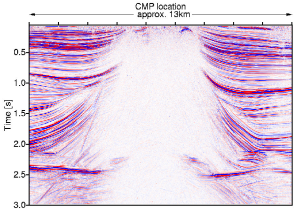

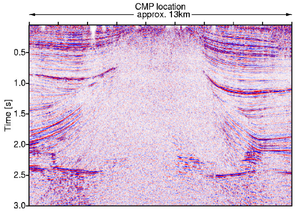

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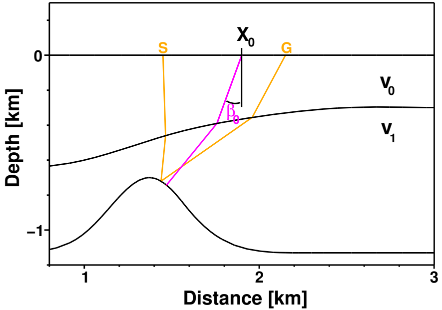

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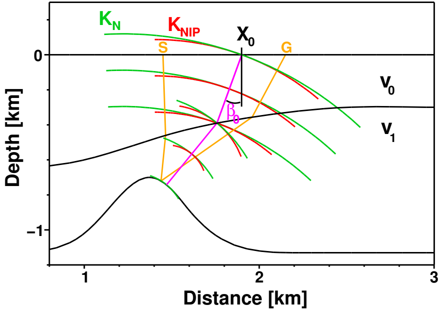

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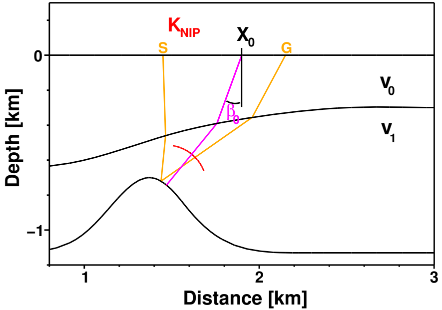

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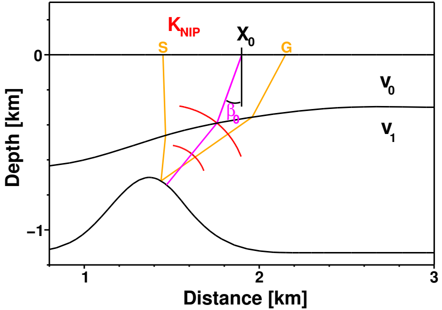

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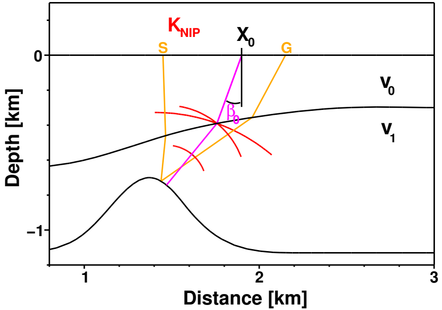

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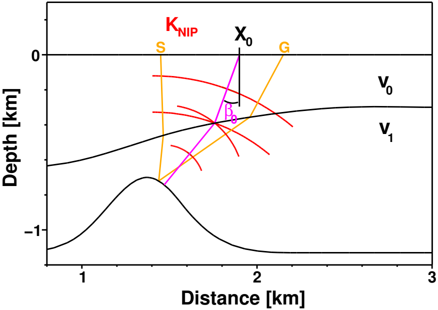

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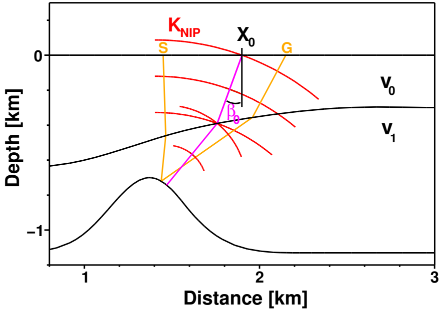

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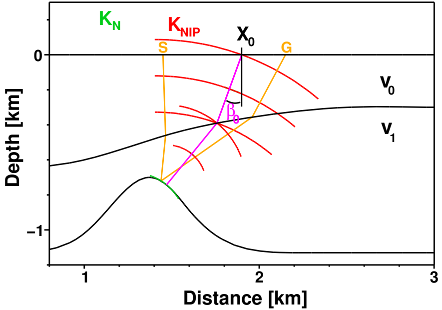

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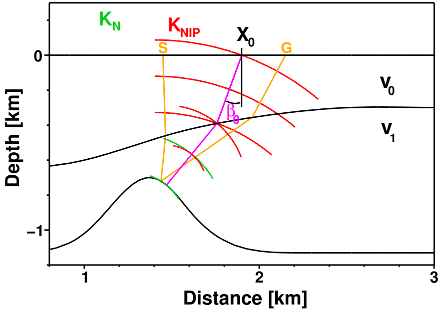

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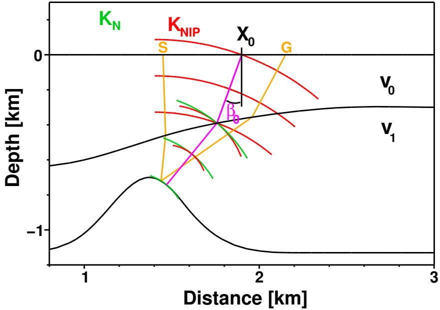

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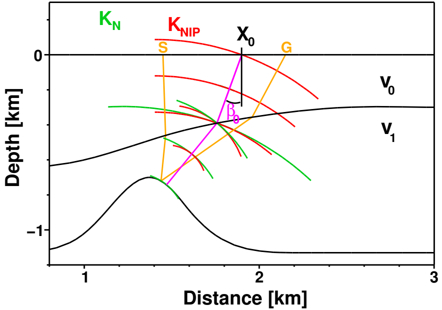

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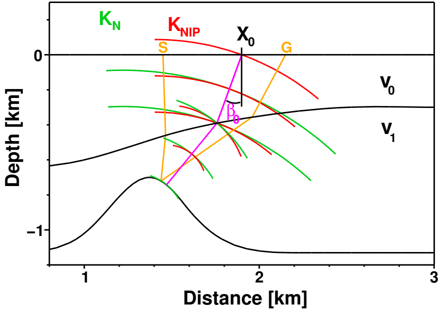

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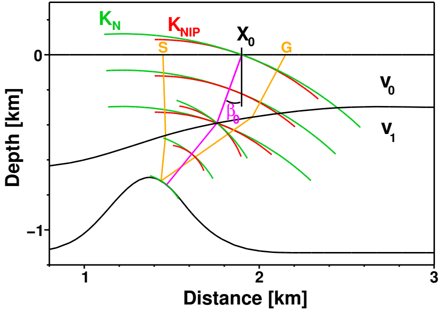

Land data processing

Specific problems:

- Sparse data

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- Low signal-to-noise ratio

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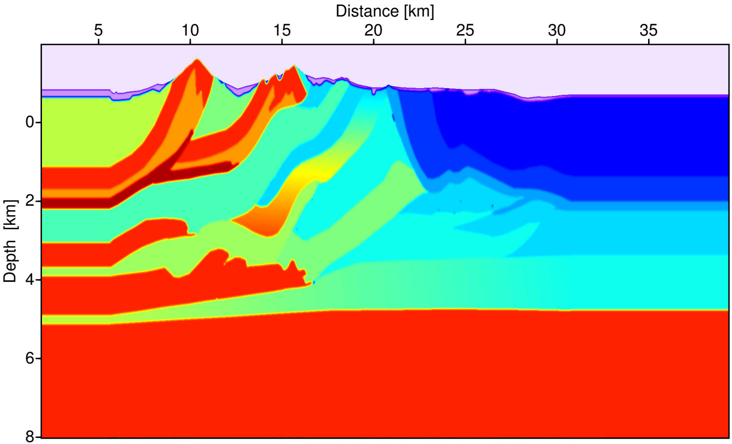
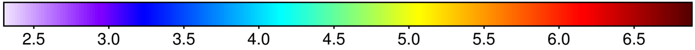
➥ directly addressed by the CRS stack

Synthetic data example



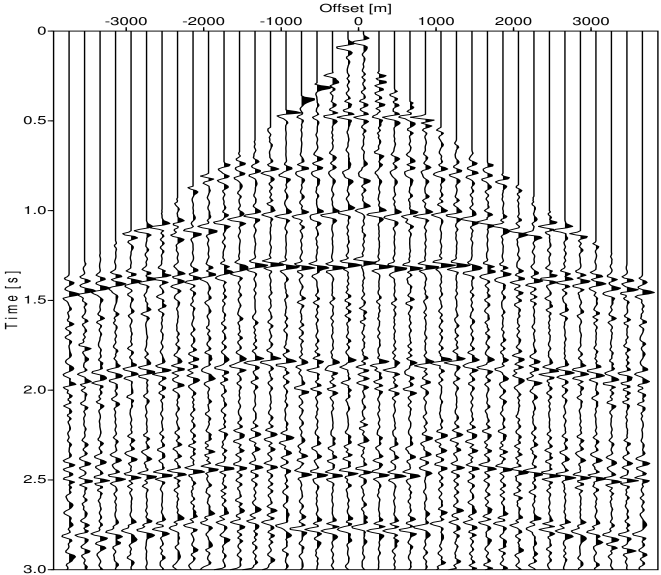
Velocity model [km/s]



Velocity model similar to Canadian Foothills structures

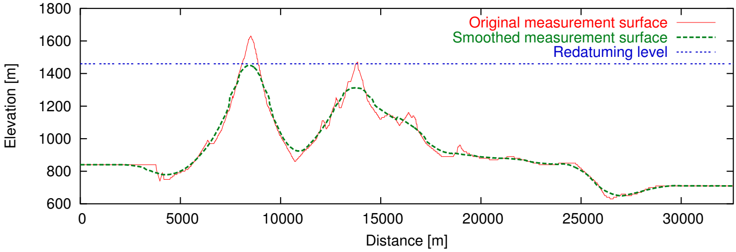
created and kindly provided by Samuel H. Gray

Synthetic example



CMP-Gather at km 15

CRS operator for smooth topography

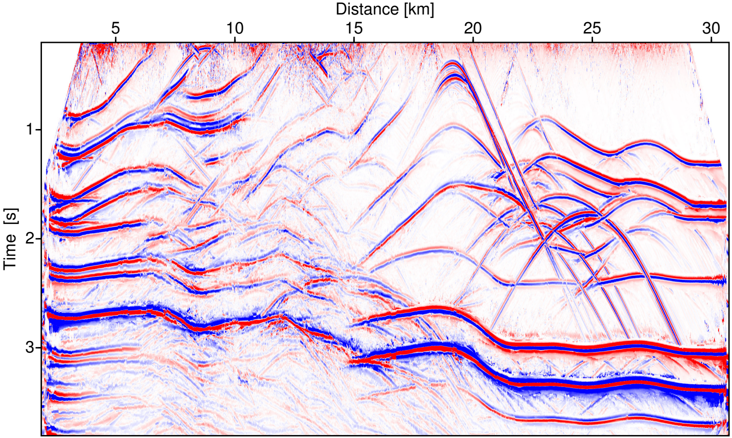


Smooth topography description:

$$
\begin{aligned}
t_{\mathrm{hyp}}^2(m_x, h_x) &= \left(t_0 + \frac{2\,\sin\beta_0}{v_0\,\cos\alpha_0}\; m_x \right)^2 \\
&+ \frac{2\,t_0}{v_0} \left(K_{\mathrm{N}}\,\frac{\cos^2\beta_0}{\cos^2\alpha_0} - K_0\,\frac{\cos\beta_0}{\cos^2\alpha_0} \right) m_x^2 \\
&+ \frac{2\,t_0}{v_0} \left(K_{\mathrm{NIP}}\,\frac{\cos^2\beta_0}{\cos^2\alpha_0} - K_0\,\frac{\cos\beta_0}{\cos^2\alpha_0} \right) h_x^2
\end{aligned}
$$

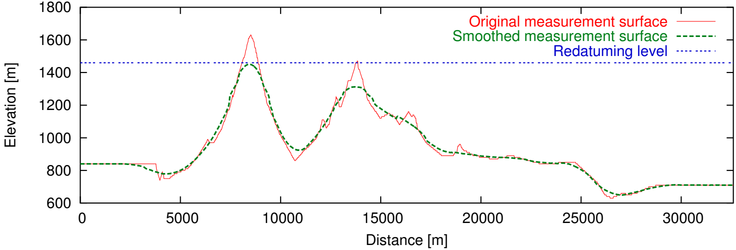
Synthetic data example

Initial CRS stack result



Stacked ZO section,
traveltimes refer to floating datum

CRS operator for arbitrary topography

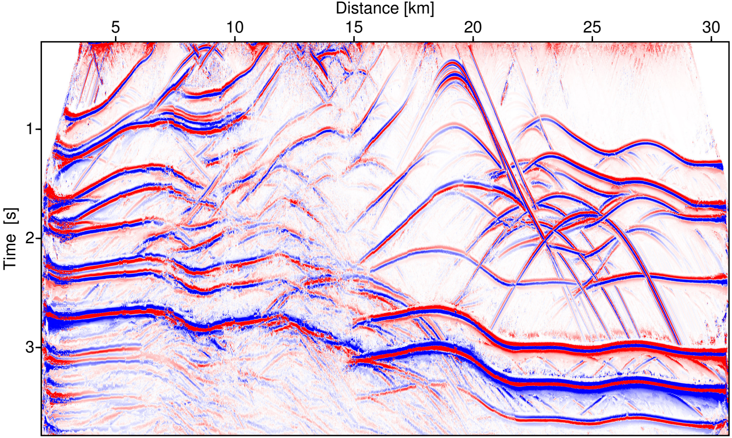


Rough topography description:

$$
\begin{aligned}
t^2_{\mathrm{hyp}}(\vec{m},\vec{h}) &= \left(t_0 - \frac{2}{v_0}\,(m_x \sin\beta_0 + m_z \cos\beta_0)\right)^2 \\
&+ \frac{2\,t_0\,K_{\mathrm{N}}}{v_0}\,(m_x \cos\beta_0 - m_z \sin\beta_0)^2 \\
&+ \frac{2\,t_0\,K_{\mathrm{NIP}}}{v_0}\,(h_x \cos\beta_0 - h_z \sin\beta_0)^2
\end{aligned}
$$

Synthetic data example

Optimized CRS stack result



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Synthetic data example

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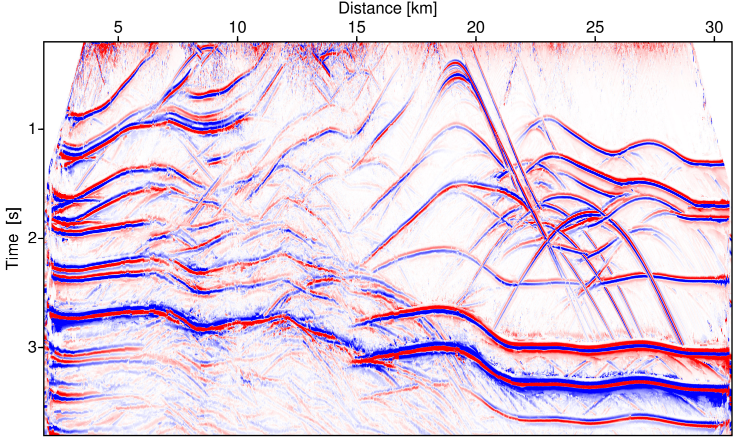

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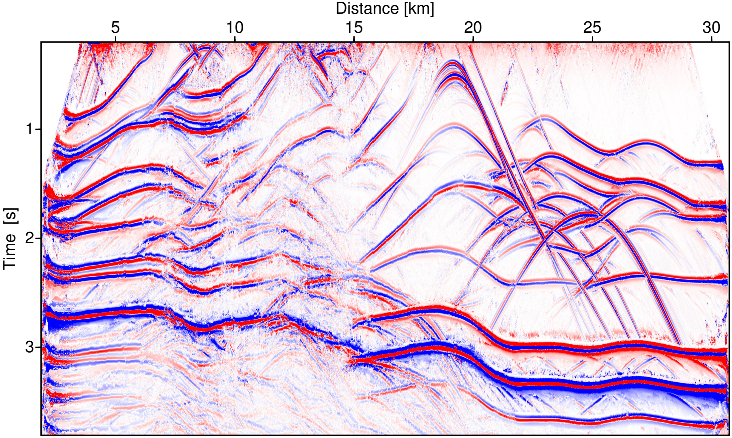
Synthetic data example

Optimized CRS stack result



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Land data processing

Specific problems:

- Sparse data
- Low signal-to-noise ratio
- Rough top-surface topography

➥ directly addressed by the CRS stack

- Near-surface velocity variations

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- Variable thickness of weathering layer

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- Near-surface velocity variations
- Variable thickness of weathering layer
- Complex near-surface geology

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- Near-surface velocity variations
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➥ CRS-stack-based residual static correction

Residual static correction

Principle:

- Cross-correlation stacks from stacked pilot traces and move-out corrected prestack traces

Residual static correction

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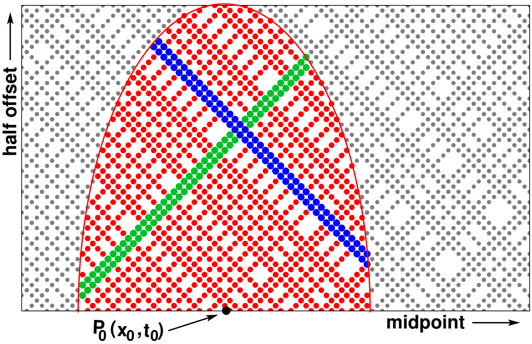
- Cross-correlation stacks from stacked pilot traces and move-out corrected prestack traces

Improvements:

- Cross-correlation stacks generated from move-out corrected CRS-supergathers



Residual static correction

Principle:

- Cross-correlation stacks from stacked pilot traces and move-out corrected prestack traces

Improvements:

- Cross-correlation stacks generated from move-out corrected CRS-supergathers
- High S/N ratio of CRS stacked pilot traces

Residual static correction

Principle:

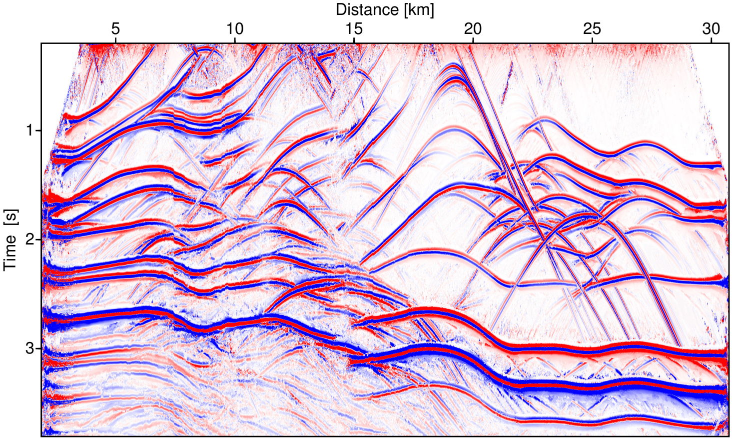
- Cross-correlation stacks from stacked pilot traces and move-out corrected prestack traces

Improvements:

- Cross-correlation stacks generated from move-out corrected CRS-supergathers
- High S/N ratio of CRS stacked pilot traces
- No datum statics needed for move-out correction

Synthetic data example

Optimized CRS stack result after RSC



Stacked ZO section,
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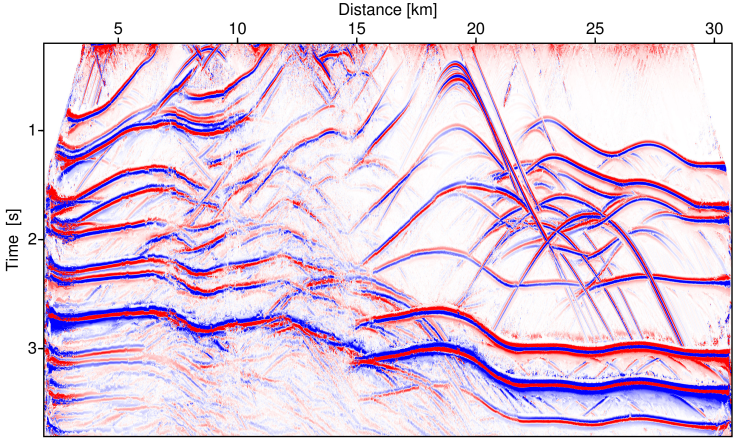
Synthetic data example

Optimized CRS stack result before RSC



Stacked ZO section,

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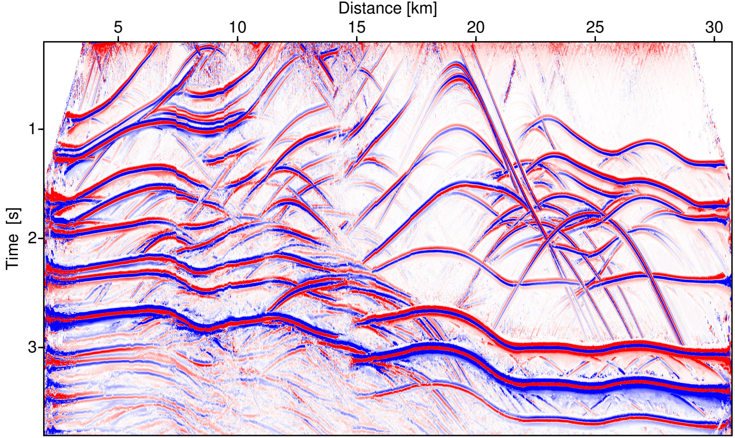

Stacked ZO section,
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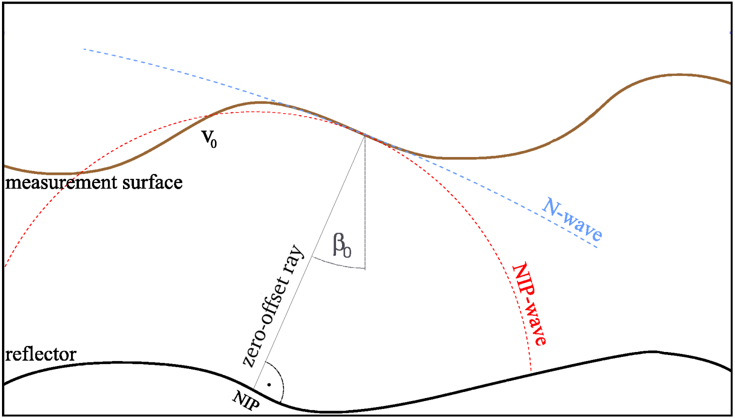
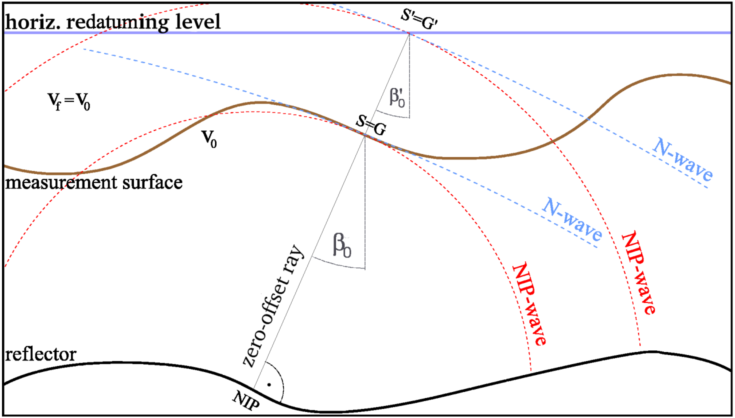
Redatuming of CRS stack results

Results related to floating datum:



Idea: Upward continuation of ZO rays to horiz. datum using known β_0 and constant redatuming velocity v_f

Redatuming of CRS stack results

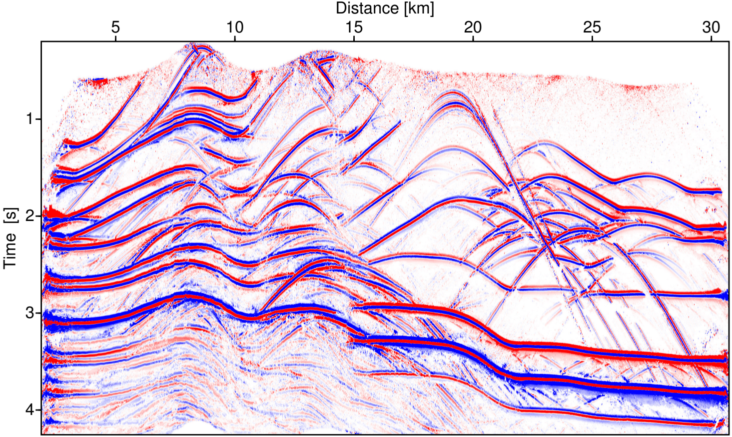


$$v_f = v_0: \quad x'_0 = x_0 + \Delta z \tan\beta_0 \quad \text{and} \quad t'_0 = t_0 + \frac{2\,\Delta z}{v_0 \cos\beta_0}\,,$$

$$K'_{\mathrm{NIP,N}} = \left(\frac{1}{K_{\mathrm{NIP,N}}} + \frac{1}{2}\,\Delta t\, v_0\right)^{-1} \quad \text{and} \quad \beta'_0 = \beta_0\,.$$

Synthetic data example

Optimized CRS stack result after RSC and redatuming



Stacked ZO section,

traveltimes refer to z=1460 m, redatuming velocity: 3.5 km/s

Real data example

**image courtesy of Saudi Aramco*

Real data example

Acquisition geometry & recording parameters

	Parameter	Value
Shots and receivers	Number of shots	1279
	Shot interval	30 m
	Number of receivers	1279
	Receiver interval	30 m
Midpoints	Number of CMP bins	2840
	Maximum CMP fold	120
	Offset range	–3602 ... 3607 m
Recording parameters	Recording time	2 s
	Sampling interval	4 ms
	Frequency content	5 - 65 Hz
	Mean frequency	30 Hz

Real data example

Acquisition geometry & recording parameters

	Parameter	Value
Shots and receivers	Number of shots Shot interval Number of receivers Receiver interval	1279 30 m 1279 30 m
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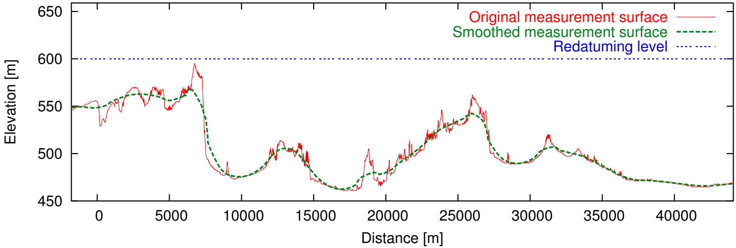


Real data example

Preprocessing & Static Correction

**conducted by TEEC*

- Bandpass filter*, corner frequencies 5-10-60-80 Hz
- Automatic gain control*, gate 500 ms
- Zerophase spike deconvolution*, operator 80 ms

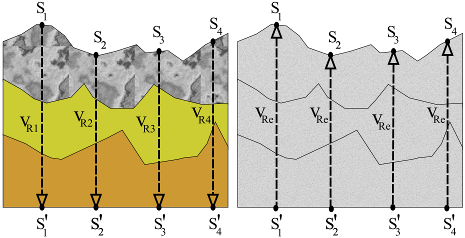
Real data example

Preprocessing & Static Correction

**conducted by TEEC*

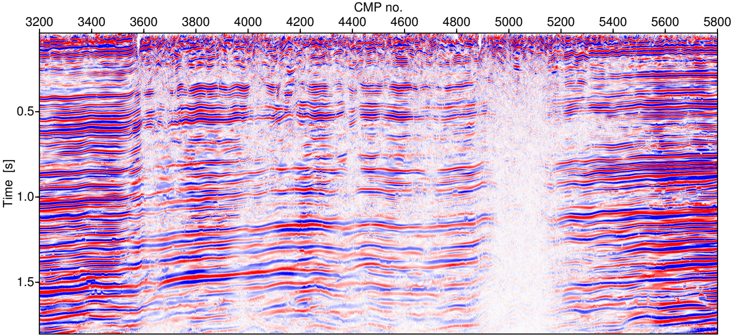
- Bandpass filter*, corner frequencies 5-10-60-80 Hz
- Automatic gain control*, gate 500 ms
- Zerophase spike deconvolution*, operator 80 ms

- Refraction statics* to horizontal datum at 500 m
- Inverse elevation statics to orig. topography using replacement velocity $v_{Re} = 3.5$ km/s



Real data example

CRS stack result

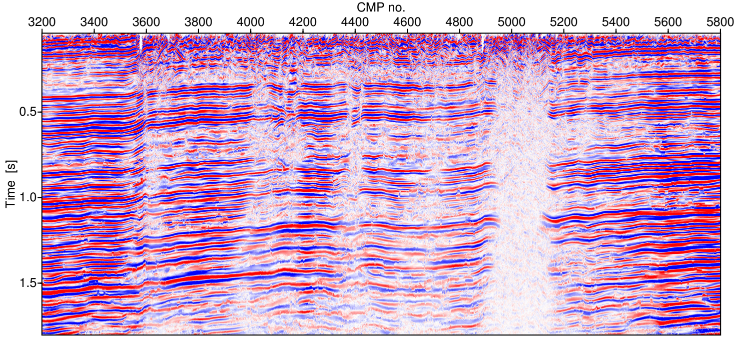


Stacked ZO section,

traveltimes refer to floating datum

Real data example

CRS stack result after RSC



Stacked ZO section,
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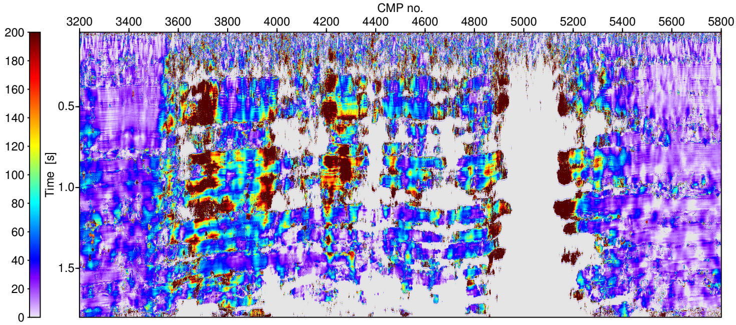
Real data example

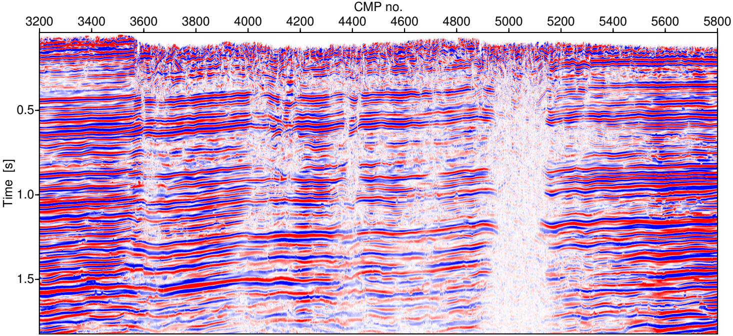
Percentage increase of coherence



CRS stack result before and after RSC

Real data example

CRS stack result after RSC and redatuming

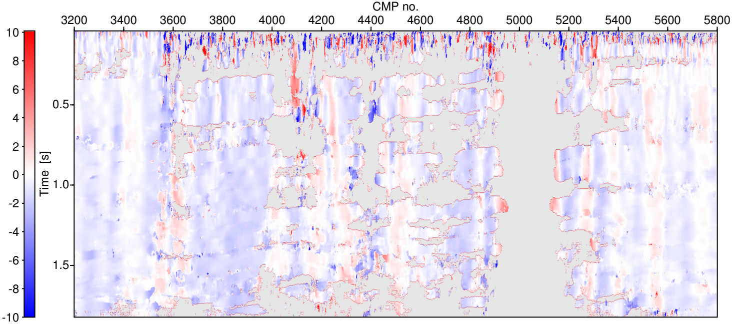


Stacked ZO section,

traveltimes refer to z=600 m, redatuming velocity: 3.5 km/s

Real data example

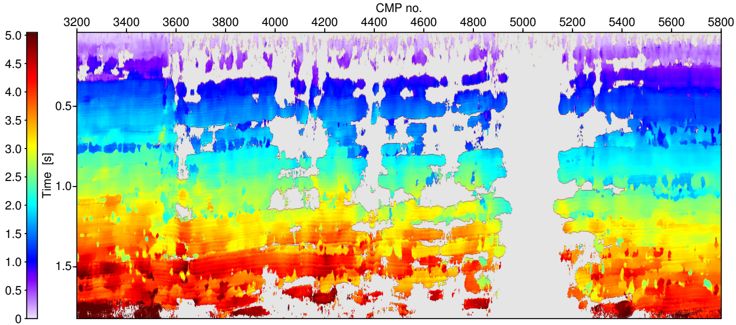
CRS stack result after RSC and redatuming



Emergence angle section [°] after redatuming,
unreliable samples masked out grey

Real data example

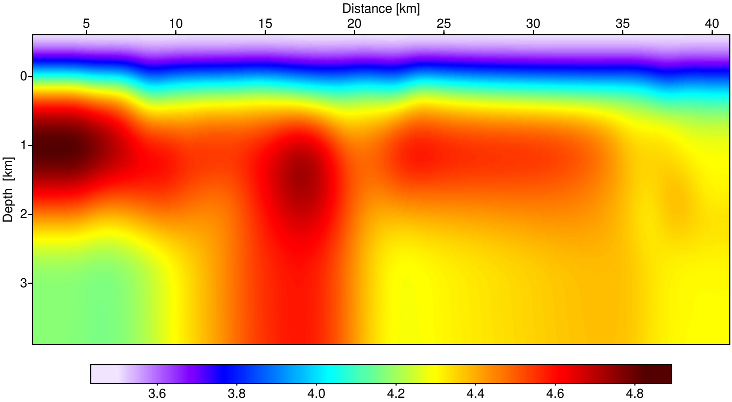
CRS stack result after RSC and redatuming



NIP-wave radius section [km] after redatuming, unreliable samples masked out grey

Real data example

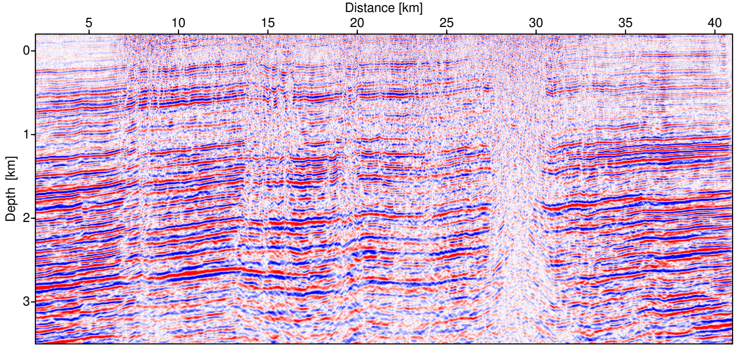
Result of tomographic inversion



Macro-velocity model [km/s]

Real data example

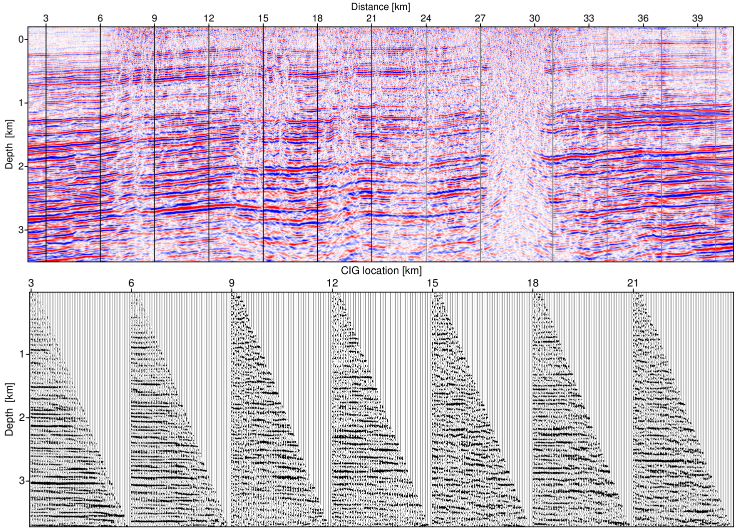
Result of PreSDM from topography



Input: Prestack data after RSC

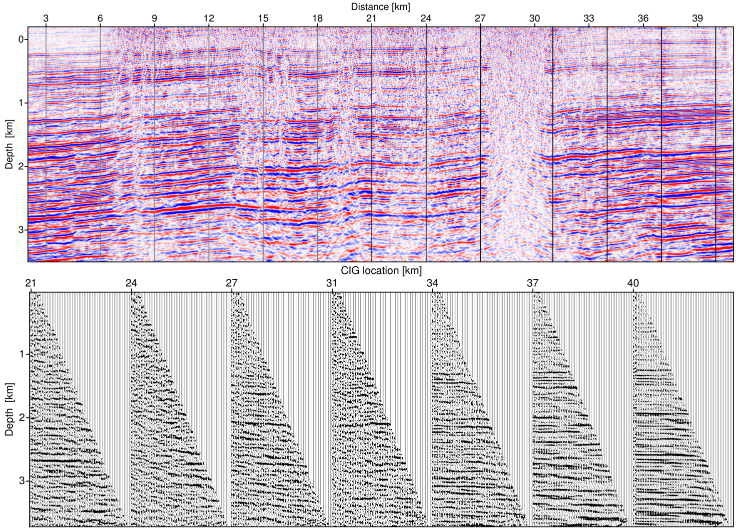
Real data example

Some common image gathers



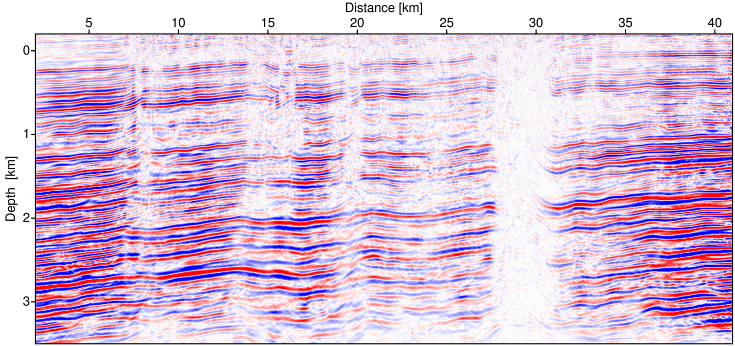
Real data example

Some common image gathers



Real data example

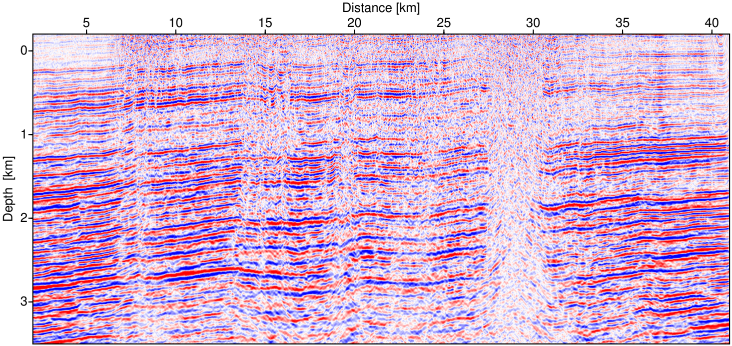
Result of PostSDM



Input: Stacked ZO section after redatuming

Real data example

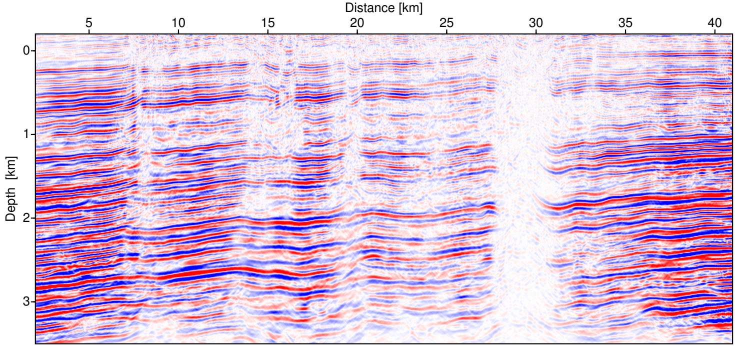
Result of PreSDM from topography



Input: Prestack data after RSC

Real data example

Result of PostSDM



Input: Stacked ZO section after redatuming

Conclusions

Data-driven CRS technology particularly suitable for complex land-data processing:

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- Accurate traveltime approximation allows for large stacking aperture in offset *and* midpoint direction
  ➥ enhanced S/N ratio and event continuity
  + more accurate and stable RSC

Conclusions

Data-driven CRS technology particularly suitable for complex land-data processing:

- Accurate traveltime approximation allows for large stacking aperture in offset *and* midpoint direction
- CRS operator considers true S&R elevations; no elevation statics needed for stack and RSC
  - ➥ enhanced resolution, more reliable attributes

Conclusions

Data-driven CRS technology particularly suitable for complex land-data processing:

- Accurate traveltime approximation allows for large stacking aperture in offset *and* midpoint direction
- CRS operator considers true S&R elevations; no elevation statics needed for stack and RSC
- Standardized output by redatuming of CRS stack and attribute sections
  - ➥ seemless transition to further processing steps

Conclusions

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Thank you for your attention

Acknowledgments

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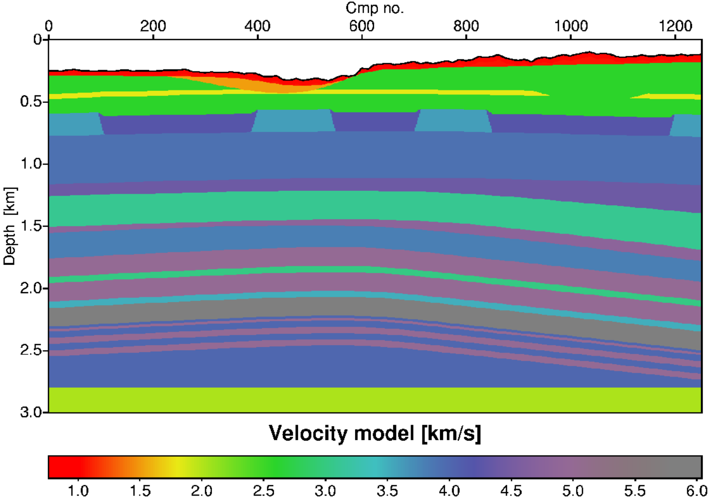
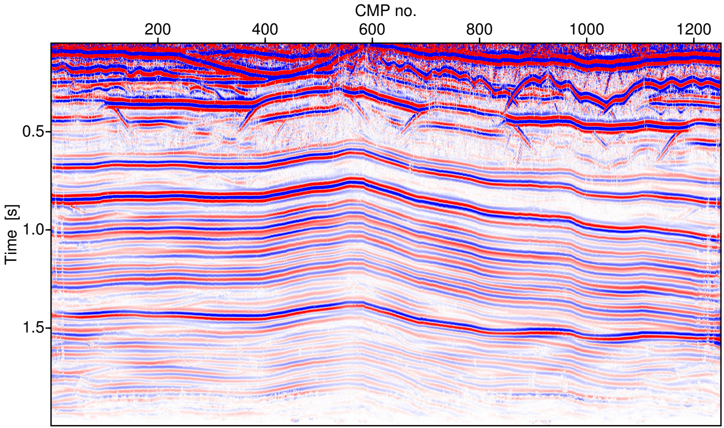
- Saudi Aramco and Samuel H. Gray for providing the real & synthetic data
- . . . and all the sponsors of the Wave Inversion Technology (WIT) Consortium, Karlsruhe, Germany

Synthetic data example 2



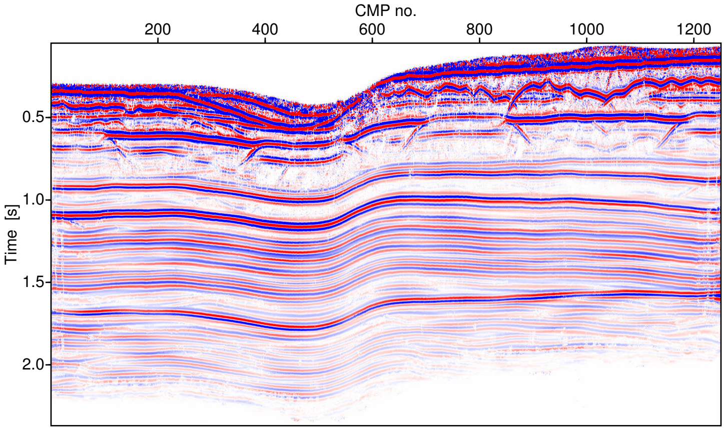
Synthetic data set provided by Saudi Aramco

CRS stack result before redatuming



ZO traveltimes referring to floating datum

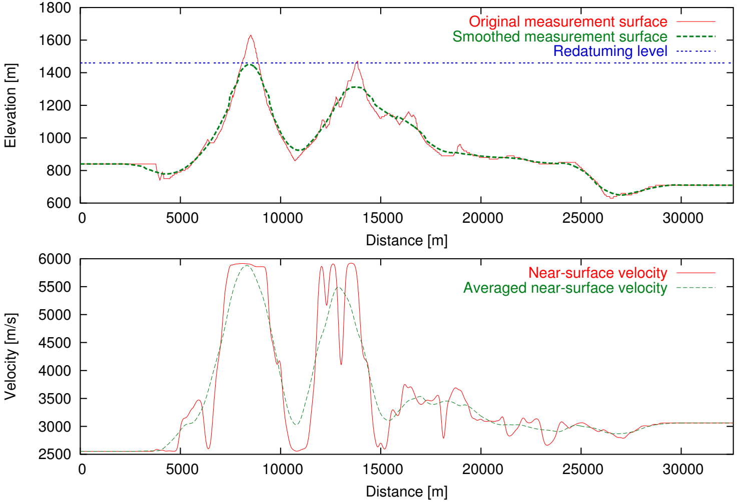
CRS stack result after redatuming



ZO traveltimes referring to horizontal datum

Redatuming velocity: 1.1 km/s

Synthetic data example 1



Topography & near-surface velocity