



4D FWI – approaches, lessons & the future

Post Convention Workshop : Advancements and the Road Ahead in 4D Seismic

Daniel Davies*, Chong Chung, David Cavalin, Fuchun Gao, Lee Saxton

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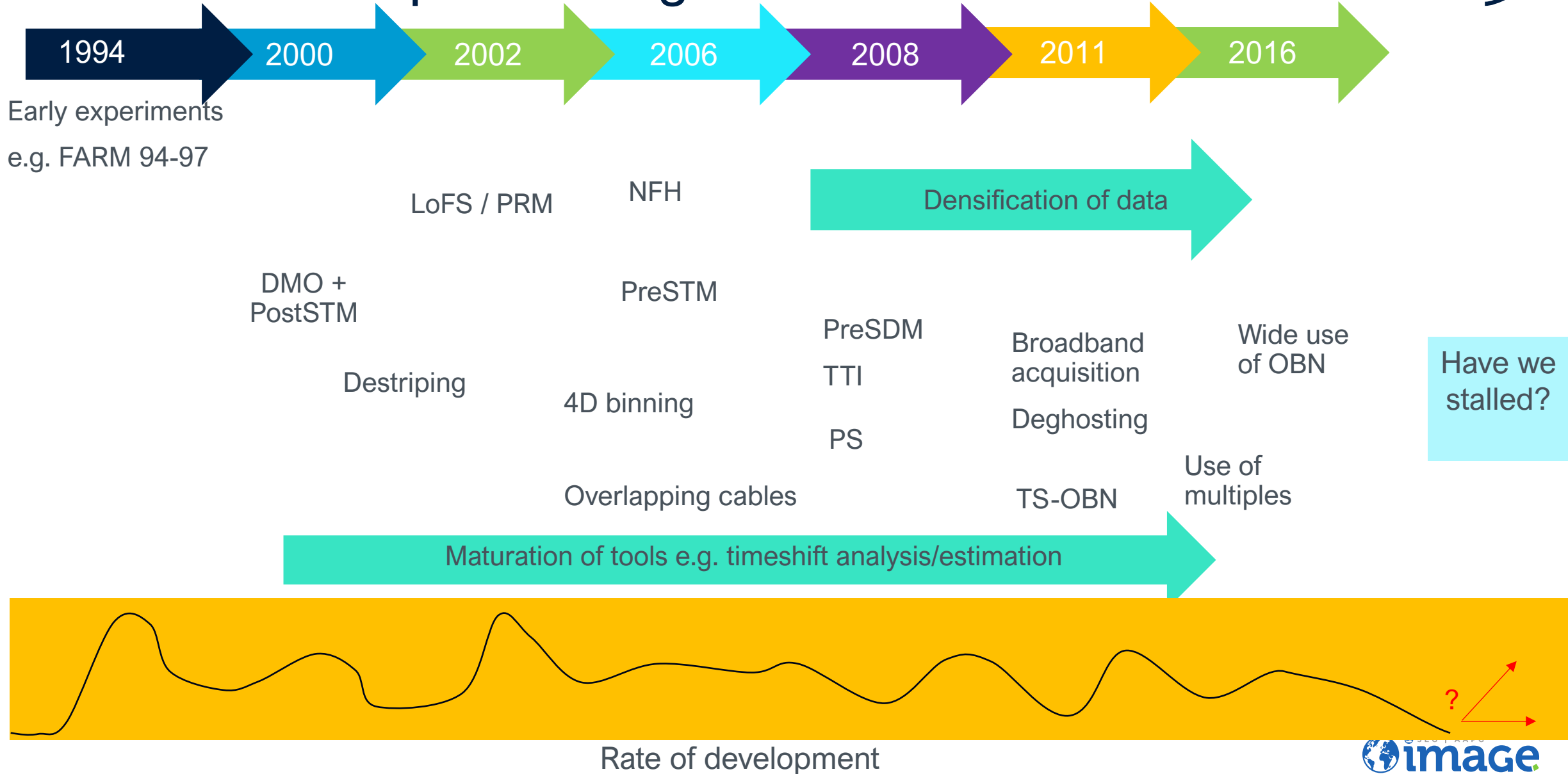


Introduction



- A brief history of 4D development
- 3D FWI imaging
- 4D FWI imaging
 - Review of methods
 - OBN case study
 - Streamer case study
- Closing comments

Evolution of 4D processing

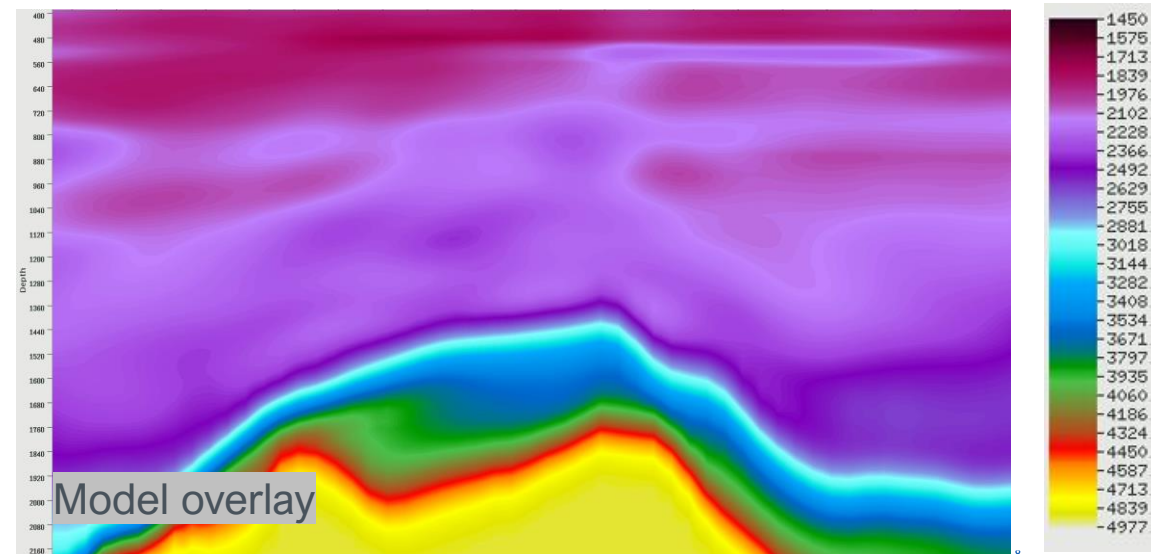
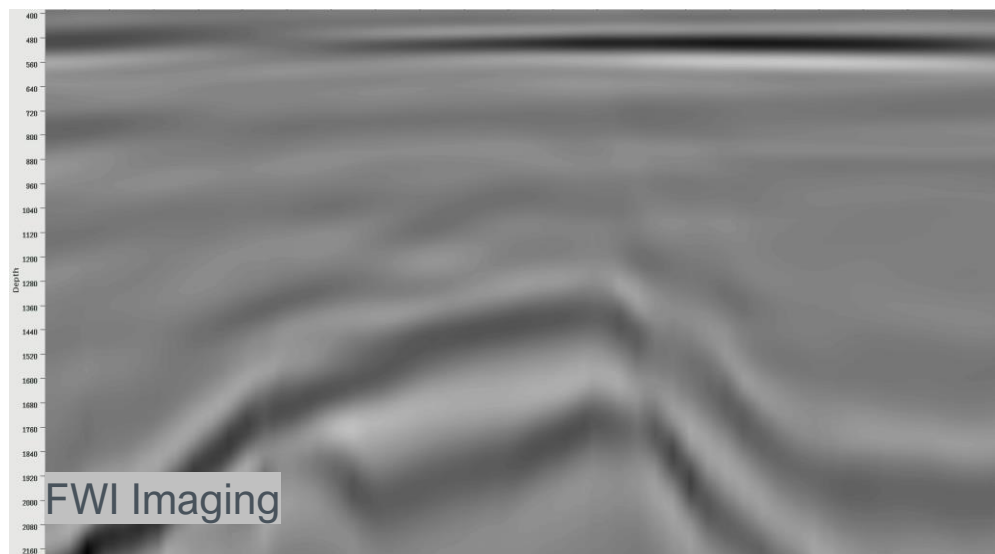
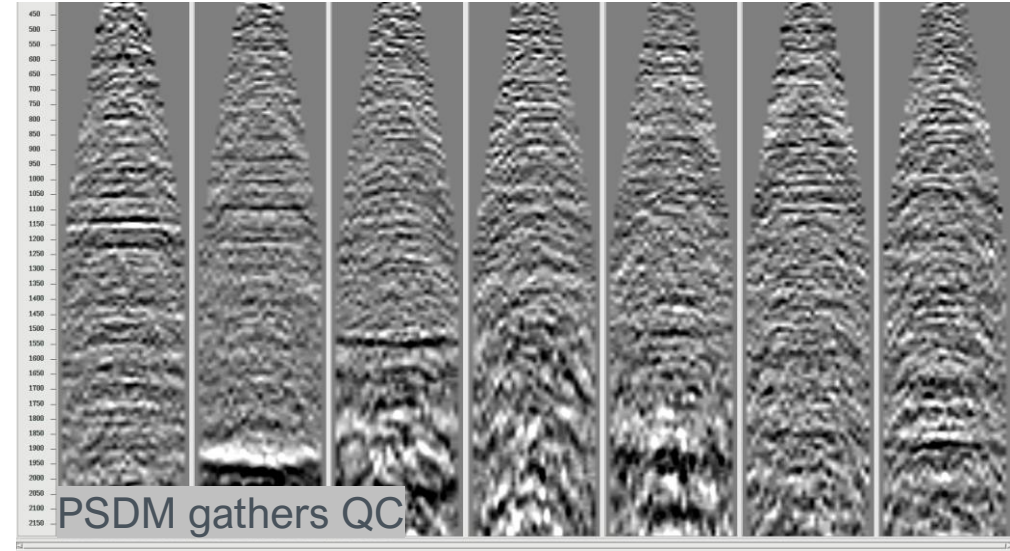
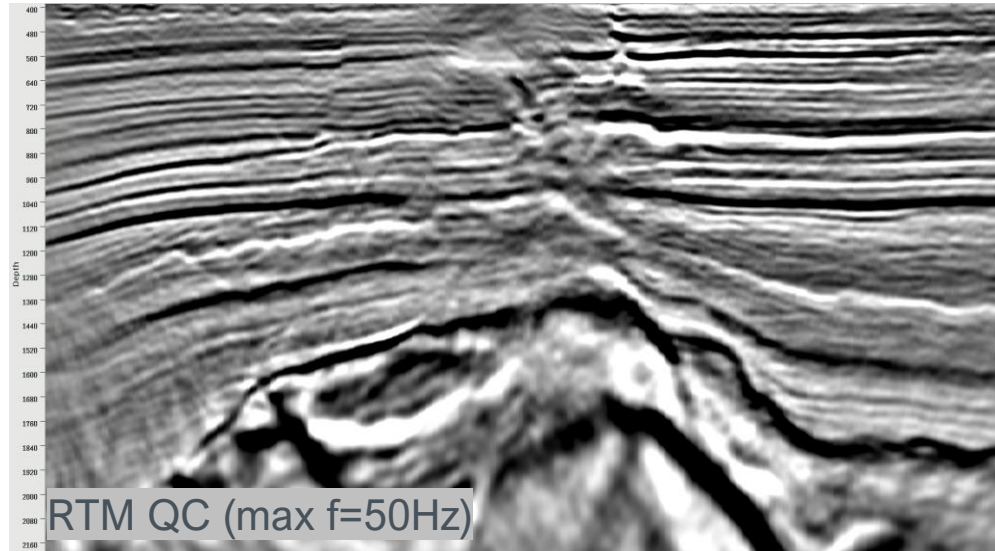


FWI imaging

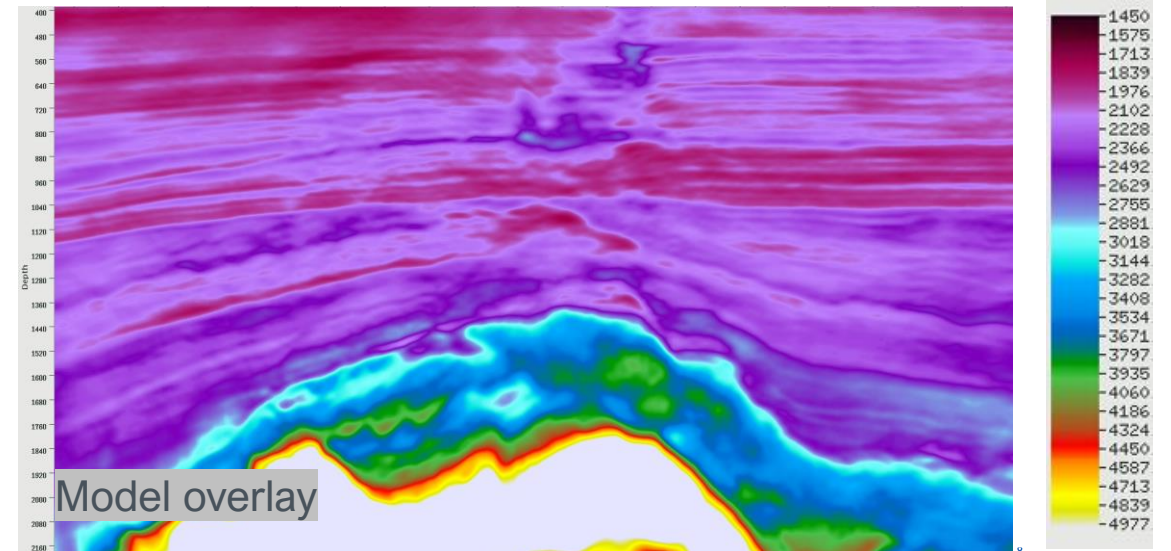
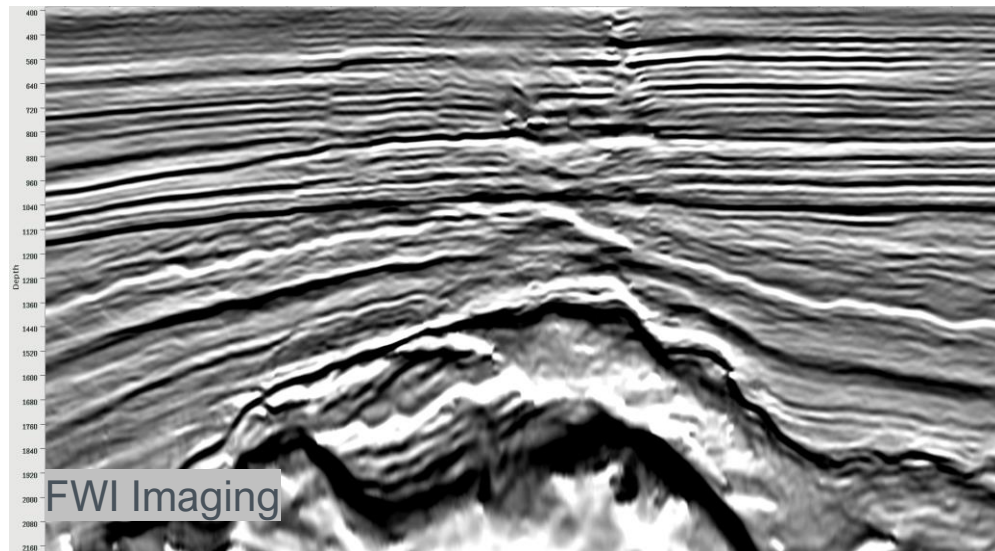
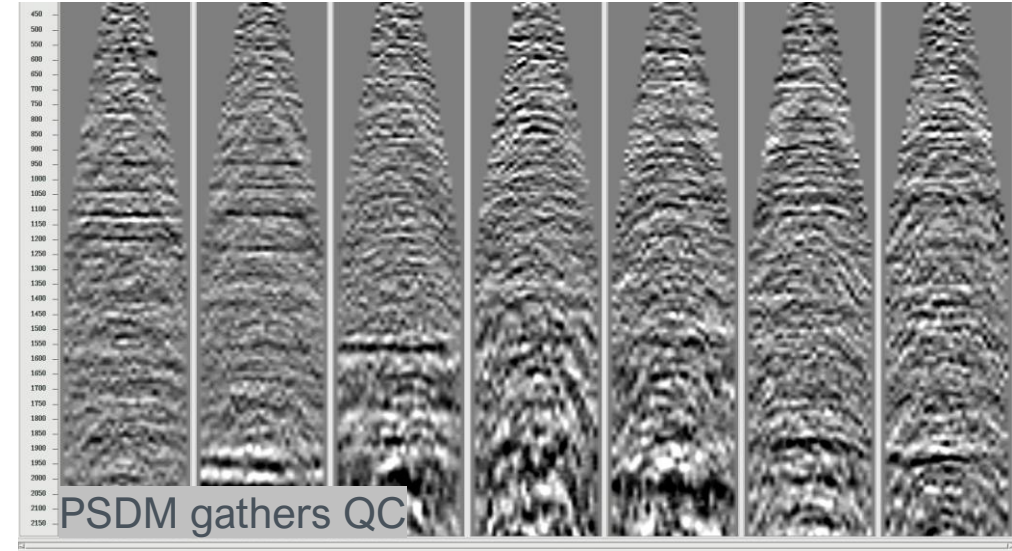
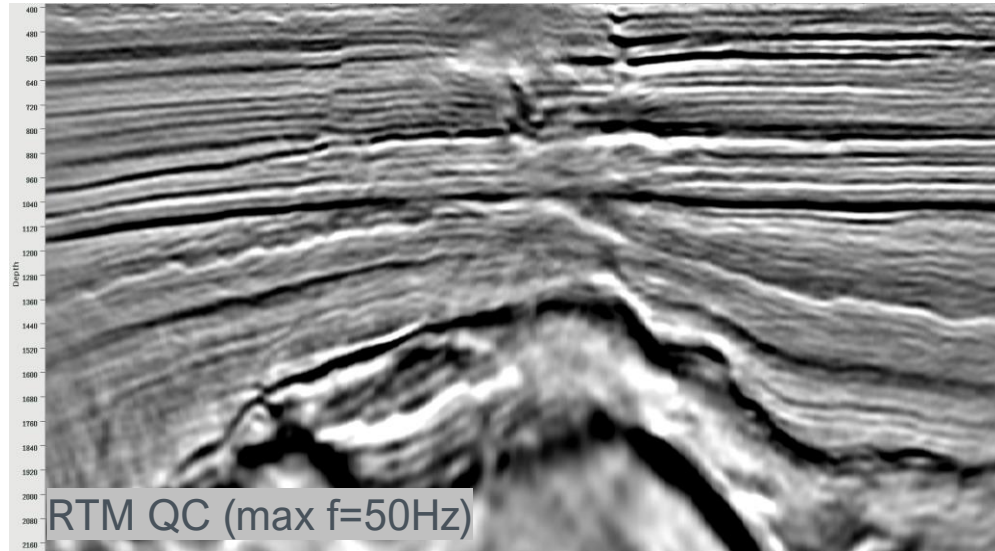


- FWI imaging is being widely adopted in 3D
- The advantages of using less maturely processed data for velocity model building leading to reduced turnaround

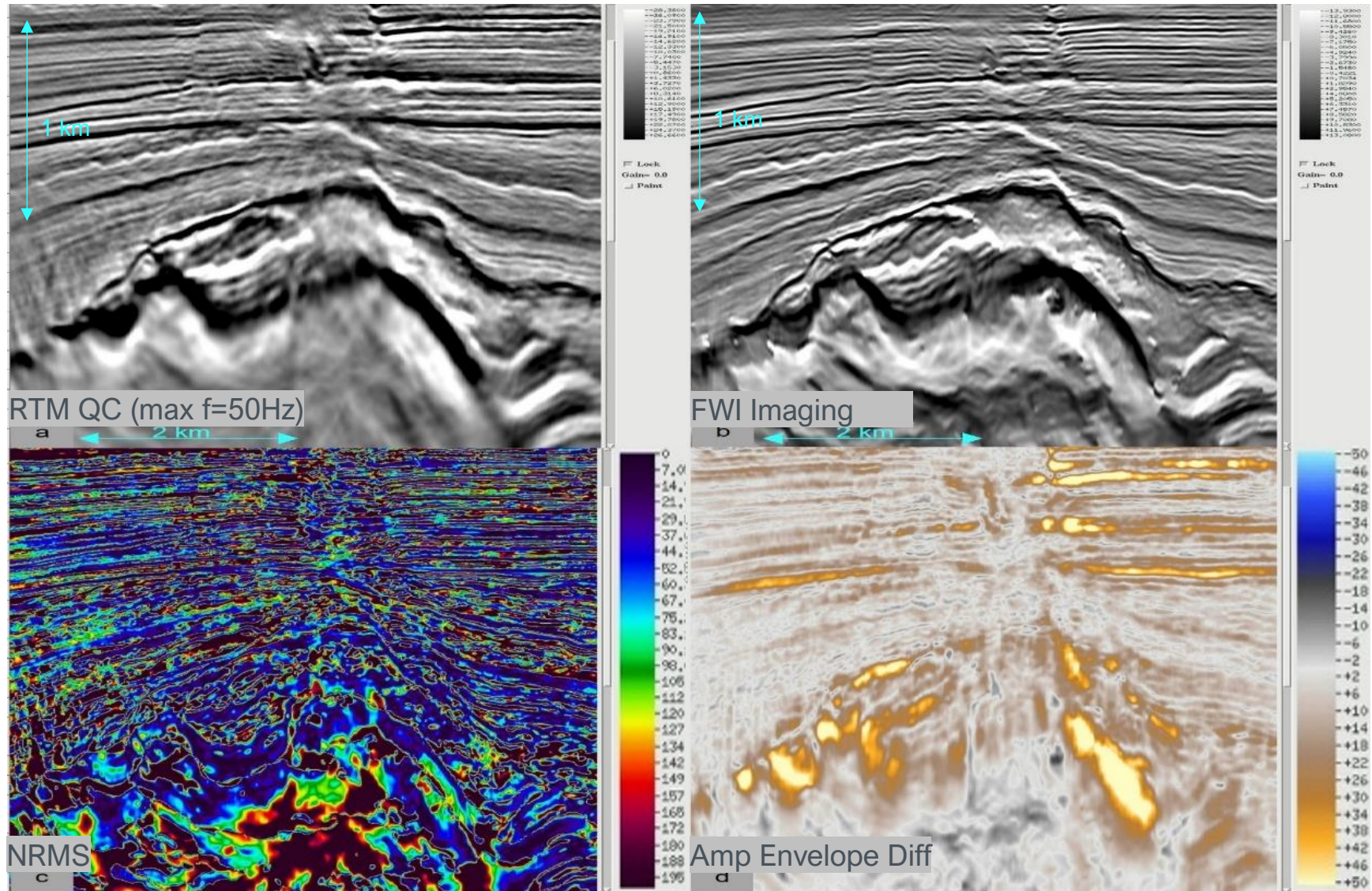
Input to FWI



50 Hz DM FWI



Attributes from the 4D world for velocity QC



FWI image is cleaner as a least squares solution

4D FWI



- Is 4D FWI imaging just as valid?

4D FWI – TGS’ toolkit



- Parallel
 - Essentially 3D FWI on each vintage of data
 - x2 the cost of 3D FWI
 - Do you need to run all the frequency bands or can you “skip” some and run
 - What additional processing do you need to apply?
 - Matching filters
 - Regularise for geometry
- Sequential
 - Similar to shot cycling for 3D FWI, you cycle surveys too at the low frequencies to get the best “average” velocity model, then perform only parallel 4D FWI at higher frequencies
 - Will it fail where there are large changes?
- Double differences
 - Highly sensitive to geometry differences – best on LoFS/PRM – not suitable elsewhere
- Joint (Gao et al, 2024)
 - Inverts for base or monitor and uses the 4D difference
- Dual sweep
 - Use of differing FWI parameters on different intervals



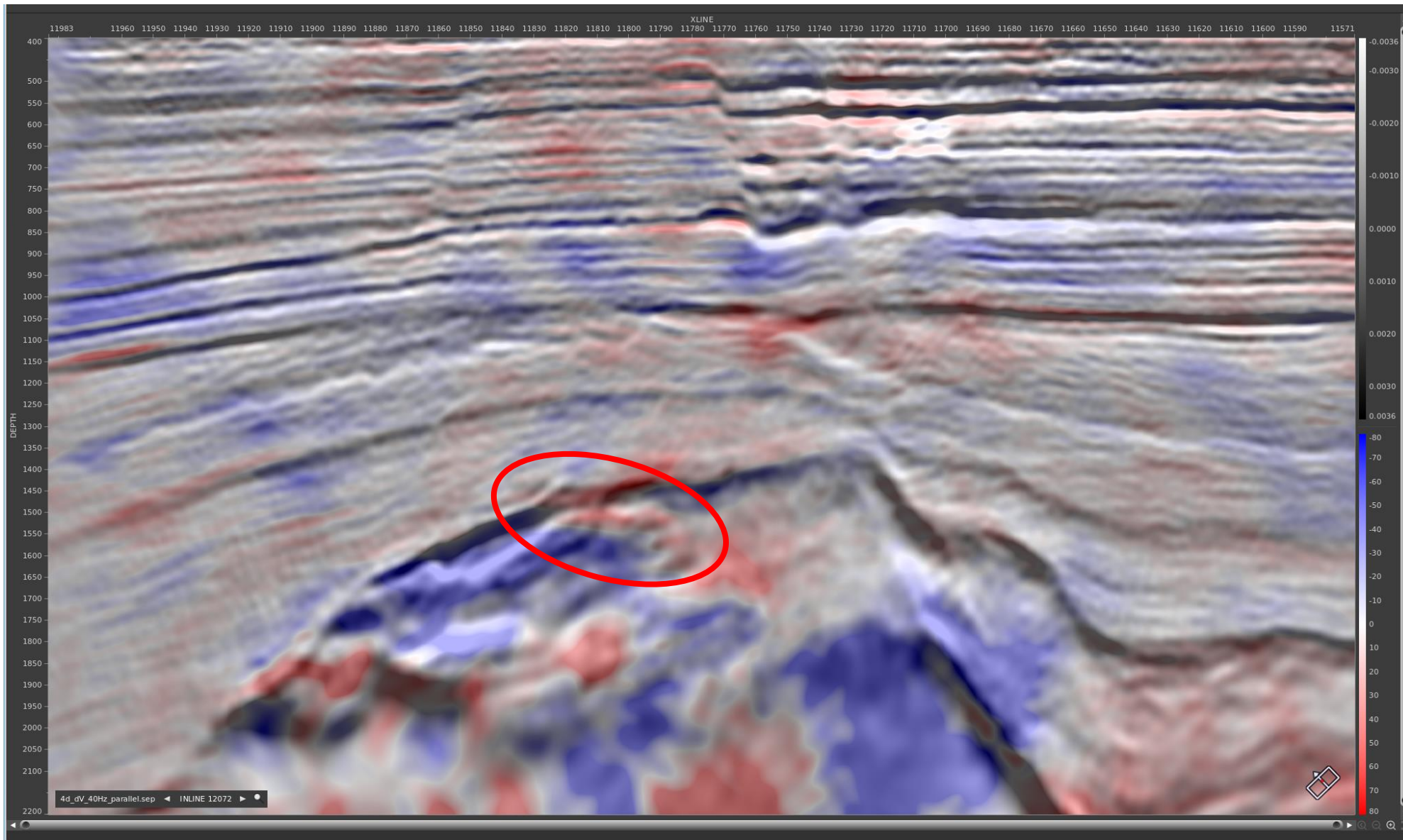
4D FWI on OBN

4D FWI – OBN example

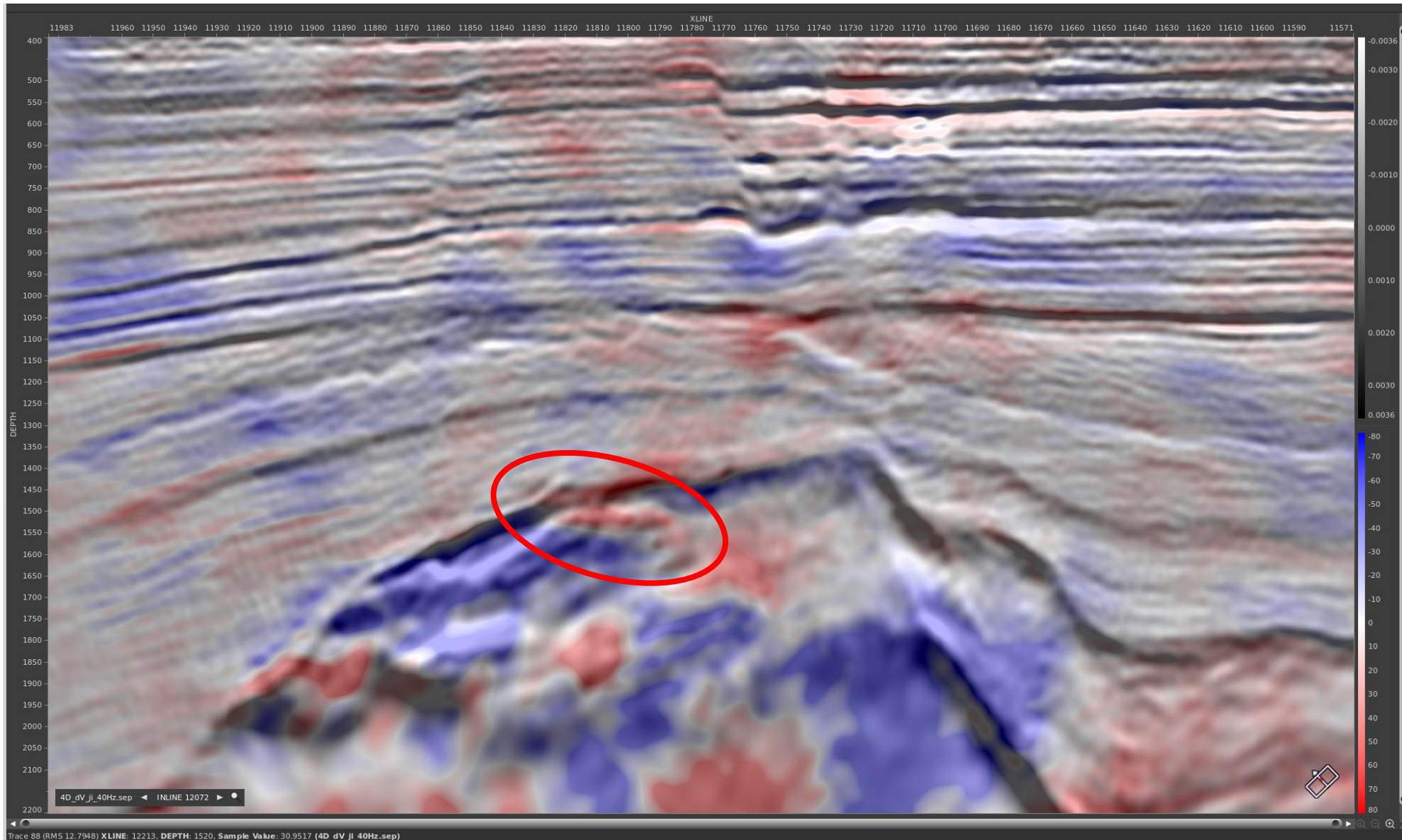


- Clair OBN data from UKCS
 - 2017 and 2023 surveys
 - 100m x 50m nodes
 - 25m shot grid
- 3D FWI performed on the 2017 data in 2022 ahead of the monitor survey
 - (previous 3D FWI imaging slides)
- Initial test performed on a 5 receiver line swath
 - Used the full shot carpet for each receiver
- Selected mutual receivers and a receiver tolerance of 5m
- Selected mutual shots within 10m

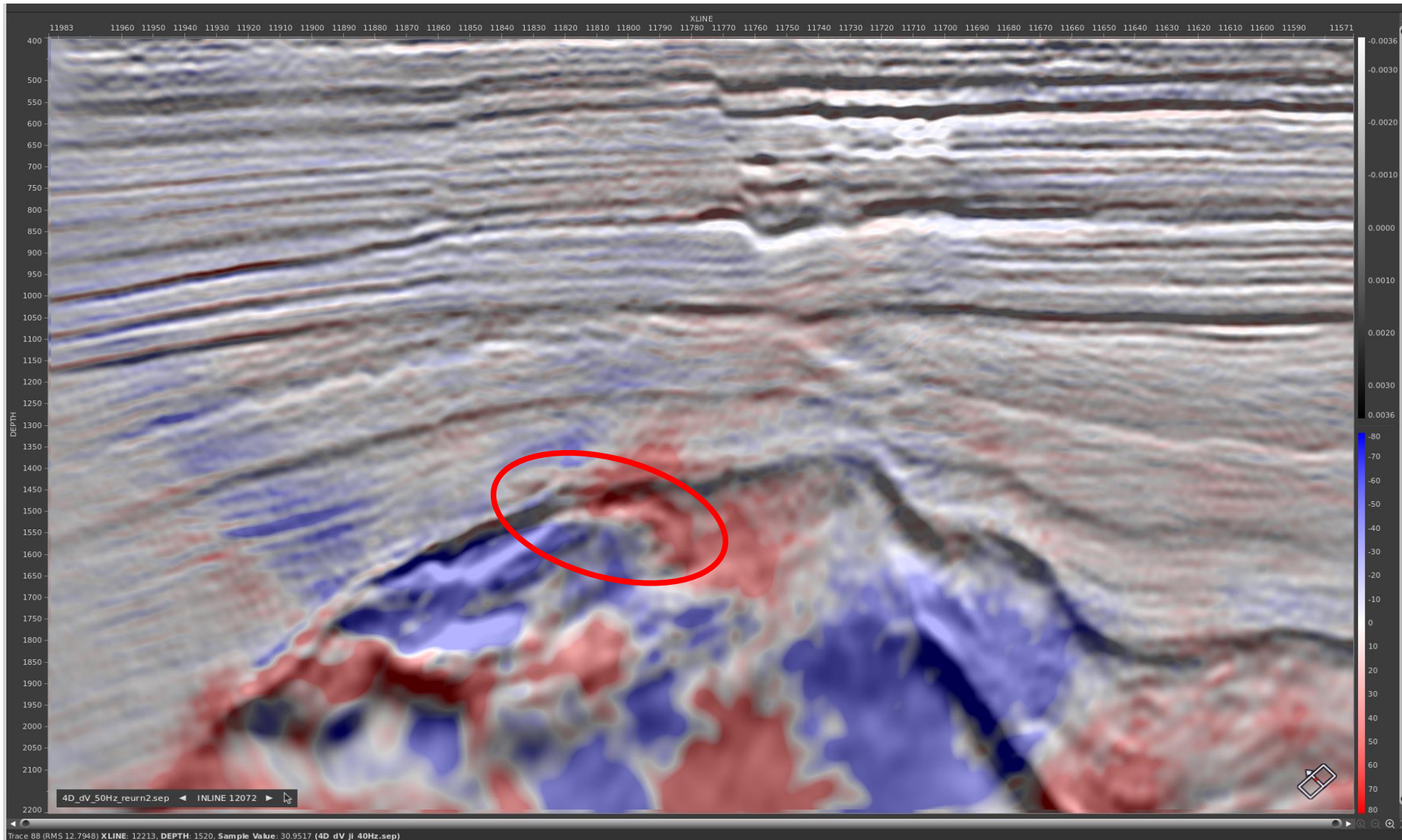
4D dV – 40Hz Parallel Inversion



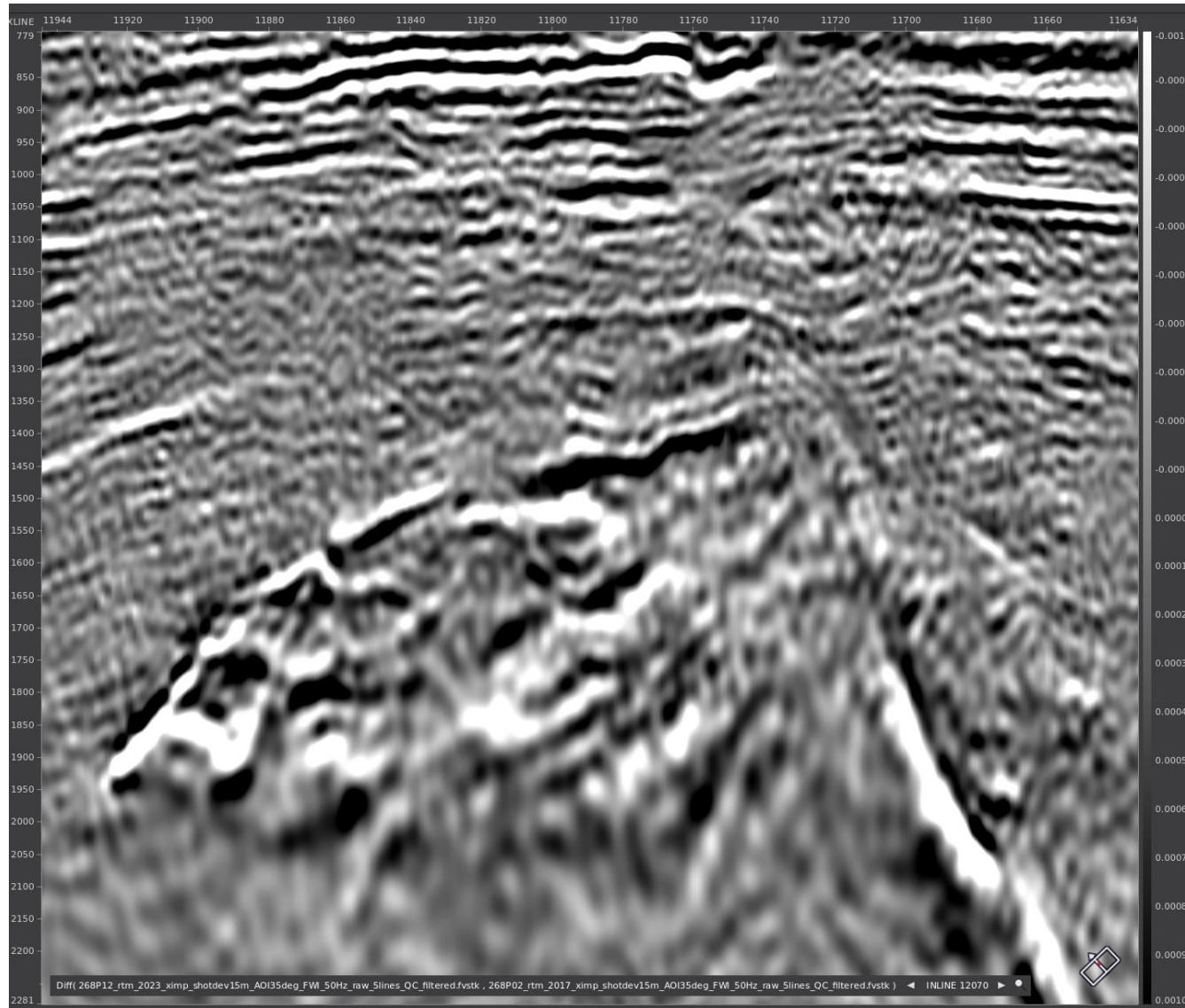
4D dV – 40Hz Joint Inversion



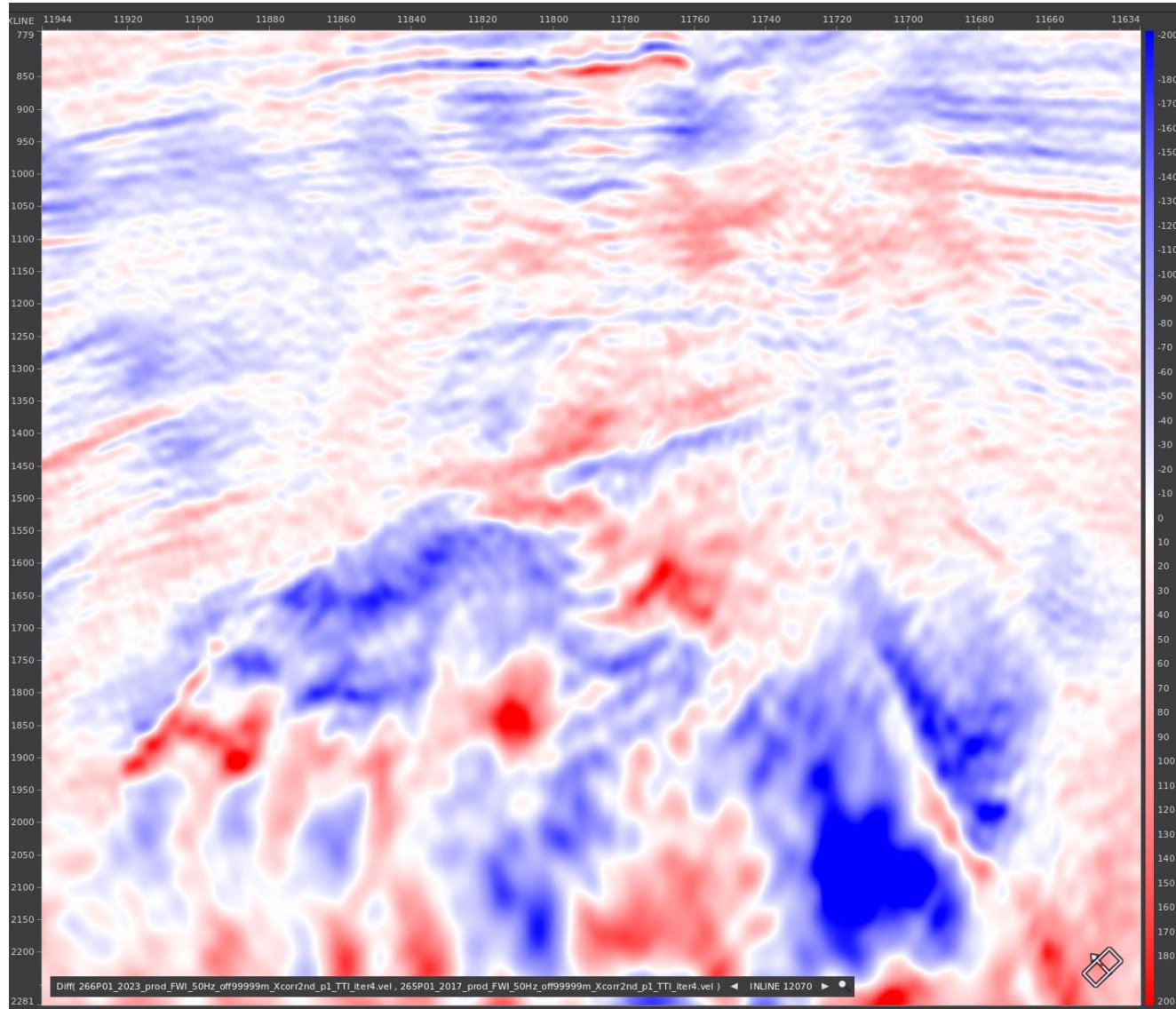
4D dV – 40Hz joint inversion, after 2 sweeps



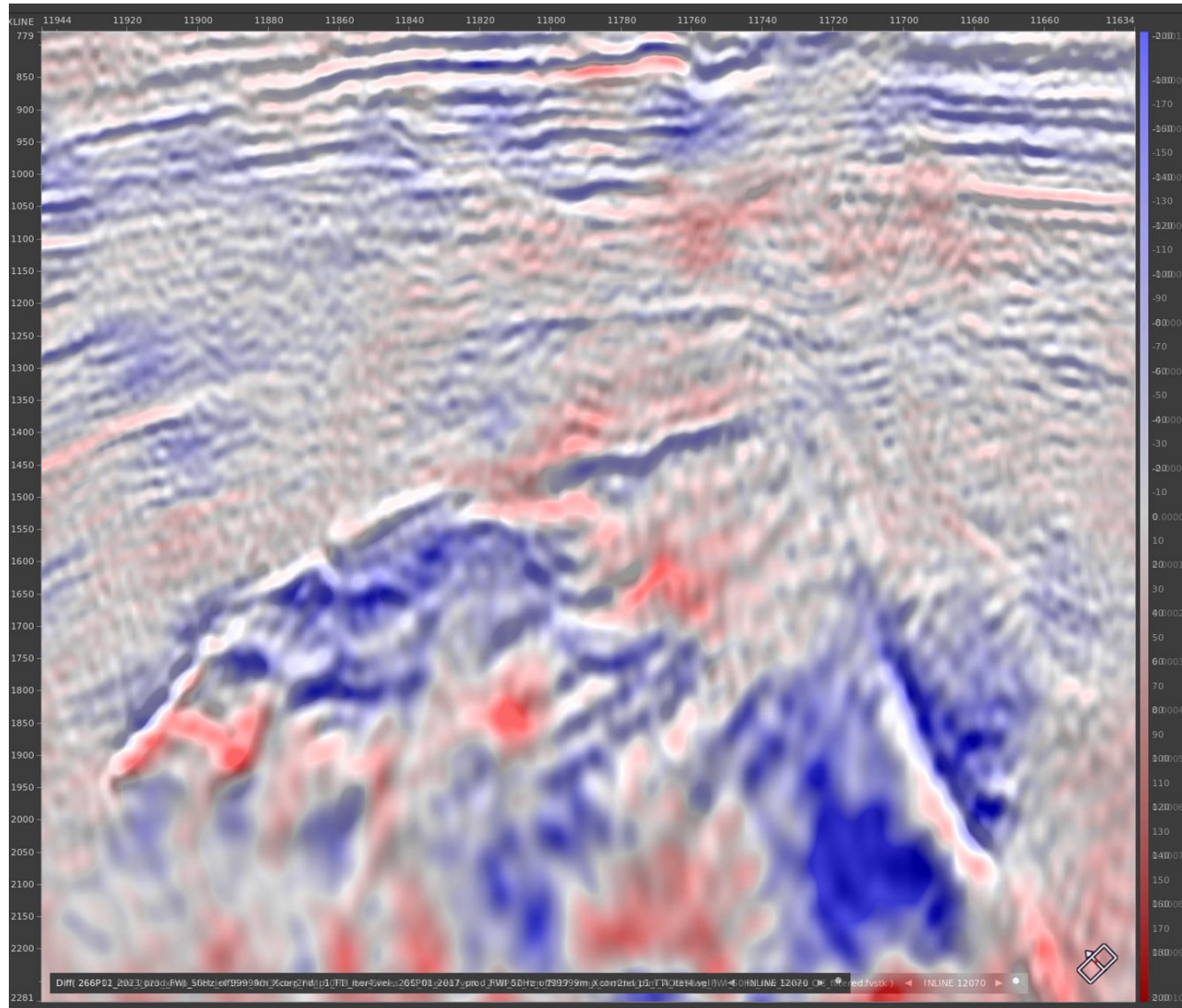
4D difference (quadrature phase)



4D FWI



overlay



4D FWI on streamer



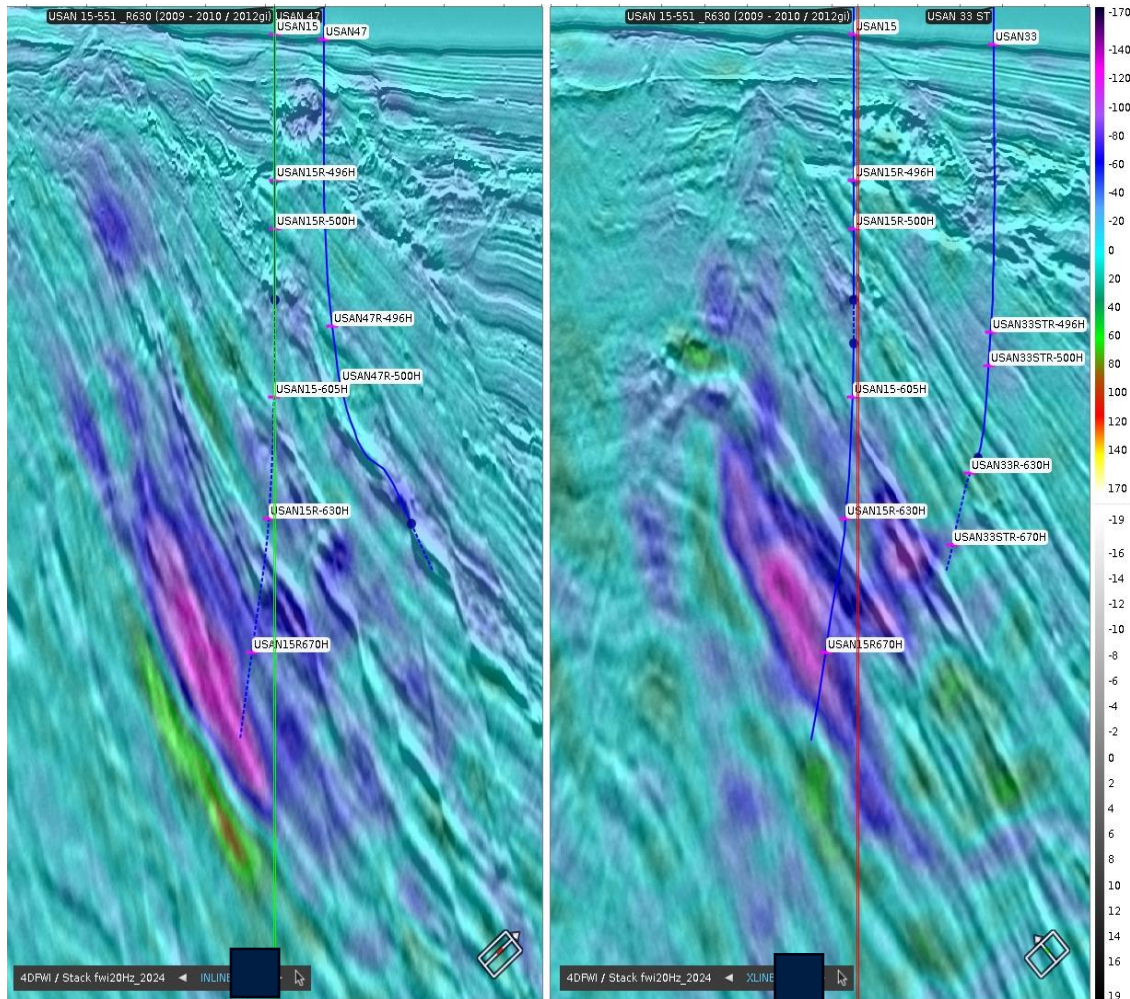
4D FWI – Streamer example



- Test 1 – proof of concept - 11 sail line swath
 - Parallel scheme
 - Using 16Hz FWI from baseline
 - Run 20Hz on both base and monitor
 - No 4D binning
- Test 2 – 21 sail line swath
 - Parallel and Joint schemes tested
 - Started from the same smoothed legacy input model

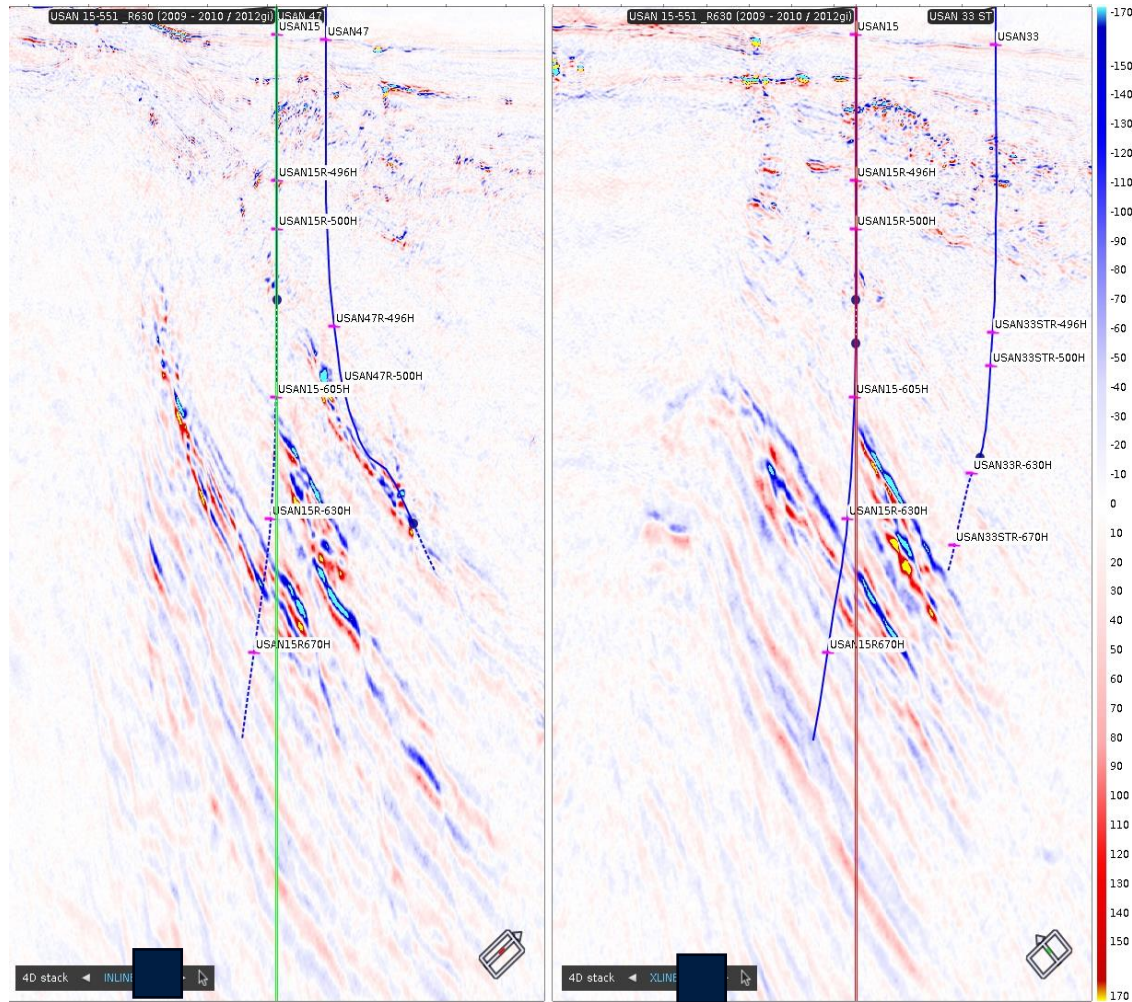
4D FWI

stack + 4DFWI

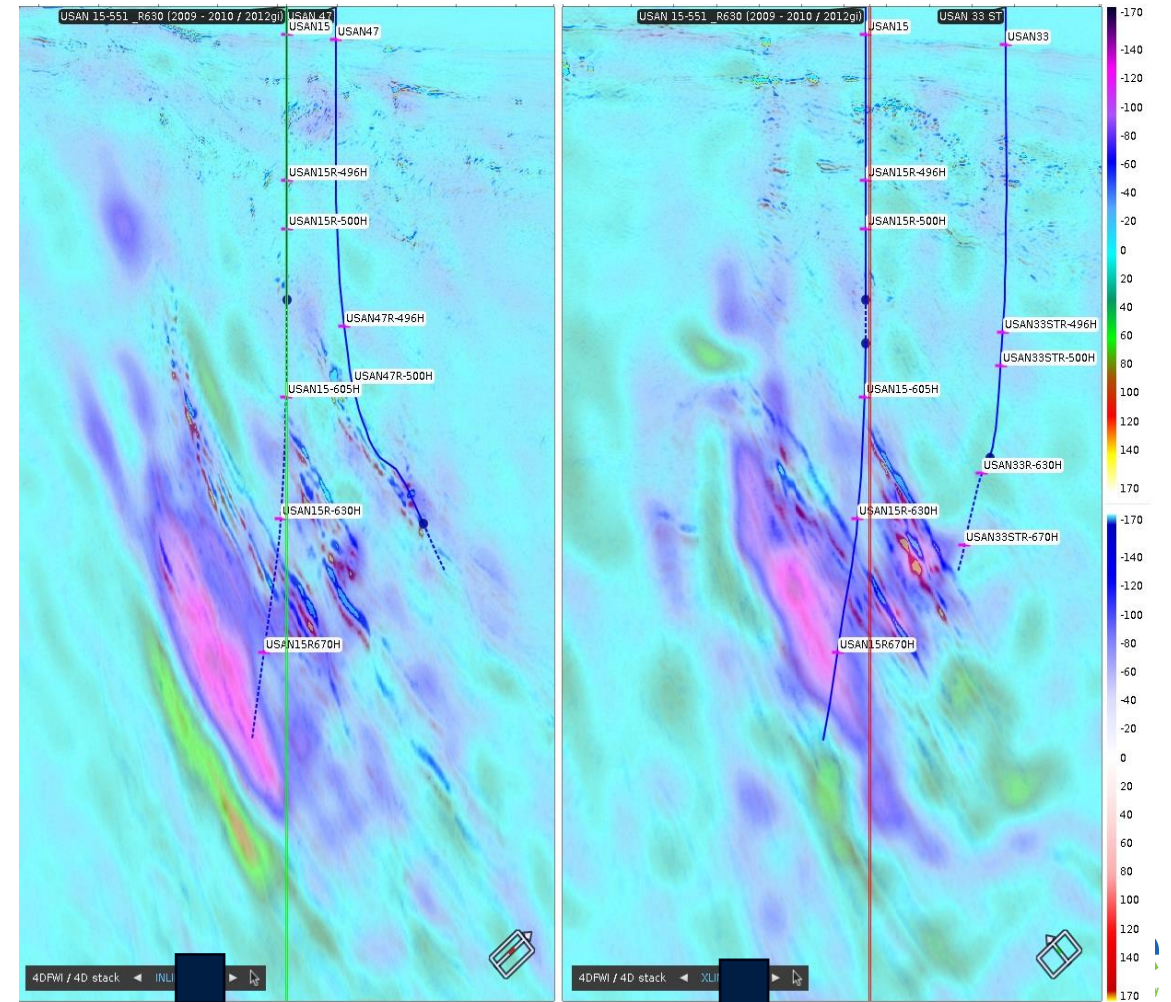


4D difference and 4DFWI

4D difference

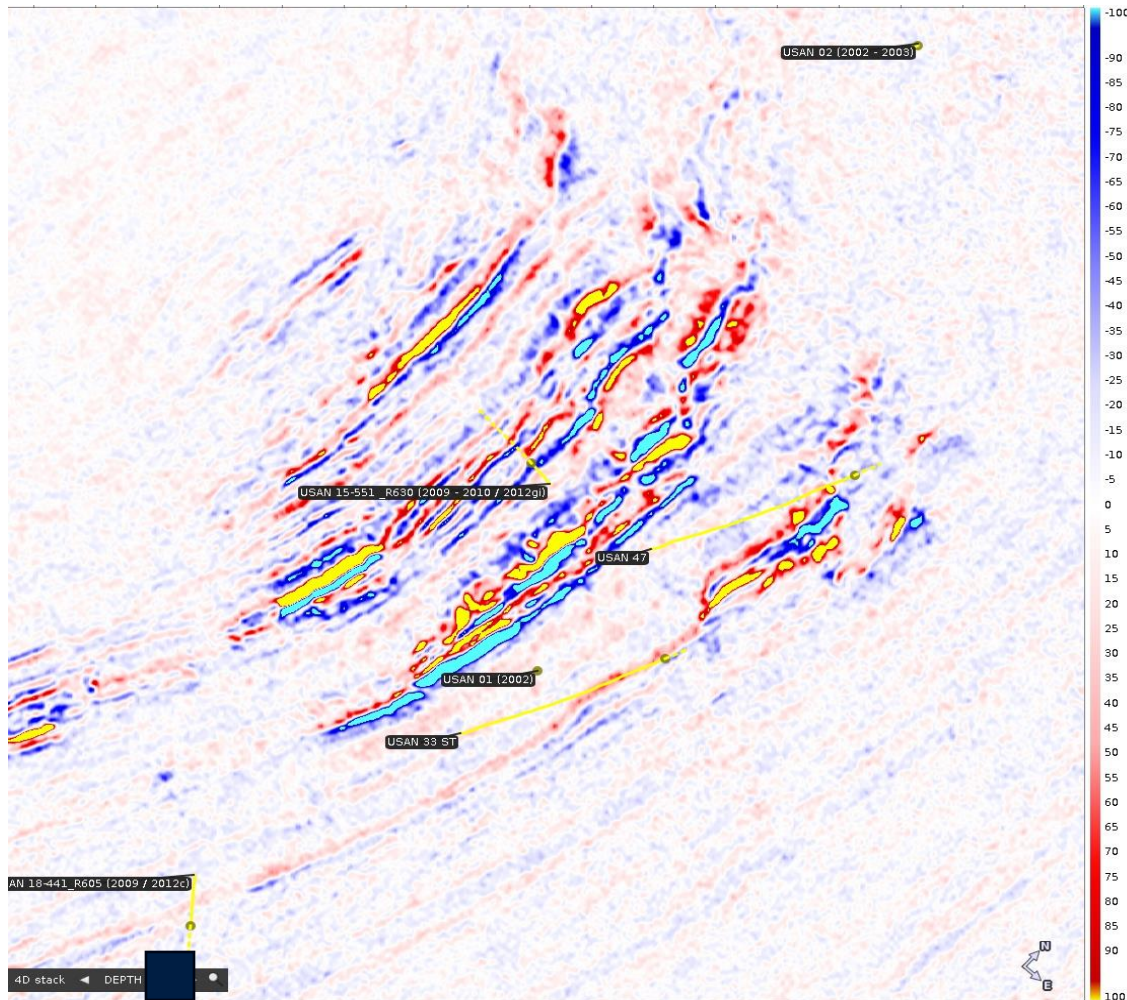


4D difference + 4DFWI

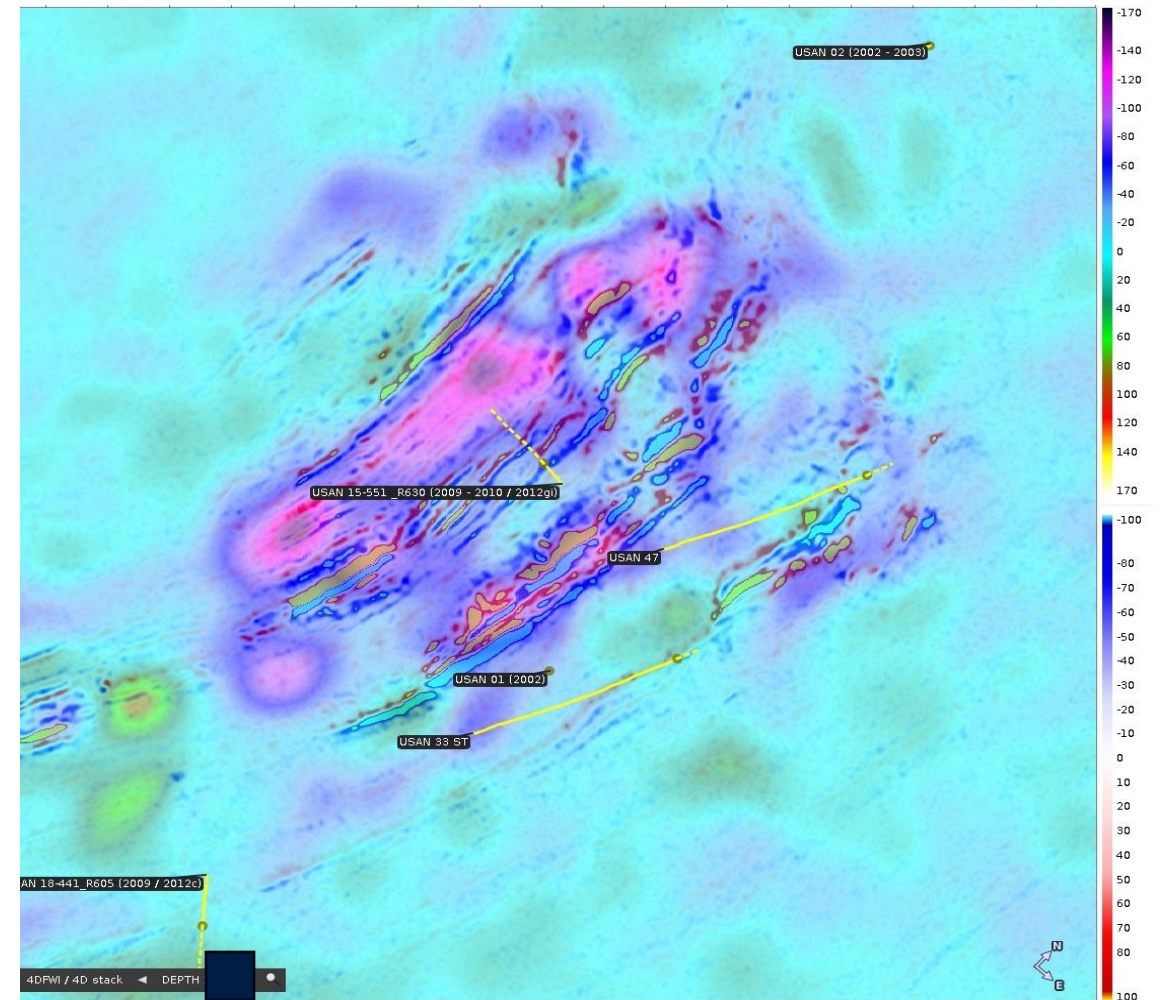


4D difference and 4DFWI

4D difference



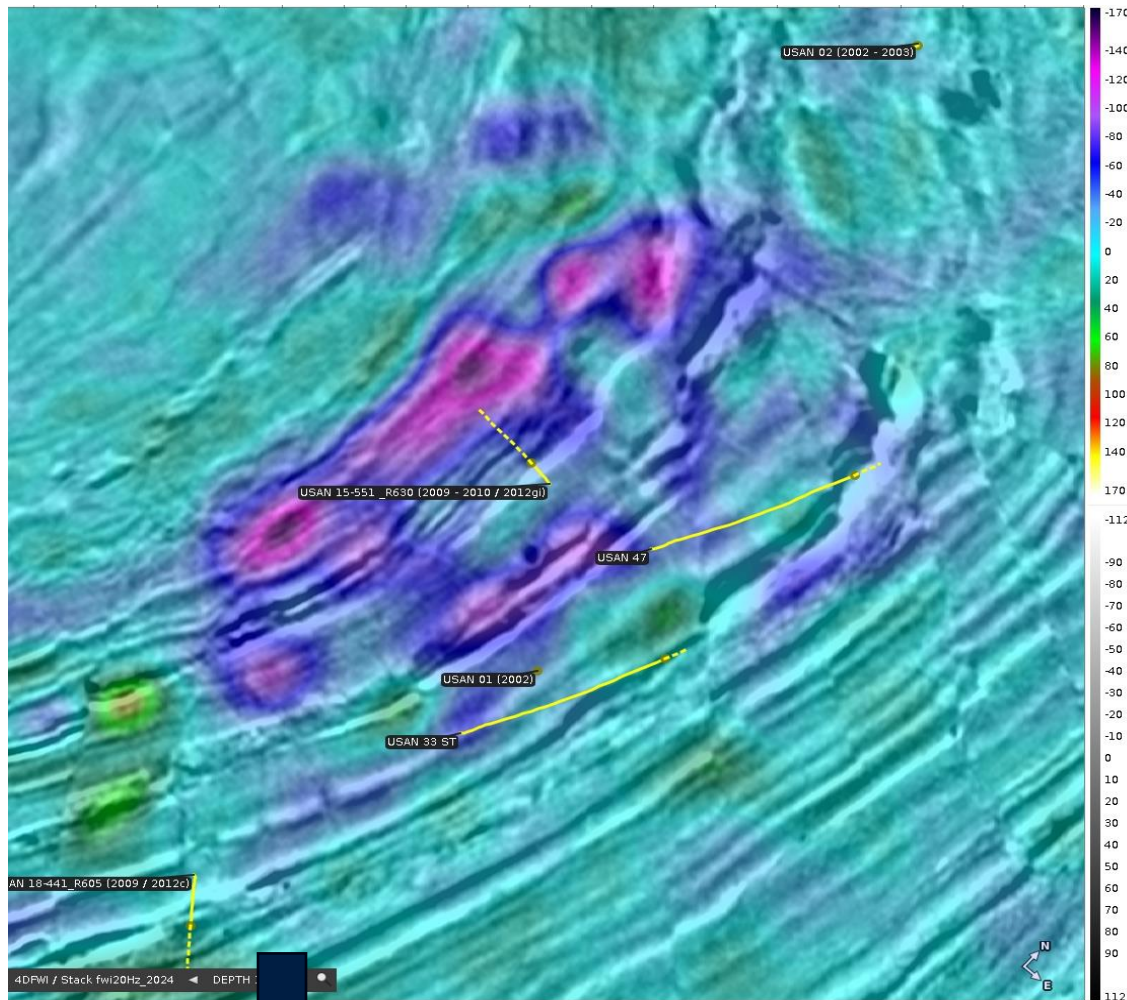
4D difference + 4DFWI



4DFWI

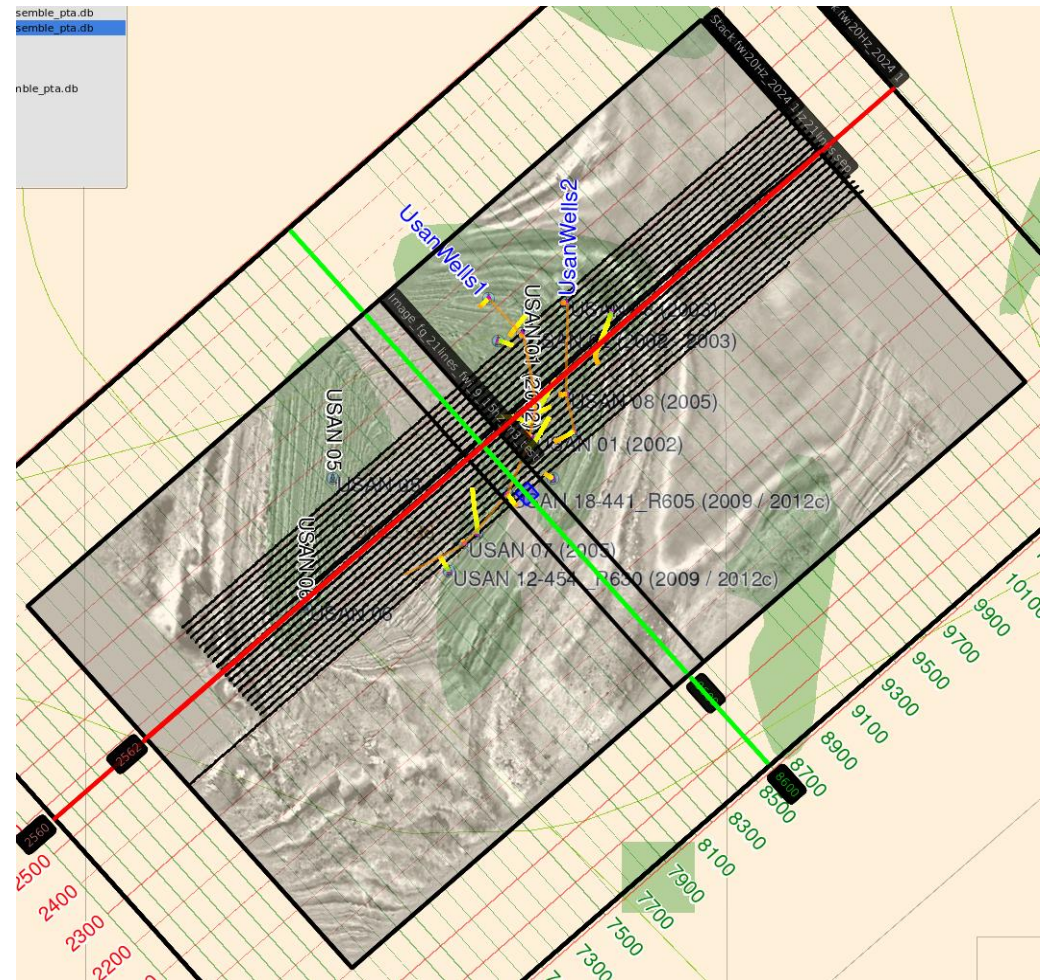


stack + 4DFWI

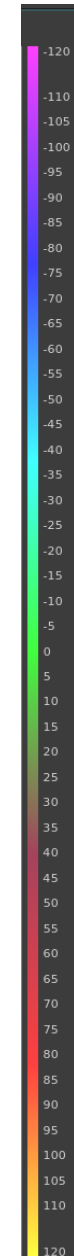
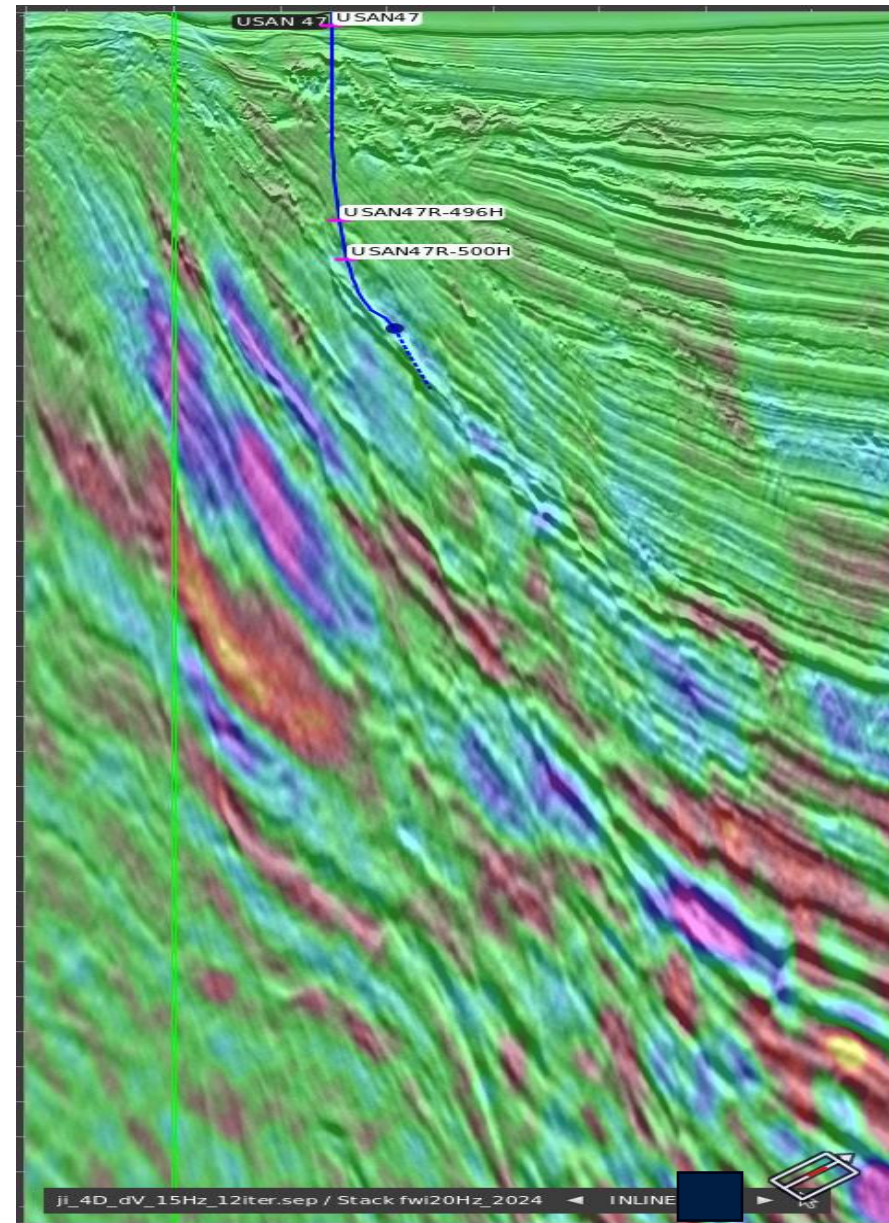
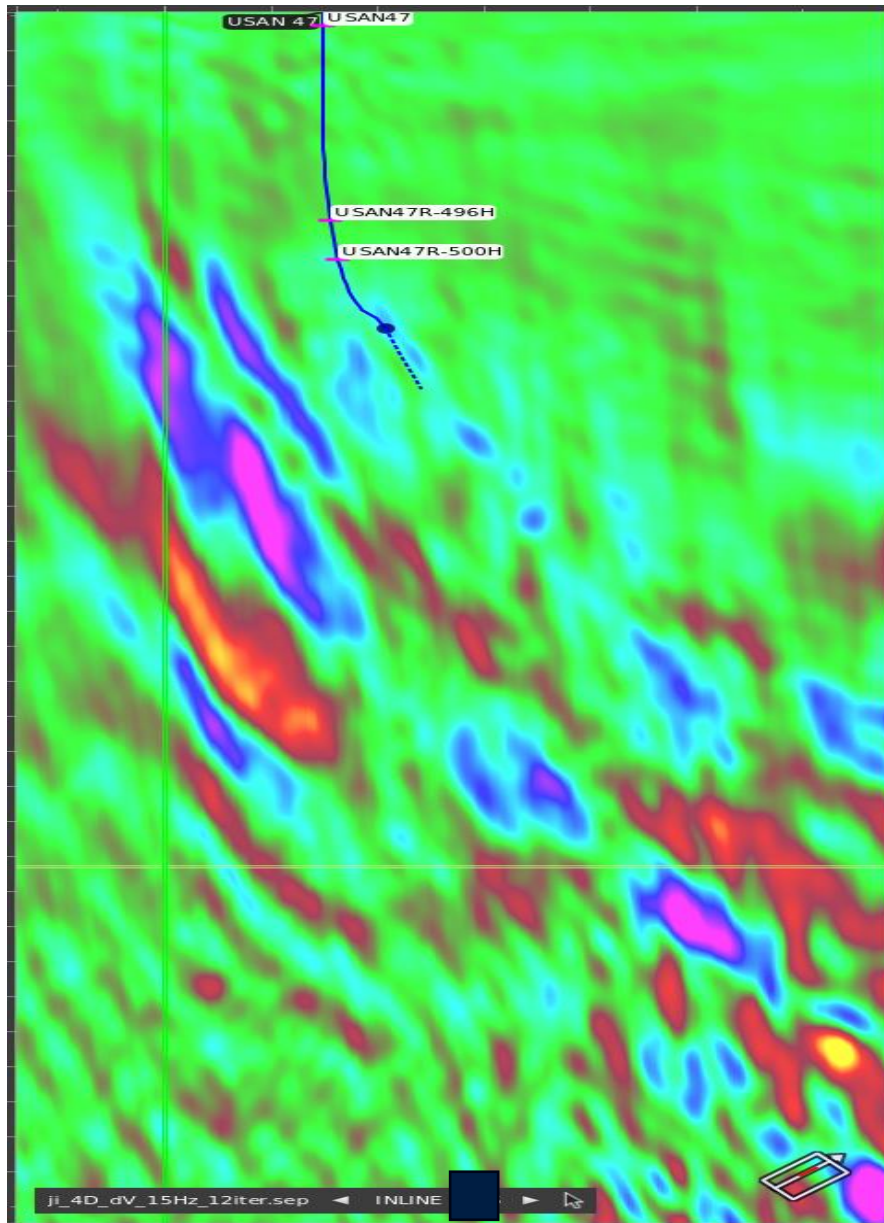


4D FWI – Streamer example

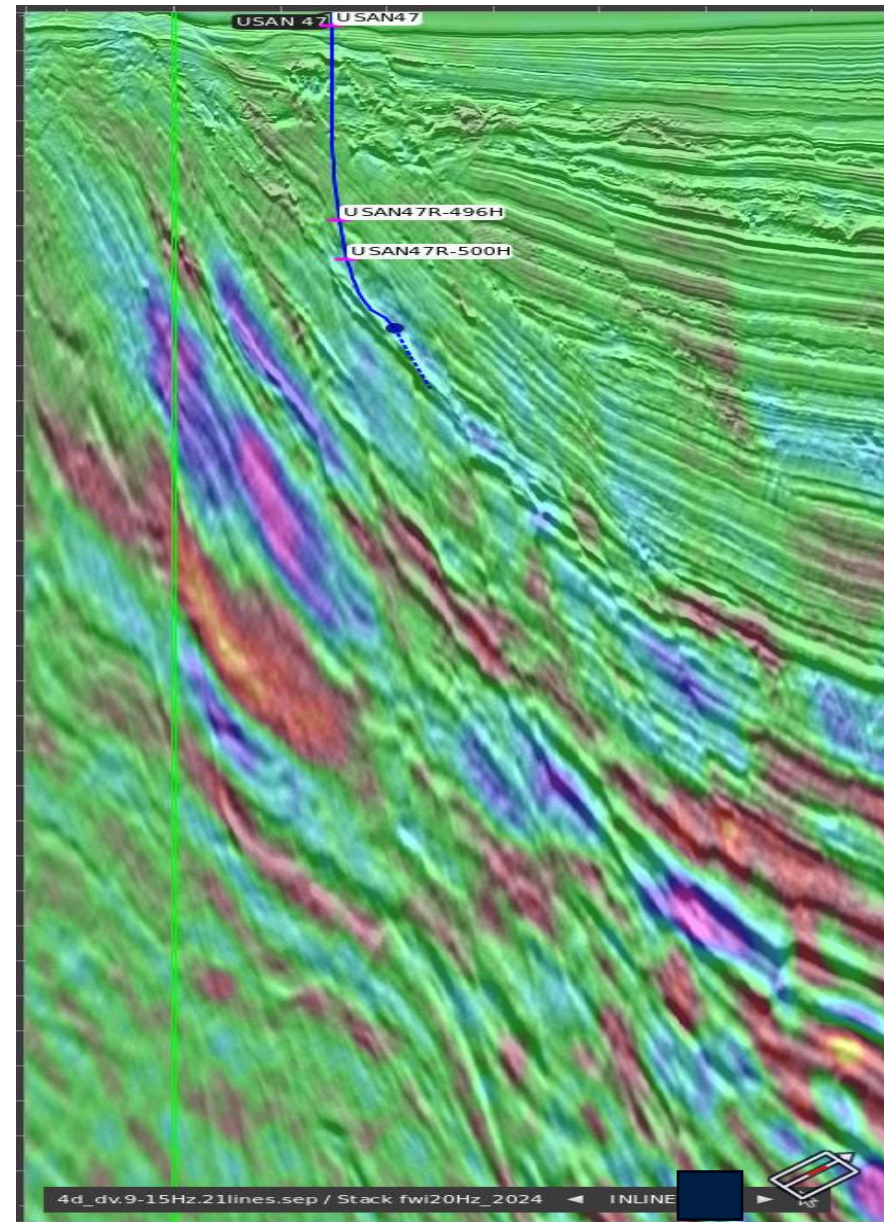
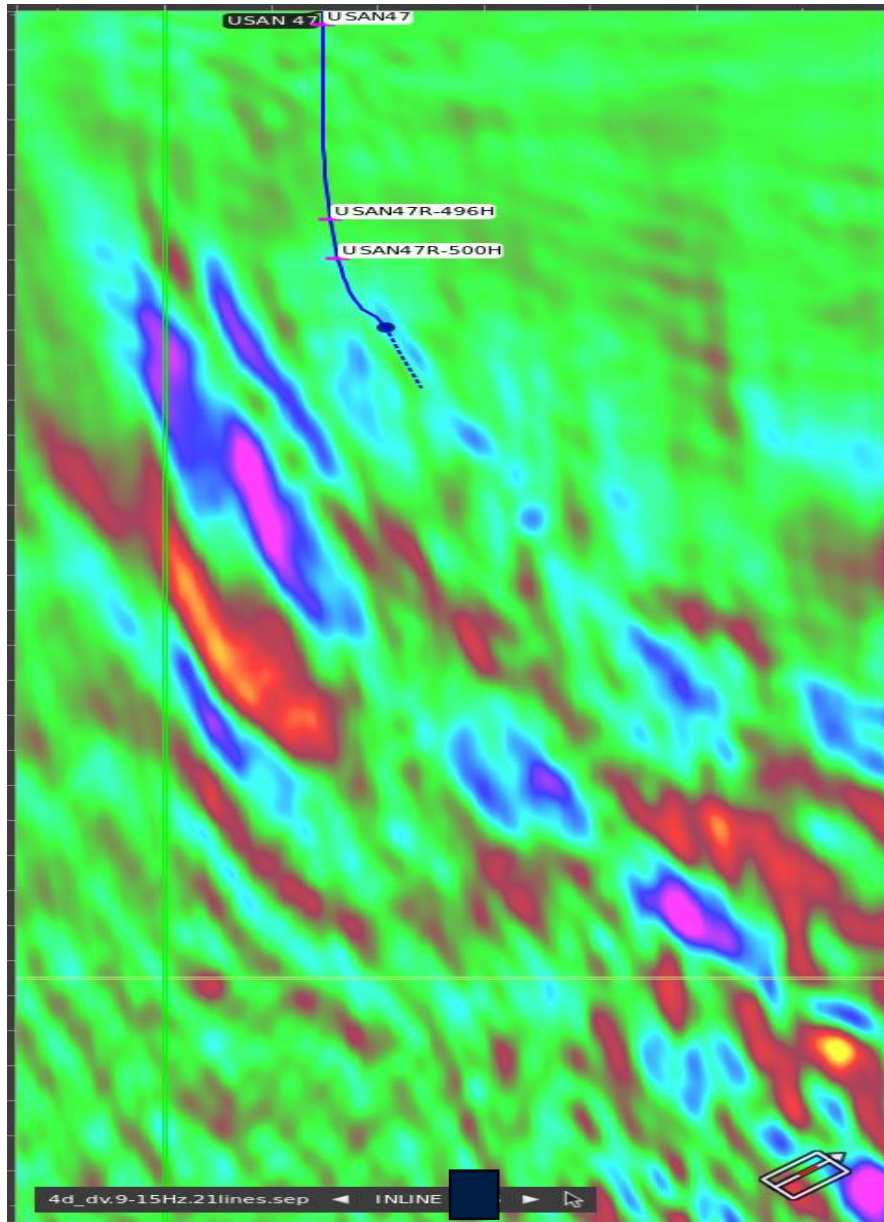
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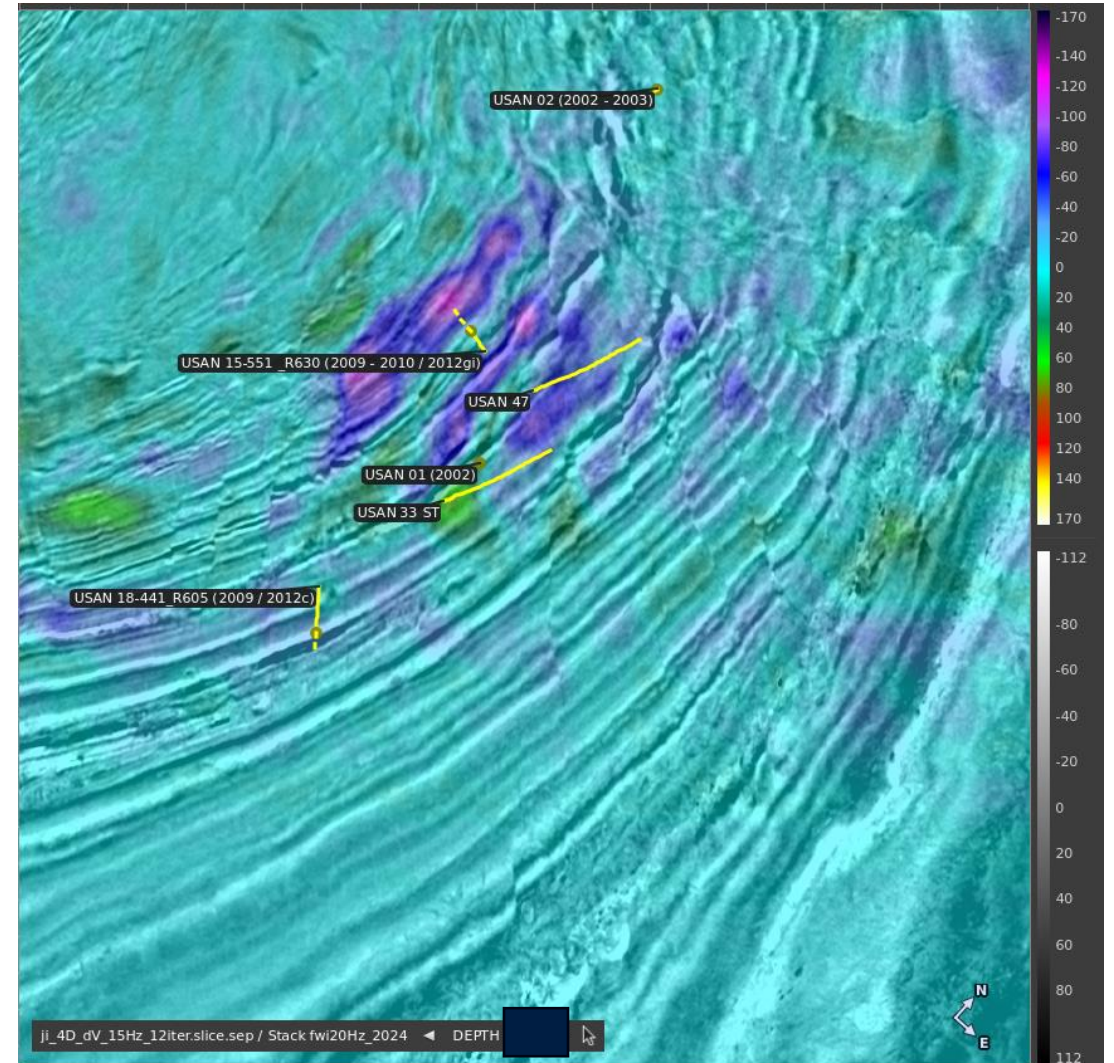
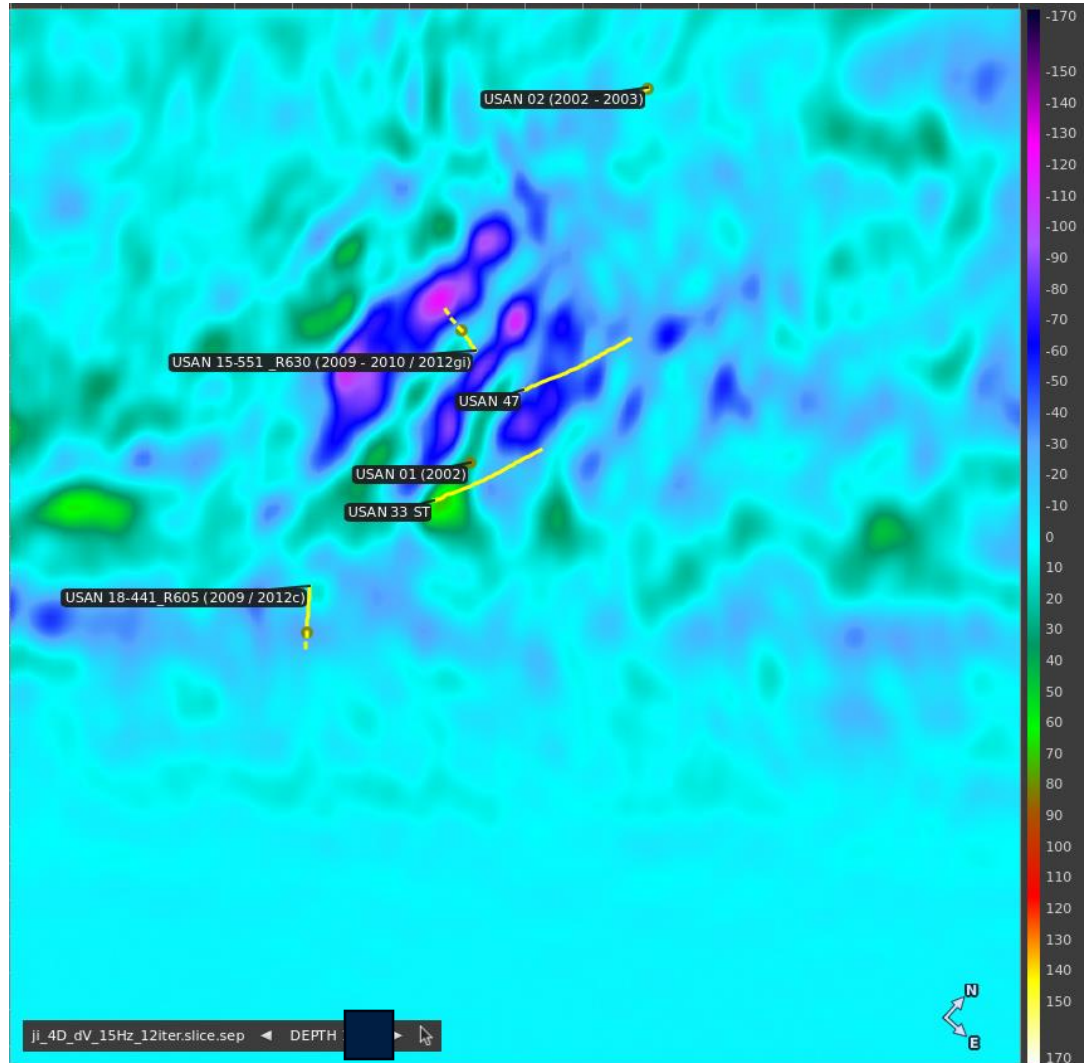
Joint inversion



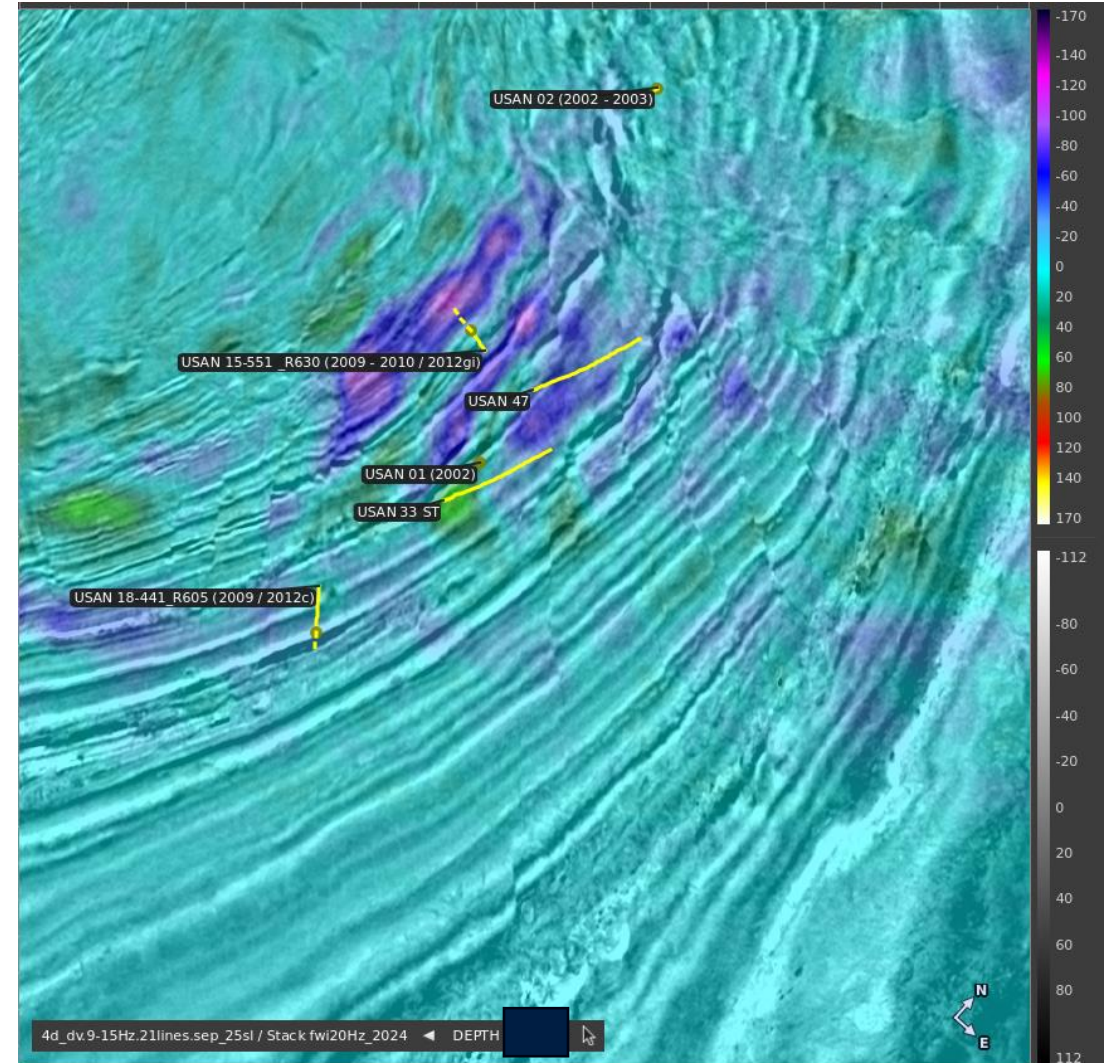
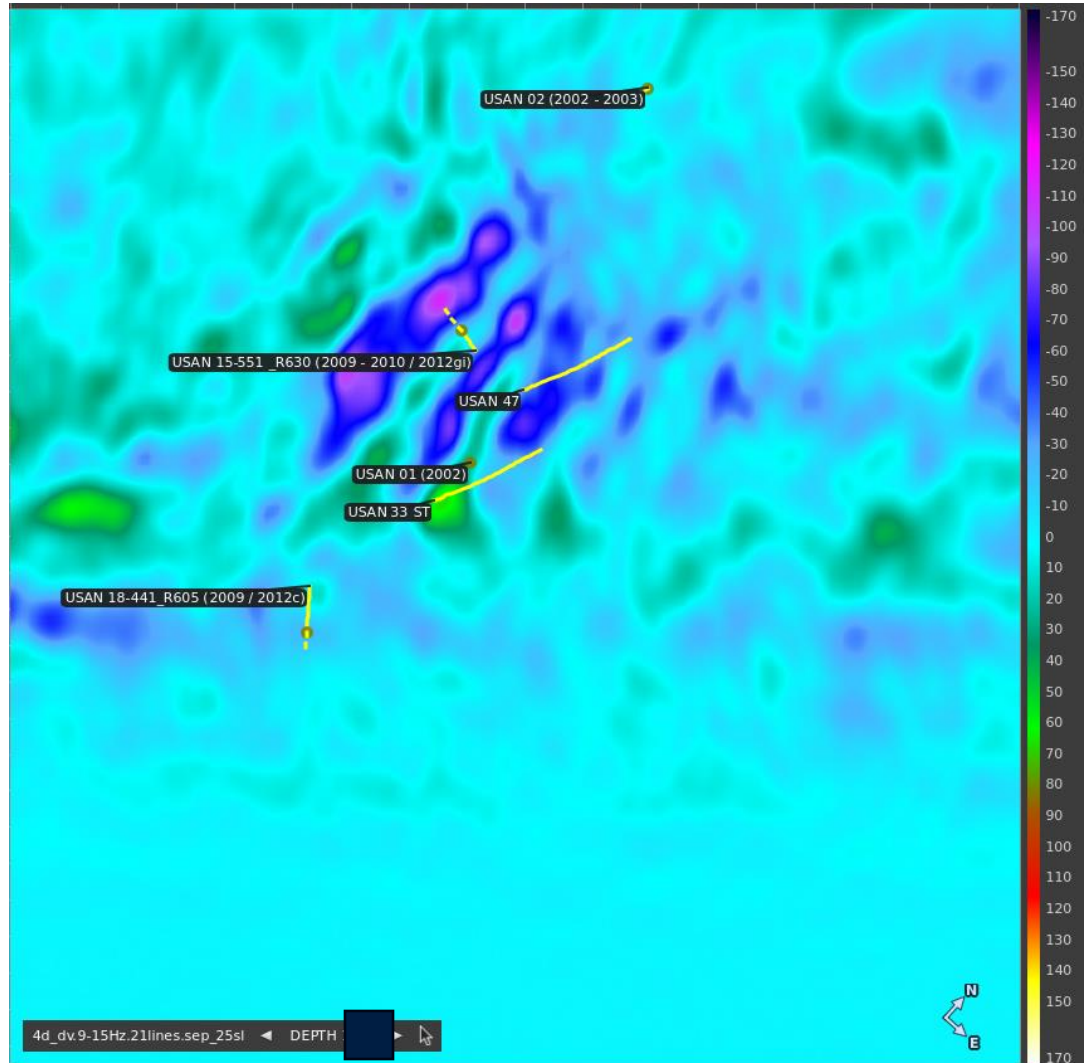
Parallel inversion



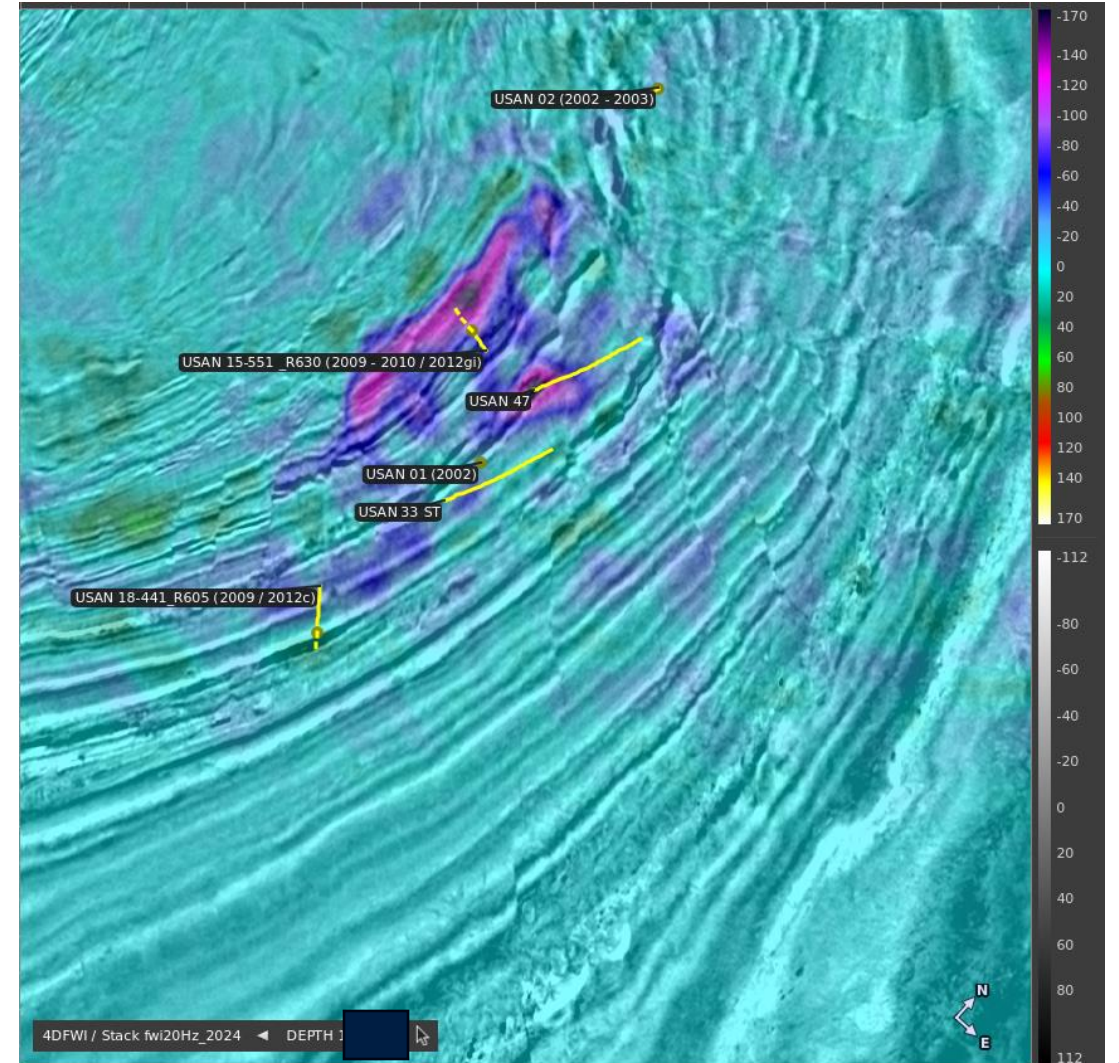
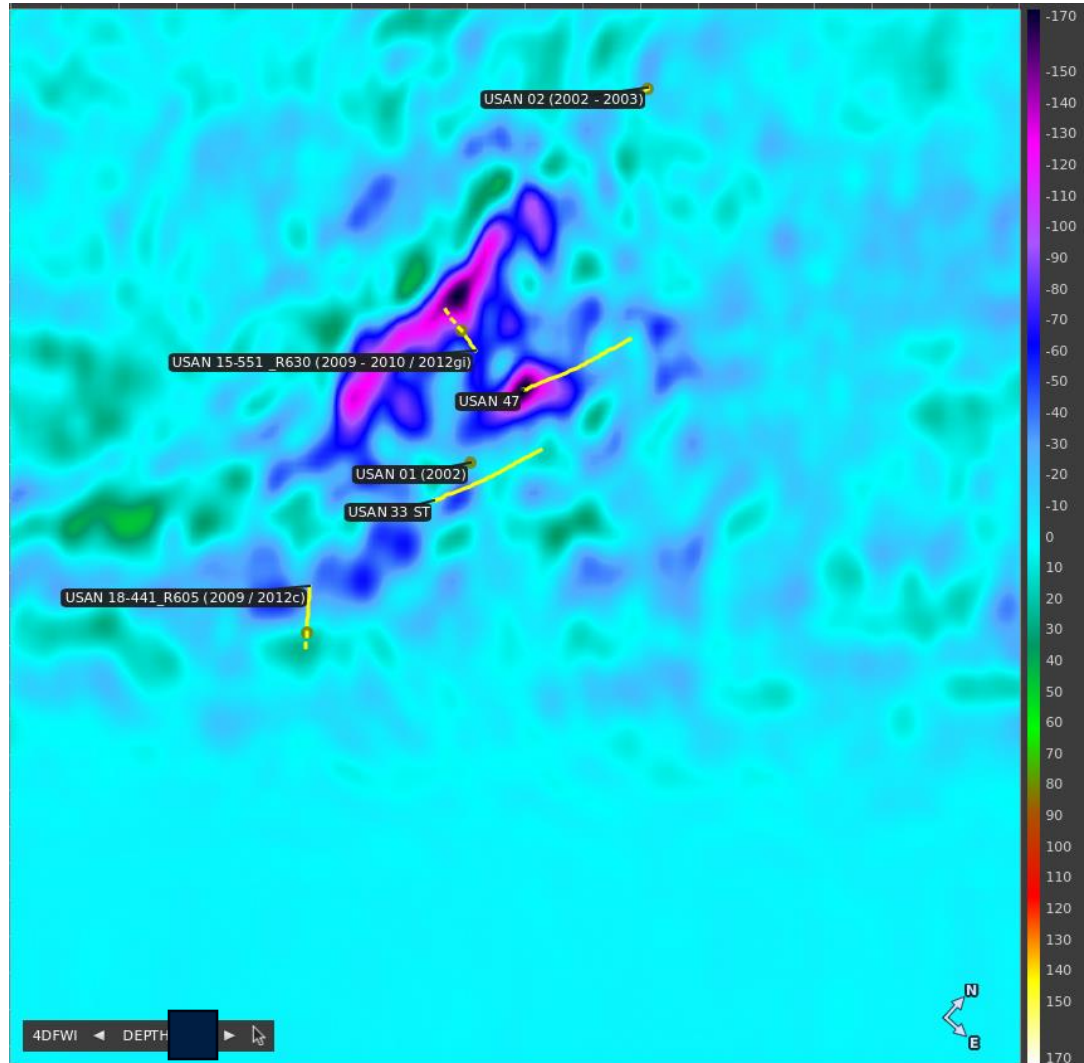
Joint Inversion (1800m)



Parallel Inversion (1800m)



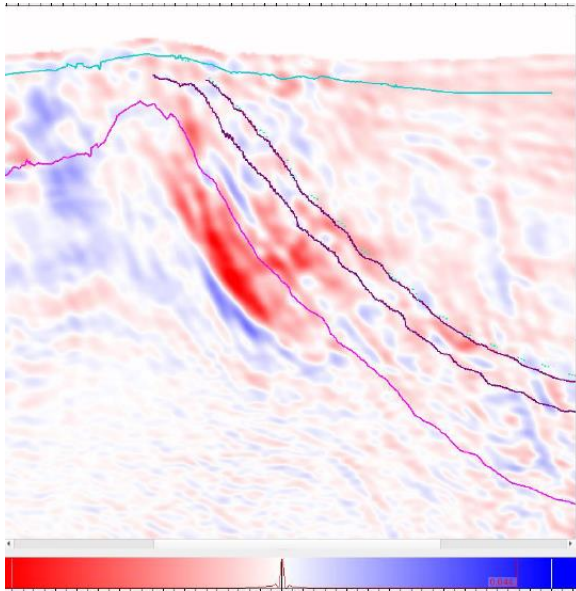
Parallel Inversion (1800m) – 11 sail lines – no binning



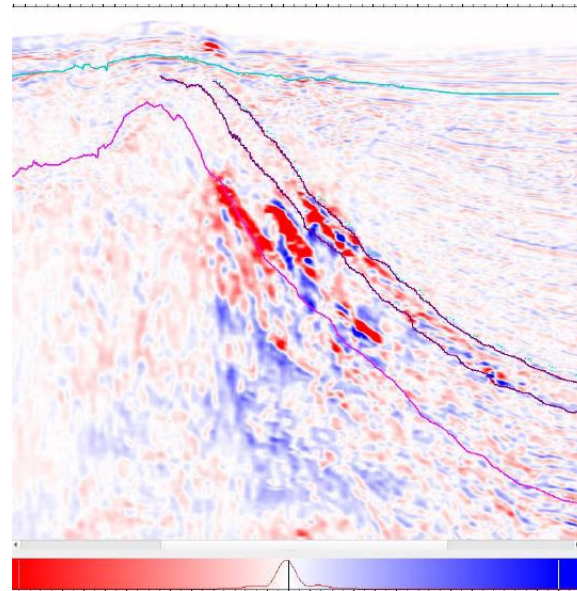
Comparison of dV/V from timeshifts, 4DFWI and reflectivity

- 4D FWI is band limited due to the nature of the test

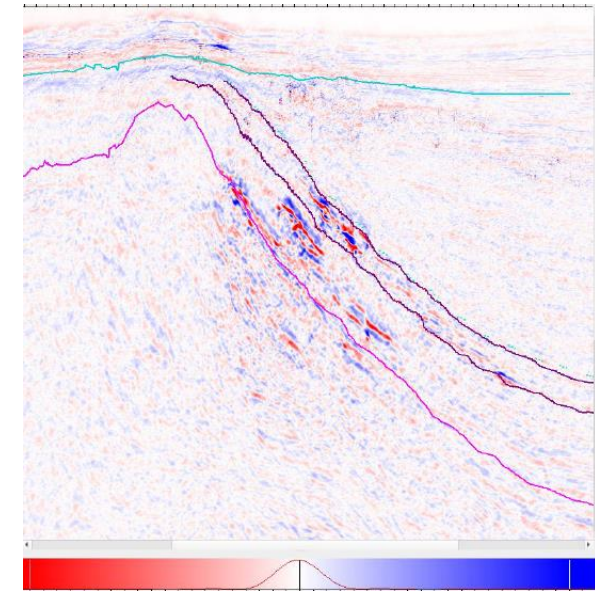
4D FWI – 20Hz



dV/V from 150Hz reflectivity



Conventional 4D difference



4D FWI - learnings



- Data regularization (shot and receiver selection) is important for both OBN and streamer
- Don't be tempted to do too small a test area
- Parallel 4D FWI is robust
 - Get away with proof of concepts by not repeating all frequency bands in some circumstances
- Joint inversion 4D FWI
 - equivalent results to the parallel with around 60% of the total iterations
- Depth calibration/registration of the two velocity models can be tricky
 - Move back to time and then back to depth with one velocity field helps interpretability
- Differences in noise content between surveys...

The future



- Acoustic appears to be working
 - It gives some insights that are hard to see on
 - More examples will help decide if what we are producing is valid
 - Are all 4D changes really velocity? What about density? Or is the effective reflectivity stamping putting in density effects into our velocity already?
 - we know acoustic isn't right, but how wrong is it?
 - Acoustic gathers are a way for us to minimize the issues
- Elastic (using V_p and Density relationships)
 - Currently running – no showrights – sorry...maybe in Galveston?
- Full Elastic
 - Inverting for V_s and density
 - V_p and AVO via ML to get density estimates
 - V_p , V_s and Density from multi-component data
 - We aren't that far away....

Acknowledgements



- We would like to thank TGS for supporting our efforts



- Clair Joint Venture Group (bp, Shell, Chevron & Harbour) for permission to share the OBN examples



- Usan production group (Esso Nigeria, Chevron, TotalEnergies & CNOOC) Nigerian Streamer example



- Bulwark as our partners in Nigeria





Thank you

Daniel.Davies@tgs.com

Daniel Davies



Energy Starts With Us