

Simultaneous model-source waveform inversion with the application of seismic-while-drilling

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**NSERC
CRSNG**



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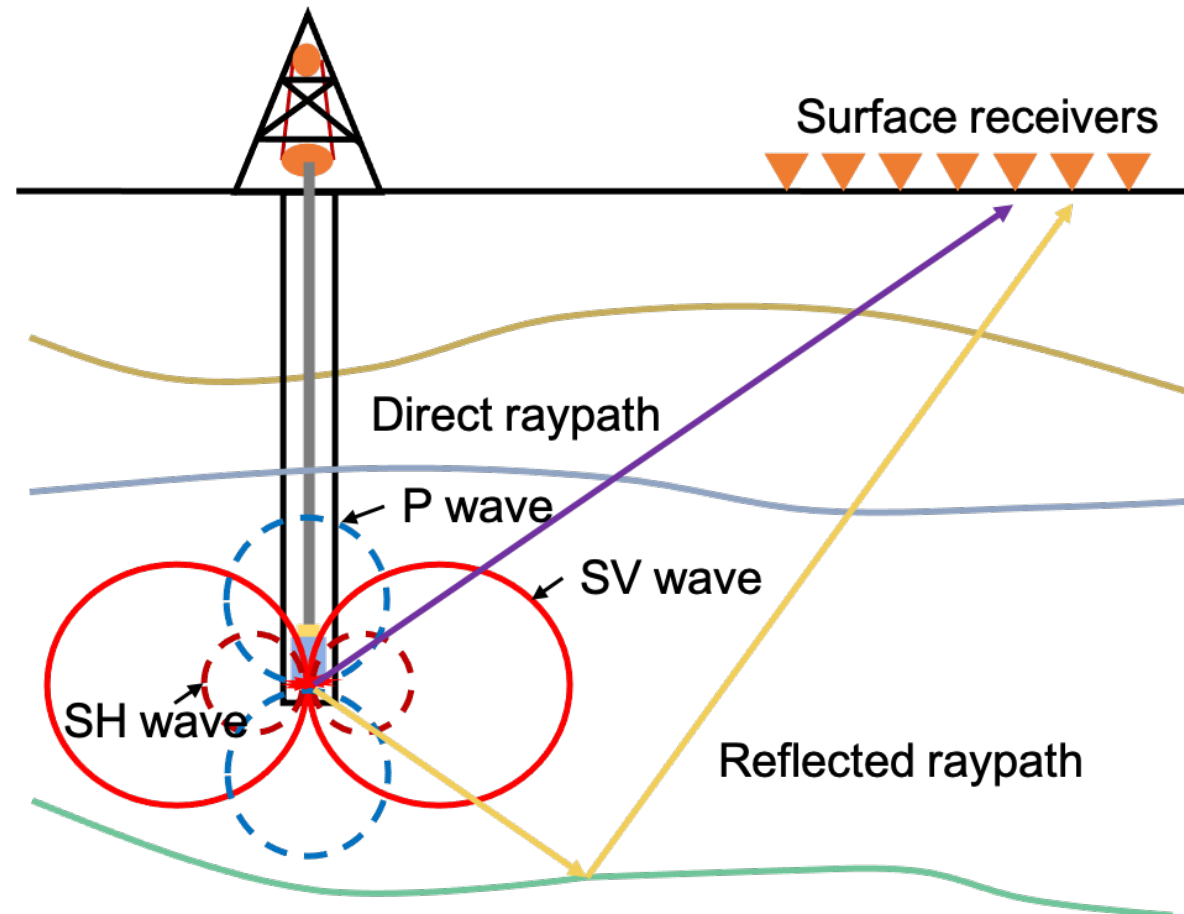
- Motivation
- Model-source simultaneous FWI
- Numerical experiments
- Discussion
- Conclusion



- **Motivation**
- Model-source simultaneous FWI
- Numerical experiments
- Discussion
- Conclusion



- Seismic-while-drilling (SWD) can support full-waveform inversion (FWI).



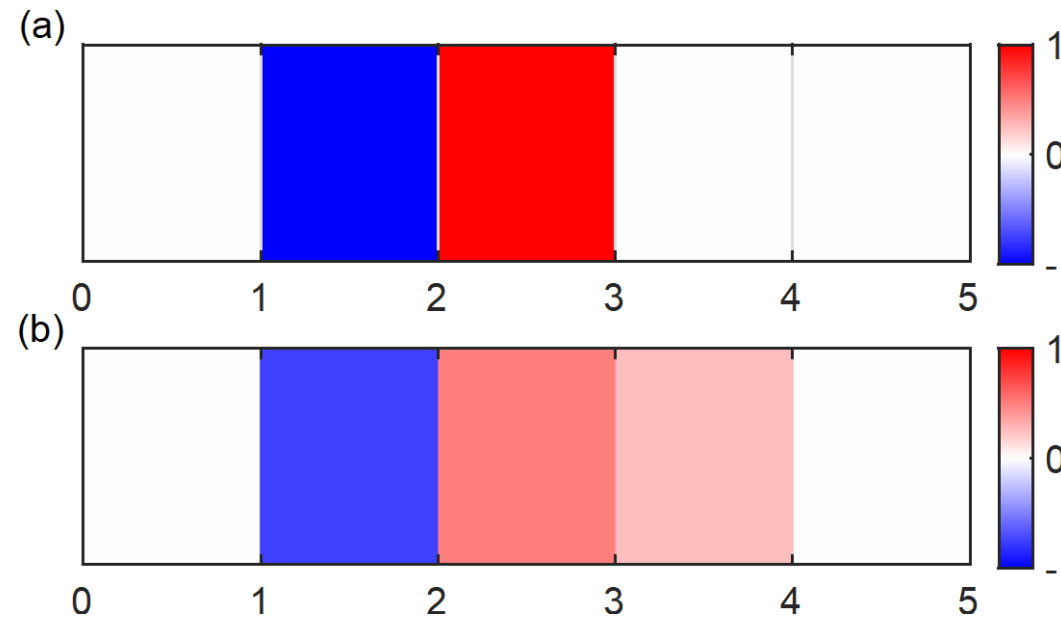
(modified after Rector and Hardage (1992))



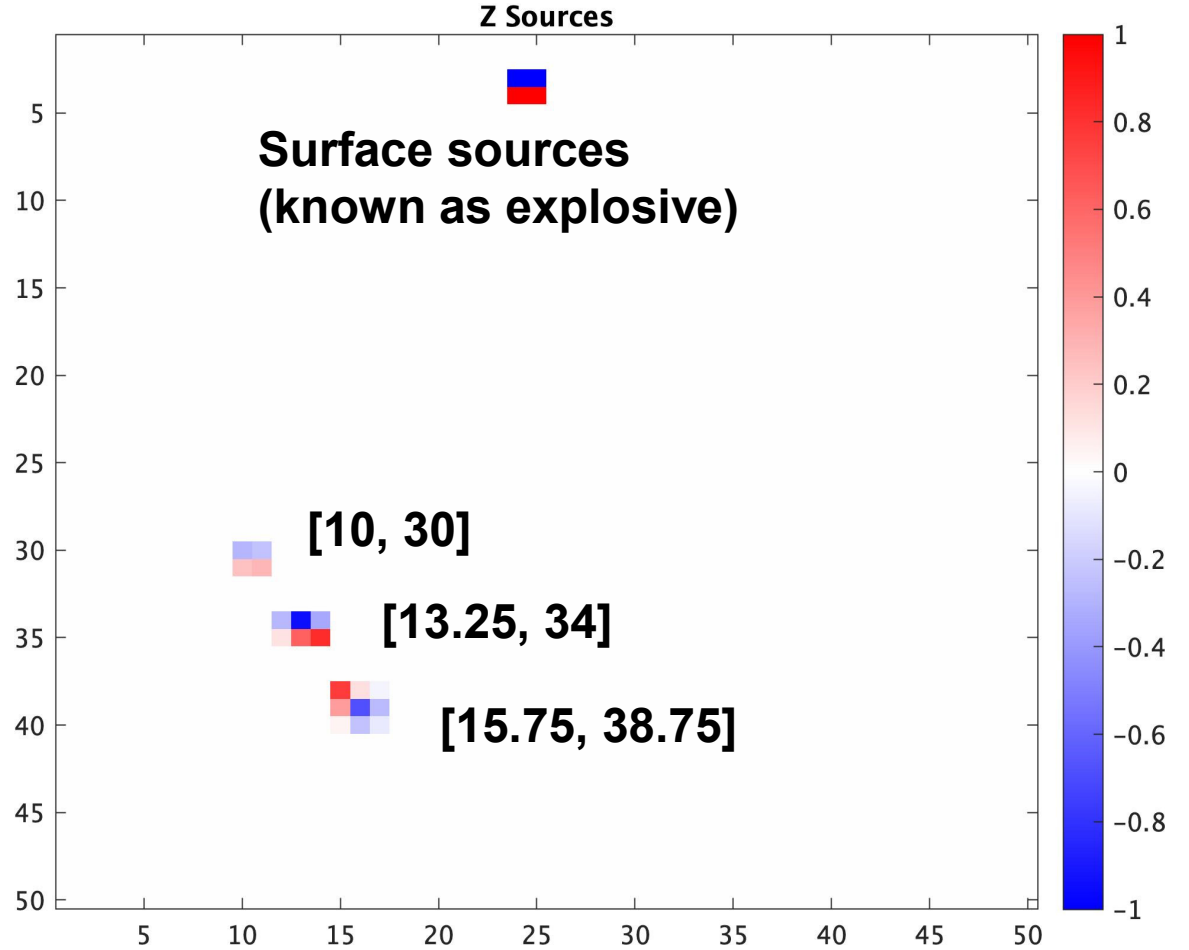
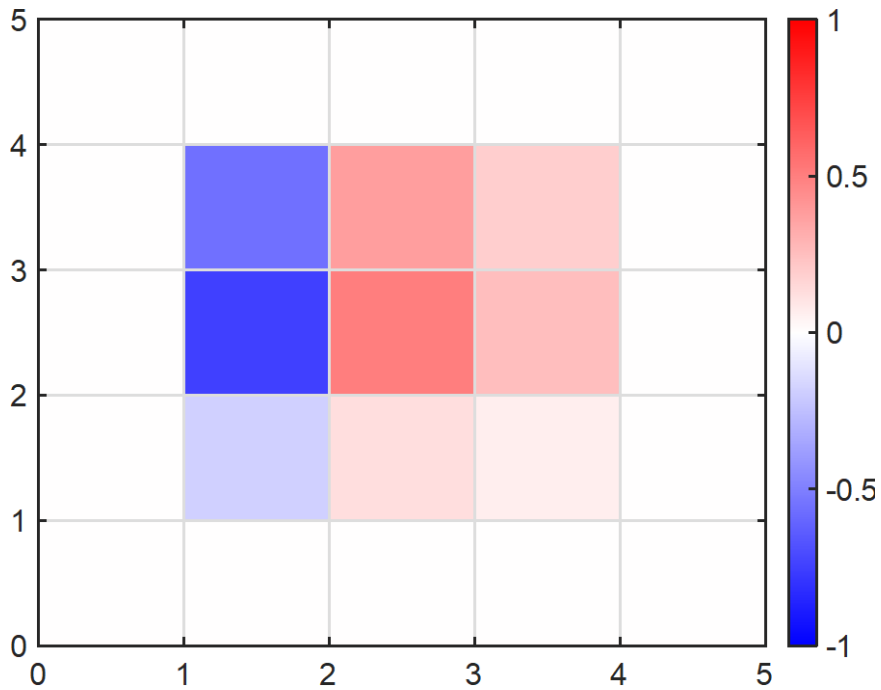
- Motivation
- **Model-source simultaneous FWI**
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$$Su = f \quad M = M_0 \begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{bmatrix}$$



$-x - z$	$-z$	$+x - z$
$-x$		$+x$
$-x + z$	$+z$	$+x + z$





$$\operatorname{argmin}_p \phi(\mathbf{p}) = \frac{1}{2} \|\mathbf{R}\mathbf{u} - \mathbf{d}\|_2^2, \text{ s.t. } \mathbf{S}\mathbf{u} = \mathbf{f}$$

$$\mathbf{H}\mathbf{p} = -\mathbf{g}$$

$$\mathbf{g} = \begin{pmatrix} \mathbf{g}_m \\ \mathbf{g}_s \end{pmatrix}$$

**Surface isotropic
sources & deeper
MT-defined sources**

**Deeper MT-defined
sources**



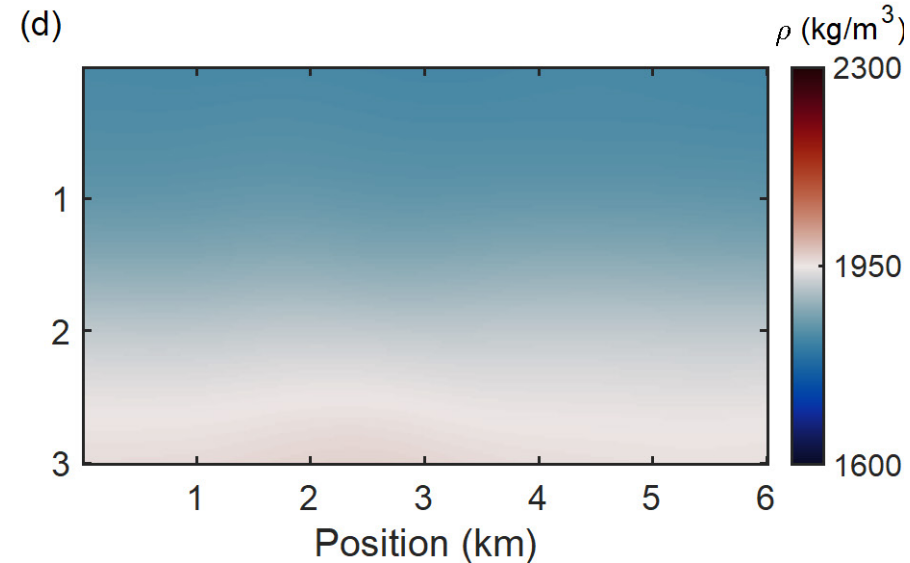
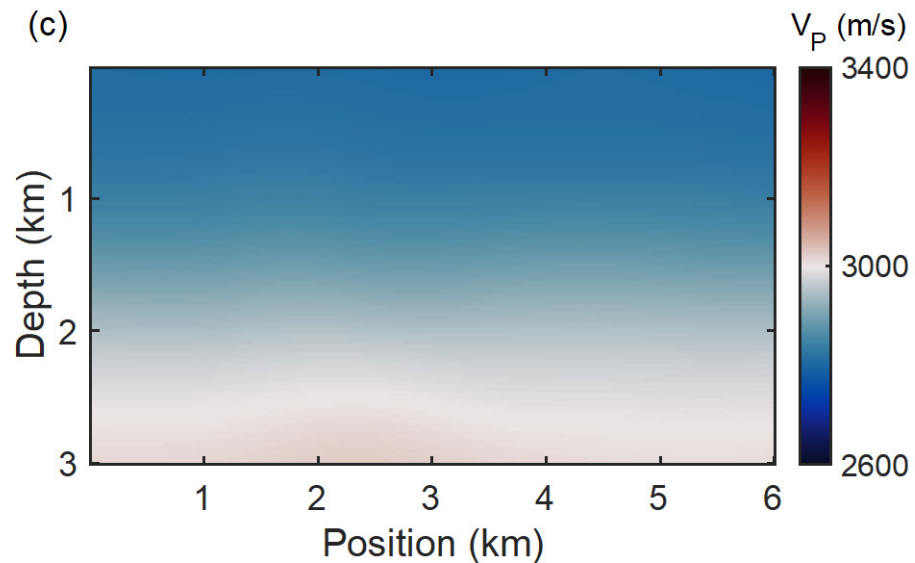
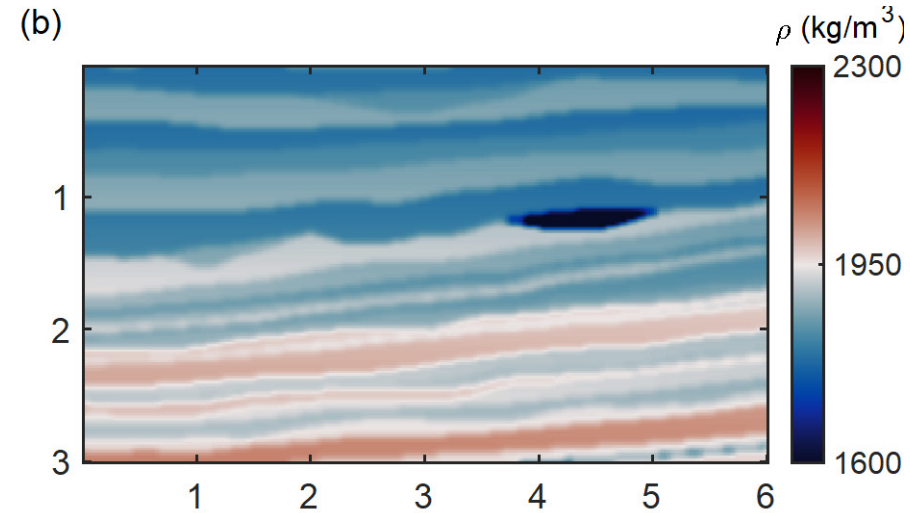
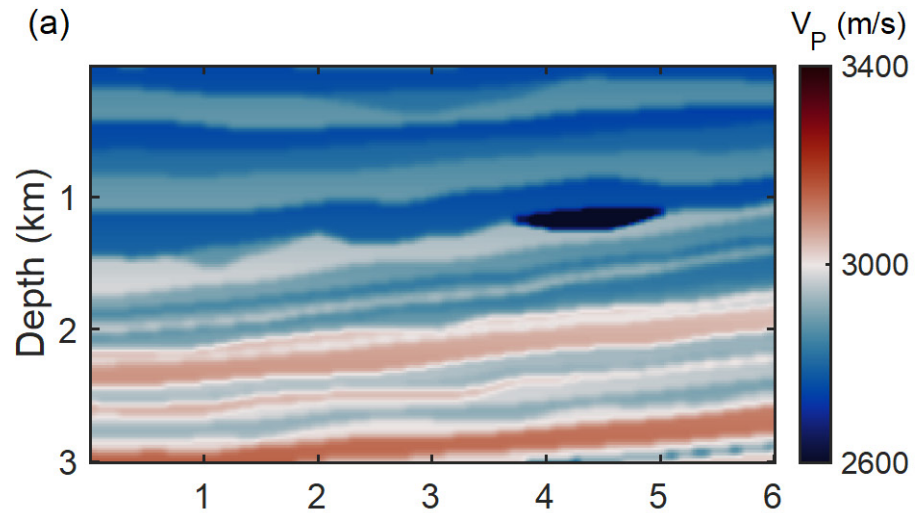
- Introduction to seismic-while-drilling
- Full-waveform-inversion review
- **Numerical experiments**
- Discussion
- Conclusion



- Quasi-static positions & independent moment tensors.
- Both data can be analyzed into discrete frequencies.
- Tuning the datasets.



True and initial models



Geometry:

$N_x = 300$

$N_z = 150$

$NPML = 10$

$dx = dz = 20$

V_S, Q_P, Q_S :

homogeneous

Multiscale:

1-15 Hz

10 bands,

12 sub-frequencies

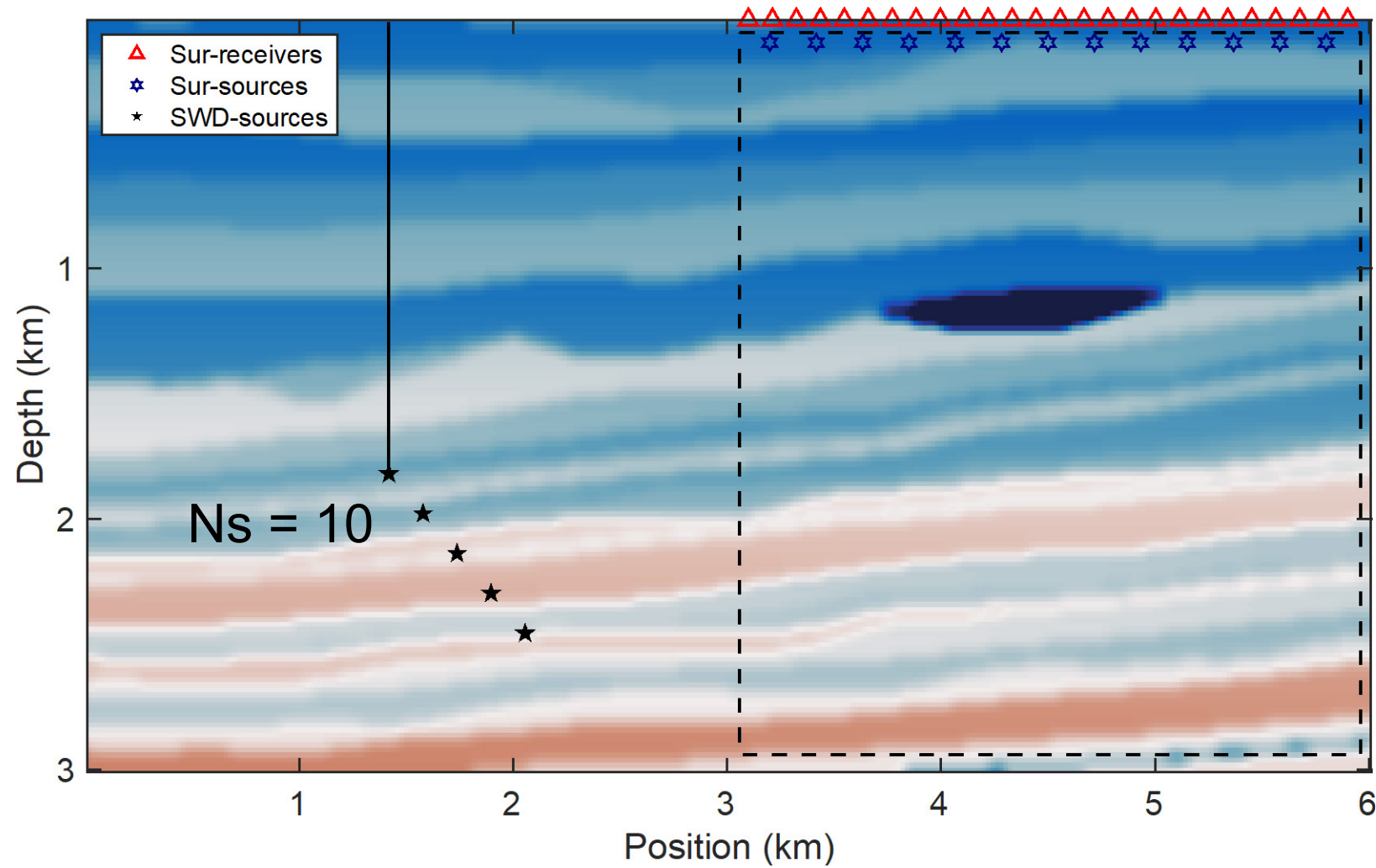
MTs:

$[-1, 1]$



Source number test: schematic acquisition

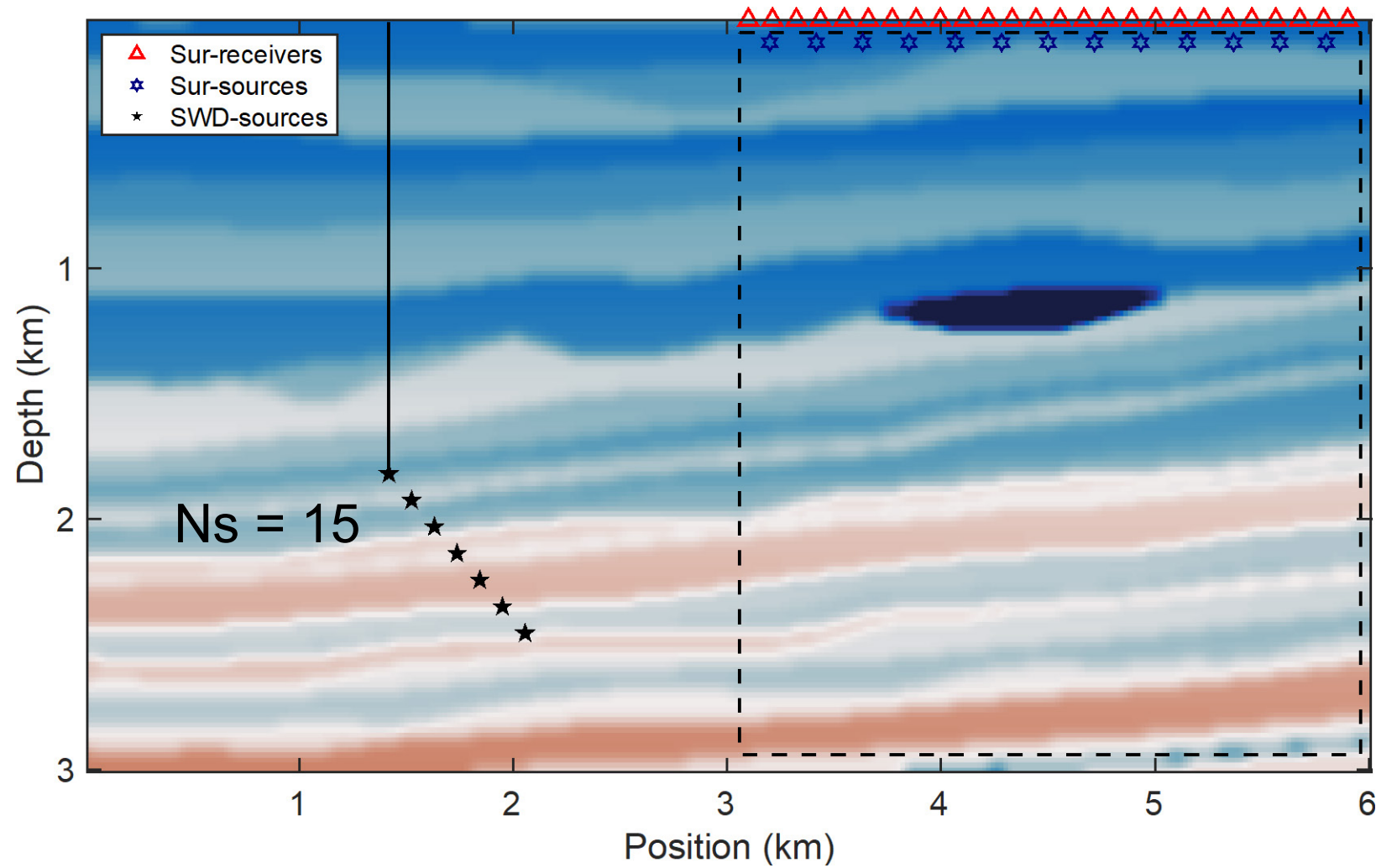
72 explosive sources, 144 receivers





Source number test: schematic acquisition

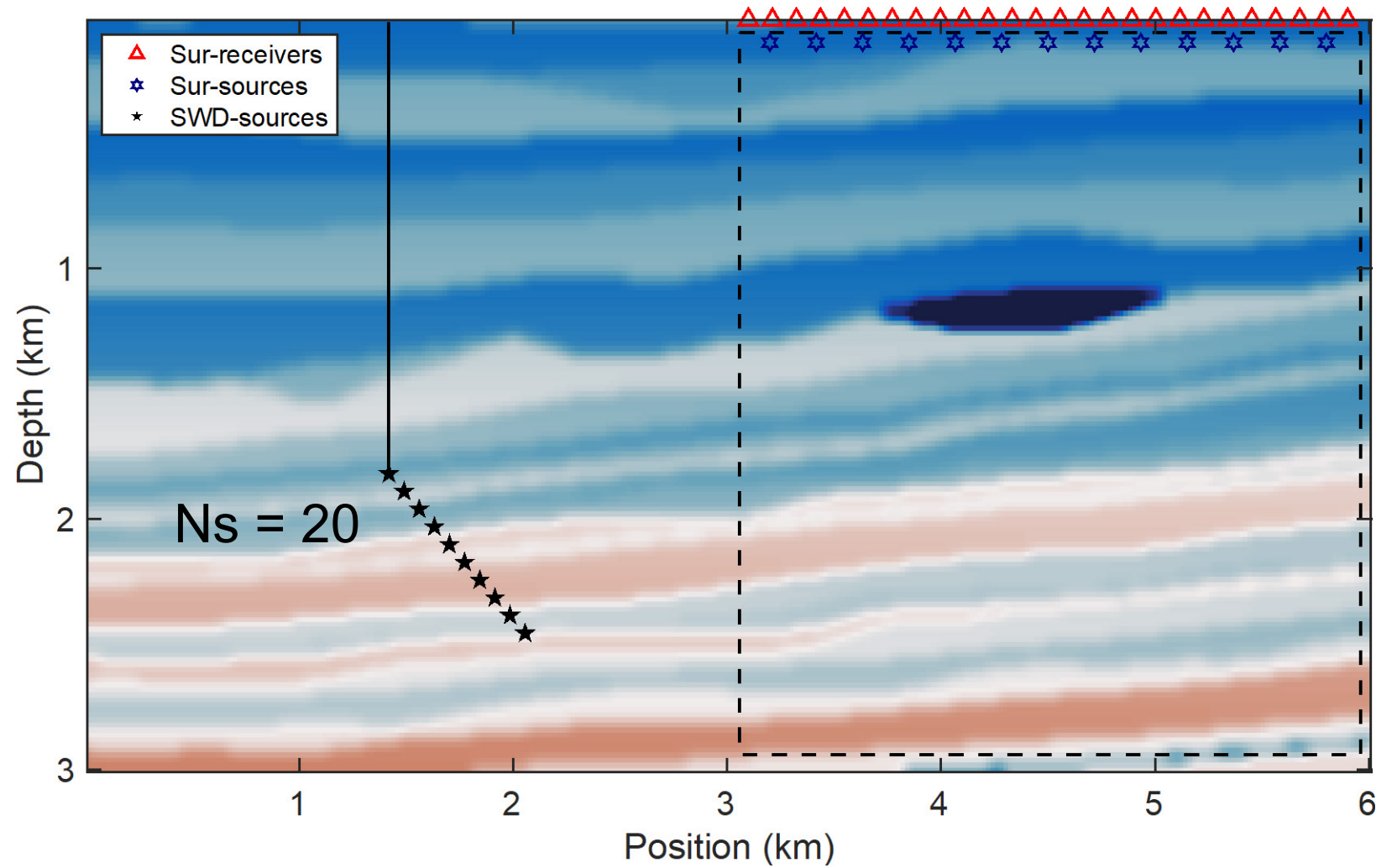
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Source number test: schematic acquisition

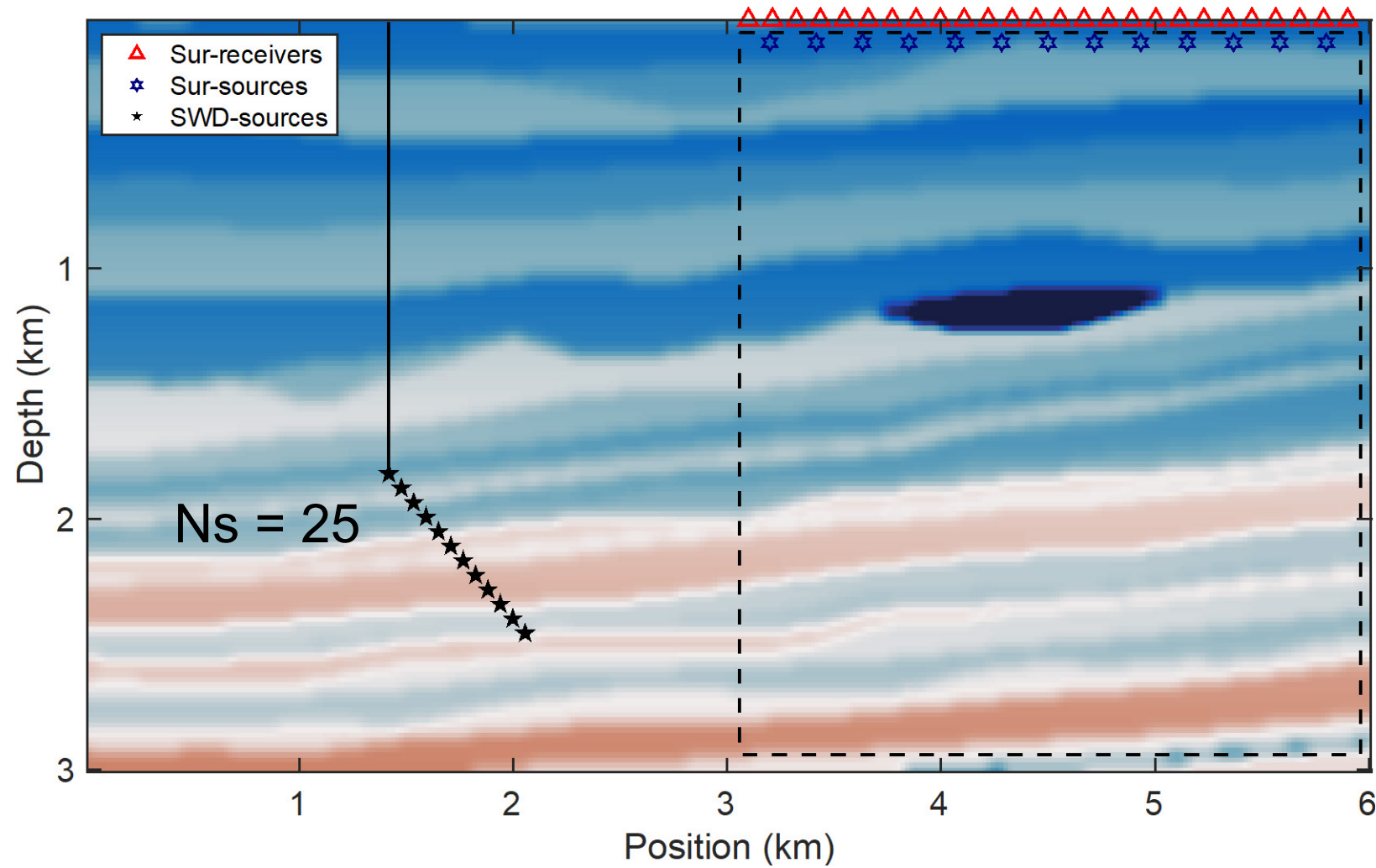
72 explosive sources, 144 receivers





Source number test: schematic acquisition

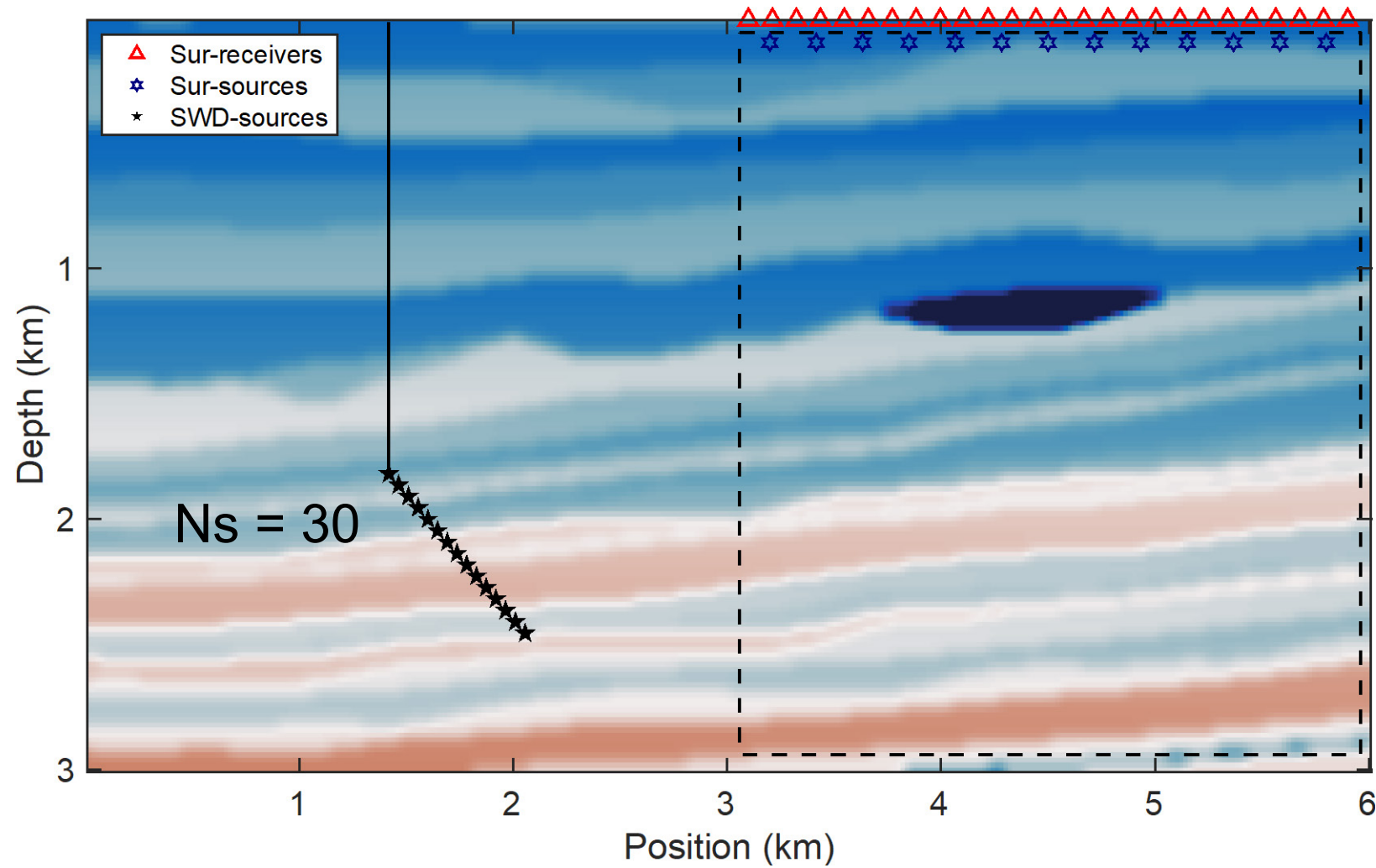
72 explosive sources, 144 receivers

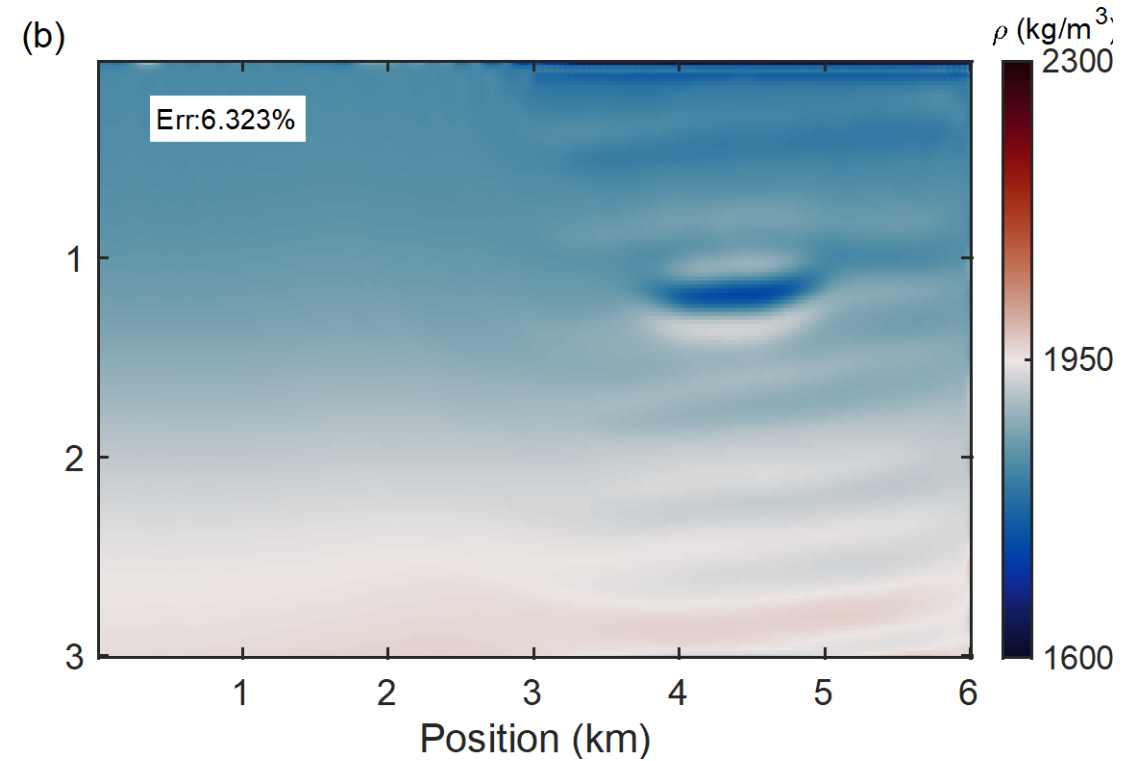
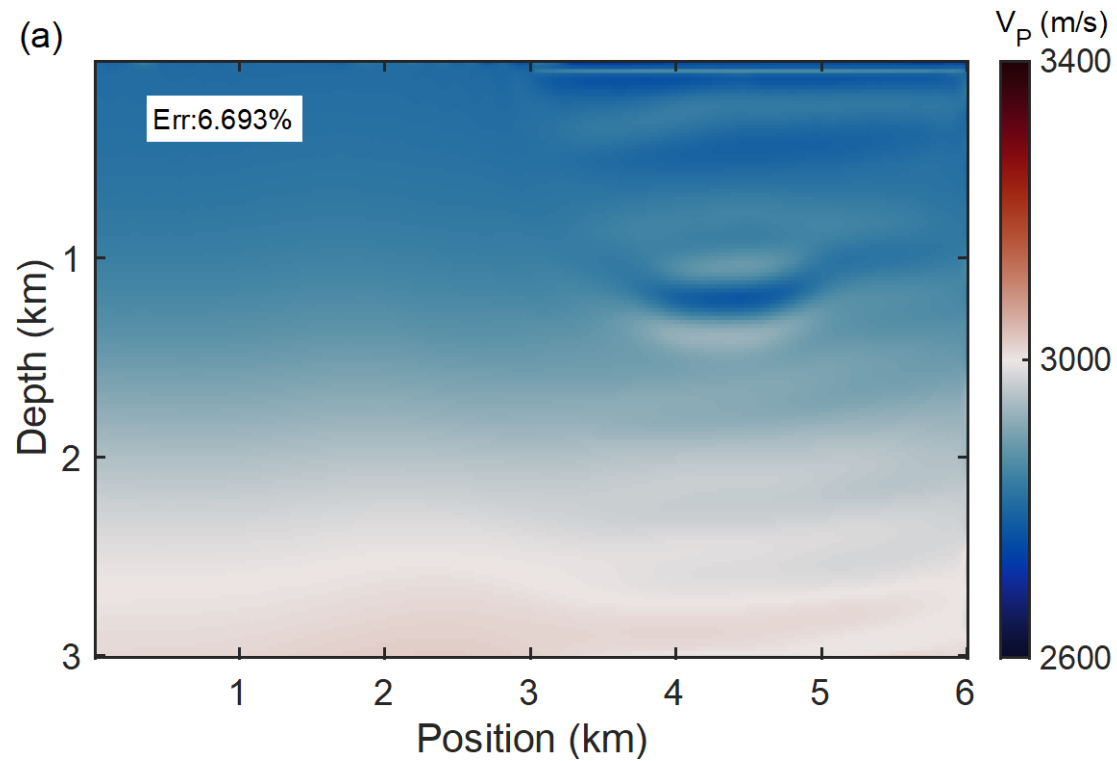




Source number test: schematic acquisition

72 explosive sources, 144 receivers

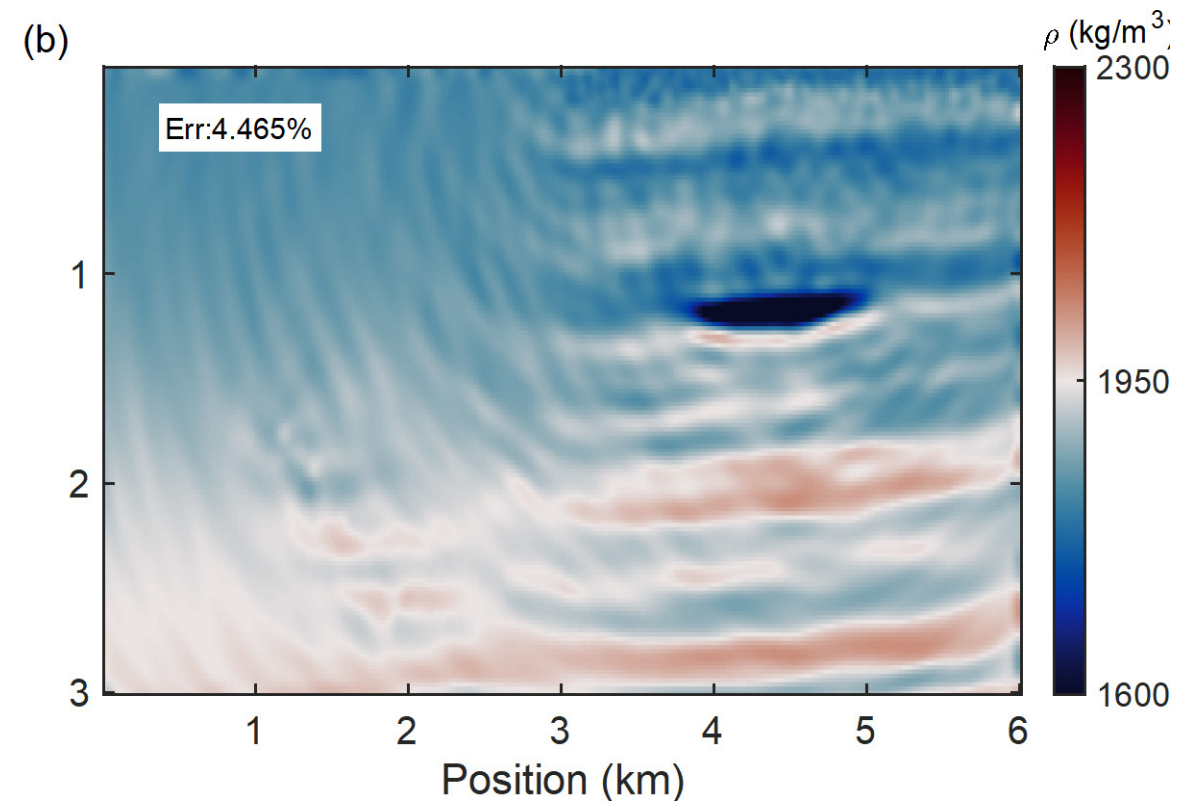
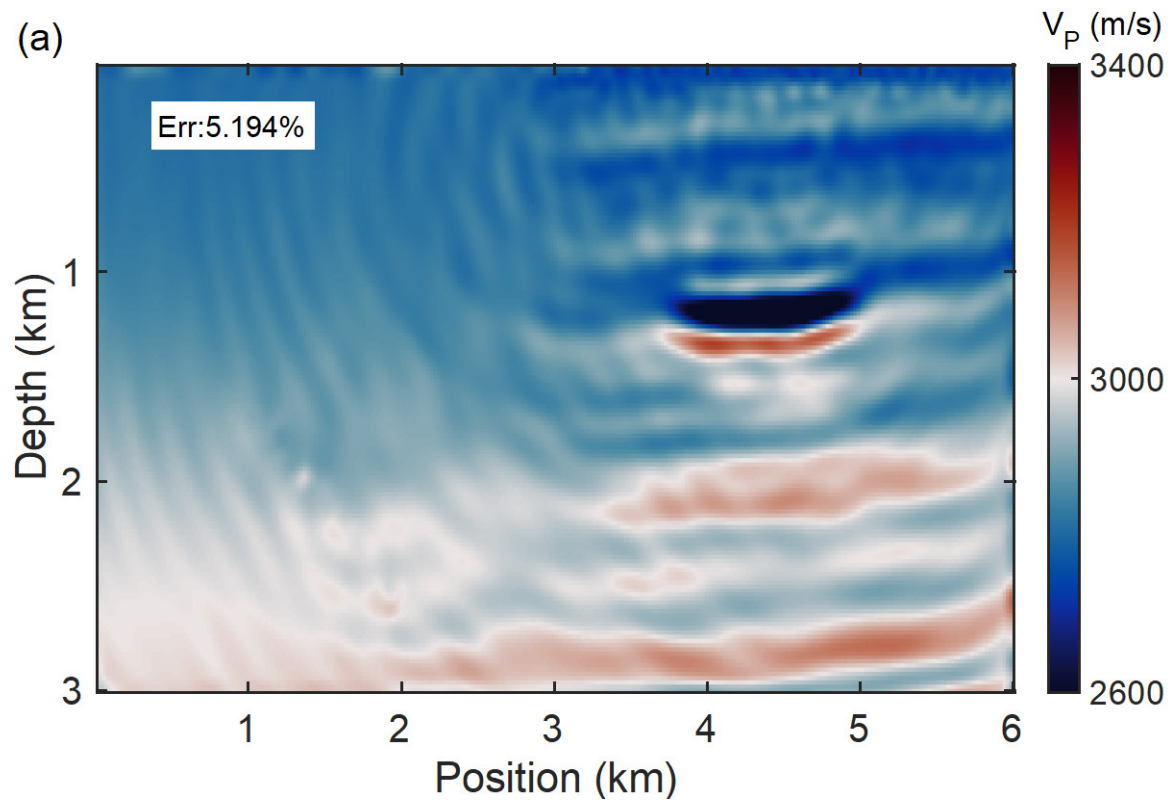
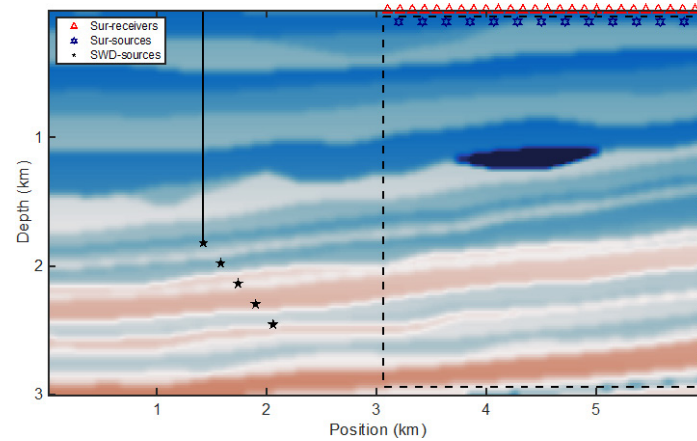




$$NRMSE = \frac{RMSE}{obs_{max} - obs_{min}}$$

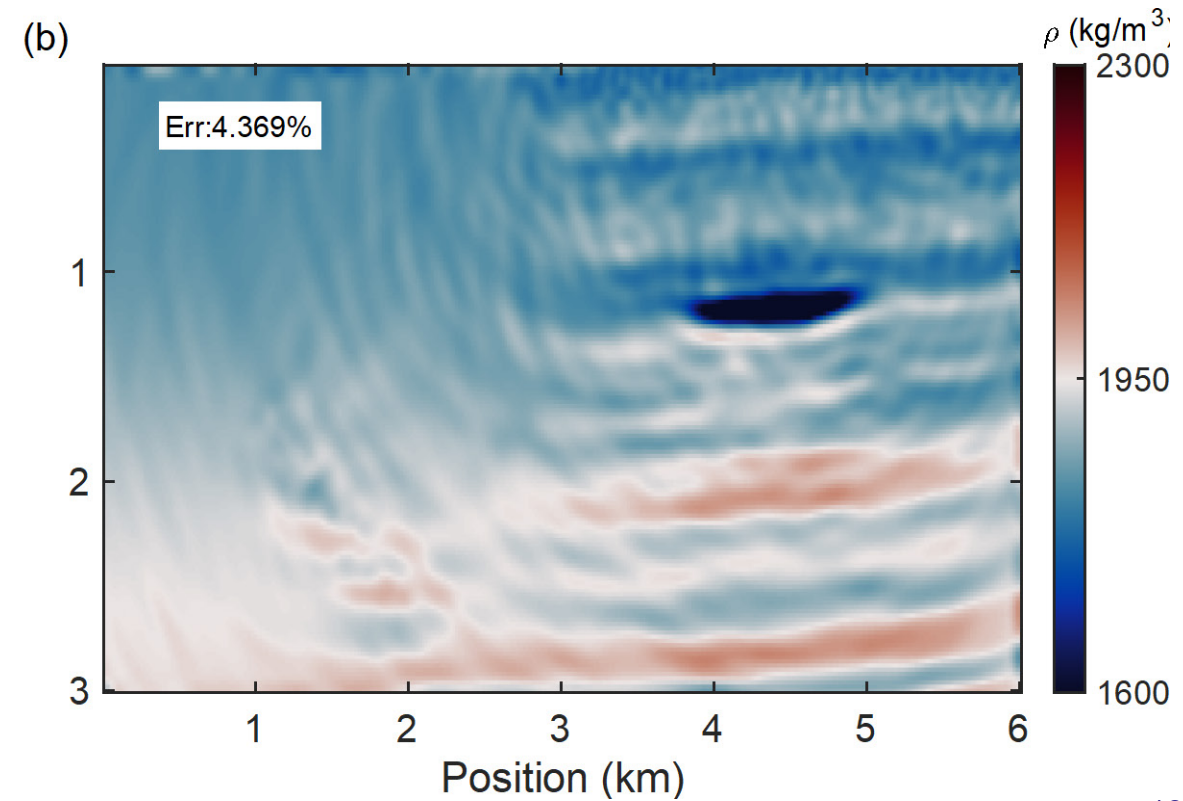
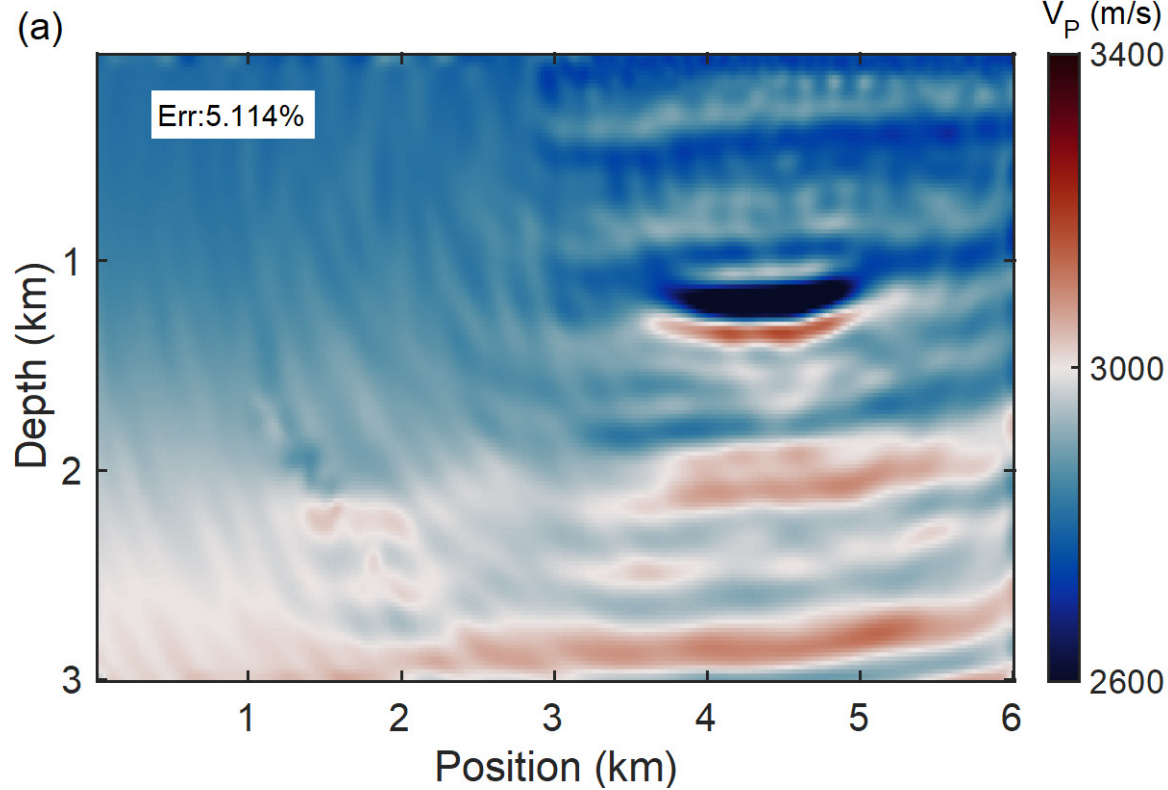
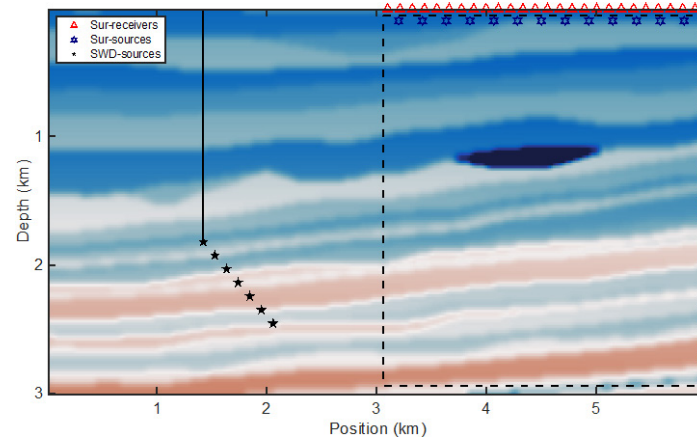


Source number test: enlarged coverage area



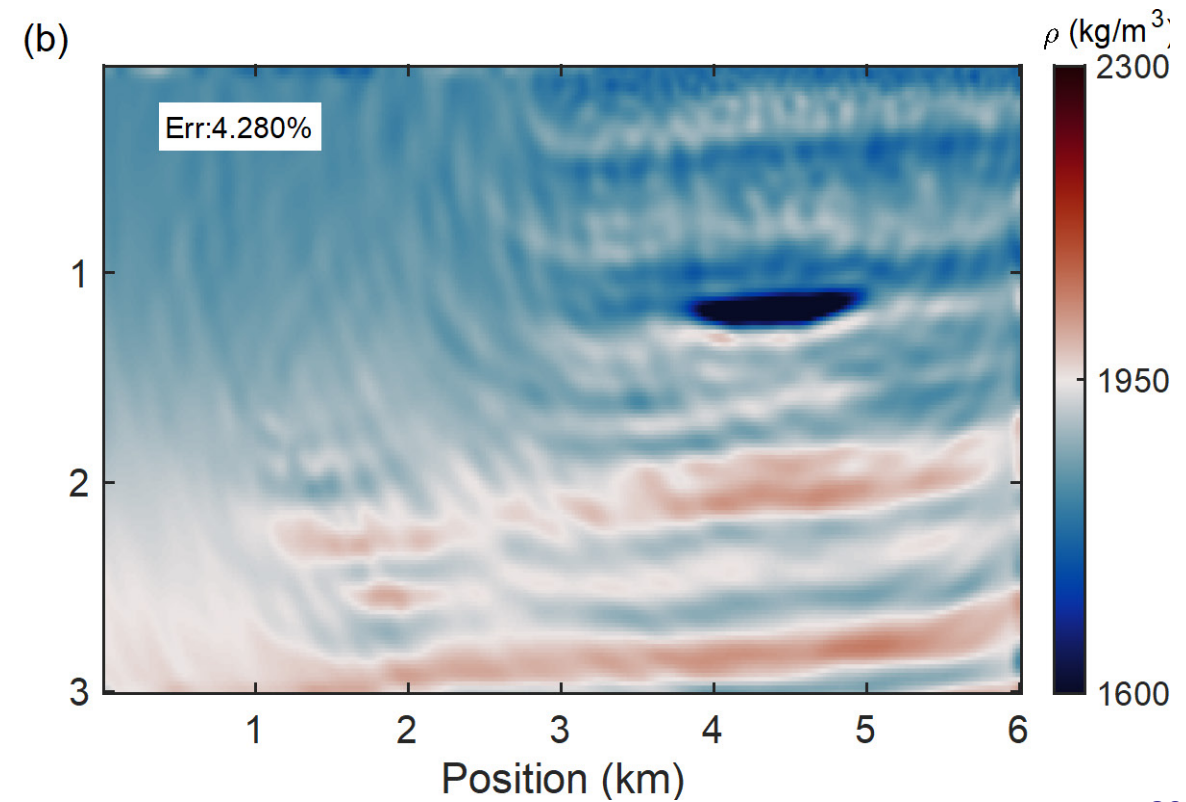
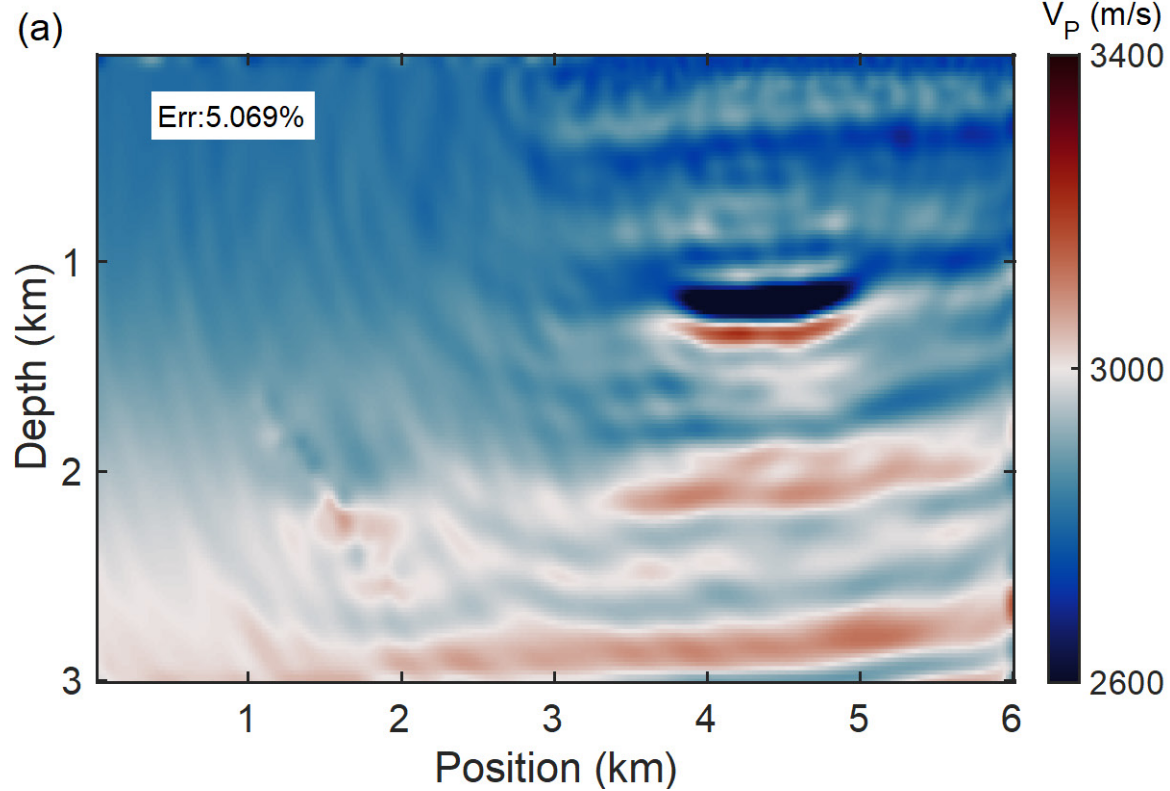
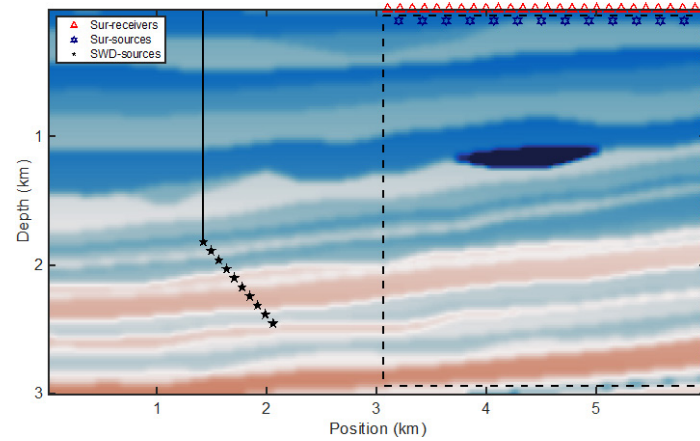


Source number test: enlarged coverage area



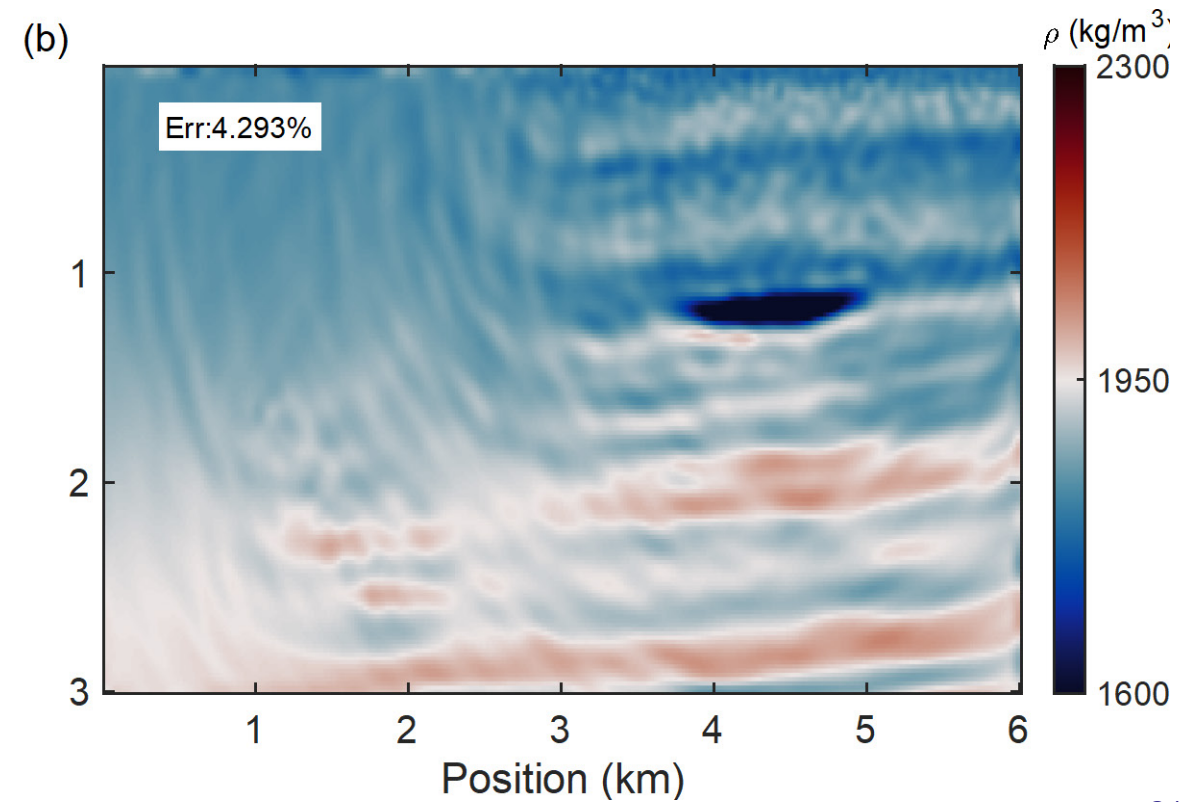
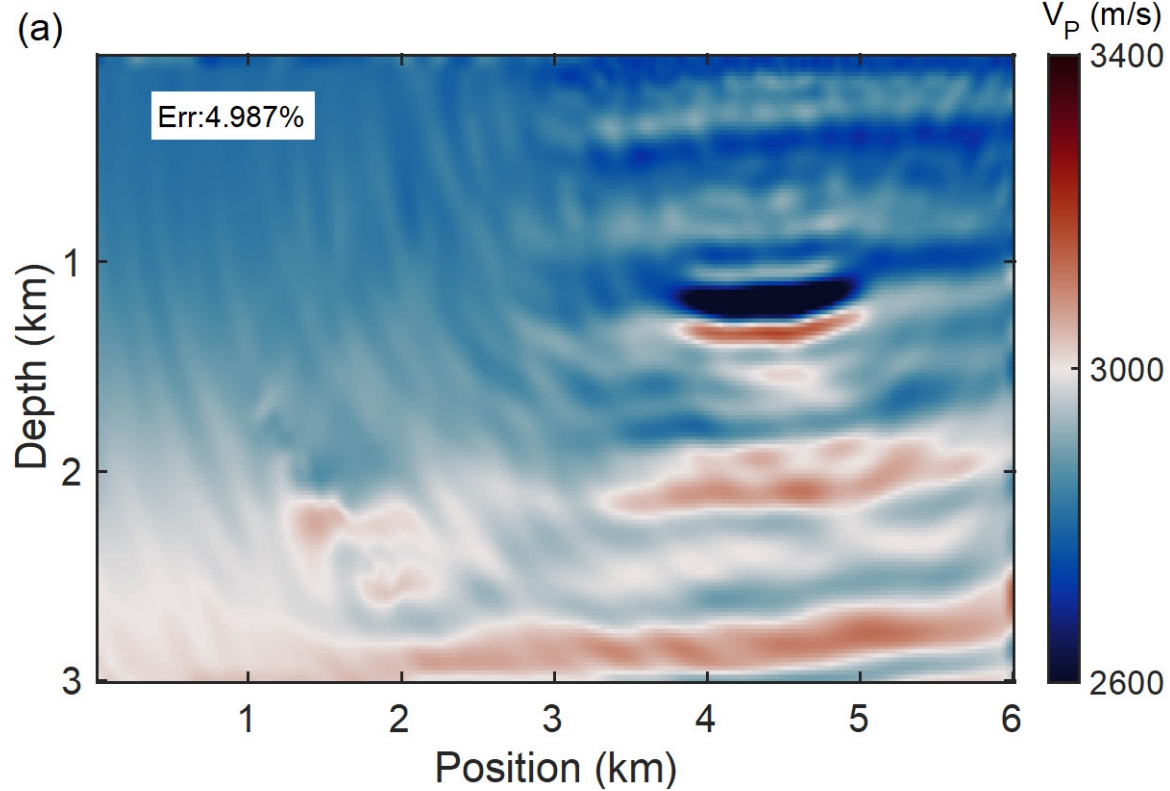
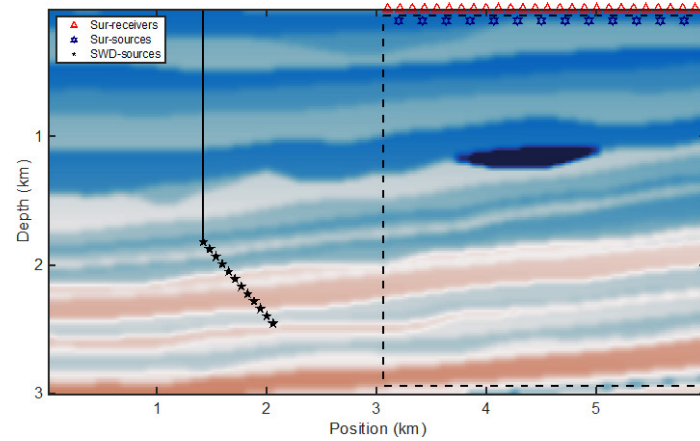


Source number test: enlarged coverage area



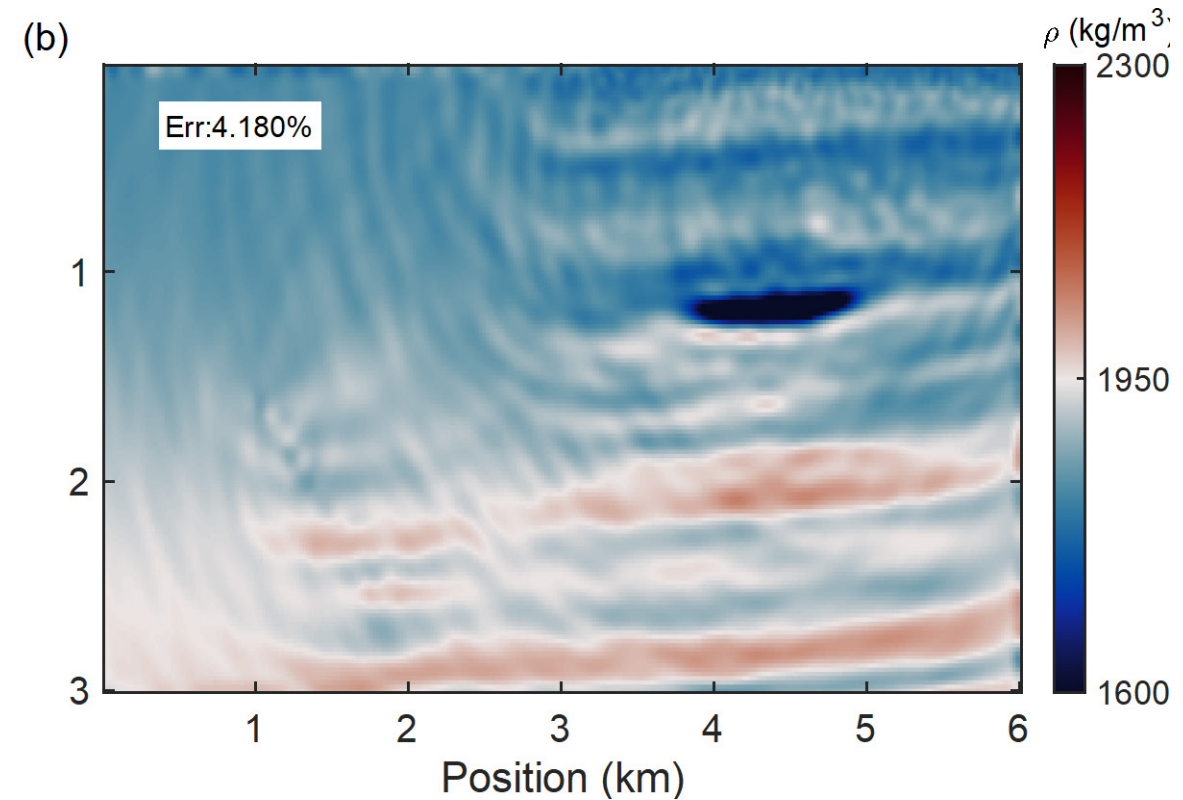
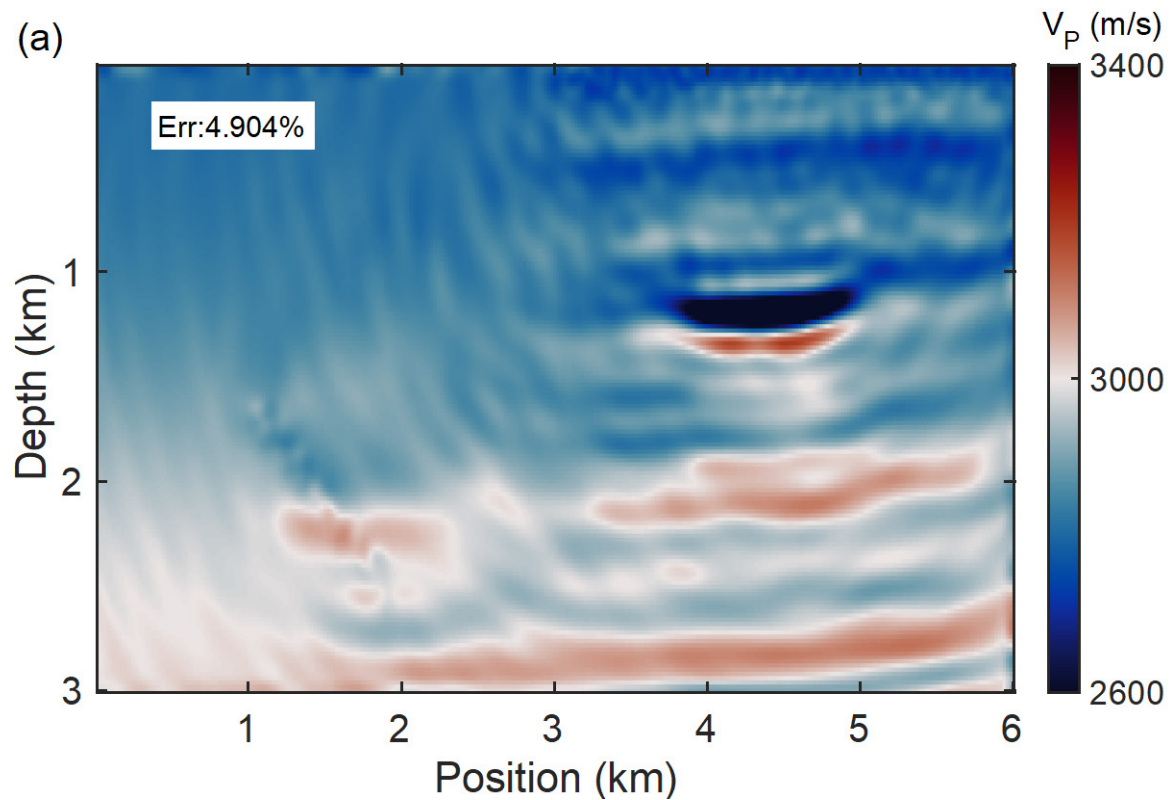
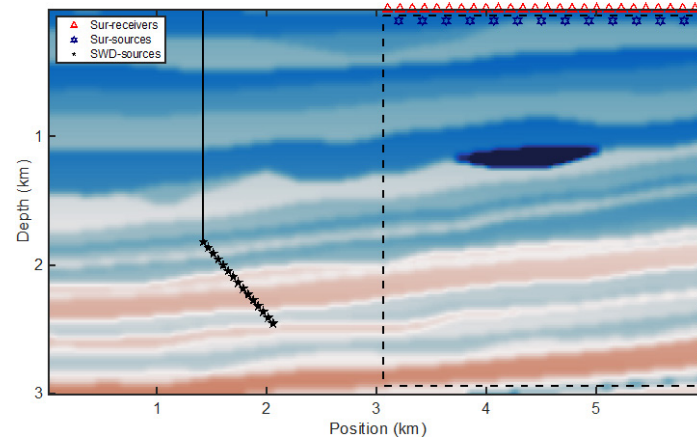


Source number test: enlarged coverage area



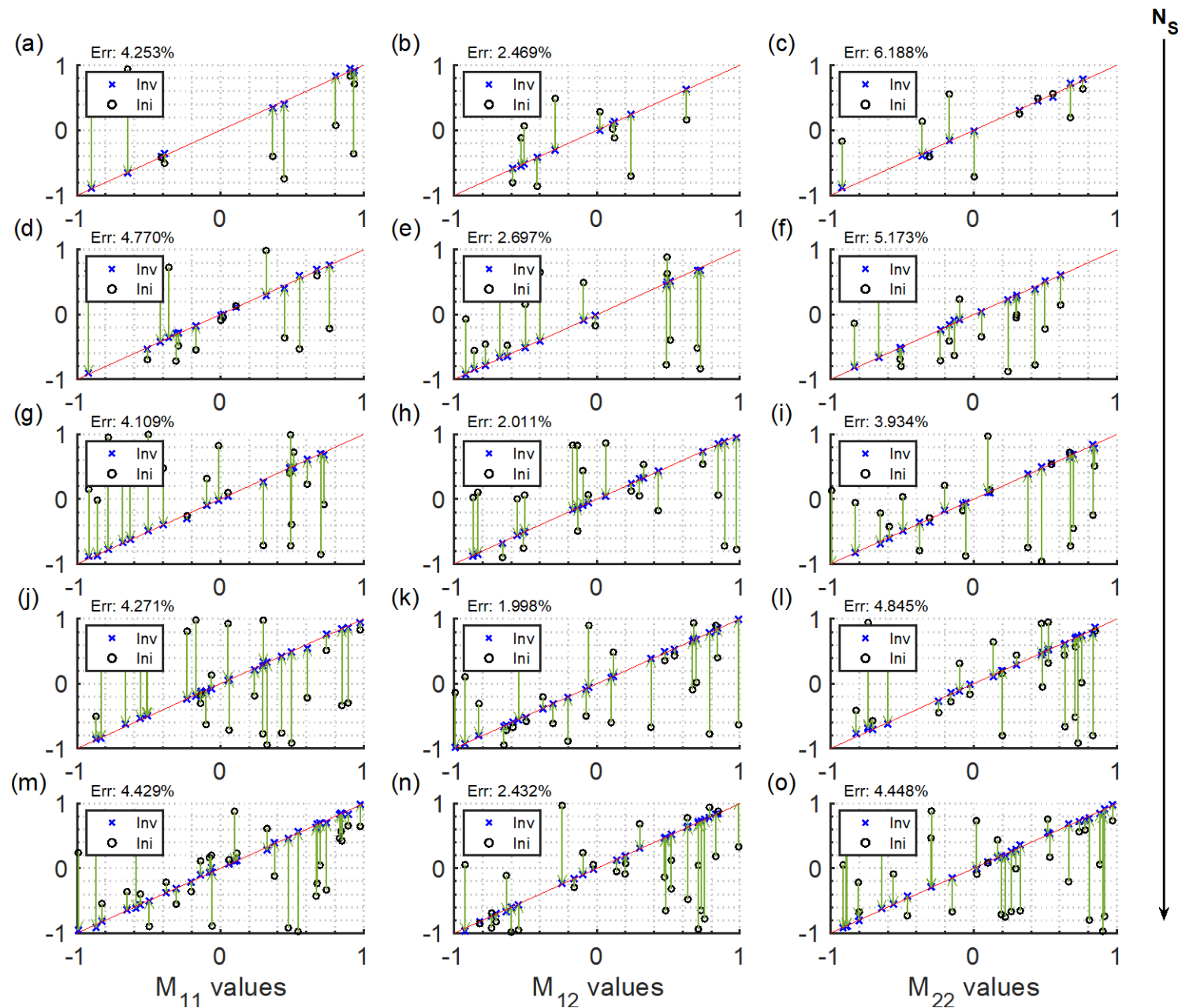


Source number test: enlarged coverage area





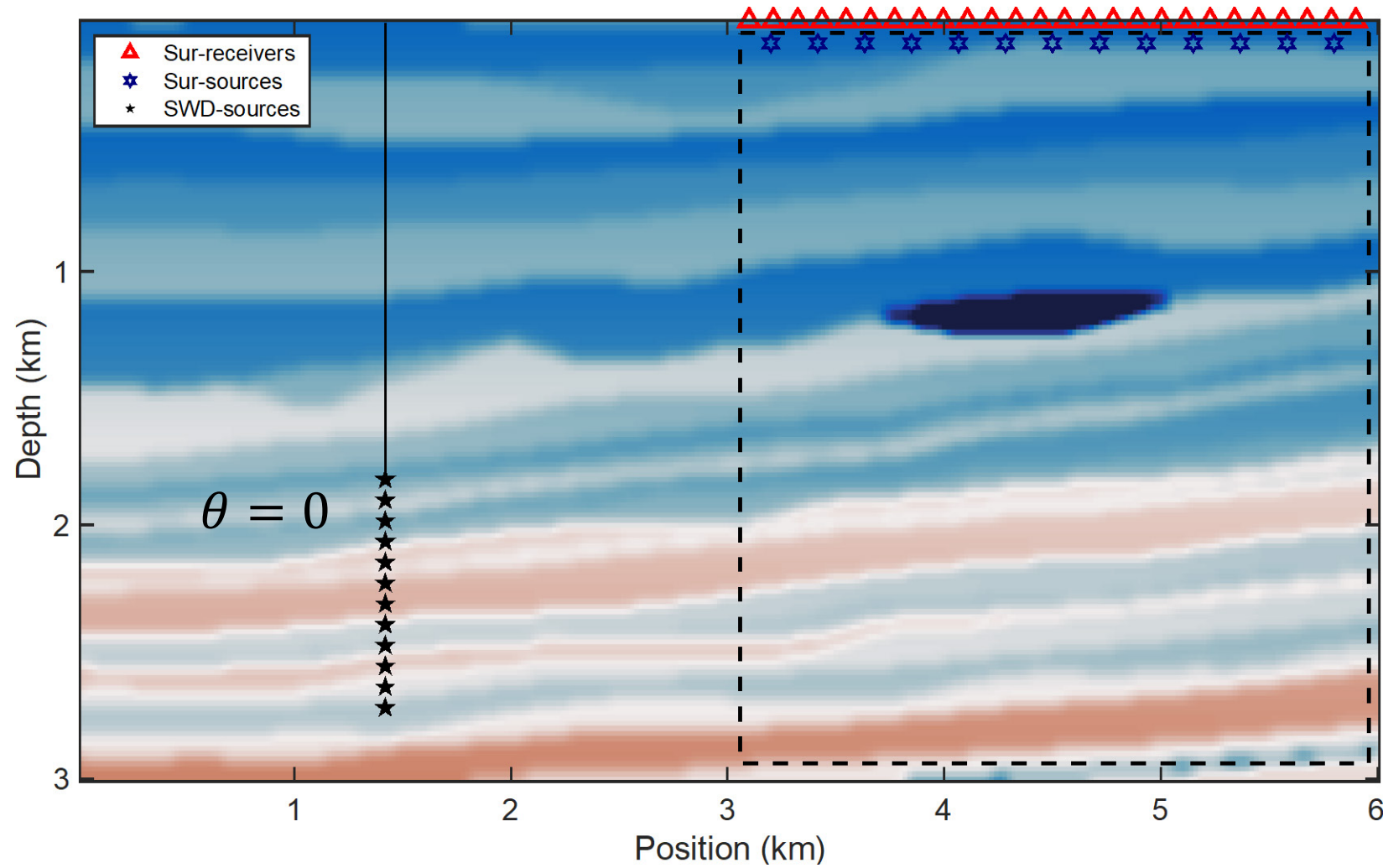
Source number test: stable MT inversion





Inclination test: schematic acquisition

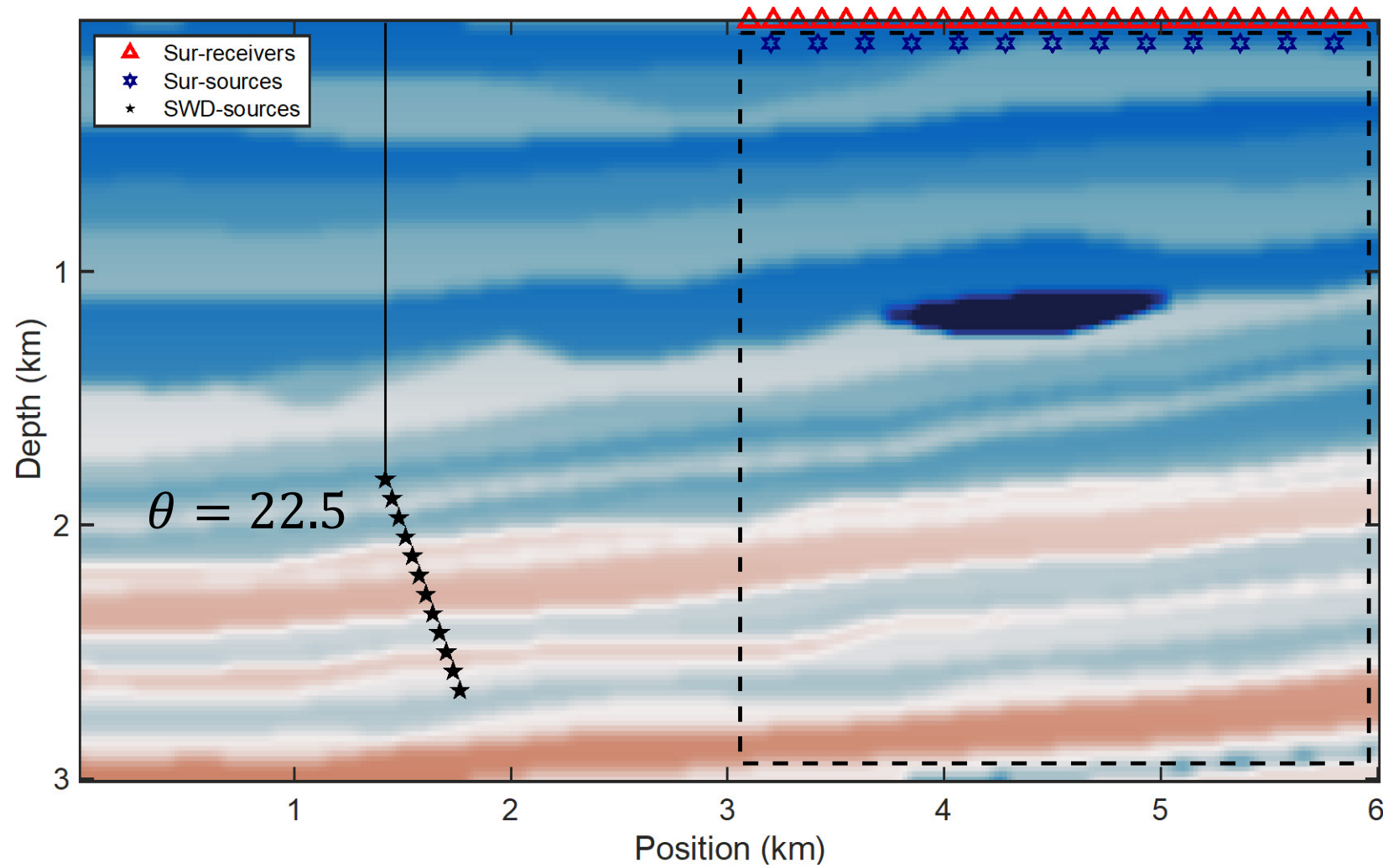
72 explosive sources, 144 receivers





Inclination test: schematic acquisition

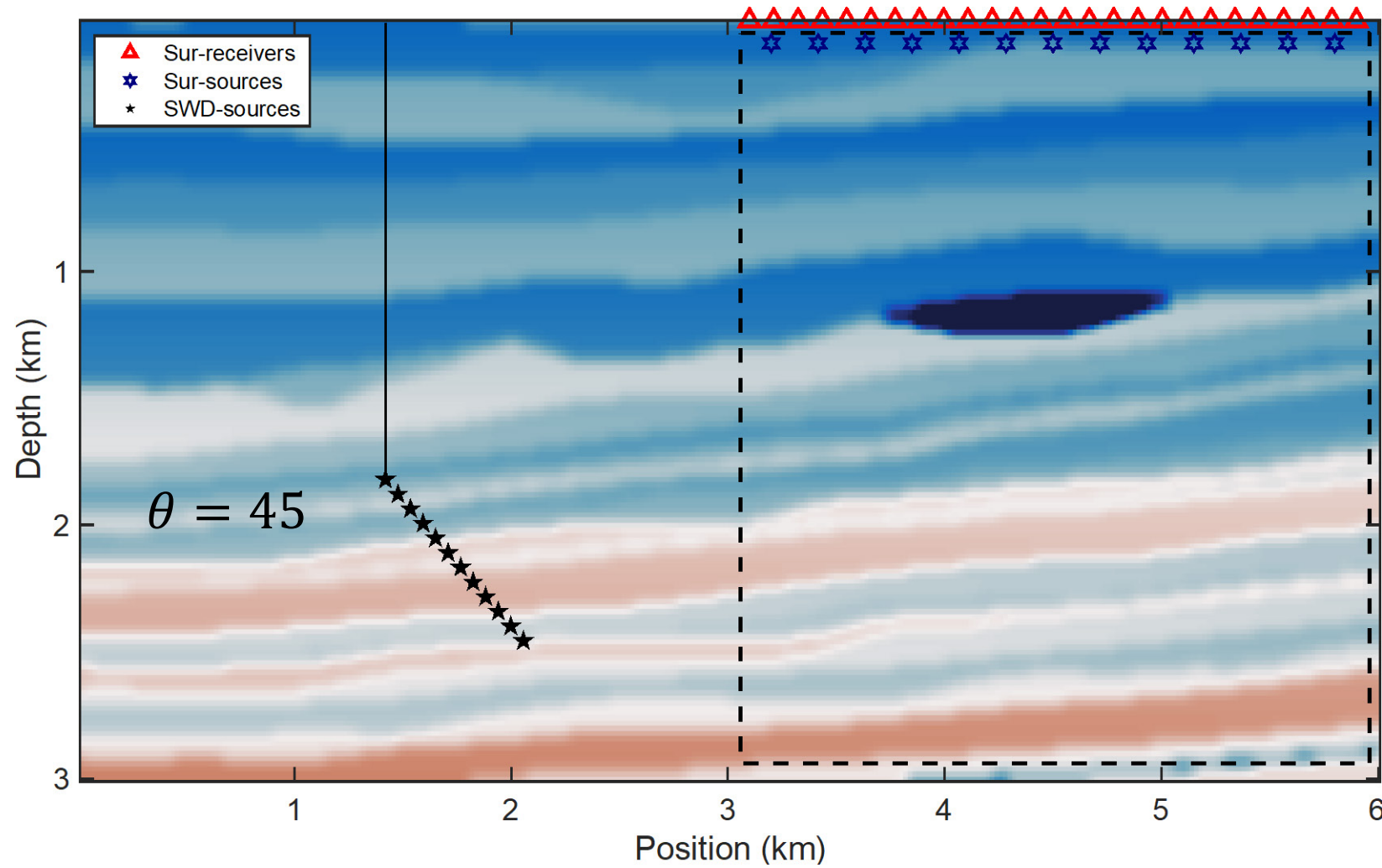
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Inclination test: schematic acquisition

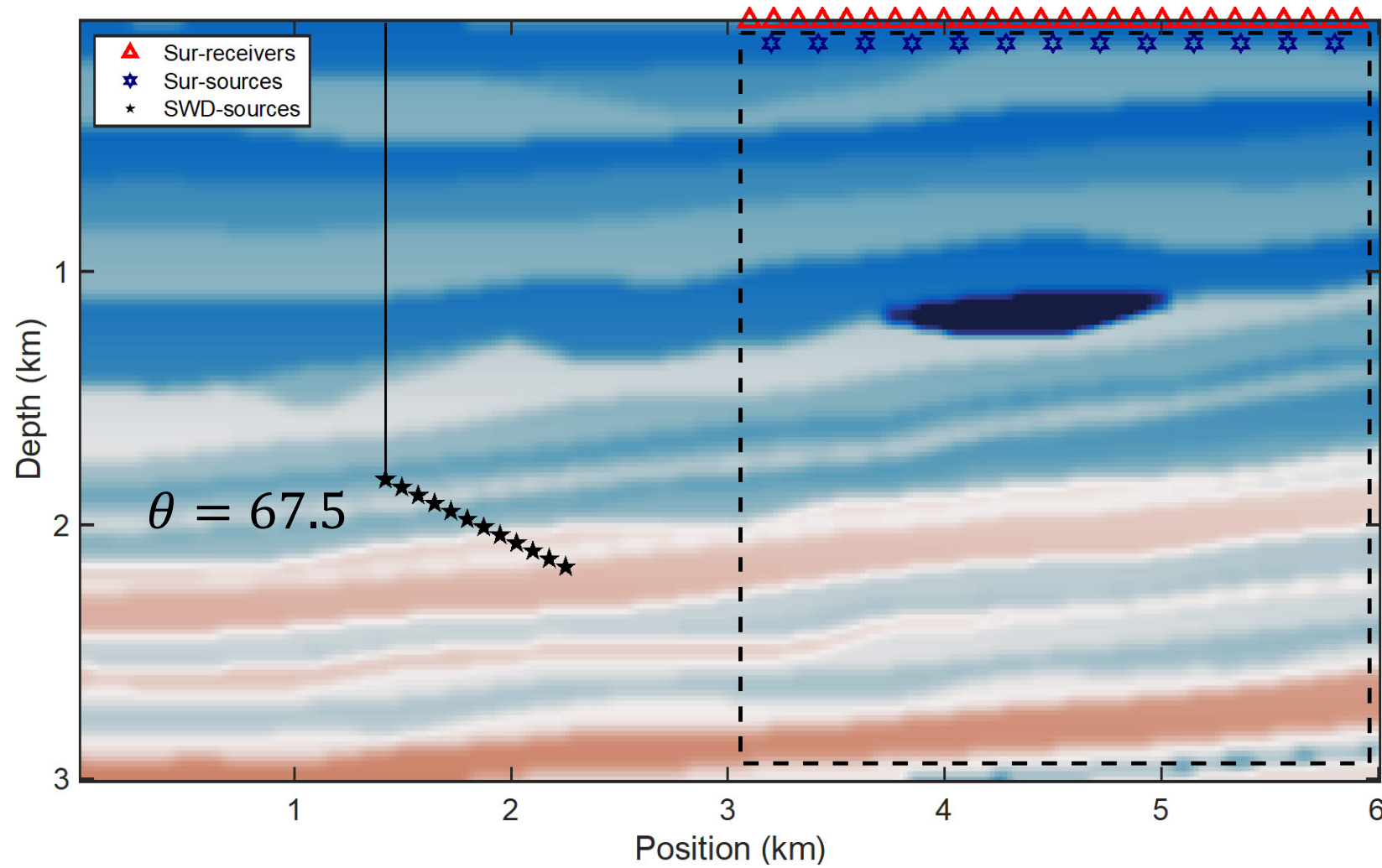
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Inclination test: schematic acquisition

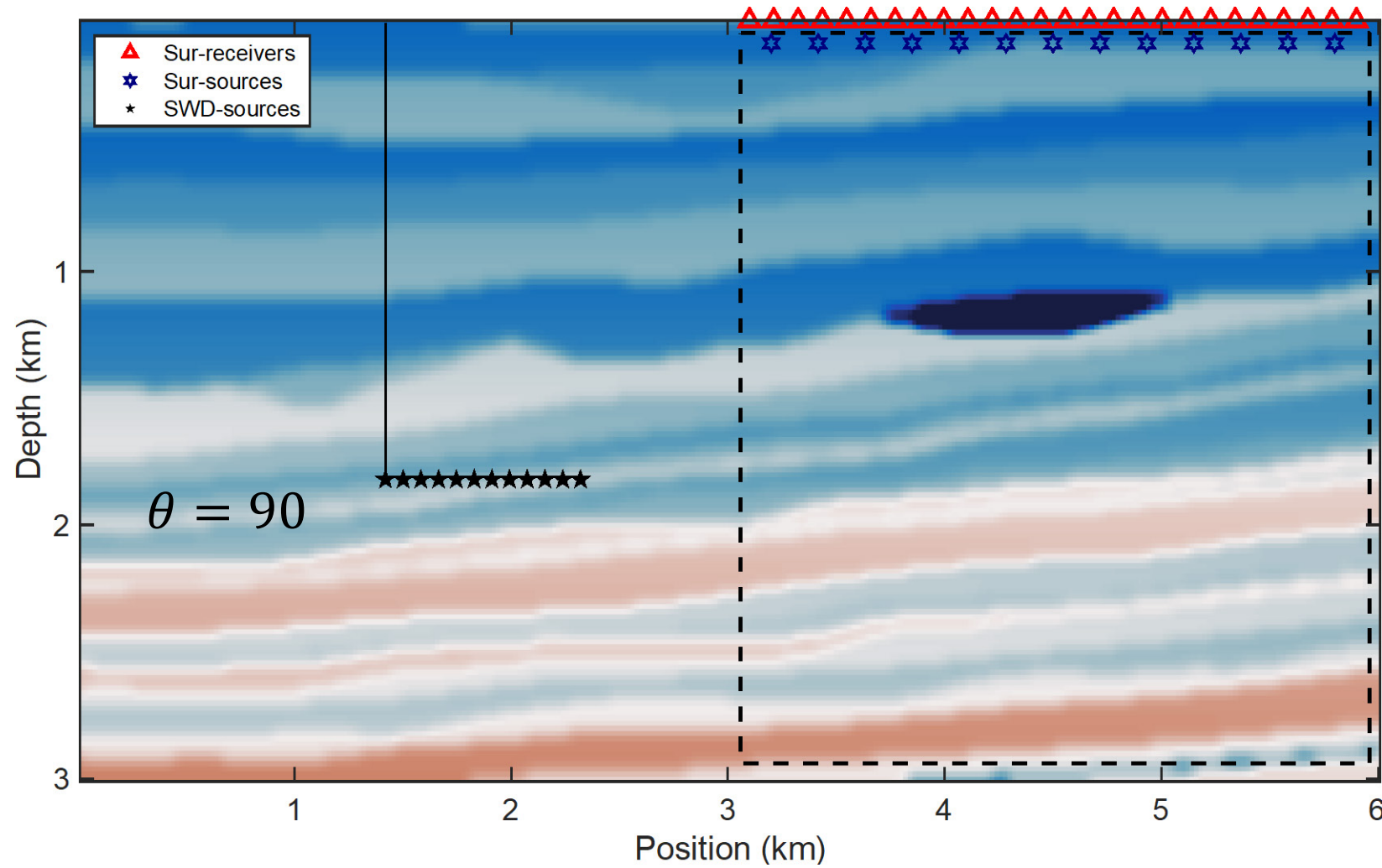
72 explosive sources, 144 receivers

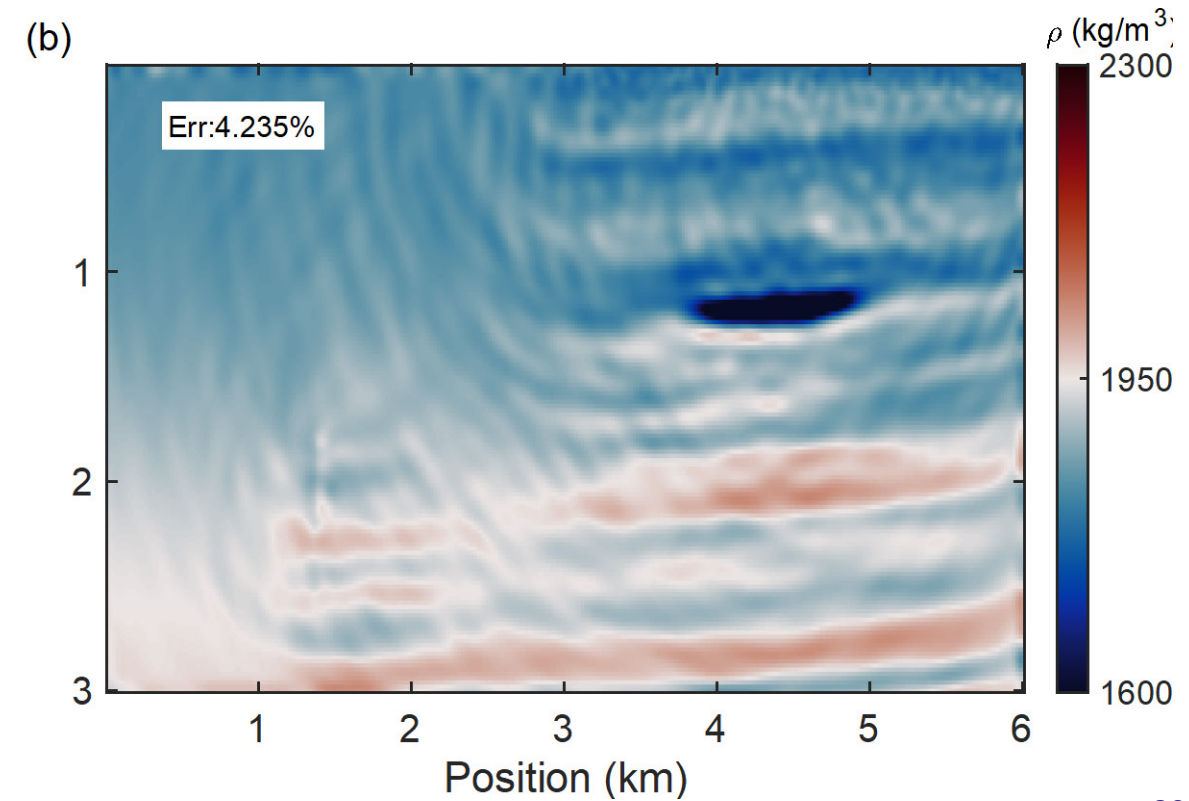
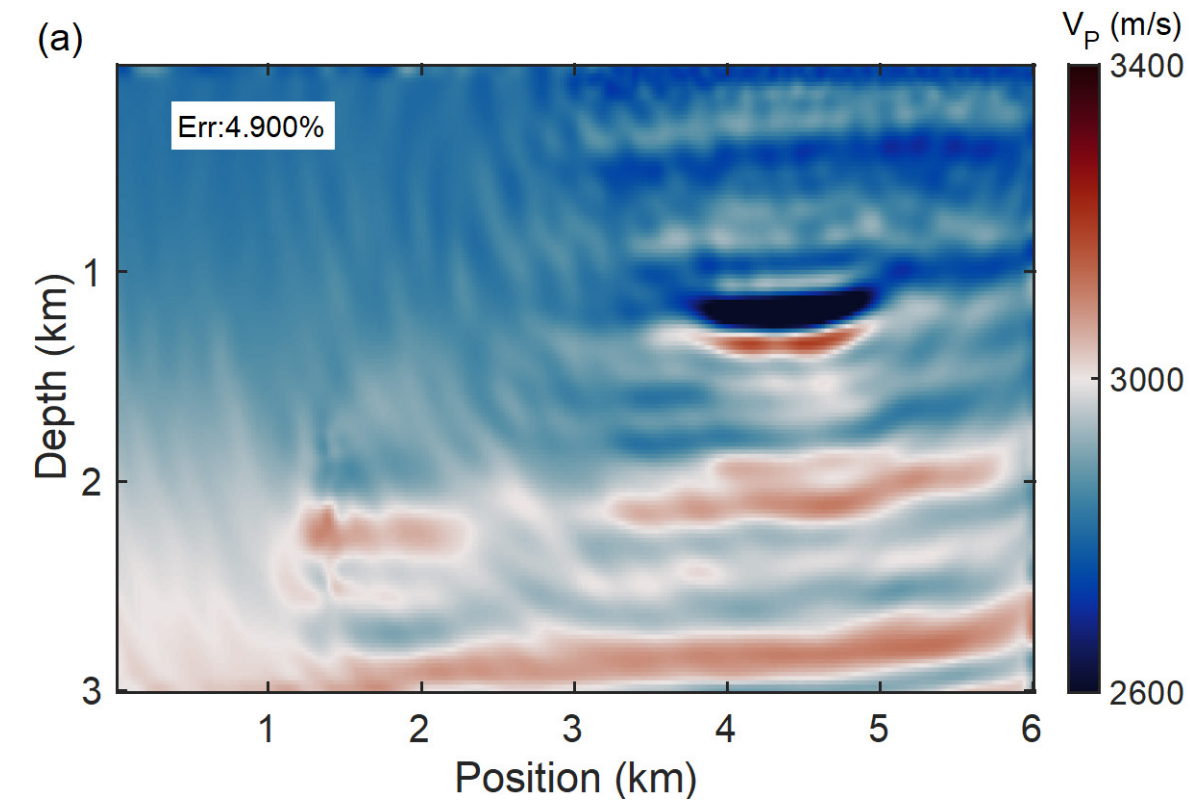
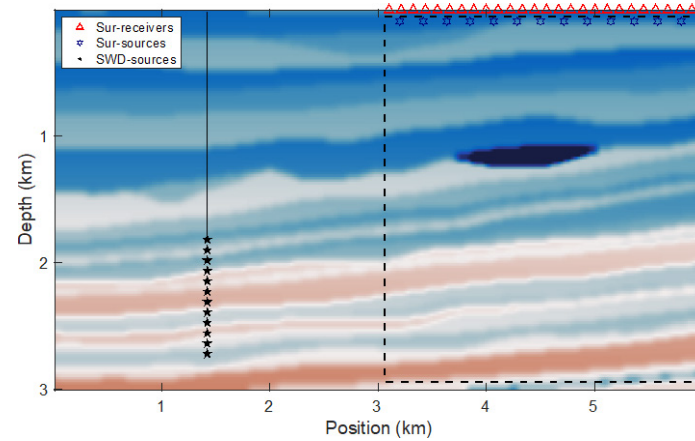


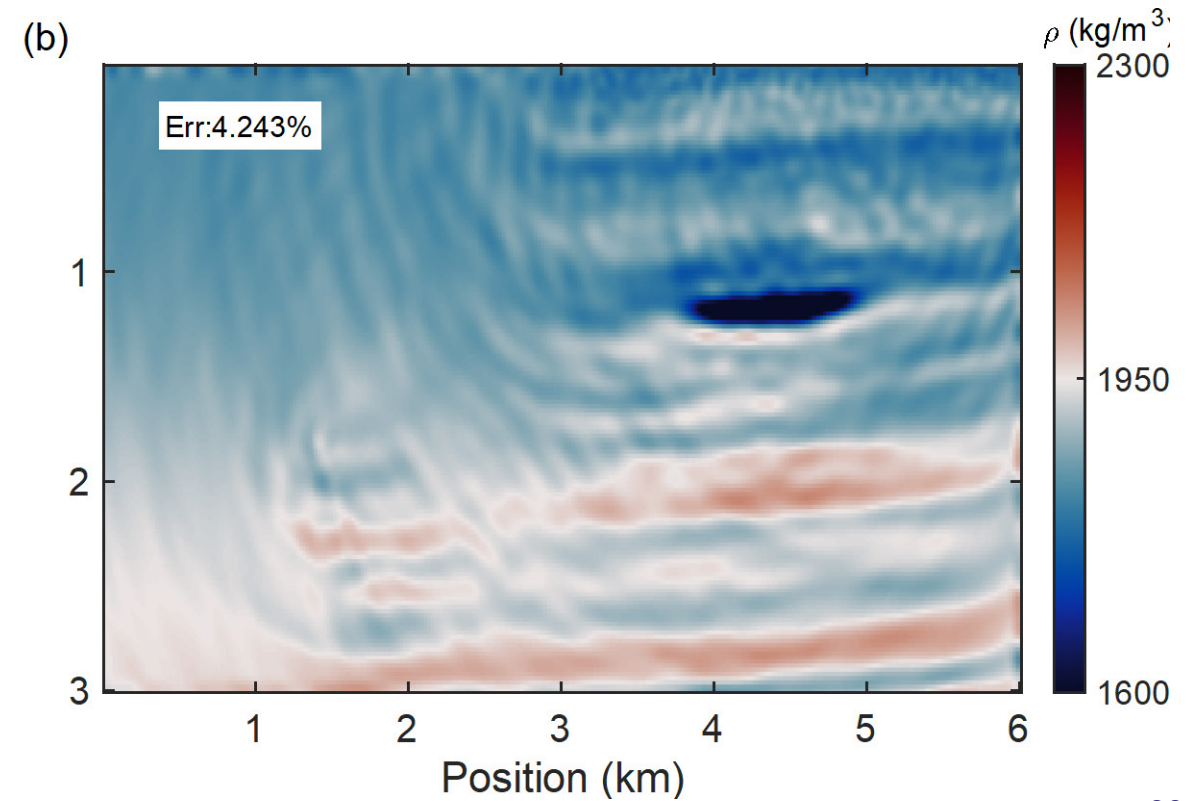
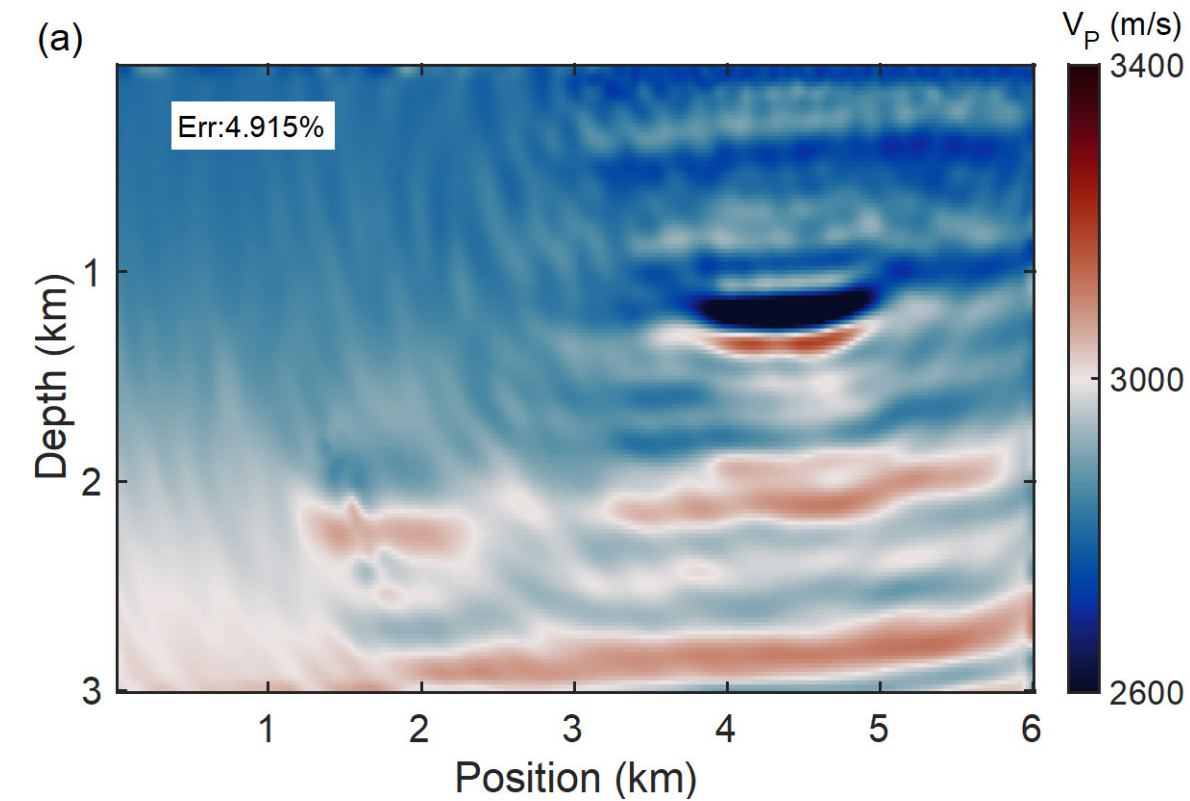
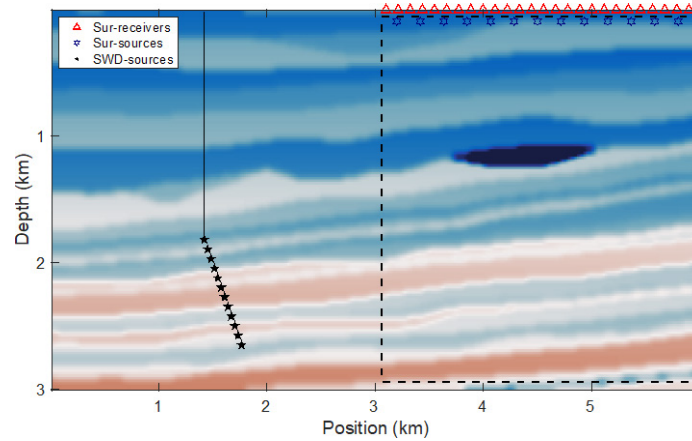


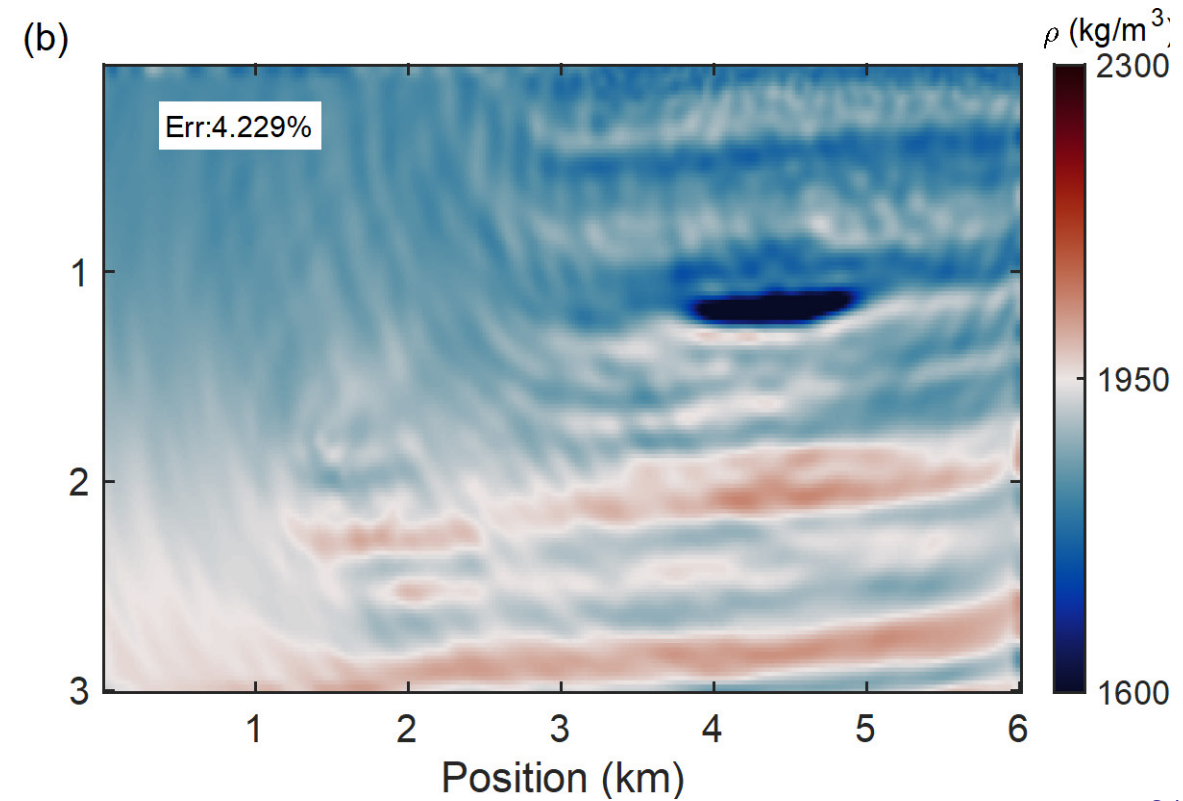
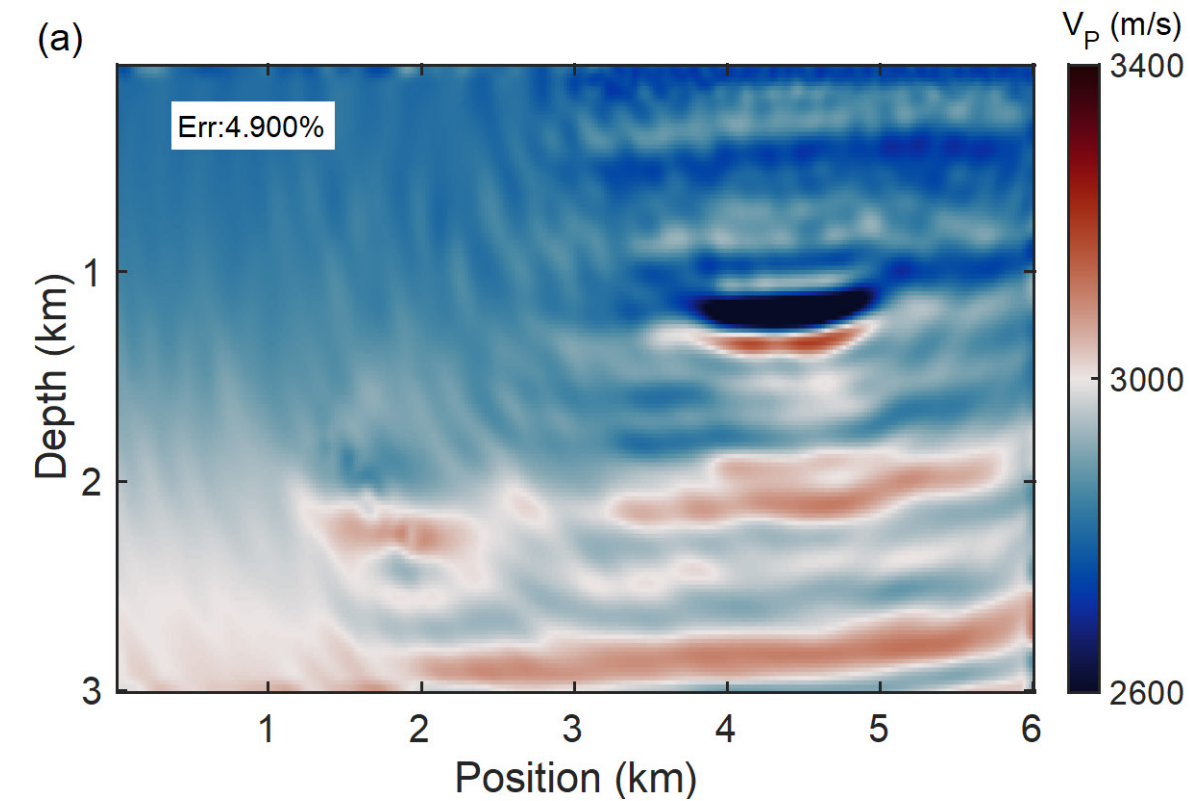
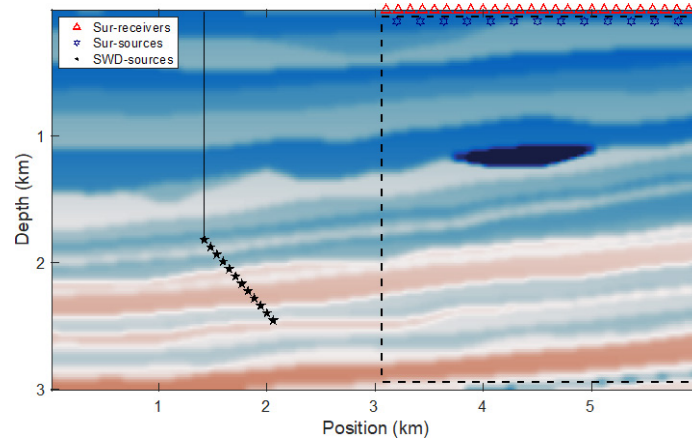
Inclination test: schematic acquisition

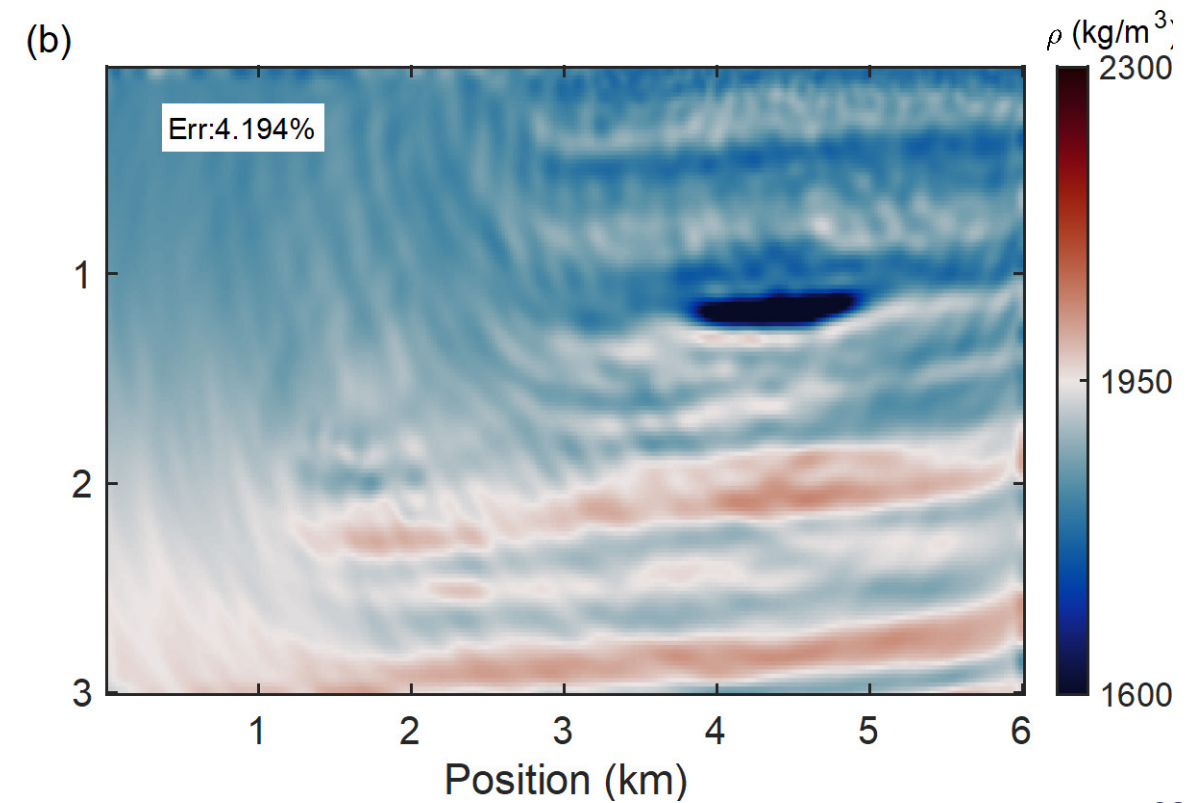
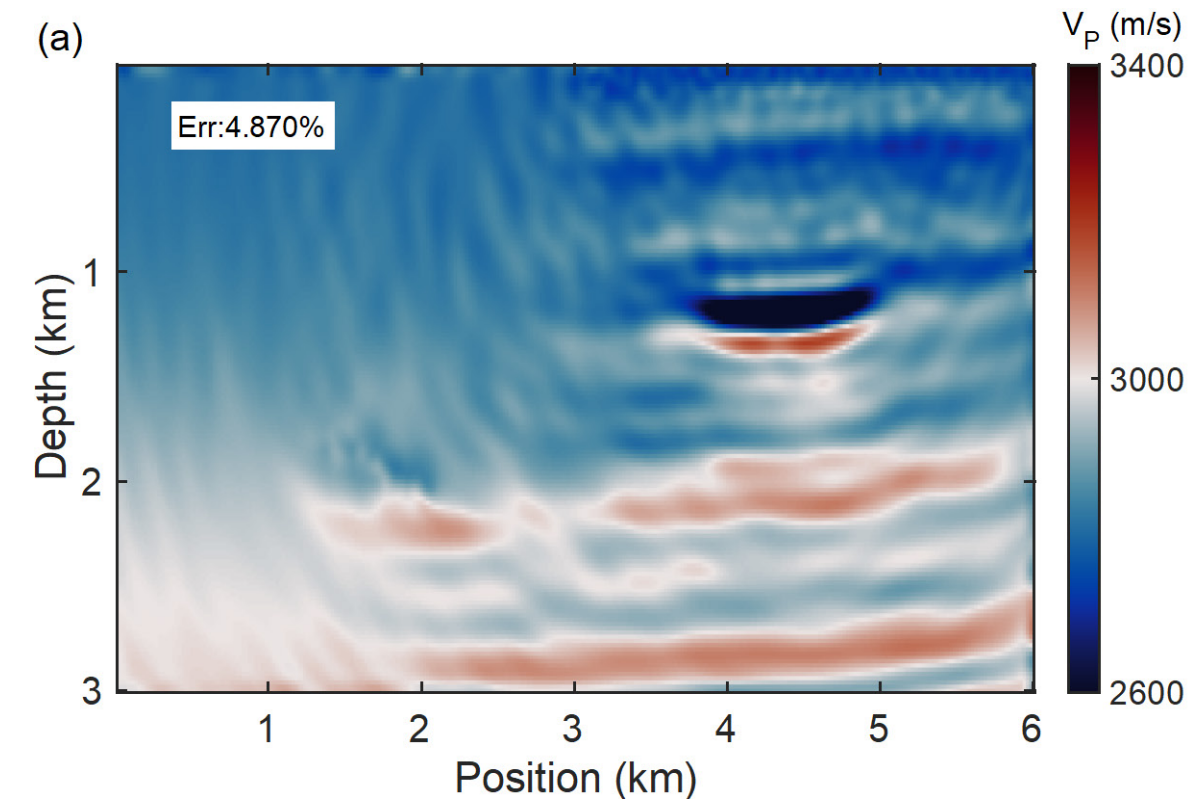
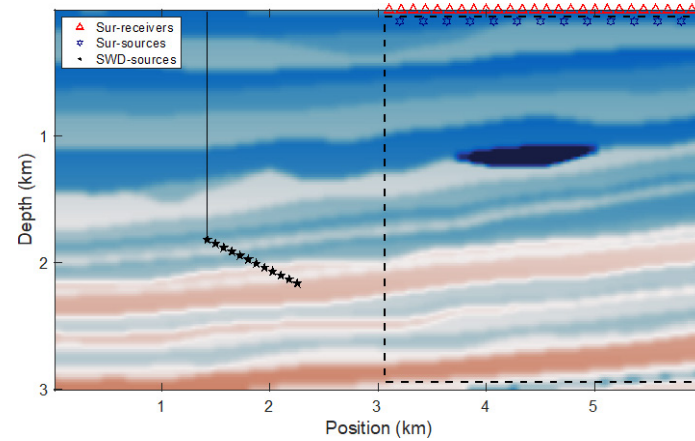
72 explosive sources, 144 receivers



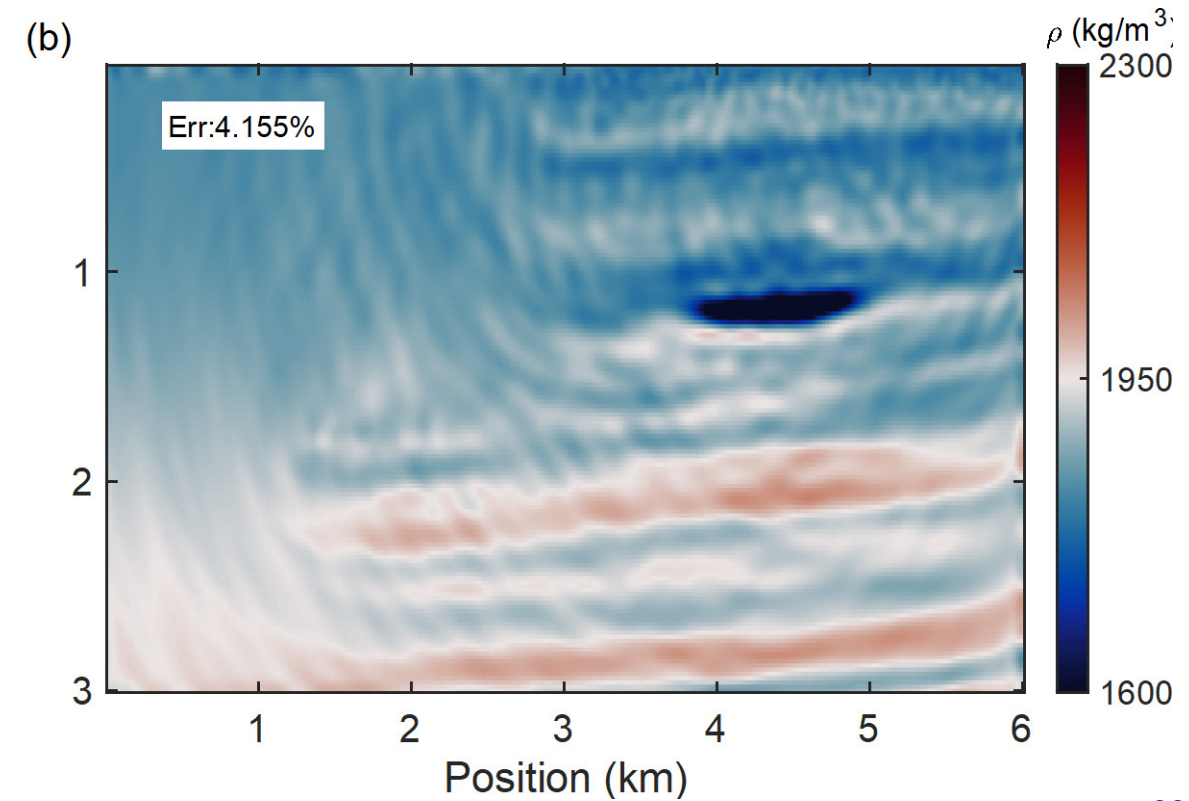
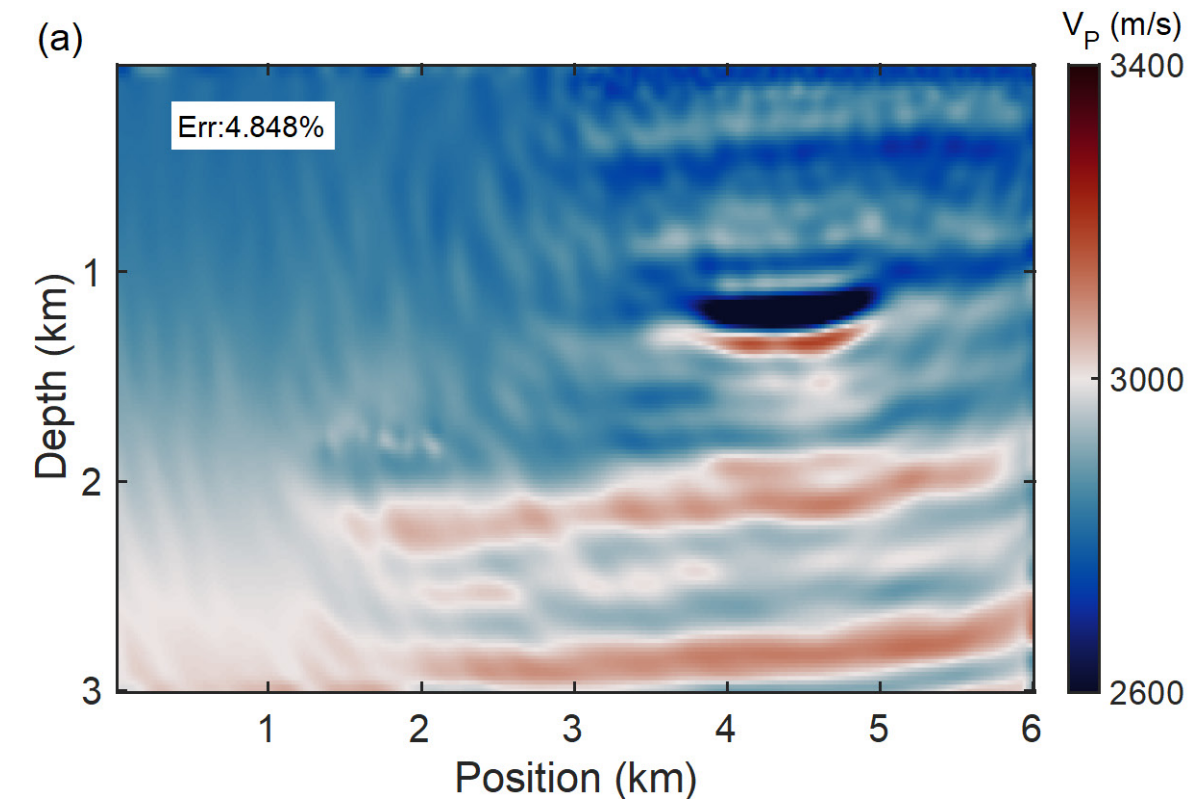
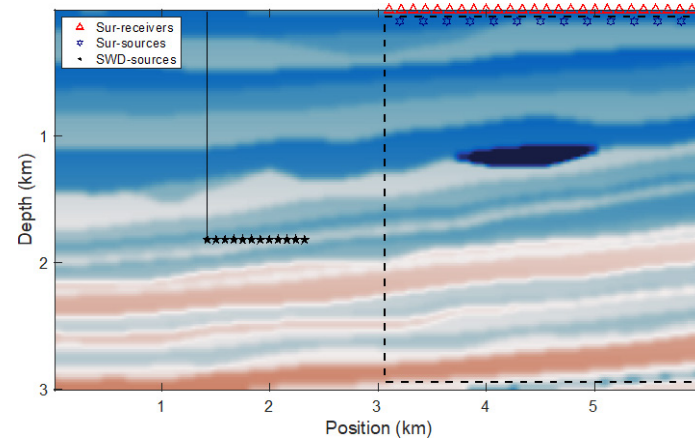






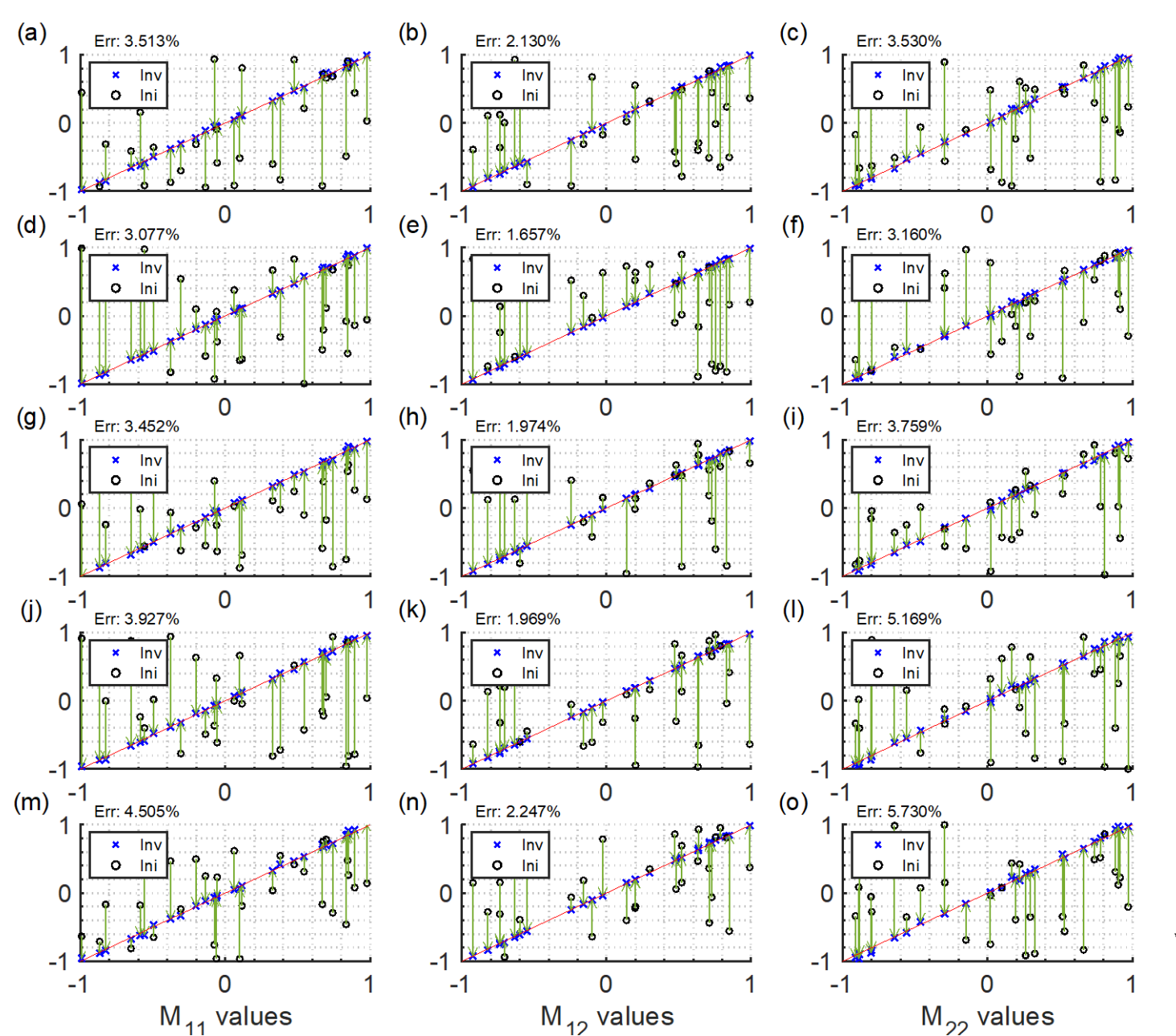


Inclination test: various aperture





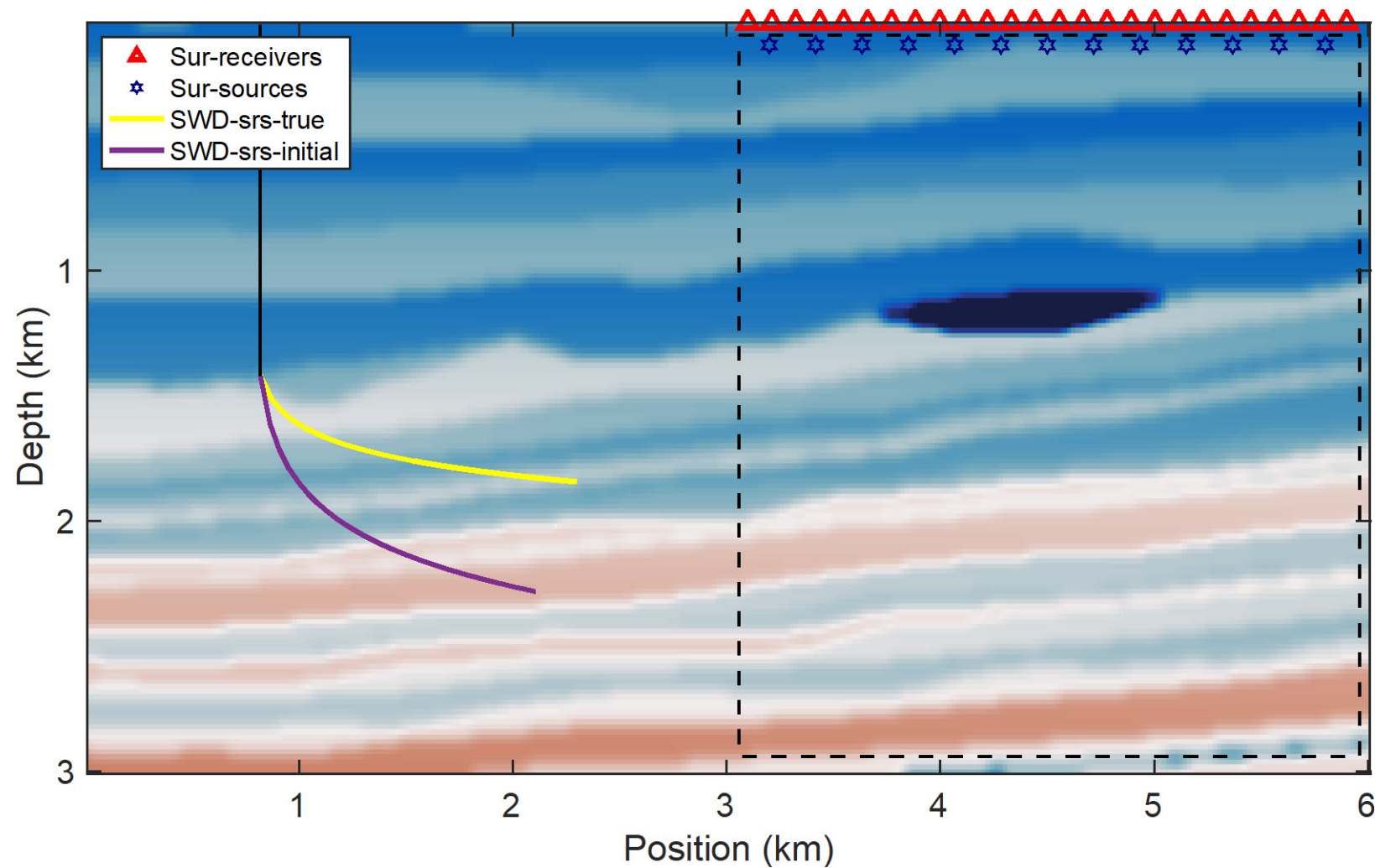
Extension test: stable MT inversion





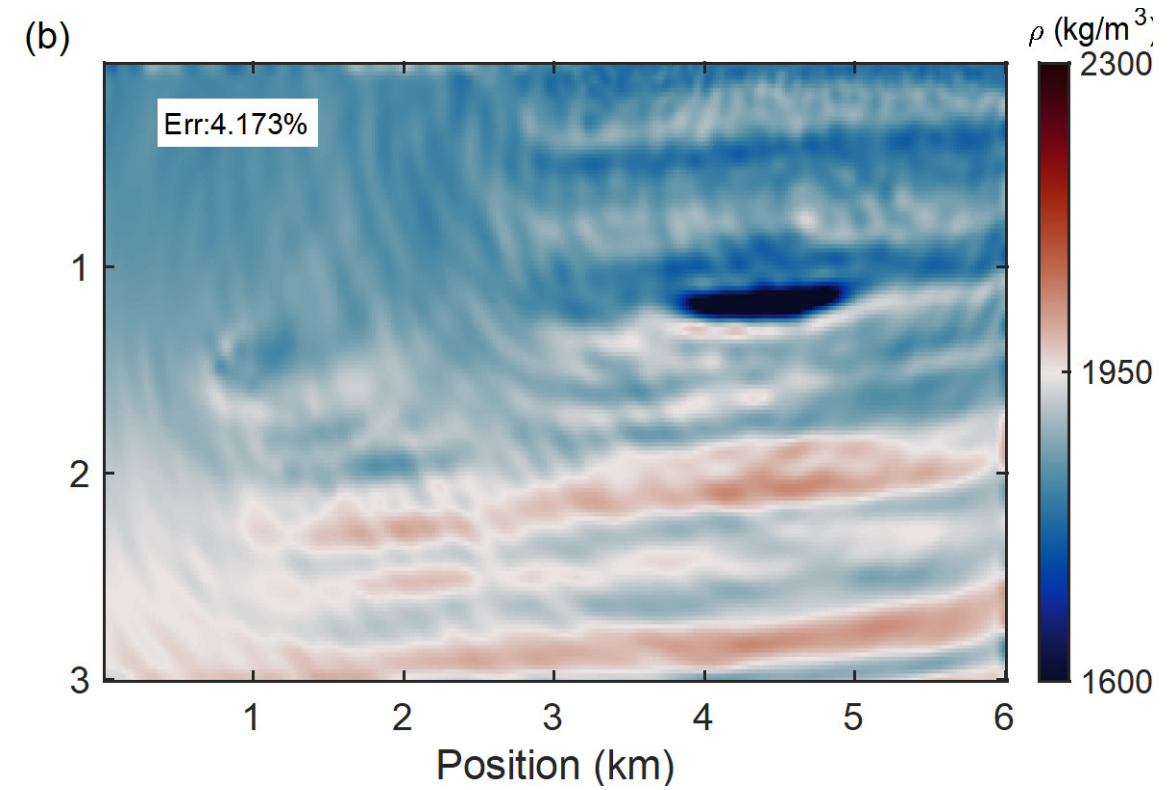
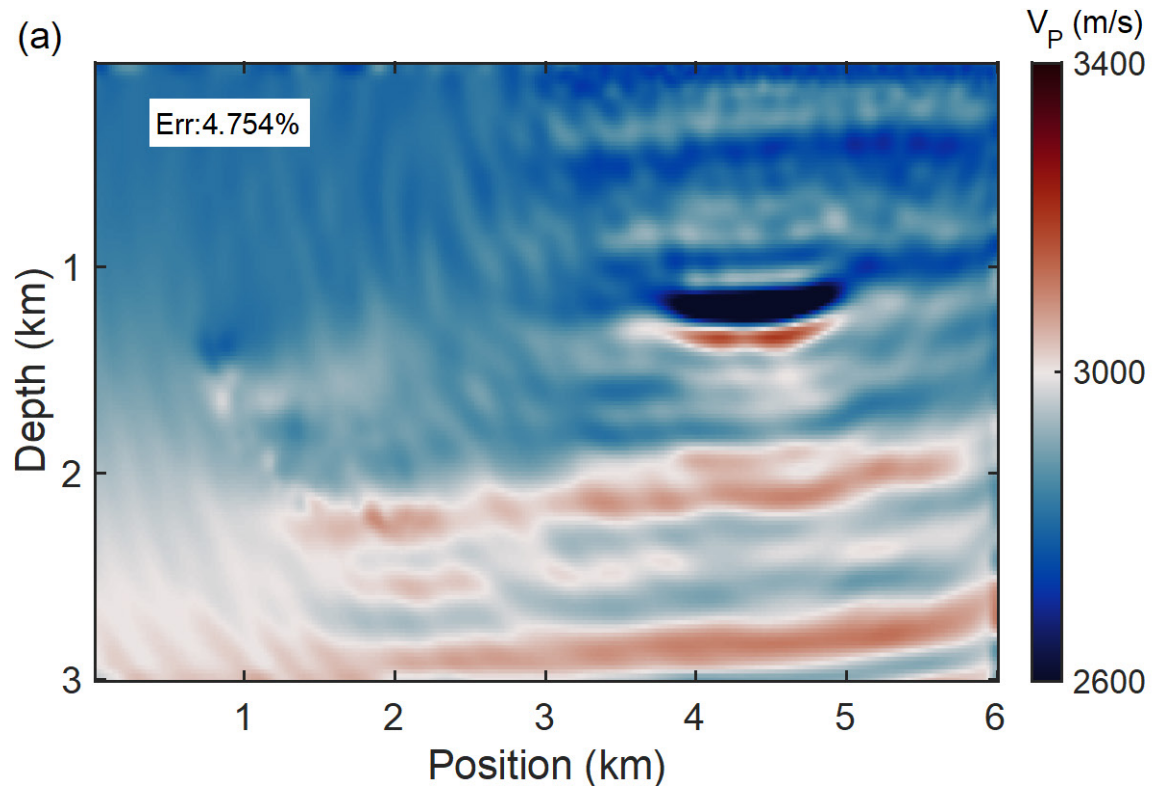
More realistic setting including trajectory estimation

72 explosive sources, 144 receivers



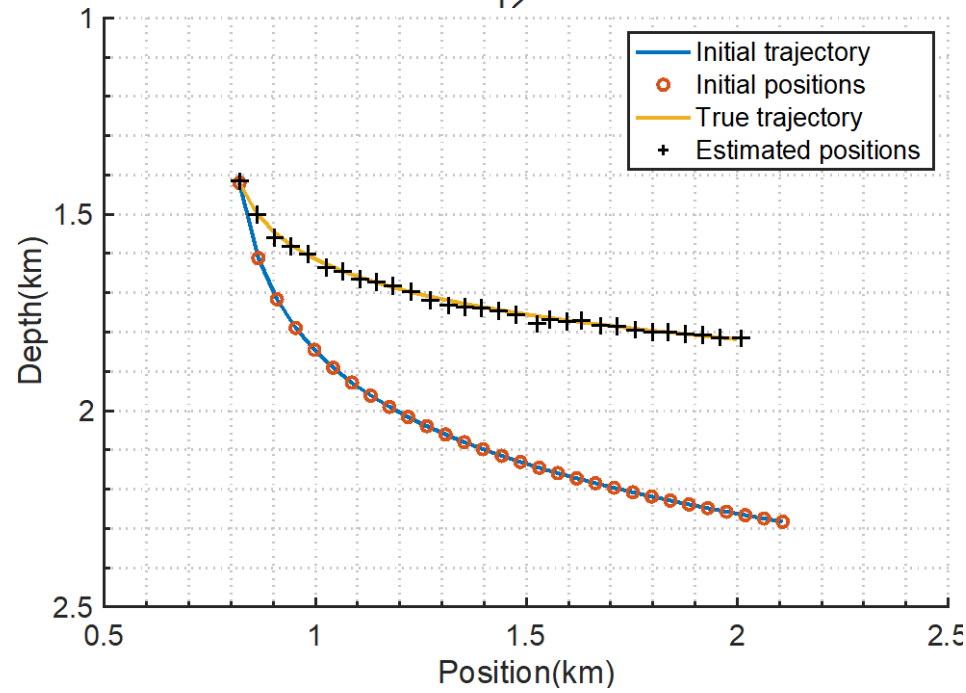
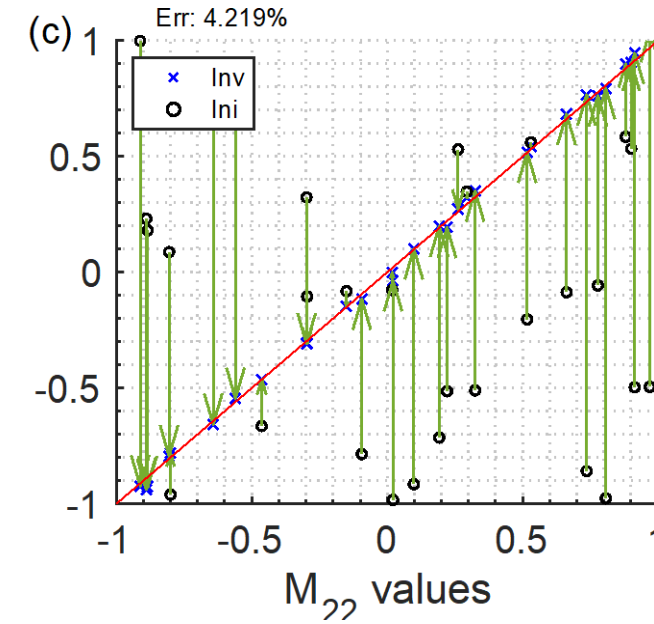
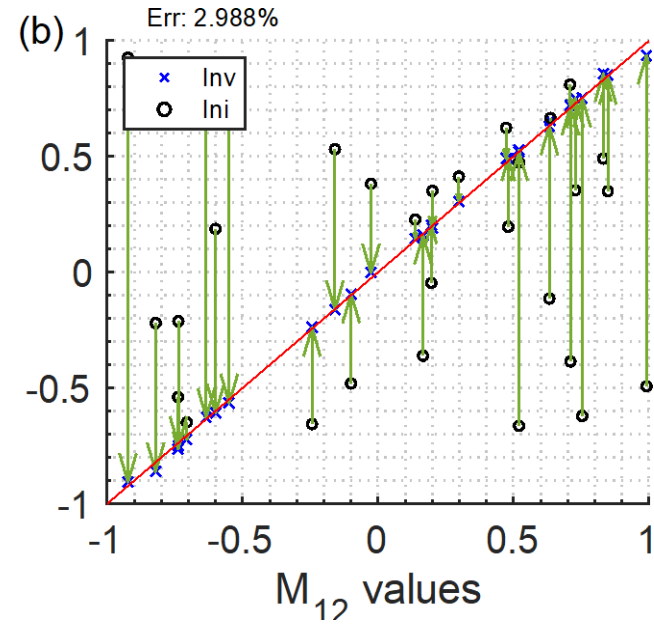
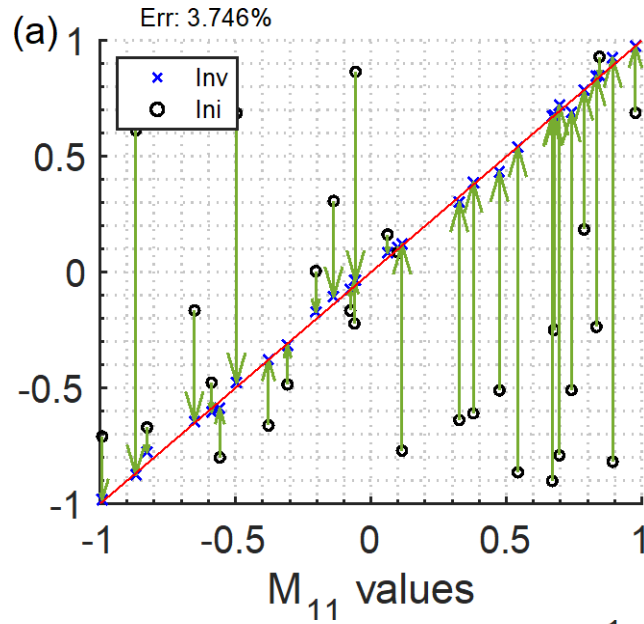


P-wave velocity and density are estimated finely





Source terms are also recovered





- Introduction to seismic-while-drilling
- Full-waveform-inversion review
- Numerical experiments
- **Discussion**
- Conclusion



- Source num test: enhancement $>$ nonlinearity.
- Inclination test: various apertures.
- Uncertainty might arise if the radiation varies with positions.



- Introduction to seismic-while-drilling
- Full-waveform-inversion review
- Numerical experiments
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- **Conclusion**



- SWD helps improve FWI models.
- Expanded possibilities for technology.
- Inversion varies with drill settings.
- Future work:
 - better integration of SWD source signature with proper frequency components.



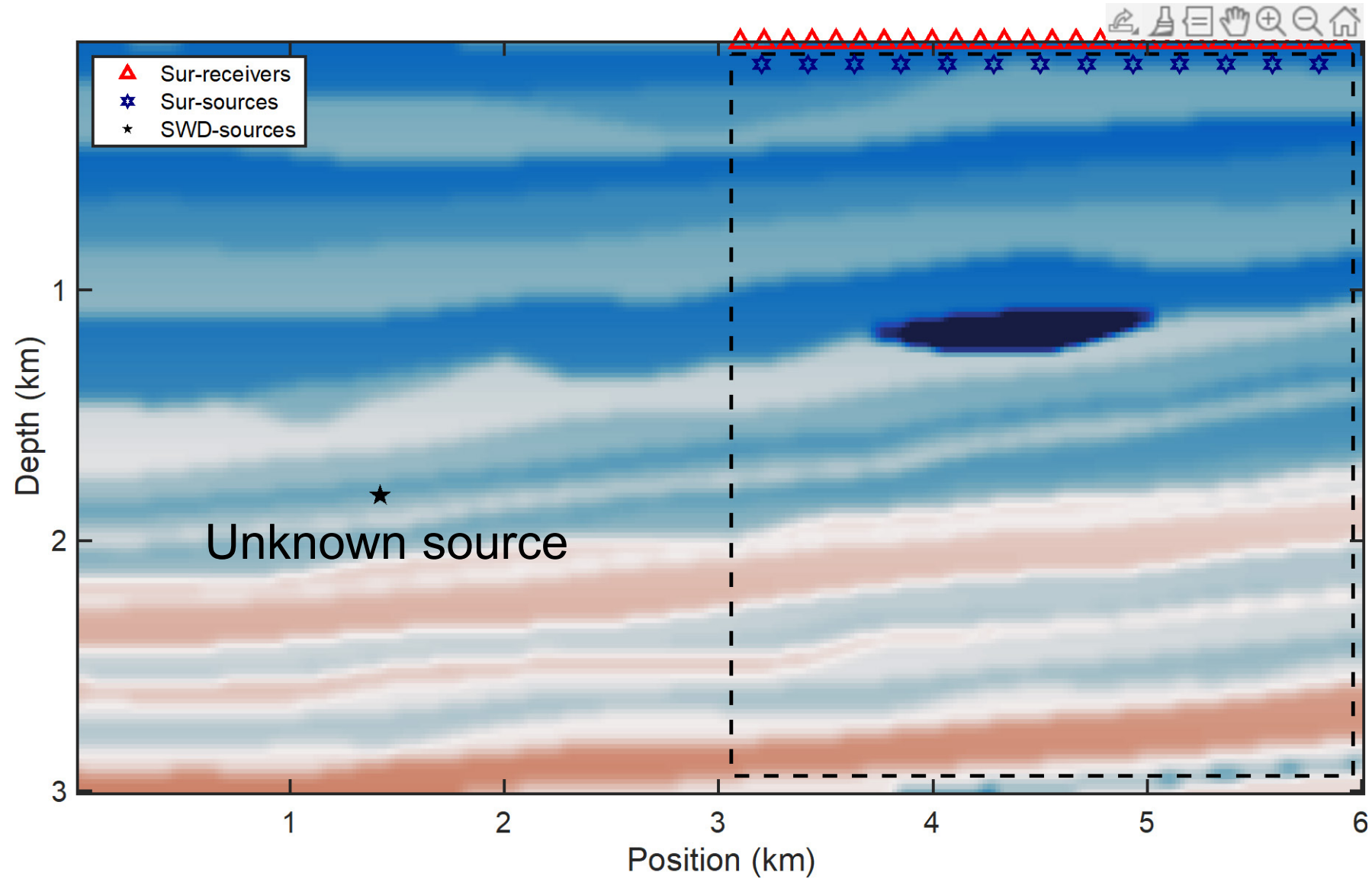
- CREWES sponsors
- NSERC
- CREWES colleagues



Appendix A:

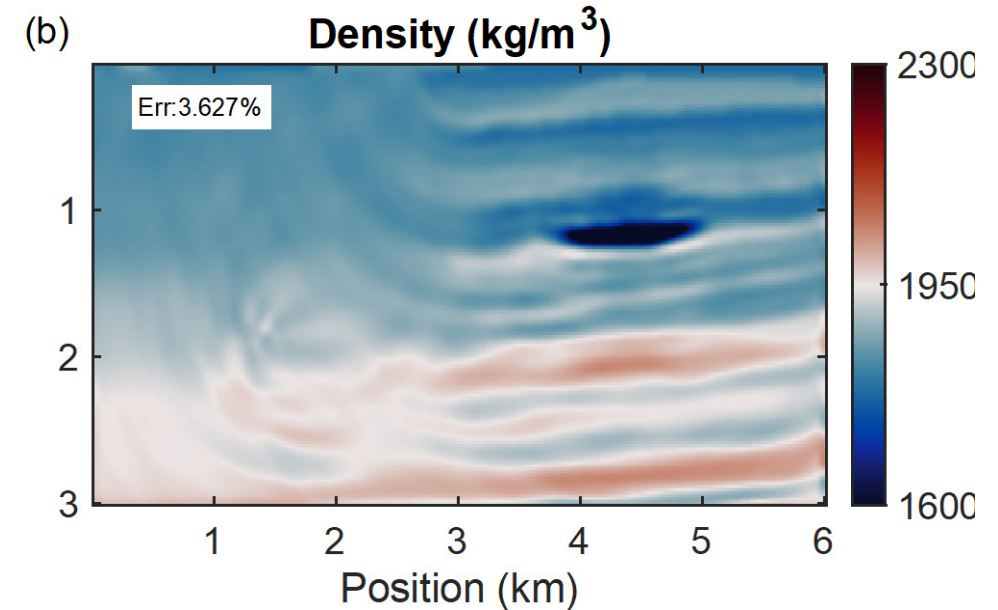
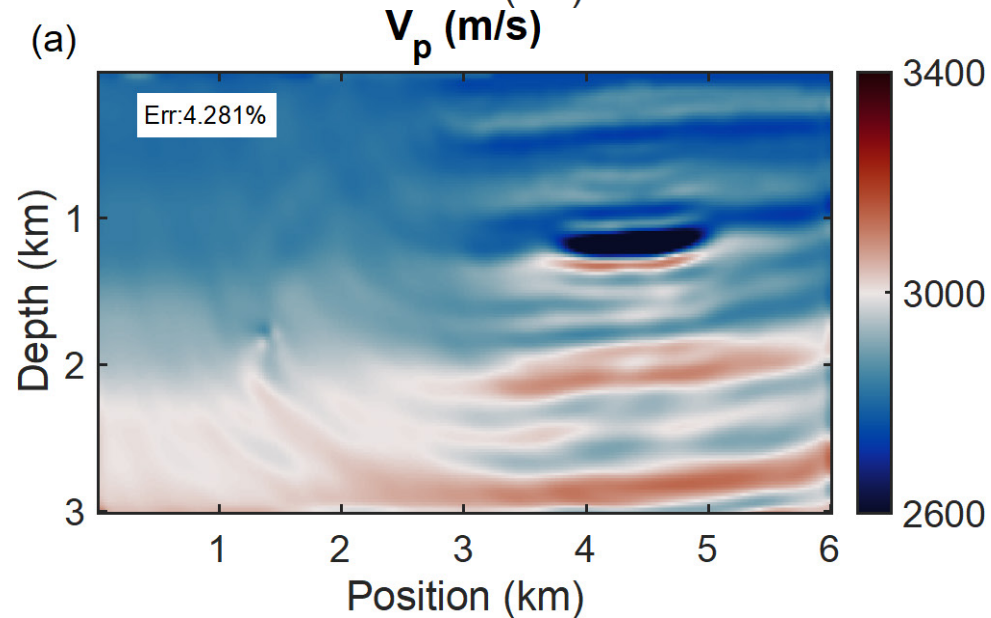
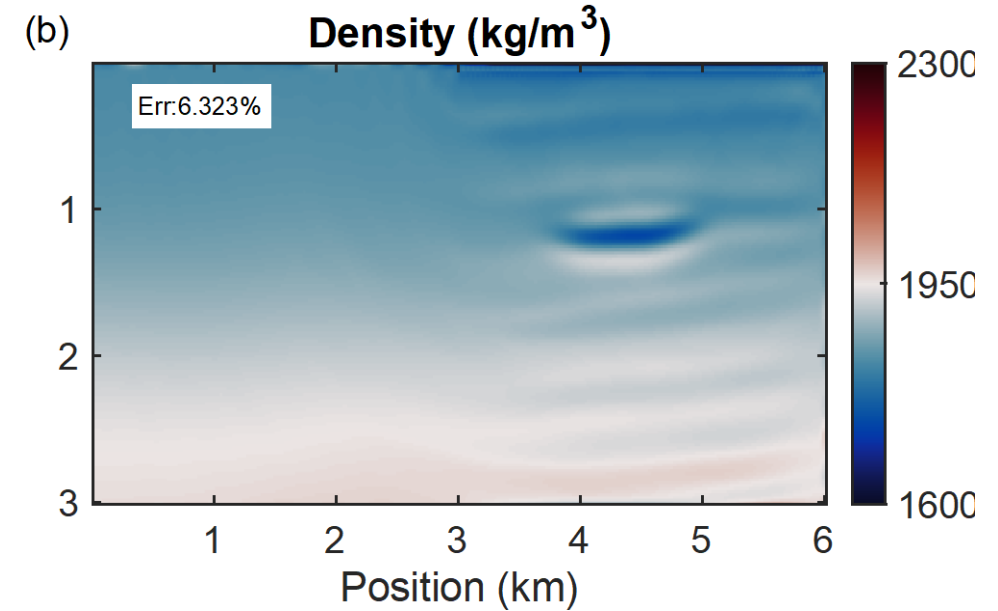
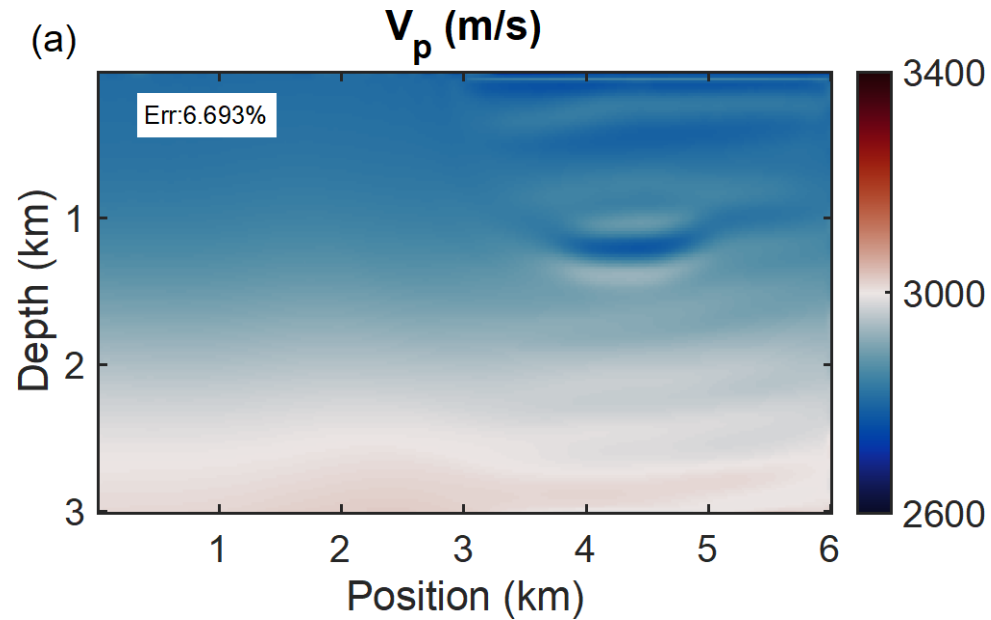
Inversion with one SWD source

72 explosive sources, 144 receivers





One SWD source provides significant improvement



Err: normalized root mean square error (NRMSE)



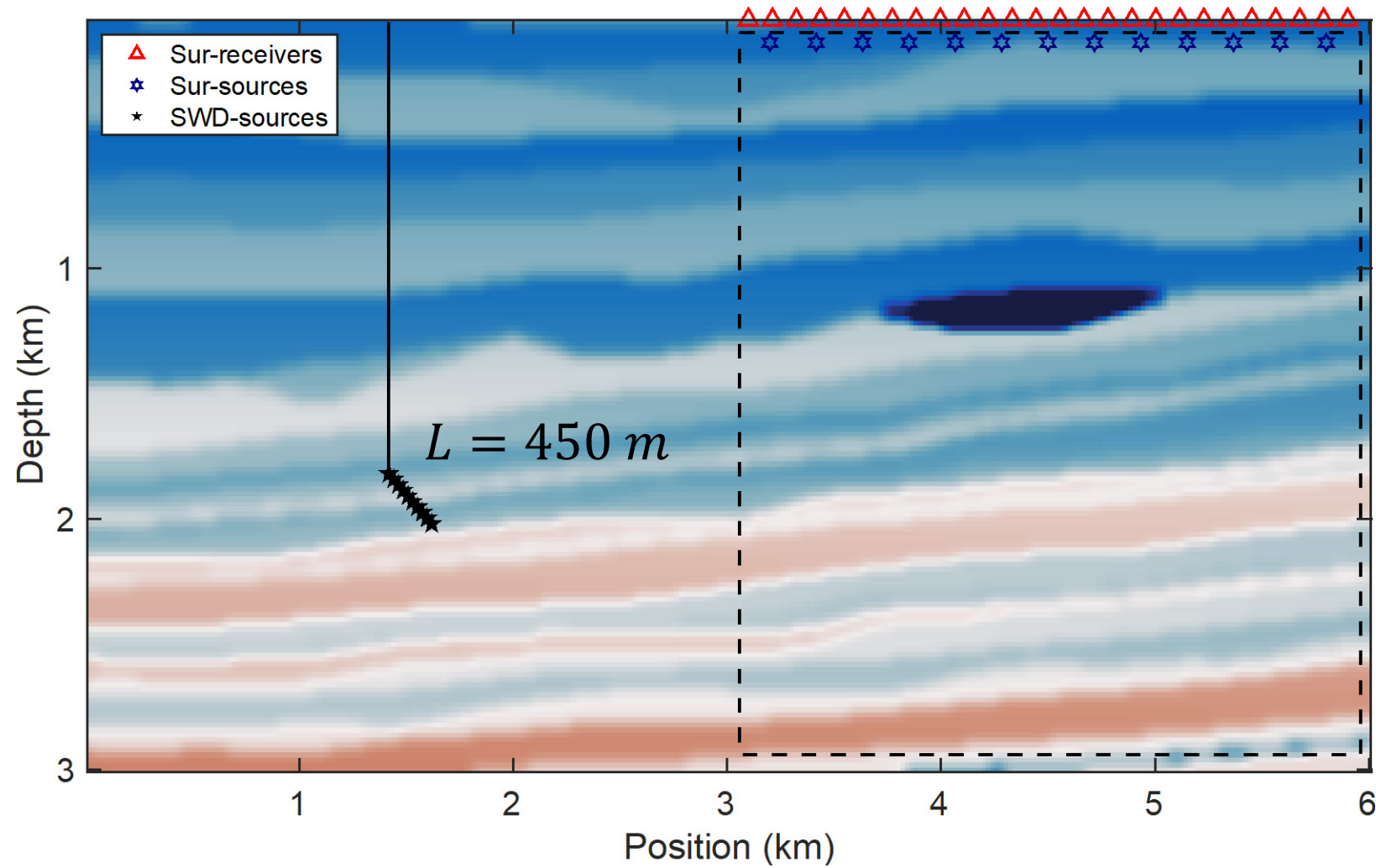
Appendix B:

Extension test



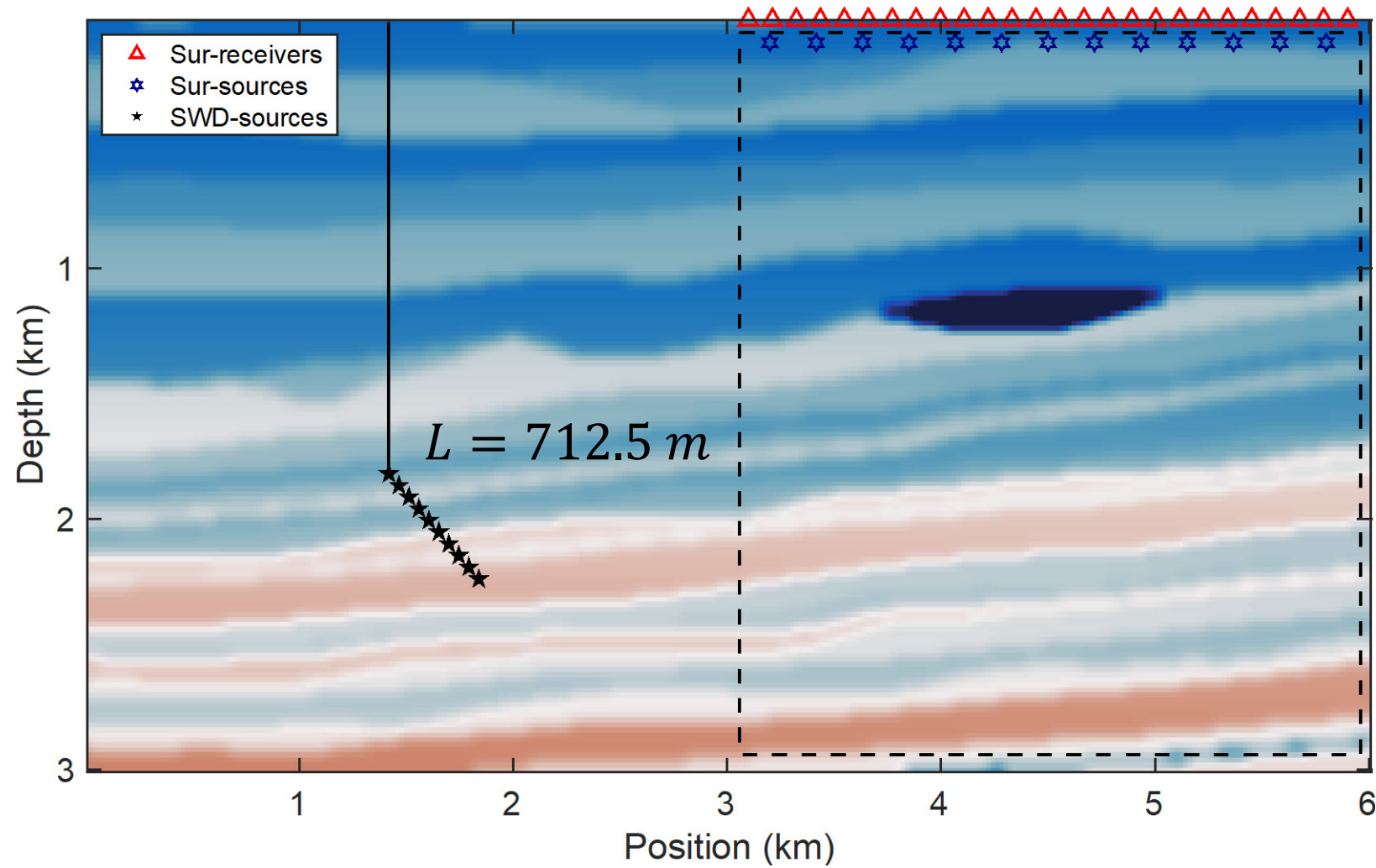
Extension test: schematic acquisition

72 explosive sources, 144 receivers





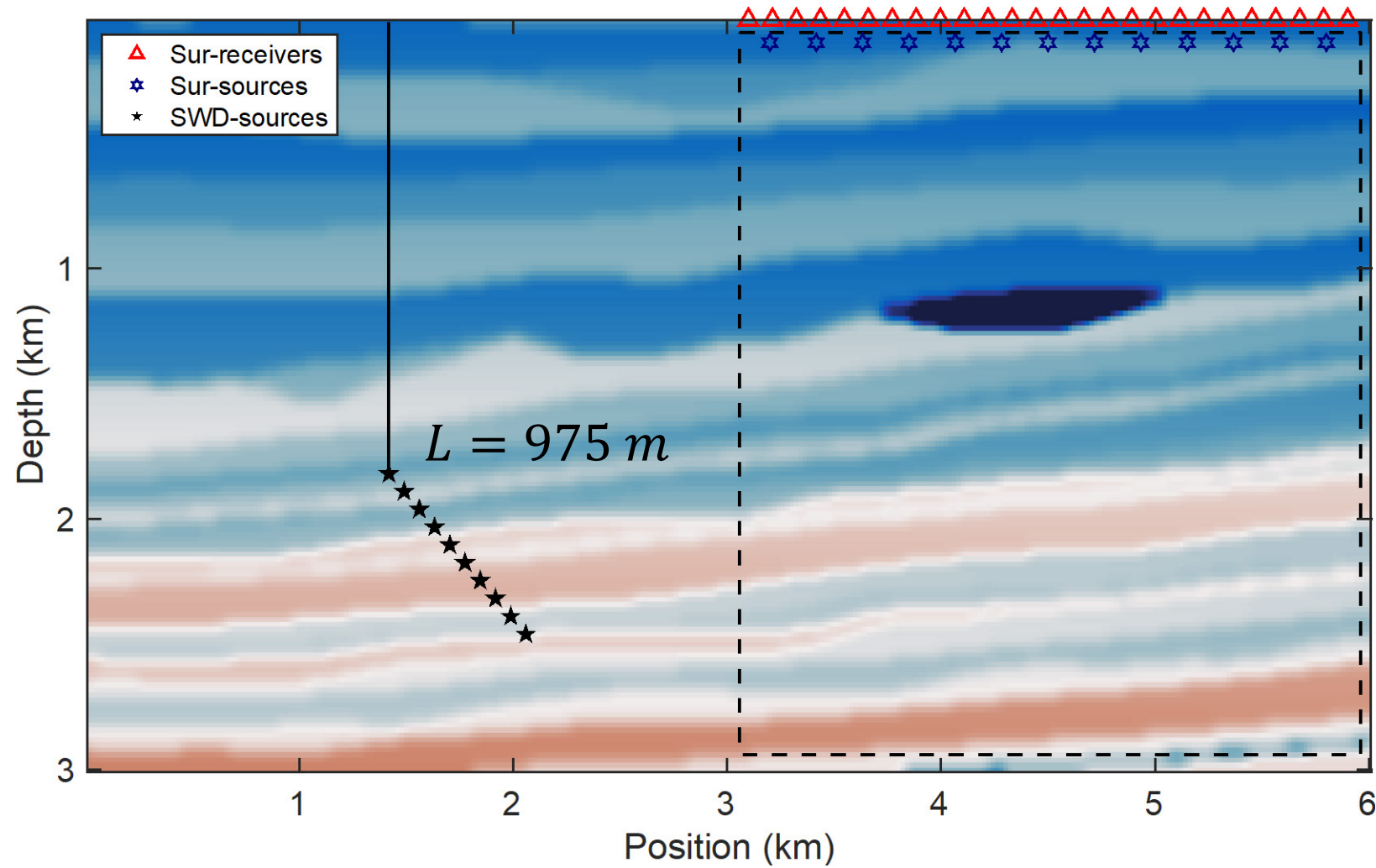
72 explosive sources, 144 receivers





Extension test: schematic acquisition

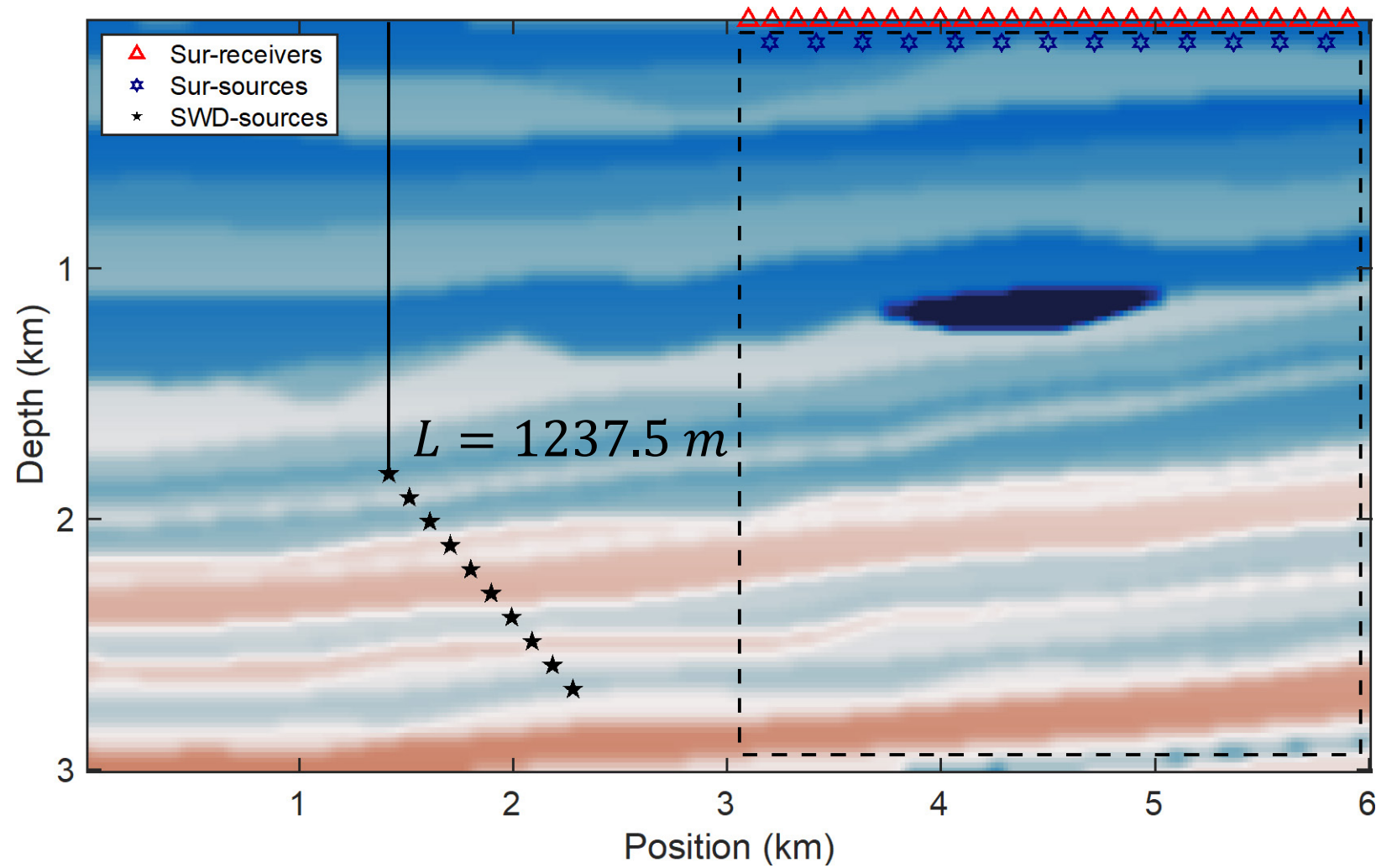
72 explosive sources, 144 receivers





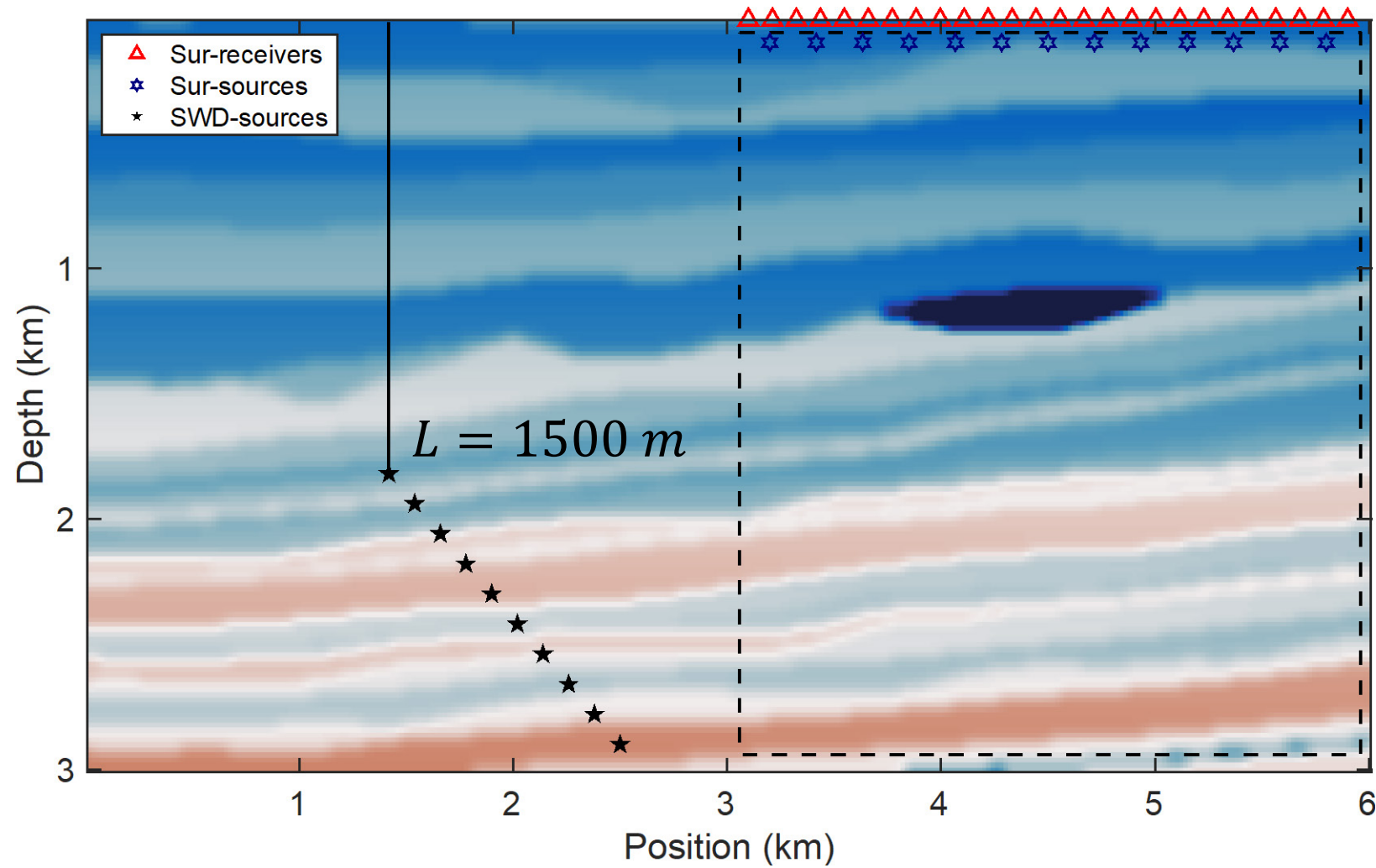
Extension test: schematic acquisition

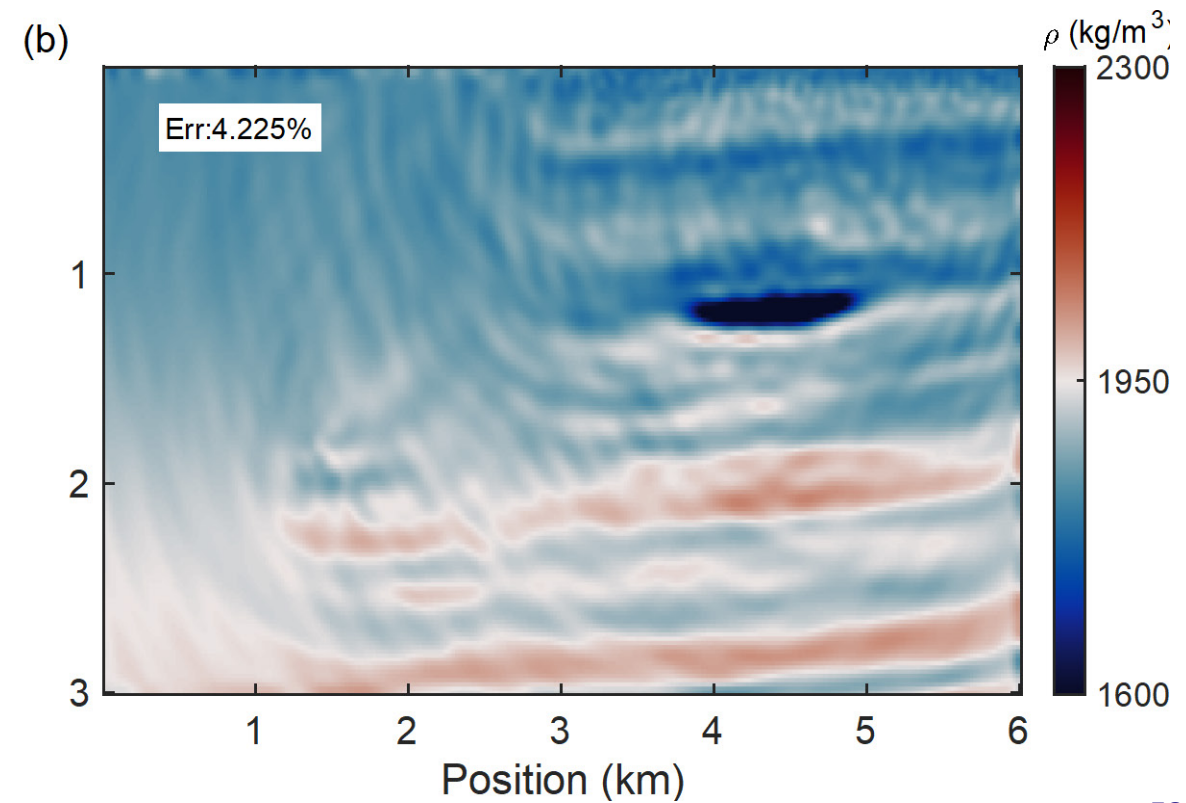
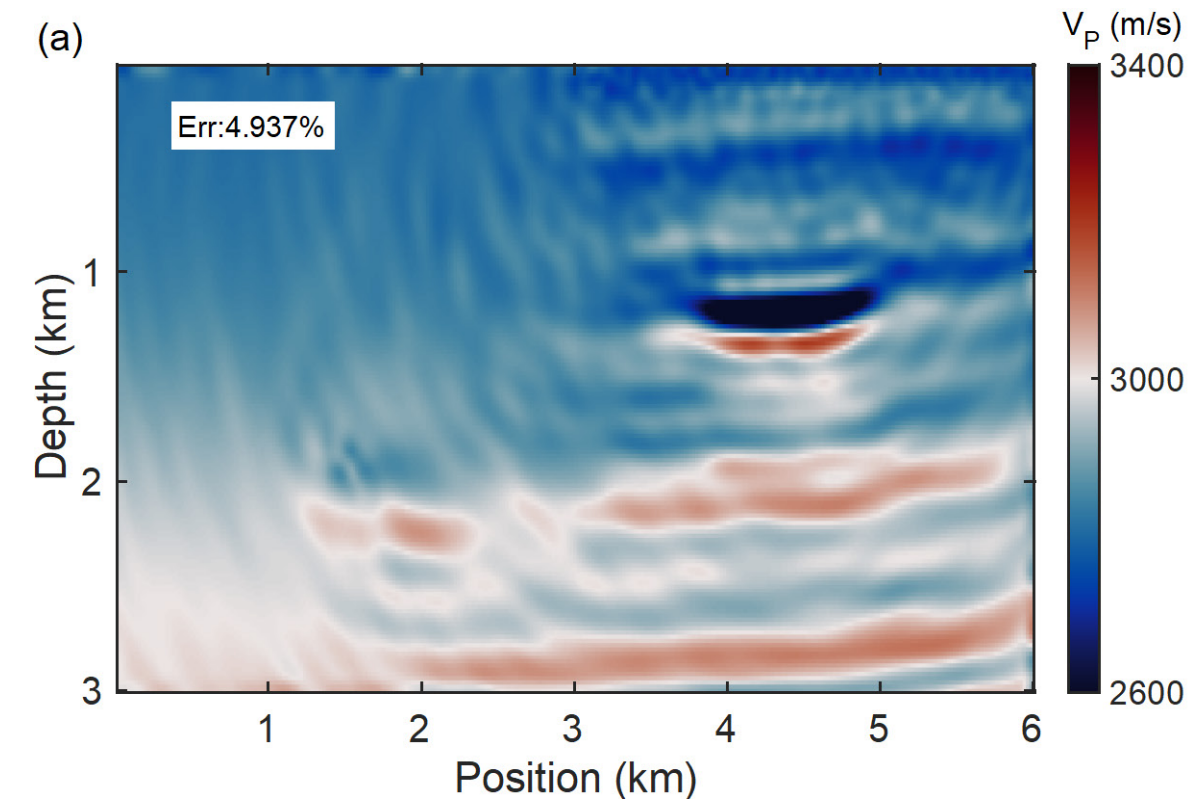
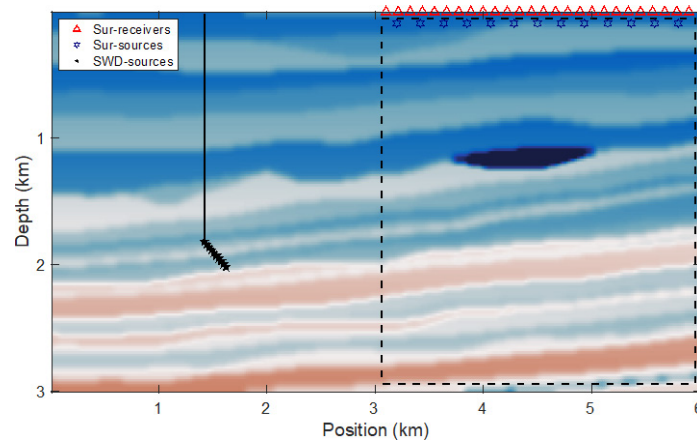
72 explosive sources, 144 receivers

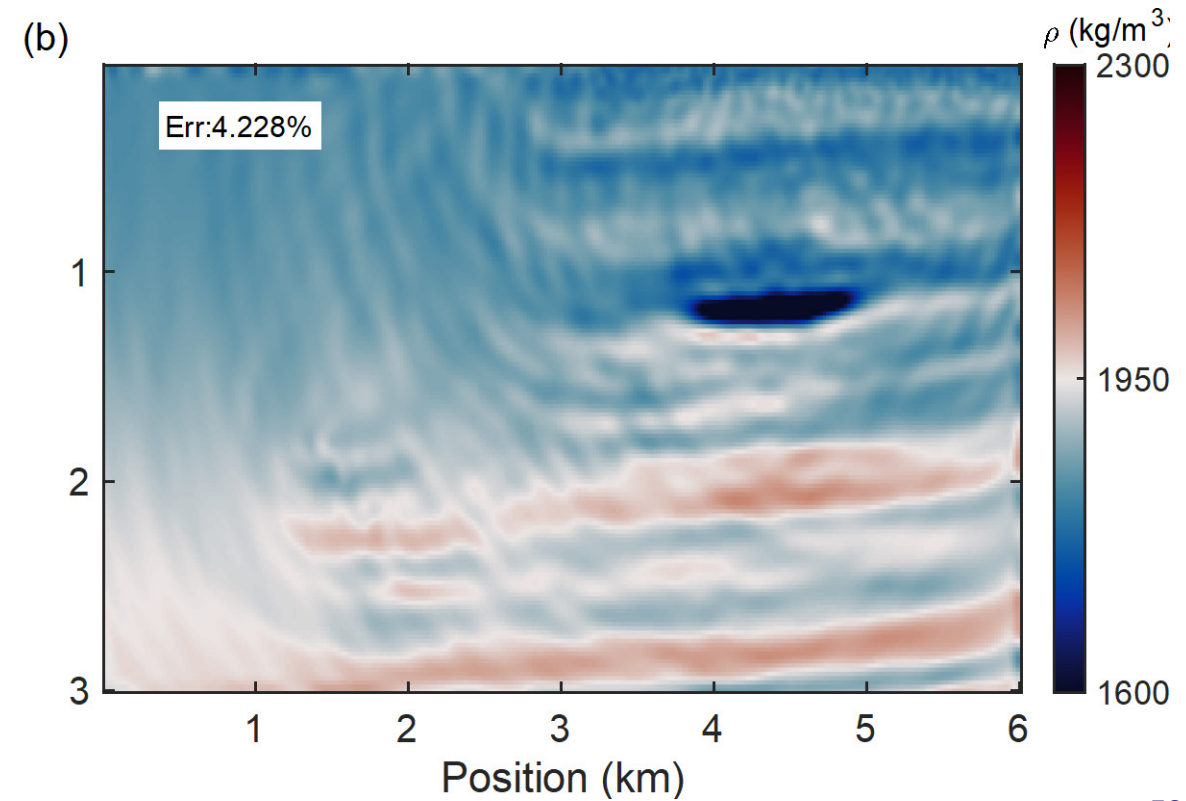
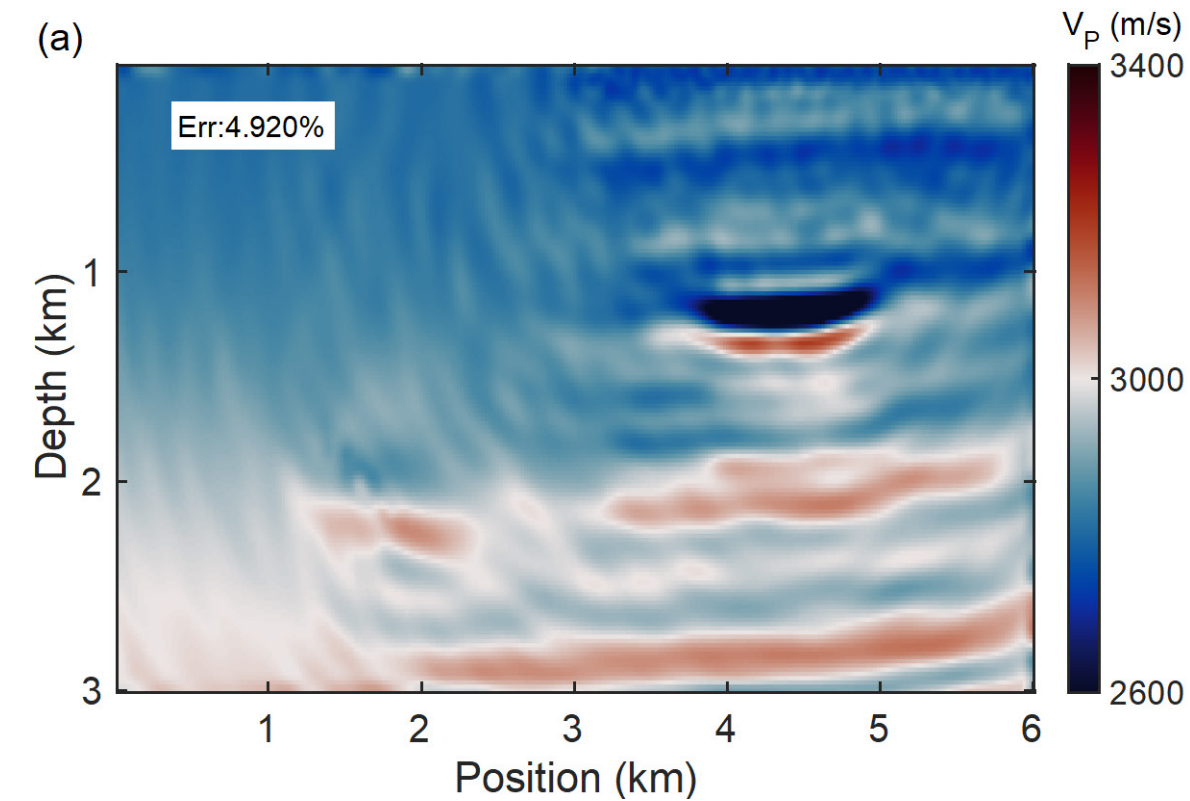
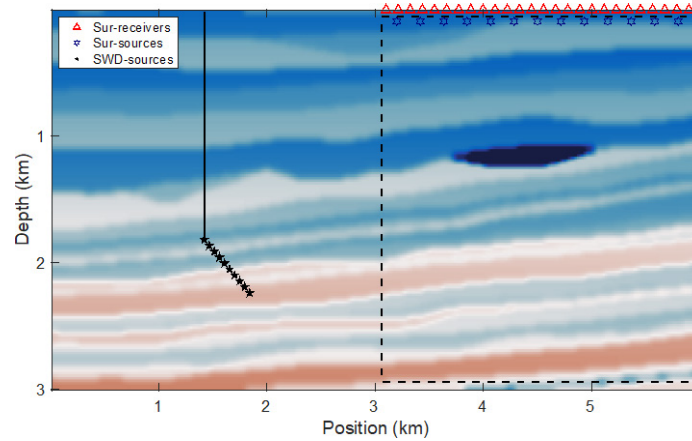


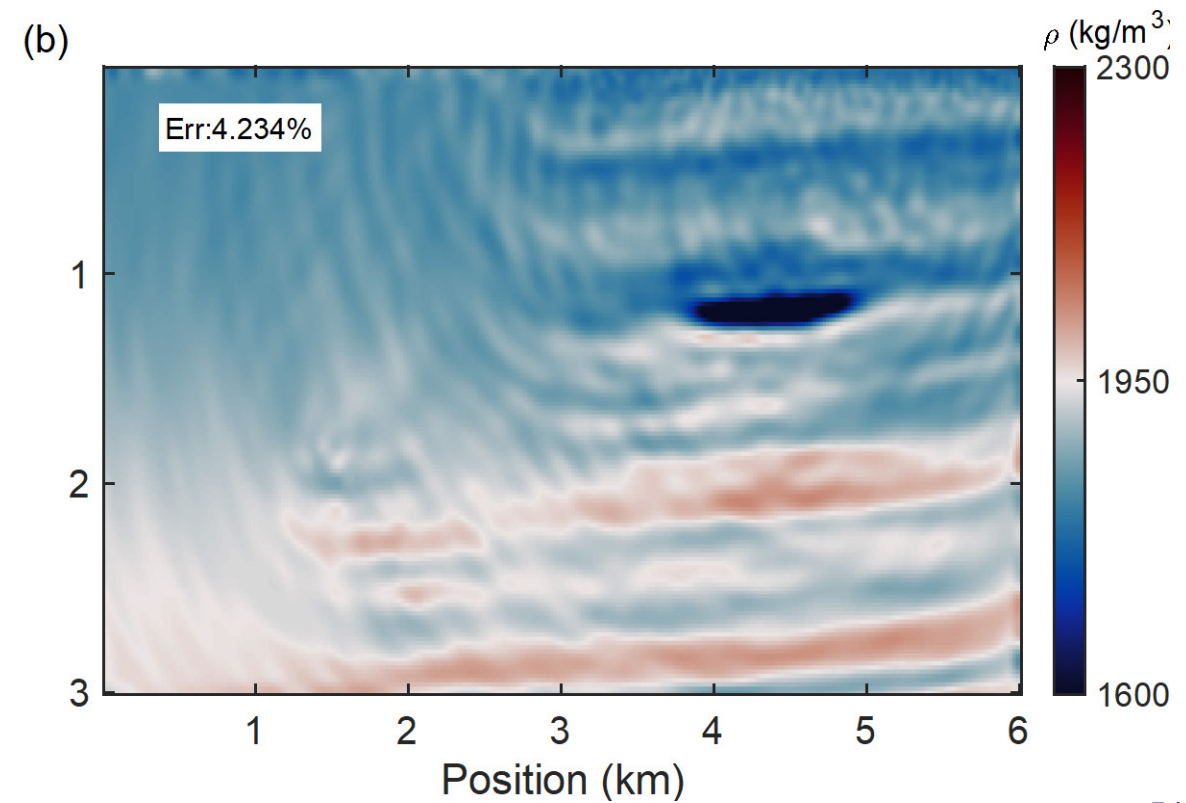
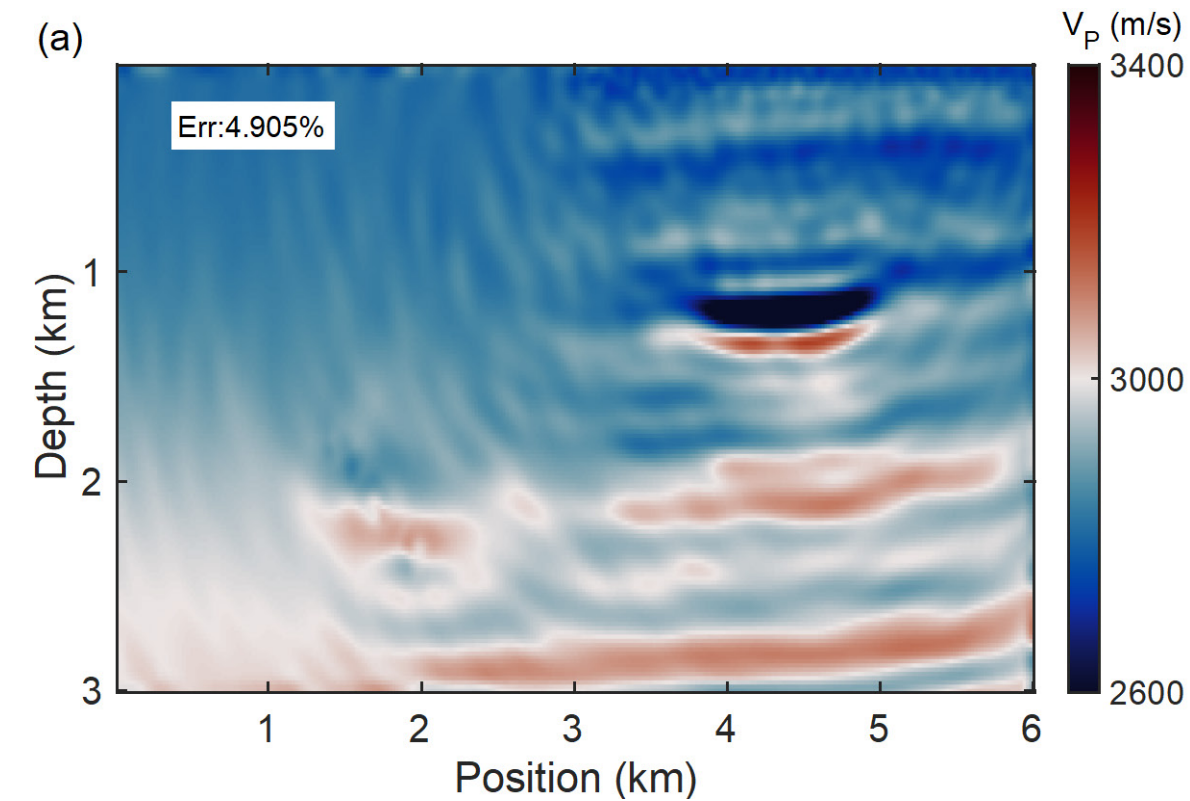
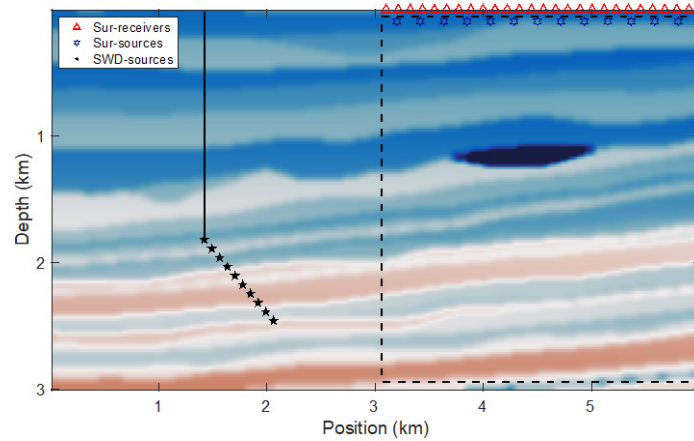


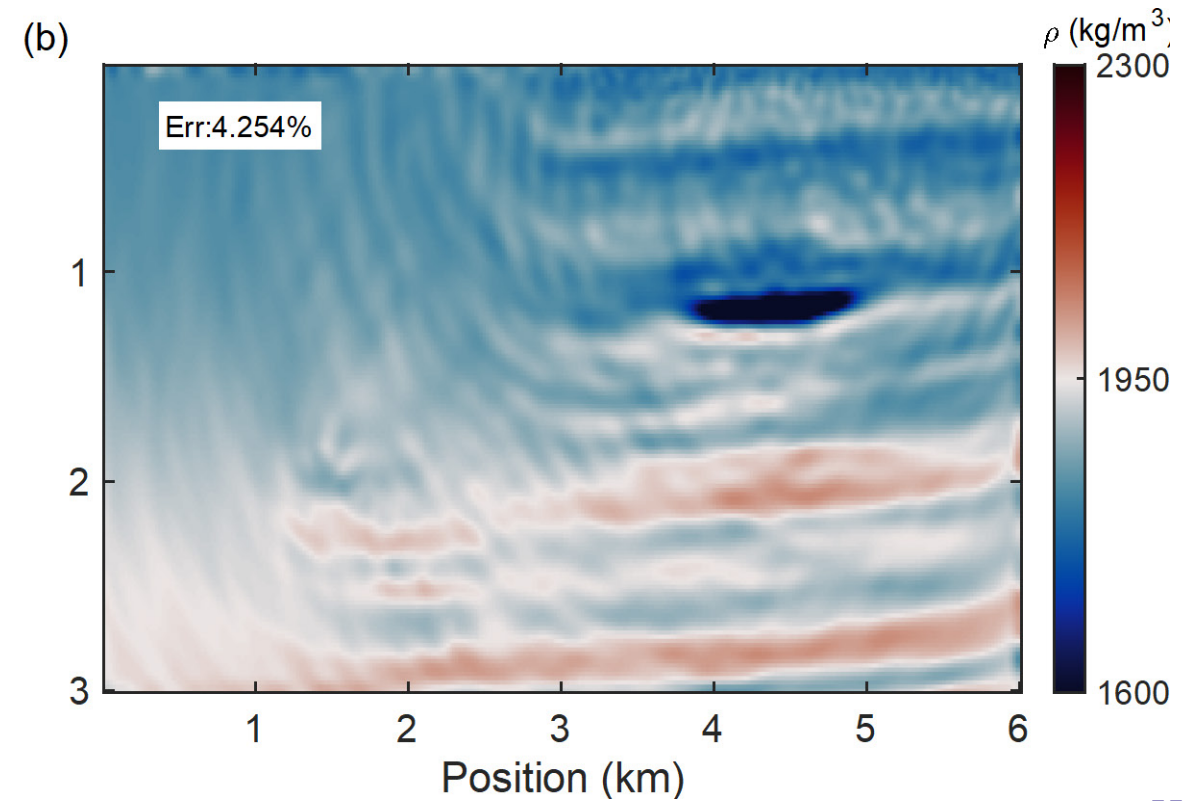
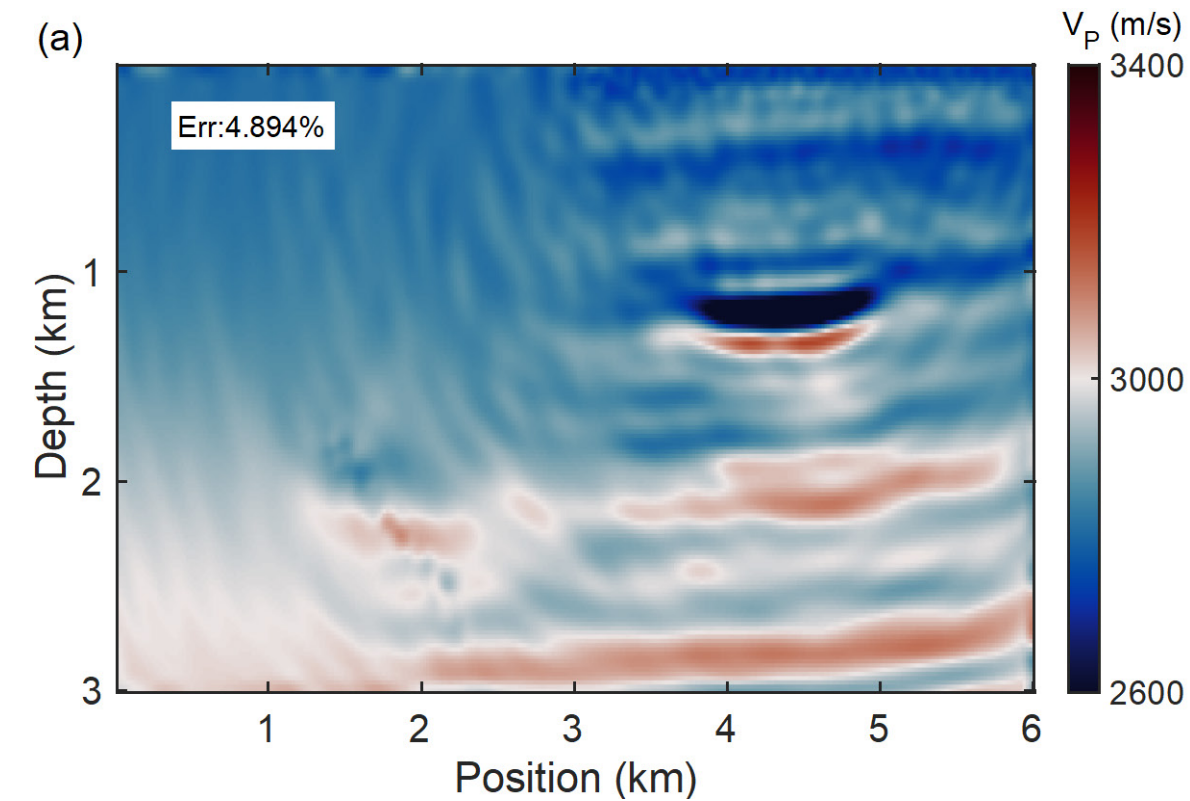
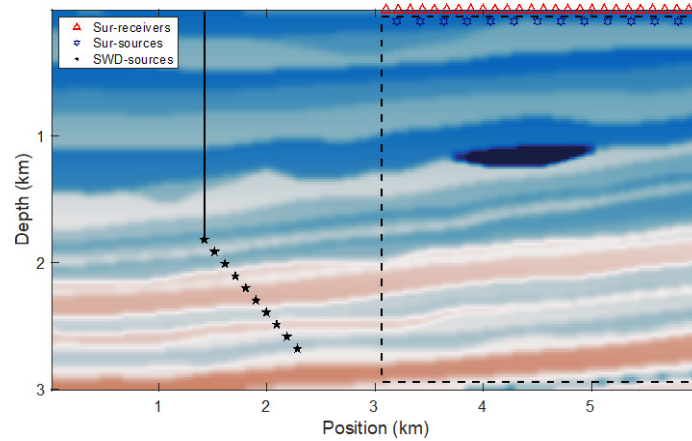
72 explosive sources, 144 receivers



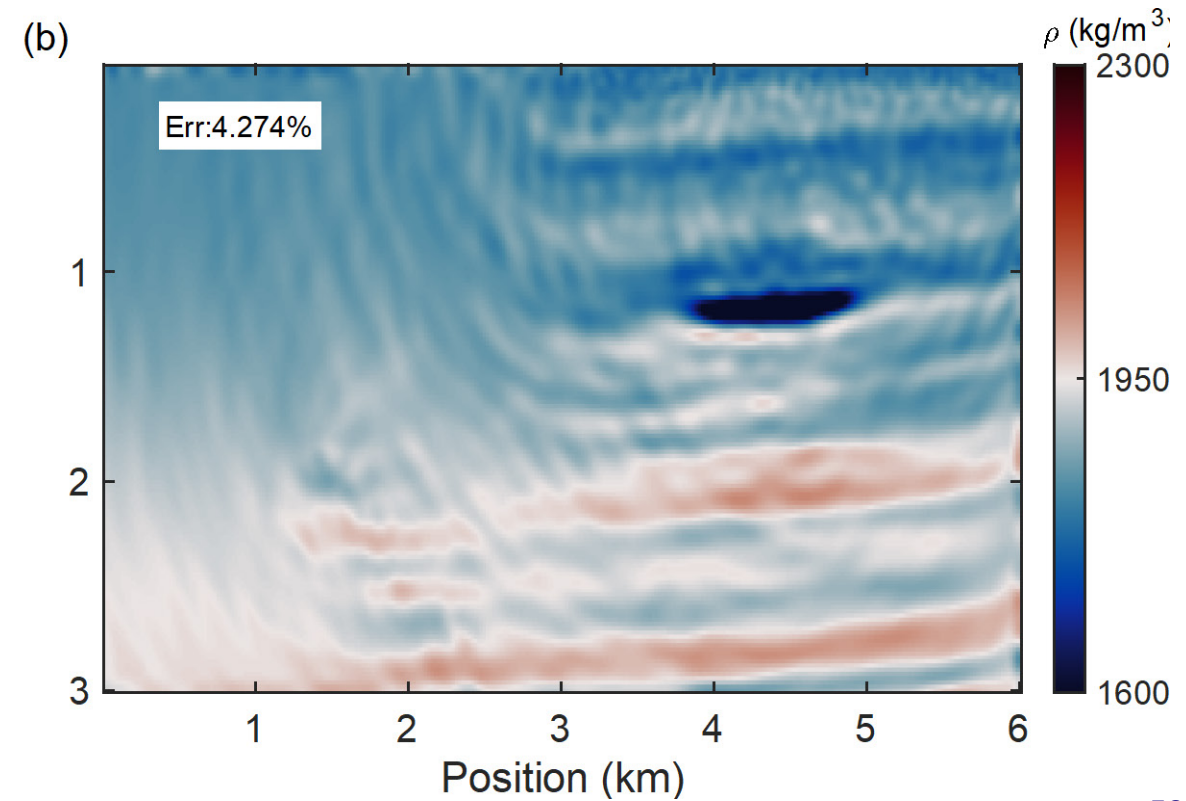
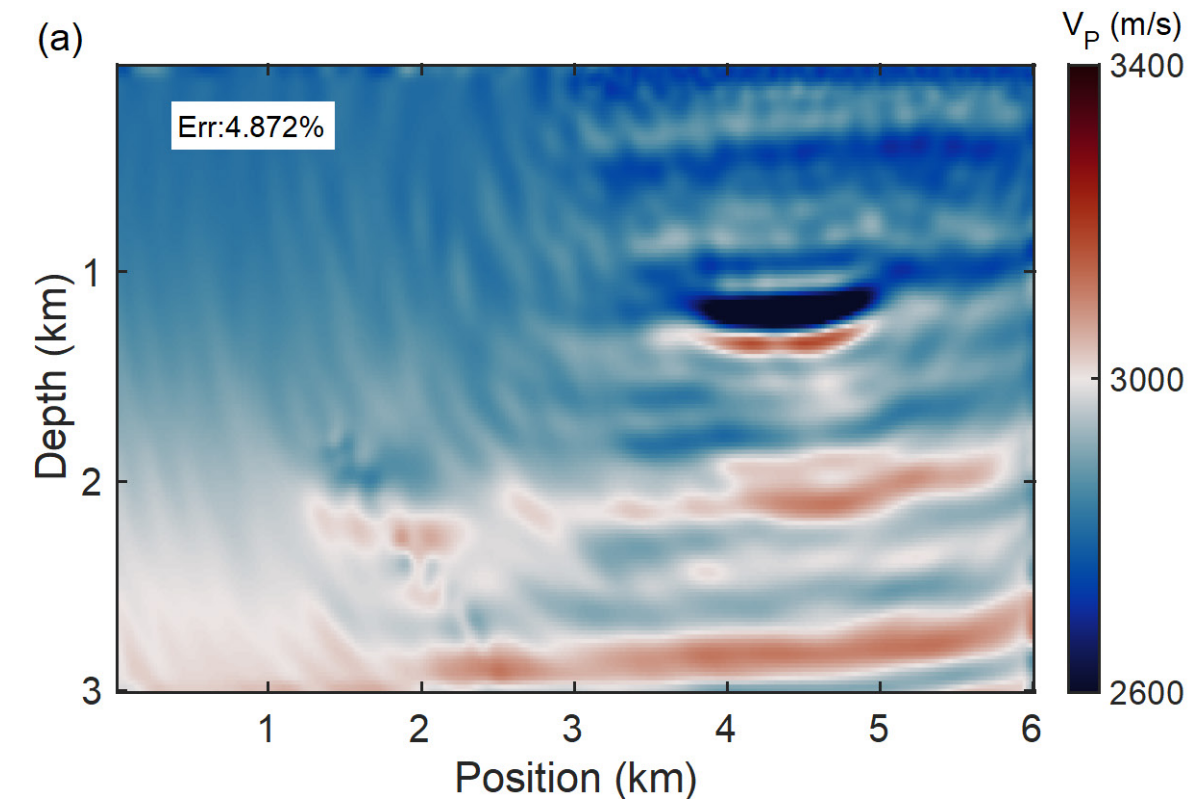
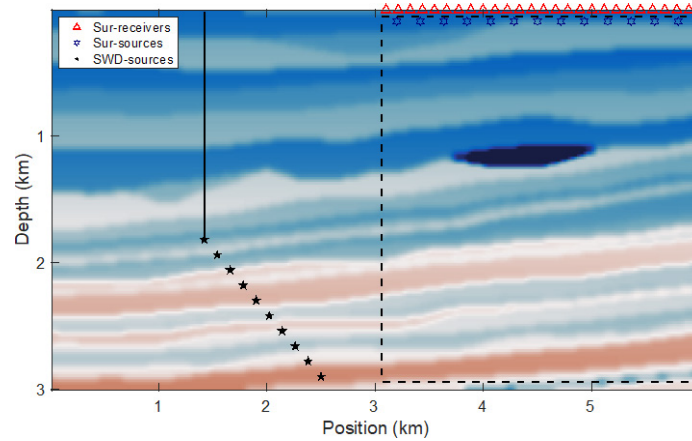






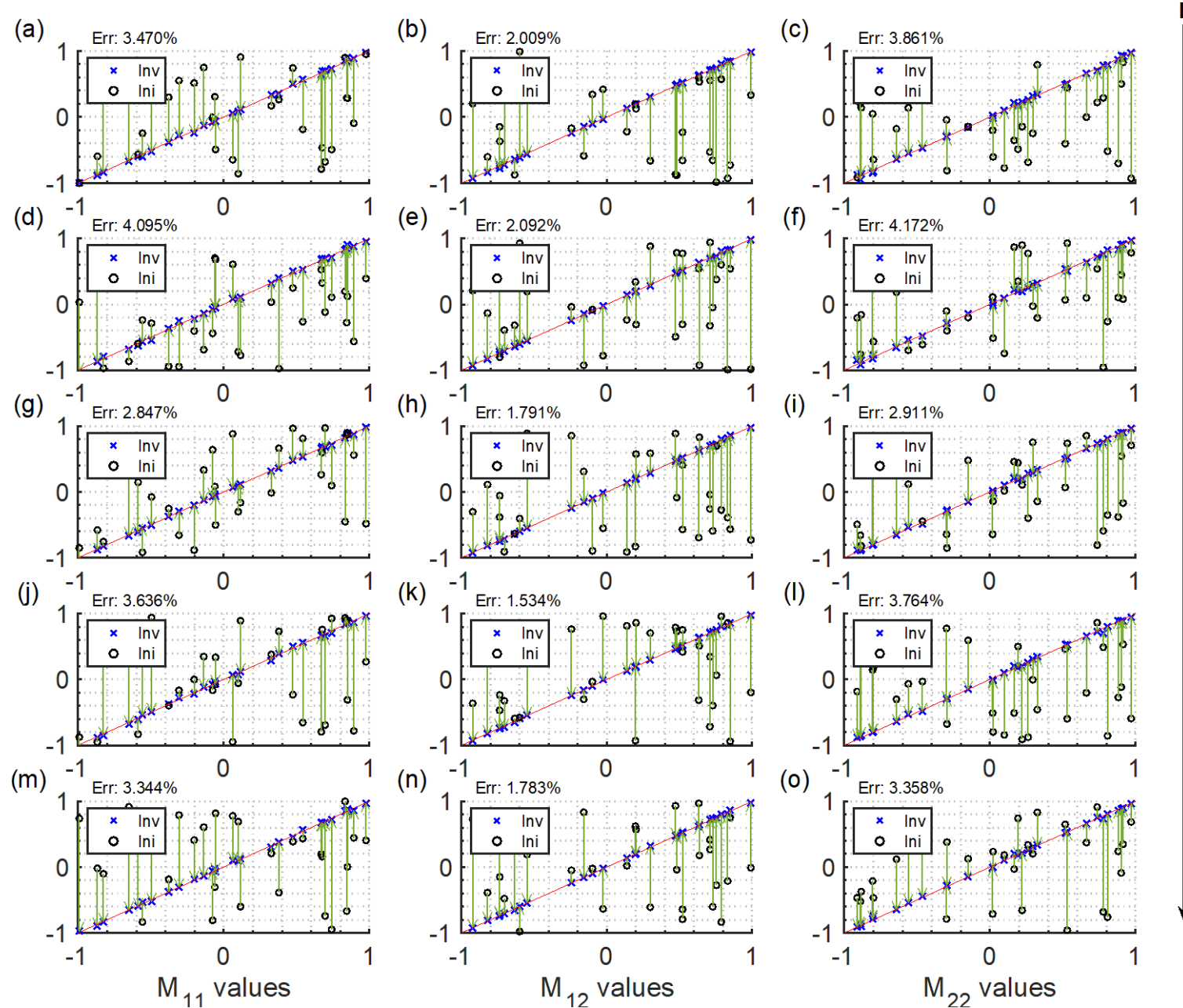


Extension test: wider aperture





Extension test: stable MT inversion





Appendix C:

Frequency components test

72 explosive sources, 144 receivers

