Compressive Sensing Project

Daniel Trad

Sponsor Meeting 2018

Outline

Compressive sensing

Sparse transforms

Irregular sampling: acquisition vs processing coordinates.

Migration-demigration deblending: RTM and Kirchhoff

Apex shifted sparse transform deblending

The feedback approach

Compressive sensing or Compressed sampling

$$y = \Phi x = \Phi \Psi \alpha$$

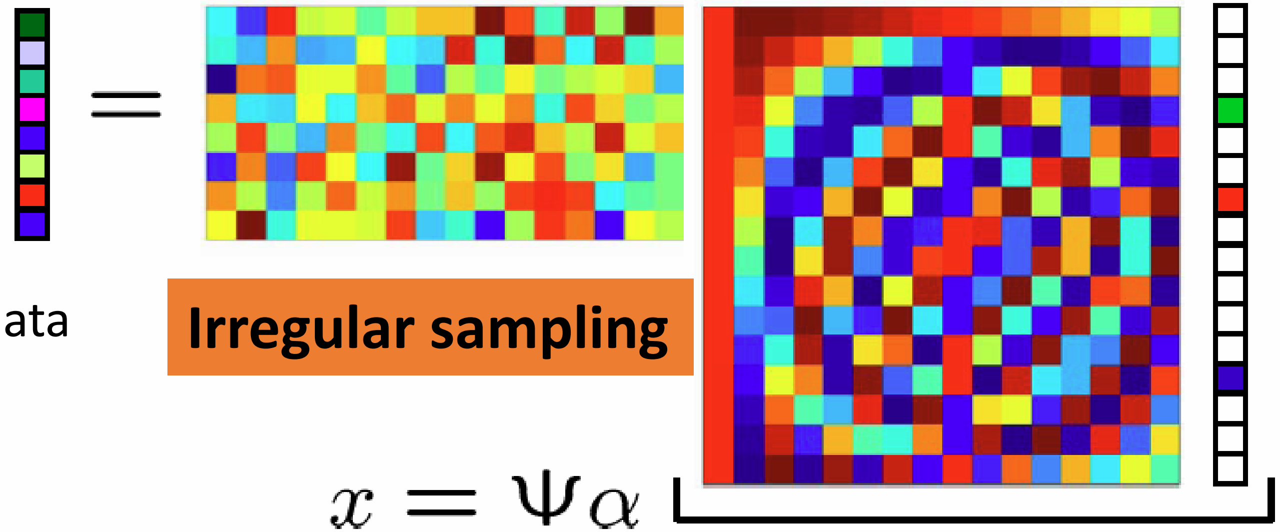
Compression

+

sampling

model

y Φ Ψ α



data

Irregular sampling

$x = \Psi \alpha$

synthesis or modeling from sparse transform

(COMPRESSION)

Adapted from Baraniuk, Romberg and Wakin 2008

Compressive sensing or Compressed sampling

$\mathbf{x}$ ➔ unknown

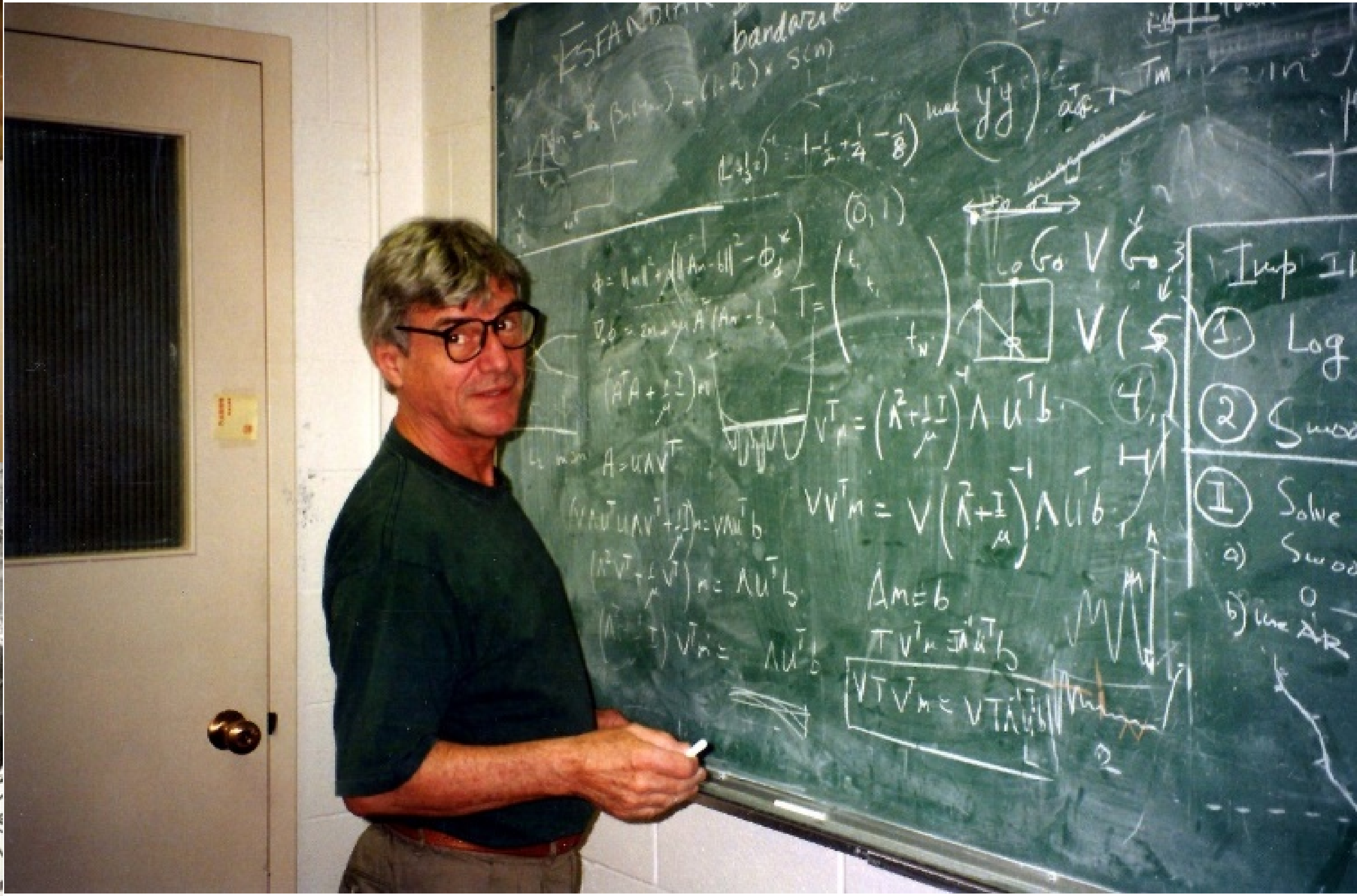
$\mathbf{y} = \mathbf{\Phi}\mathbf{x},$ Sampling from regular to irregular sampling

$\mathbf{x} = \mathbf{\Psi}\alpha,$ Transformation to convert from spread out data to dense coefficients

$\text{minimize } \|\mathbf{\Psi^H}_m\mathbf{x}\|_1$ enforce sparseness in the transform coefficients

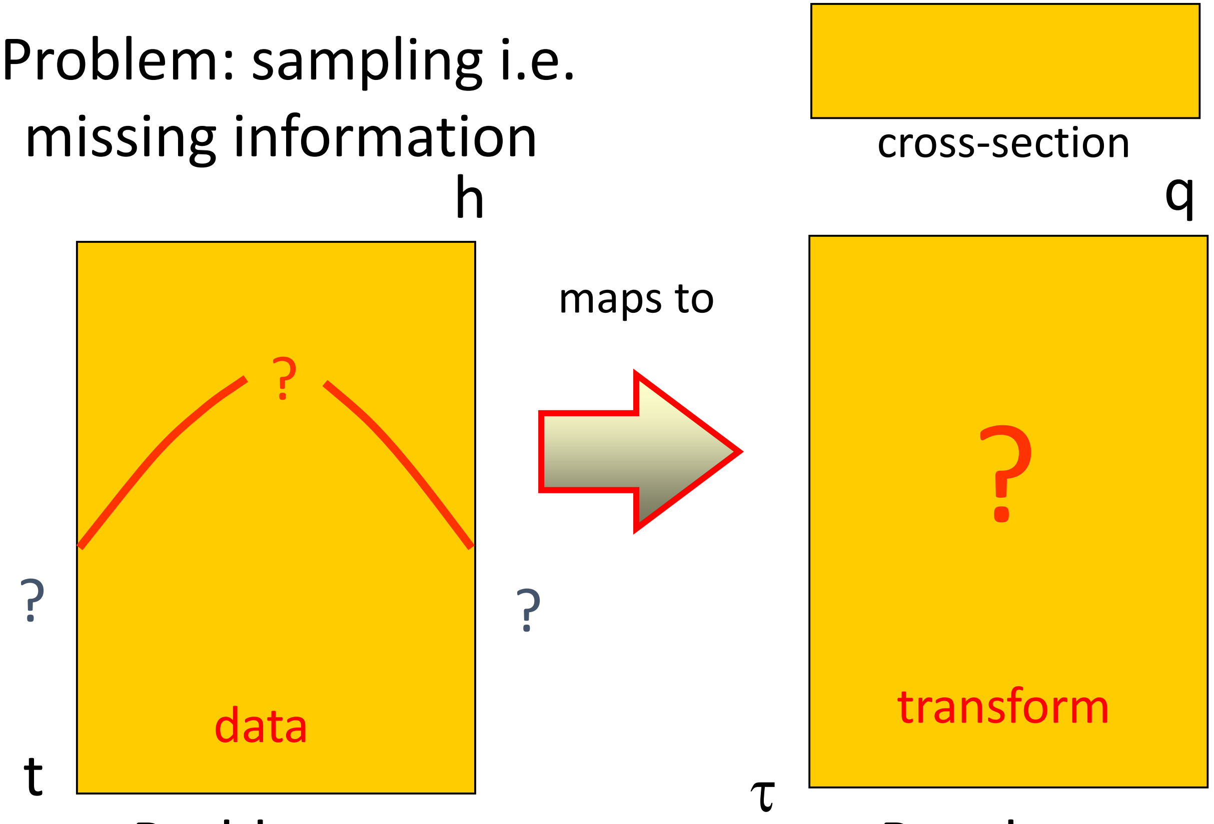
$\text{subject to } \|\mathbf{\Phi}\mathbf{x} - \mathbf{y}\|_2 \leq \sigma$ match the data where sampled

Sparse transforms



Sparse transforms

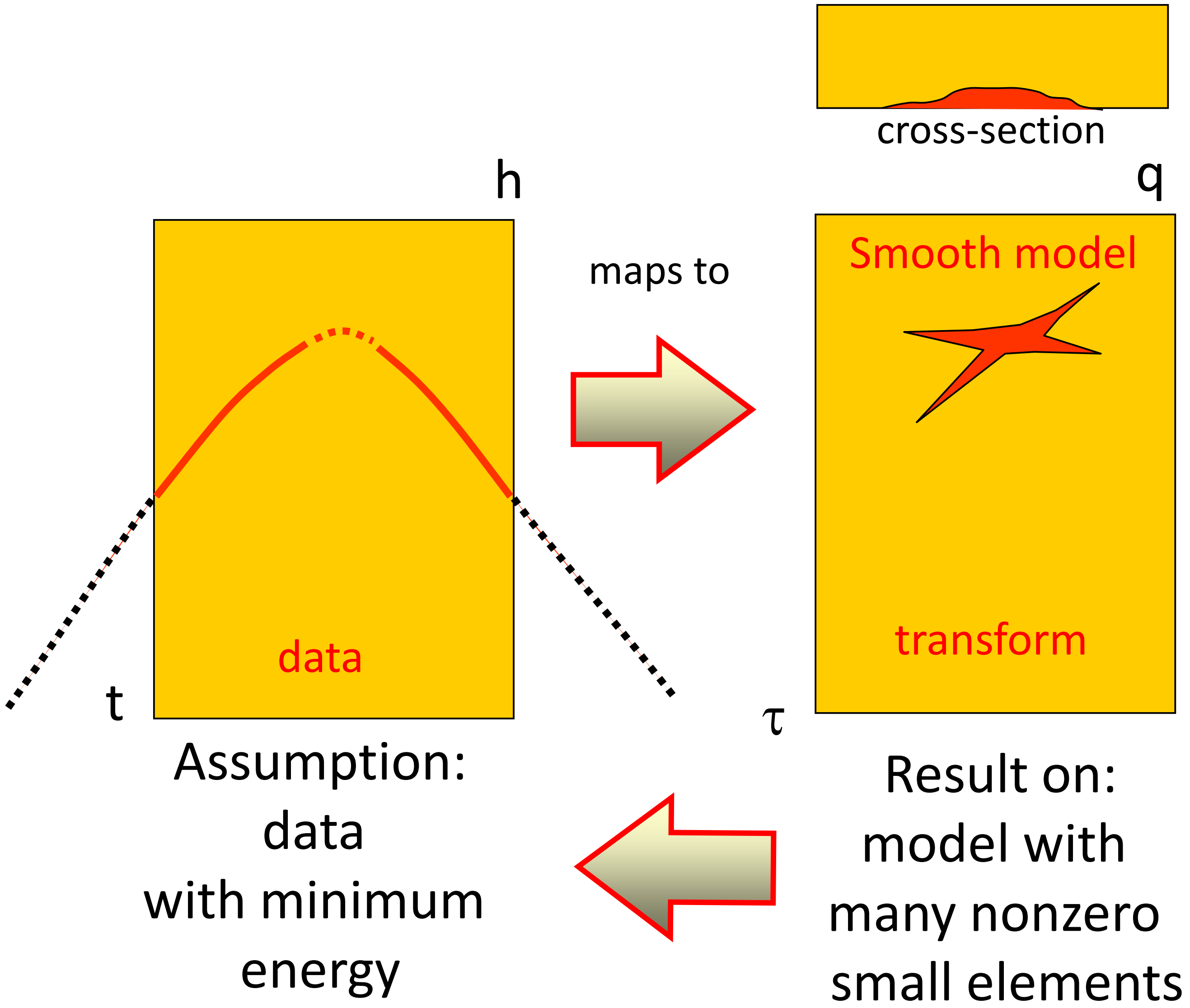
Problem: sampling i.e.
missing information



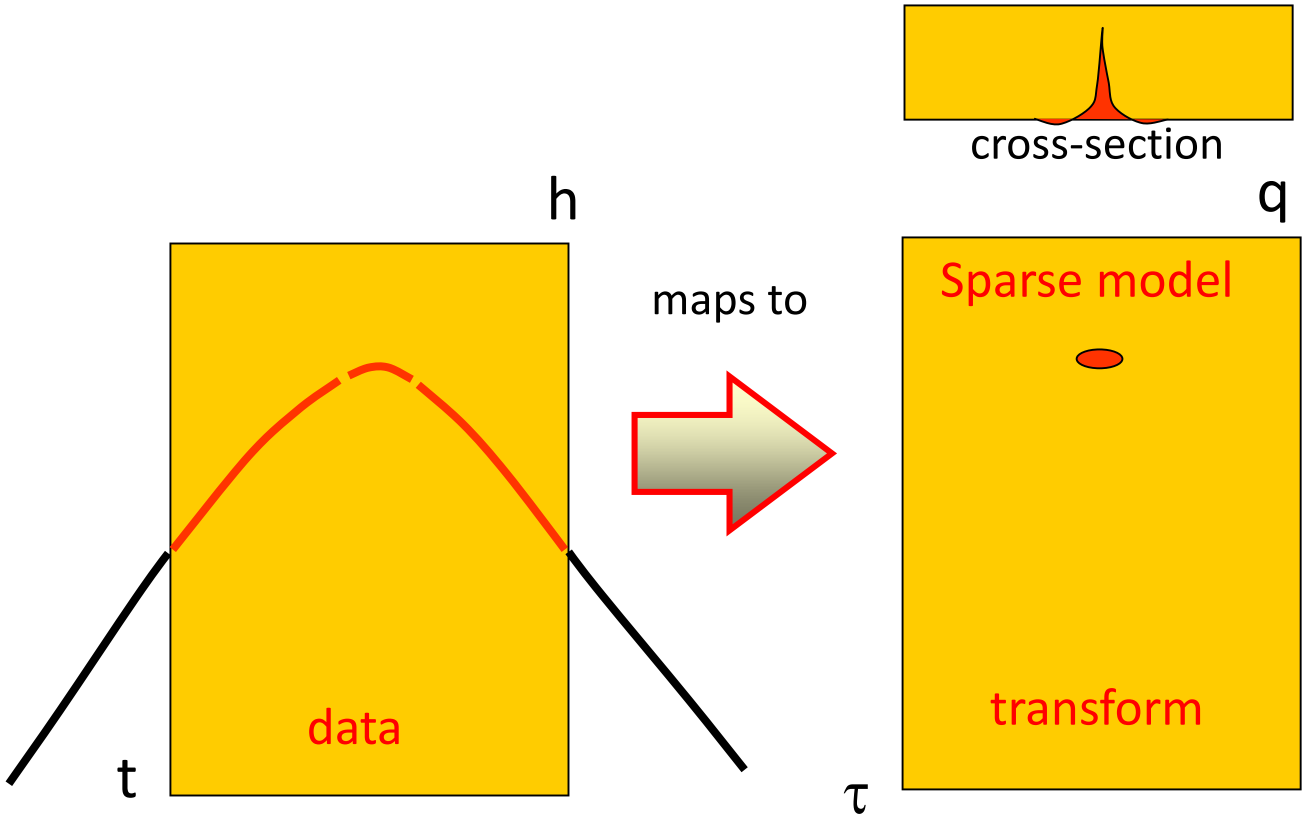
Problem:
data
are not
sufficient

Result on:
many models
fit the data
equally well

Sparse transforms



Sparse transforms



Assumption:
data
with minimum
structure

Result on:
model with
few nonzero
elements

Sparse transforms formulation

$$\mathbf{d} = \mathbf{L}\mathbf{m},$$

Modeling (inverse transform)
data and model can be regular or irregular

$$\text{minimize } \|\mathbf{m}\|_1$$

enforce sparseness in the transform coefficients

$$\text{subject to } \|\mathbf{L}\mathbf{m} - \mathbf{d}\|_2 \leq \sigma$$

match the data where sampled

$$\|\mathbf{W_m}\mathbf{m}\|_2 = \|\mathbf{m}\|_1$$

Alternative method for l1 inversion using l2

L contains any kind of mapping (regular or irregular)
The sampling operator is built in the design of the transform.

Sparse transforms formulation as used in interpolation

Liu and Sacchi, Minimum Weighted Norm Interpolation of Seismic Records, Geophysics Vol 69, No 6, November / December 2004.

$$\mathbf{d} = \mathbf{TLm}$$

Transformation and sampling operator

$$\text{minimize } \|\mathbf{W_m L^H x}\|_2$$

enforce sparseness in the transform coefficients

$$\text{subject to } \|\mathbf{Tx} - \mathbf{d}\|_2 \leq \sigma$$

match the data where sampled

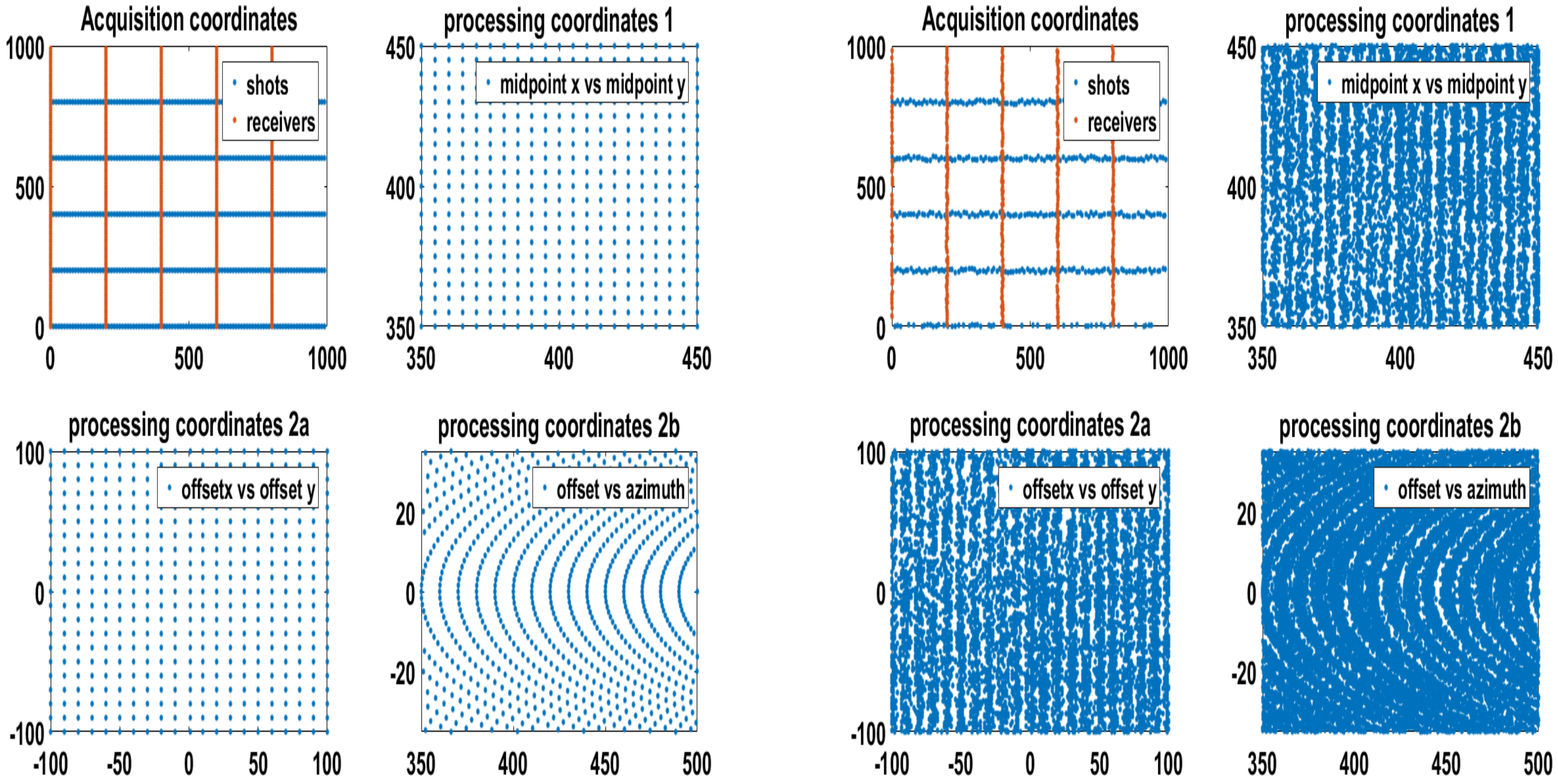
$\mathbf{L} = \mathbf{\Psi},$ Synthesis or modeling

$\mathbf{T} = \mathbf{\Phi},$ Sampling, regular or irregular

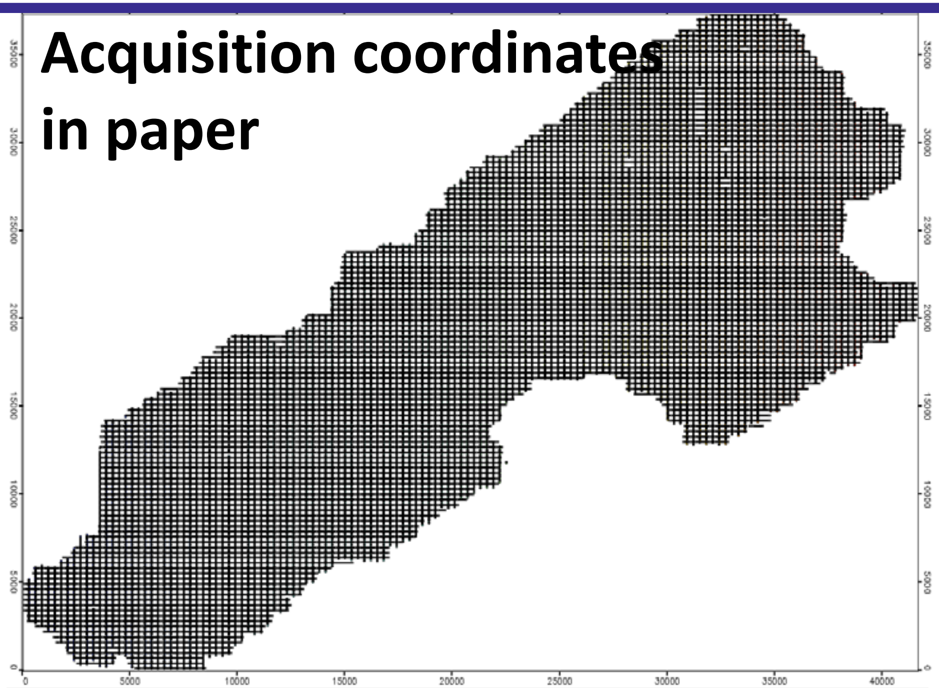
$\mathbf{m} = \alpha,$ Model, sparse coefficients obtained through sparse inversion

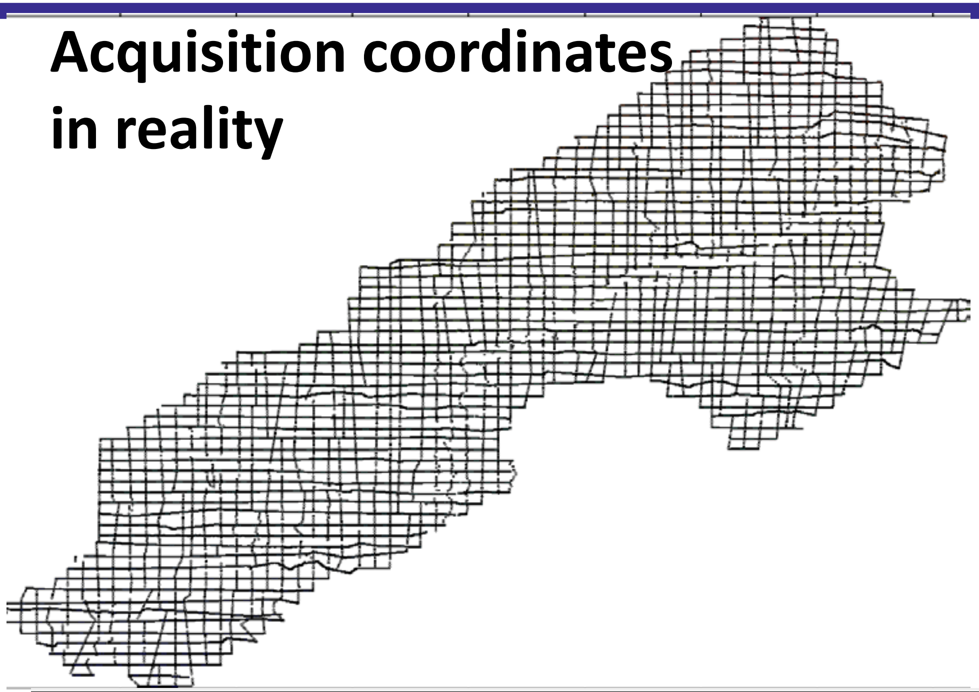
$\mathbf{d} = \mathbf{y}$ Data, sampled version of **x** or **Lm**

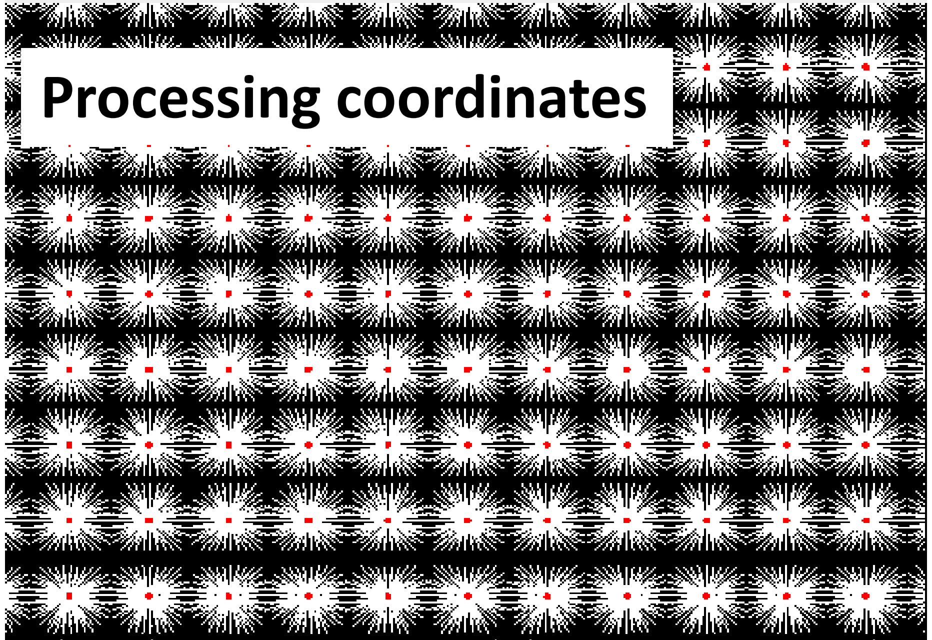
Do we need irregular acquisitions for interpolation?

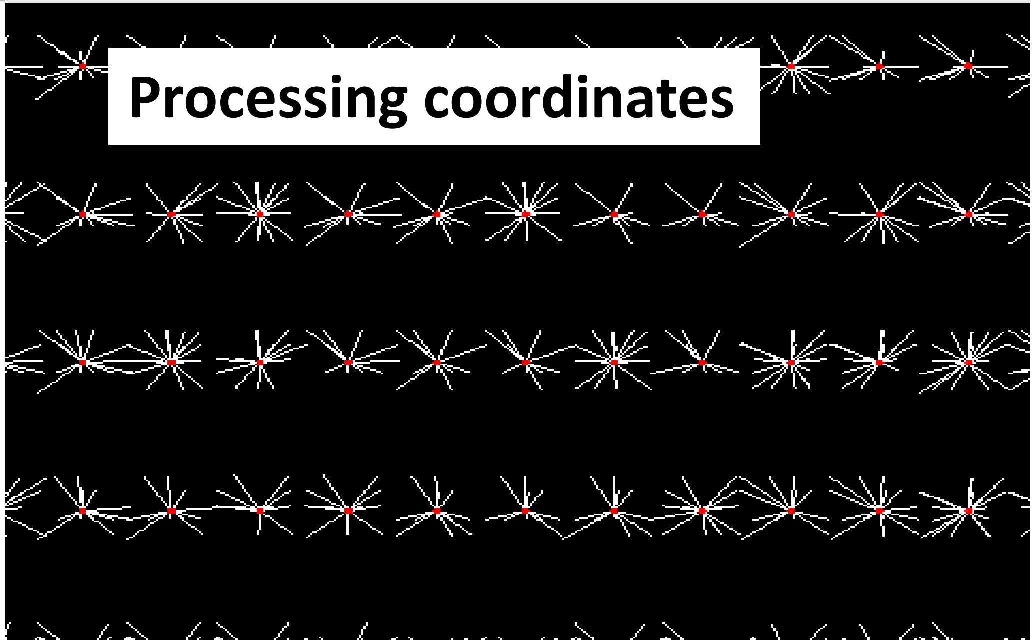


Do we need irregular acquisitions for interpolation?









Compressive sensing, sparse transforms and deblending

Blended acquisitions allow to increase the **illumination** for by maintaining the **acquisition cost** reasonable

Processing of blended data is **challenging,** each trace contains different sources, offsets and azimuths

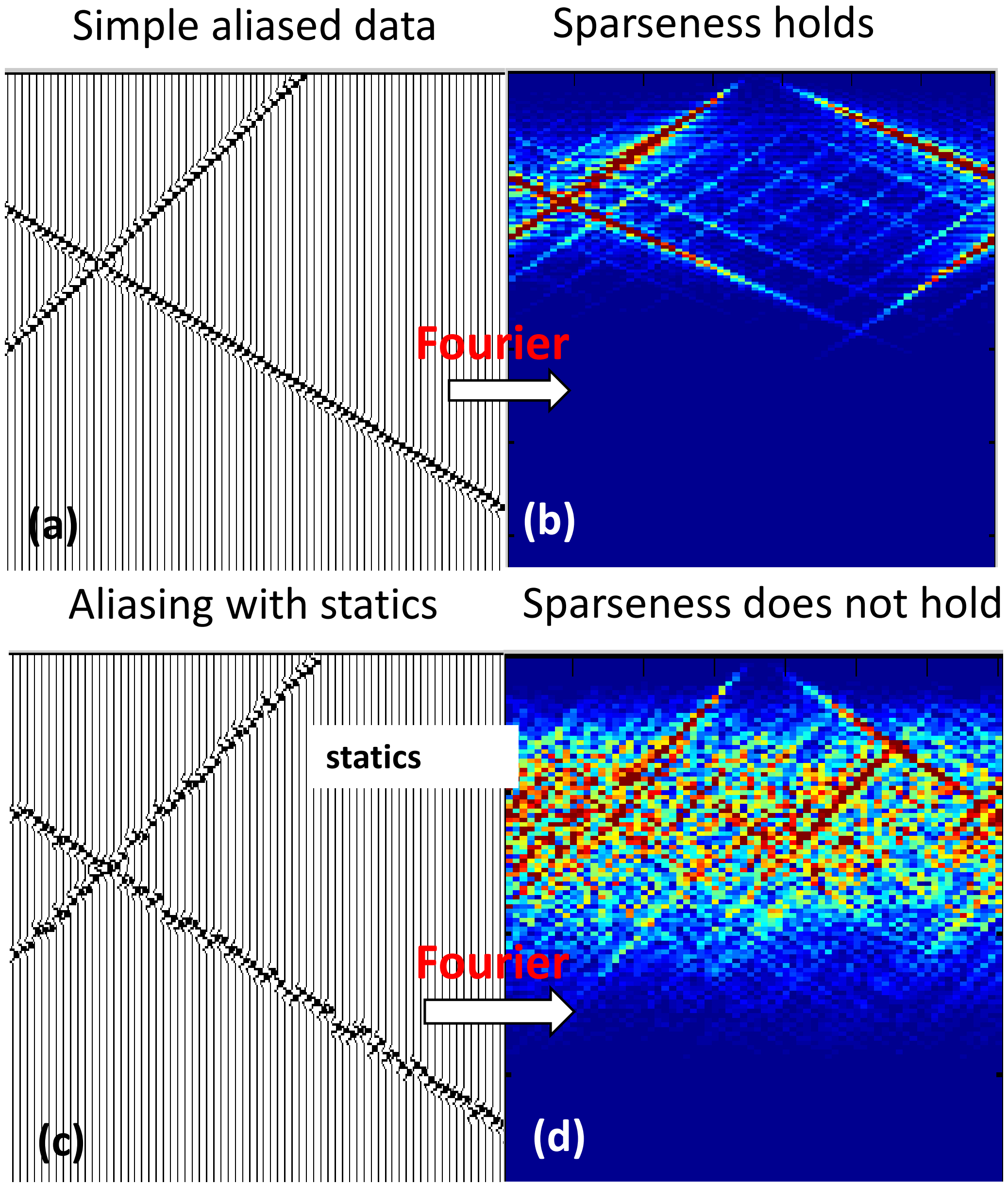
To extract information from blended data, we need to transform them into a format that we can process (**deblending)** which is a form of regularization.

The **deblending** process may not be necessary for **migration** or **full waveform inversion**, but it is required to extract enough information from the data to proceed to these steps.

Standard regularization techniques, for example 5D, have to be modified to address noise rather than sampling.

Problems with sparseness in raw data

Interpolation raw data is a different game than for processed data



May need irregular acquisition coordinates for deblending

Coherence is affected by near surface.
Need statics corrections

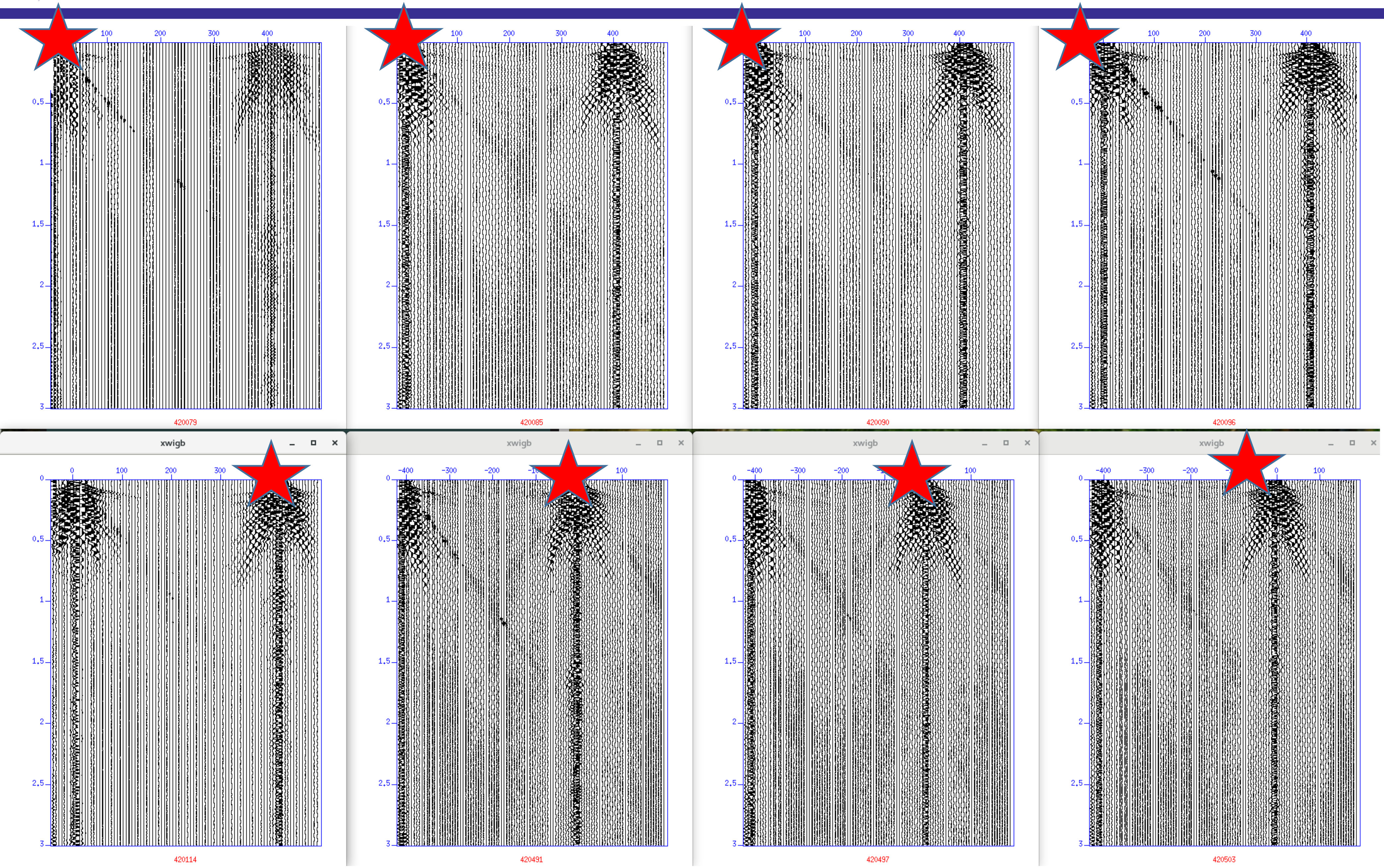
For example:
sparse Radon
not very different from
standard Radon
for raw land data

Noise attenuation tools to eliminate interference:

- Data are replicated as many times as sources are blended and data sorted in such a way that interference appears incoherent or with different velocities or slopes. Many standard tools like FK, Radon, FX, can be used to remove the interference.

(problem too many patents about things we have always done)

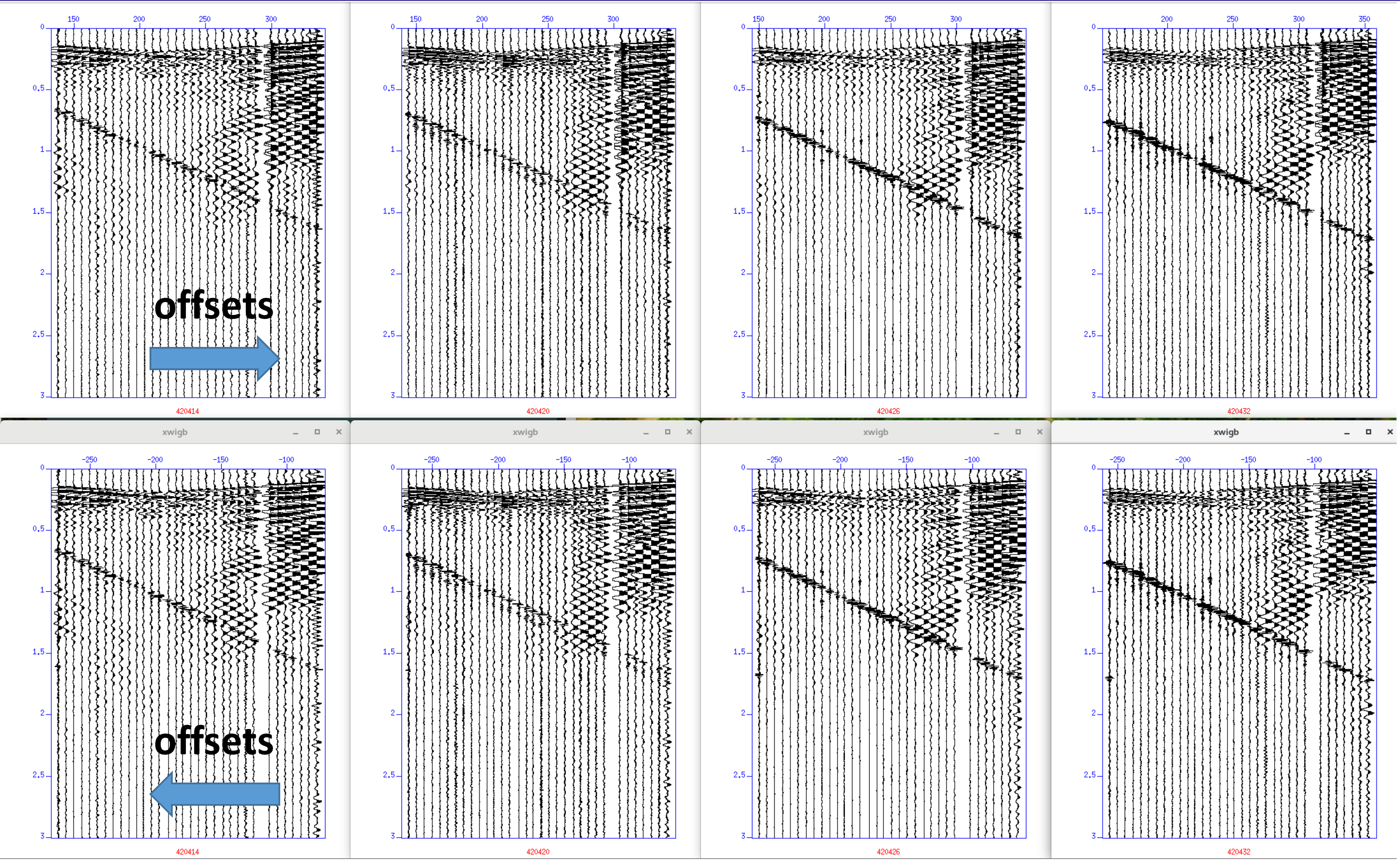
CREWES blended data from Brooks (shot gathers)



Geometry 1

Geometry 2

CREWES blended data from Brooks (receiver gathers)



Geometry 1

Geometry 2

Noise attenuation tools to eliminate interference:

- Data are replicated as many times as sources are blended and data sorted in such a way that interference appears incoherent or with different velocities or slopes. Many standard tools like FK, Radon, FX, can be used to remove the interference.

Multidimensional inversion:

- Uses focusing of coherent energy in a multidimensional frame.
- Similar to MWNI with sampling replaced by a blending+sampling matrix.
- Usually exploits some time or space perturbation on the shooting which makes the interference to appear incoherent on same spatial direction.

$$\mathbf{d} = \mathbf{T}\,\mathbf{x}$$

References, Verschhurr, Sacchi, Abma, …

$$\begin{pmatrix} x(2) \\ x(3) \\ x(5) \end{pmatrix} = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x(1) \\ x(2) \\ x(3) \\ x(4) \\ x(5) \end{pmatrix}$$

Noise attenuation tools to eliminate interference:

- Data are replicated as many times as sources are blended and data sorted in such a way that interference appears incoherent or with different velocities or slopes. Many standard tools like FK, Radon, FX, can be used to remove the interference.

(problem too many patents … lawyers: please get a real job…)

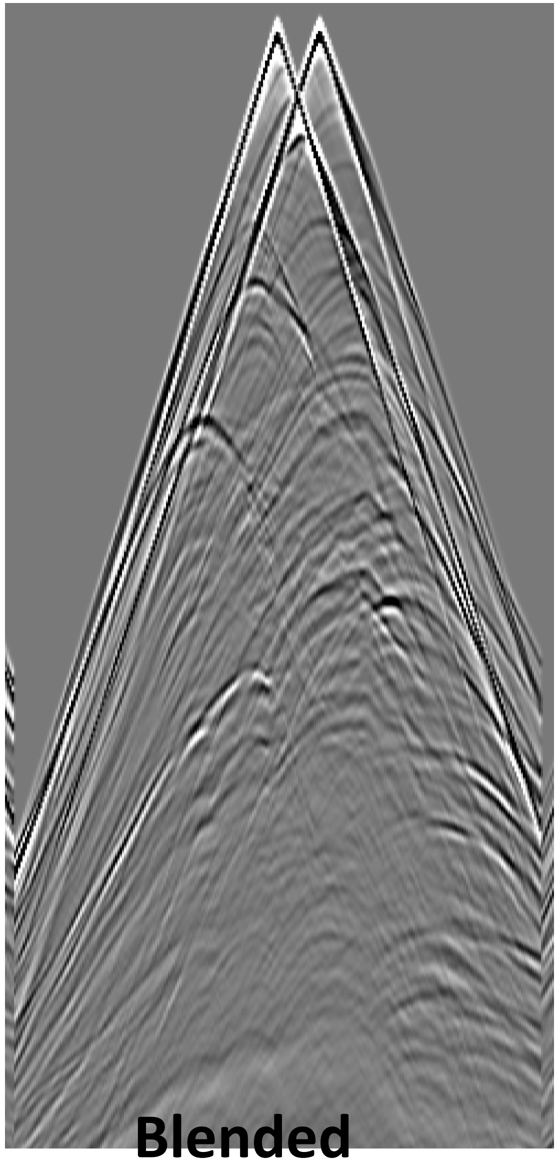
Multidimensional inversion:

- Uses focusing of coherent energy in a multidimensional frame.
- Usually exploits some time or space perturbation on the shooting which makes the interference to appear incoherent on same spatial direction.

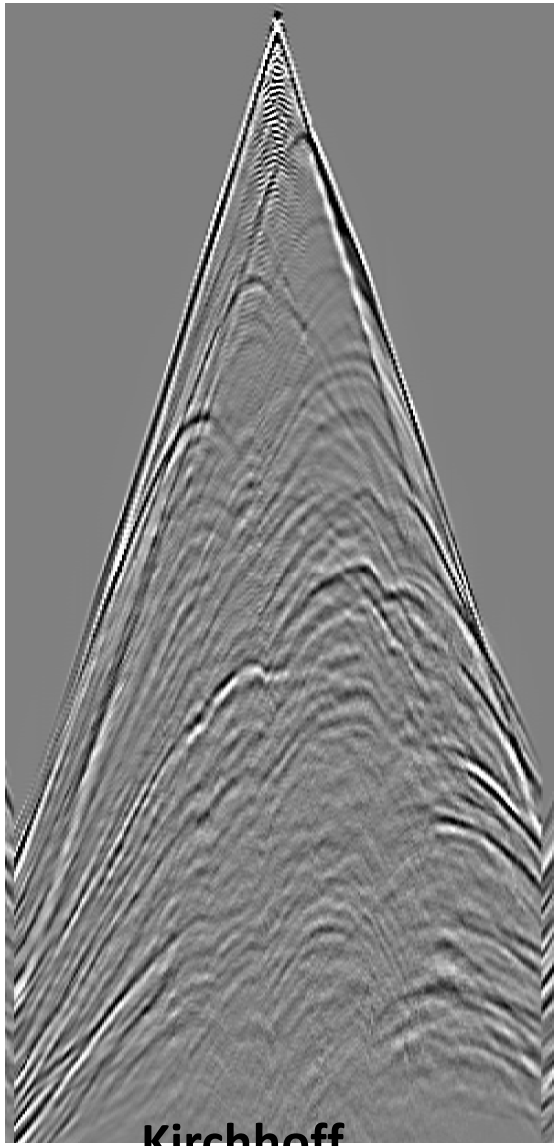
Physical transformations:

- Uses Green functions (migration/demigration) to separate shots.
- Predictions can be used as masks to help tools mentioned above, or as actual data.

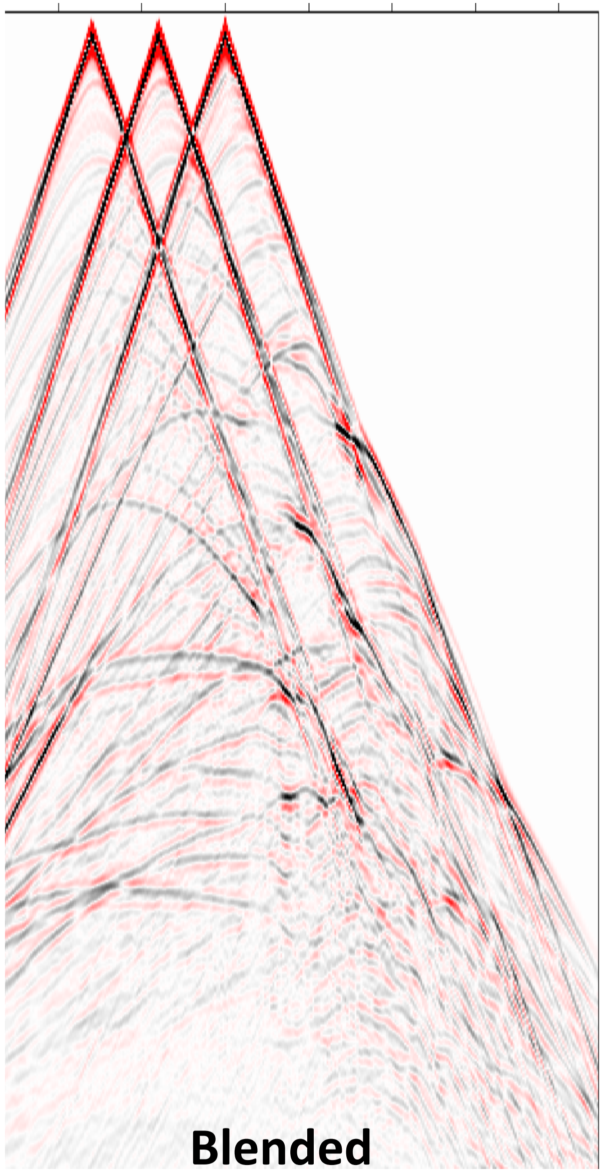
Deblended shots with migration/demigration



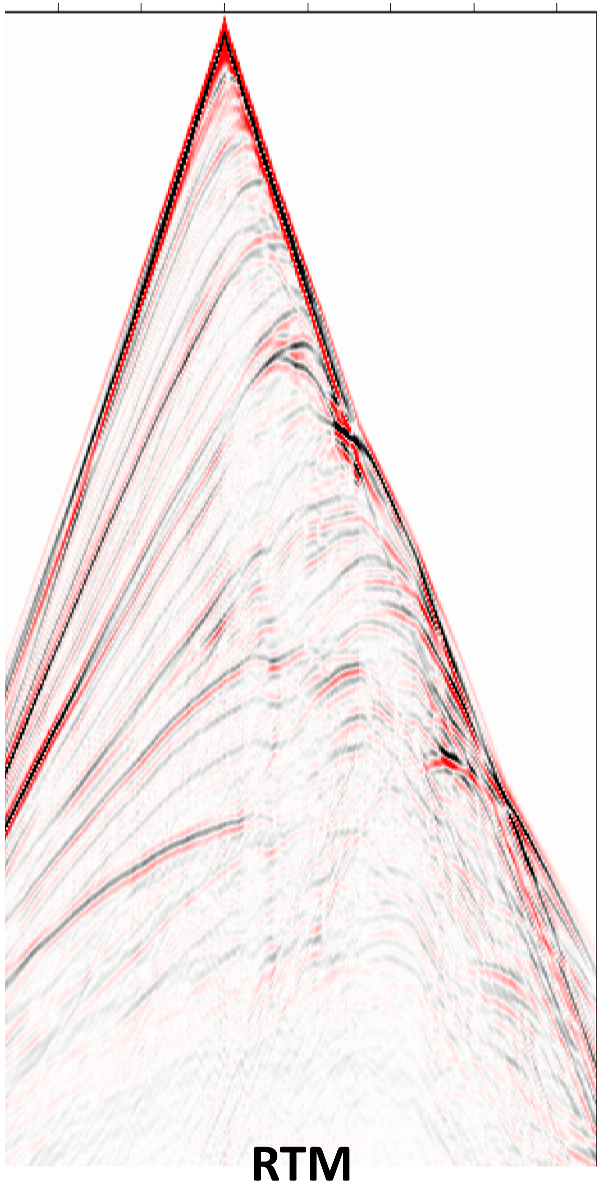
Blended shots (FD)



Kirchhoff deblended

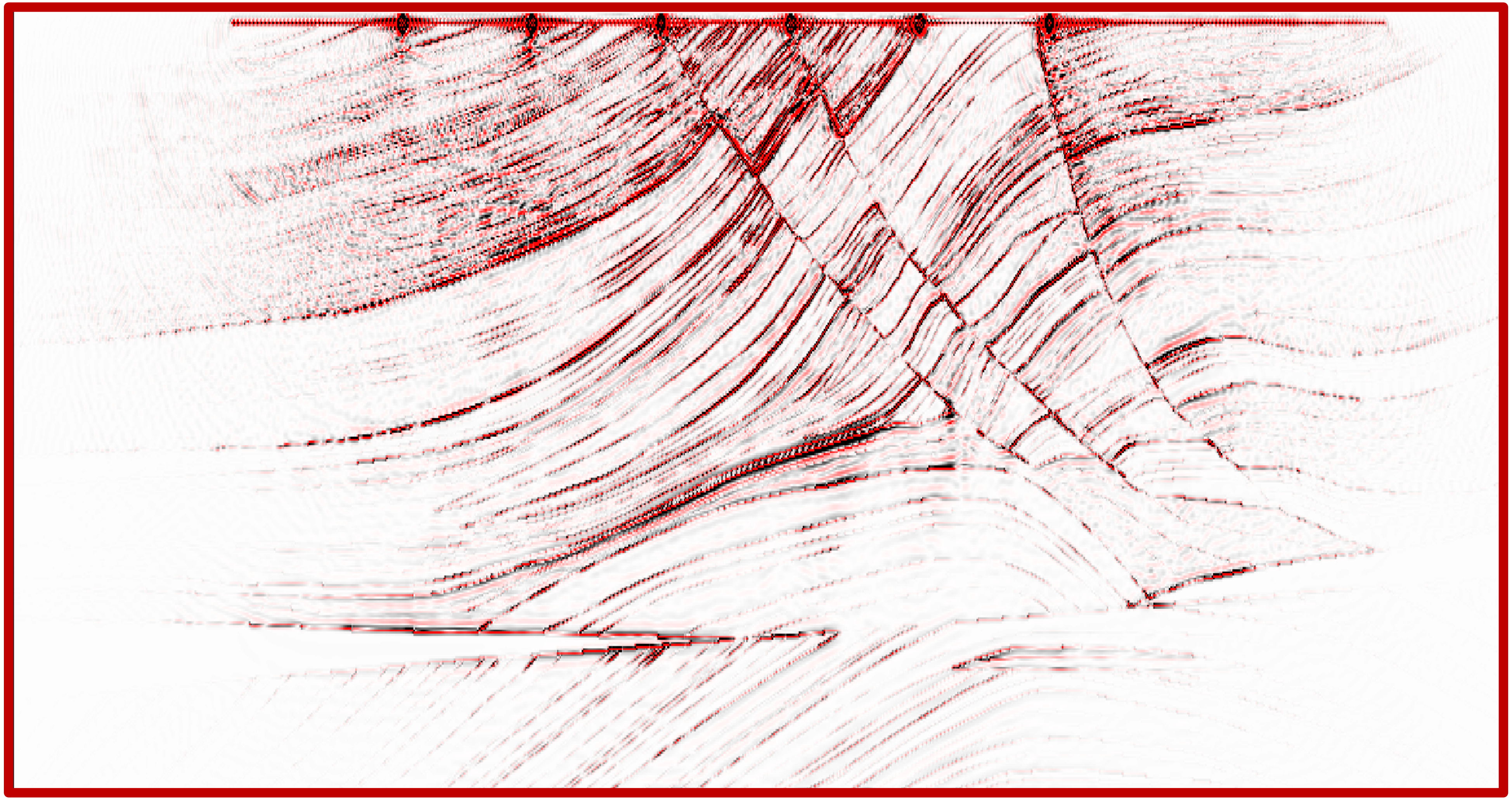


Blended shots (FD)

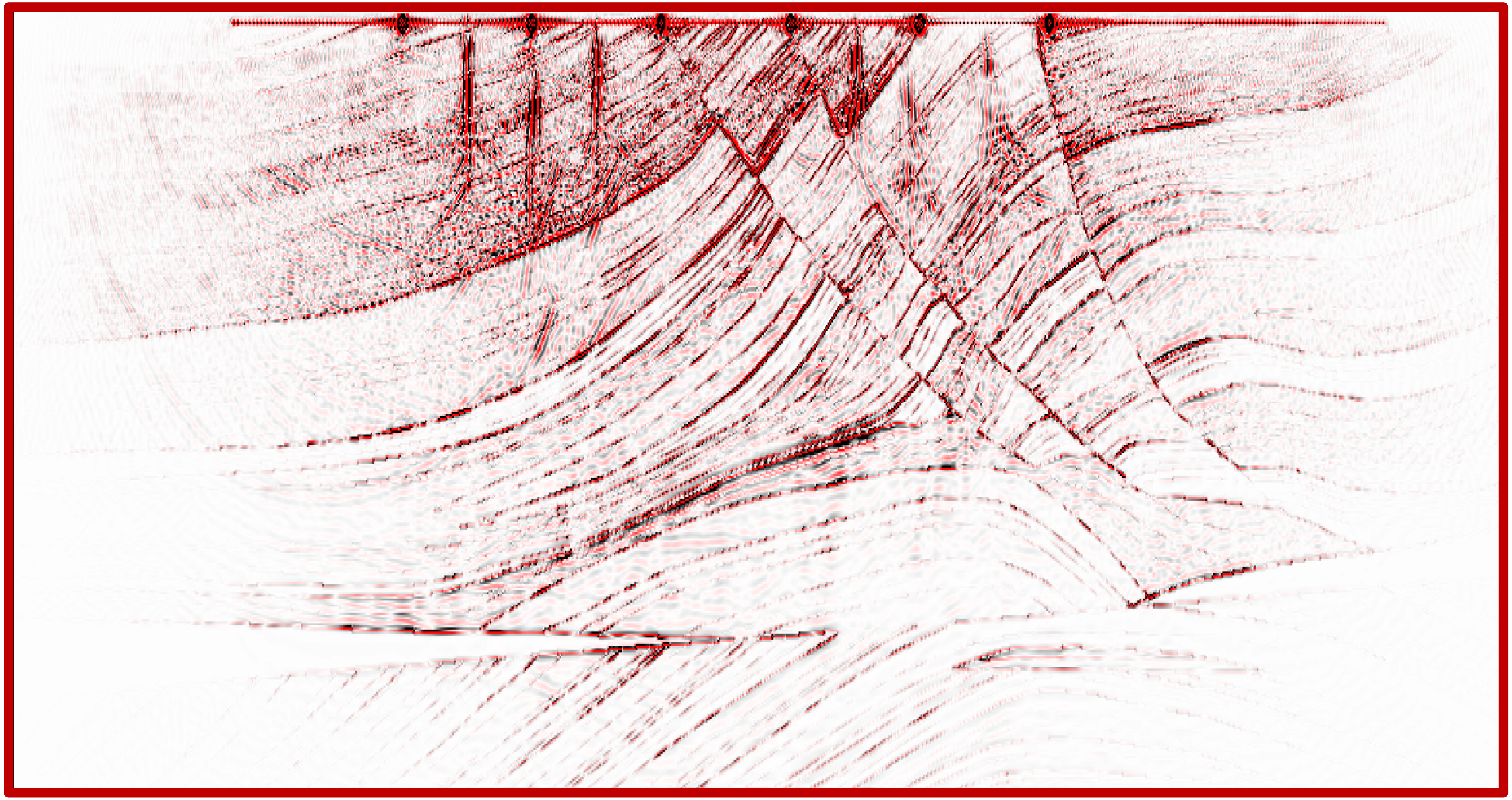


RTM deblended

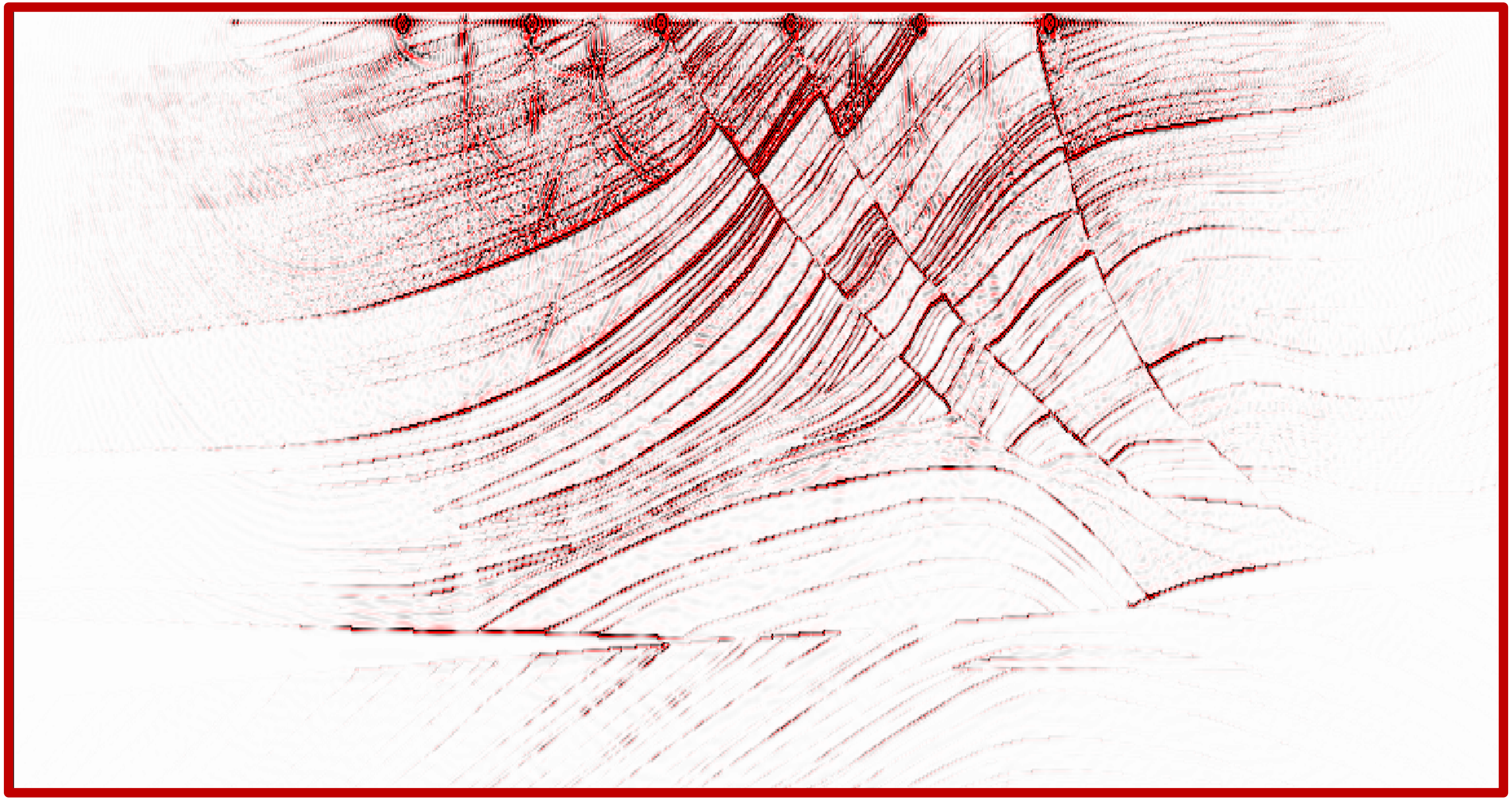
RTM 6 shots never blended



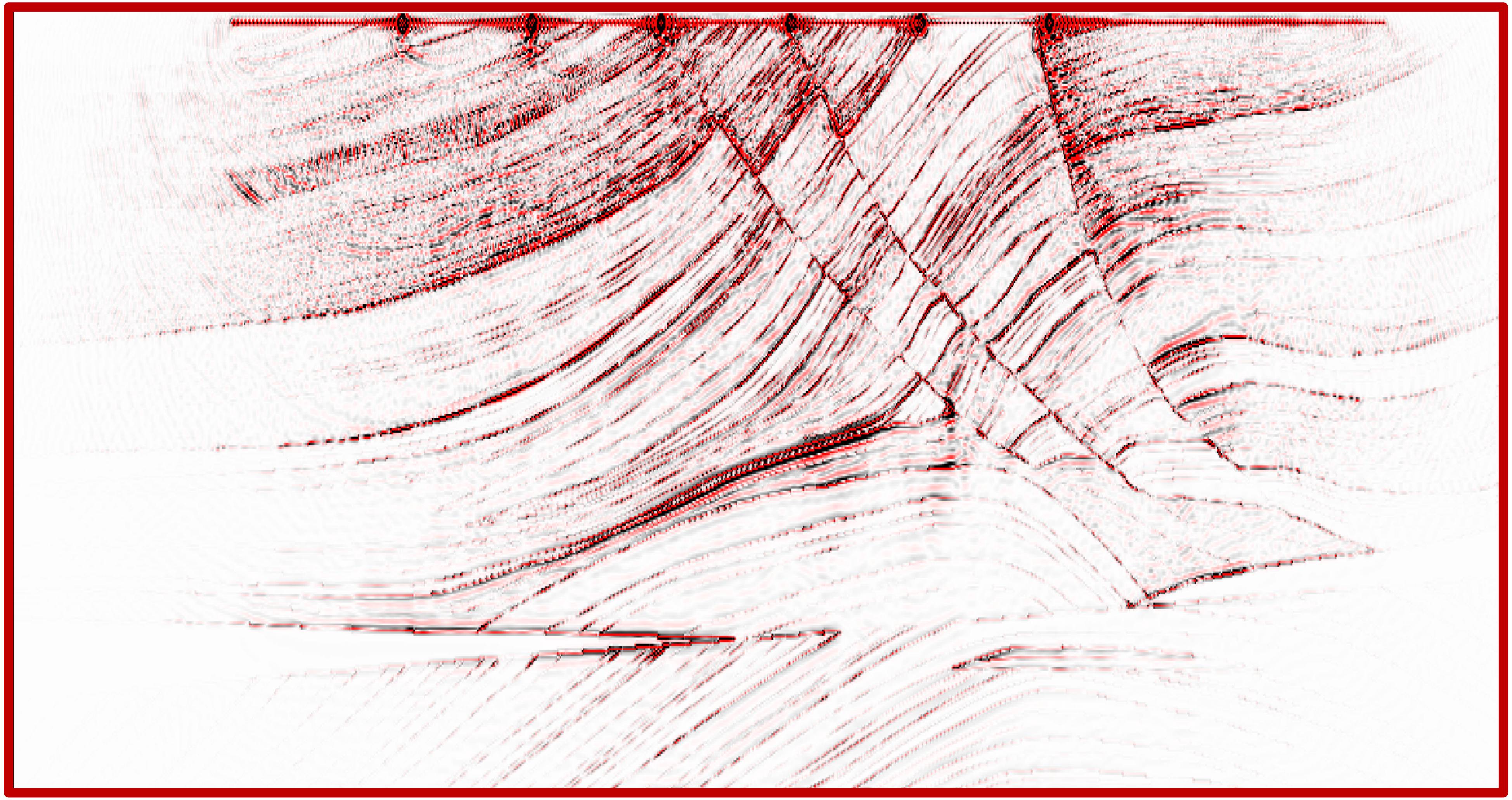
RTM 6 shots blended in groups of 3 (time = 2 shots)



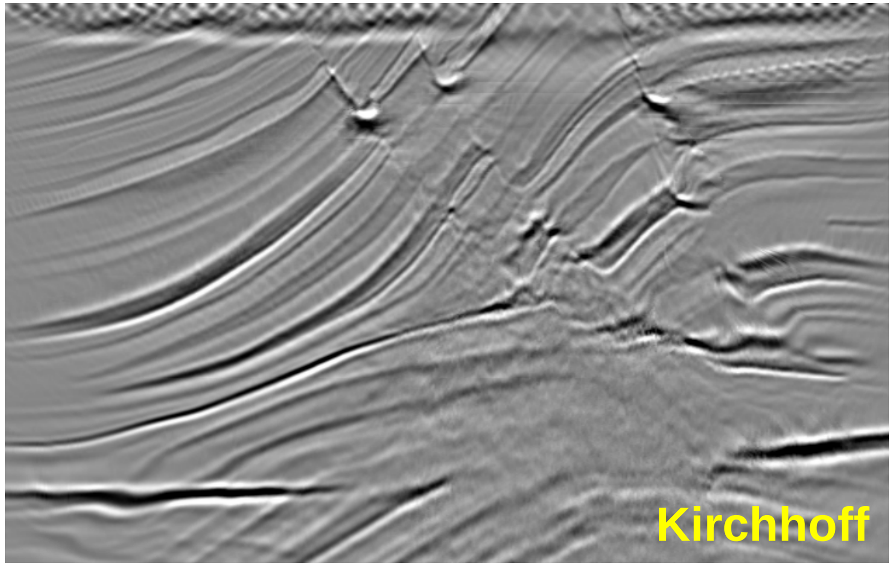
LSRTM 6 shots blended in groups of 3 (time = 2 shots)

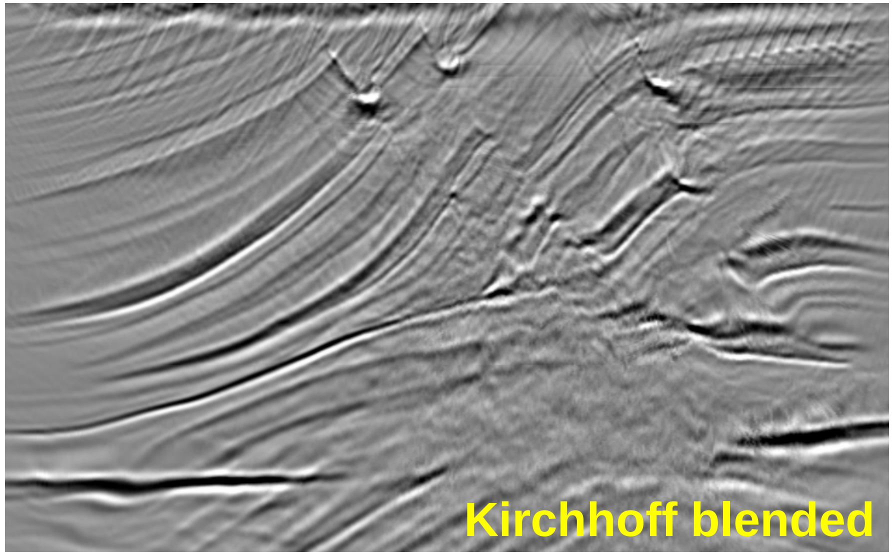


RTM 6 shots blended in groups of 3 (time = 2 shots) after deblending

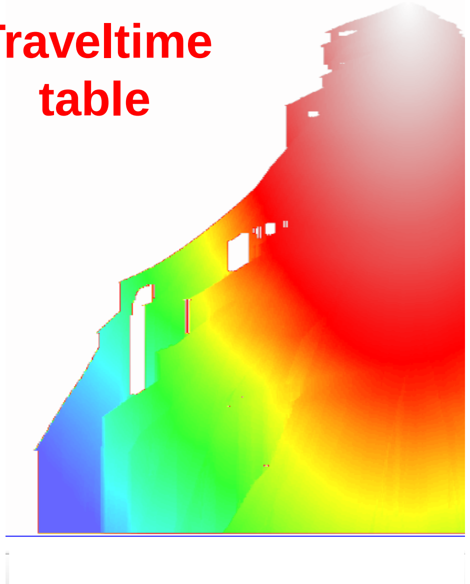


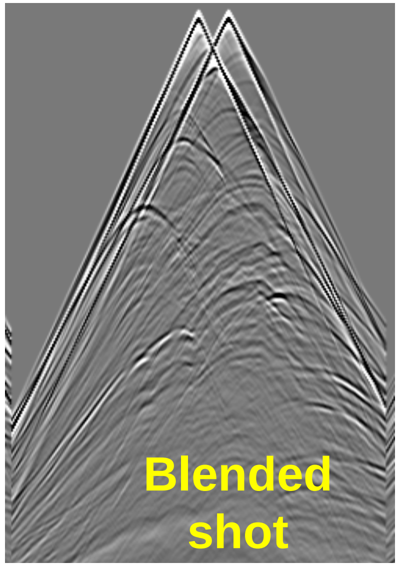
Kirchhoff

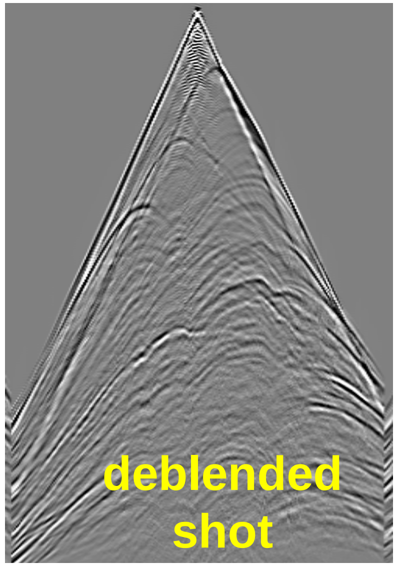


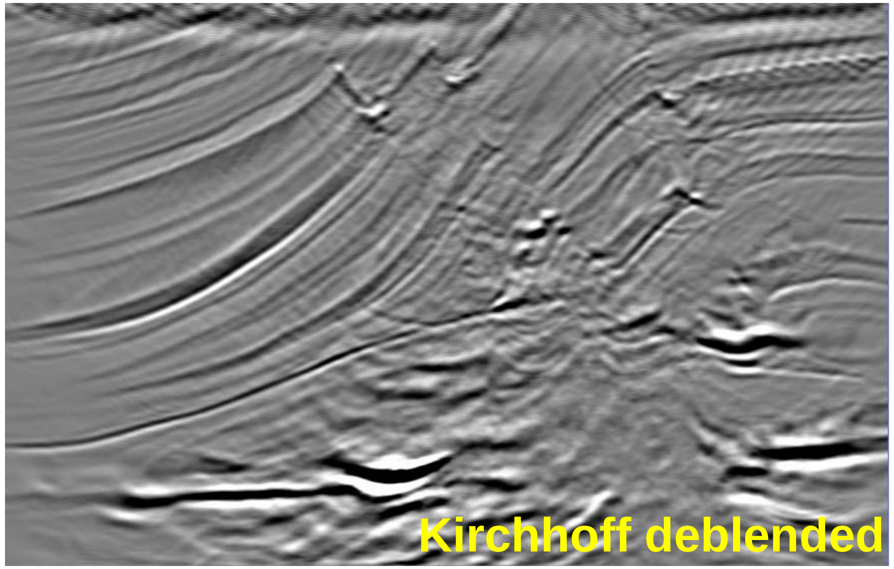


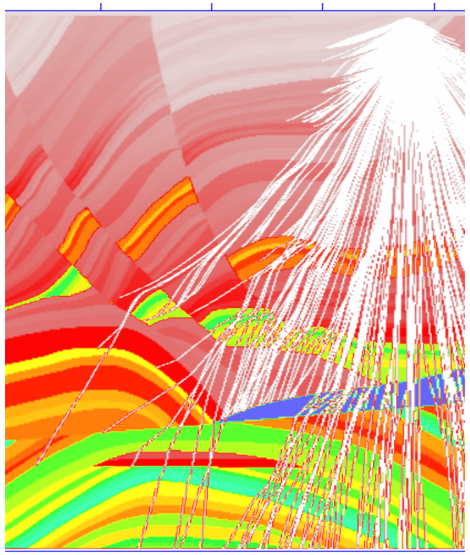
Traveltime table



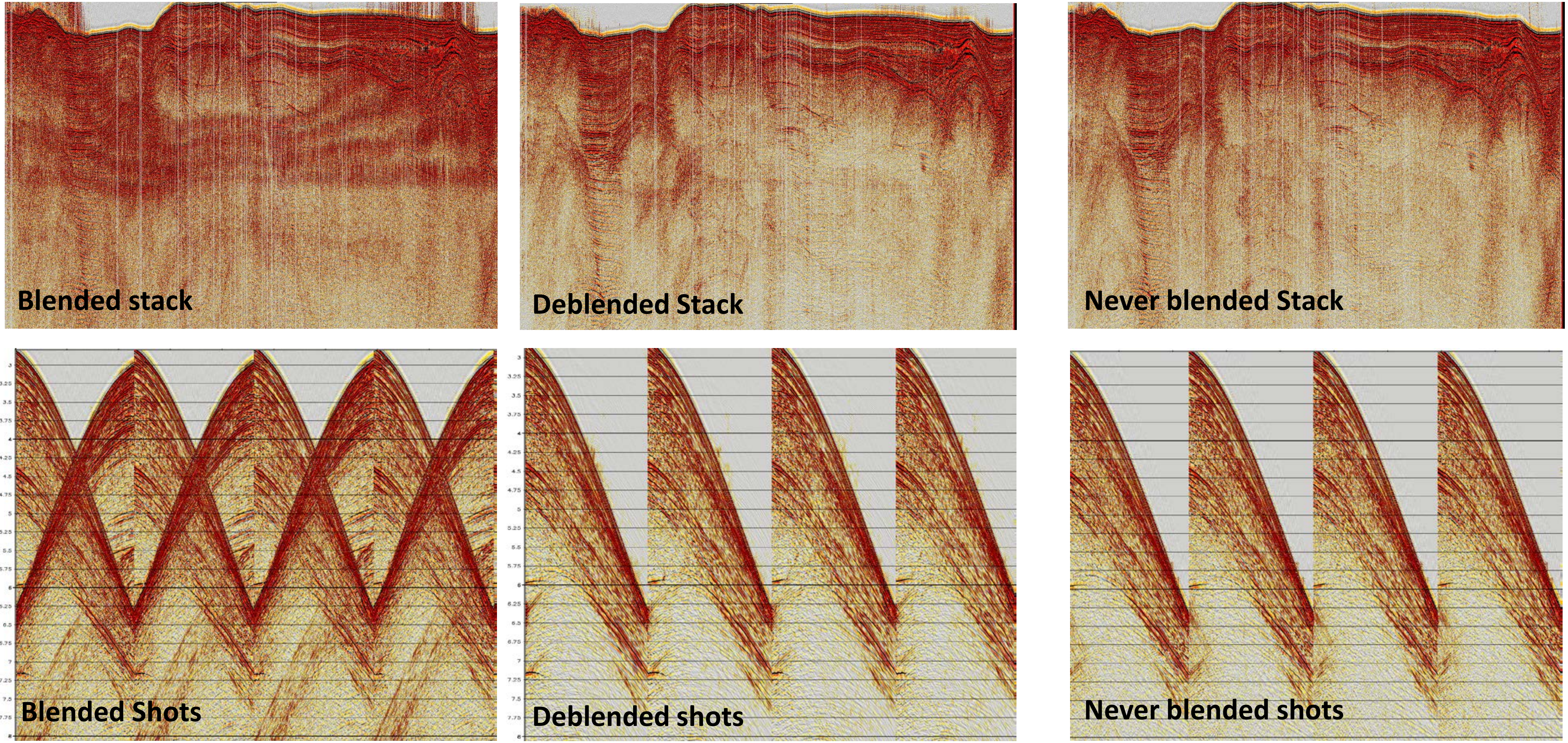






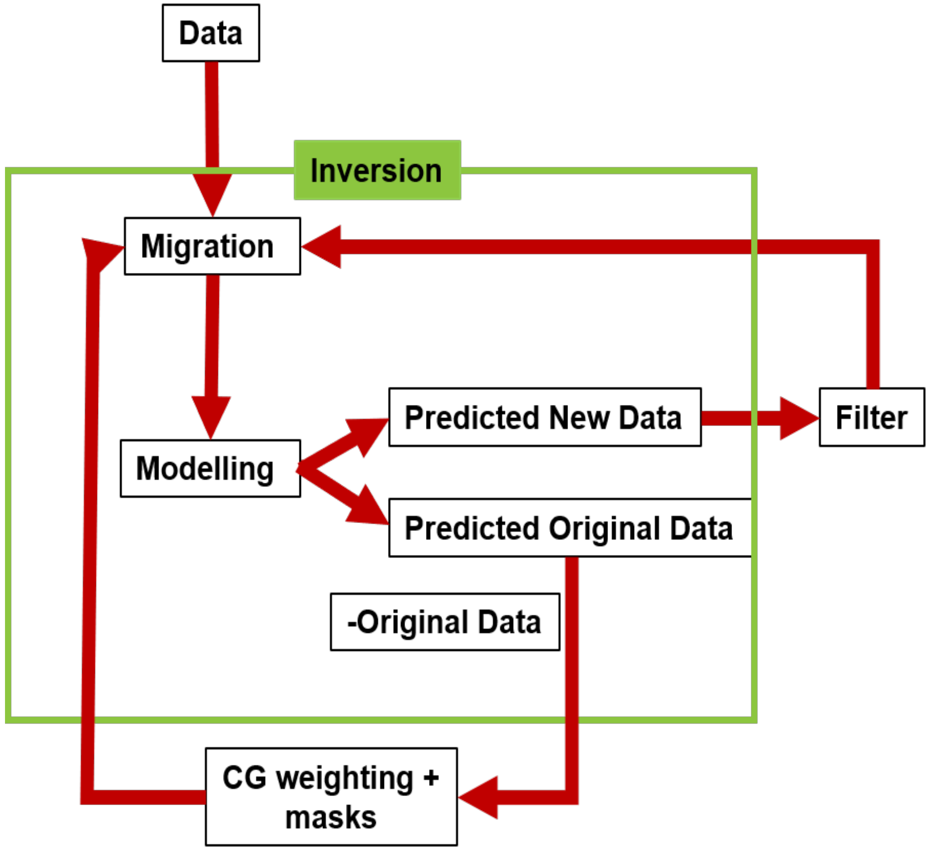


Apex Shifted Radon transform



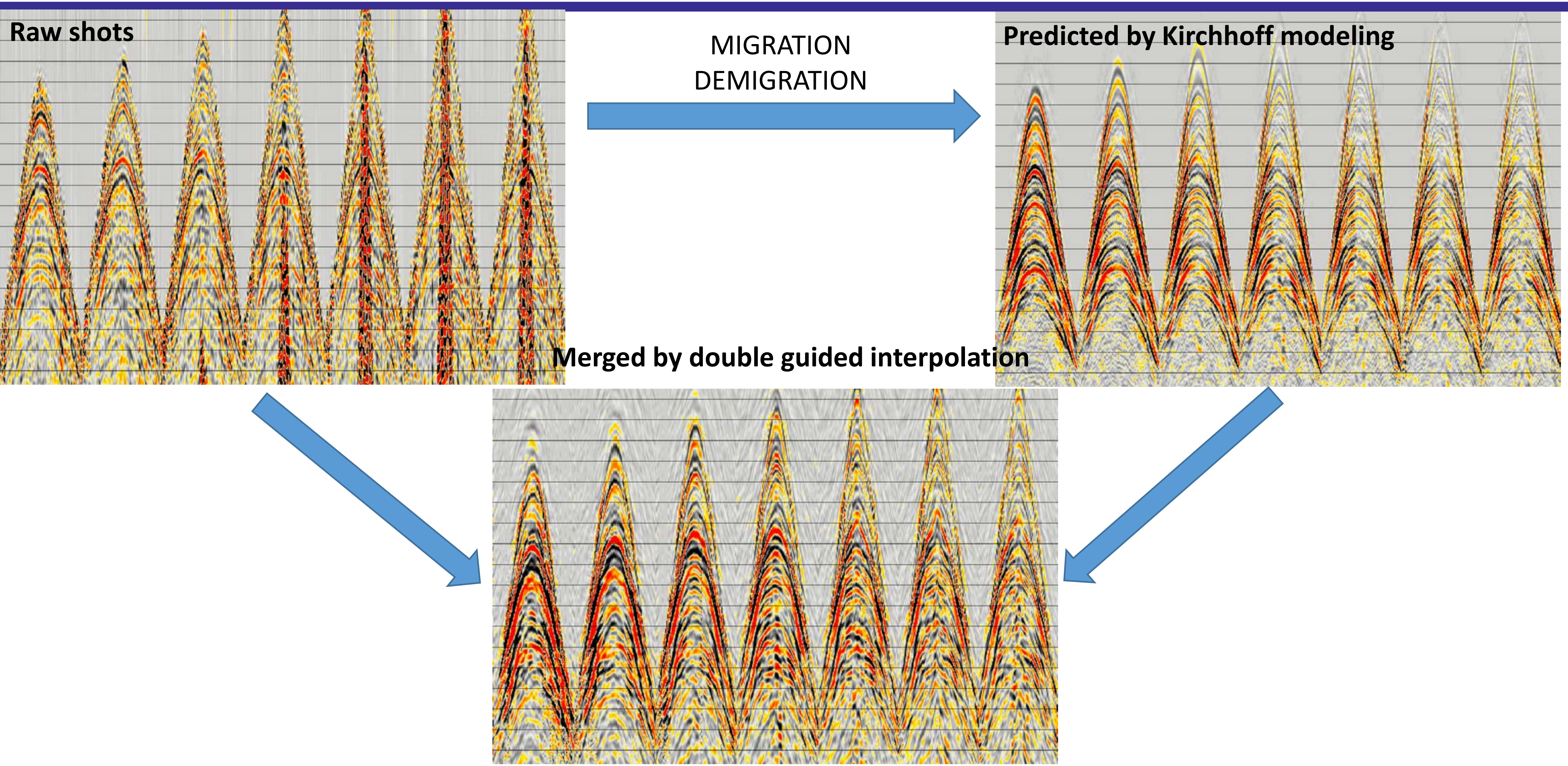
From Trad et. al, SEG2012

The feedback approach



Possible migration-demigration flow.
Filter can include other inversion processes like 5D regularization or matching filters

The feedback approach



Trad, D., 2015, Least squares Kirchhoff depth migration: implementation, challenges, and opportunities, in 2015 SEG.

Conclusions

- Compressive sensing, as used in mathematics, is the same as sparse transforms as used in geophysics for 40 years.

- Compressive sensing as used in geophysics, is the same as sparse transforms plus deblending.

- Irregular acquisition not needed for interpolation before migration but maybe needed for deblending (and CS)

- Complications for blended data can be solved by well known denoising/inversion techniques but can fail in challenging conditions.

- Physical transforms is a promising deblending technique that allows us to use prior information, but maybe limited by the quality of the prior information.

Acknowledgments

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RIPED, PetroChina

Saudi Aramco

Sinopec

TGS

NSERC CRSNG

CSEG Canadian Society of Exploration Geophysicists