

# Time-lapse VSP results from the CaMI.FRS

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# VSP surveys were performed 2017-2020

- Vibe source (10Hz-150Hz), 3C geophones, Silixa (2017) and Fotech (2018) DAS interrogators
- Fall 2020 survey data not processed

## Geophones

2019-2018 (7t CO<sub>2</sub>)

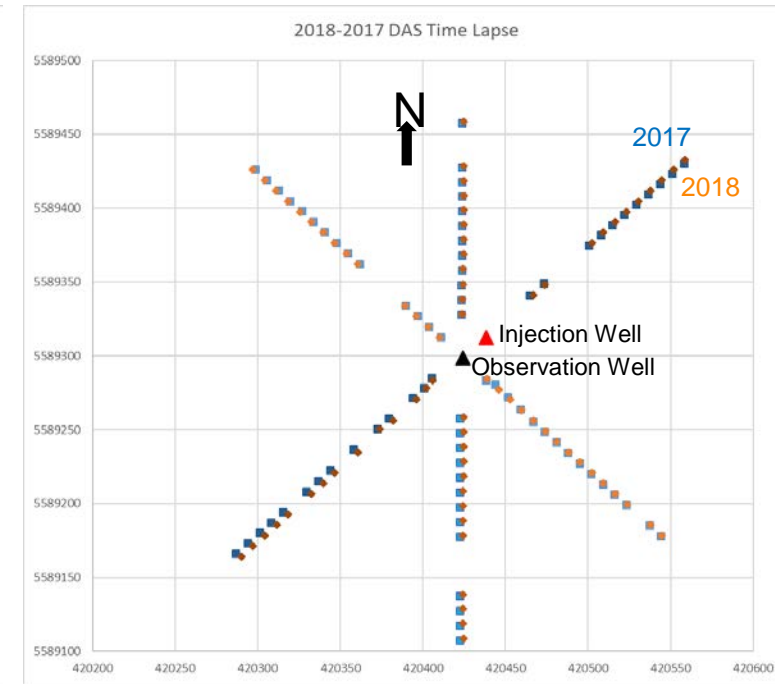
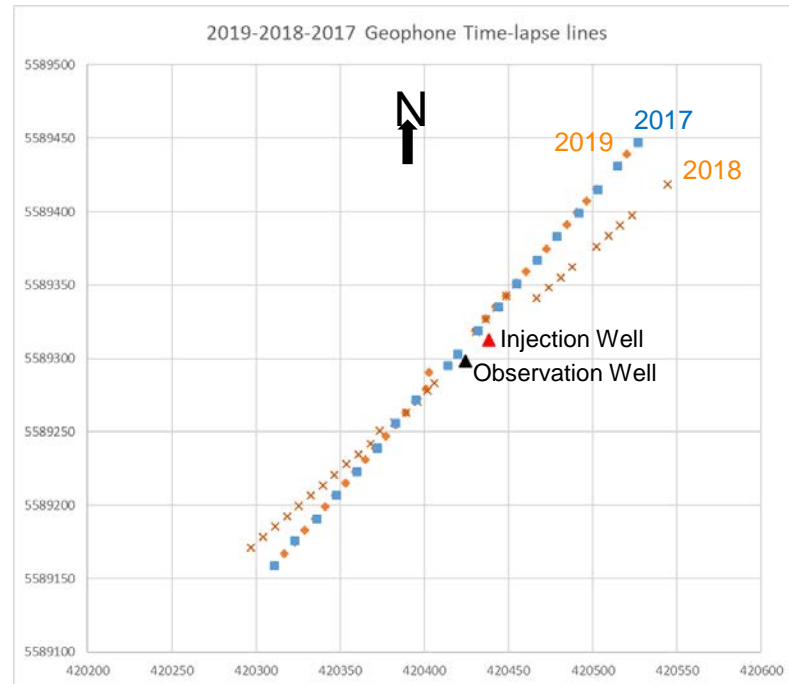
2019-2017 (15t CO<sub>2</sub>)

## DAS

2018-2017 (8t CO<sub>2</sub>)

Injection well is 20m to the NE of the geophysics well

These lines span up to 160m to 190m offset





# NRMS and Predictability gauge repeatability

Normalized root-mean-square:

$$NRMS = \frac{200 \times RMS(a_t - b_t)}{RMS(a_t) + RMS(b_t)}$$

- Low value means traces a & b are similar
- Calculated over a time window
- Sensitive to amplitude, phase differences, and random noise

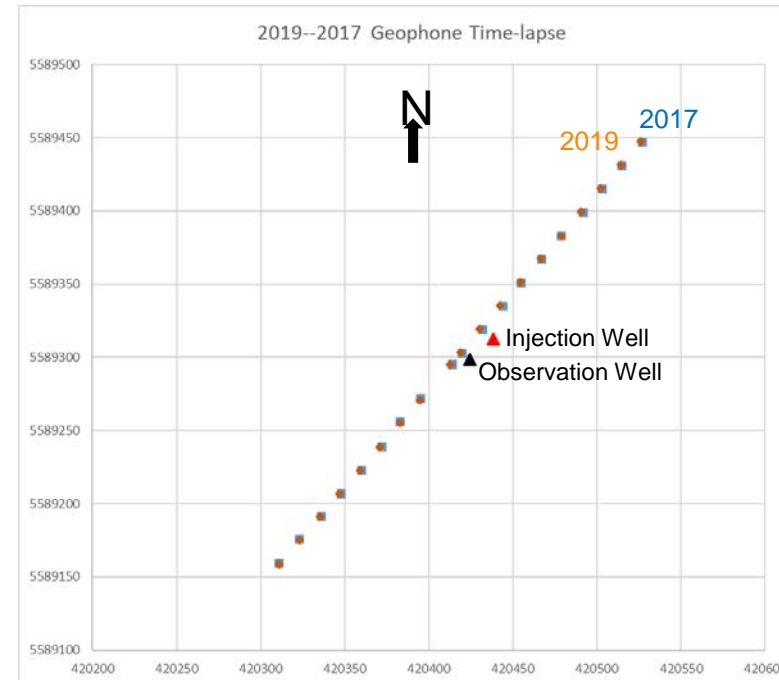
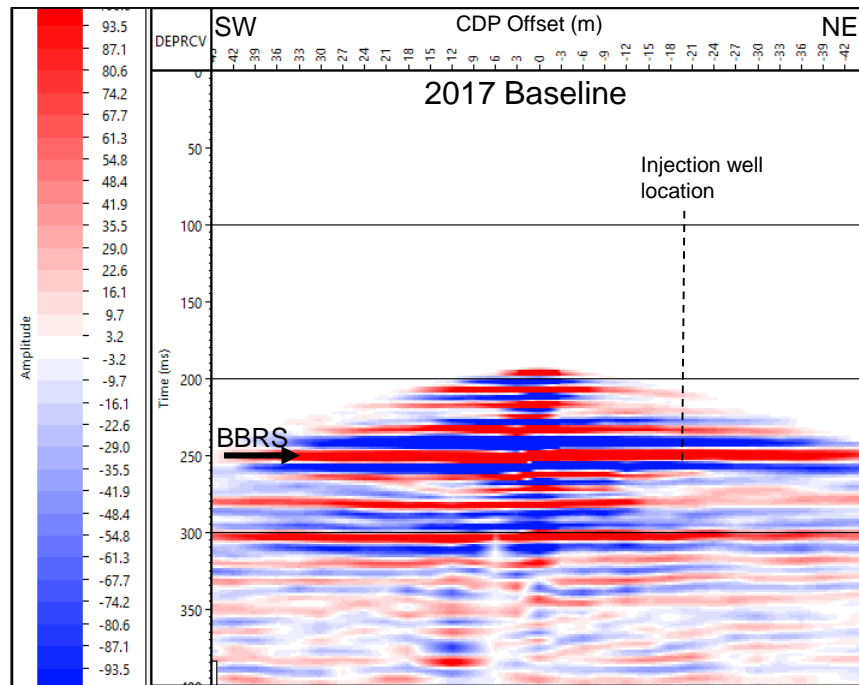
Predictability:

$$PRED = \frac{\sum(\varphi_{ab}(t) \times \varphi_{ab}(t))}{\sum(\varphi_{aa}(t) \times \varphi_{bb}(t))}$$

(Kragh and Christie, 2010)

- High value means traces a & b are similar
- Based on correlations and autocorrelations  $\varphi$  of traces a & b for time window t
- Sensitive to correlation lag, reflectivity differences, random noise

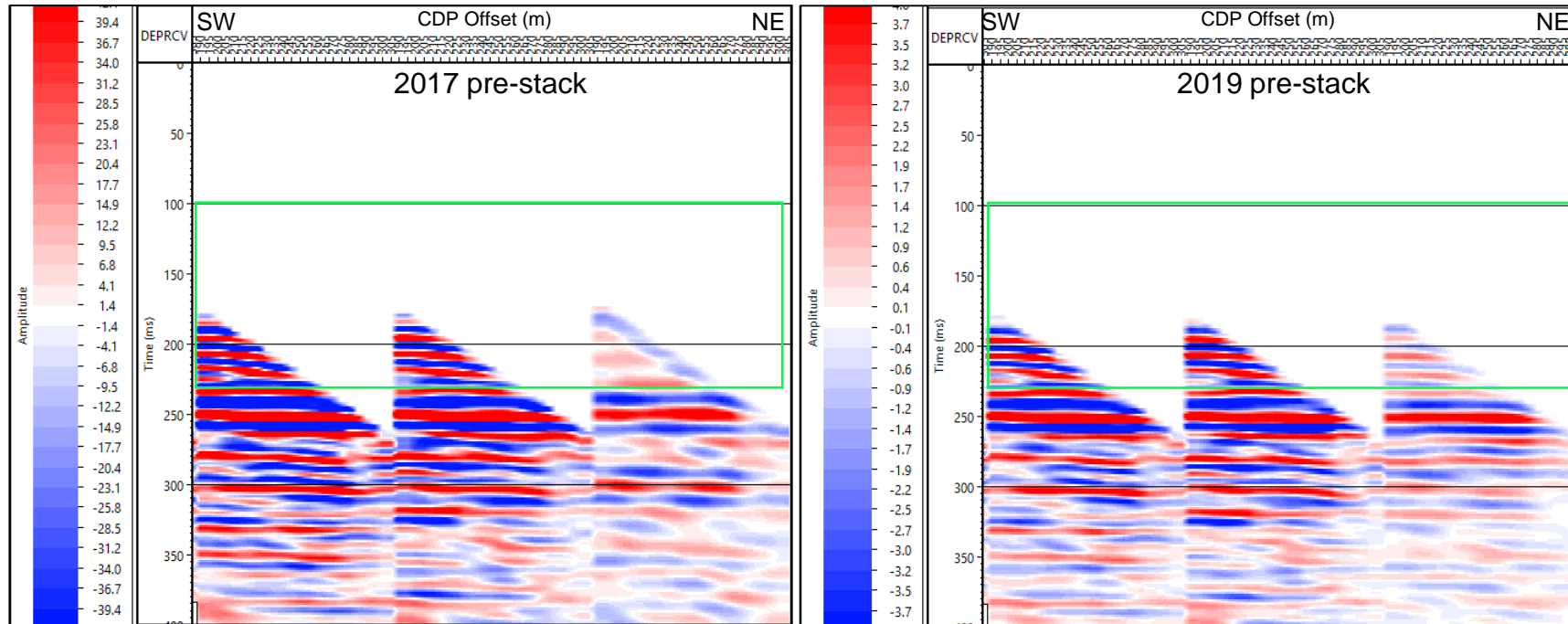
- Strong positive reflection at the top of the reservoir, Basal Belly River Sandstone (BBRS)
- Challenging to scale the BBRS reflection for time-lapse
- Limited data above BBRS at injection well offset (20m) with low amplitude, low fold data





# Unable to exclude reservoir from shape filter design

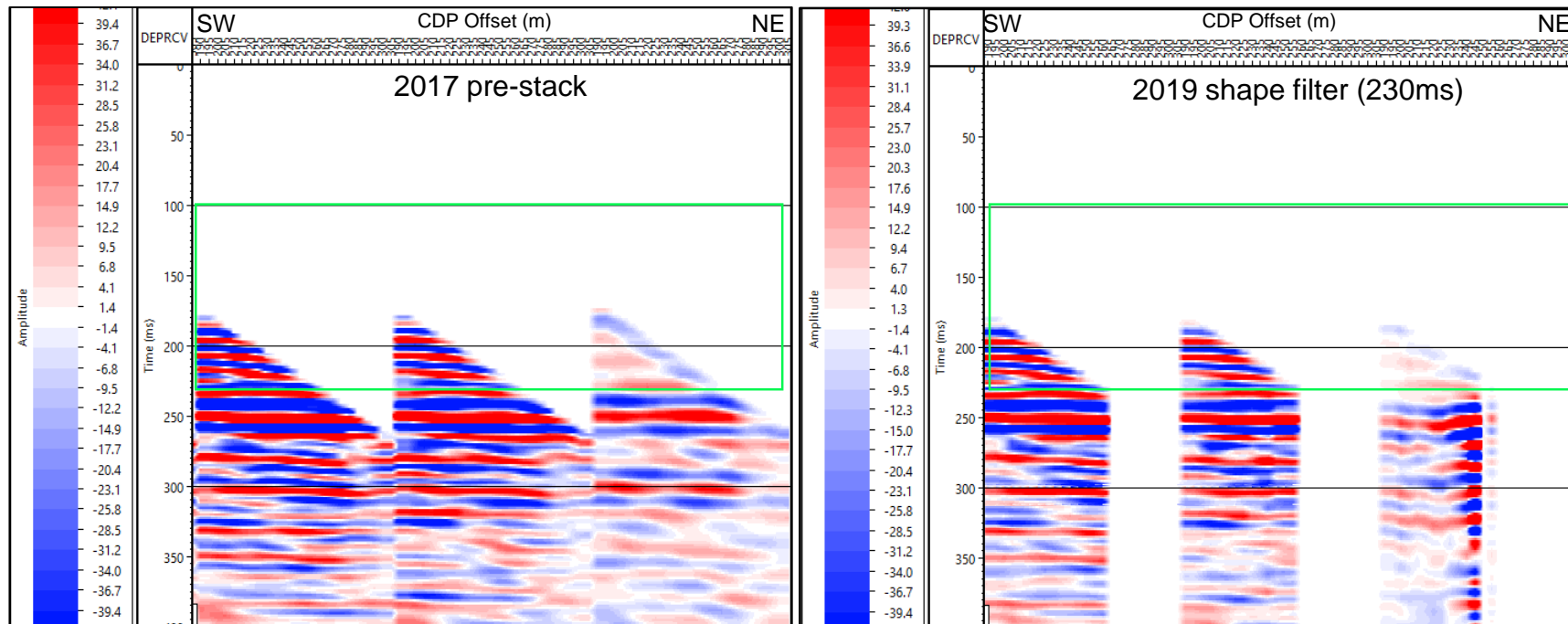
- BBRS at 250ms
- 0-230ms and 0-240ms windows had deleterious effect on data





# Unable to exclude reservoir from shape filter design

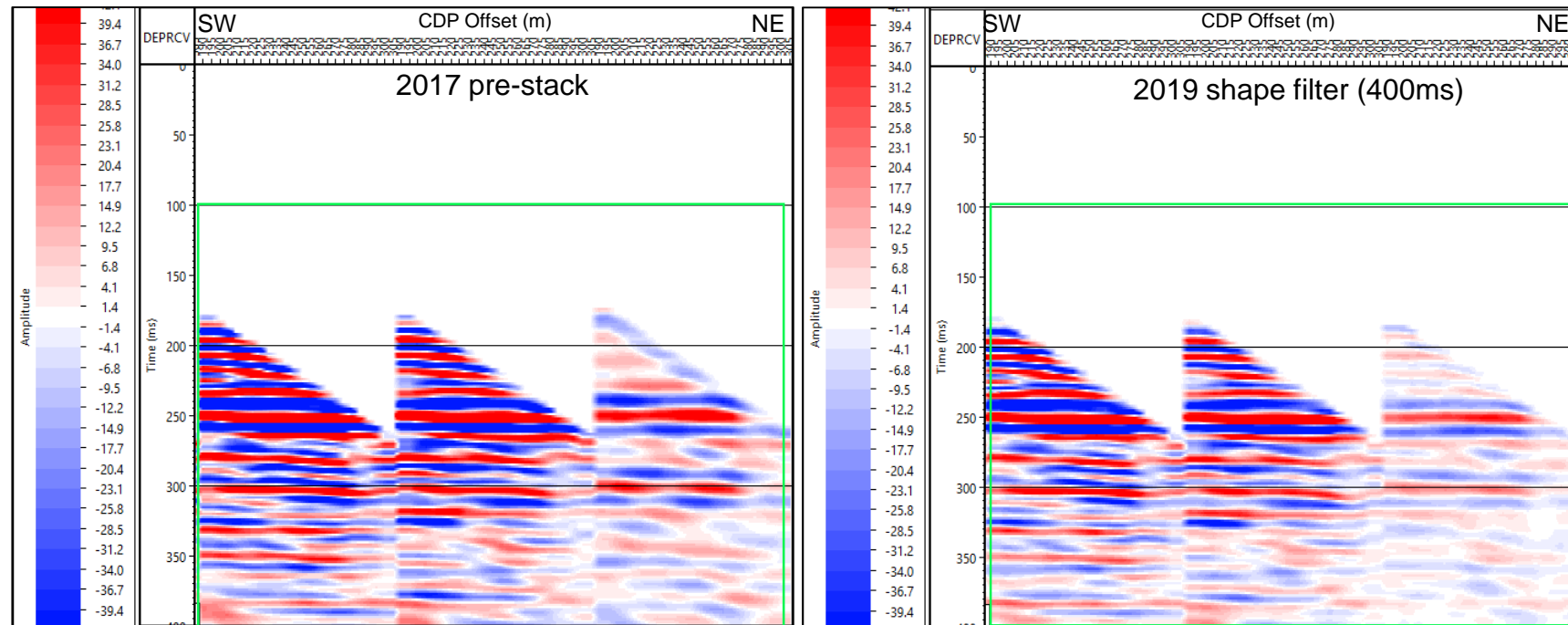
- BBRs at 250ms
- 0-230ms and 0-240ms windows had deleterious effect on data
- BBRs reflection amplitudes scaled poorly, useful data is cut-out





# Shaping filter includes BBRS reflection

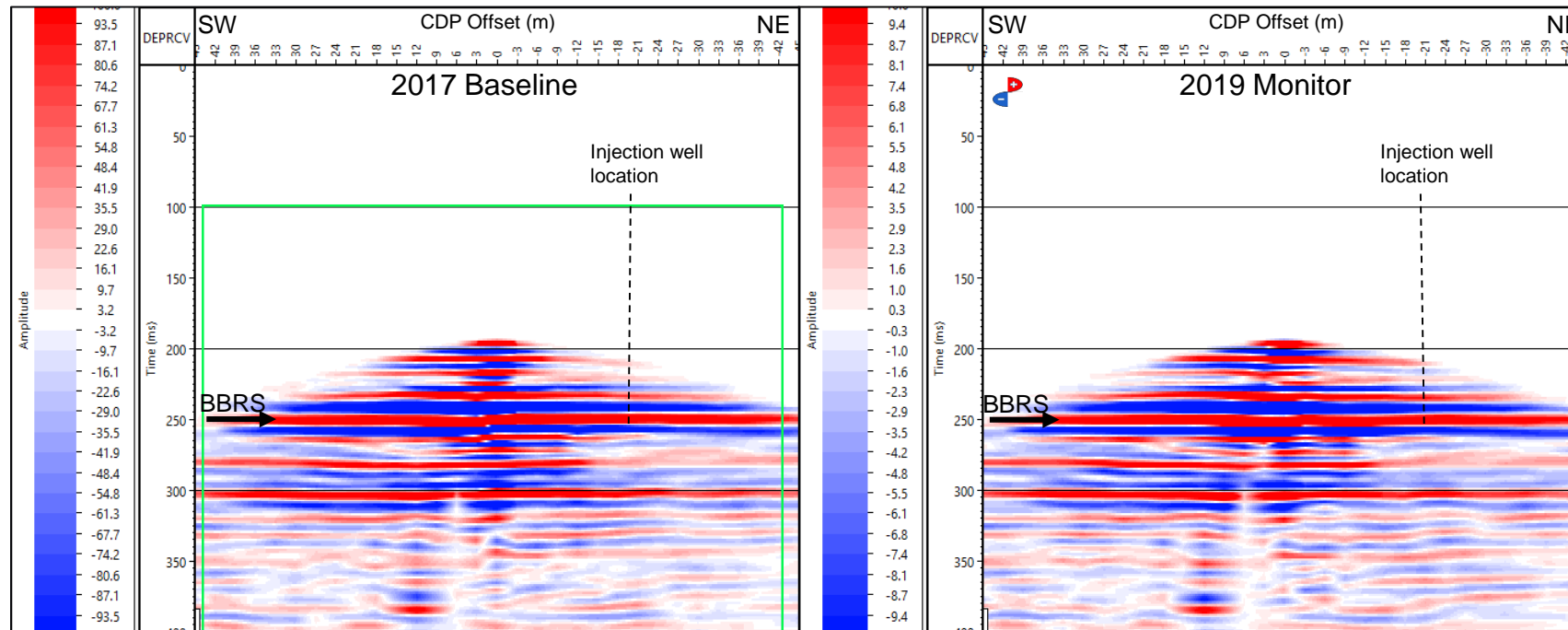
- 0ms-400ms shaping filter includes reservoir and as much coherent signal below as possible
- Intended to scale amplitude and phase without altering local CO<sub>2</sub> anomaly too much





# Shaping filter applied to 2019 monitor data

- Filter applied to pre-stack, TWT gathers







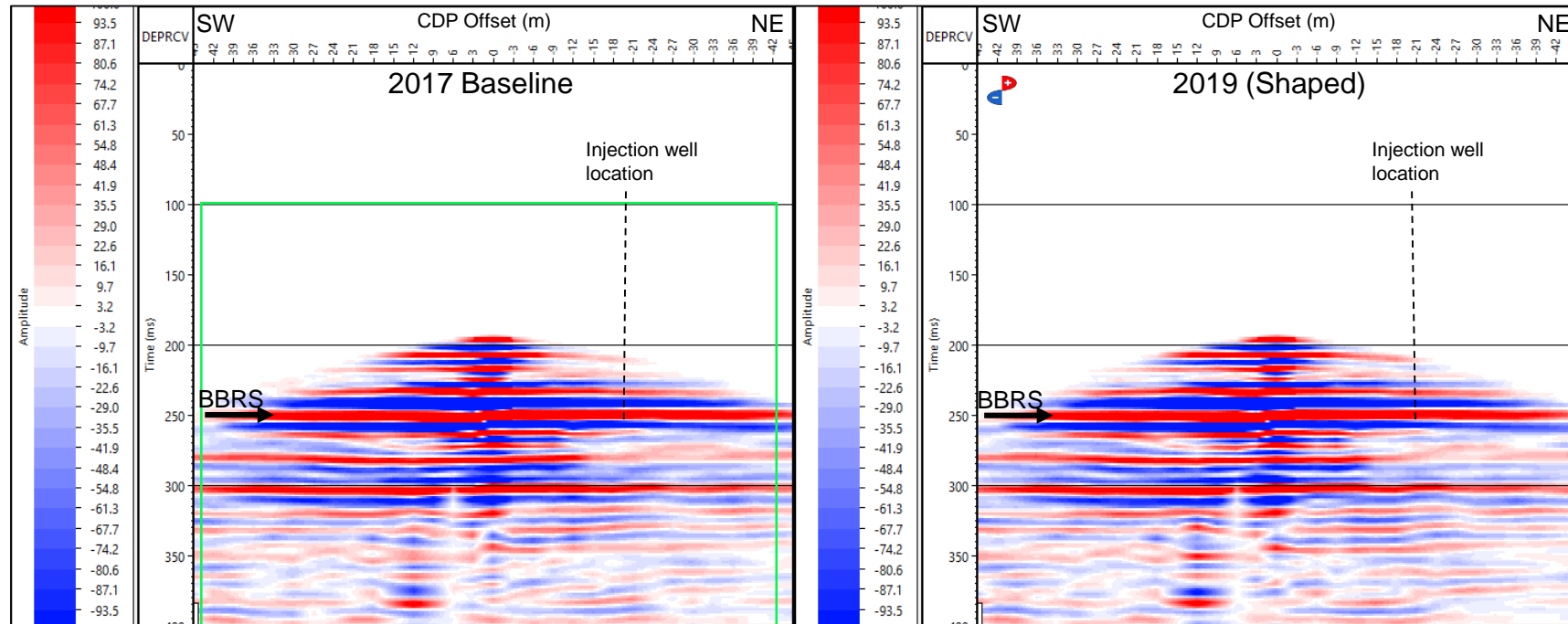
# Shaping filter applied to 2019 monitor data

- Filter applied to pre-stack, TWT gathers
- 400ms design window, 40ms filter operator length
- Shaped 2019 matches 2017 quite well

0-400ms	
NRMS	PRED
15.6%	98.9%

230ms-270ms	
NRMS	PRED
12.3%	99.4%





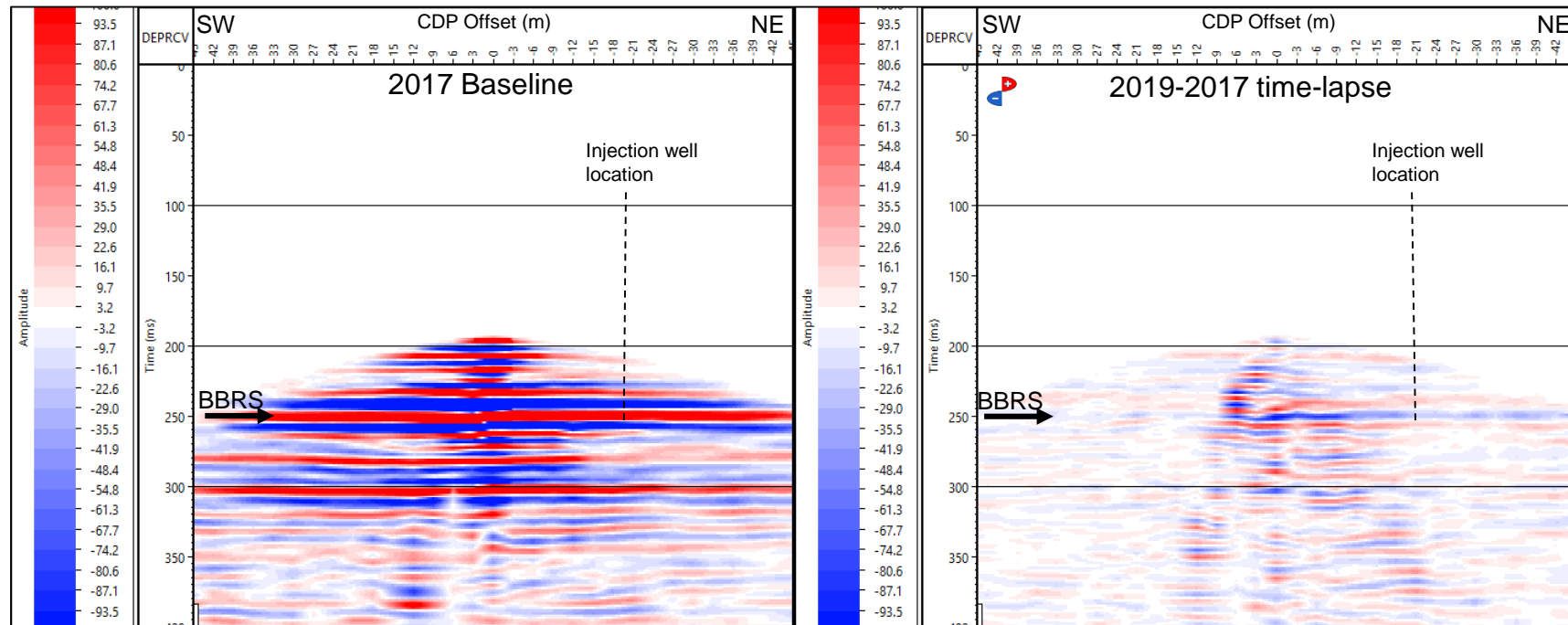
# Full-stack time lapse

- Affected by residuals from high amplitude near offset shots
- This is a consistent problem across all VSP lines

0-400ms	
NRMS	PRED
15.6%	98.9%

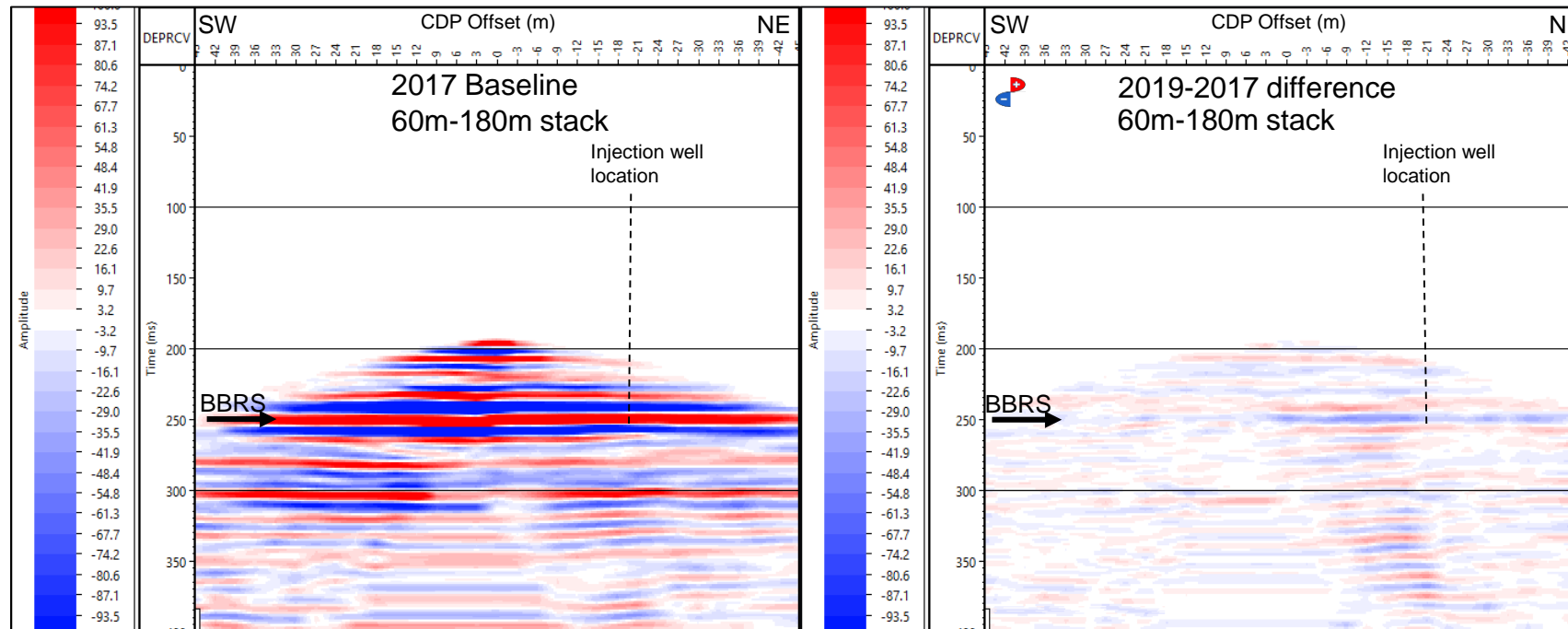
230ms-270ms	
NRMS	PRED
12.3%	99.4%





# Removing near offset shots reduces residual amplitude

- <50m offset shots cause most of the unwanted residuals
- 60m offset shot still causing problems



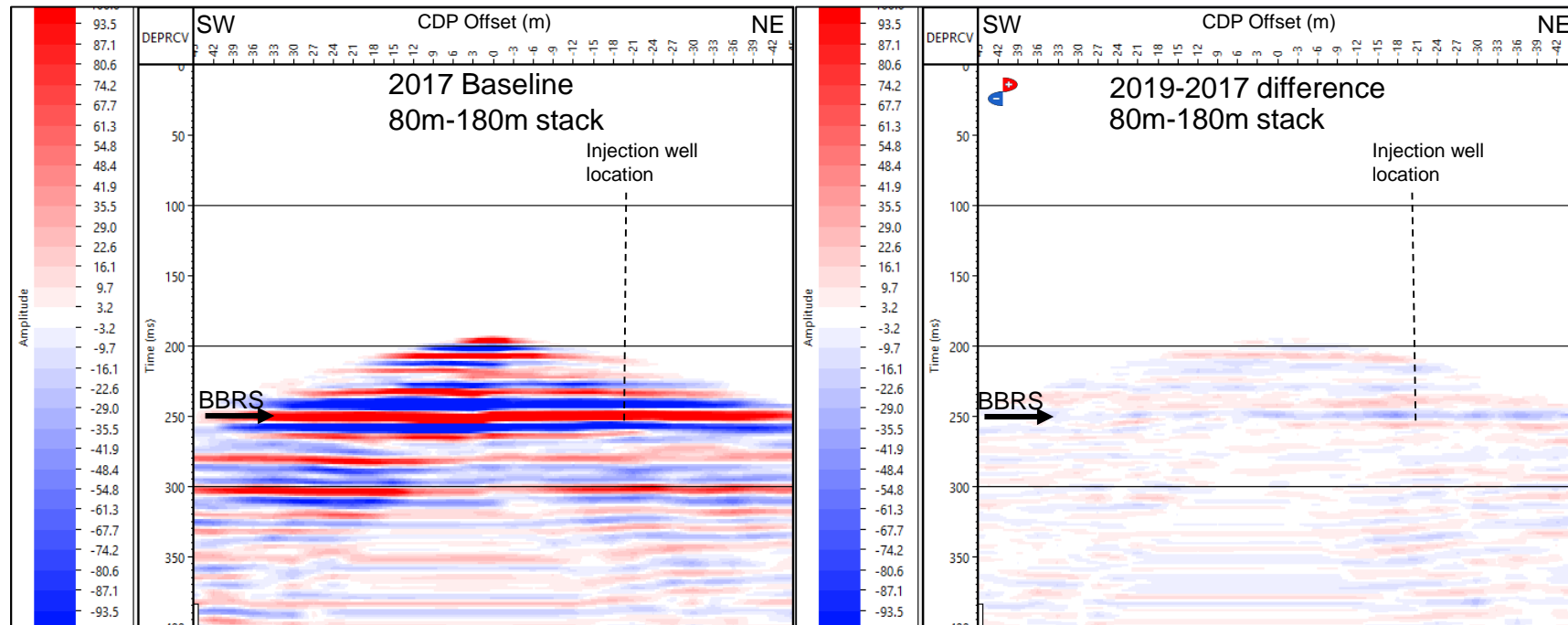


# Removing near offset shots reduces residual amplitude

- 80m-180m mid-far offset stack has the lower fold, frequency content, but good NRMS
- BBRs amplitude successfully reduced to nearly zero on the SW side
- Minor negative amplitude anomaly may be present within general BBRs residual to the NE

0-400ms	
NRMS	PRED
11.8%	99.2%

230ms-270ms	
NRMS	PRED
8.3%	99.8%



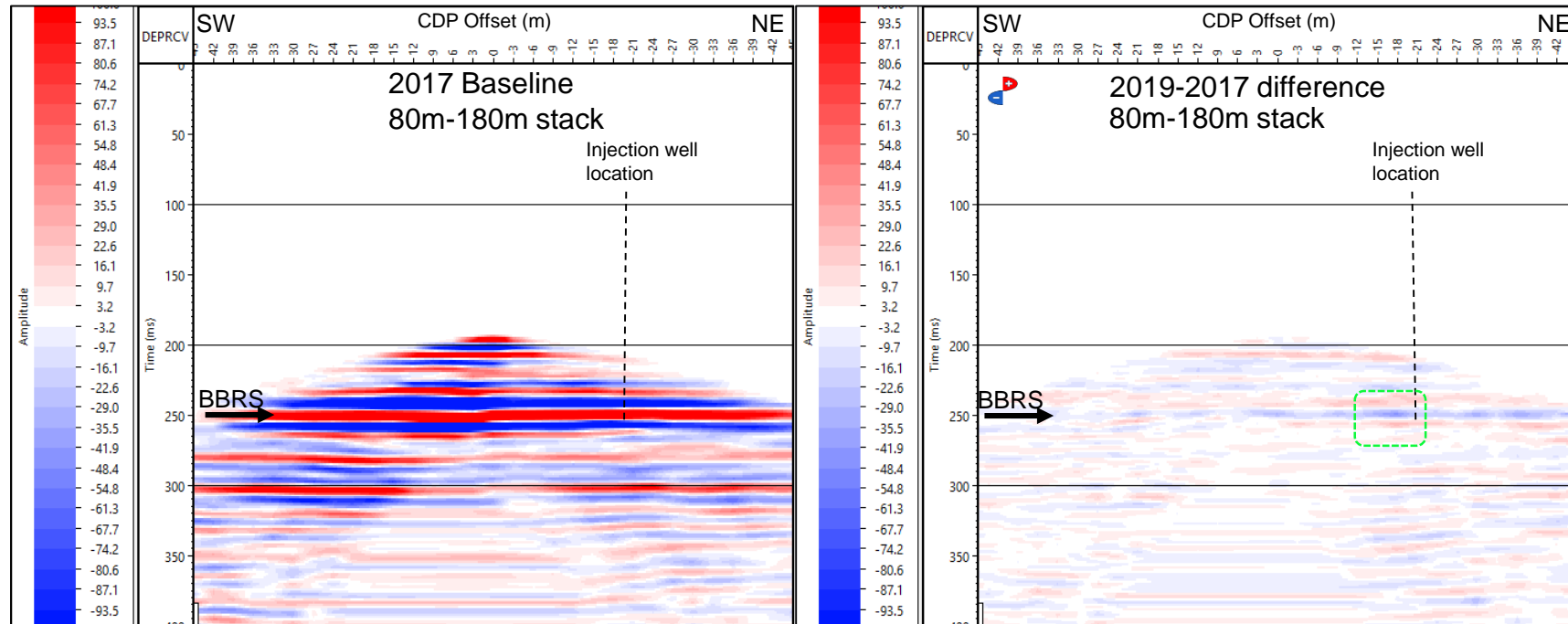


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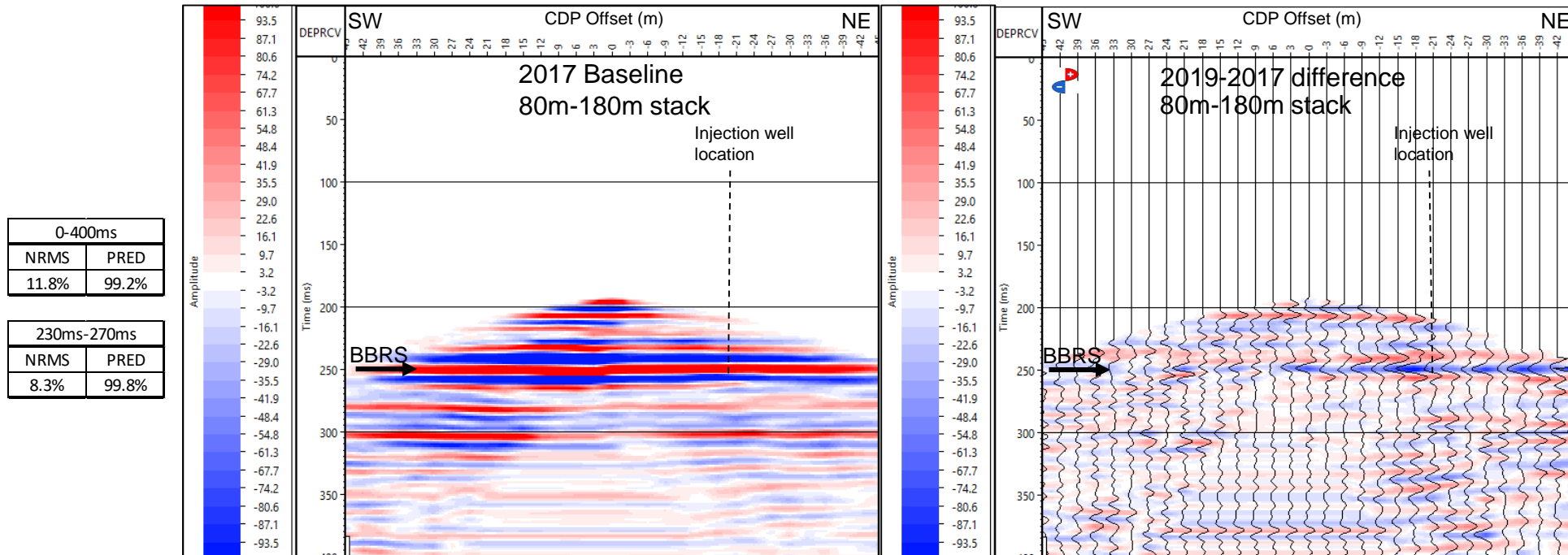
230ms-270ms	
NRMS	PRED
8.3%	99.8%





# Lateral resolution contributes to uncertainty

- The most negative residual near the well is only on one 3m bin
- Successful removal of high amplitude BBRS reflection in most of the section
- Difficult to distinguish anomaly from poorly scaled shot





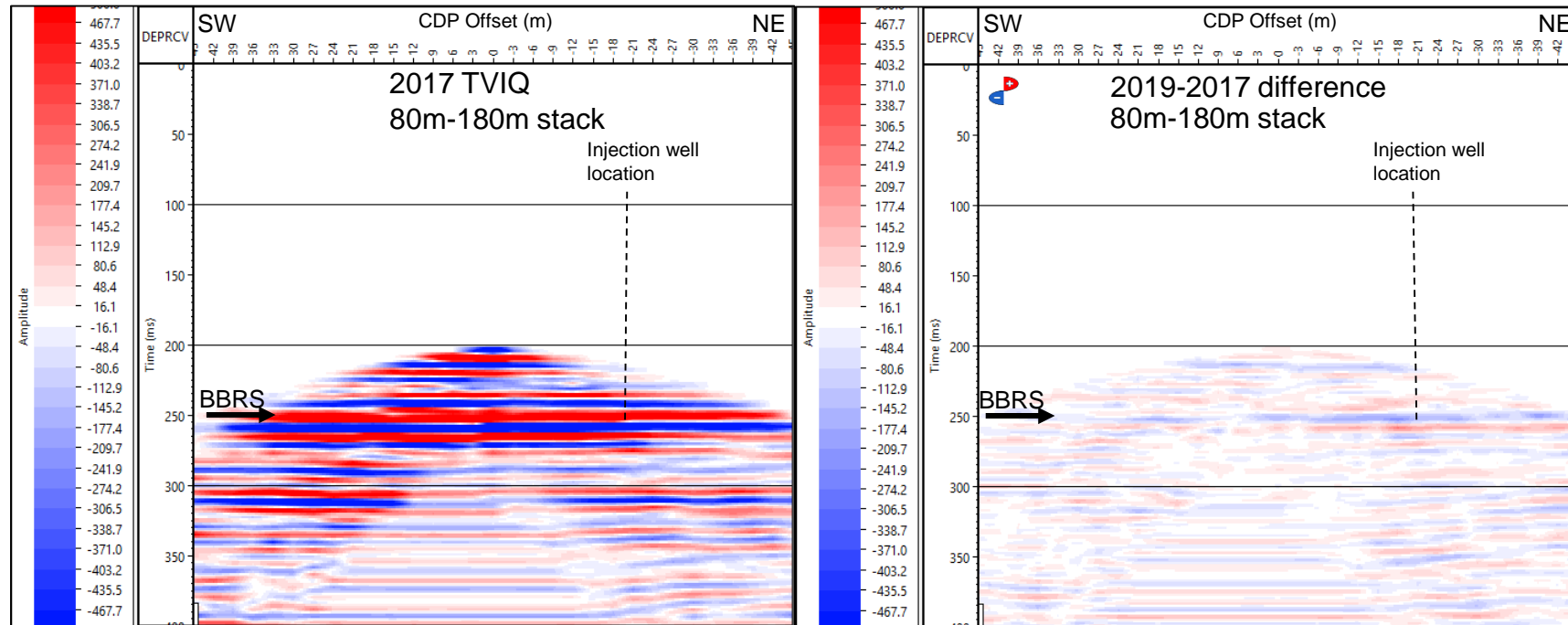
# Time-variant inverse Q filter

- 1D 5 layer attenuation model designed from 2018 MEMS Accelerometer VSP
- Inverse Q filter raises amplitudes of high frequencies based on two-way travel-time
- Intended to improve vertical resolution of reservoir, generally worsens NRMS and PRED
- 2% increase in NRMS from TVIQ filter

0-400ms	
NRMS	PRED
14.4%	98.7%

230ms-270ms	
NRMS	PRED
10.2%	99.6%





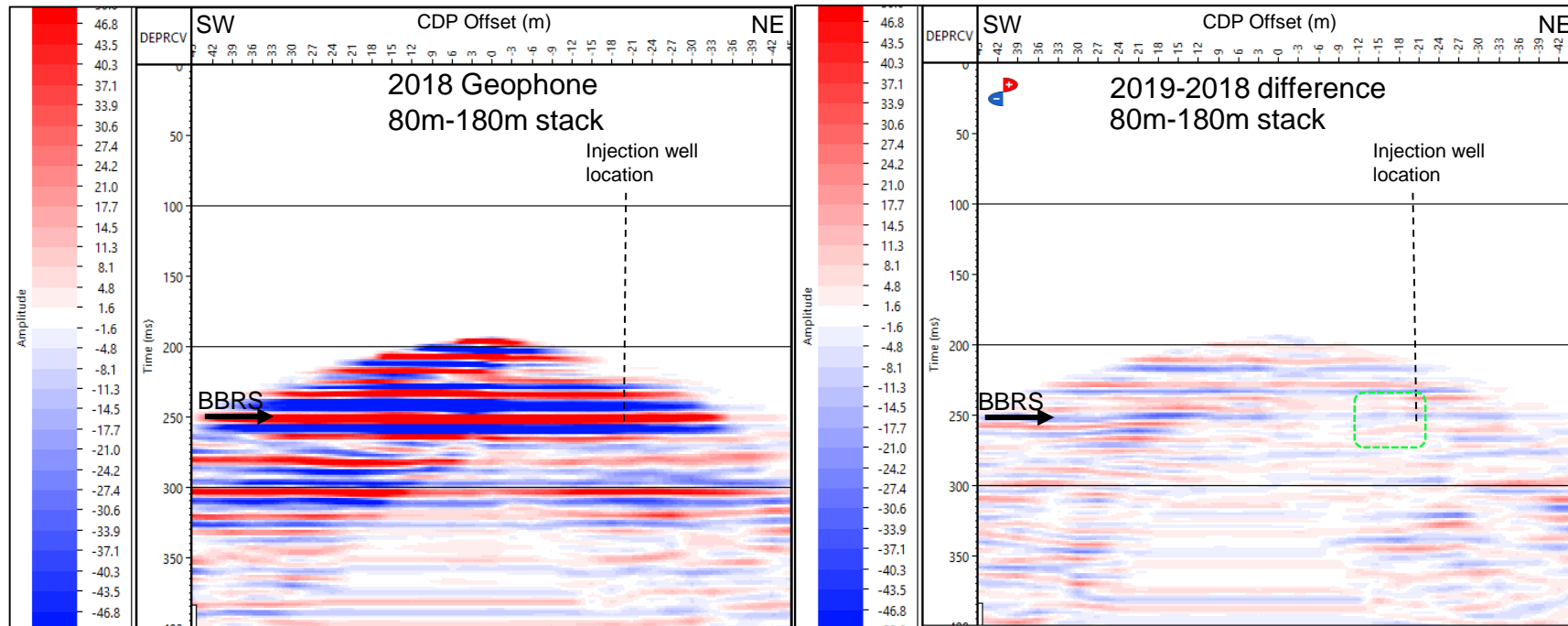
# 2019-2018 results have worse NRMS and PRED

- No CO<sub>2</sub> amplitude anomaly evident above background
- 2%-4% higher NRMS than 2019-2017 result
- SW residuals likely skewing NRMS compared to 2019-2017

0-400ms	
NRMS	PRED
17.8%	98.5%

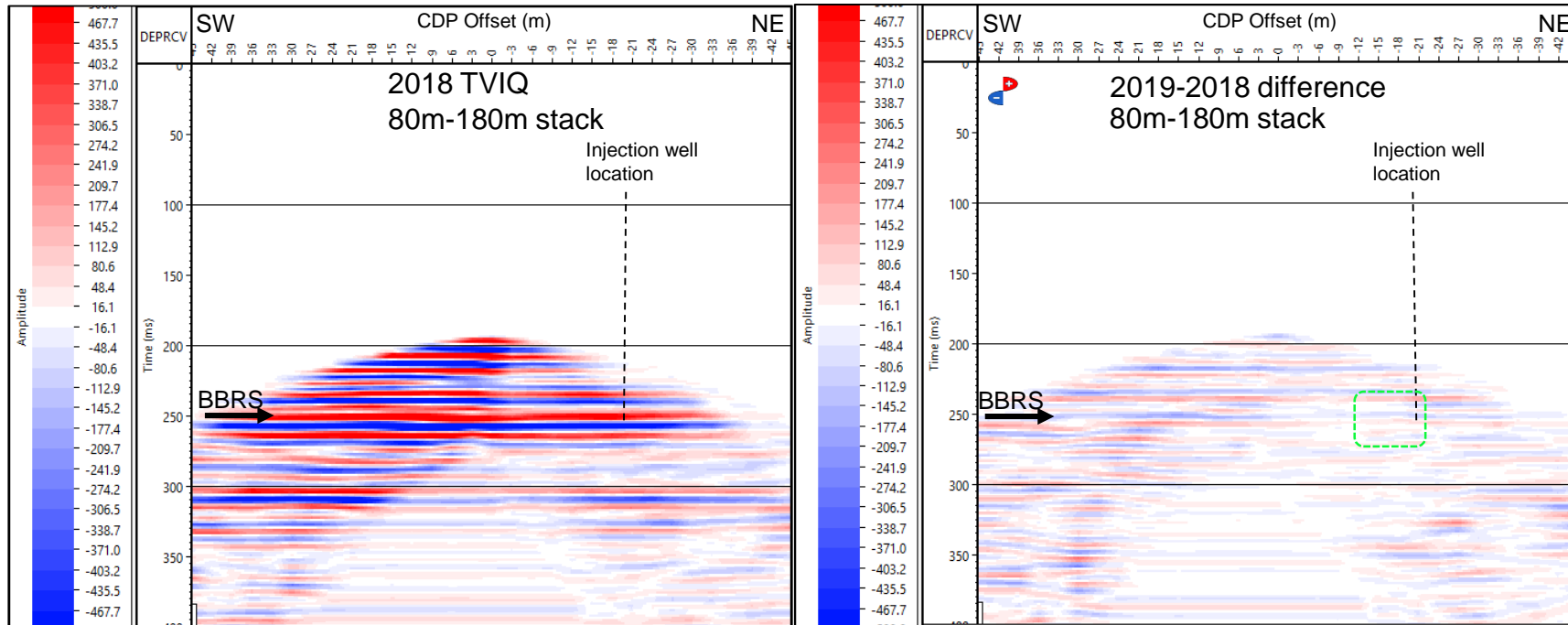
230ms-270ms	
NRMS	PRED
12.5%	99.4%





- No CO<sub>2</sub> amplitude anomaly evident above background
- 2%-4% higher NRMS than 2019-2017 result
- SW residuals likely skewing NRMS compared to 2019-2017

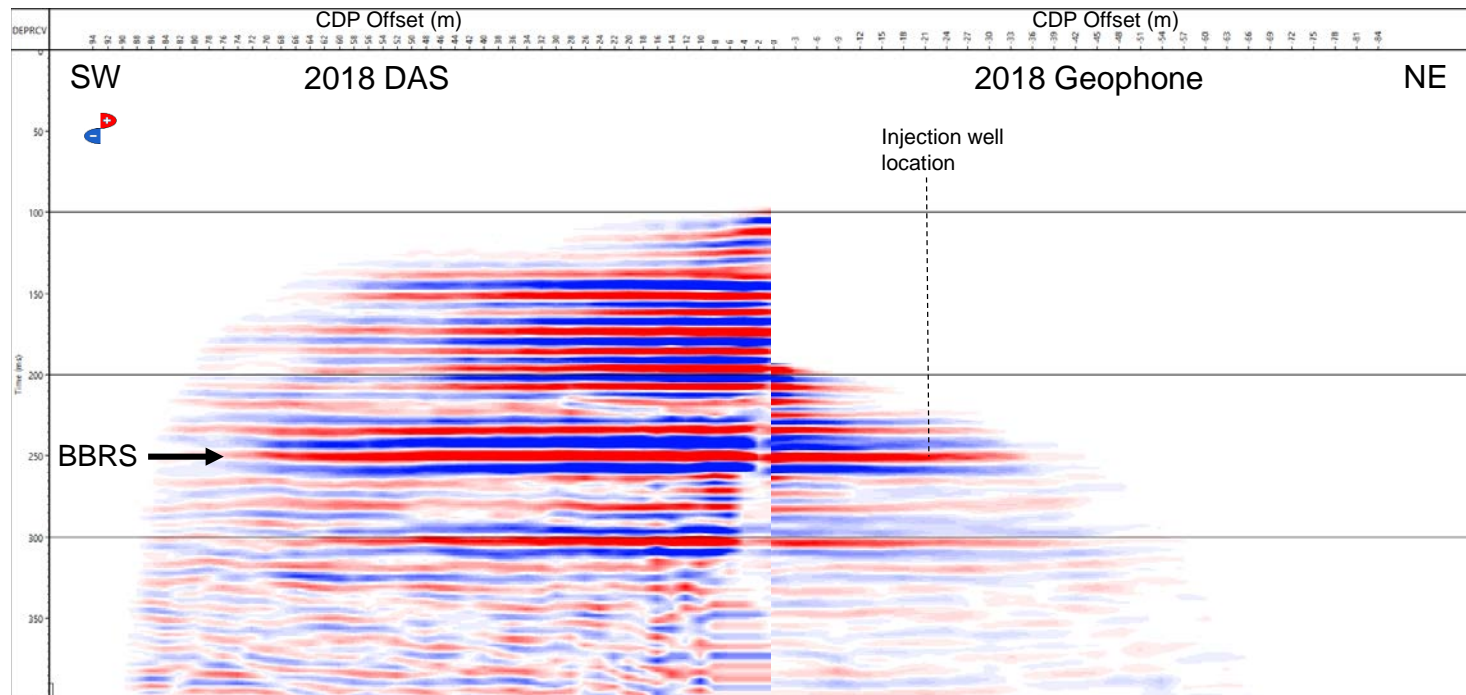
0-400ms	
NRMS	PRED
23.6%	97.5%
230ms-270ms	
NRMS	PRED
17.7%	98.8%





# DAS data has significantly more coverage

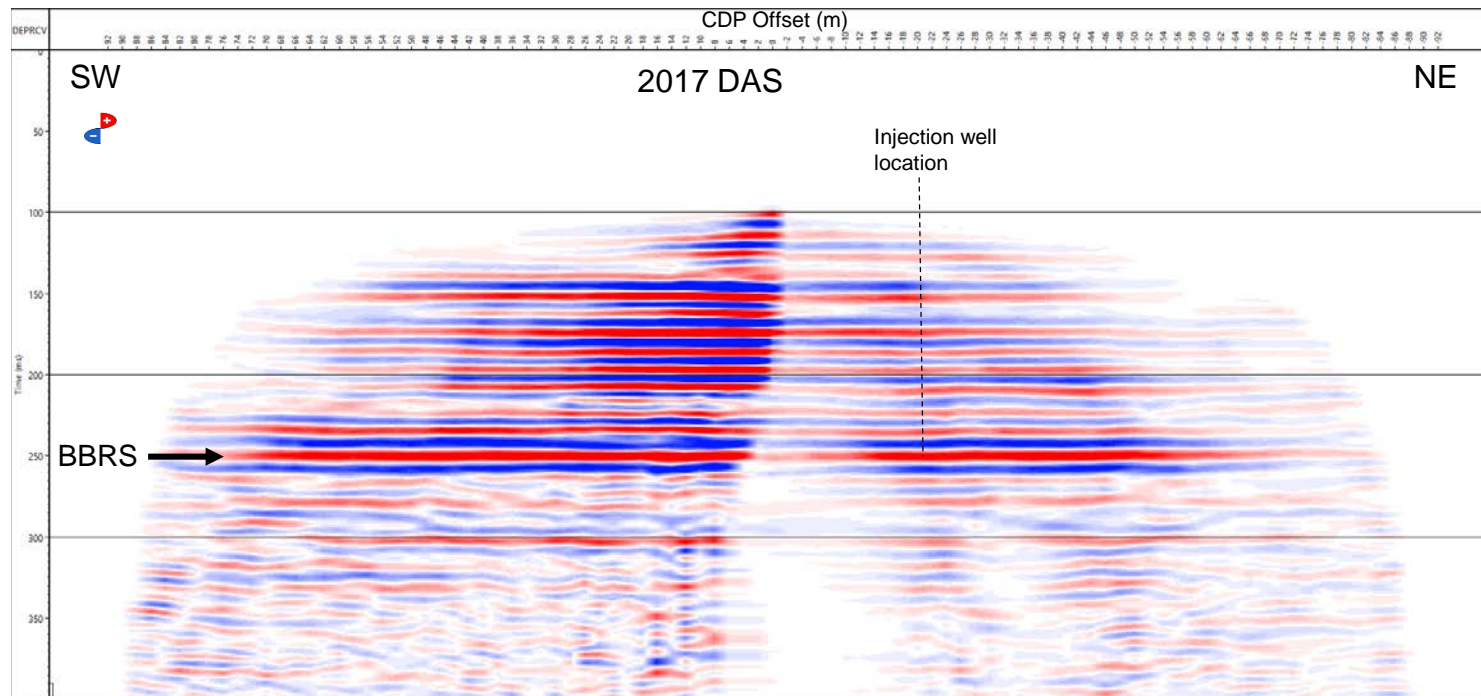
- Geophone data lacks shallow and far-offset reflections
- DAS has ~100ms of reflection data above the BBRS injection zone
- Excluding BBRS from pre-stack shaping filter was not successful, used 400ms window again





# DAS data has more variables at play for repeatability

- Different interrogators, Silixa (2017) and Fotech (2018)
- Different trace spacing (0.25m vs 0.67m) required stacking traces to yield 2m trace spacing
- 2017 baseline is lower amplitude for near offset CDPs, unclear why (both pre- and post-stack)
- These DAS data are integrated from strain rate to strain, but not scaled for particle velocity<sup>1</sup> and broadside insensitivity

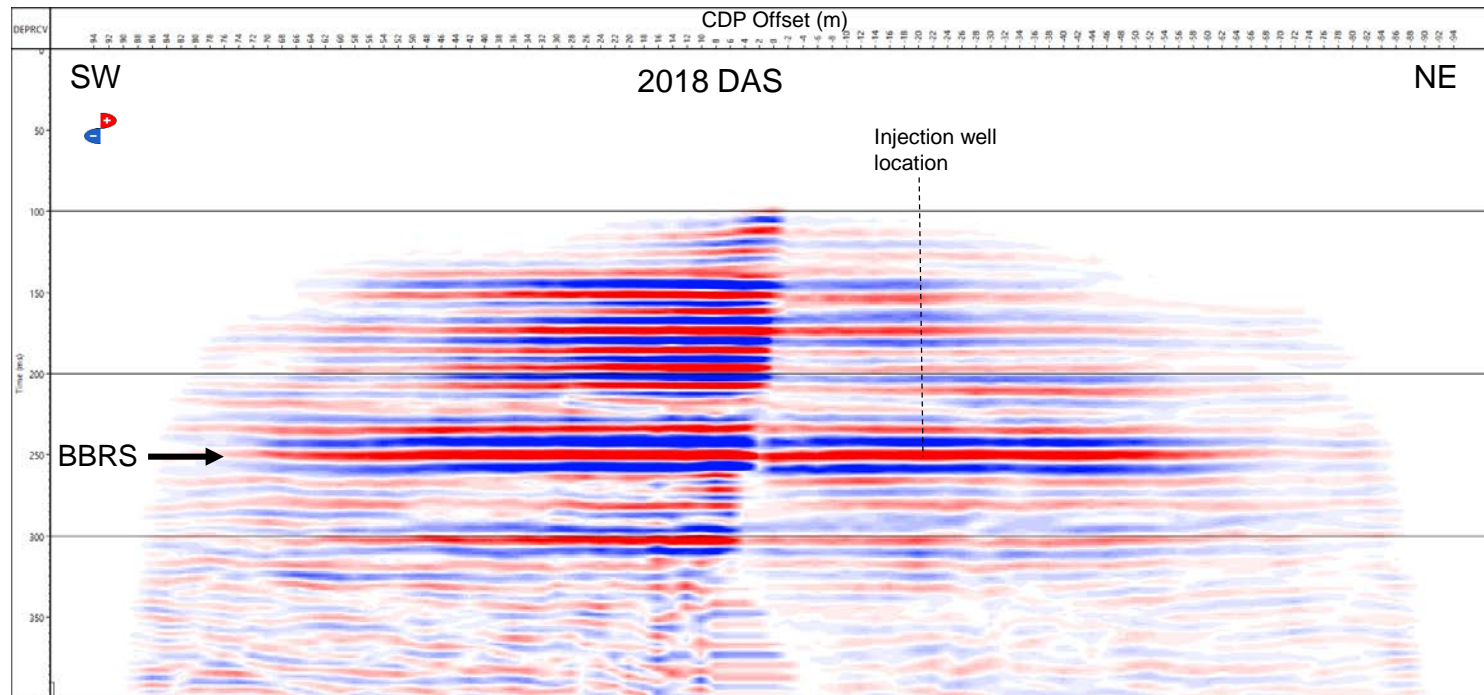


<sup>1</sup> Daley et. al, 2015



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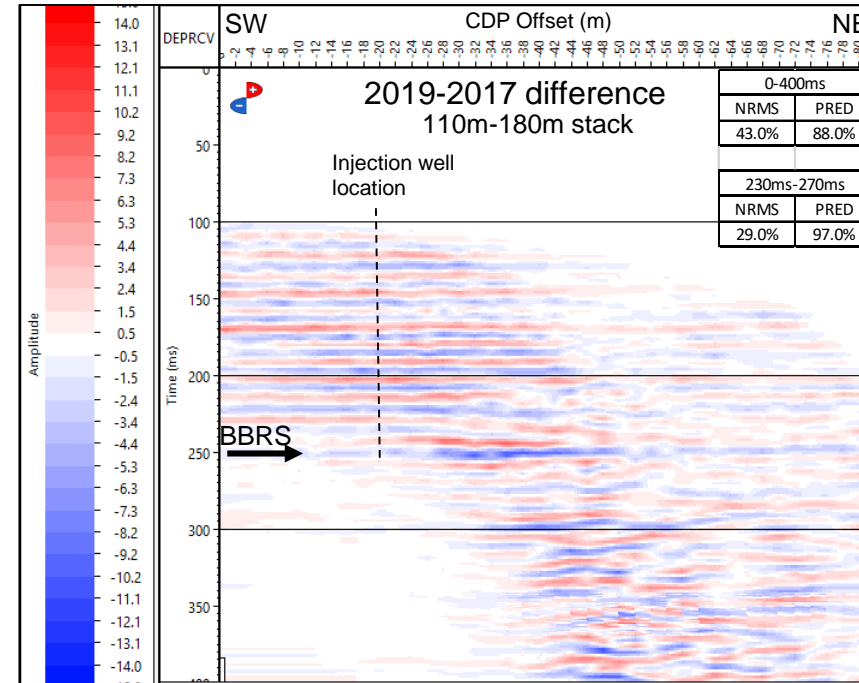
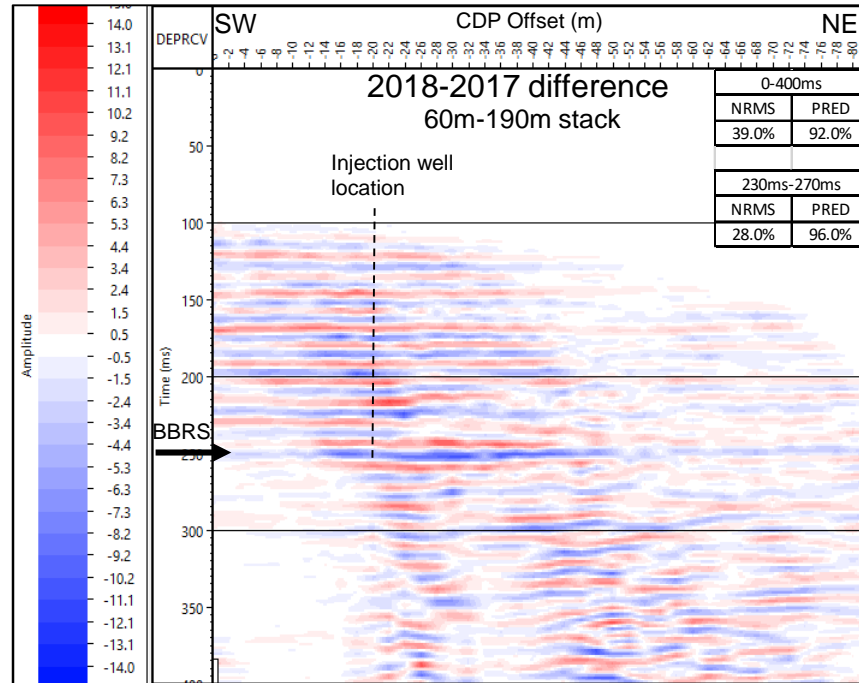


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# Mid- and far-offset shots more reliable

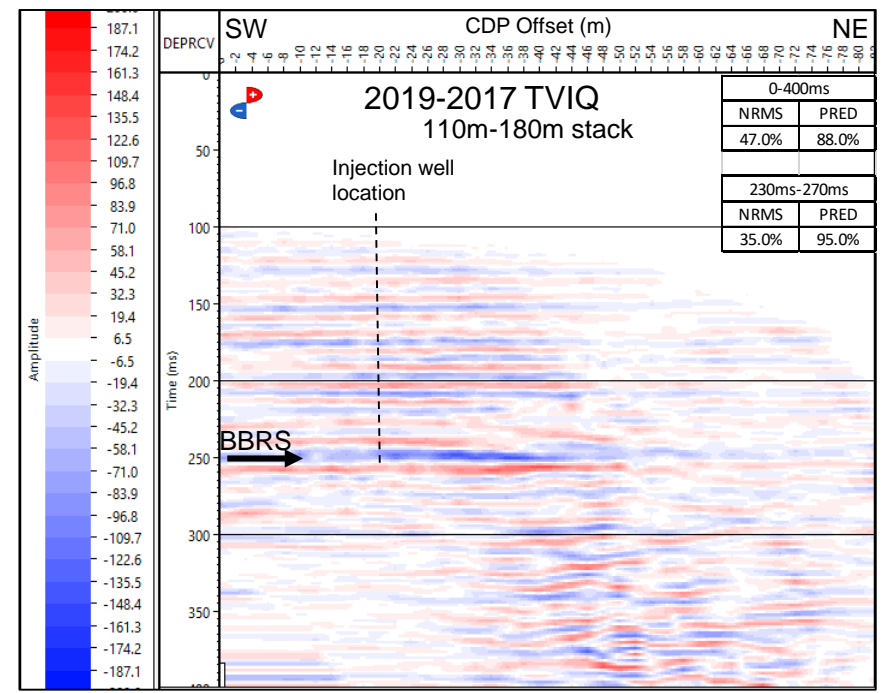
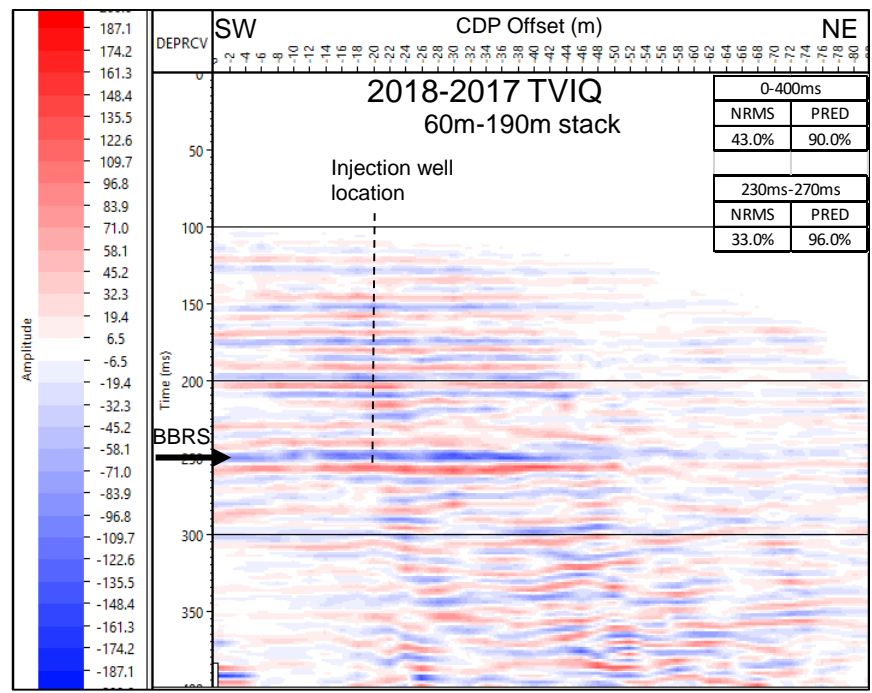
- Significant residual amplitude from BBRS reflection
- No obvious negative residual from CO<sub>2</sub>
- NRMS and PRED are ~15% higher than geophone results, require significant improvement to be useful





# Mid- and far-offset shots more reliable

- Significant residual amplitude from BBRs reflection
- No obvious negative residual from CO<sub>2</sub>
- NRMS and PRED are ~15% higher than geophone results, require significant improvement to be useful

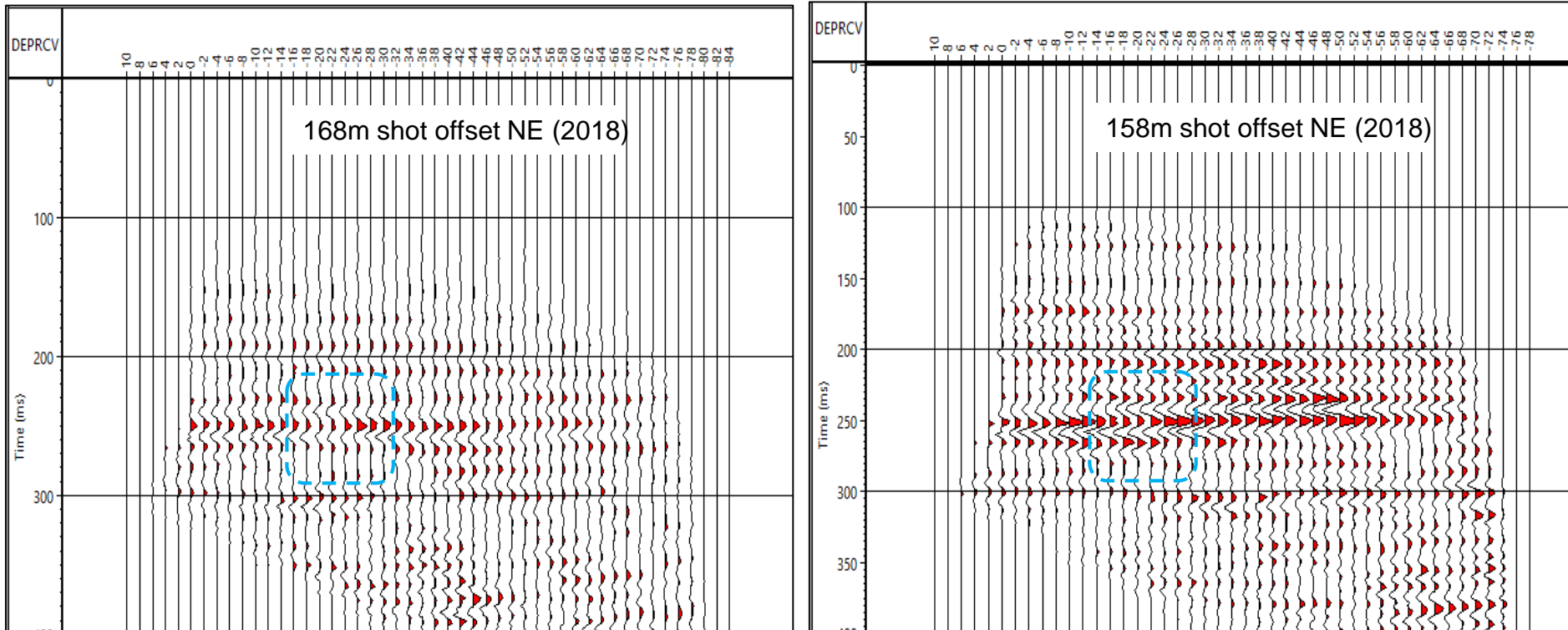






# Unaltered 2018 CDP gathers show dimming of BBRS

- Consistent dimming around 16m-22m in 2018 CDP gathers
- Not evident in full- or far-offset VSP CDP stack
- AVA modeling and inspection of raw gathers should help prove or disprove





- Geophone data highly repeatable: NRMS = 8%-15%, PRED = 99%
- Lower repeatability scores for DAS: NRMS = 25%-40%, PRED = 83%-97%
- Time-variant inverse-Q filter generally worsens NRMS and PRED by 1%-5%
- Possible CO<sub>2</sub> anomaly in the time-lapse geophone and pre-stack 2018 DAS: Amplitude decrease near injection well

## **Future work on VSP time-lapse**

- Scale DAS for broadside insensitivity, particle velocity
- Attempt shaping filter on individual CDP gathers rather than TWT shot gathers
- Re-process 2018-2017 with even farther offsets
- Solve scaling/residual issues for near offset shots to improve fold and resolution
- Process 2020 monitor surveys





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- Vista software help files, Schlumberger



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