Least-squares RTM of a seismic-while-drilling dataset

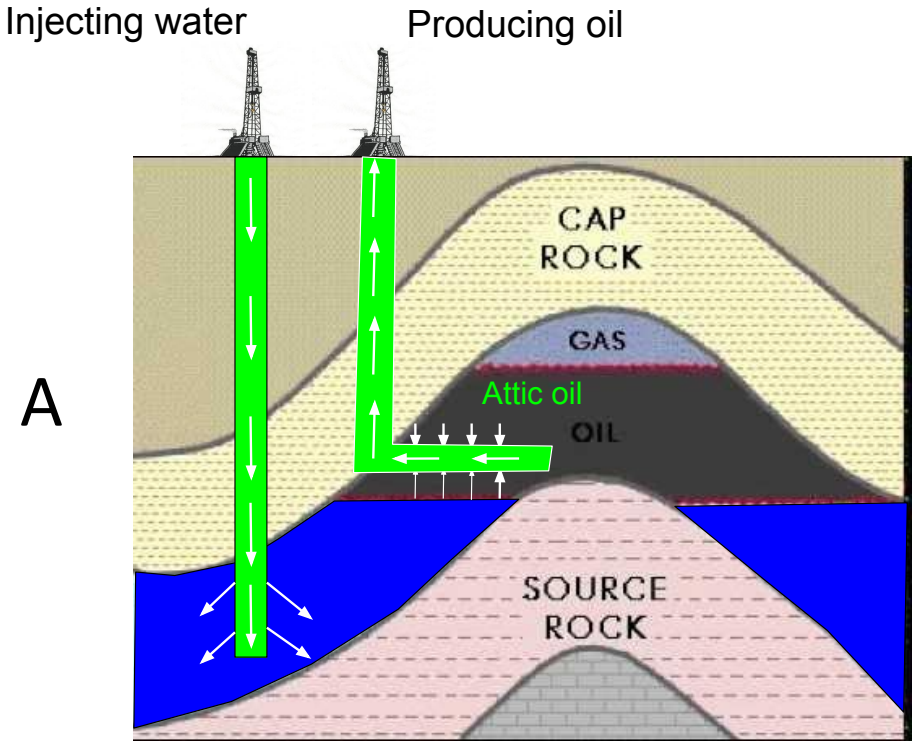
Nasser Kazemi, Daniel Trad, Kris Innanen, and Roman Shor

CREWES sponsors meeting
November 30, 2018

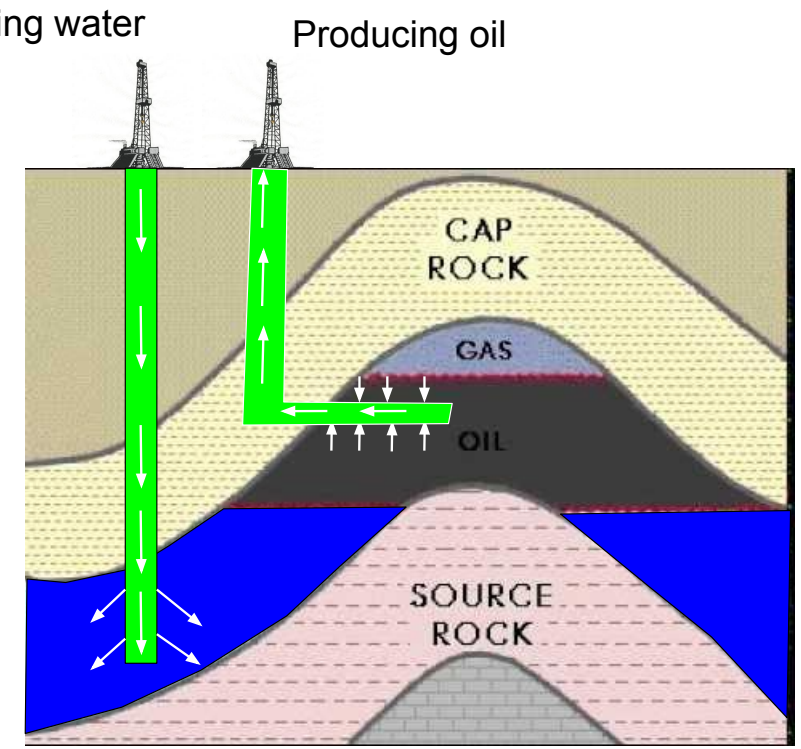
CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE
NSERC CRSNG
UNIVERSITY OF CALGARY FACULTY OF SCIENCE Department of Geoscience

Motivations: Geosteering and Well placement issues

Scenario A



Scenario B



- Statoil Hydro Troll field: 2.4 b$ (Based on OTC-17110).
- Chevron Alba (John Hampson) 225 M$ of additional production in 3 wells.

Reports from Chemali, 2011.

Sources of uncertainties

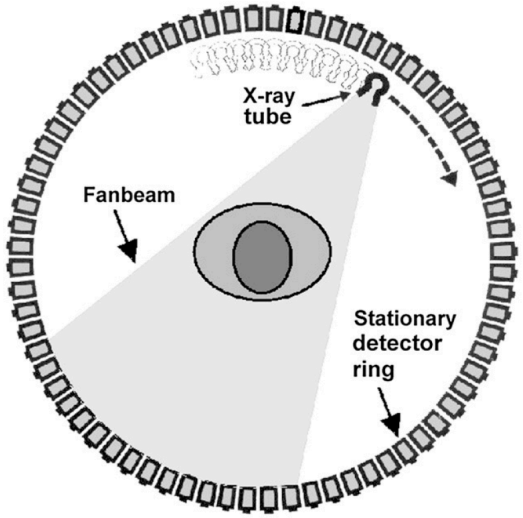
- ❑Geology
- ❑Time to Depth conversion
- ❑Sub-seismic events
- ❑Depth imaging

Uncertainties of depth imaging

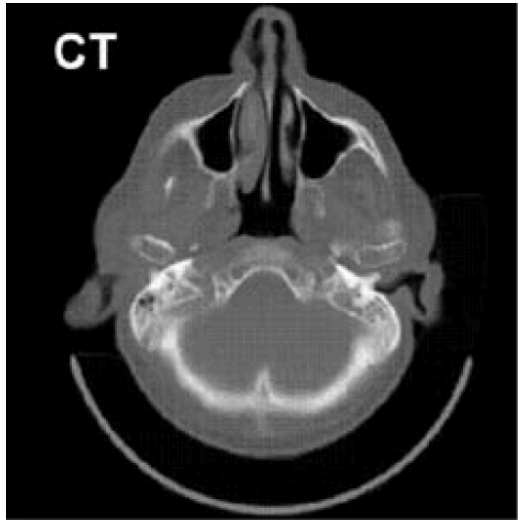
- ❑ Migration operator falls behind the physics
- ❑ Inaccurate velocity
- ❑ Acquisition footprint
- ❑ Seismic Bandwidth
- ❑ Non-uniform illumination

Non-uniform illumination

CT scan

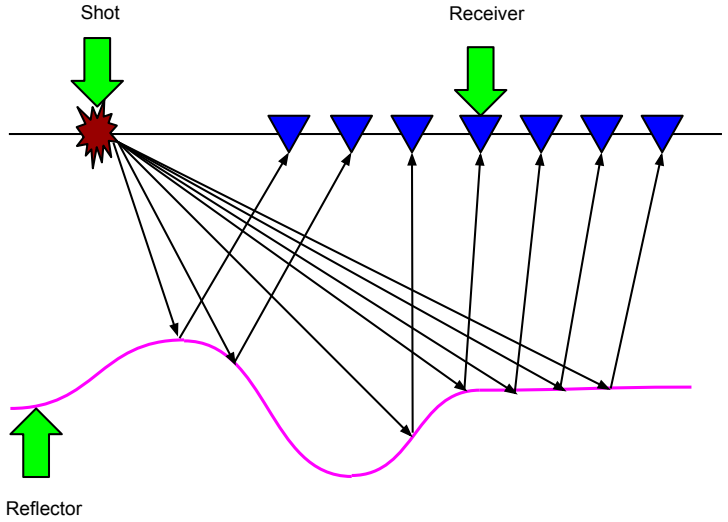


Goldman, 2007

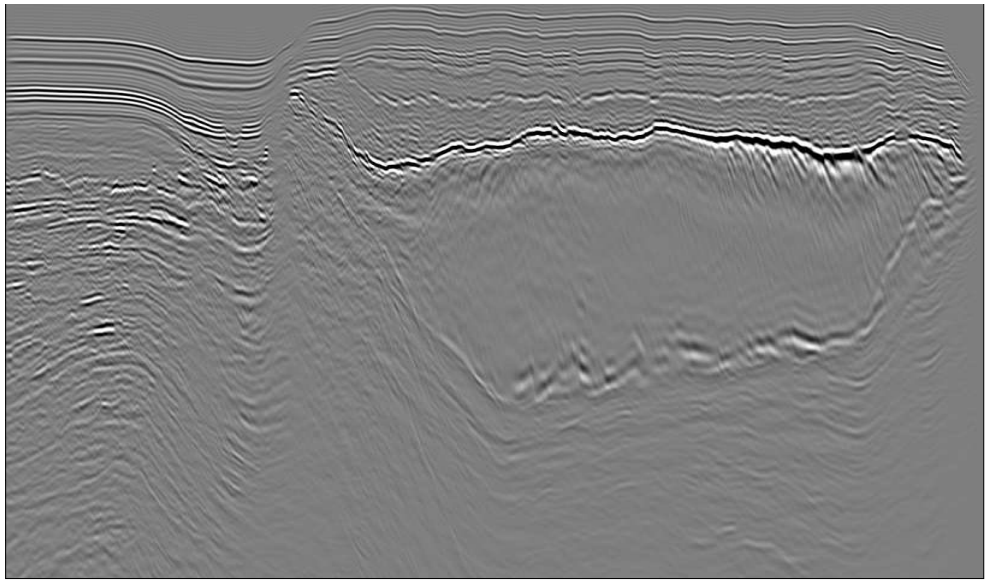


Greenspan, 2008

Surface seismic



Kazemi Nojadeh, 2017



Kazemi, 2018

Non-uniform illumination

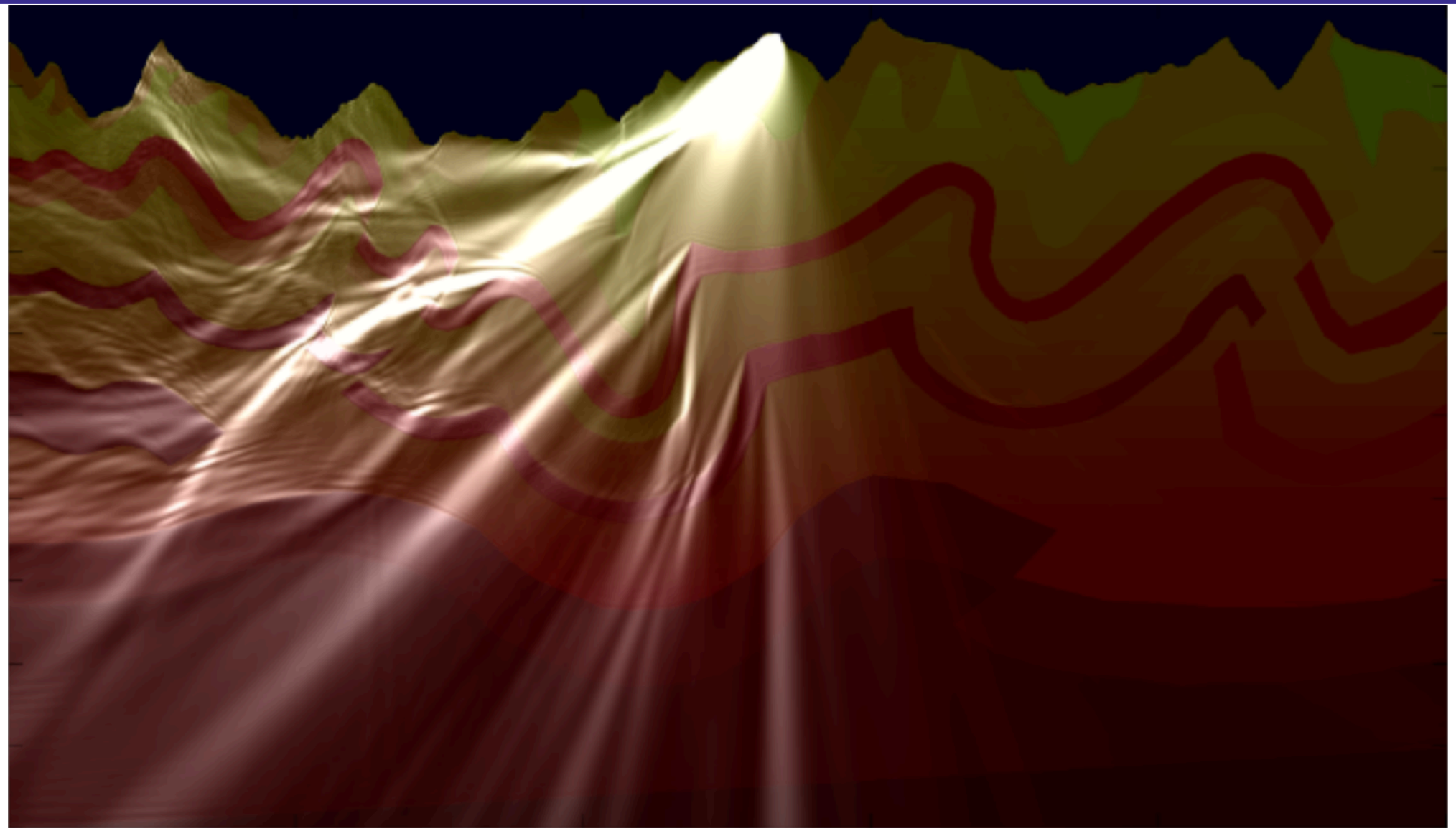
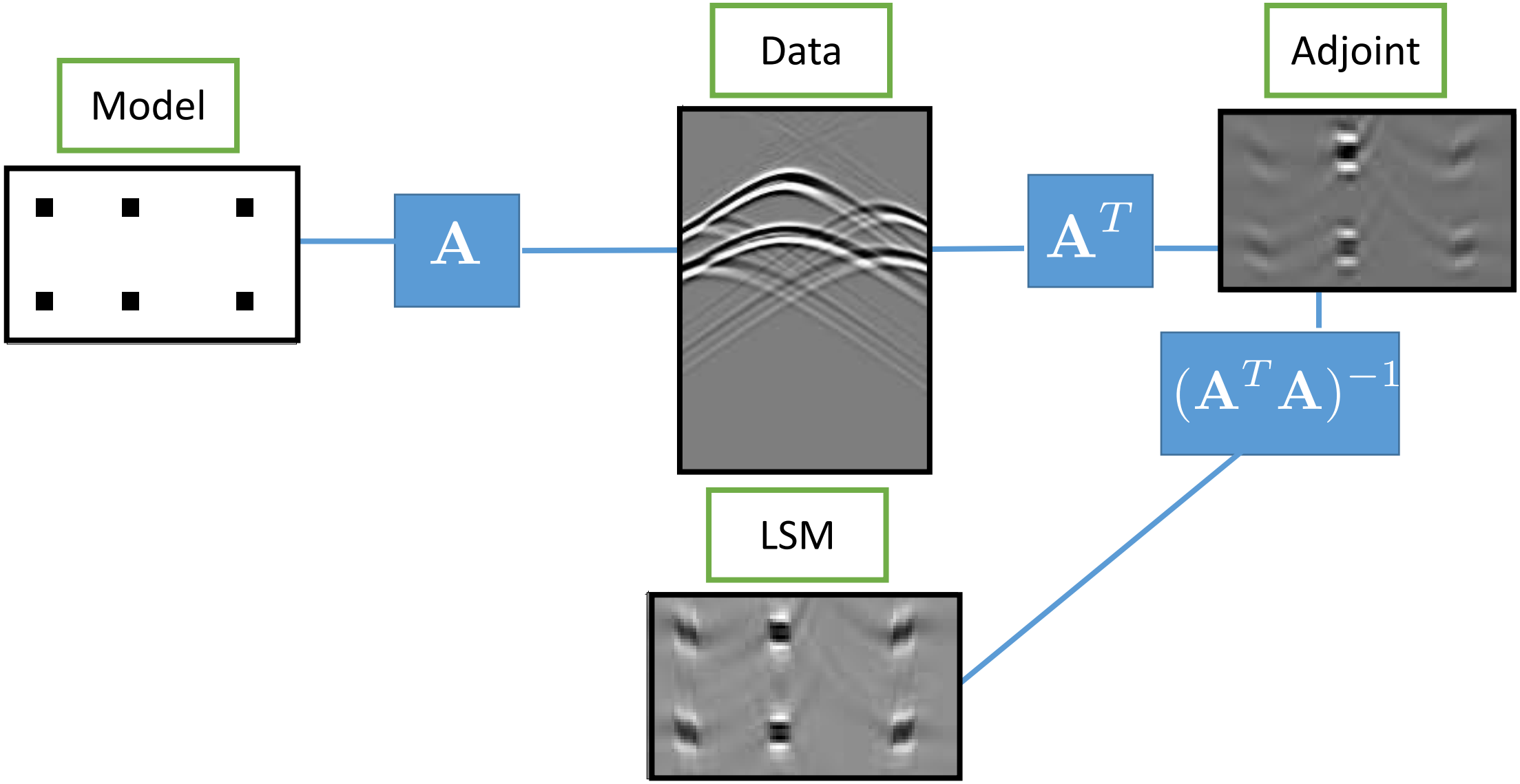
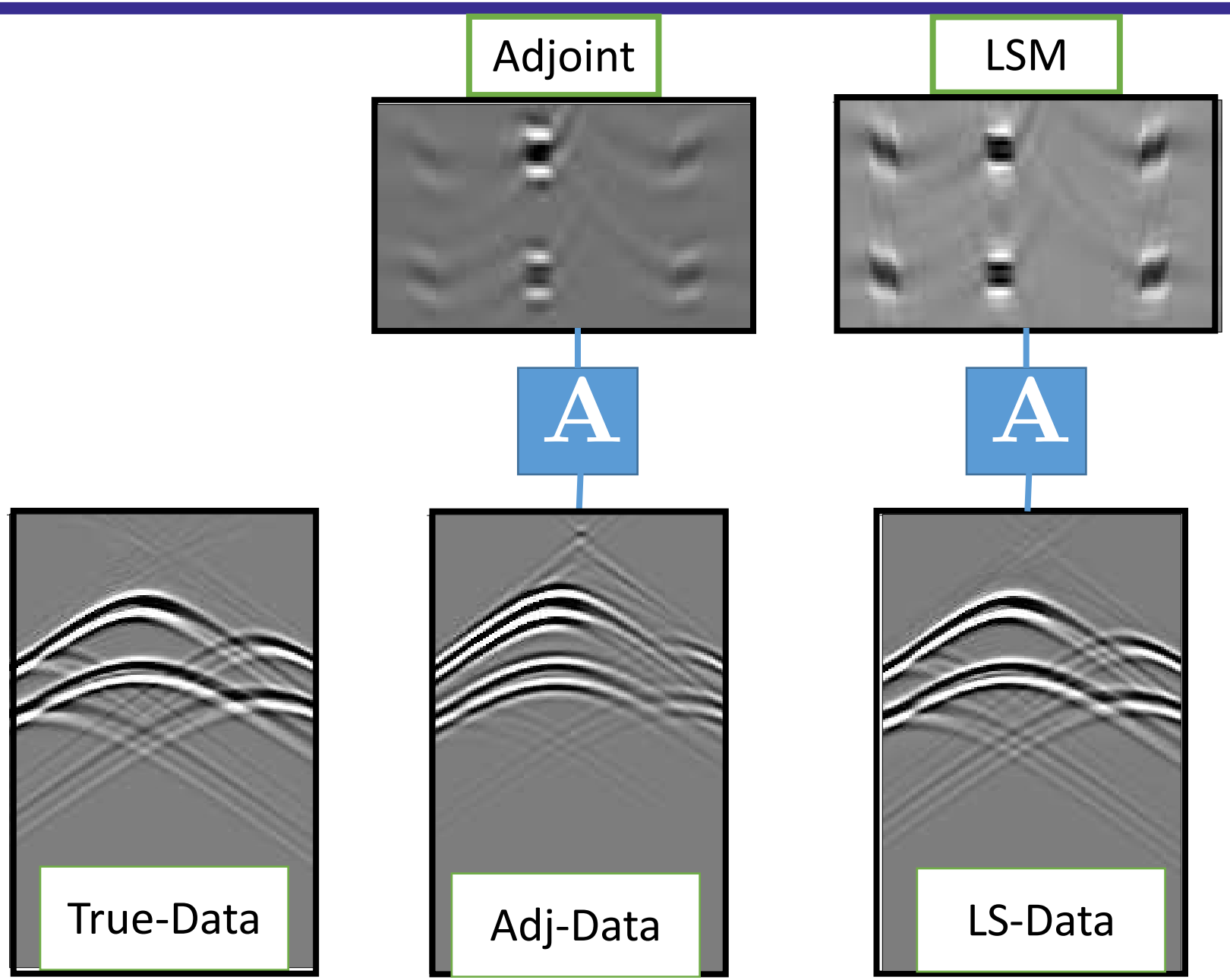


Figure adapted from acceleware. Note: Figure is shown for illustration purposes only.

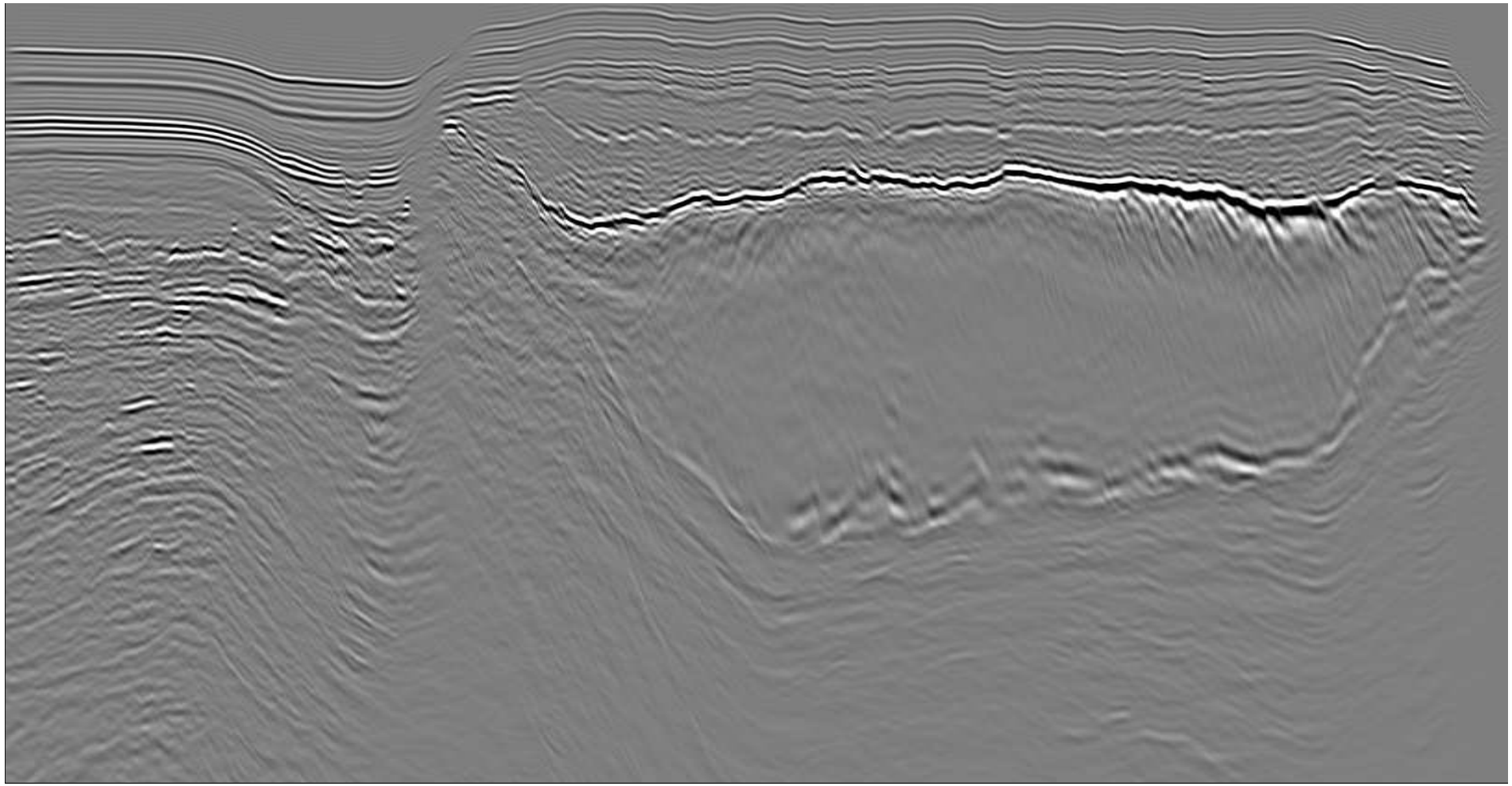
Improving illumination with LSM



Improving data fitting with LSM

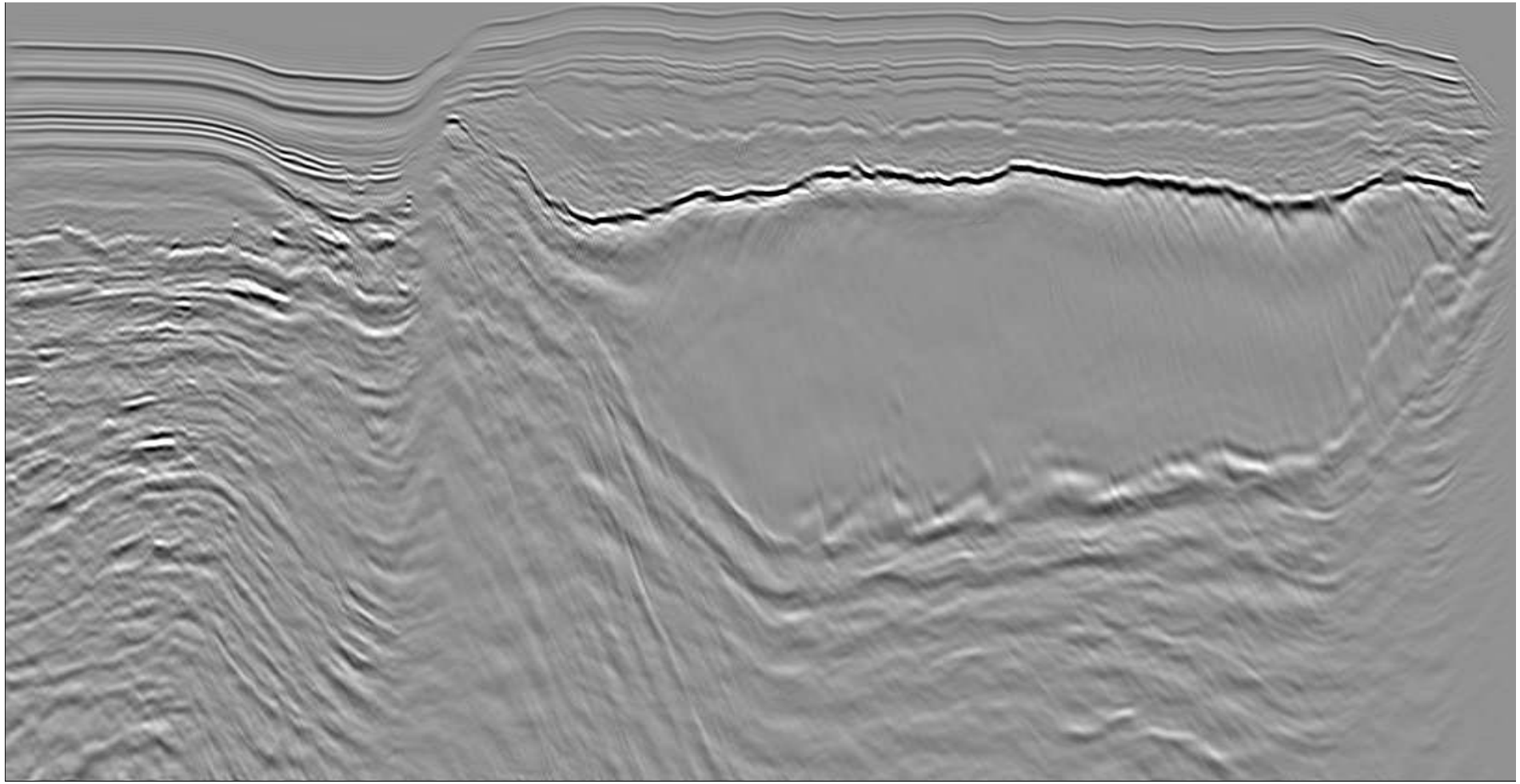


Inversion (LSM) vs. Adjoint migration



Adjoint migration of Gulf of Mexico dataset, Kazemi, 2018.

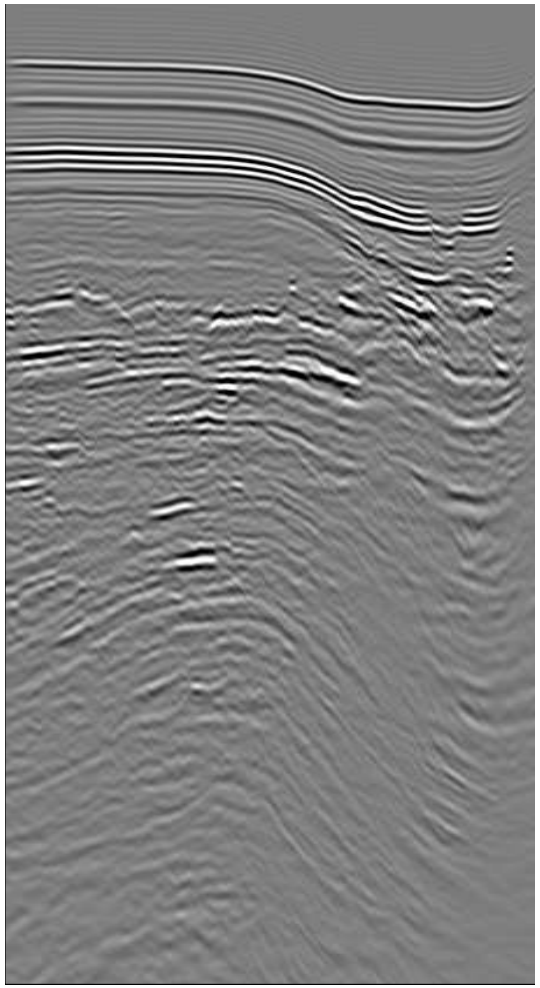
Inversion (LSM) vs. Adjoint migration



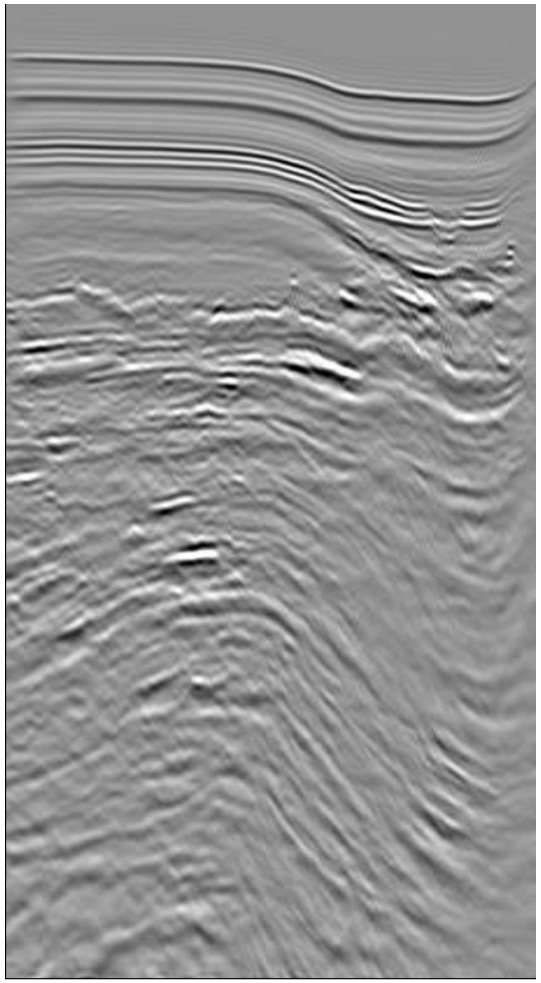
LS migration of Gulf of Mexico dataset, Kazemi, 2018.

Inversion (LSM) vs. Adjoint migration

Adjoint



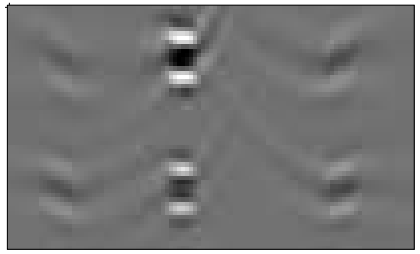
Least squares



Adjoint vs. LS migration of Gulf of Mexico dataset, Kazemi, 2018.

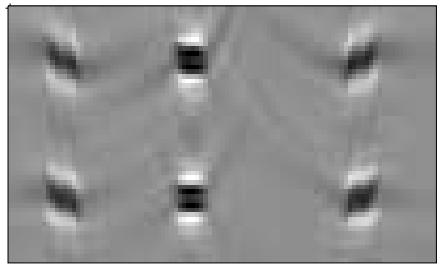
Pros and cons of LSM

Migration



Inversion (LSM):

Merits:	Demerits:
Balanced amplitudes	Computational time
Attenuated artifacts	Null space of the operator
Better resolution	
Reduced acquisition footprint	



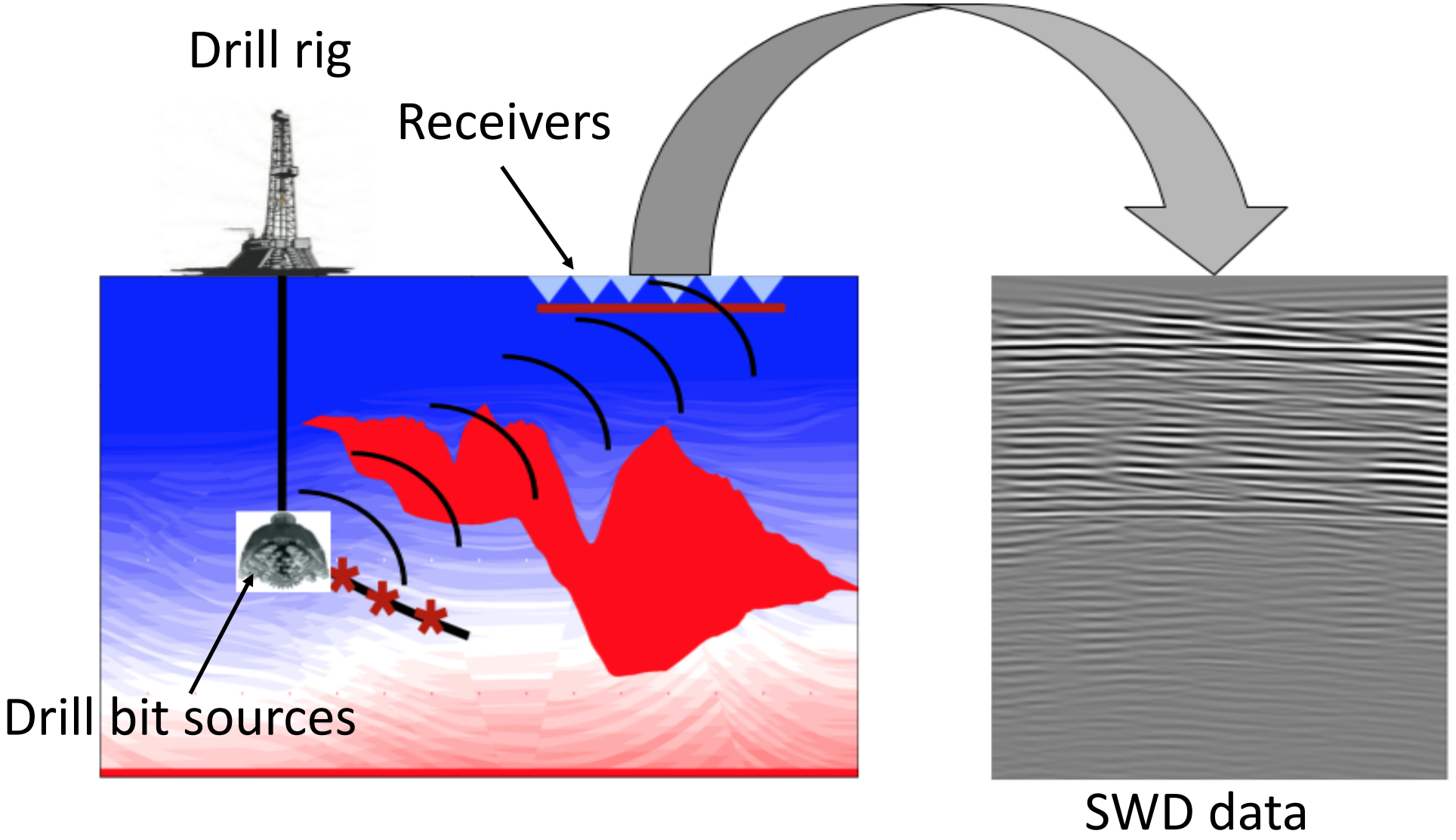
Kazemi Nojadeh, 2017.

Towards uniform illumination

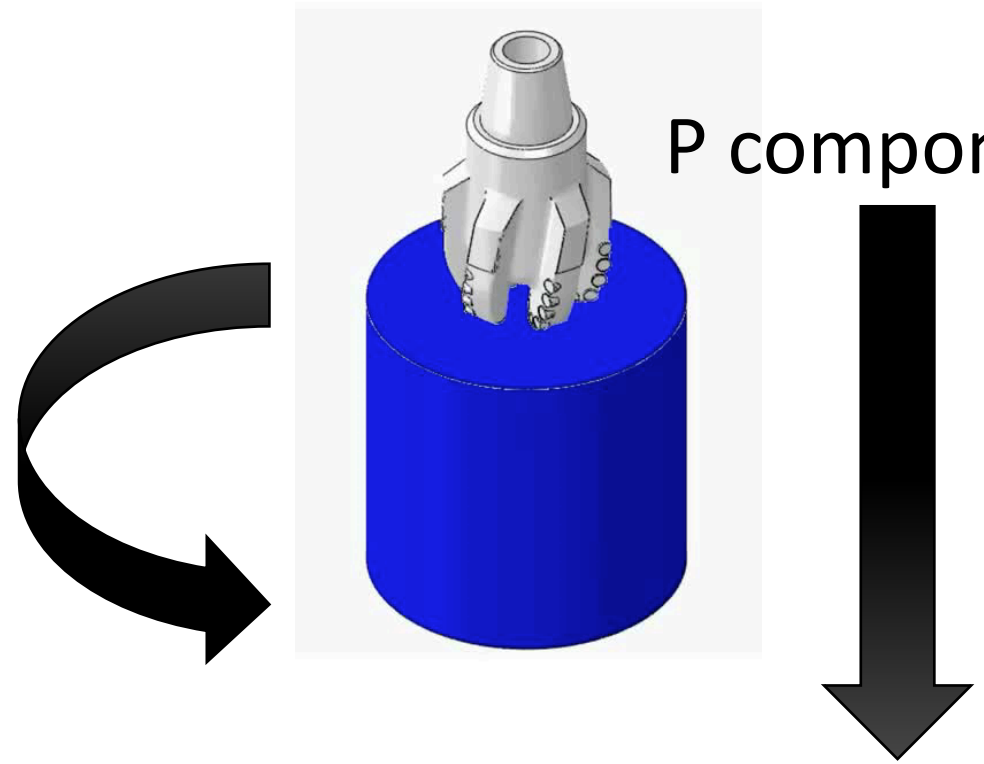
Proposal:

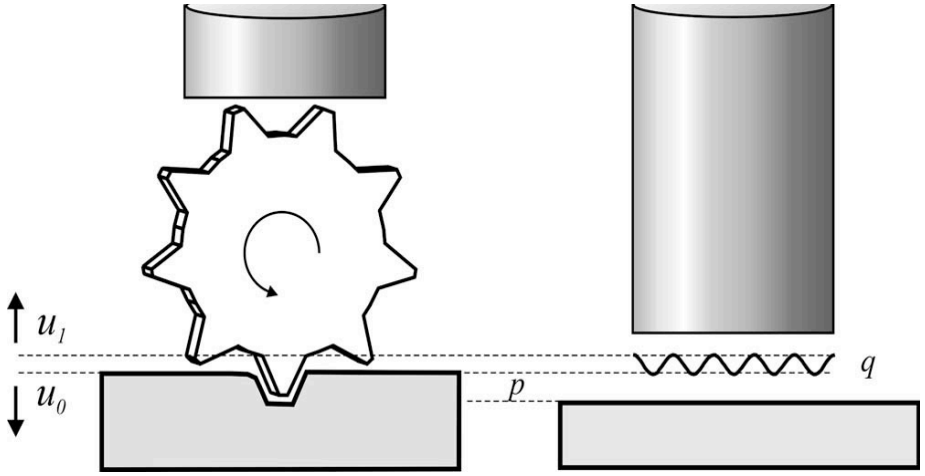
- Add new sources and receivers with different configurations.
- Seismic-while-drilling acquisition can add new insight about the subsurface.
- Seismic-while-drilling will help to reduce the null space of the migration operator.

SWD acquisition



Drill bit- rock interaction





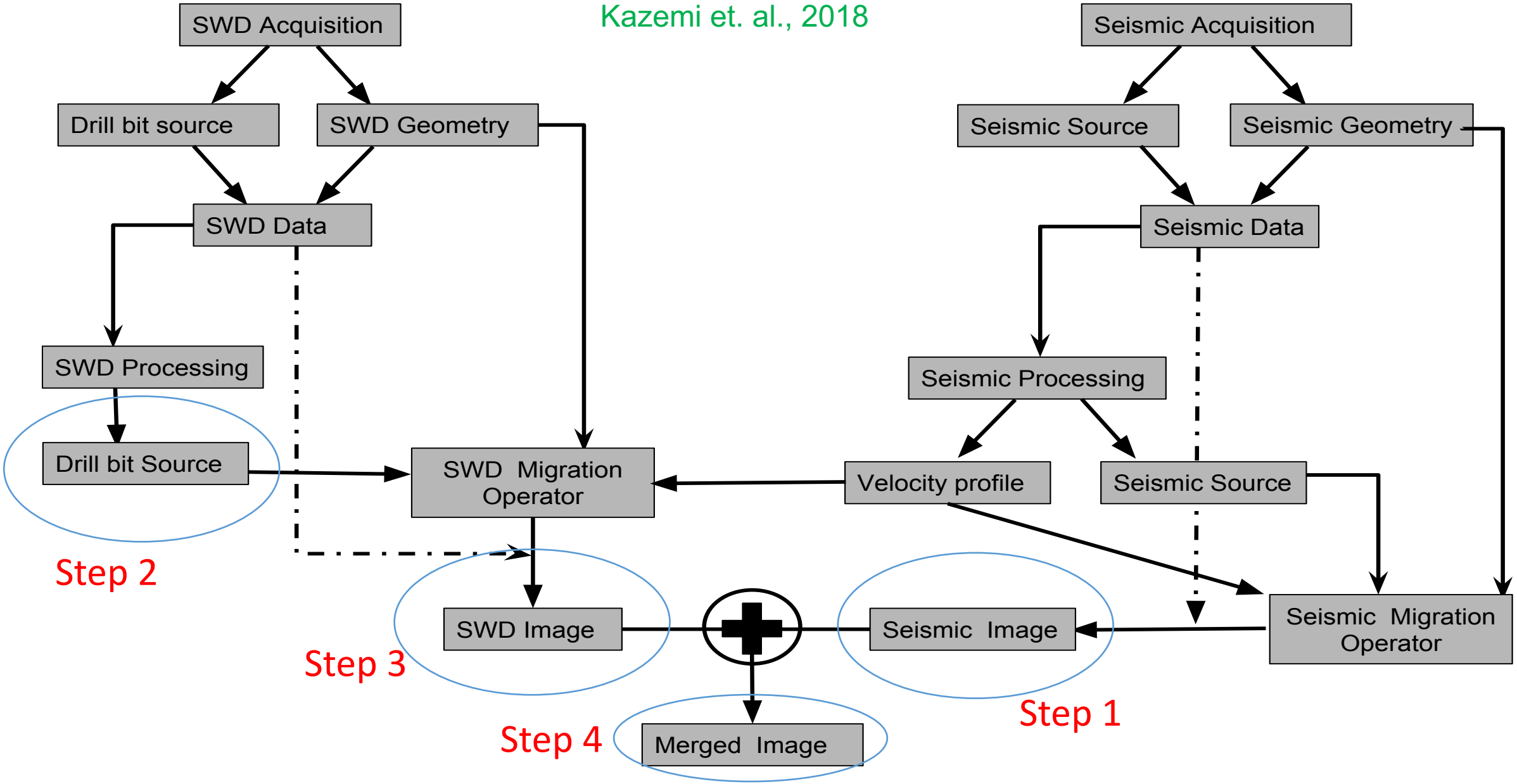
Poletto and Bellezza, 2006

- Displacement, harmonic waves, boundary conditions: source signature.
- Drill bit source is non-impulsive and correlative.

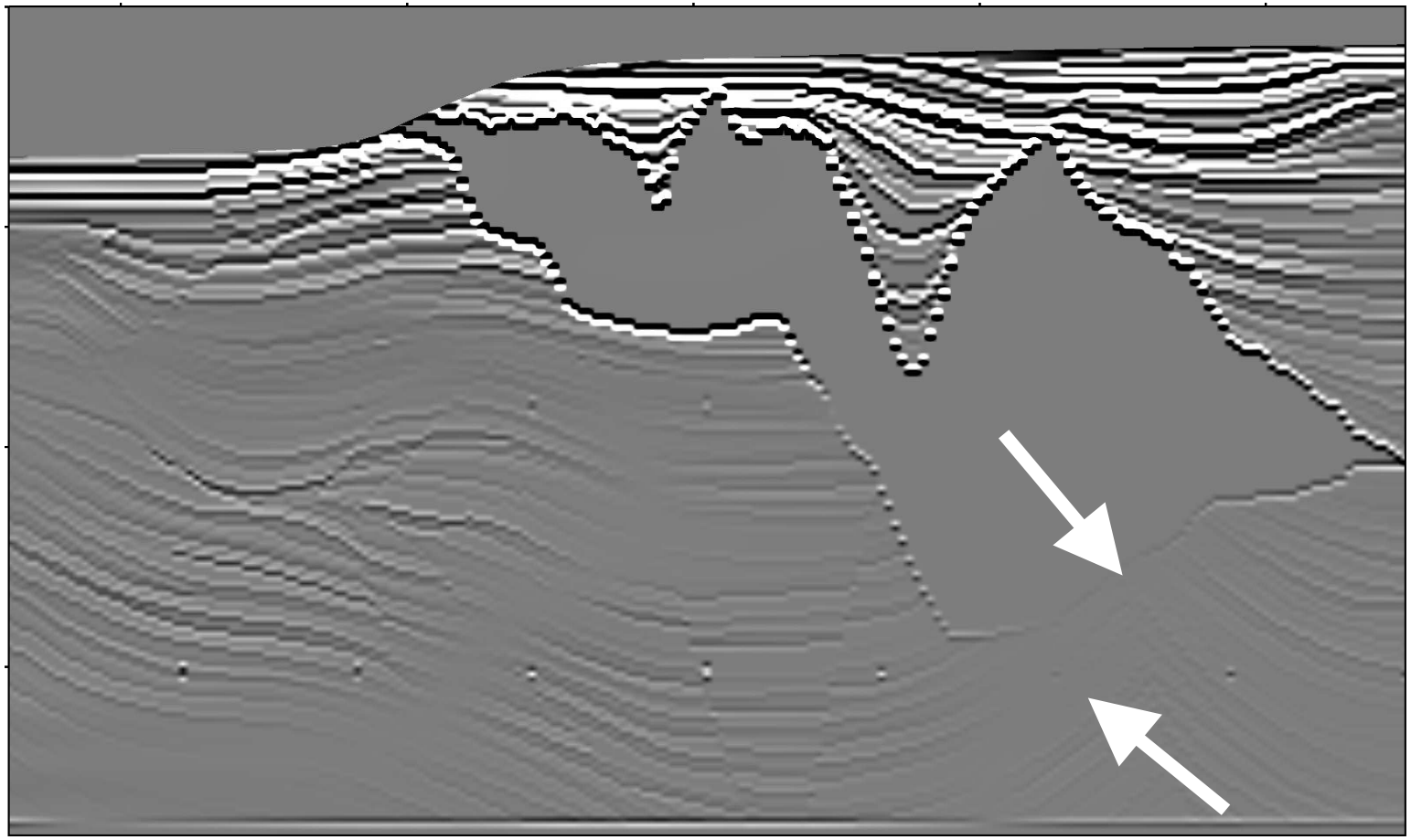
Added value of SWD data

- ❑ Geosteering
- ❑ Optimized Well placement
- ❑ Interactive decision making for drilling
- ❑ Reducing the drilling risks
- ❑ Reducing uncertainties- improving illumination

SWD+surface seismic imaging workflow



Step1: Surface seismic image



Step2: SWD source signature estimation

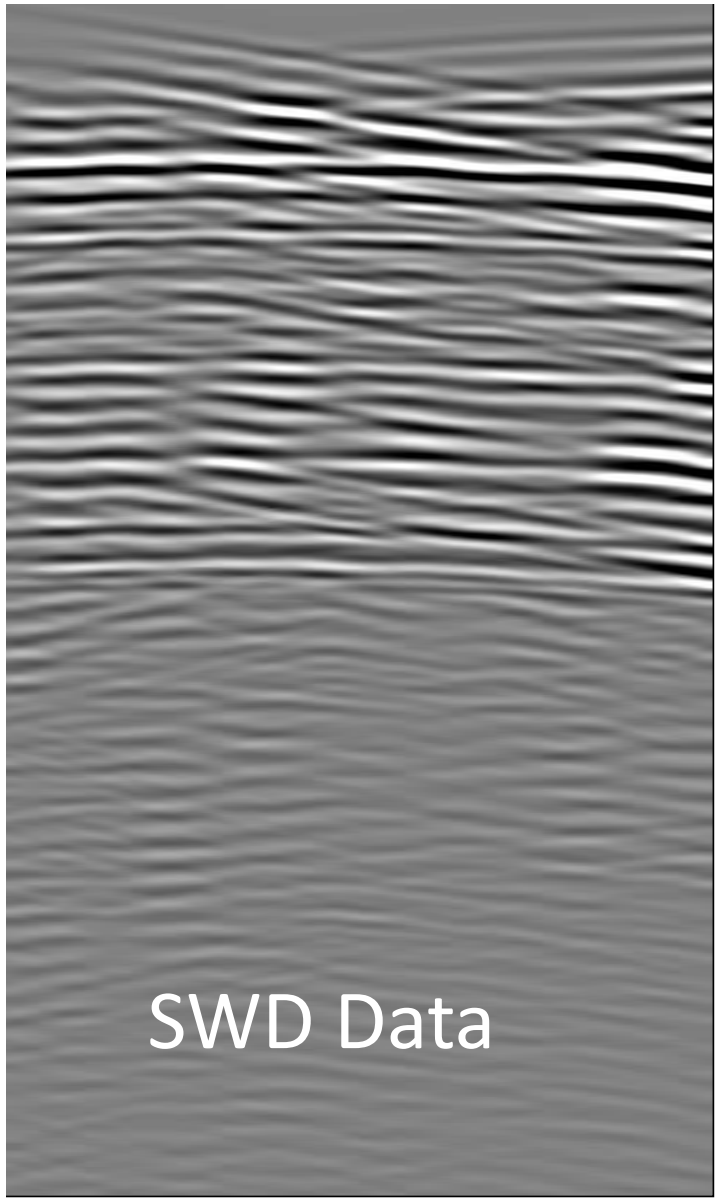
- Solve for the reflectivity: SMBD algorithm, Kazemi and Sacchi, 2014.

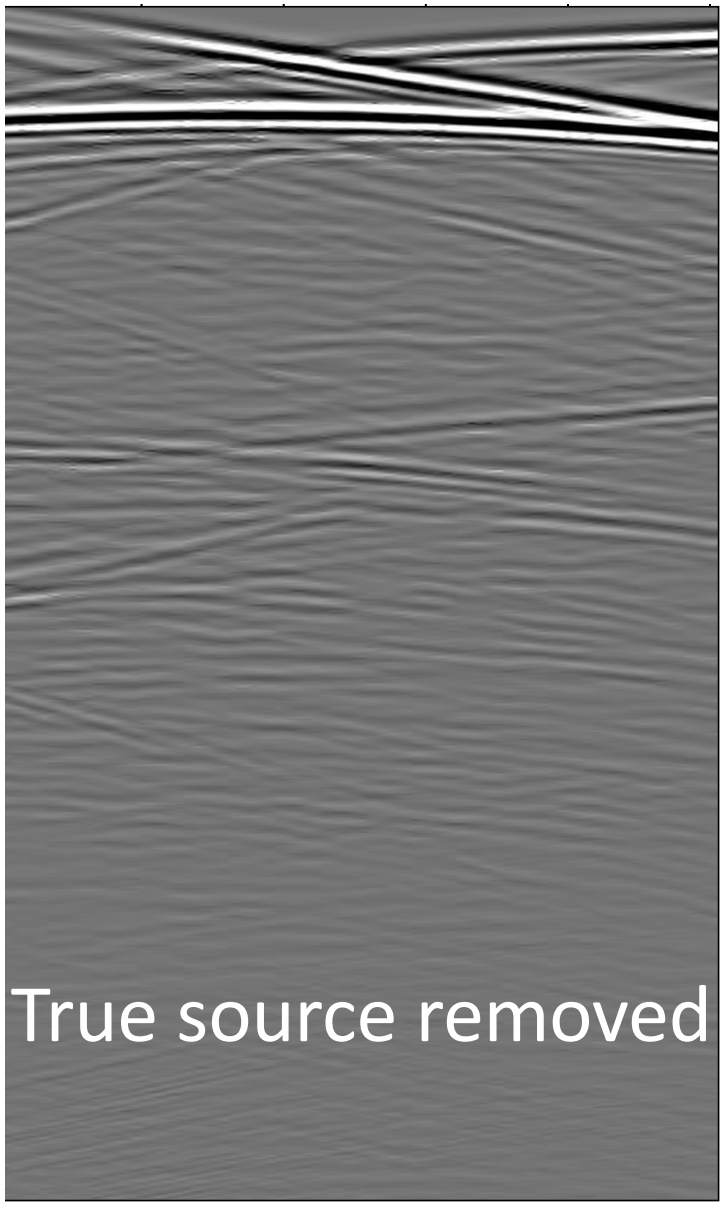
$$\hat{\mathbf{x}} = \underset{\mathbf{x}}{\operatorname{argmin}} \quad \frac{1}{2}||\mathbf{A}\,\mathbf{x}||_2^2 + \lambda \sum_i (\sqrt{x_i^2 + \epsilon^2} - \epsilon), \quad \text{subject to} \quad \mathbf{x}^T\mathbf{x} = 1$$

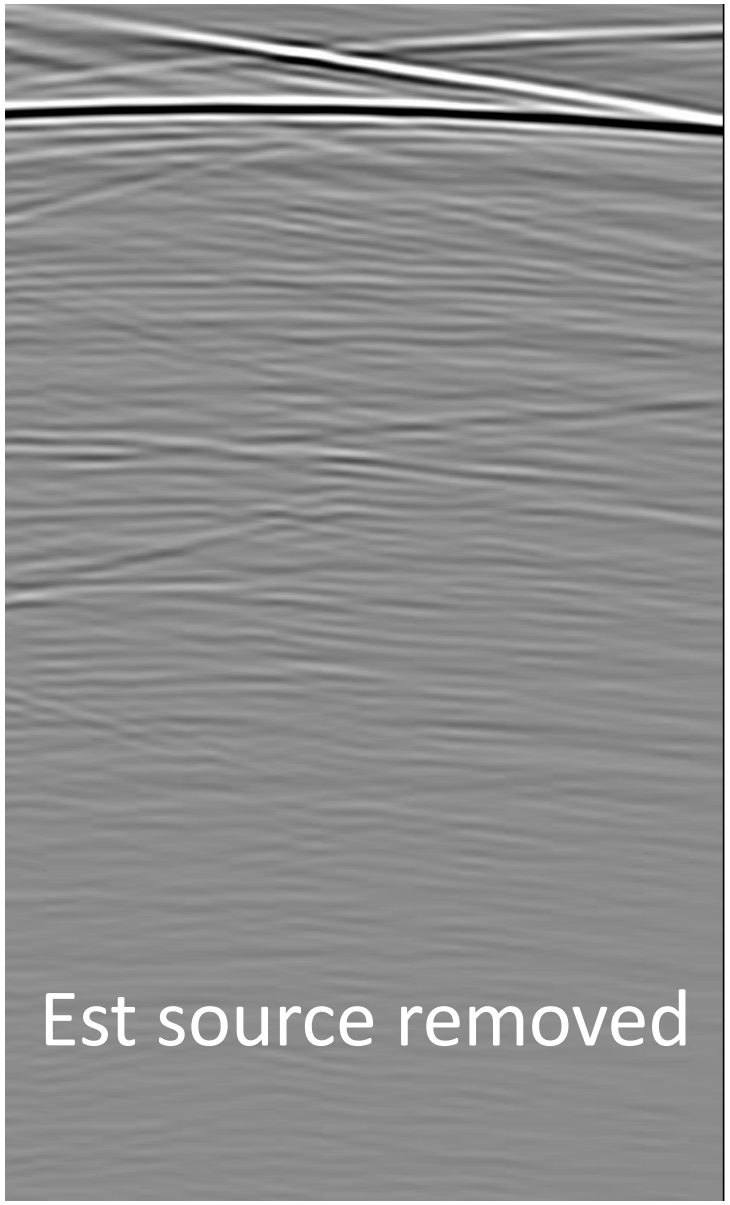
- Estimate SWD source signature: least squares estimator

$$\hat{\mathbf{w}}_{SWD} = \underset{\mathbf{w}_{SWD}}{\operatorname{argmin}} \quad \frac{1}{2}||\mathbf{X}\,\mathbf{w}_{SWD} - \mathbf{d}||_2^2$$

Step2: SWD source signature estimation

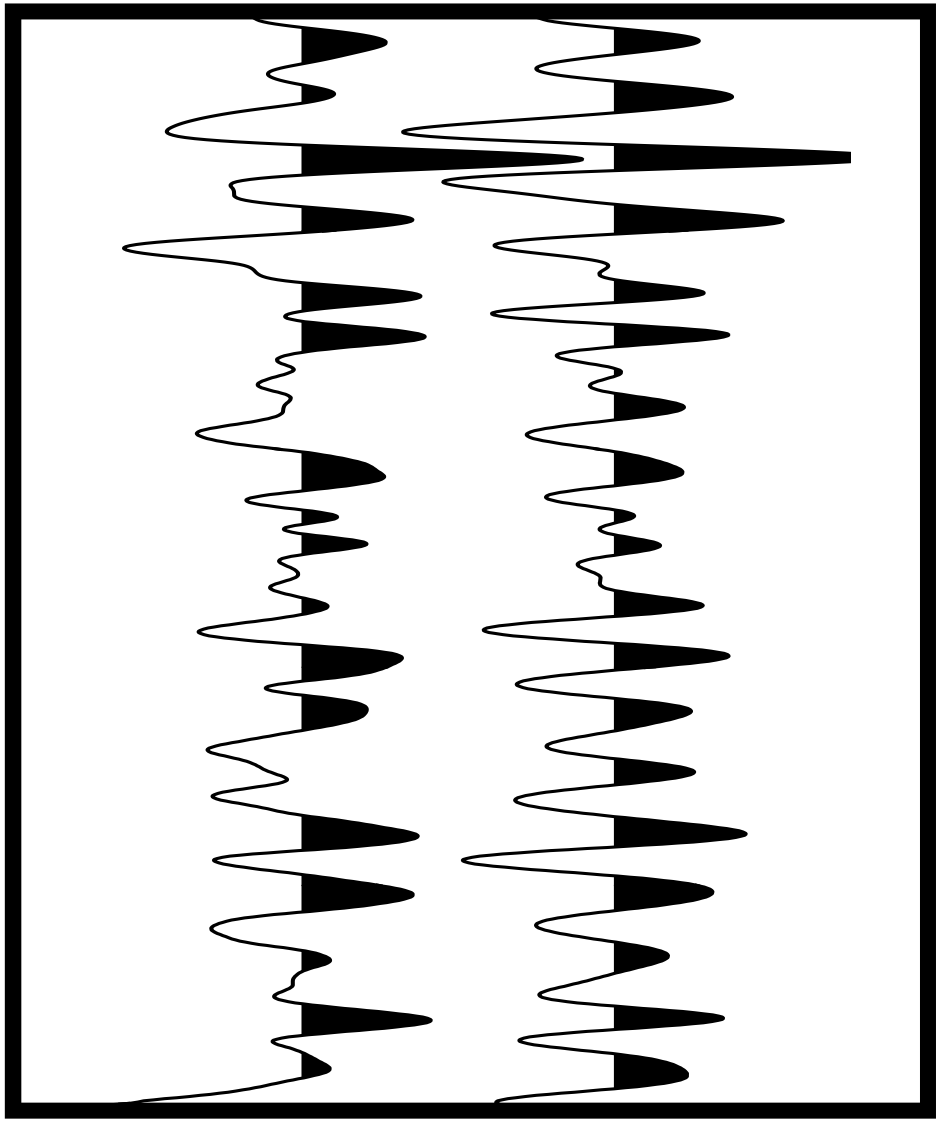




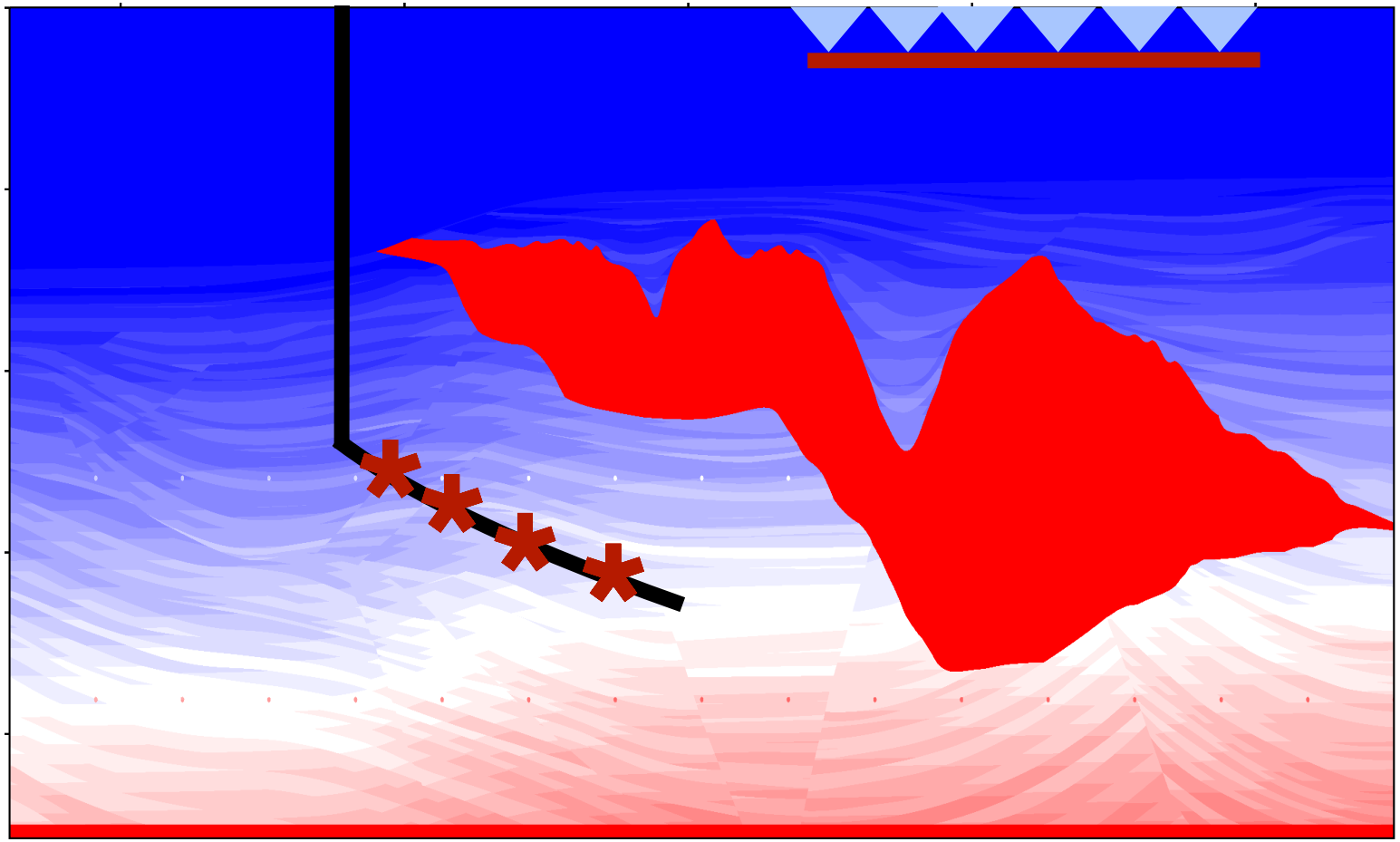


Step2: SWD source signature estimation

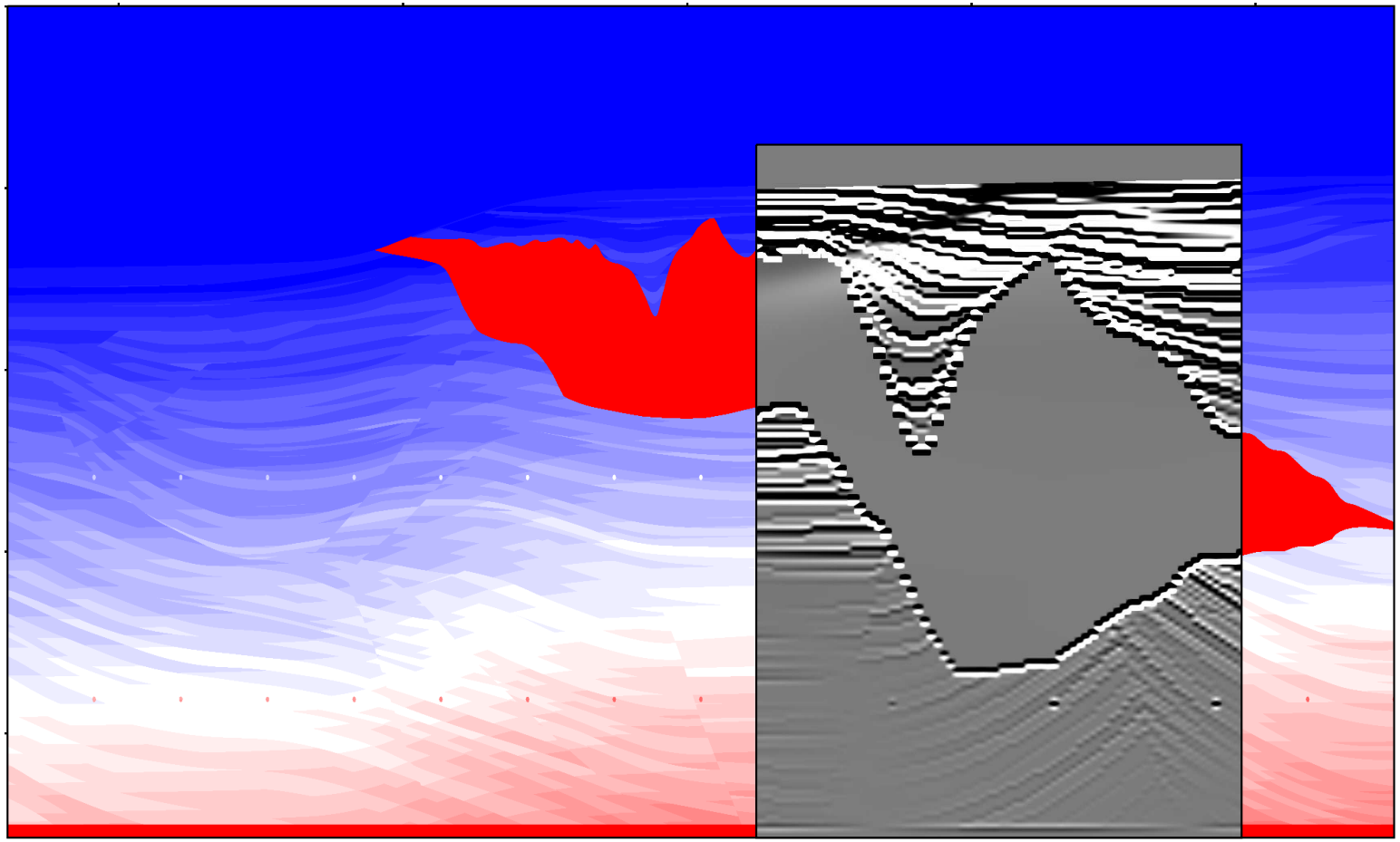
Original Estimated



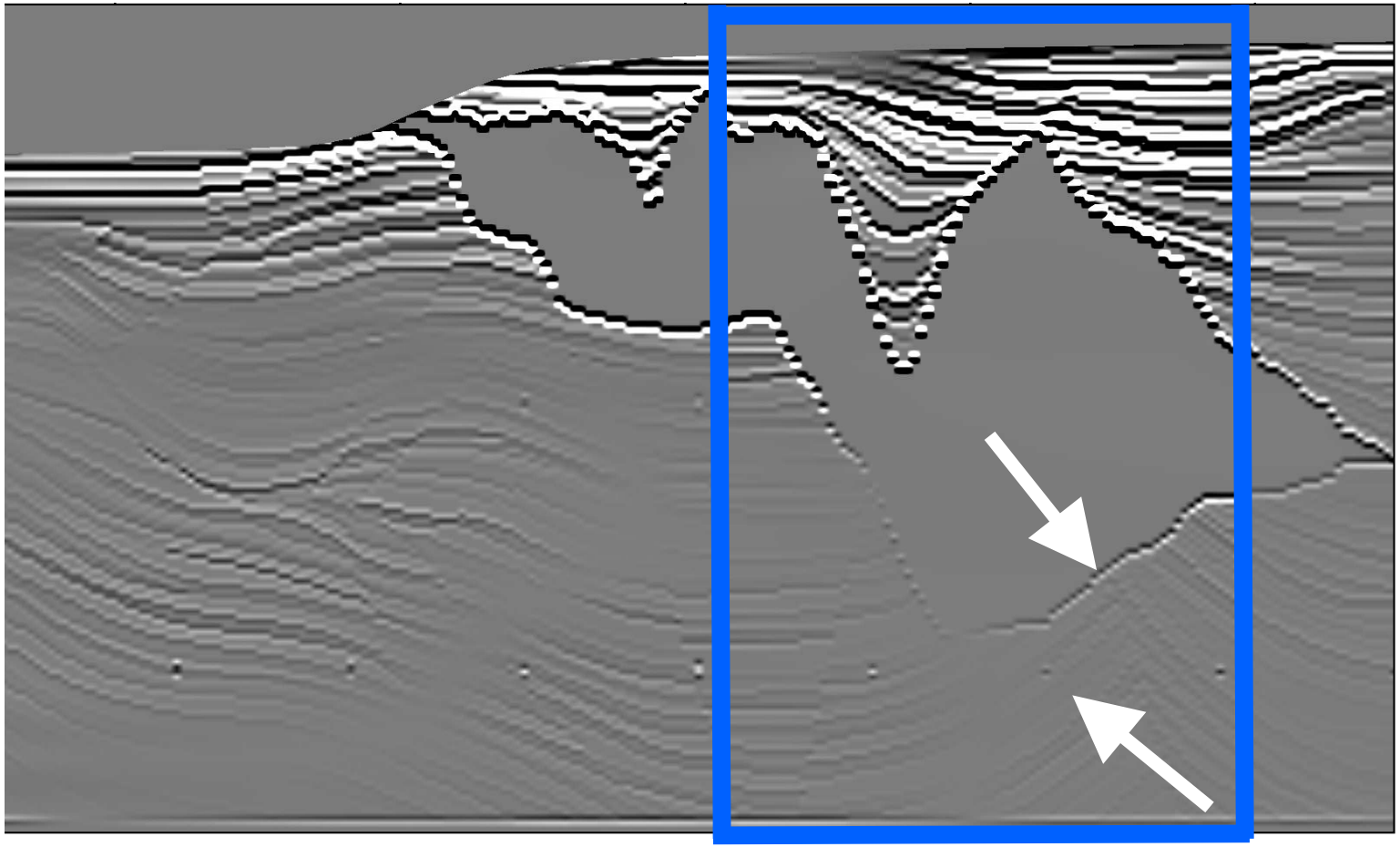
SWD acqusition



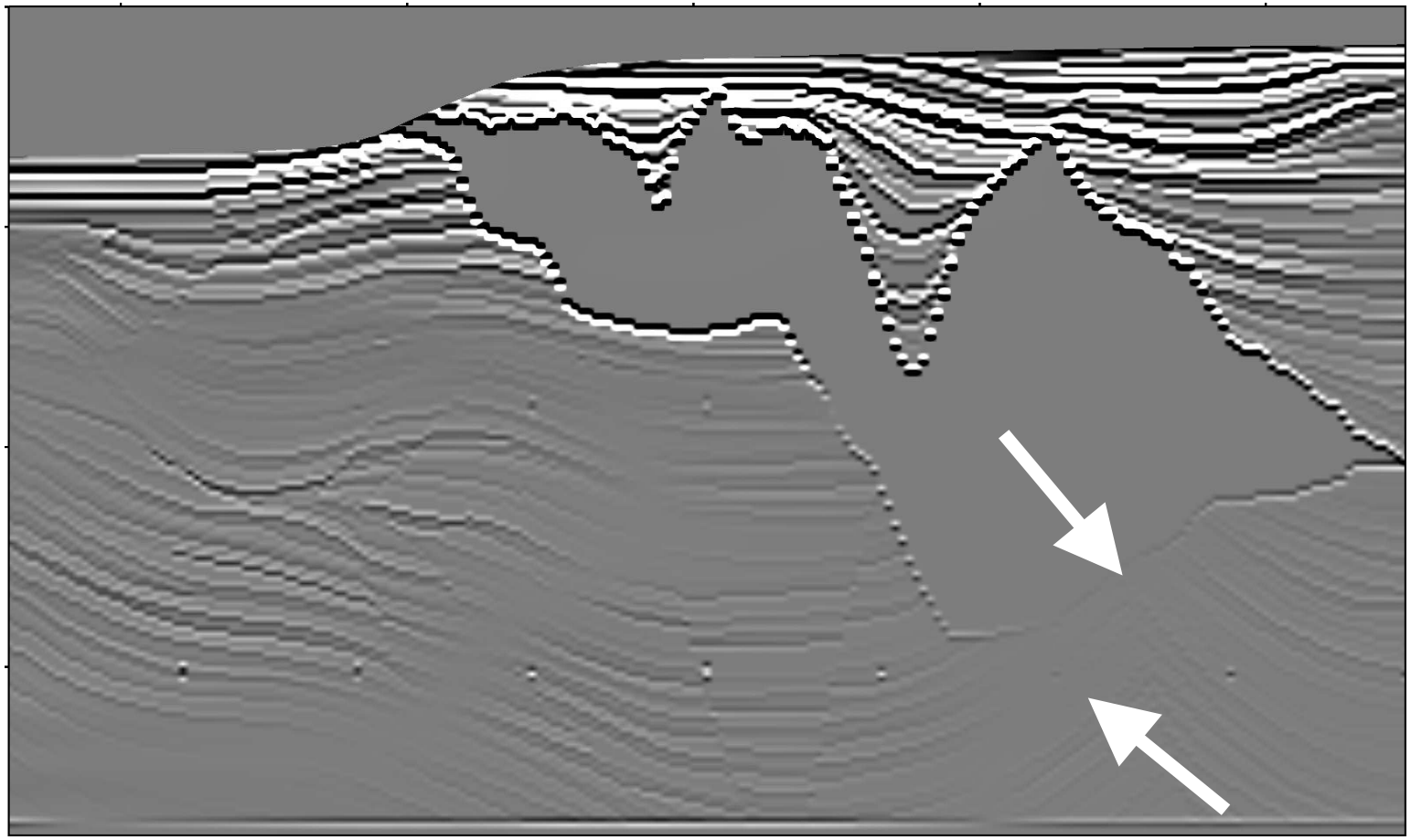
Step 3: SWD image



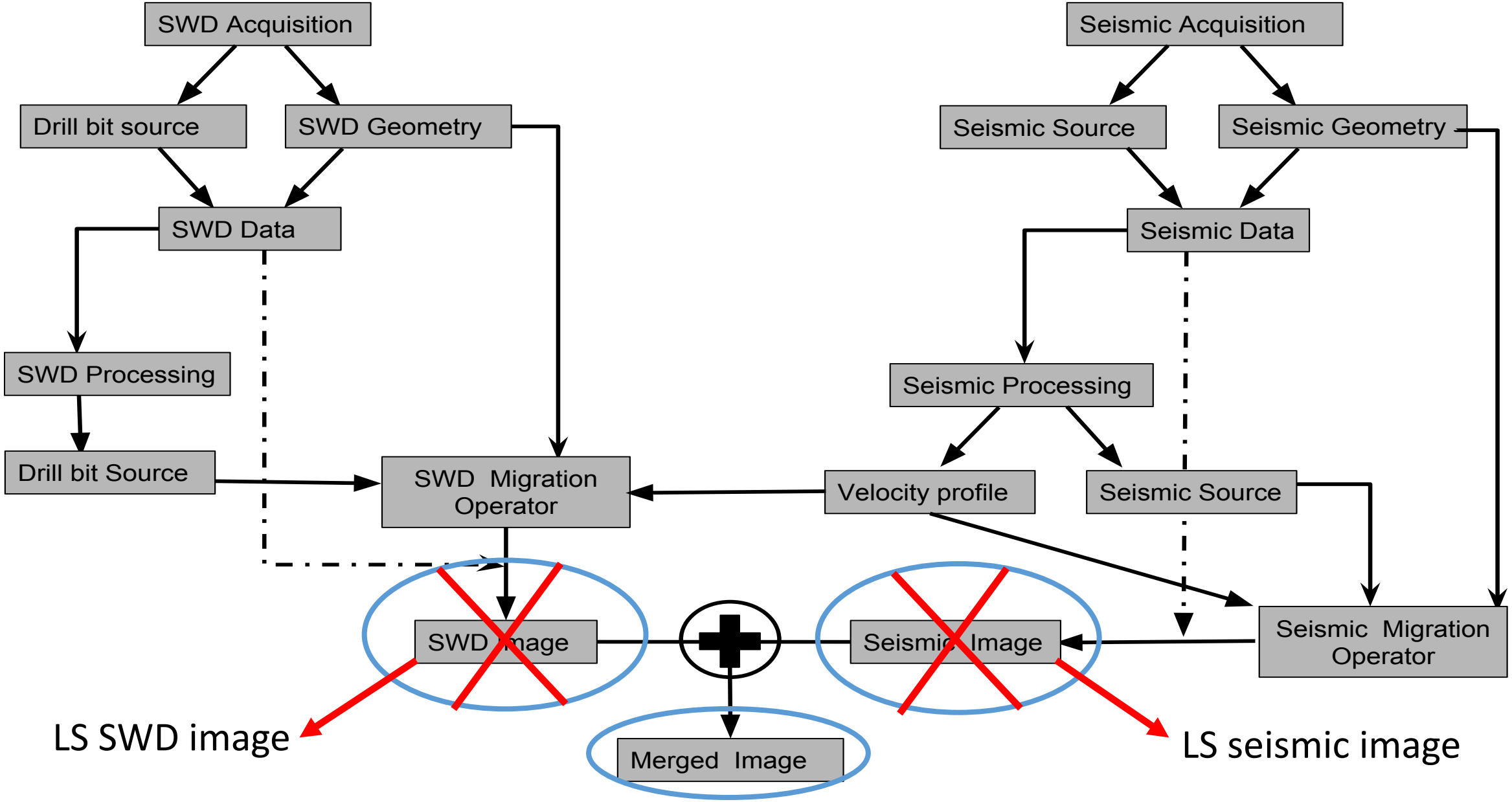
Step4: SWD+Surface seismic image



Surface seismic image



Best of both worlds



Least squares migration

The general least-squares cost function

$$\mathbf{m}_{LS} = \underset{\mathbf{m}}{\operatorname{argmin}} \|\mathbf{Lm} - \mathbf{d}\|_2^2 + \mu\mathcal{R}(\mathbf{m})$$

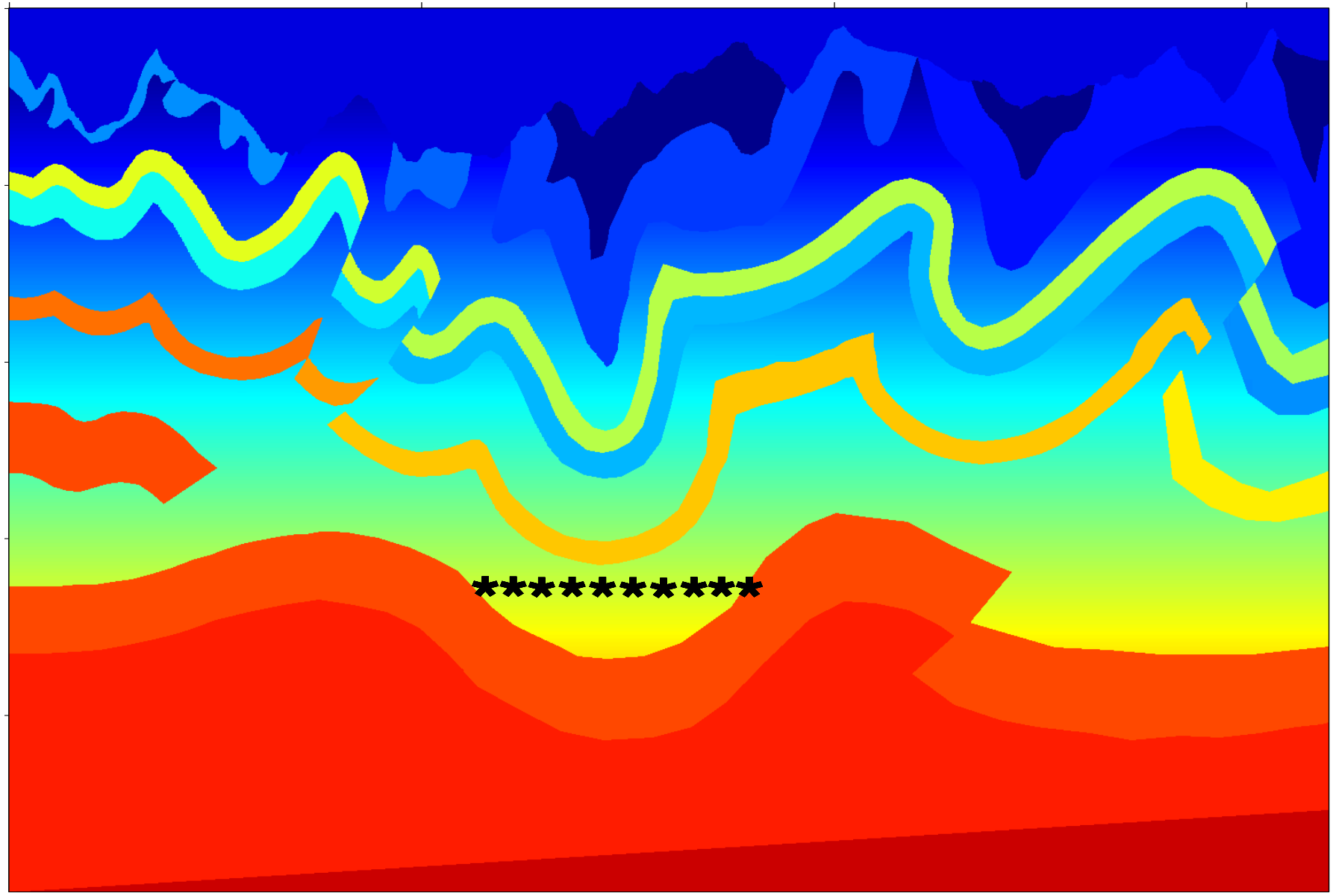
The one that we use

$$\mathbf{m}_{LS} = \underset{\mathbf{m}}{\operatorname{argmin}} \|\mathbf{Lm} - \mathbf{d}\|_2^2 + \mu\|\mathbf{Dm}\|_2^2$$

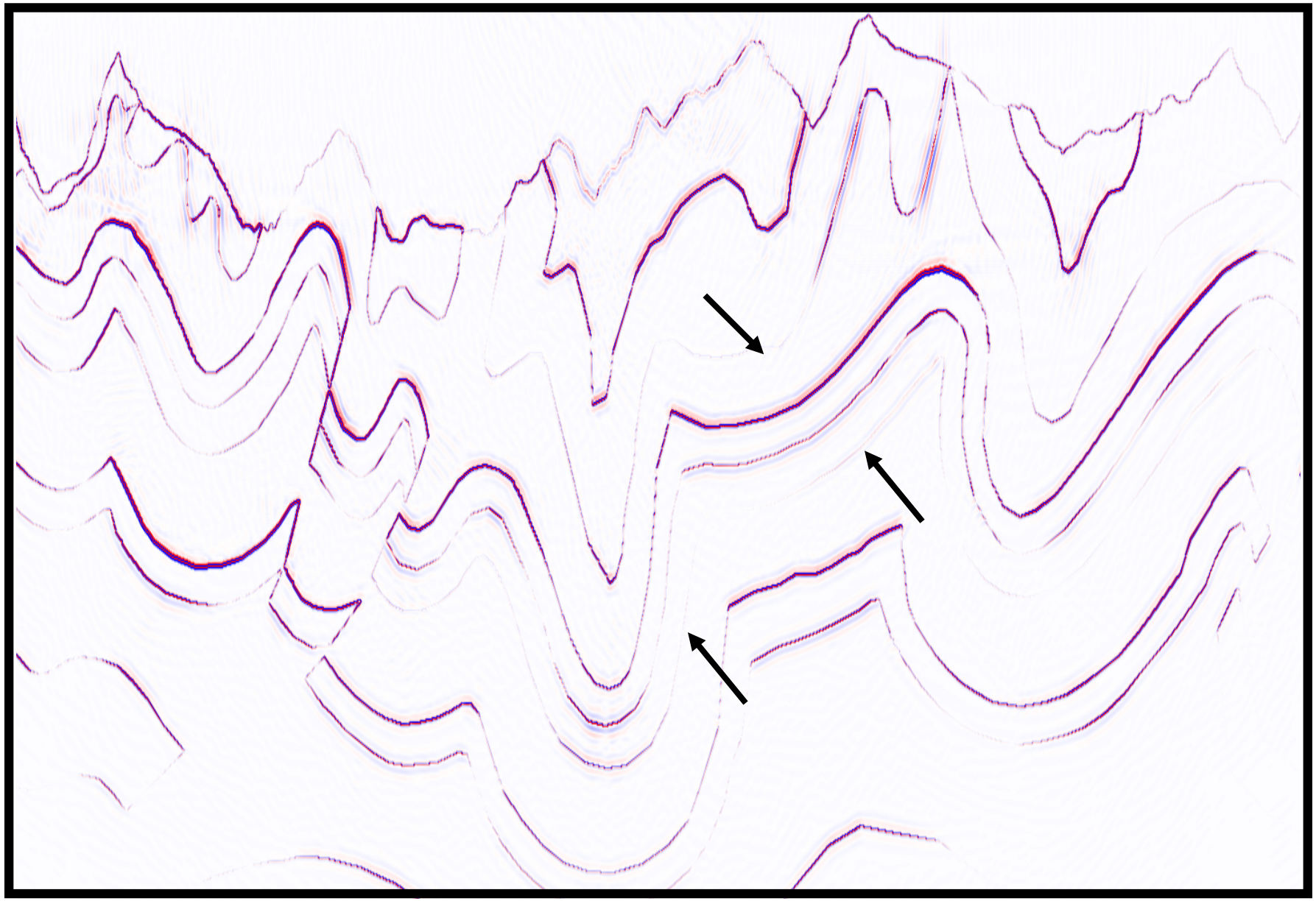
D is second order derivative operator and μ is regularization term.

To minimize the cost function, we use Conjugate gradient with regularization.

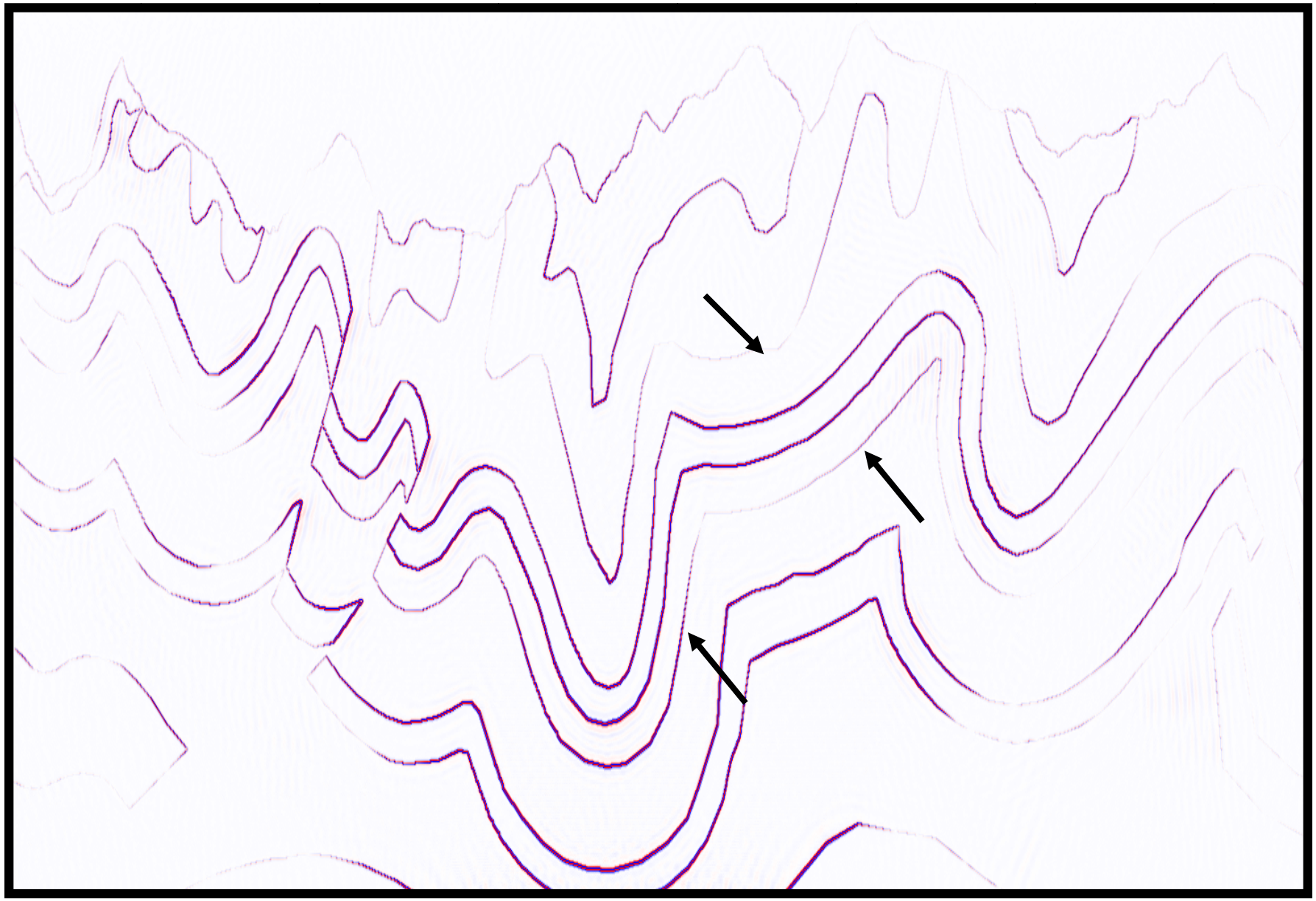
Surface and SWD acquisition on BP model



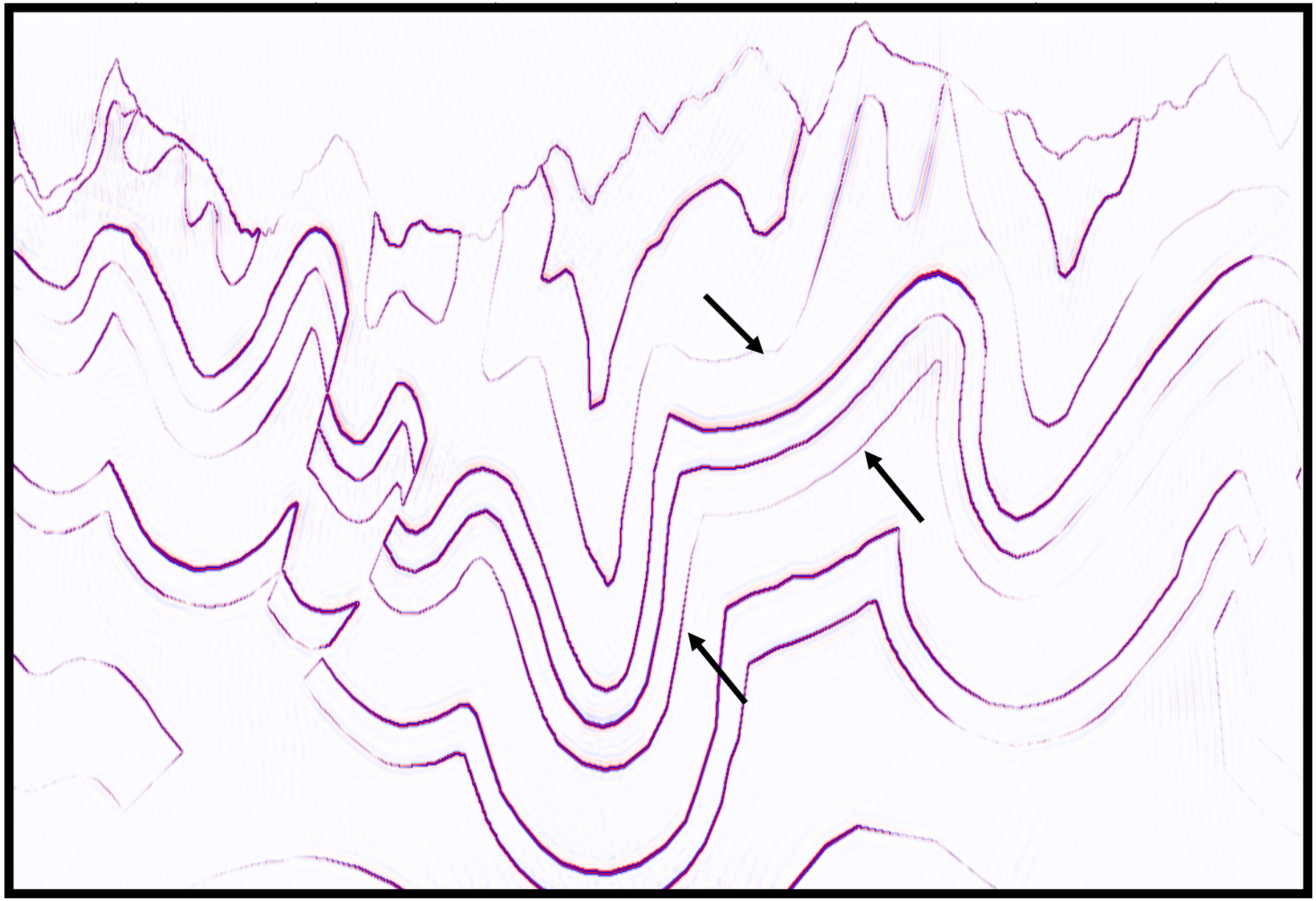
LSRTM of surface seismic data



LSRTM of SWD data

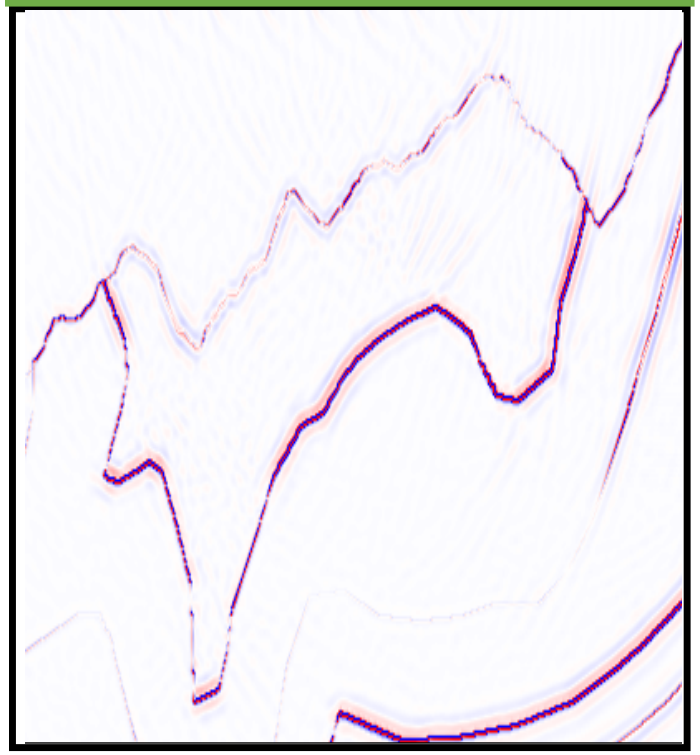


LSRTM of surface seismic+SWD data

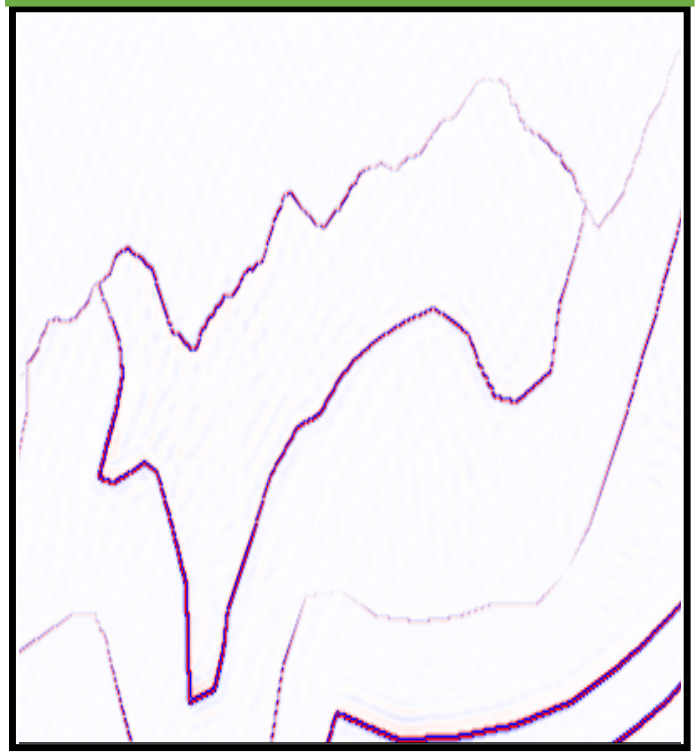


Zoomed version: Shallow part

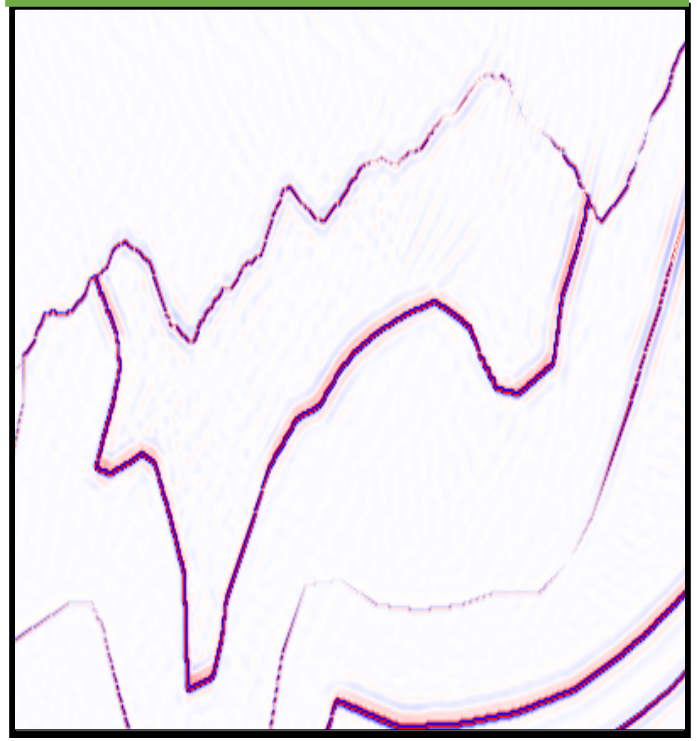
Surface migration



SWD migration

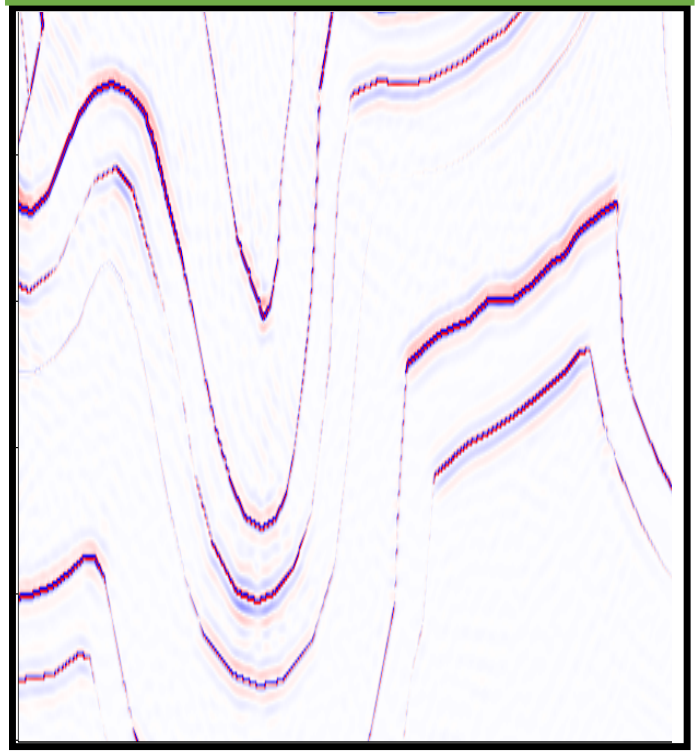


Surface+SWD migration

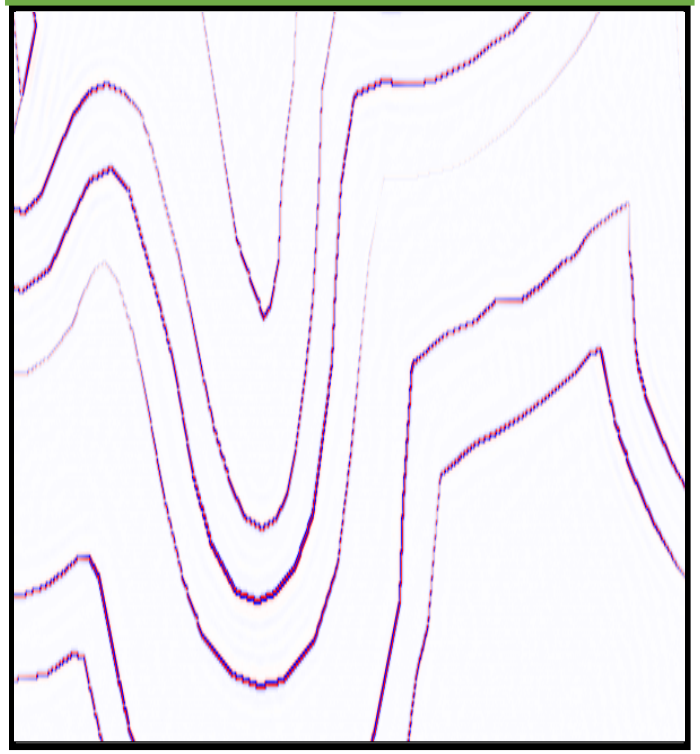


Zoomed version: Deeper part

Surface migration



SWD migration



Surface+SWD migration

Conclusions

Minimizing depth imaging uncertainties results in better production.

Uncertainties of depth imaging are discussed.

Poor subsurface illumination inherent in seismic imaging is shown to be one of the major sources of uncertainties.

Seismic-While-Drilling imaging combined with surface seismic improved subsurface illumination.

More elegant approach like joint inversion of the SWD and surface seismic data could improve the performance of the proposed approach.

Acknowledgments

We would like to thank the following sponsors for supporting this research:

Canada First Research Excellent Fund

Sponsors of CREWES consortium

NSERC

References

Greenspan, H., Super-Resolution in Medical Imaging, *The Computer Journal*, Volume 52, Issue 1, 2009, Pages 43–63.

Goldman, L.W., Principles of CT and CT Technology, *J. Nucl. Med. Technol*, Volume 35, 2007, Pages 115-128.

Kazemi Nojadeh, N., Efficient algorithms for least squares wave equation migration and source signature estimation, 2017.

Kazemi, N., Shot-record extended model domain preconditioners for least-squares migration, *Submitted to Geophysics*, 2018.

Chemali, R., Advanced Geosteering for Optimal Exploitation of Hydrocarbon Reserves, *SPE Distinguished Lecturer Program*, 2011.

Poletto, F., and Bellezza, C., Drill-bit displacement-source model: Source performance and drilling parameters, *Geophysics*, 2006, 71(5),F121-F129.

Kazemi, N., and Sacchi, M., Sparse multichannel blind deconvolution, *Geophysics*, 2014, 79(5), V143-V152.

Kazemi, N., Shor, R., and Innanen, K., Illumination compensation with seismic-while-drilling plus surface seismic imaging, *in 80th EAGE Conference and Exhibition*, 2018.