Optimization of Ultra Sparse Acquisition and Advanced 4D Imaging for Monitoring of the Sleipner CO_2 Plume

F. Oggioni*, M. Ledger, S. Hou, S. Hollingworth, and F. Barracano

Search and Discovery Article #80760 (2026)**
Posted April 28, 2026

*Adapted from extended abstract based on oral presentation given at CCUS (Carbon Capture, Utilization, and Storage Conference), Woodlands, Texas, March 30 - April 1, 2026.
 DOI:10.1306/80760Oggioni2026

Abstract

Developing strategies that balance technical objectives with operational efficiency, while maintaining the ability to track CO_2 movement and verify long-term storage security, is a key challenge in carbon storage monitoring. In this paper, we explore the potential of an automated workflow for optimizing Ocean Bottom Node (OBN) surveys using field data from the latest 2023 high density survey at the Sleipner storage site in Norway. Our novel workflow delivers a cost-effective 4D seismic solution, maintaining high-quality imaging results for both assessing CO_2 conformance and ensuring secure containment.

The 2023 OBN seismic survey used by Guzman et al. (2025) for full-wavefield imaging (FWI) of the Sleipner CO_2 plume was acquired with a 300x50m receiver geometry. This original geometry was decimated to a 300x300m grid for the purpose of this work and used as reference geometry, and a FWI workflow was run up to a maximum frequency of 14Hz. The optimization algorithm was then applied to this reference geometry to identify the optimal, cost-effective subset of nodes and their position, for plume 4D monitoring. The selected subset of nodes (50 nodes) was then used as input to 14Hz FWI and 4D attributes were compared to those from reference 300x300m grid (318 nodes).

The optimized decimated receiver carpet yields a high-quality image of the CO_2 plume, with 4D attributes comparable to those of the full node grid test, demonstrating that FWI using 15% of the nodes (50 vs 318 nodes) achieves an optimal balance between image quality and computational cost. The results of the decimated nodes test were also compared to the full-density update (300m x 50m spacing) showing a comparable update of the CO_2 anomaly while utilizing only 5% of the total nodes (50 vs >900 nodes). Furthermore, shot decimation tests were performed on both dense and optimized node grids, showing how optimized node geometry can be used in conjunction with a sparser shot carpet, while still delivering high quality 4D results.

Ultra-sparse acquisition geometries, when combined with advanced full-wavefield imaging techniques, demonstrate the potential for jointly recovering the 4D CO_2 response and imaging the overburden, which is essential for plume conformance and containment. This approach has the potential to enable operators to meet regulatory technical requirements while minimizing acquisition costs.

References

Gardner, G.H.F., Gardner L.W. and Gregory A.R. [1974] Formation velocity and density - the diagnostic basics for stratigraphic traps. Geophysics 39: 770–780.

Martinez R., Vinje V., Moore H. and Hollingworth S. [2025] Full-wavefield imaging the Sleipner CO_2 plume using multi-azimuth OBN data. 86th EAGE Annual Conference & Exhibition, Jun 2025.

Oggioni F., Ledger M., Porjesz R., Hou S., Hollingworth S. and Barracano F. [2025a] Ultra sparse node optimization for CO_2 monitoring and containment, First EAGE Workshop on Geophysical Techniques for Monitoring CO_2 Storage

Oggioni F., Ledger M., Porjesz R., Hou S., Hollingworth S. and Barracano F. [2025b] Optimization of ultra sparse acquisition and advanced 4D imaging for CO_2 monitoring, Sixth EAGE Global Energy Transition Conference & Exhibition (GET 2025).

SPE · AAPG · SEG

CCUS

Carbon Capture, Utilization, and Storage

Optimization of ultra sparse acquisition for monitoring of the Sleipner CO_2 plume

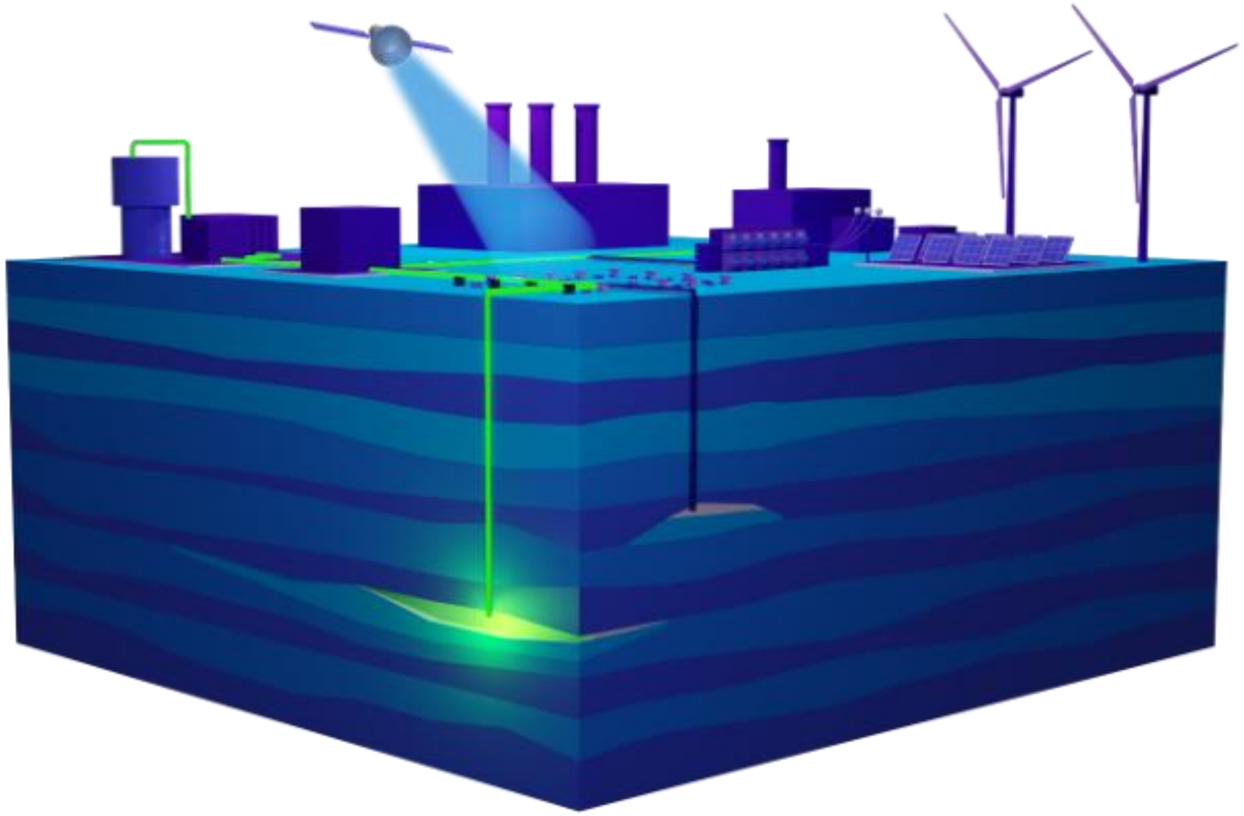
F. Oggioni*, M. Ledger, S. Hou, S. Hollingworth, F. Barracano

VIRIDIEN

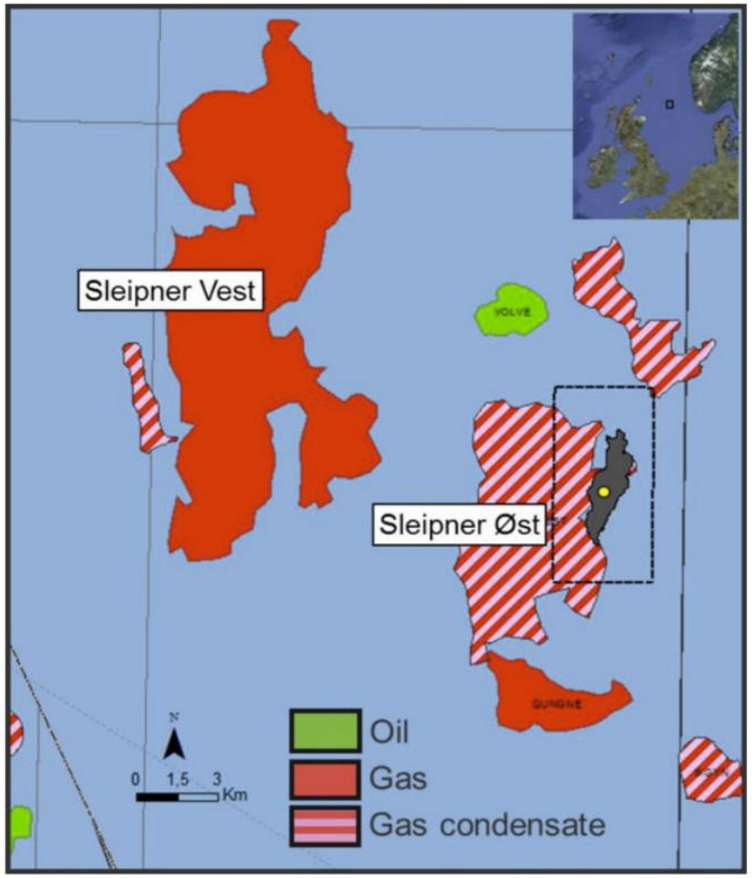
OUTLINE

CHALLENGES OF CO_2 MONITORING

- Conformance
- Containment
- Confidence
- Acquisition Cost



SLIEPNER CO_2 PLUME



Furre and Eiken (2014)

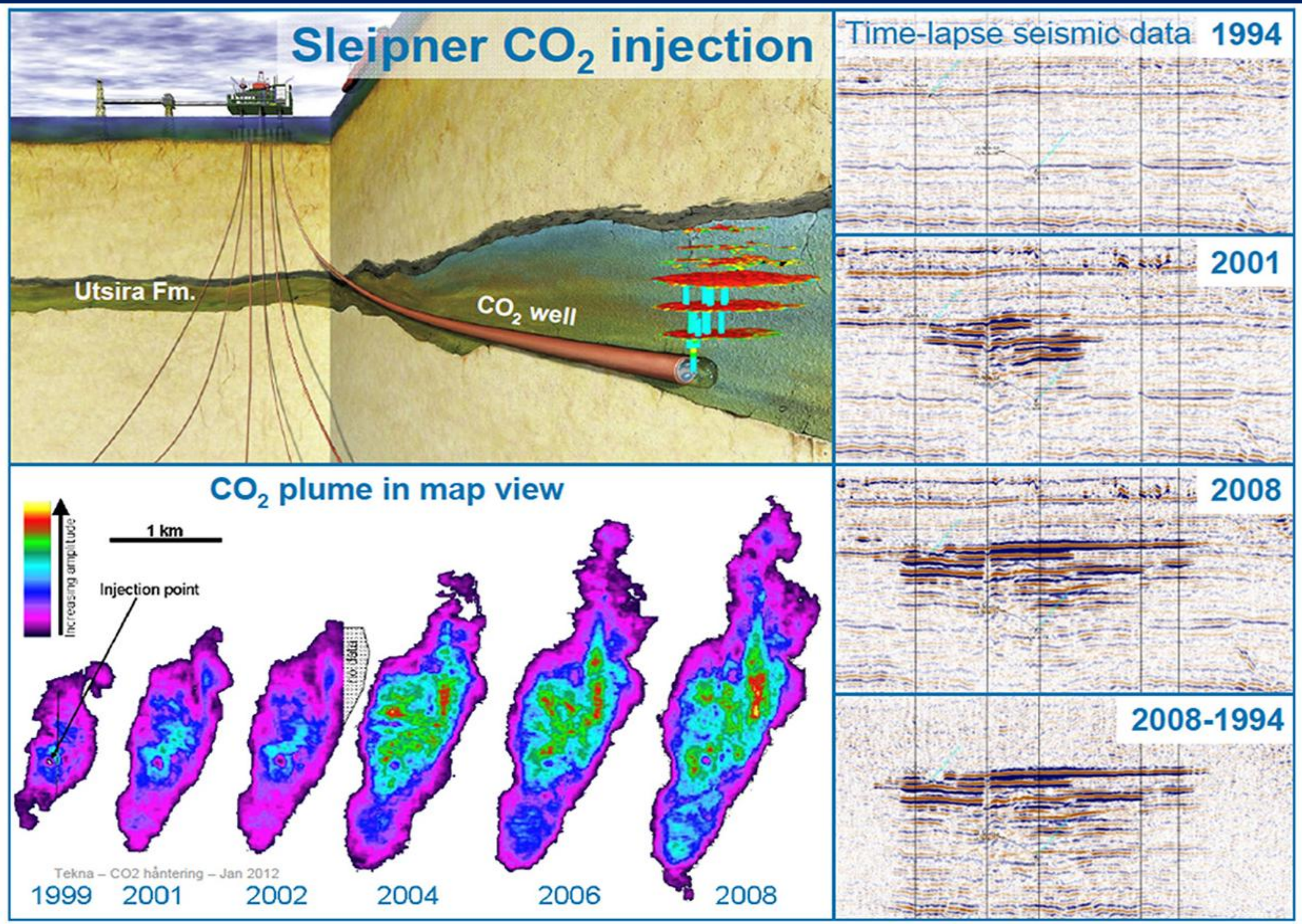
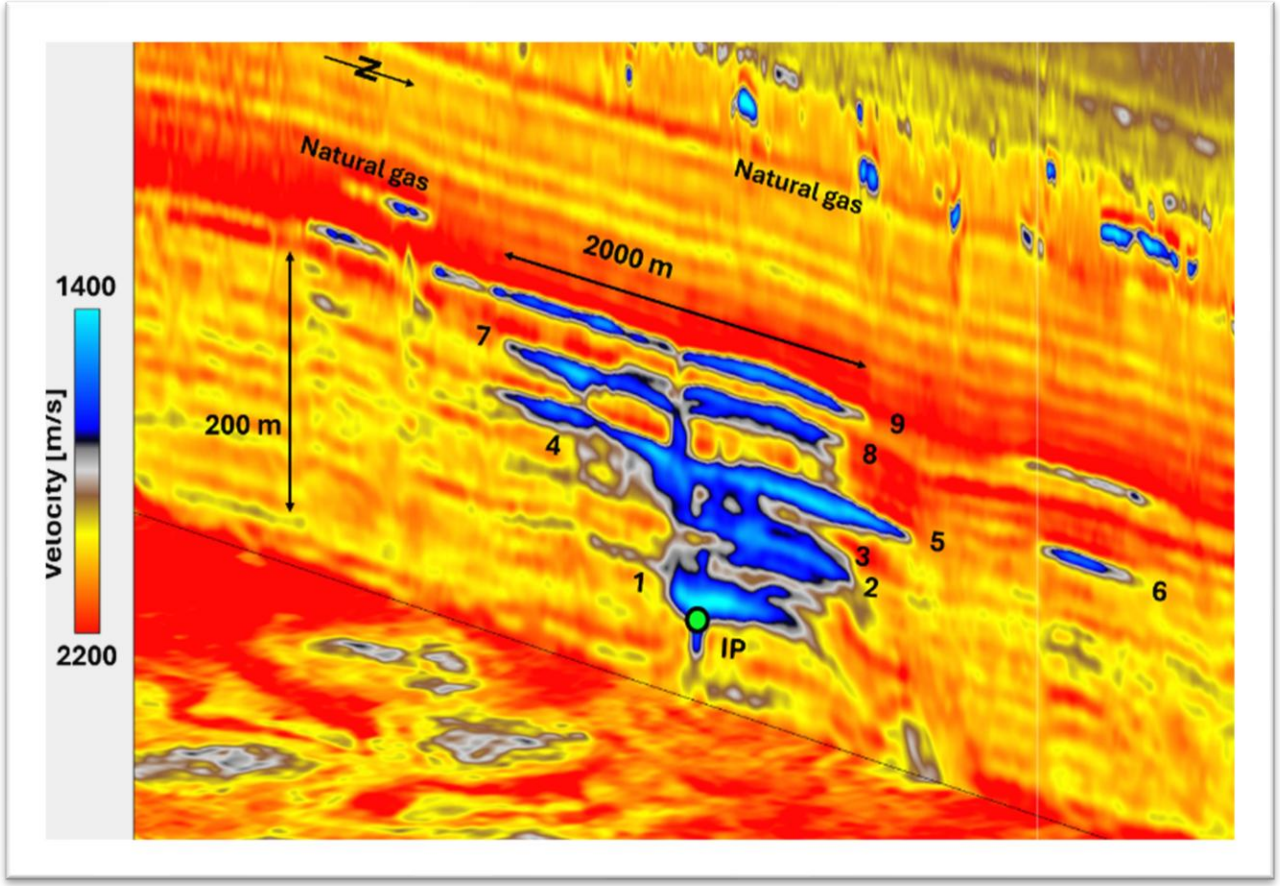
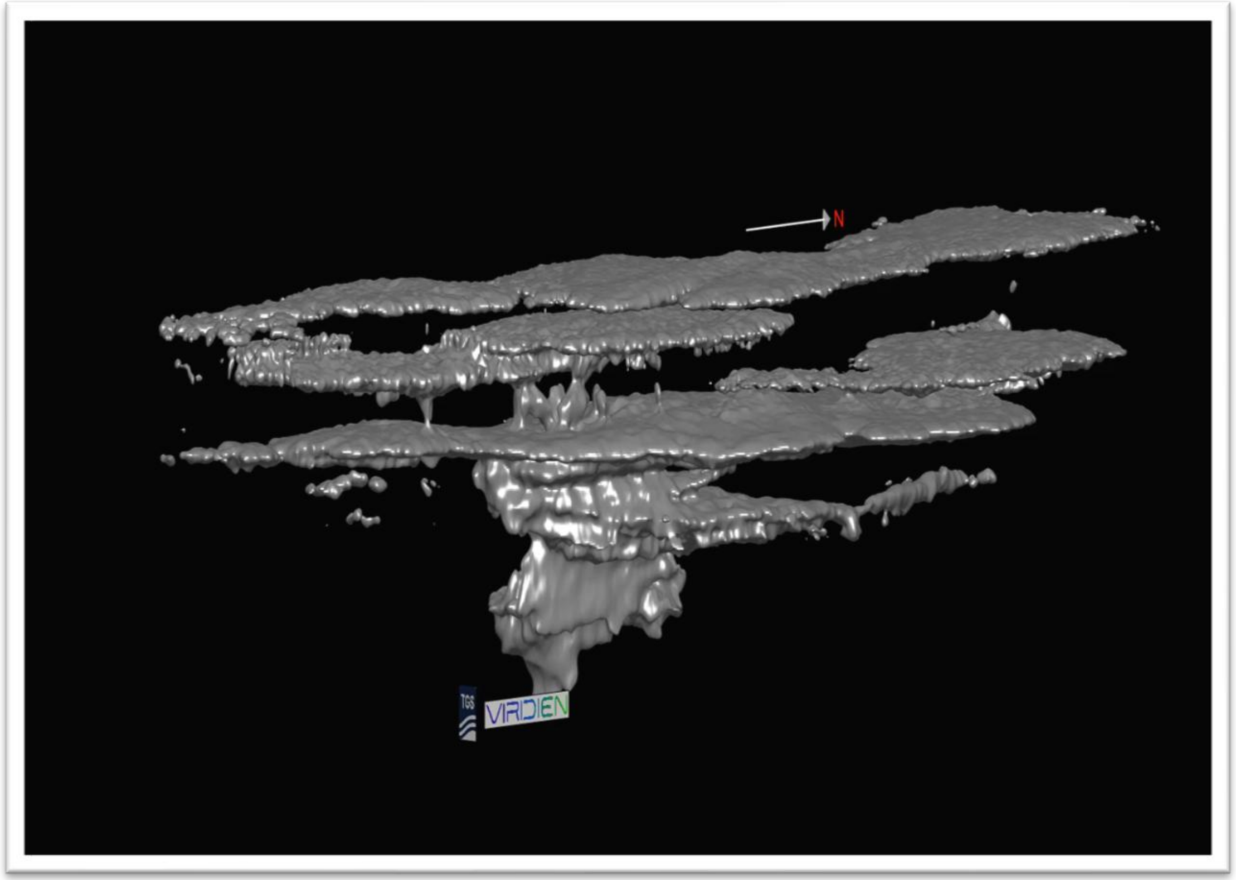


Image courtesy of Equinor ASA

How many nodes do we need to monitor the CO_2 plume?



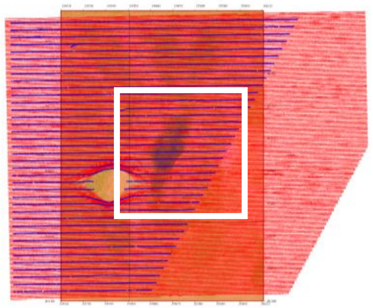


Martinez R., Vinje V., Moore H. and Hollingworth S. [2025] Full-wavefield imaging the Sleipner CO2 plume using multi-azimuth OBN data.
Martinez R., Vinje V. Moore H., Hollingworth S. and P. Ringrose [2025] FWI- based imaging of heterogenous aquifers: Insite from the Sleipner storage site.

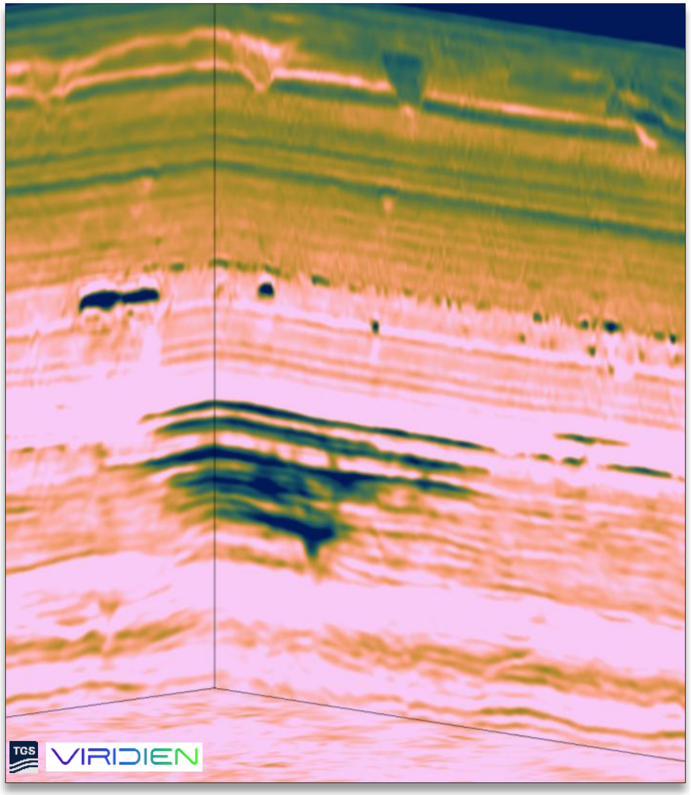
OPTIMIZATION WORKFLOW

Full FWI:
- 951 receivers
- Rec spacing 50X300m

Optimization test:
- 318 receivers
- Rec spacing 300X300m

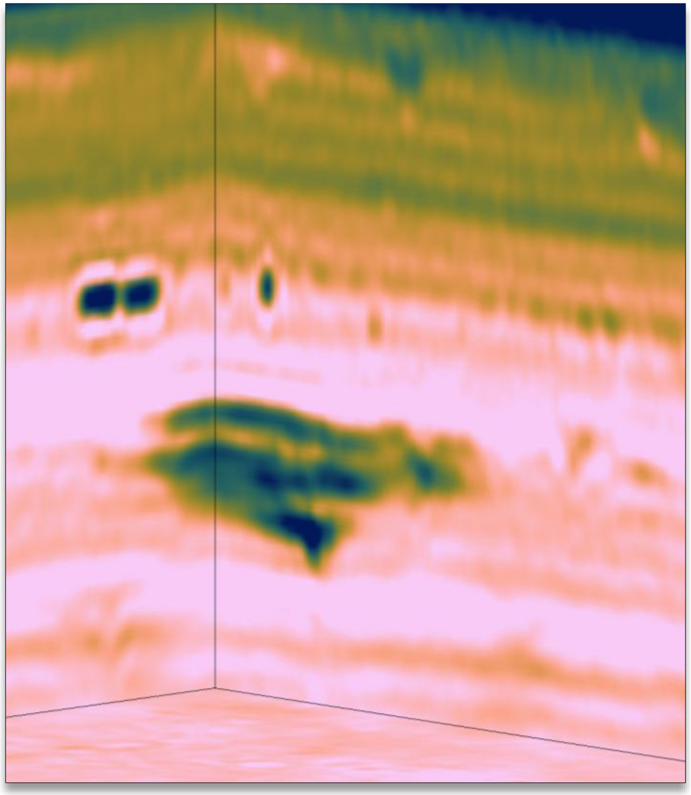


FWI @70Hz 50x300m receiver grid
(Martinez et al., 2025)



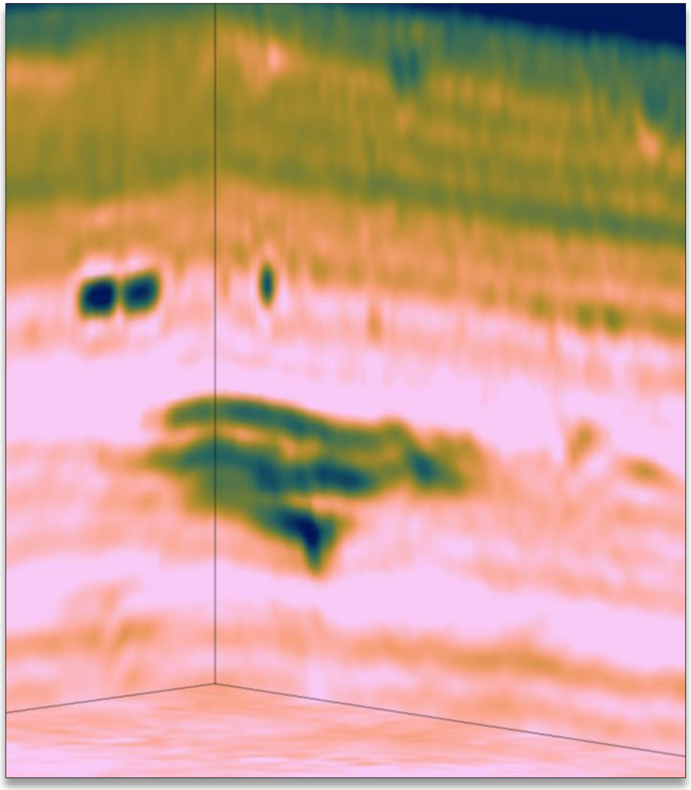
951 nodes

FWI @14Hz 100x300m receiver grid
(Martinez et al., 2025)



951 nodes

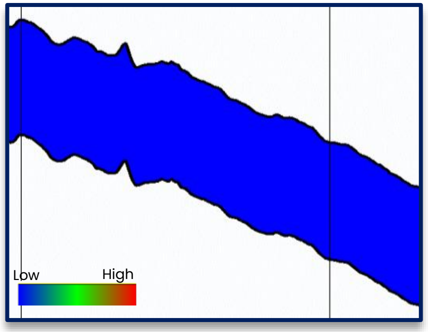
FWI @14Hz 300x300m receiver grid



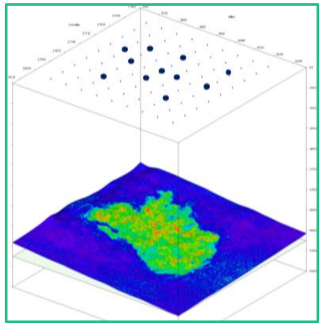
318 nodes

OPTIMIZATION WORKFLOW

Synthetic or Recorded data

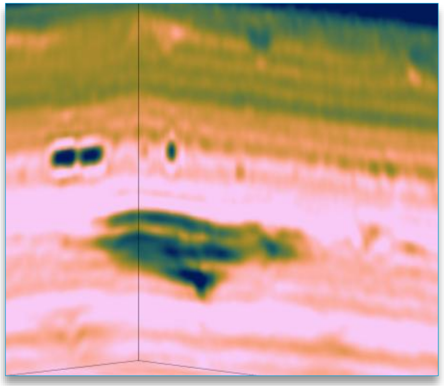


Design & Optimization



Field deployment

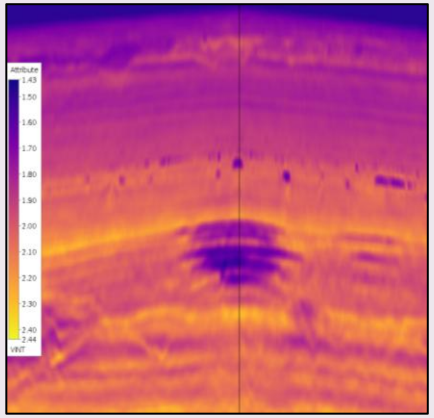
Data Imaging & 4D



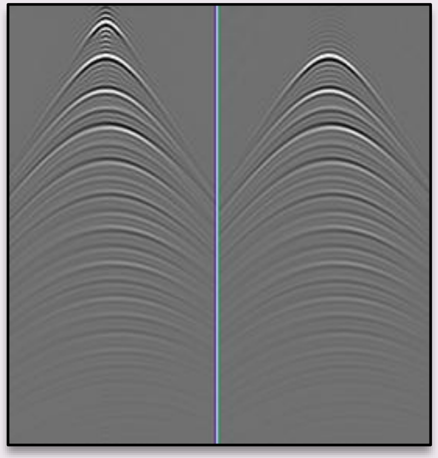
OPTIMIZATION WORKFLOW

Dense grid (synthetic or recorded) → **Imaging & Inversion** → **Attribute extraction** → **Node Selection**

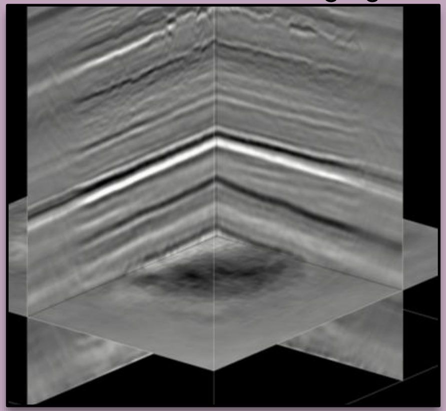
Elastic Properties



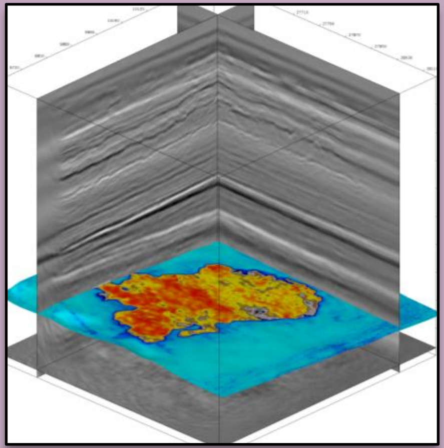
Recorded Data

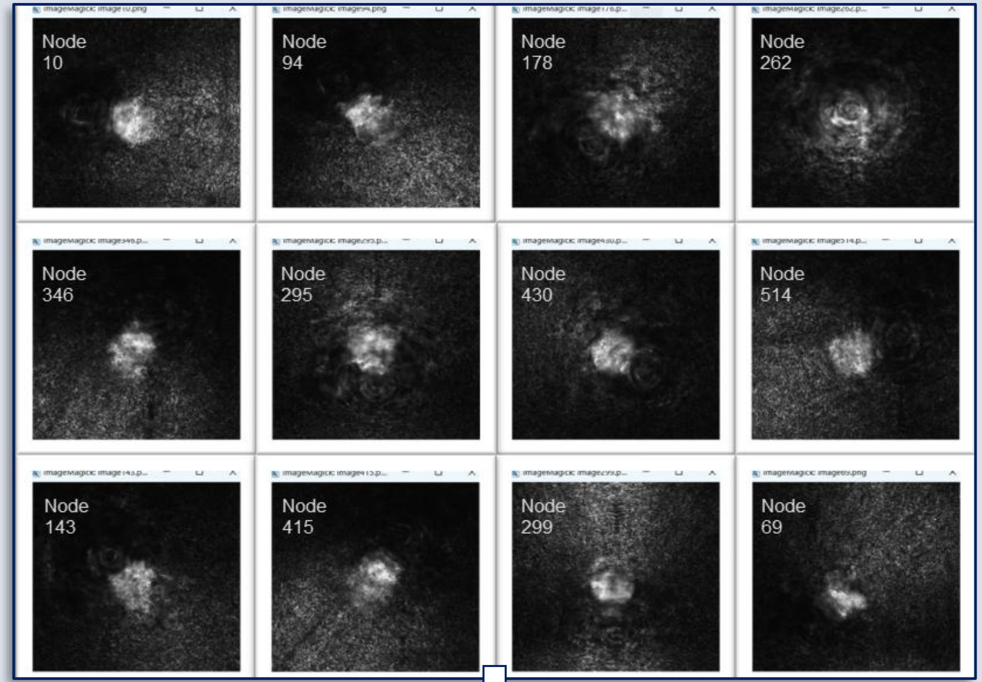


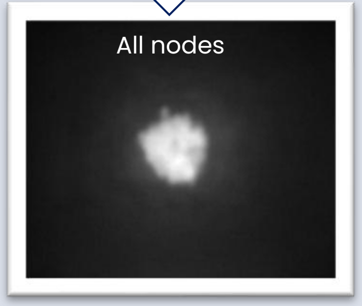
Full Wavefield Imaging



4D-FWI

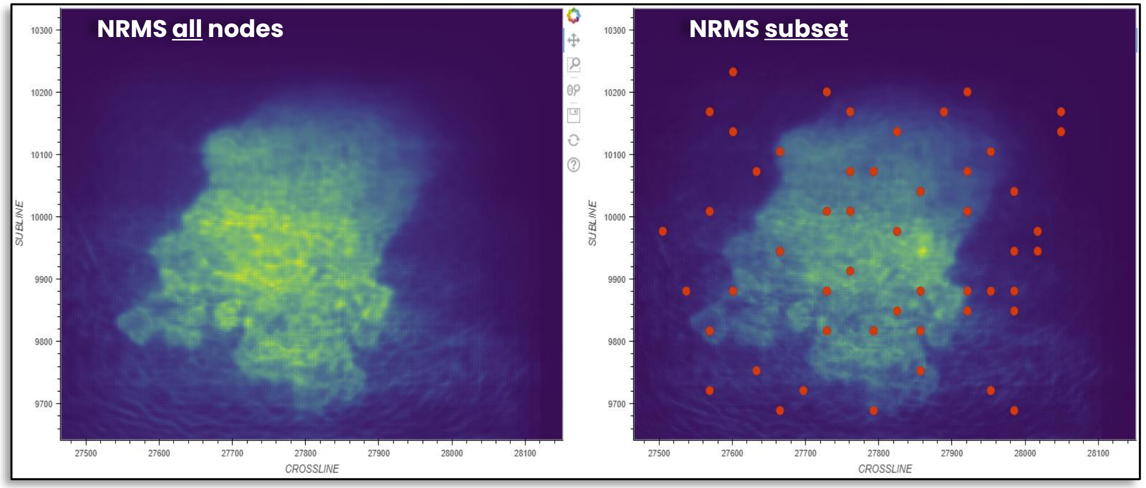


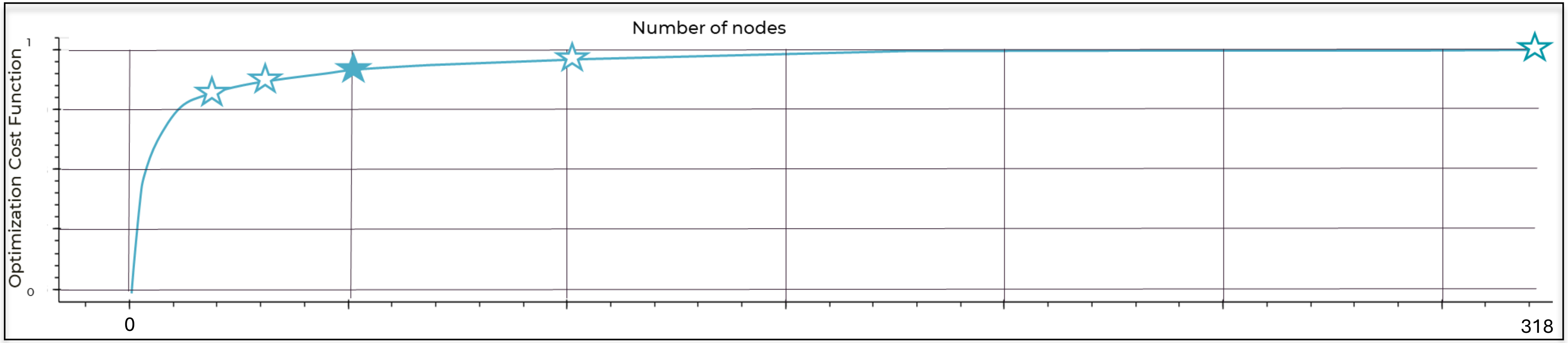




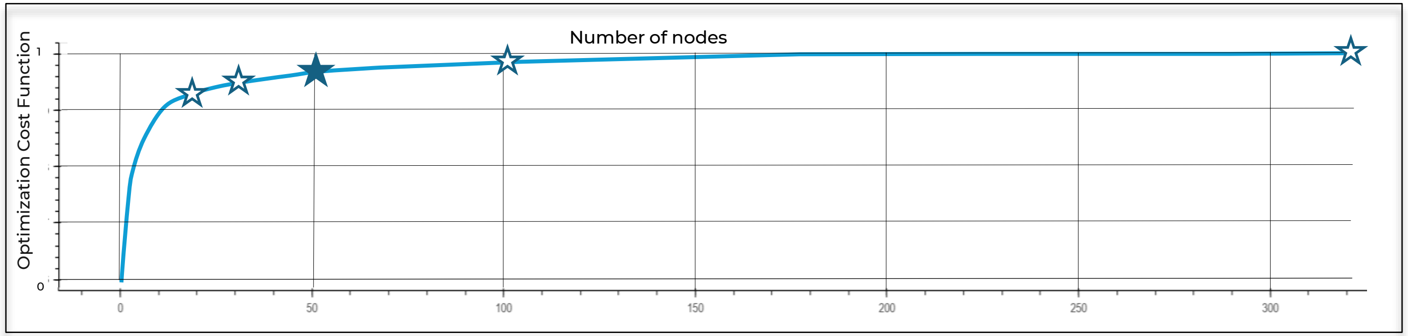
OPTIMIZATION WORKFLOW

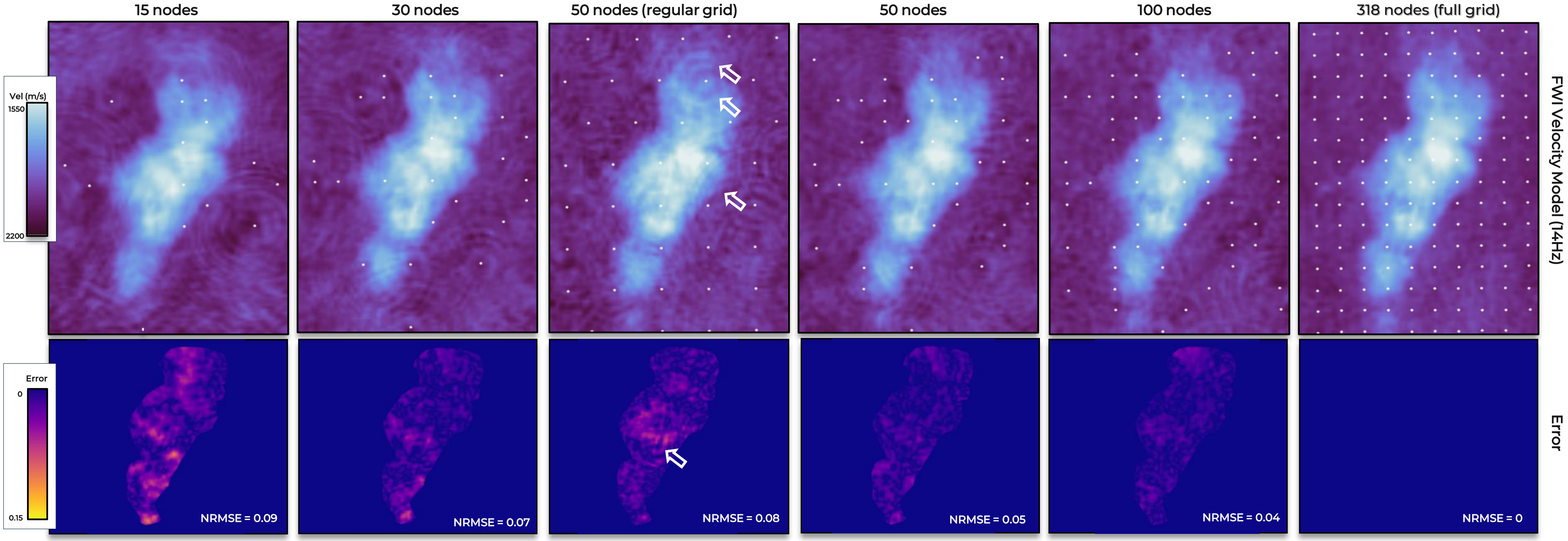
Dense grid (synthetic or recorded) → **Imaging & Inversion** → **Attribute extraction** → **Node Selection** → **Design Optimal Geometry**





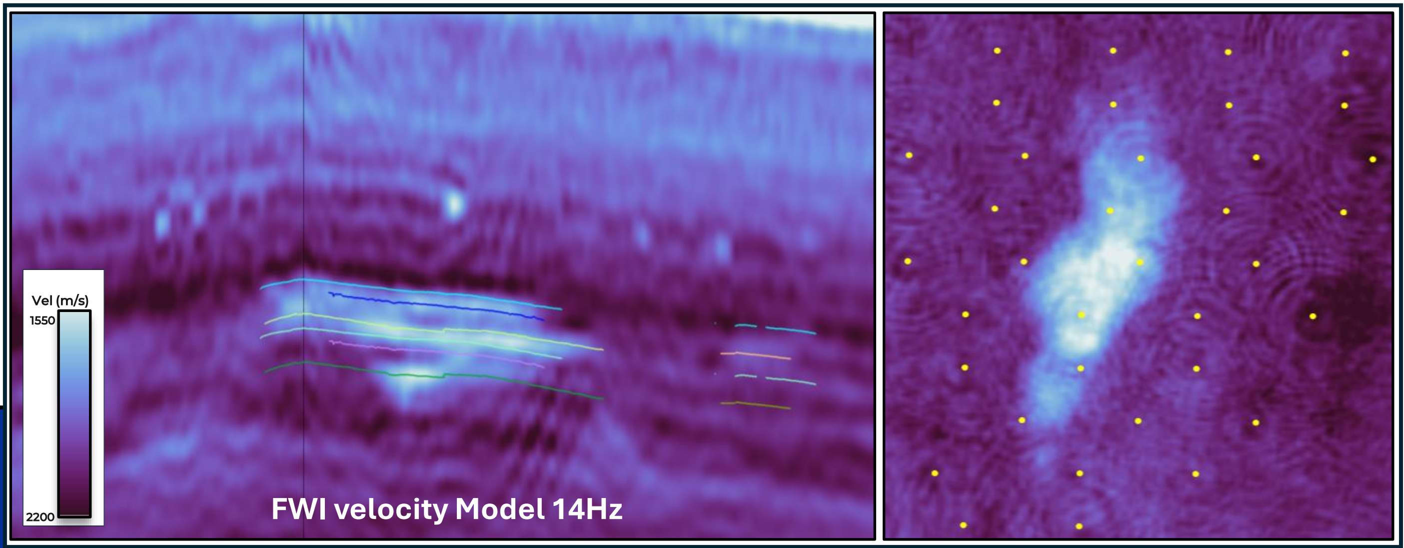
NODE OPTIMIZATION RESULTS

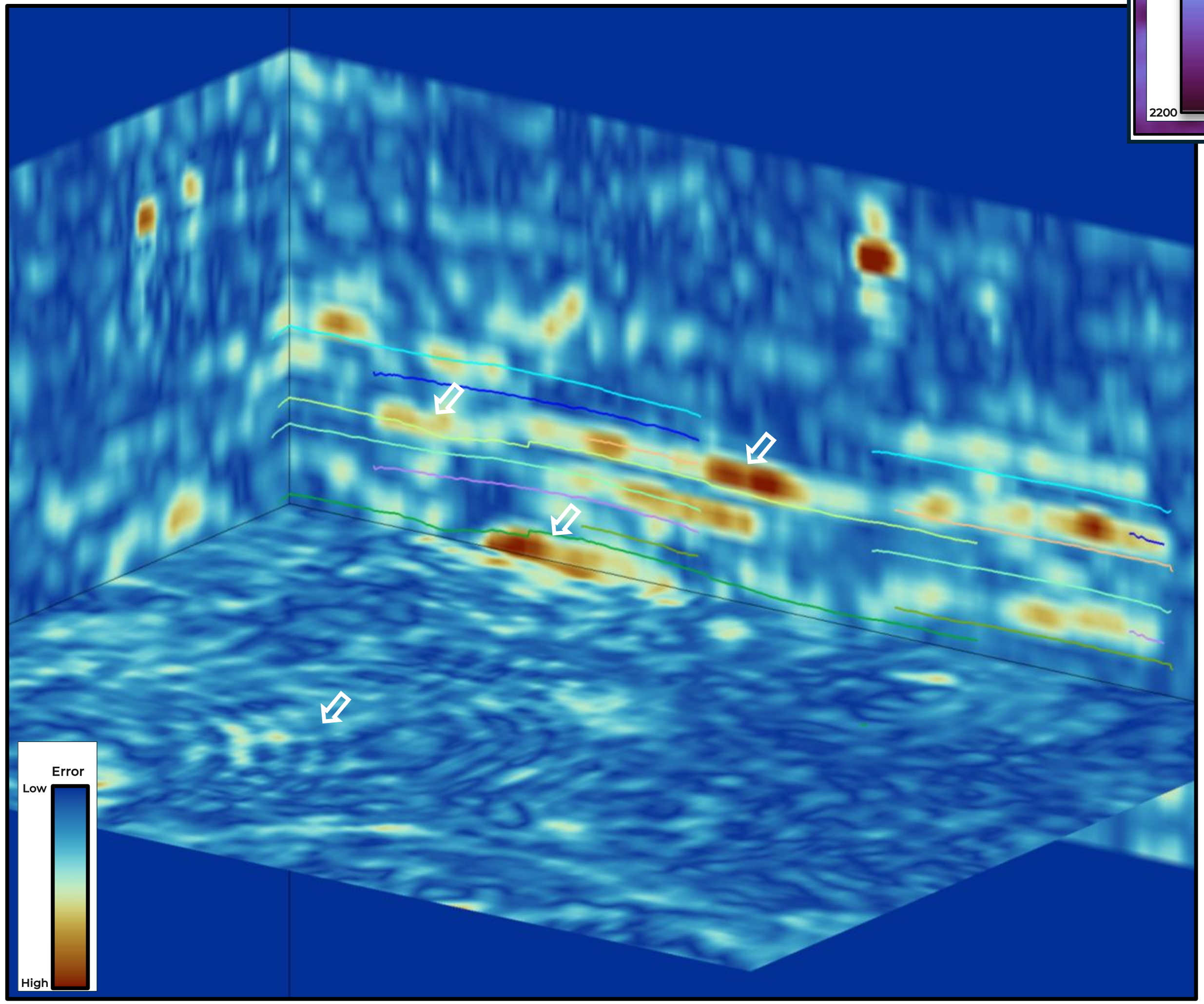


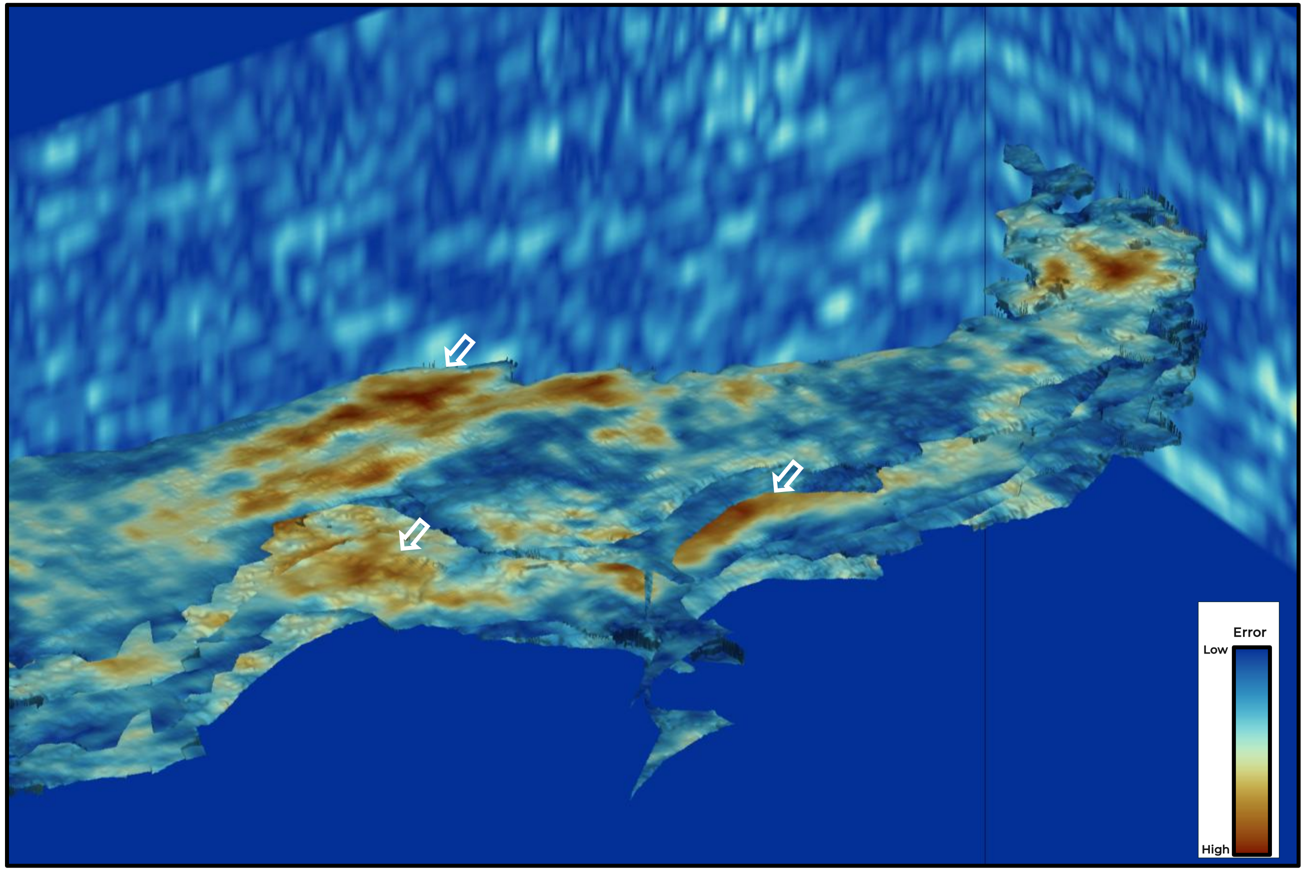


600X900M GRID
(50 NODES)

Decimation NRMS Volumetric QC

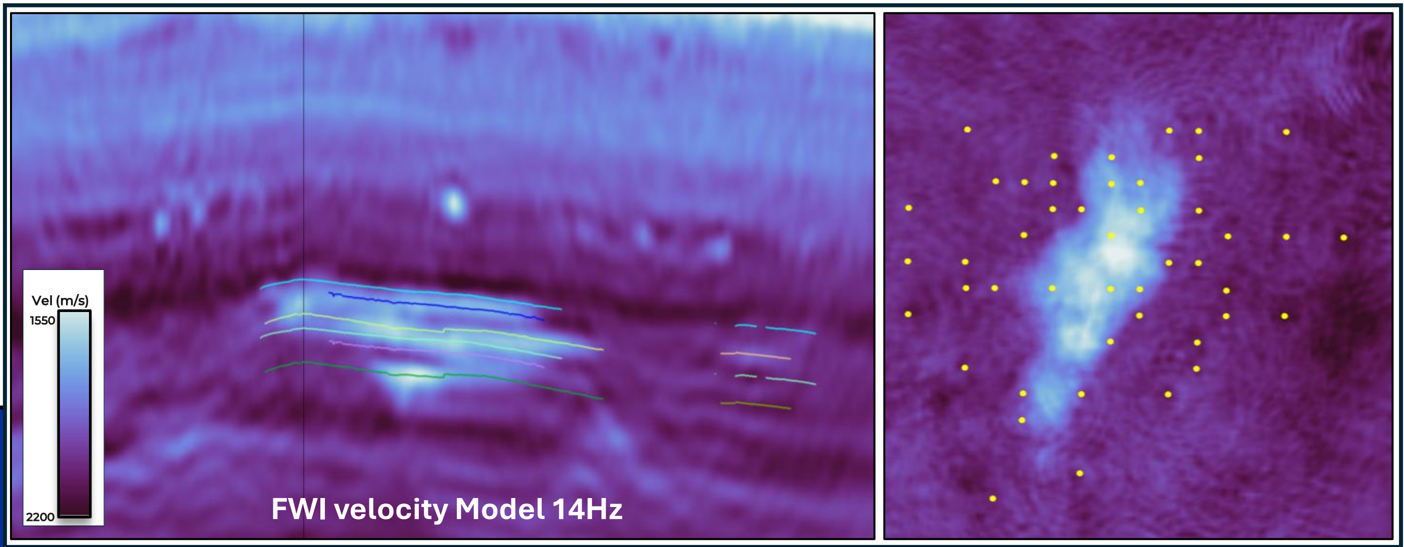


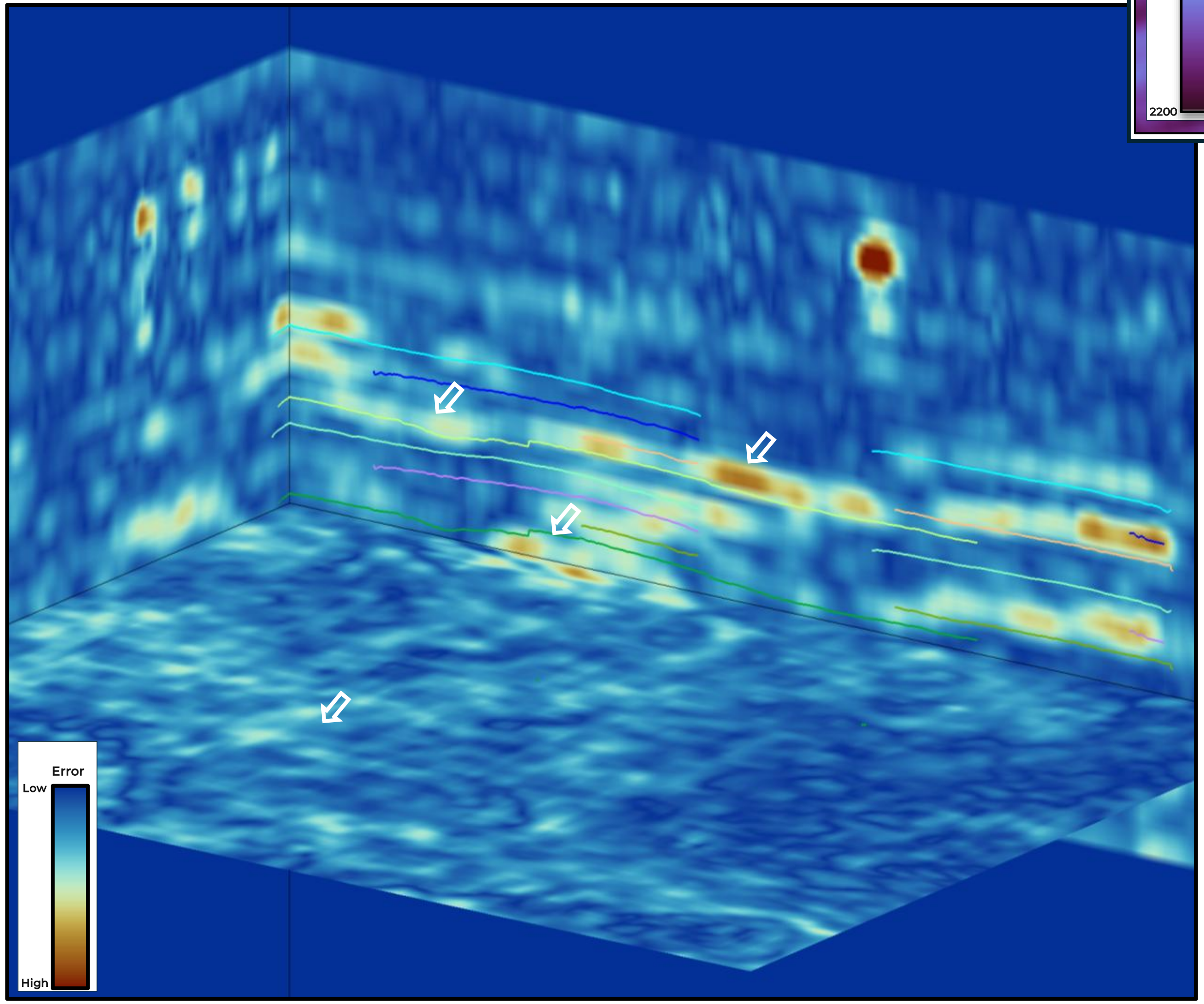


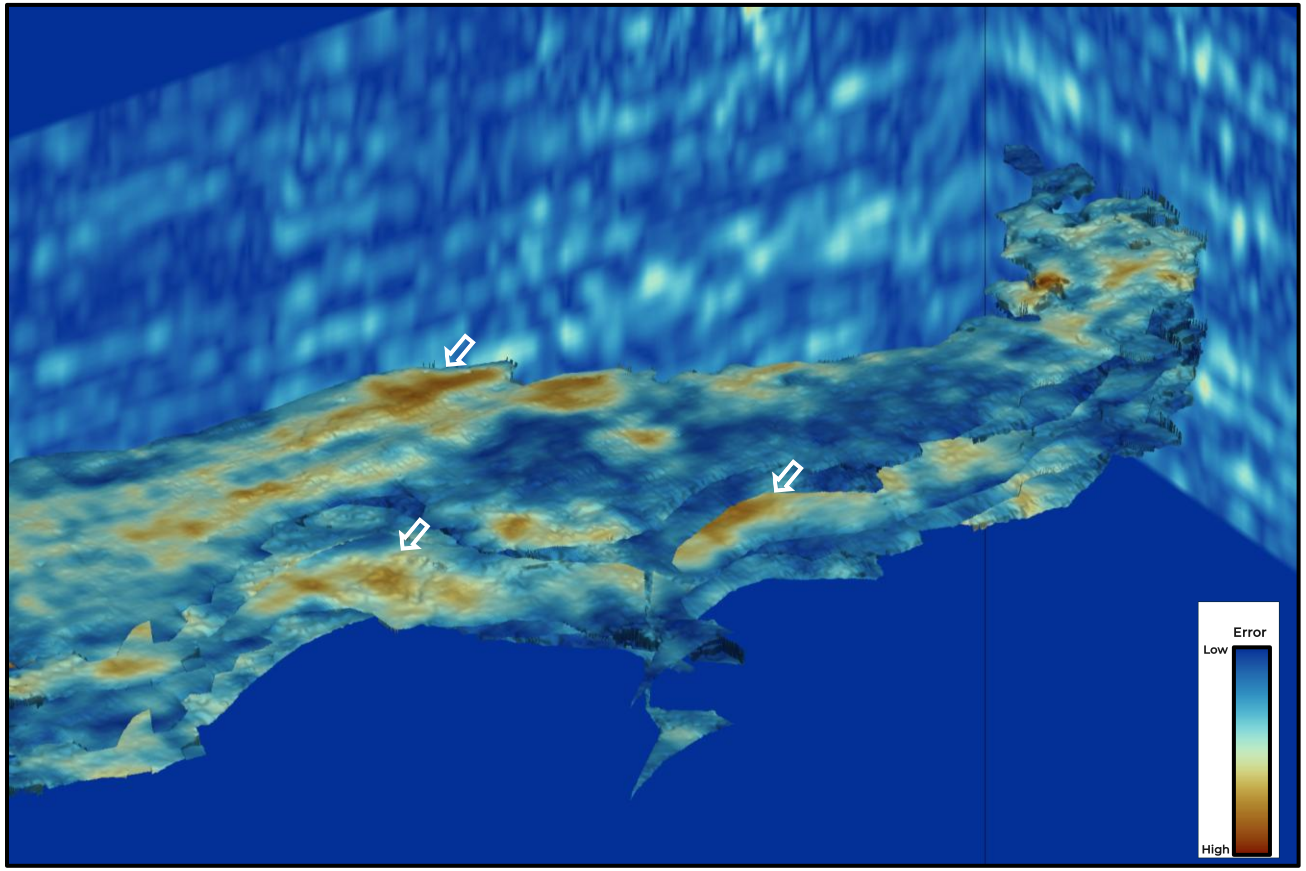


OPTIMISED GRID
(50 NODES)

Decimation NRMS Volumetric QC

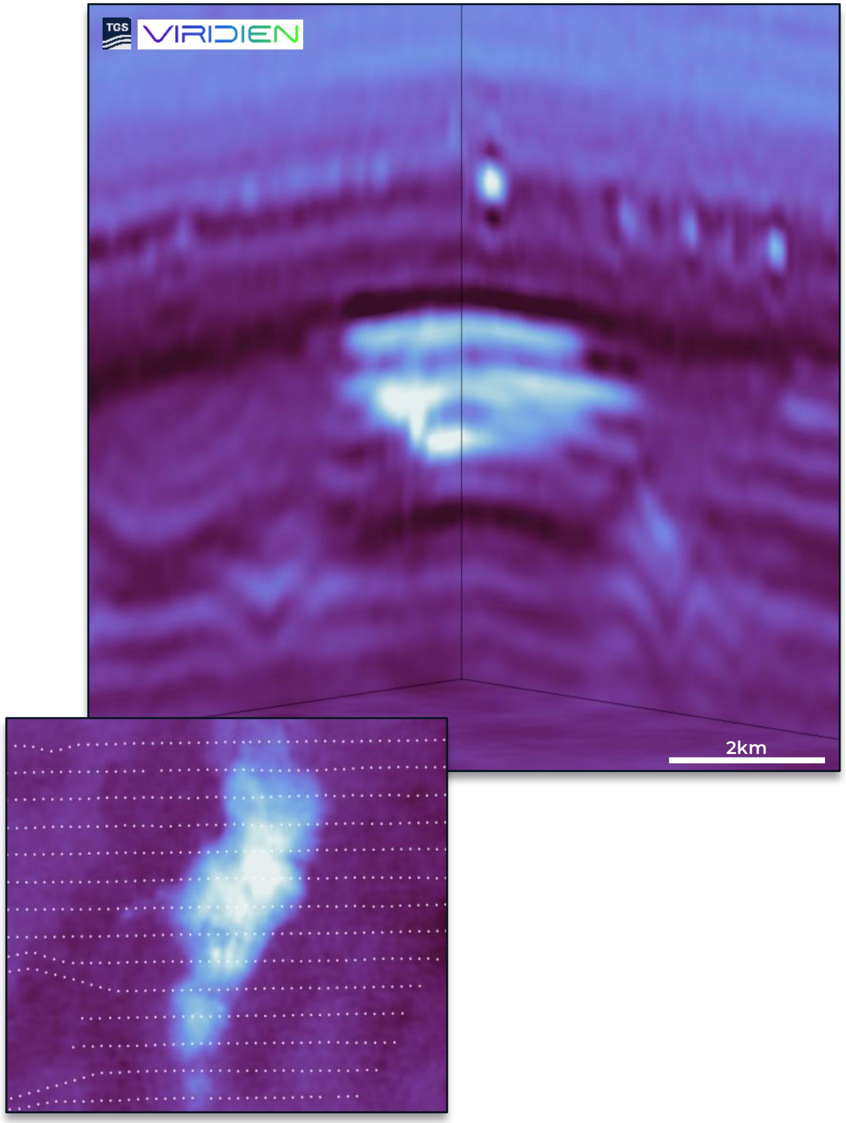




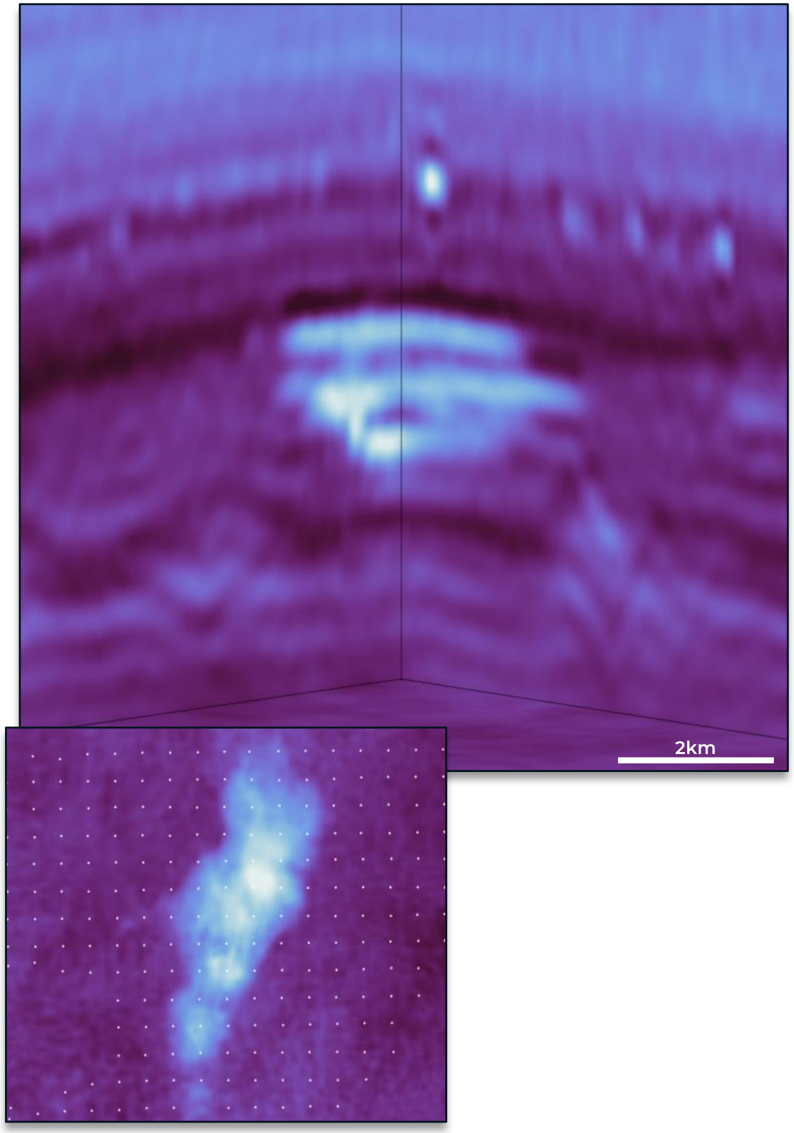


NODE OPTIMIZATION RESULTS

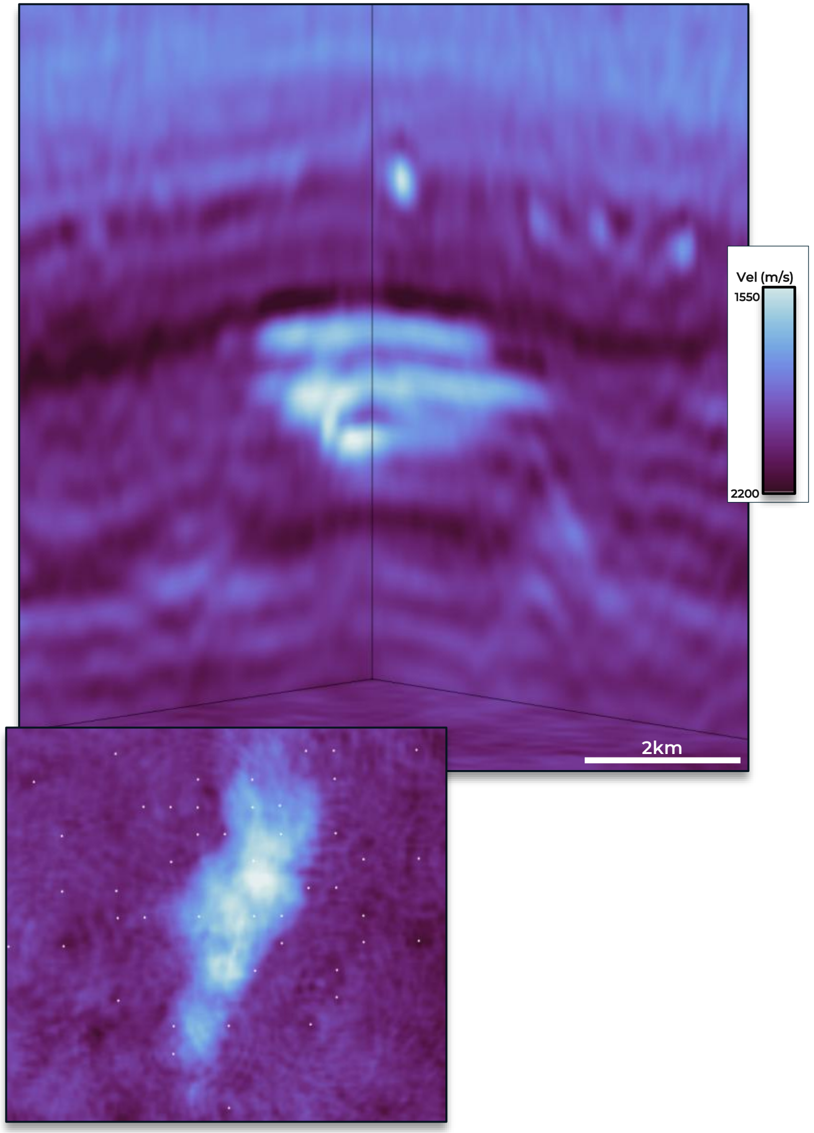
951 nodes
100x300m receiver grid



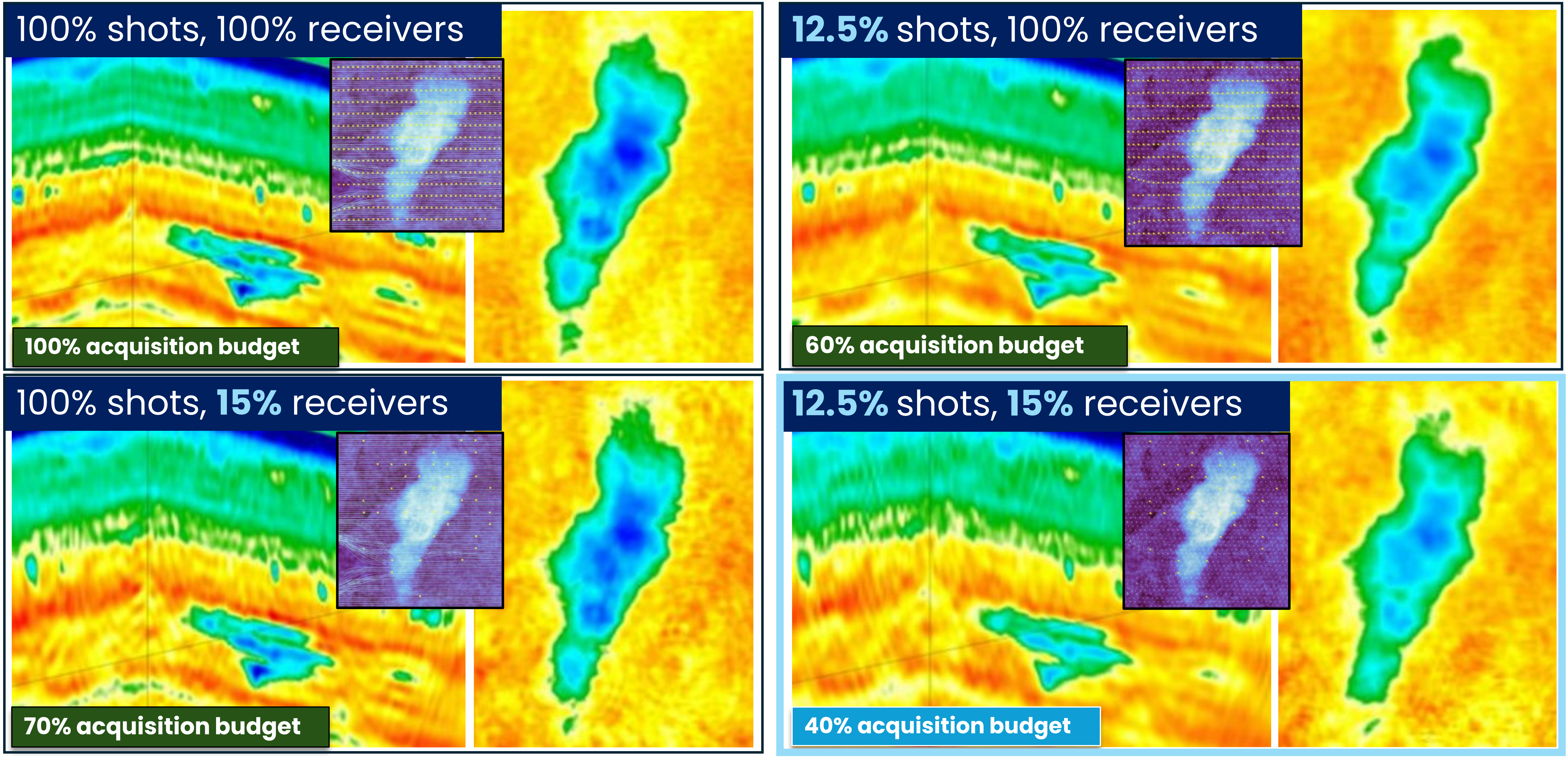
318 nodes
300x300m receiver grid



50 nodes
Optimized grid



SHOT DECIMATION & OPTIMIZED NODES

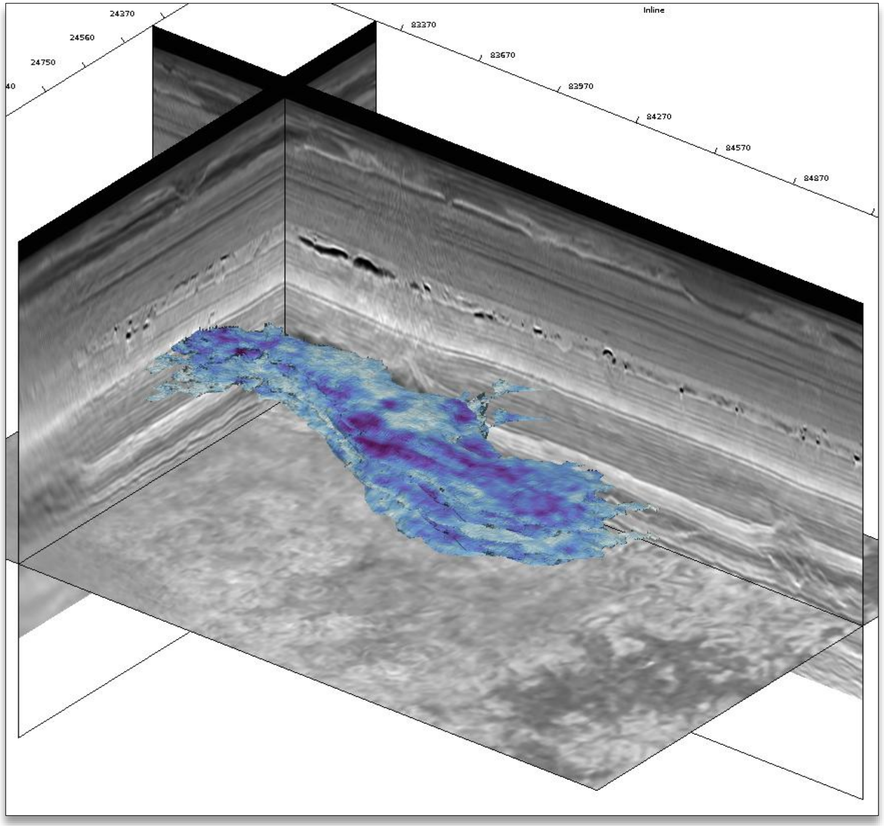


CONCLUSIONS

- ✓ **Conformance & Containment:** significant potential for jointly recovering the **CO_2 response** and imaging the **overburden** and target **risk profiles**.

- ✓ **Confidence:** the workflow is based on the **plume model** from reservoir, and it is **tailored** to each storage site.

- ✓ **Acquisition costs:** node optimization combined with full wavefield imaging identifies perfect **balance** between **monitoring** and **acquisition**.



Thank you for listening!

Thanks to my colleagues and co-authors at Viridien:

Matt Ledger, Robert Porjesz, Song Hou, Steve Hollingworth, Fabio Barracano, Ricardo Martinez and Vetle Vinje

Thanks to Viridien Earth Data (EDA) for permission to publish this work and to TGS for permission to publish the 2023 dense OBN results.