Utah Forge
Monitored Well: 16B(78)-32

Hydraulic Fracture Monitoring of Well 16A
16A(78)-32 Frac Stages 3R through 10
Strain Monitoring Fracture Driven Interactions (FDI)
From well 16B Fiber Optics
Field Operations: Apr 2024

Neubrex Energy Services (US), LLC

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Last update: July 27, 2024

Acknowledgements

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We thank the many stakeholders who are supporting this project, including Smithfield, Utah School and Institutional Trust Lands Administration, and Beaver County as well as the Utah Governor’s Office of Energy Development and Utah’s Congressional Delegation.

During field operations, Neubrex worked with many operational experts and received critical assistance from many people, including Alan Reynolds, Leroy Swearingen, Kevin England, John McLennan, Joe Morris, Garth Larson, Monty Keown, Dr. Mukul Sharma, Ben Dyer, Dr. Peter Meir, and Neubrex Ops Chief Wayne Fishback. Working frac, drilling, water management crews and HSE managers were instrumental in getting the surface and downhole work accomplished in a safe and effective manner.

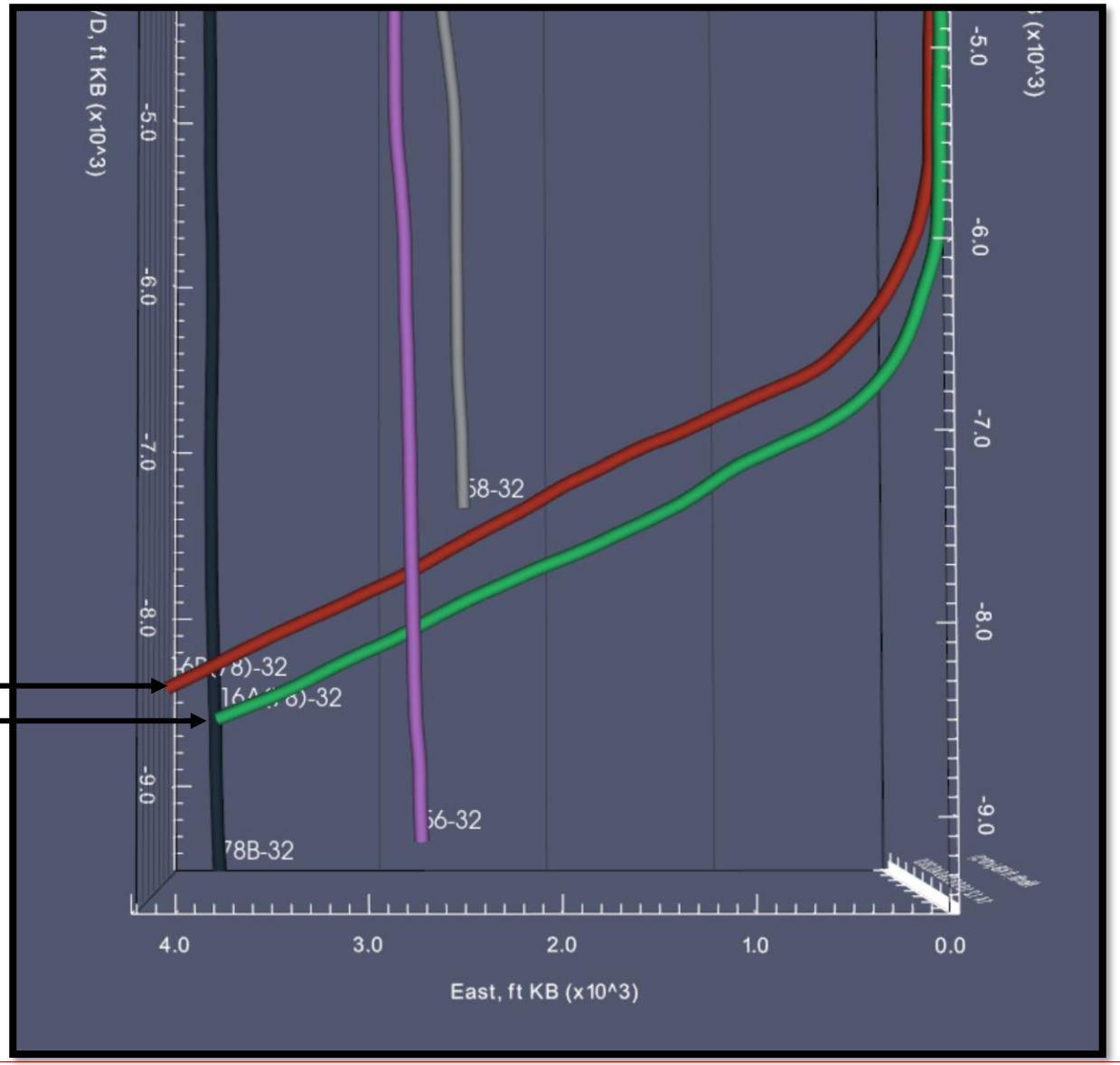
16A Well (Green) and Monitor Well 16B (Red) Renderings

VIEW LOOKING SOUTH

The 16B well is instrumented
With a fiber optic cable
That contains 2 single mode
Fibers and one multi mode
Fiber. Green is the treatment
Well. Red is the monitor well.

Monitor Well 16B

Treatment well
16A



Well 16A Frac Cluster Depths in MD RKB

	Measured Depth (Referenced to KB = 32 ft)								
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8	Frac Plug
Stage 3R (16A)	Open-hole	10,560 - 10,580	10,120 - 10,140						
Frac Plug #1									10,095
Stage 4 (16A)	10,070 - 10,076								
Frac Plug #2									10,045
Stage 5 (16A)	10,020 - 10,026								
Frac Plug #3									9,995
Stage 6 (16A)	9,970 - 9,976	9,959 - 9,962[1]							
~~Frac Plug #4~~									~~9,945~~
Stage 7 (16A)	9,898 - 9,901	9,850 - 9,853	9,798 - 9,801						
Frac Plug #4									9,745
Stage 8 (16A)	9,720 - 9,723	9,695 - 9,698	9,670 - 9,673	9,645 - 9,648	9,620 - 9,623	9,595 - 9,598	9,570 - 9,573	9,545 - 9,548	
Frac Plug #5									9,520
Stage 9 (16A)	9,490 - 9,493	9,470 - 9,473	9,445 - 9,448	9,420 - 9,423	9,395 - 9,398	9,370 - 9,373	9,345 - 9,348	9,320 - 9,323	
Frac Plug #6									9,295

Well 16B(78)-32 Well Header File Information

Daily Completion Report

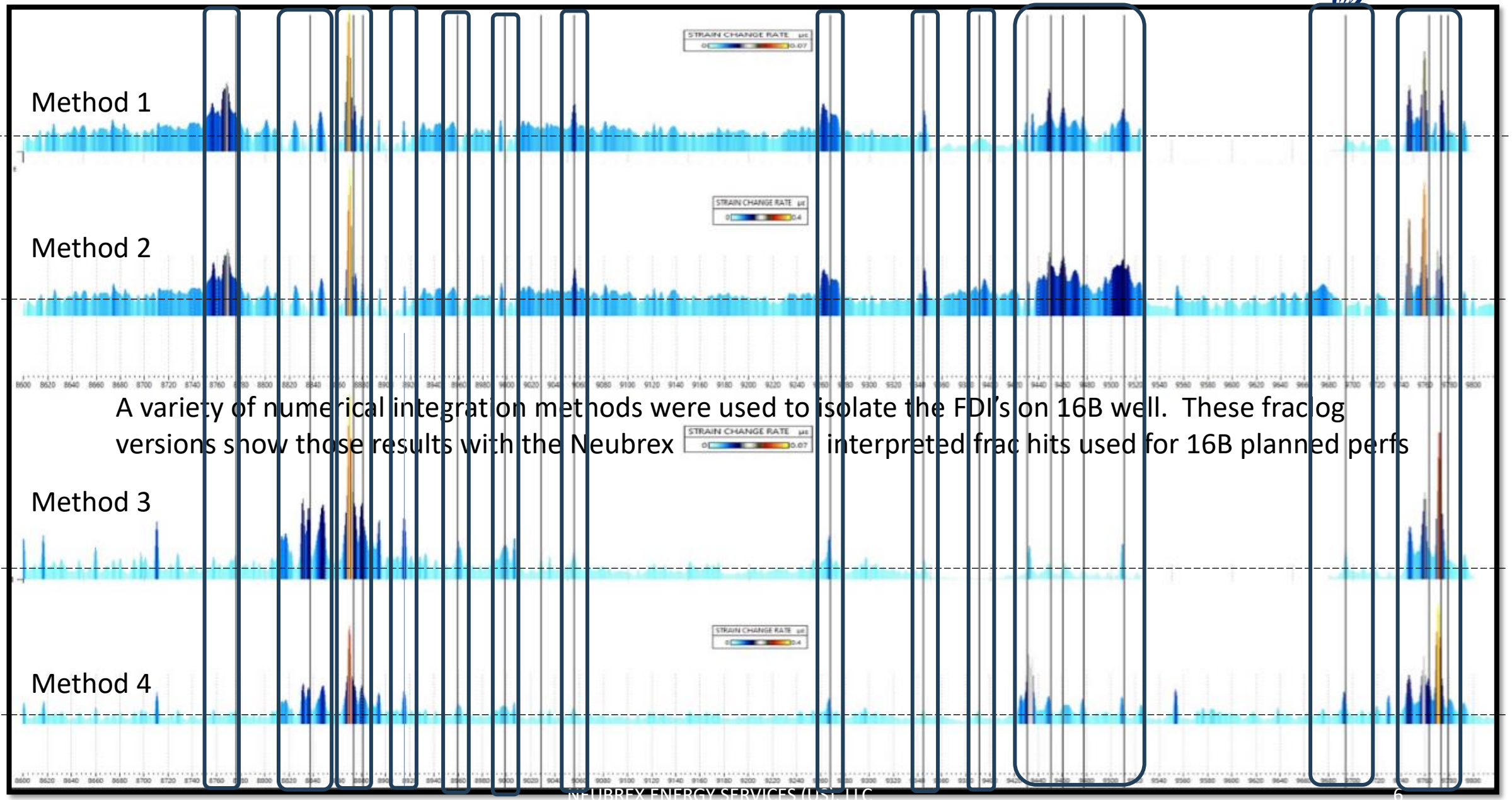
Well ID: FORGE 16B(78)-32 **Job ID: 16B(78)-32STIM1** **Wel**

Field: FORGE Sect: 32 Town: 26S Rng: 9W

Report No: 8 **Repo**

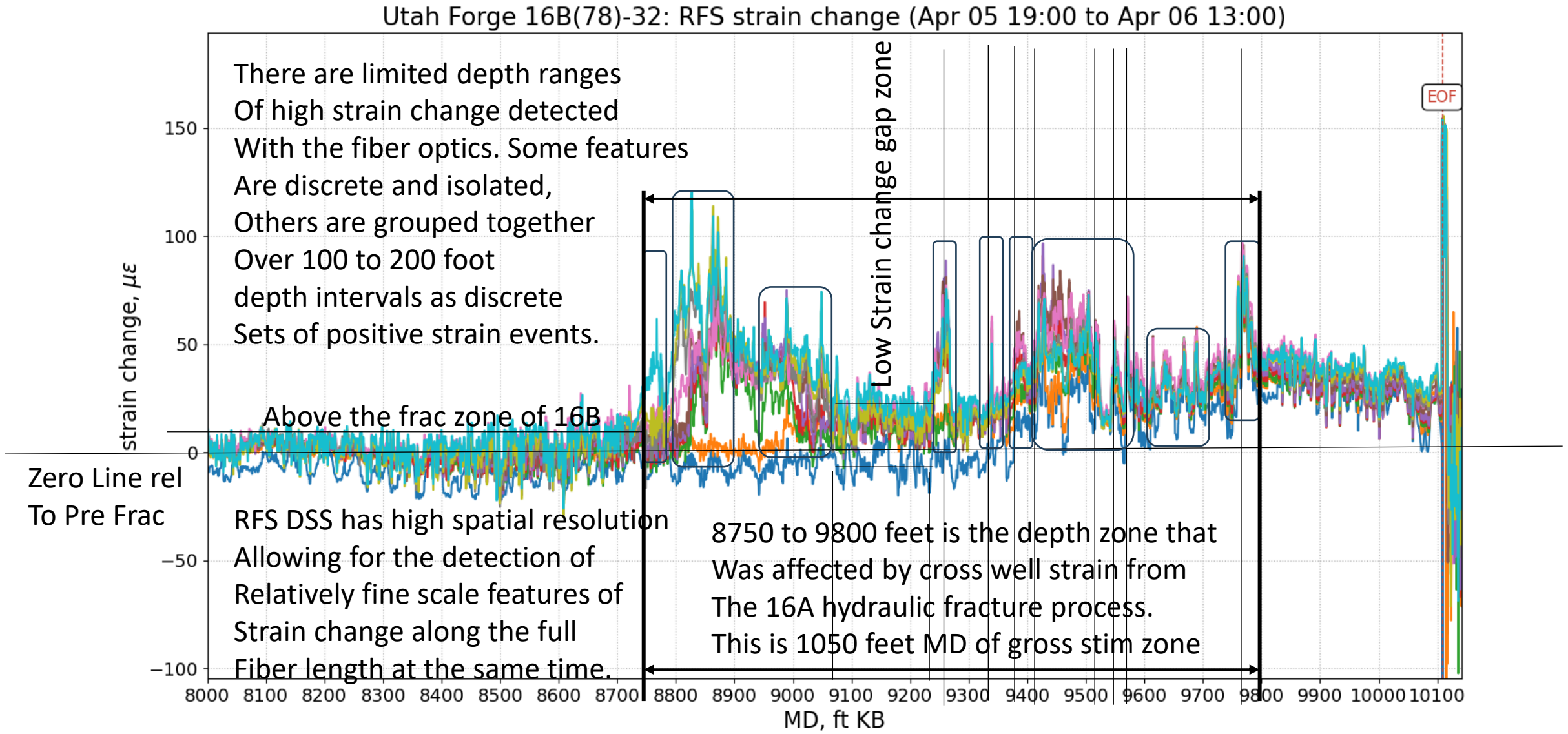
Operator:	Utah FORGE	**Rig:**	UDES WOR105	**Wellbore:**	Original Wellbore	**Daily Cos**	
Measured Depth (ft):	10947.0	**Completion Days (act.):**	8	**Orig RKB Elev(ft):**	30.5	**AFE No.**	
Vertical Depth (ft):	8357.0			**Last BOP Test:**	16-Mar-24	---	

Neubrex RFS DSS based FracLogs on 16B from 16A Frac Stages

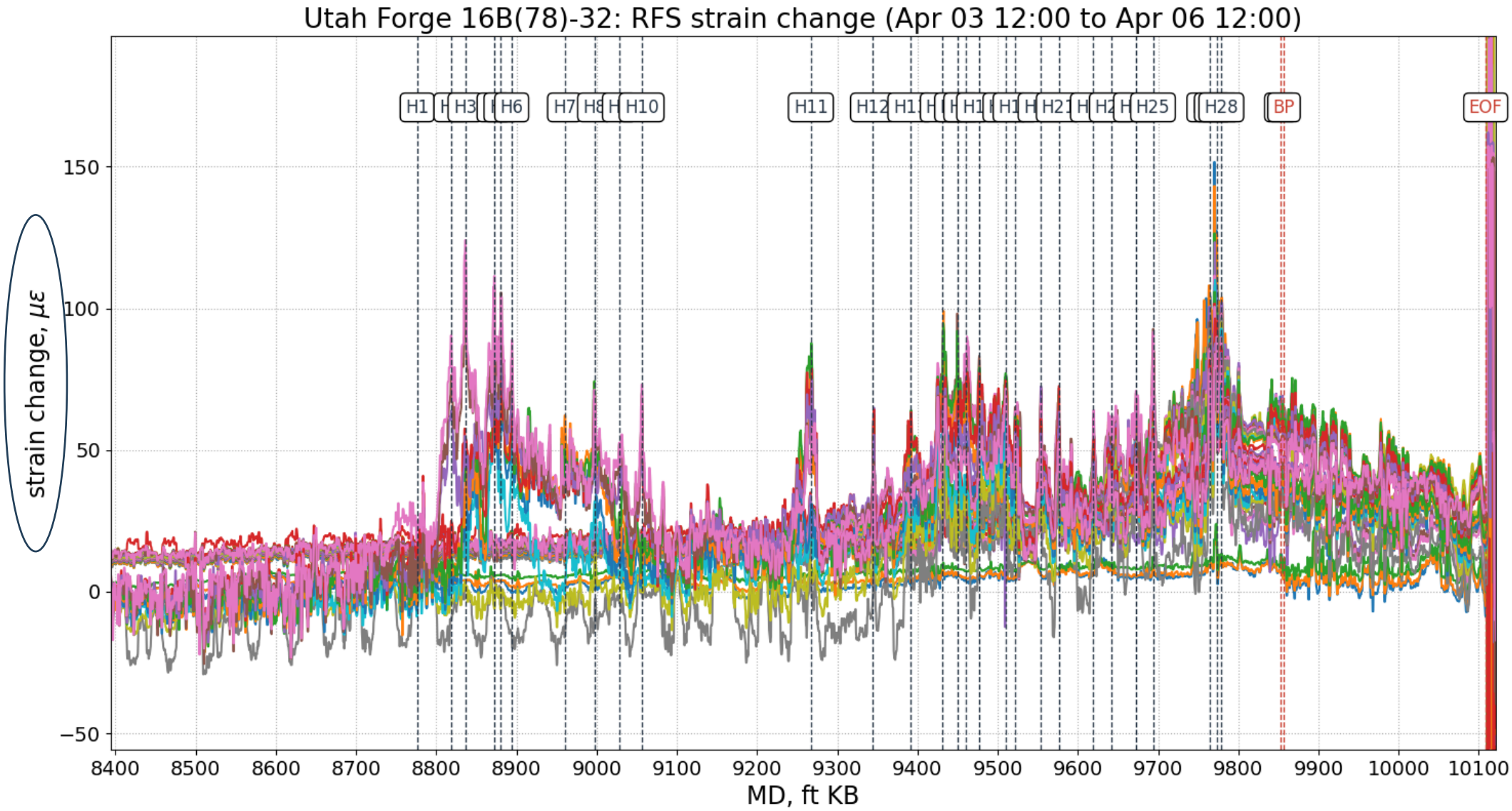


A variety of numerical integration methods were used to isolate the FDI's on 16B well. These frac log versions show those results with the Neubrex interpreted frac hits used for 16B planned perfs

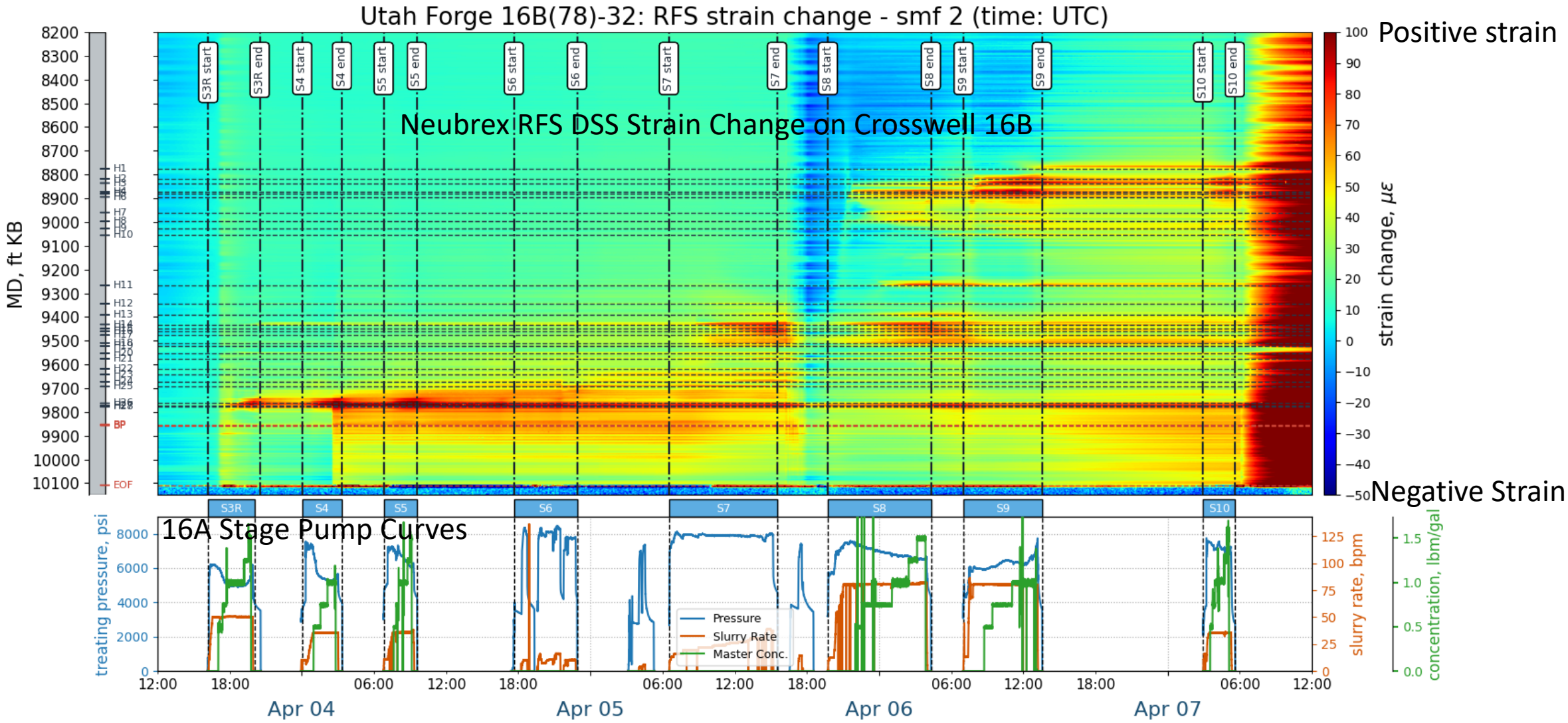
Well 16B – RFS DSS strain change – select traces over time



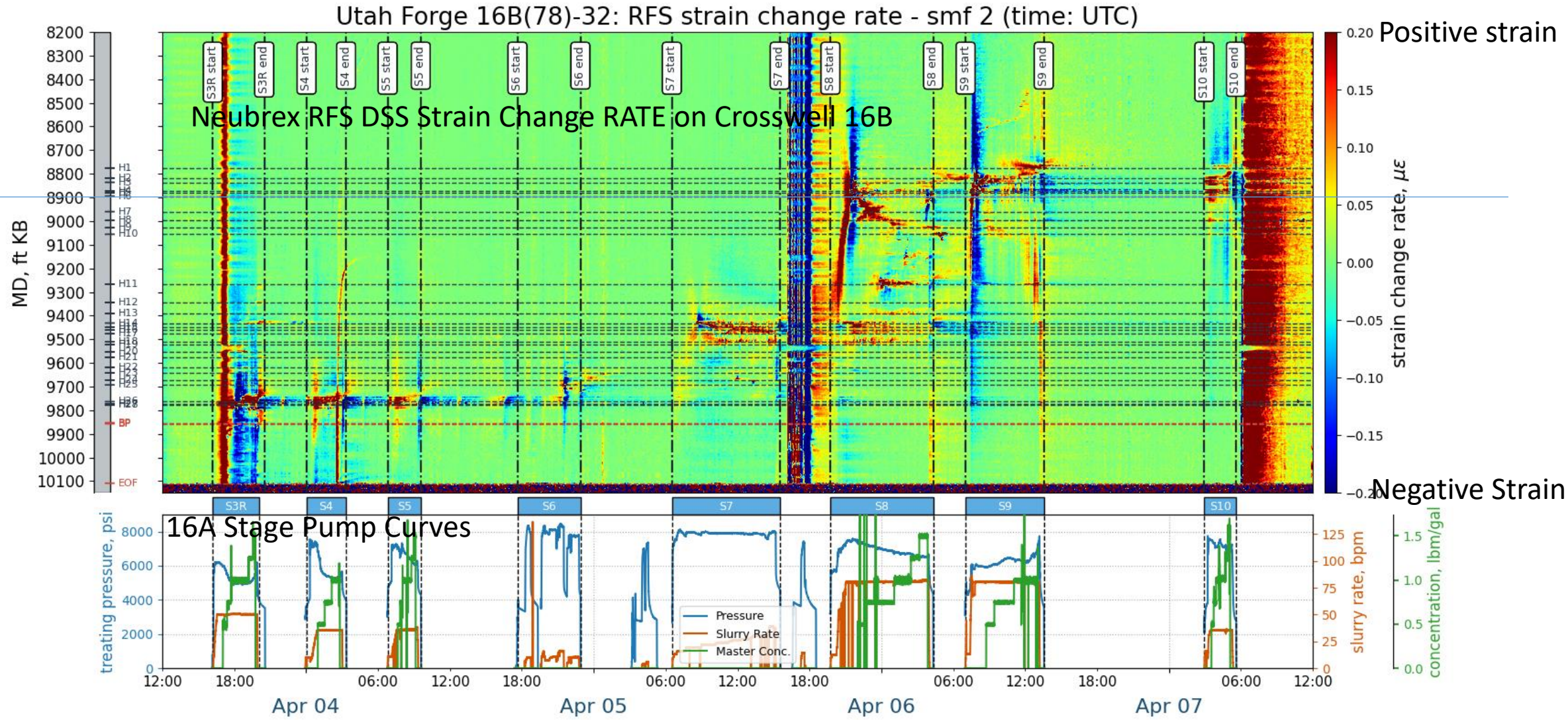
Well 16B – selected FDI locs picked on RFS DSS data



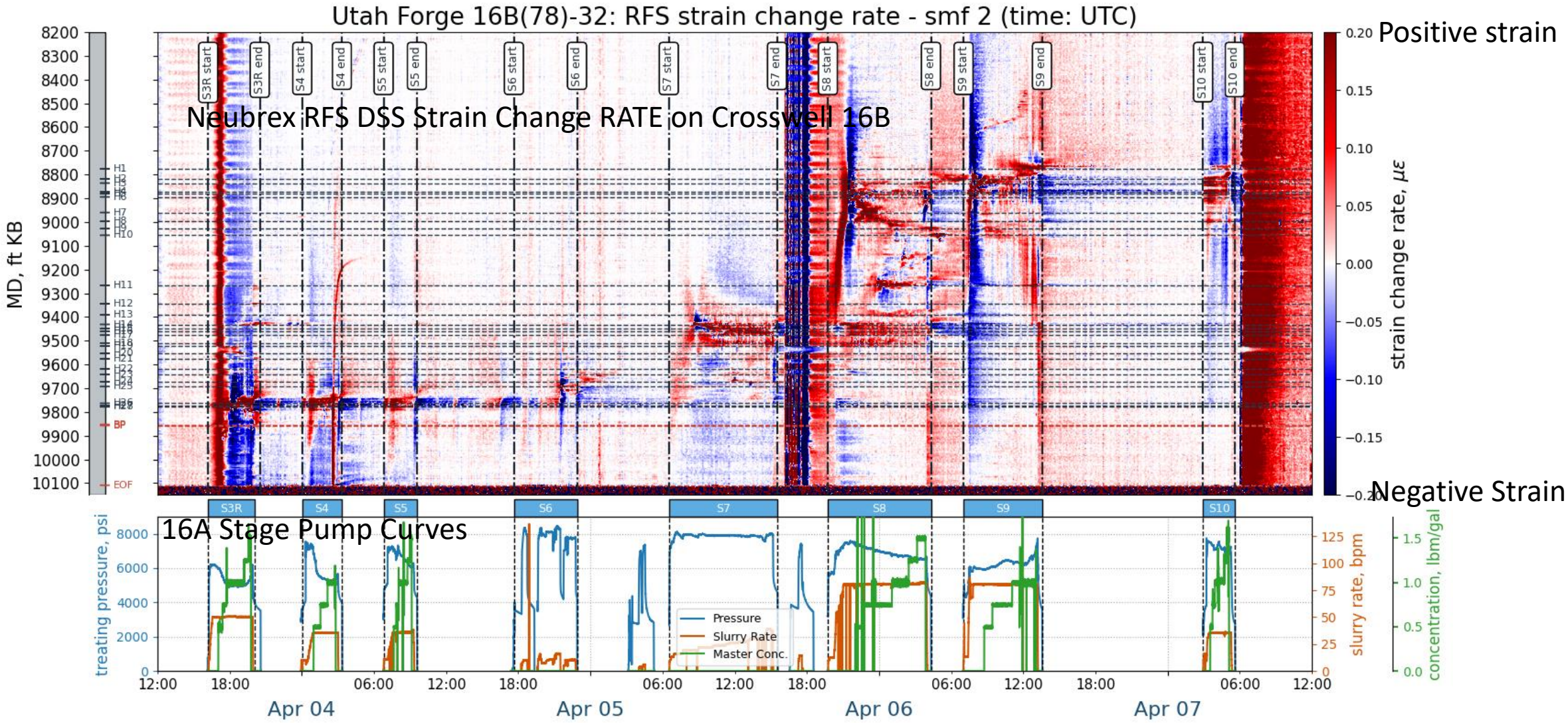
Well 16B – RFS DSS strain change from baseline profile prior to frac operations produced from 16A frac with Interpreted Fracture Driven Interactions (FDI) as dotted Lines



Well 16B – RFS DSS strain change RATE with time differential of 30 seconds produced from 16A frac with Interpreted Fracture Driven Interactions (FDI) as dotted Lines



Well 16B – RFS DSS strain change RATE with time differential of 30 seconds produced from 16A frac with Interpreted Fracture Driven Interactions (FDI) as dotted Lines (RED BLUE Color)



Timeline – This report Covers Evolution 2 of Project

Project timeline and acquisition settings

Name	Target	Neubrex acquisition	
		start	end
Evolution 0	Cementing	Jul 13, 2023, 04:39	Jul 14, 2023, 11:14
Evolution 1	Post-cementing monitoring	Jul 15, 2023, 12:18	Jul 20, 2023, 15:40
Evolution 2	Interaction with stimulation on well 16A	Apr 1, 2024, 12:00	Apr 7, 2024, 16:00

This report covers the fiber optic monitoring of frac stimulation
On Wells 16A from the Crosswell 16B Monitor Well using Fiber optics in 16B.

Primary method of monitoring is Distributed Fiber Optic Sensing using Rayleigh Frequency Shift Distributed Strain Sensing Method.

Project and report timeframe

- This Report period:
  - **Apr 01, 2024, 19:25** (UTC)
  - **Apr 07, 2024, 22:30** (UTC)

- This covers stimulation on **well 16A stages 3R through 10**

Fiber Optic Information – “Shell Cable”

End of Fiber Cable:
Fiber termination info and depth received from Operator.

Table 2. Fiber termination depths

Name	KB, ft	Termination, ft BF	Fibers
16B(78)-32	31	10,108.46	SM/MM

There are 2 separate sensing cables installed on this well (names are after casing tally)

- Shell cable (starts at 10,108.46 MD ft KB)
- Silixa cable (starts at 10,001.22 MD ft KB)

All measurements presented in this Report were made on “Shell cable” also known as the UT Cable.

Casing tally – basic well and casing info from Tally

Table 3. Casing tally header

As Ran FORGE 16B(78)-32 Audited to KB — **Instrumentation Casing Running Tally**

Casing	Torque (ft-lbs) Min	Max	Opt
7" 38# P110EC VAM TOP HT	20,850	25,450	23,150
7" 38# P110MS VAM TOP HT	20,850	25,450	23,150

Average Joint Length 4.5"	12.68					
Average Joint Length 5.5"	12.58					
TD:	10208.40					
Ground Level	10177.40					
Rat hole:	0.00					

Open Hole	9.500"				
7" 38# P110EC VAM TOP HT	Drift: 5.795"				
7" 38# P110MS VAM TOP HT	Drift: 5.795"				
11.75" 65 lb/ft P110/125, BTC	Drift: 10.526"				
Cross-over from MS to EC	~ 8100'				

Fibre Start	10,108.46	ft			
Toe Gauge	N/A	ft			
Heel Gauge	7,056.67	ft			
Stick-Up	7.56	ft	2.86		
KOP#1	5500.00	ft			
Landing Point	7,000.00	ft			
Int Csg	4,837.00	ft			
KB (To Csg Bowl)	31	ft			

If you have any questions regarding instrumentation and CCP installation on this tally please contact the originator - Alan Reynolds - 757 304 1977

Item	JT #	Mud Fill	Comments	Threads off length	Cumm Length	Bottom Depth	Top Depth	Centralizers	CCP	Jt #	Protectors	Comments
David Lynch Float Shoe	A			2.67	2.67	10,208.40	10,205.73	David Lynch Float Shoe		A		
7" 38# P110EC VAM TOP HT	A			47.10	49.77	10,205.73	10,158.63	One 9.125" Centralizer		A		31 0700 0913 S5V8S - pre-installed
7" 38# P110EC VAM TOP HT	1		Test Shoe?	46.96	96.73	10,158.63	10,111.67	None		1	7000-35-01SRN20.3	
Termination Sub	B		Shell Fibre Start	6.43	103.16	10,111.67	10,105.24	None		B	None	
7" 38# P110EC VAM TOP HT	2			46.99	150.15	10,105.24	10,058.25	One 9.125" Centralizer		2	7000-35-01SRN20.3	31 0700 0913 S5V8S
7" 38# P110EC VAM TOP HT	3			47.02	197.17	10,058.25	10,011.23	None		3	7000-35-01SRN20.3	
7" 38# P110EC VAM TOP HT Pup	Pup D			10.01	207.18	10,011.23	10,001.22	One Eccentralizer		Pup D	7000-35-01SRN20.3	30 0700 0900 S5V8S 0403
7" 38# P110EC VAM TOP HT Pup	Pup A		Silixa Fibre Start	20.09	227.27	10,001.22	9,981.13	One Eccentralizer		Pup A	7000-35-01SRN20.3	31 0700 0900 S5V8S 0403
7" 38# P110EC VAM TOP HT	4			46.02	273.29	9,981.13	9,935.11	One 9.125" Centralizer		4	7000-98-01-76-01P-4C	31 0700 0913 S5V8S
7" 38# P110EC VAM TOP HT Pup	C		Full Optical Suite	10.38	283.67	9,935.11	9,924.73	One 9.125" Centralizer		C	7000-35-01SRN20.3	31 0700 0913 S5V8S

Measurement Units

The time zone and unit system

Measurement units

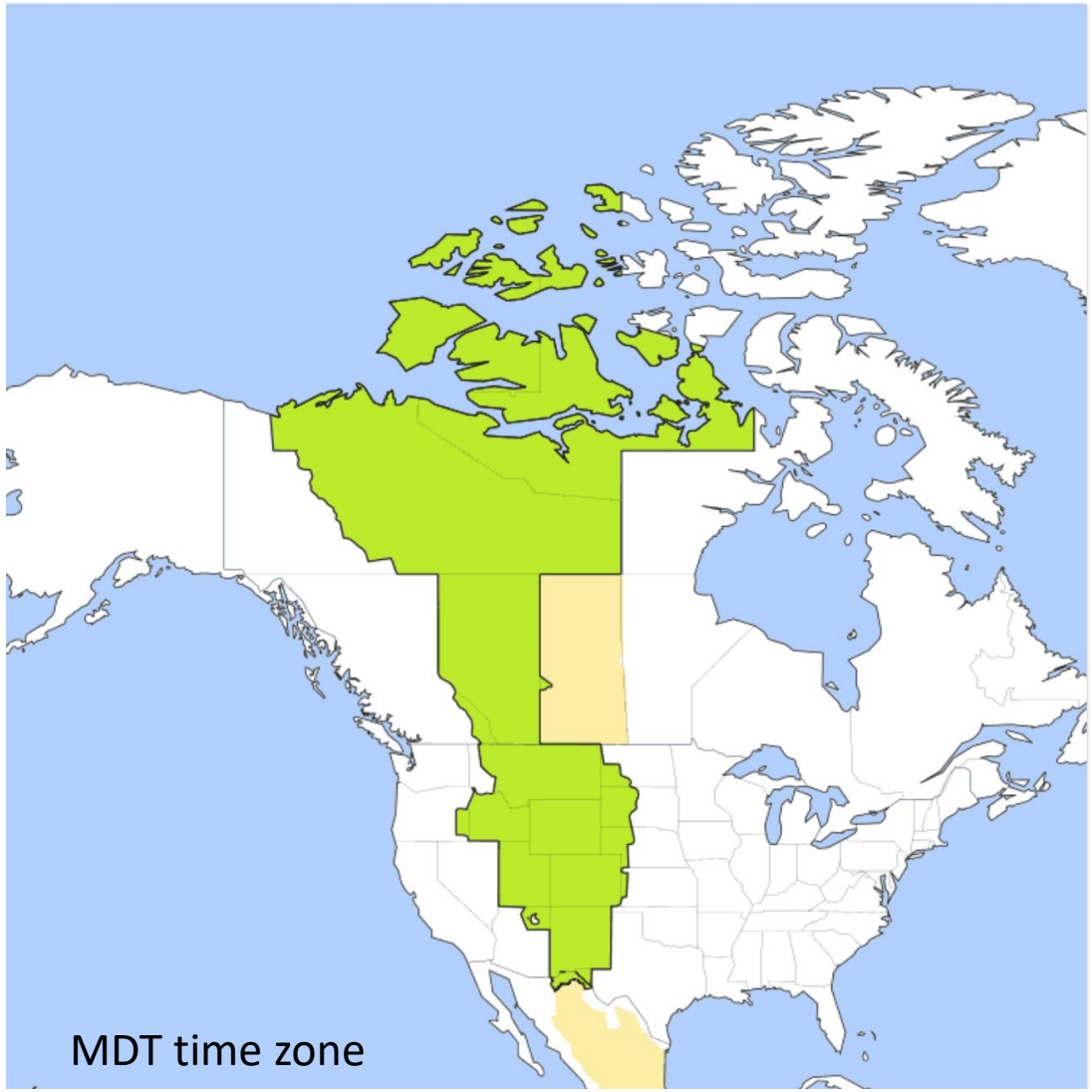
- Imperial (US) units are used in the report
  - Distance – foot, ft
  - Temperature – Fahrenheit degree, °F
  - Pressure – pound per square inch, psi

- Values of strain reported as micro-strain, με
  - Unless stated otherwise

Time zone- All reported times in report are UTC TIME

- Results reported in this document are in ***Coordinated Universal Time (UTC)***

- Local time zone was ***Mountain Daylight Time (MDT)***
  - UTC Offset: UTC −6

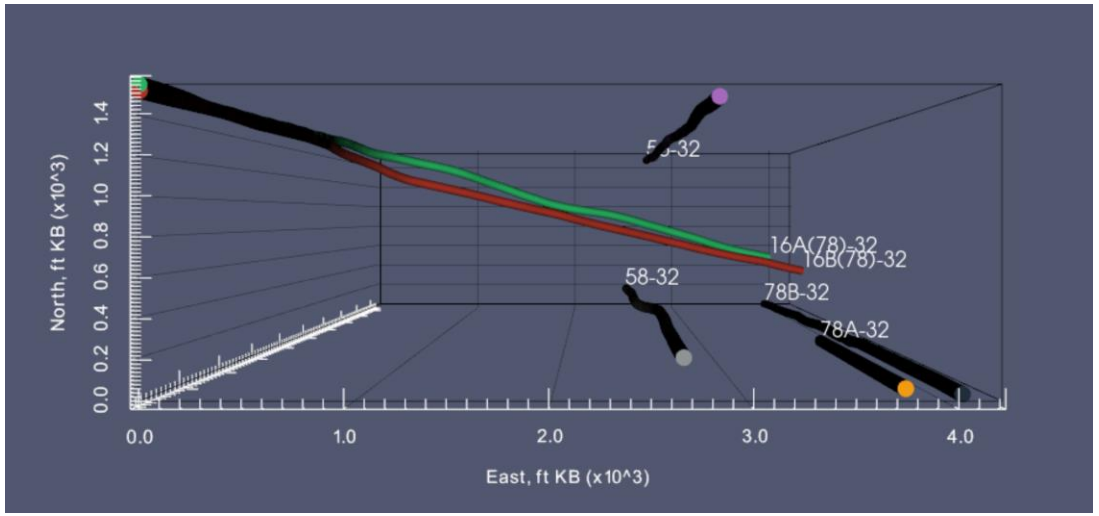


Well Survey Renderings

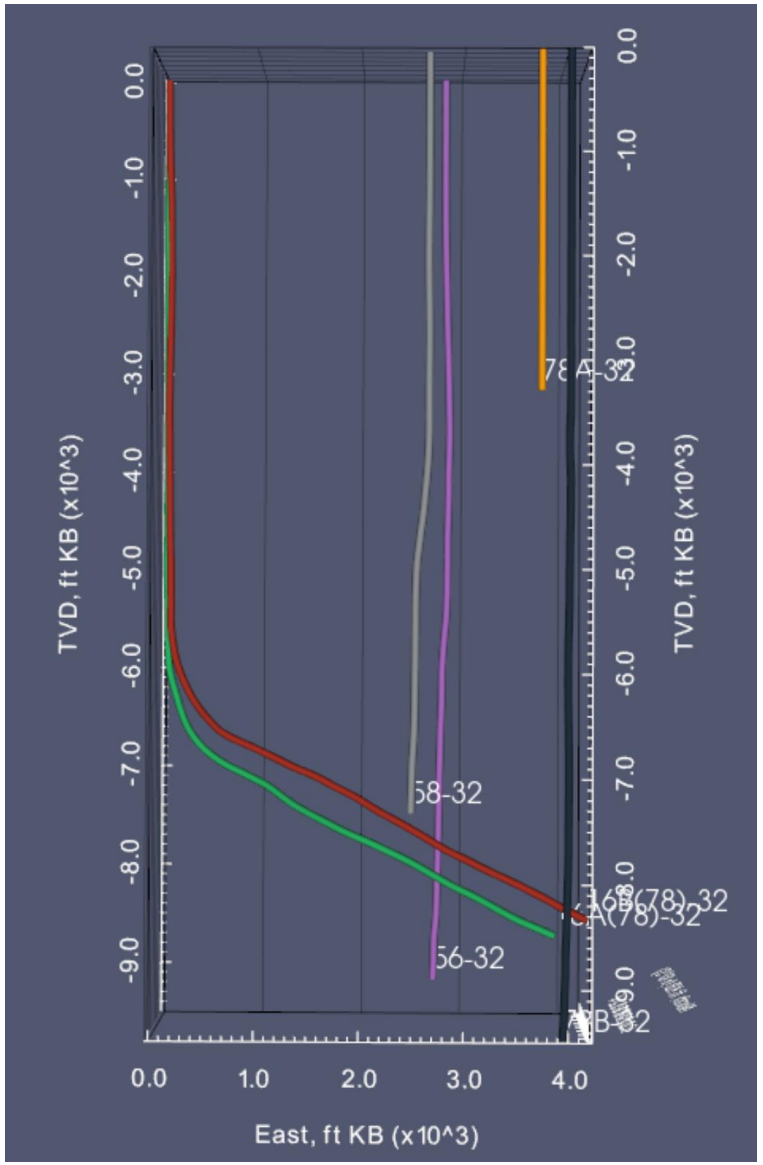
Based on schematics and deviation survey data provided by Operator

Monitored well

Birds Eye View

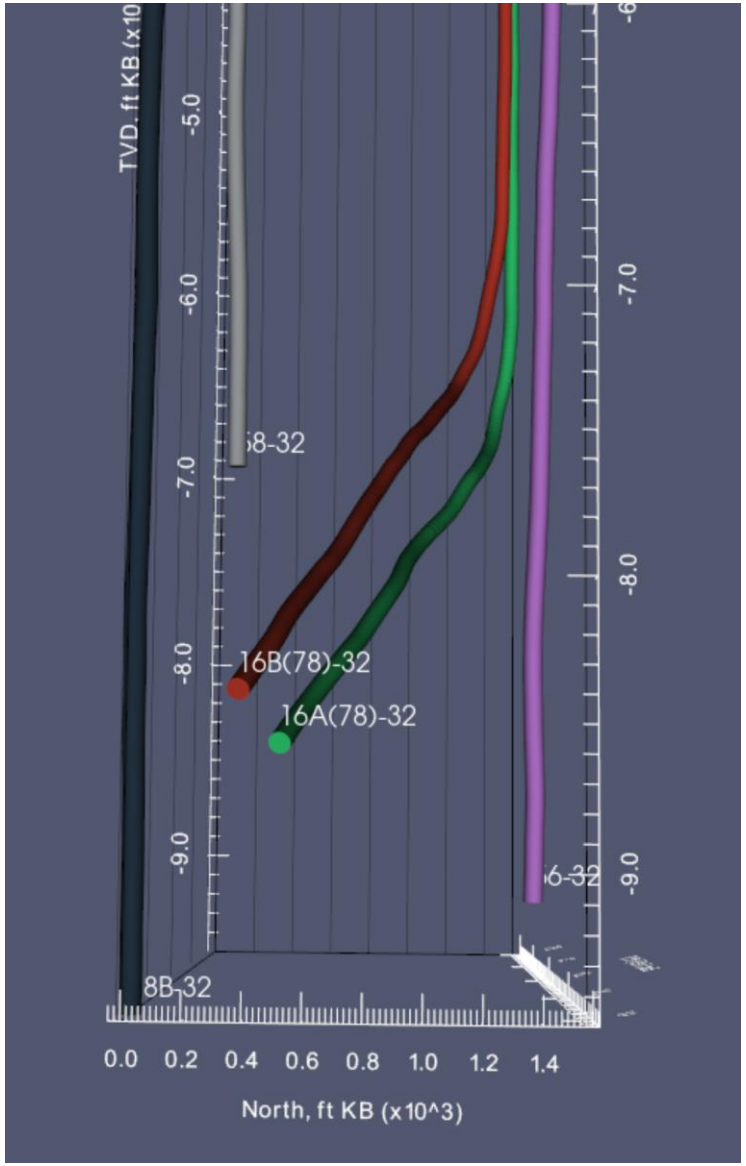


Side View

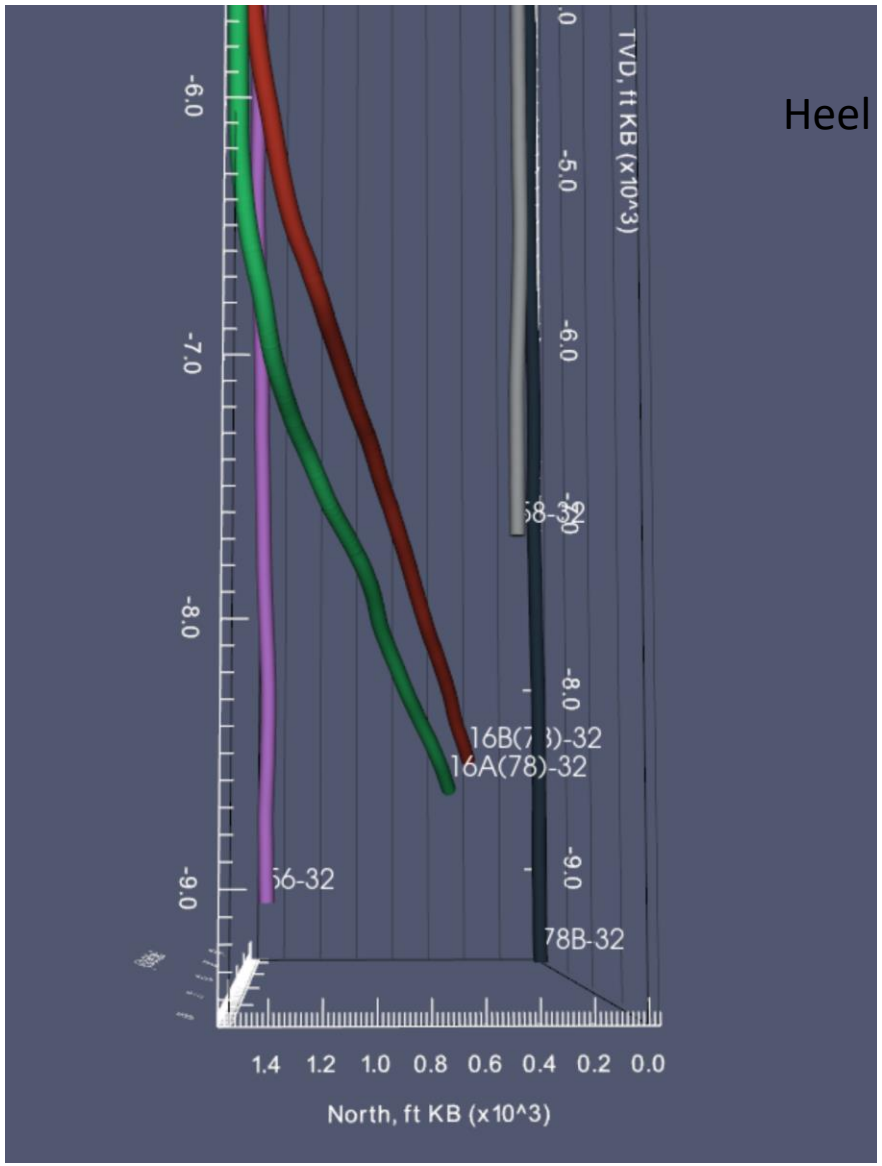


Monitored well

Oblique View

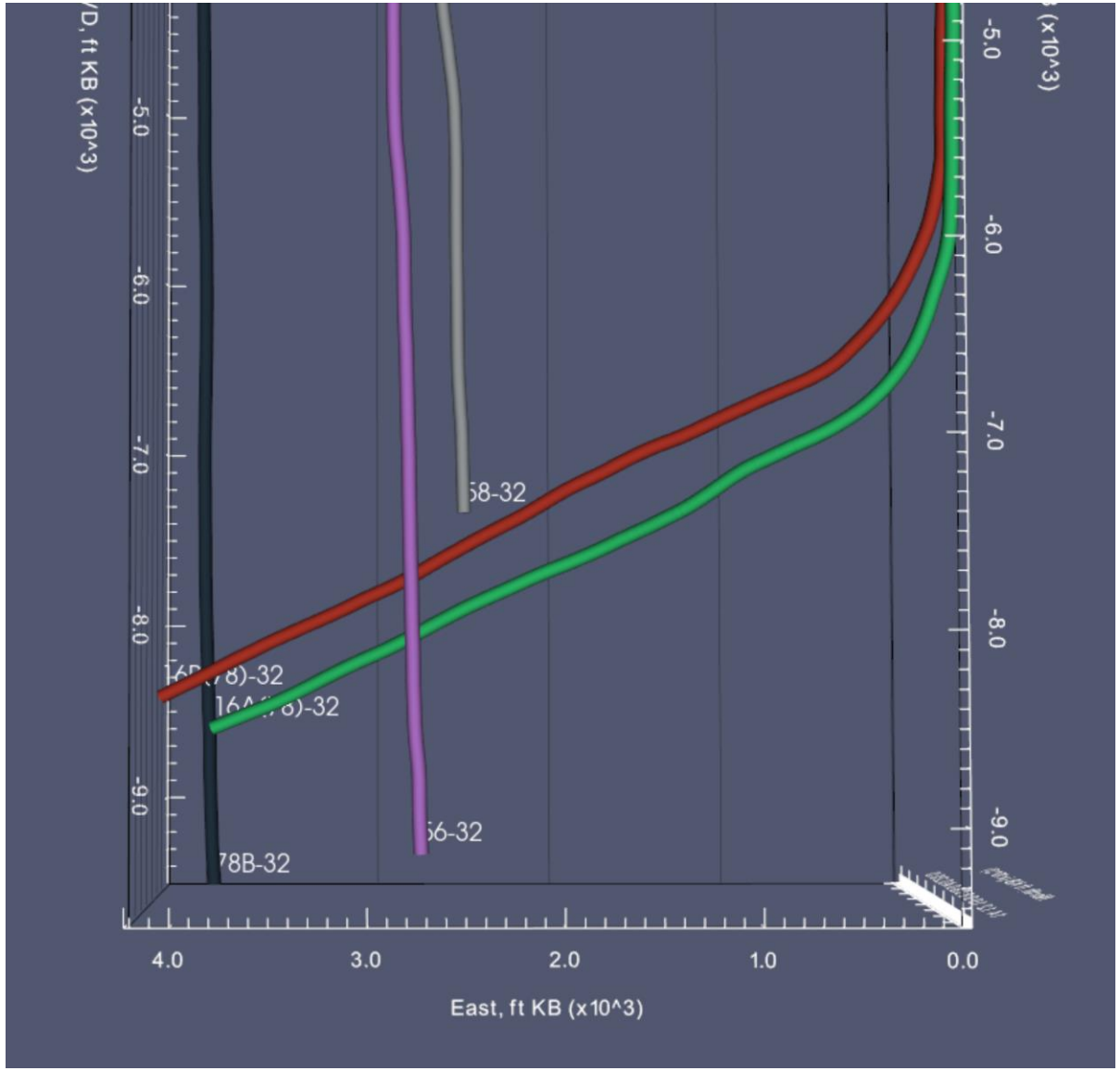


Heel View



Treatment and Monitor Well

The vertical wells are
Not monitored as part
Of this report.



Measurement types and target

Information on measurements type and acquired signals

Measurements type

- Monitoring target:
  - Strain and temperature changes on the monitored well 16B

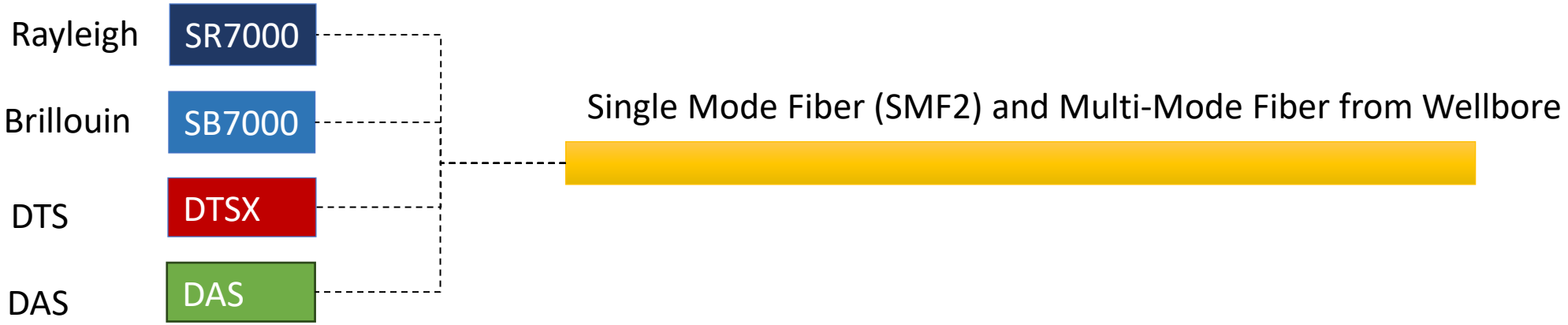
- Measurements:
  - Rayleigh Frequency Shift Distributed Strain Sensing (RFS DSS)
    - (from reference time and depths) strain change in micro strain units.
    - Rayleigh frequency shift, profile time to profile time, strain change rate (dRFS/dt)
    - Measured on Single Mode Fiber (SMF2)
  - Brillouin absolute Total strain
    - Brillouin center frequency (BGS Center Frequency) converted to strain
    - Measured on Single Mode Fiber (SMF2)
  - DTS
    - Raman based temperature measurements on multi mode fiber (MMF)

Fiber connection schematics

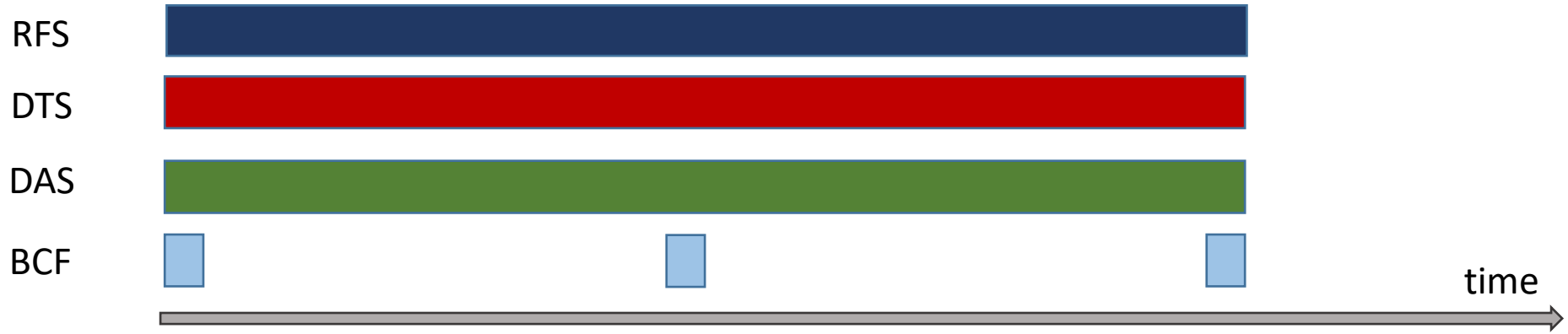
Connection of NBX instruments to permanent wellbore fibers

Connection scheme and survey timing schematics

- Instruments are connected to the different SM and/or MM fibers
  - Continuous acquisition of DTS, RFS, and DAS was achieved during the survey time



Measurements types and sensing pattern over time



Fibers

- The following fibers were used during data acquisition:

Table 4. Fibers used during acquisition

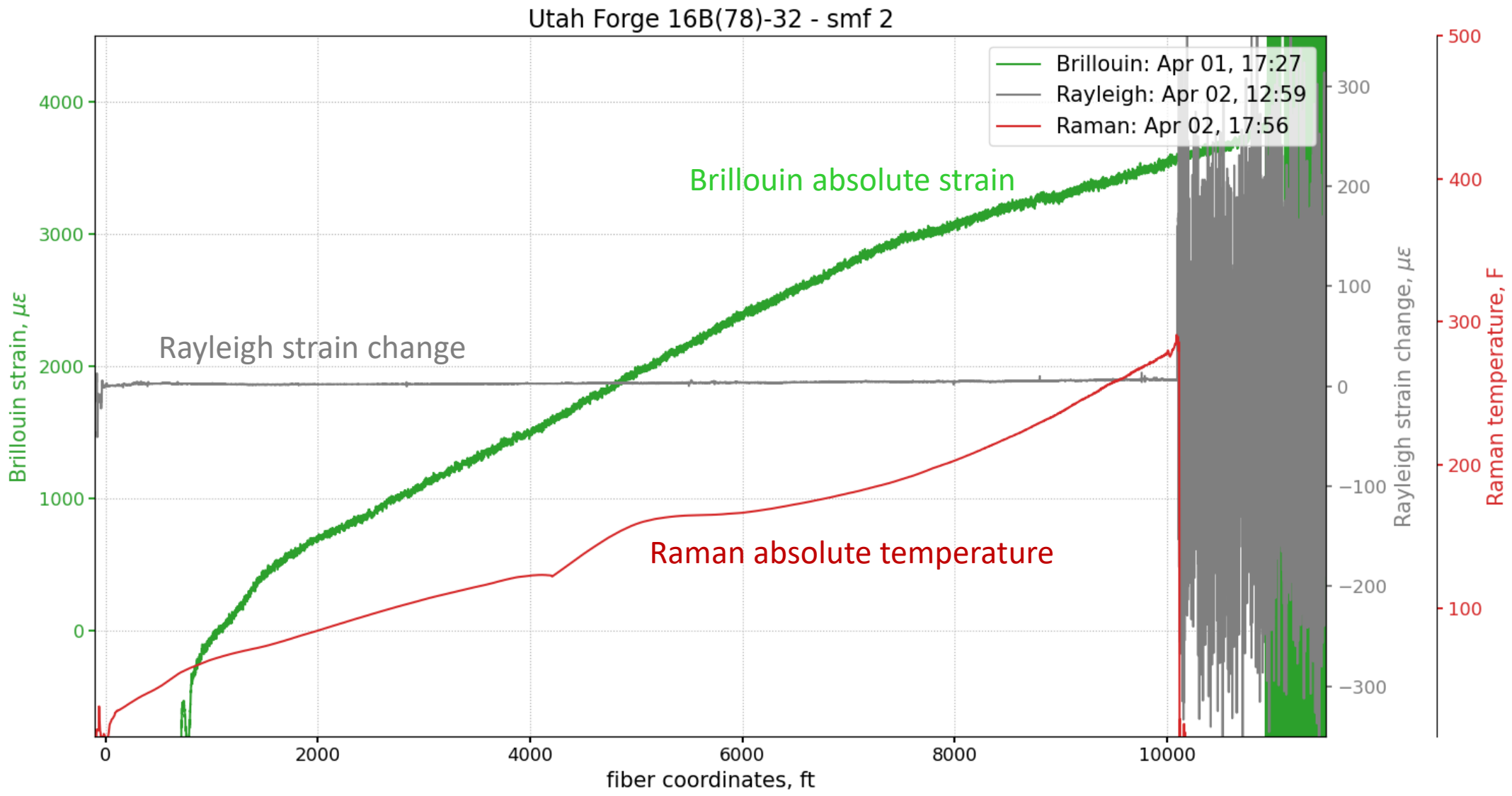
Name	Type	IOR	Length
SMF 2	SM	1.4782	10,108.46
MM 2	MM	1.4790	10,108.46

Depth calibration

This Section contains the depth mapping of the fiber optics on monitored wells.

Depth calibration between fiber optic measurements and well measured depth features is an essential and critical component of fiber optic data processing.

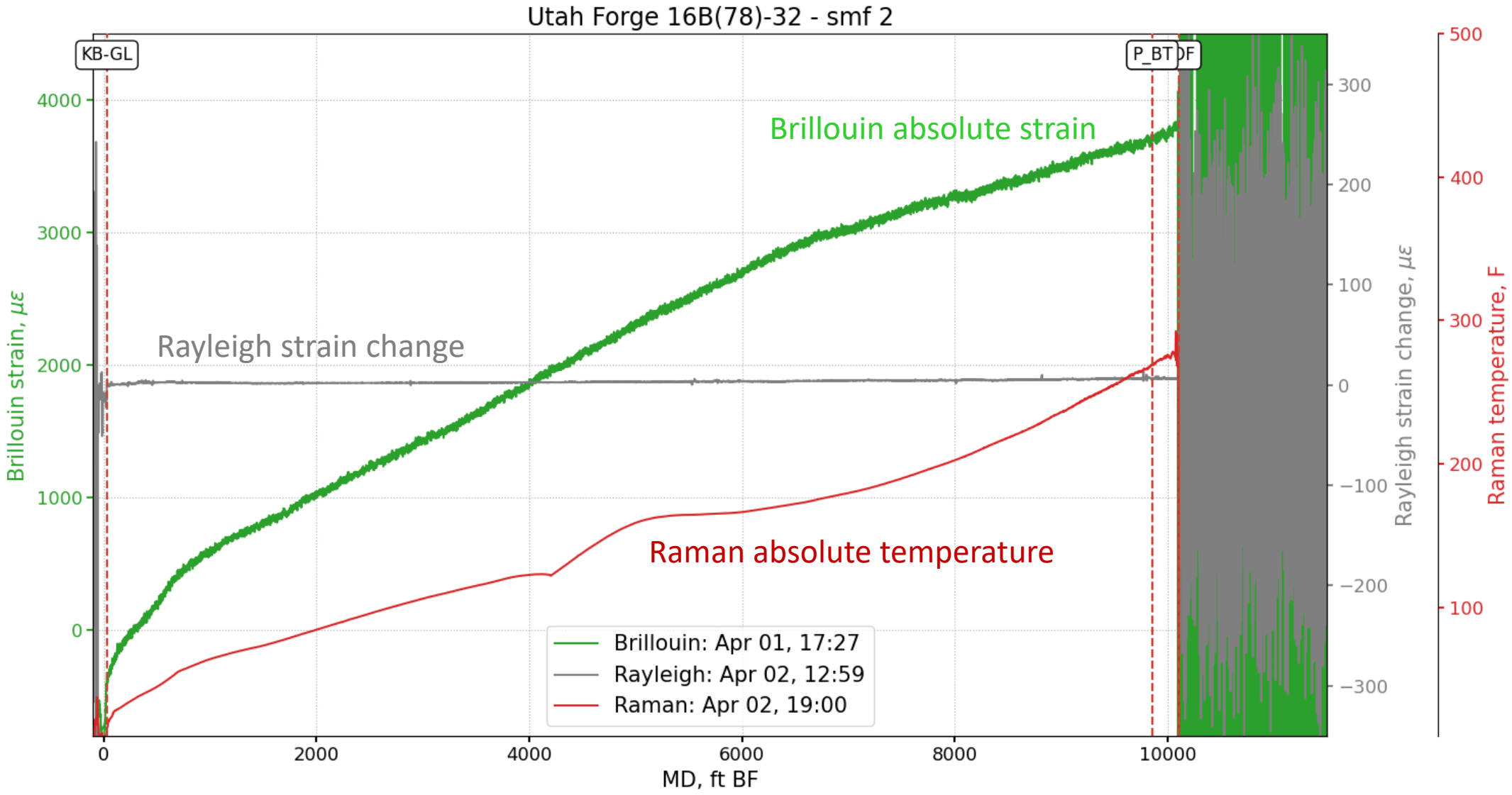
SMF 2 – fiber coordinates (Original lengths, no calibration)



Depth calibration findings from Neubrex workflow and data

- Final measured depth of the fiber termination = **10,108.46 MD, ft KB**
- KB = **31.0 ft MD**
  - Casing tally report
  - Reference location: GL
- **Depth Contraction coefficient (SMF 2/MMF 2)**:
  - RFS = 0.9947
  - BCF = 0.9947
  - DTS = 1.0030
- **Offset Correction Distances (SMF 2/MMF 2)**:
  - RFS: 582.14 ft
  - BCF: 775.57 ft
  - DTS: 419.96 ft

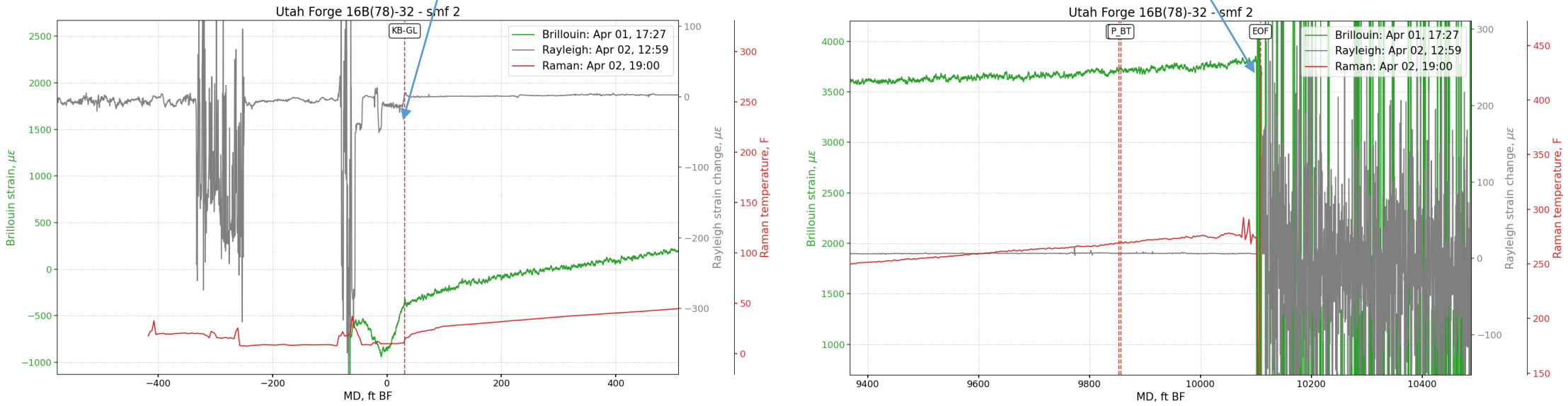
SMF 2 – depth calibrations applied to BCF, RFS, and DTS



SMF 2 – depth calibration at Wellhead and Termination

wellhead and GL

termination



Brillouin, Rayleigh, and Raman signals distributions

Summary of Depth Calibration – Fiber to Well MD Results

- The following offsets were determined and are used in all subsequent plots to convert fiber coordinates to Well MD coordinates
- Conversion method:
  - scaling factor is applied first, then offset applied

Well 16B – SMF 2/MMF 2

Data type	Offset, ft	Scaling factor
Brillouin	775.57	0.9947
Rayleigh	582.14	0.9947
DTS	419.86	1.0030

Measurements Data

Summary of measurements using RFS, DTS, and BCF

RFS = Rayleigh Frequency Shift fiber optic measurement

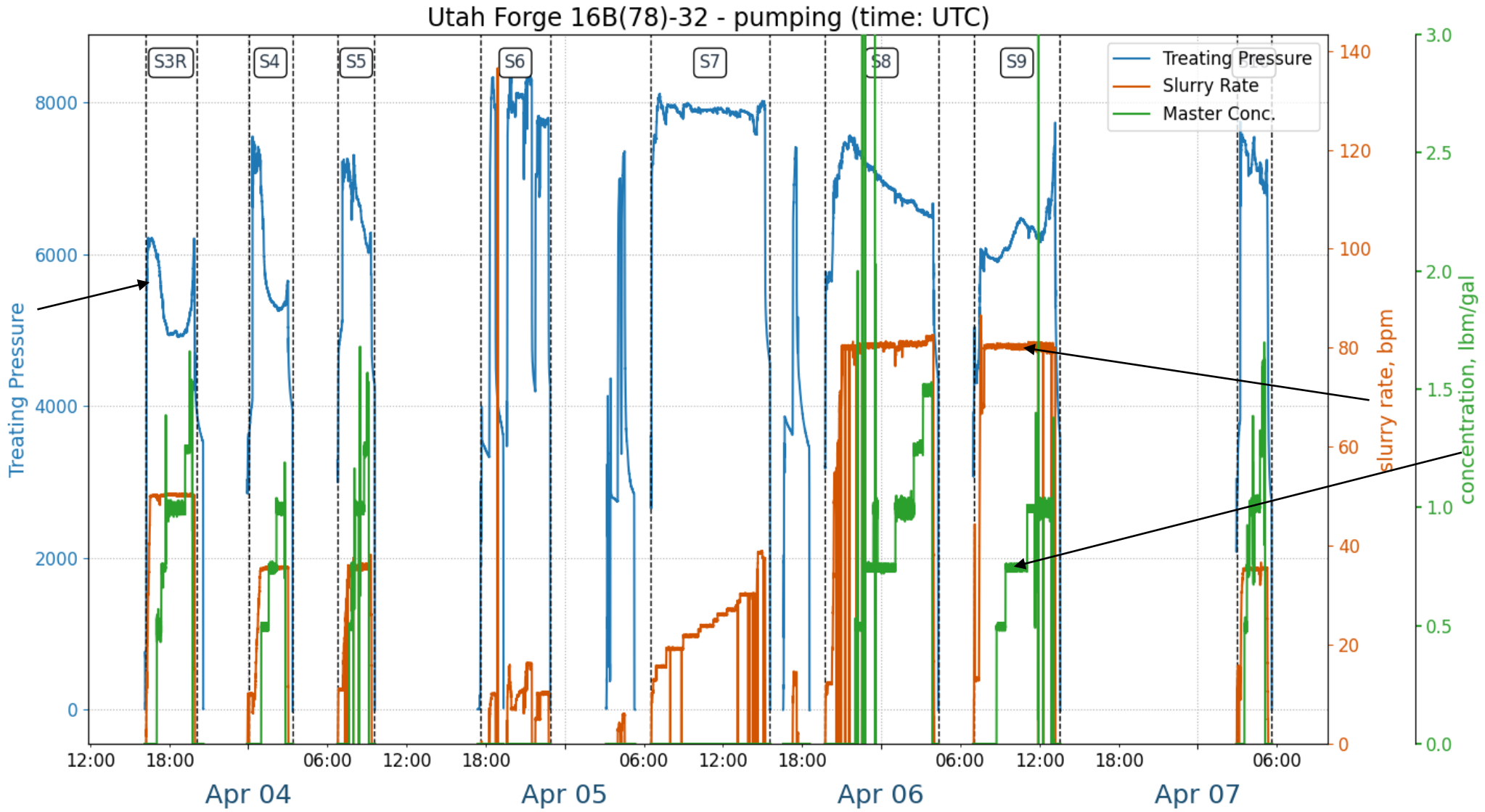
DTS = Distributed Temperature Sensing fiber optic measurement

BCF = Brillouin Center Frequency fiber optic measurement

Pumping data

As received from Operator.

Well 16A – frac pumping data – Frac Stages 3R to 10



SMF Optical Loss Analysis using Neubrex SR7000 Rayleigh IU

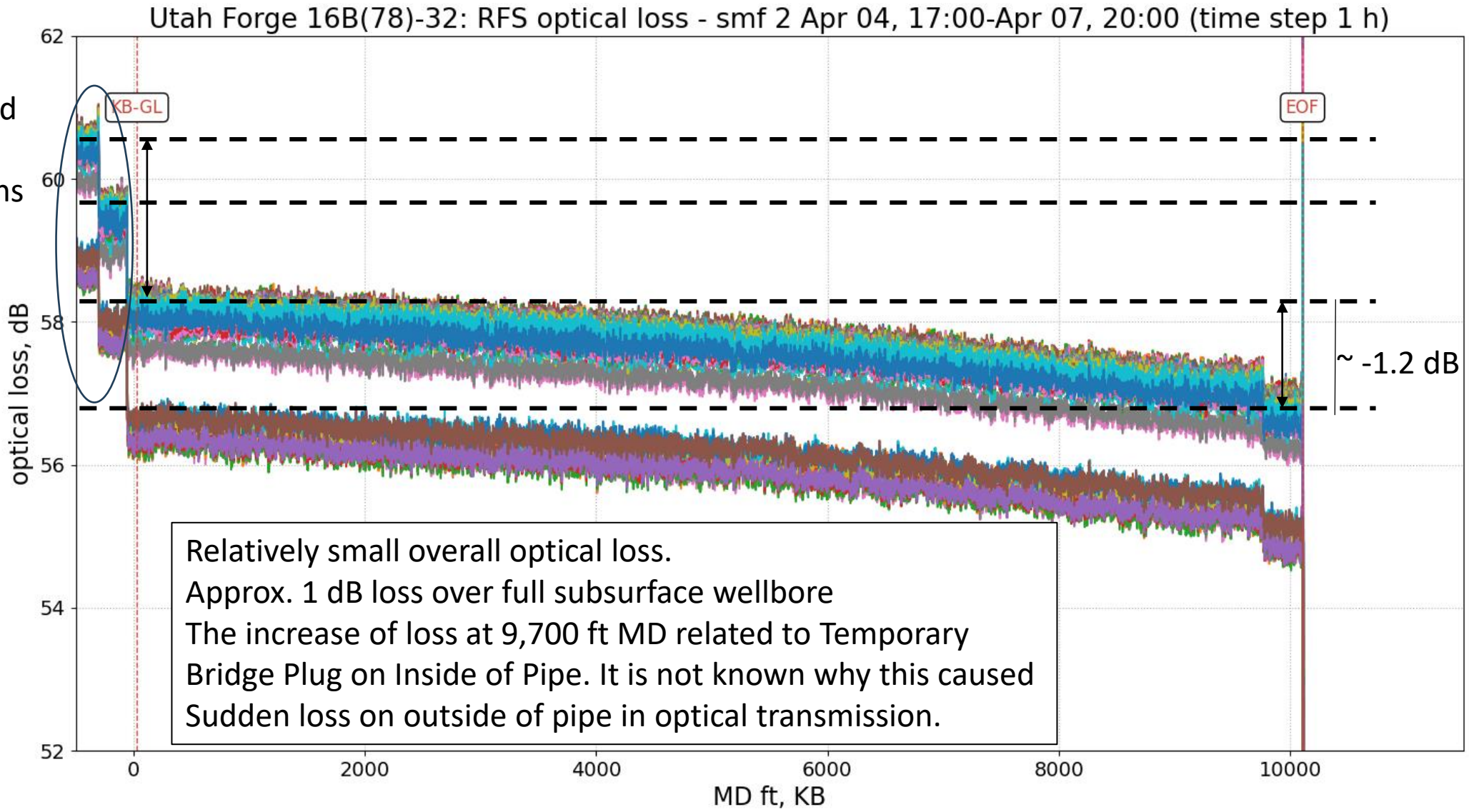
Optical loss on SM fiber based on Rayleigh measurements/data.

Much better optical loss resolution than hand-held OTDR

Resolution 0.67 ft (0.2m) per depth sample

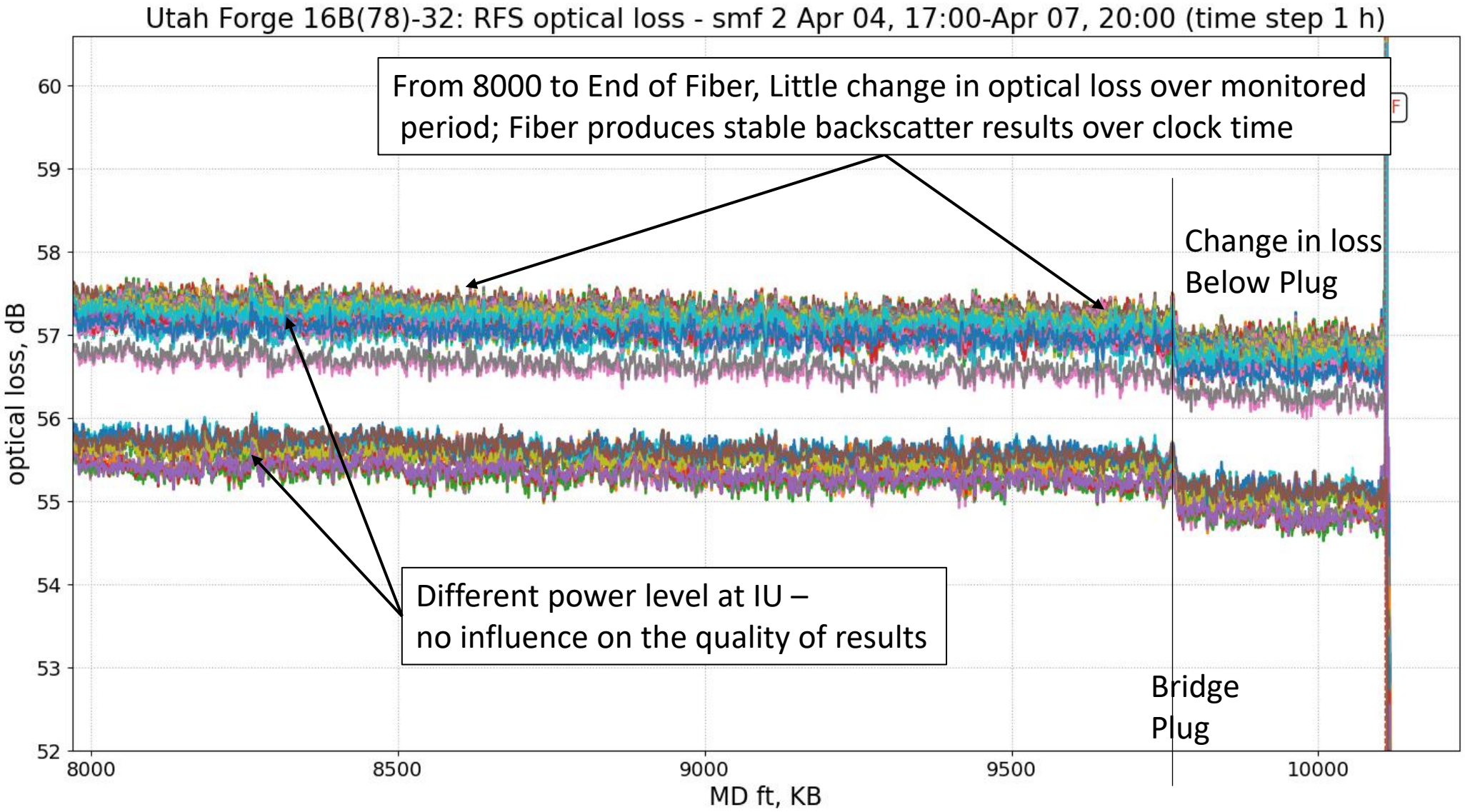
Well 16B(78)-32 – optical loss distribution

~ -2.0 dB
Loss related
To Surface
Connections



Relatively small overall optical loss.
Approx. 1 dB loss over full subsurface wellbore
The increase of loss at 9,700 ft MD related to Temporary Bridge Plug on Inside of Pipe. It is not known why this caused Sudden loss on outside of pipe in optical transmission.

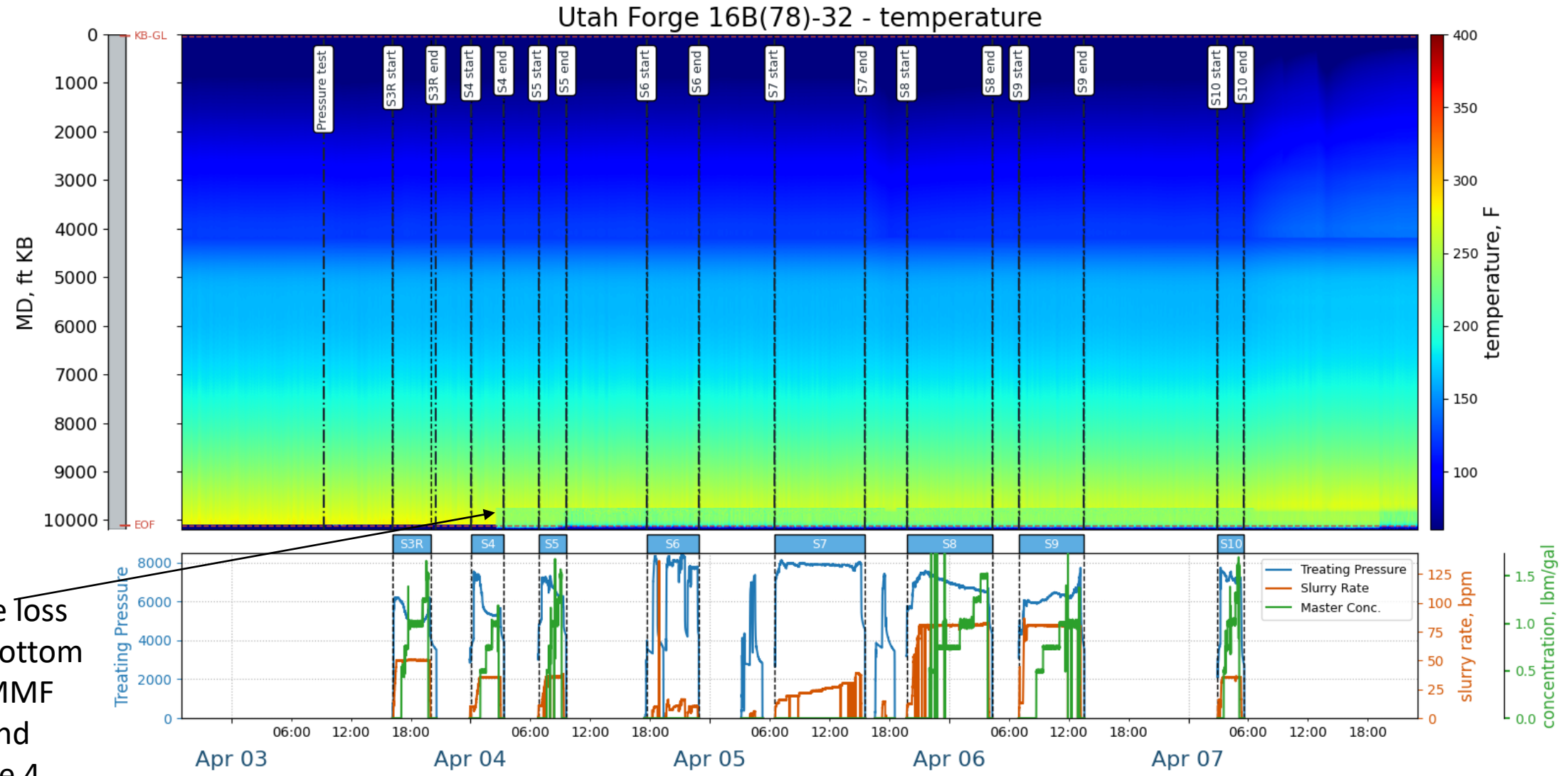
Well 16B(78)-32 - SMF 2 – optical loss distribution (step 1 h)



Distributed Temperature Sensing

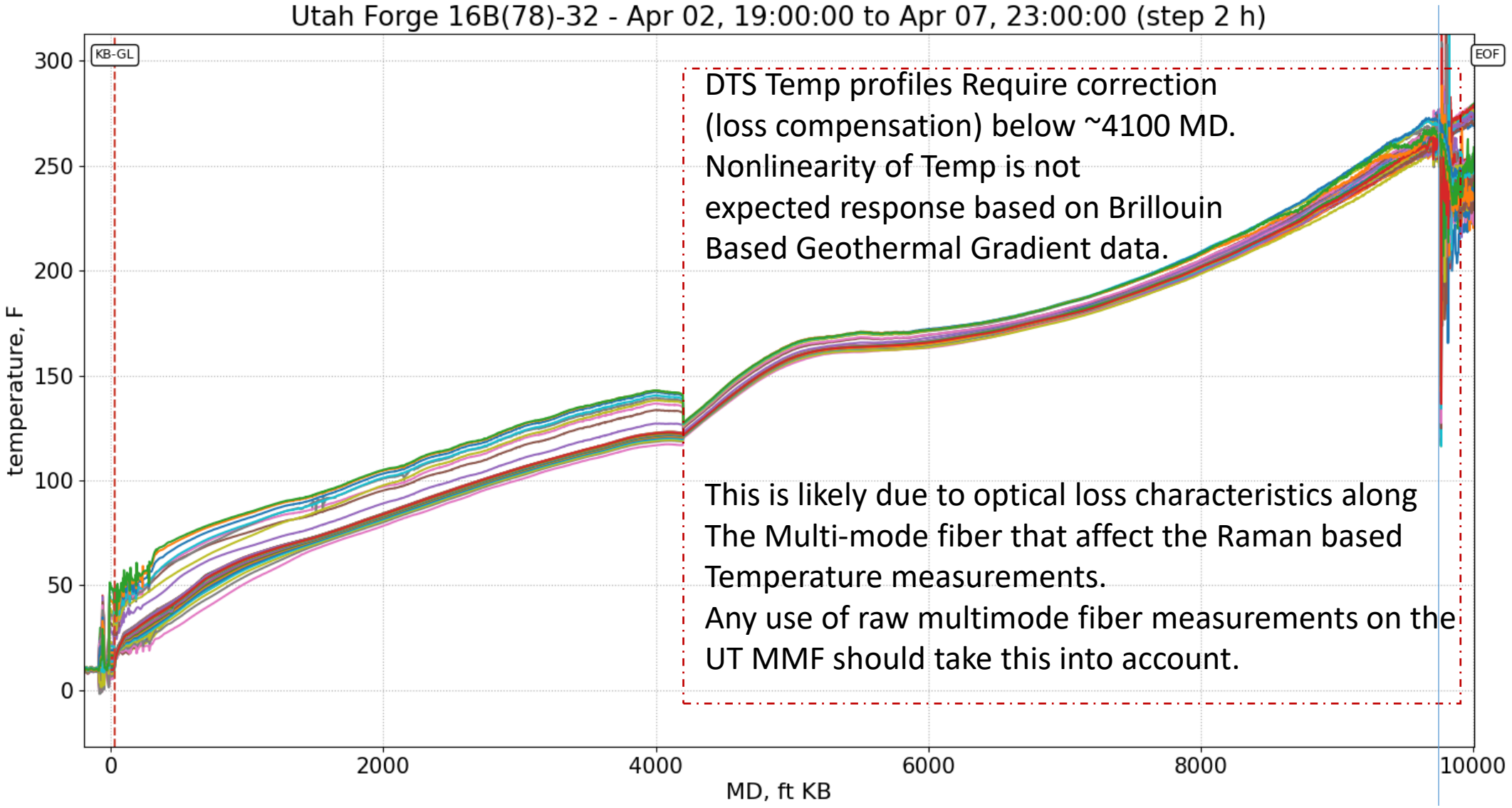
-- first trace: Apr 02, 2024, 19:00:40
-- last trace: Apr 07, 2024, 21:19:51
-- number of traces: 3,416
-- number of samples per trace: 4,348
-- average temporal interval (sec): 129

Well 16B – DTS temperature overview with Stage Annotate

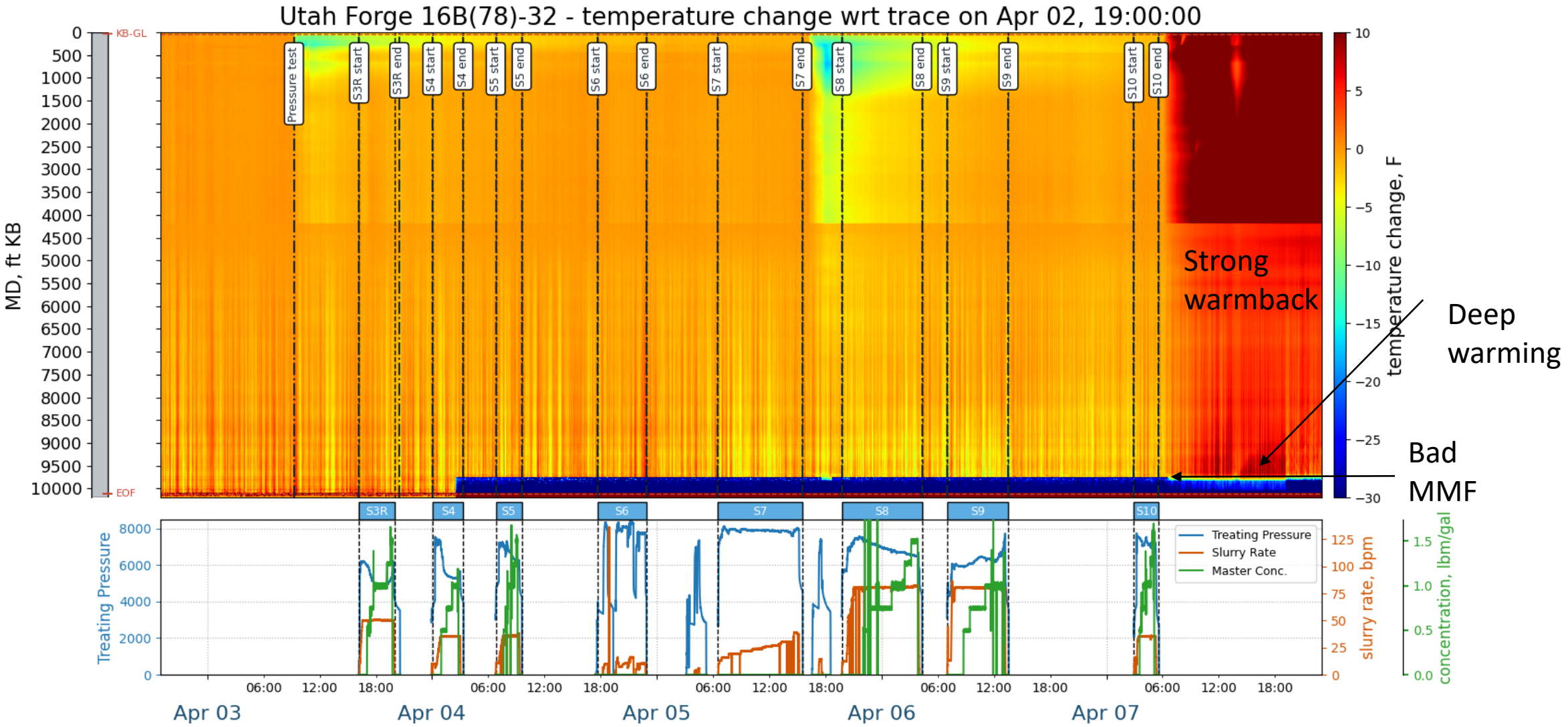


Note loss
Of bottom
Of MMF
At end
Stage 4

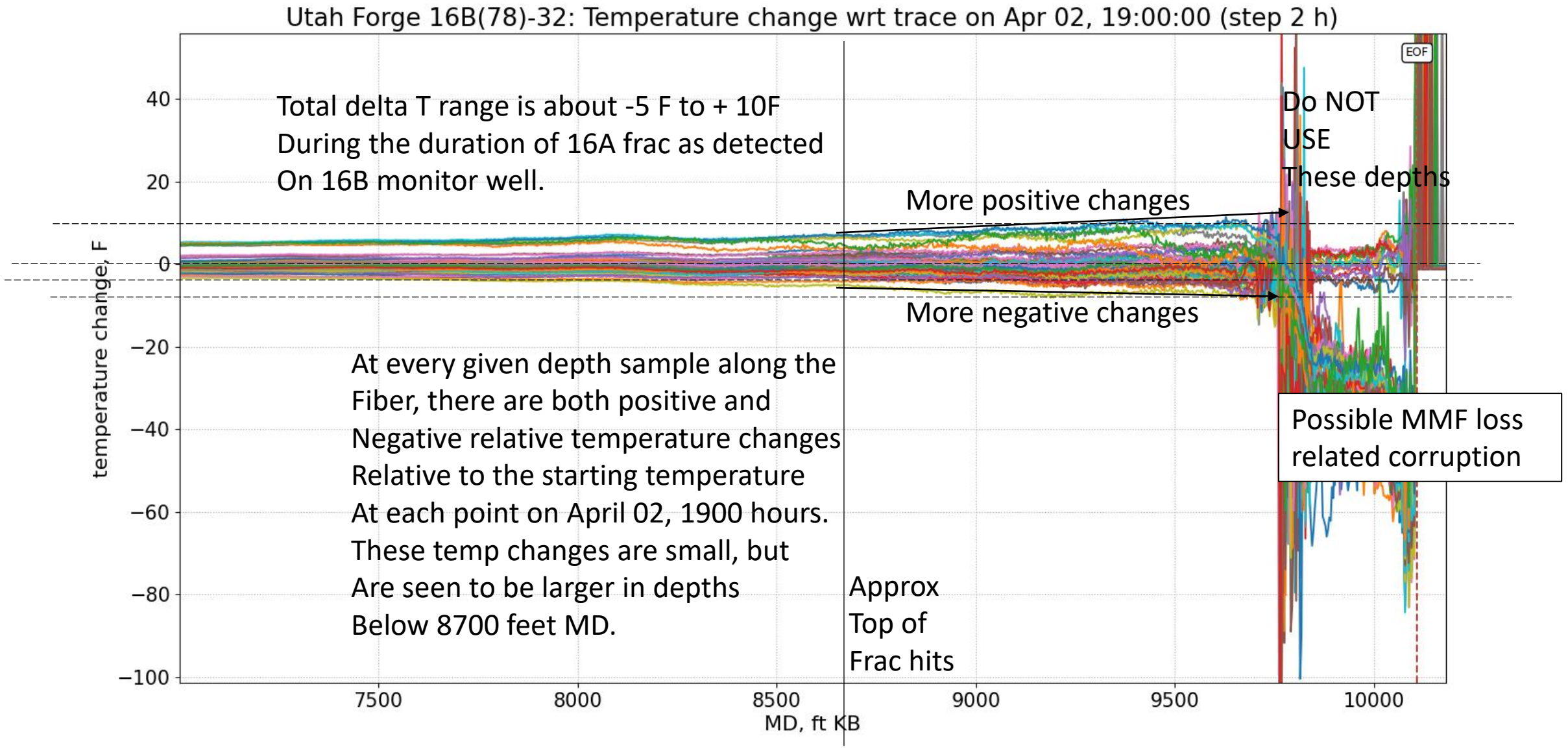
Well 16B – DTS selected traces of RAW DTS DATA on MMF



Well 16B – DTS temperature change wrt baseline April 02



Well 16B – DTS temperature changes at depths



Brillouin Absolute Total Strain using Neubrex Brillouin SB-8200

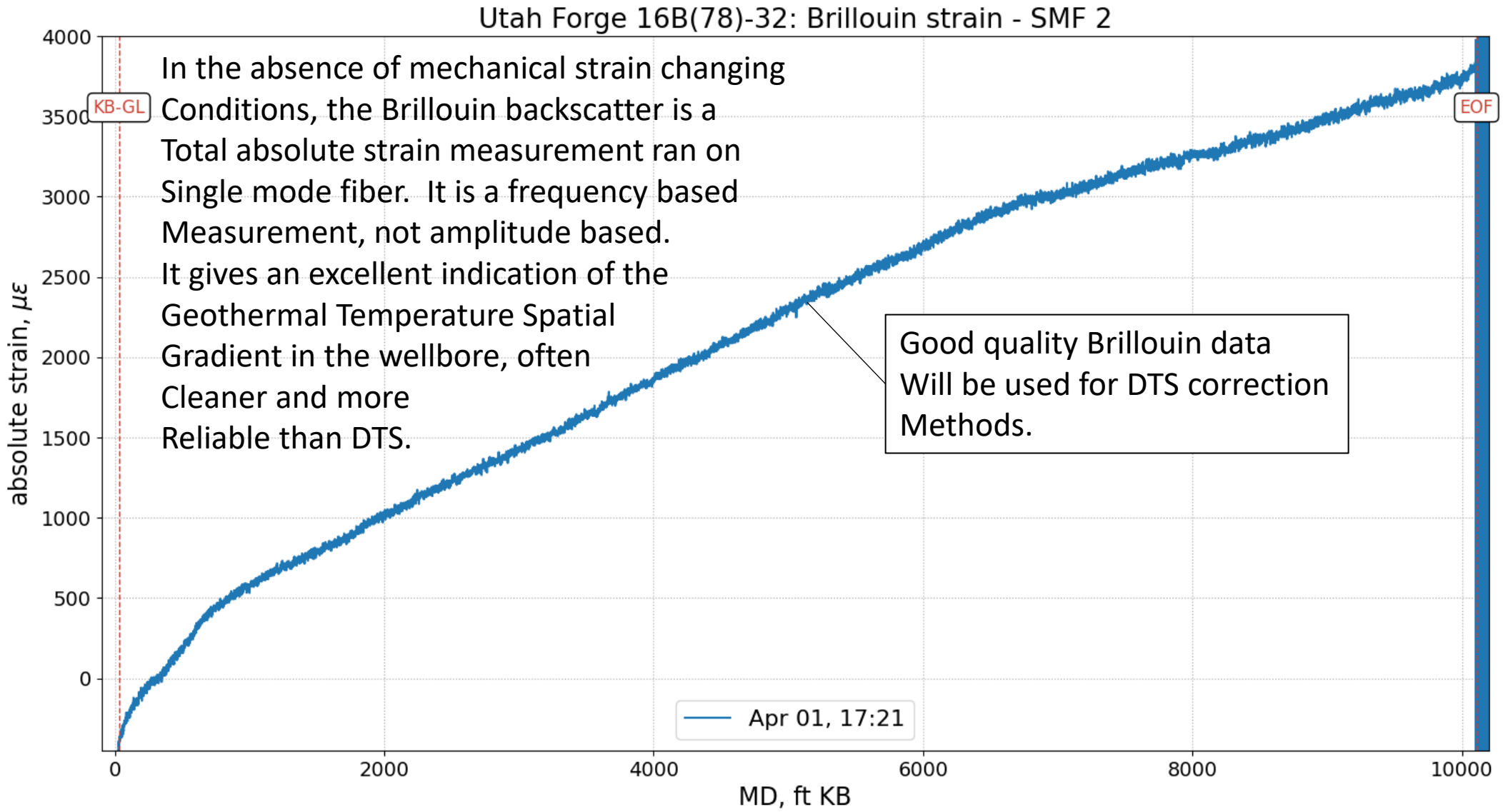
-- first trace: Apr 01, 2024, 17:21:33

-- last trace: Apr 01, 2024, 17:27:38

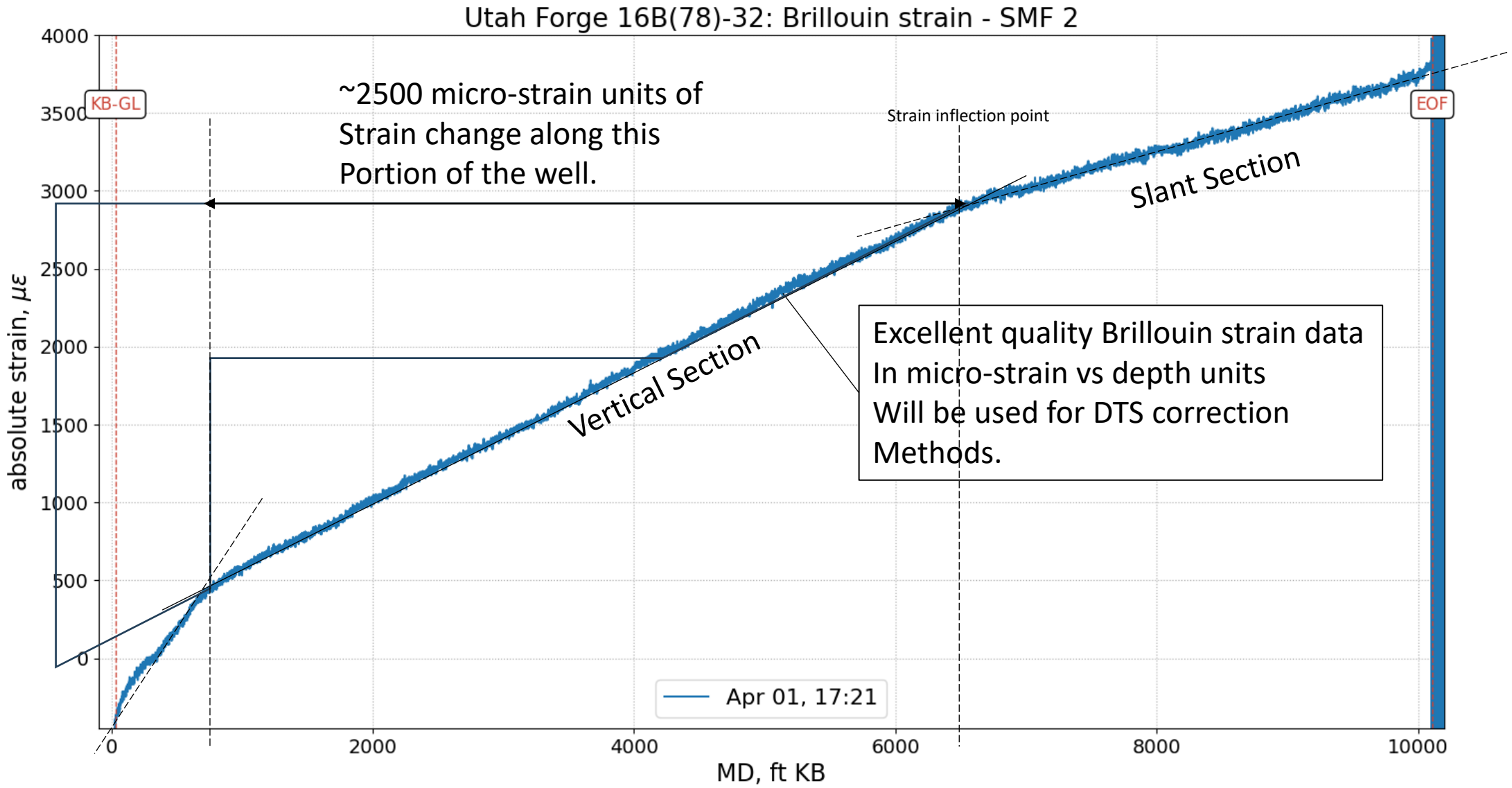
-- number of traces: 2

-- number of samples per trace: 78,349

Well 16B – Brillouin absolute strain



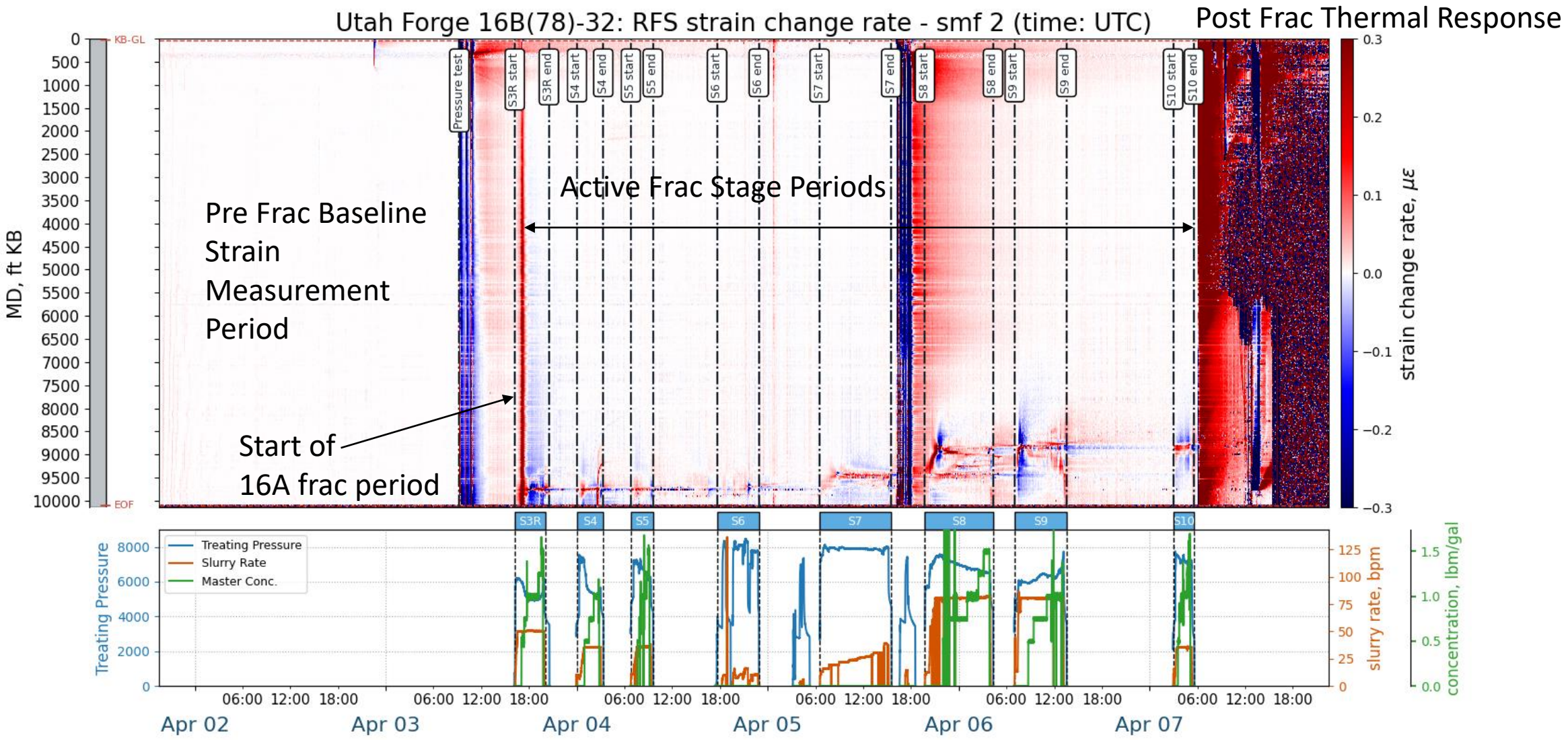
Well 16B – Brillouin absolute strain



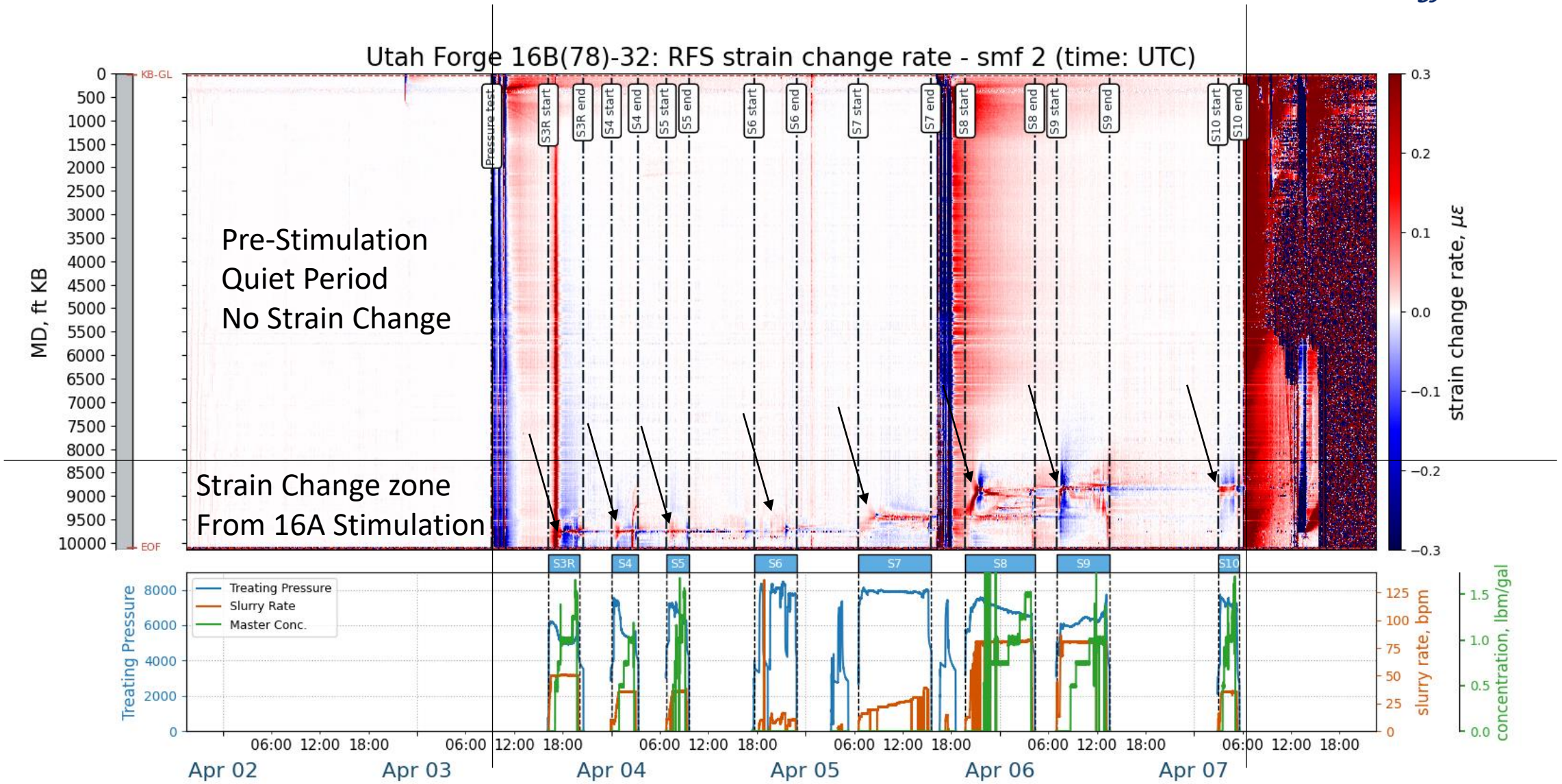
RFS DSS – strain change rate

-- first trace: Apr 01, 2024, 19:24:44
-- last trace: Apr 07, 2024, 22:30:34
-- number of traces: 10,680
-- number of samples per trace: 39,175
-- average temporal interval (sec): 50

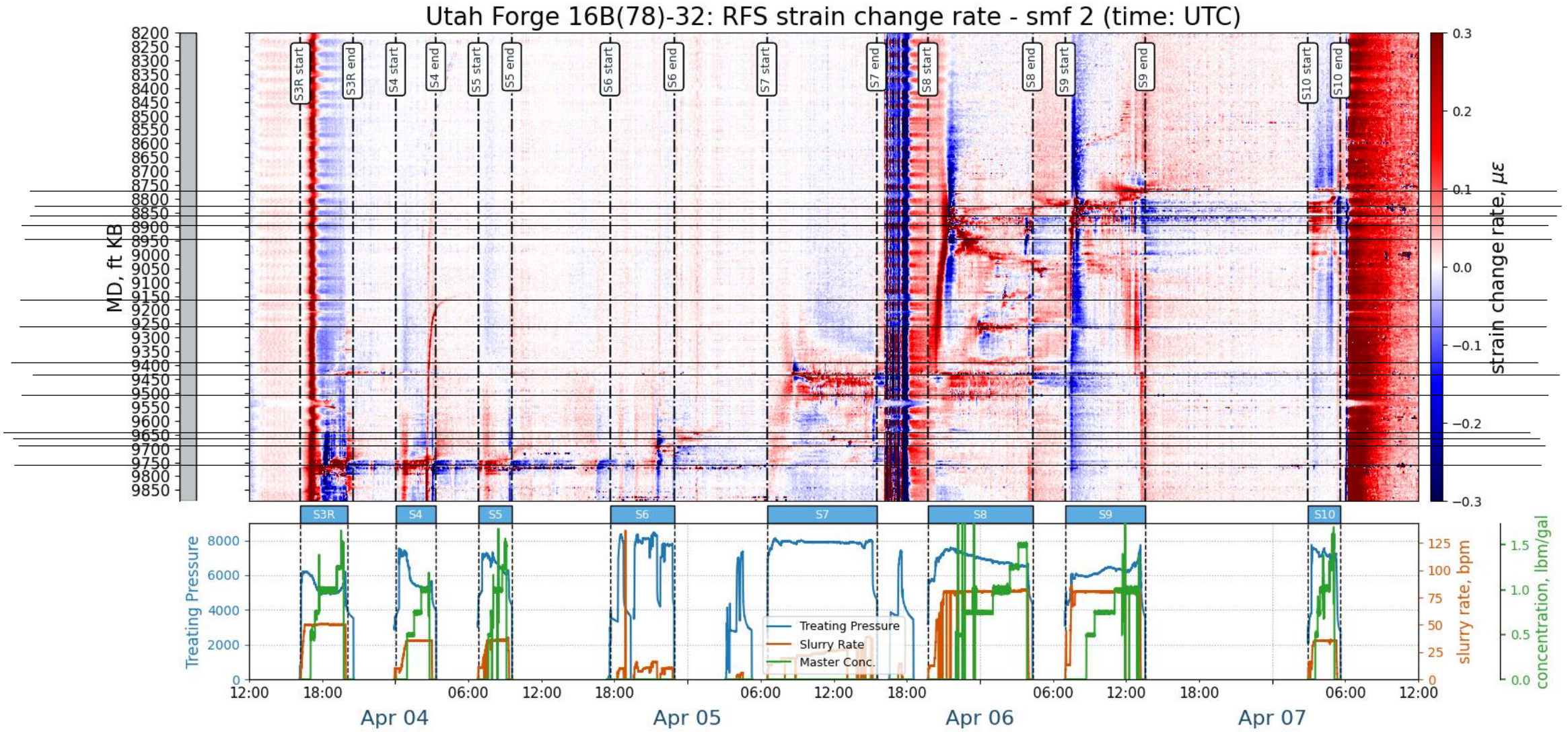
Well 16B – RFS DSS strain rate – overview of FDI frac hits



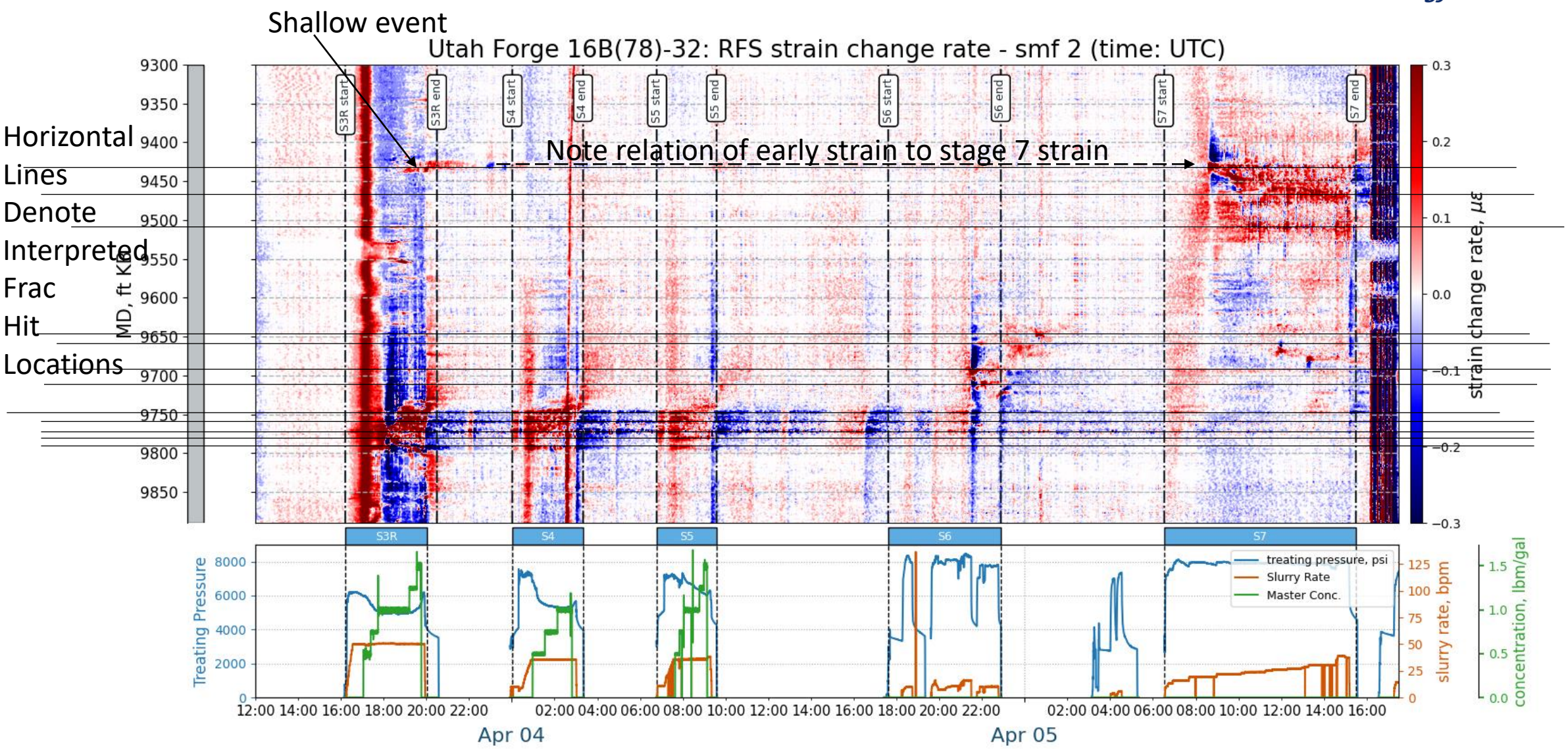
Well 16B – RFS DSS strain rate – Xwell Frac Driven Interactions



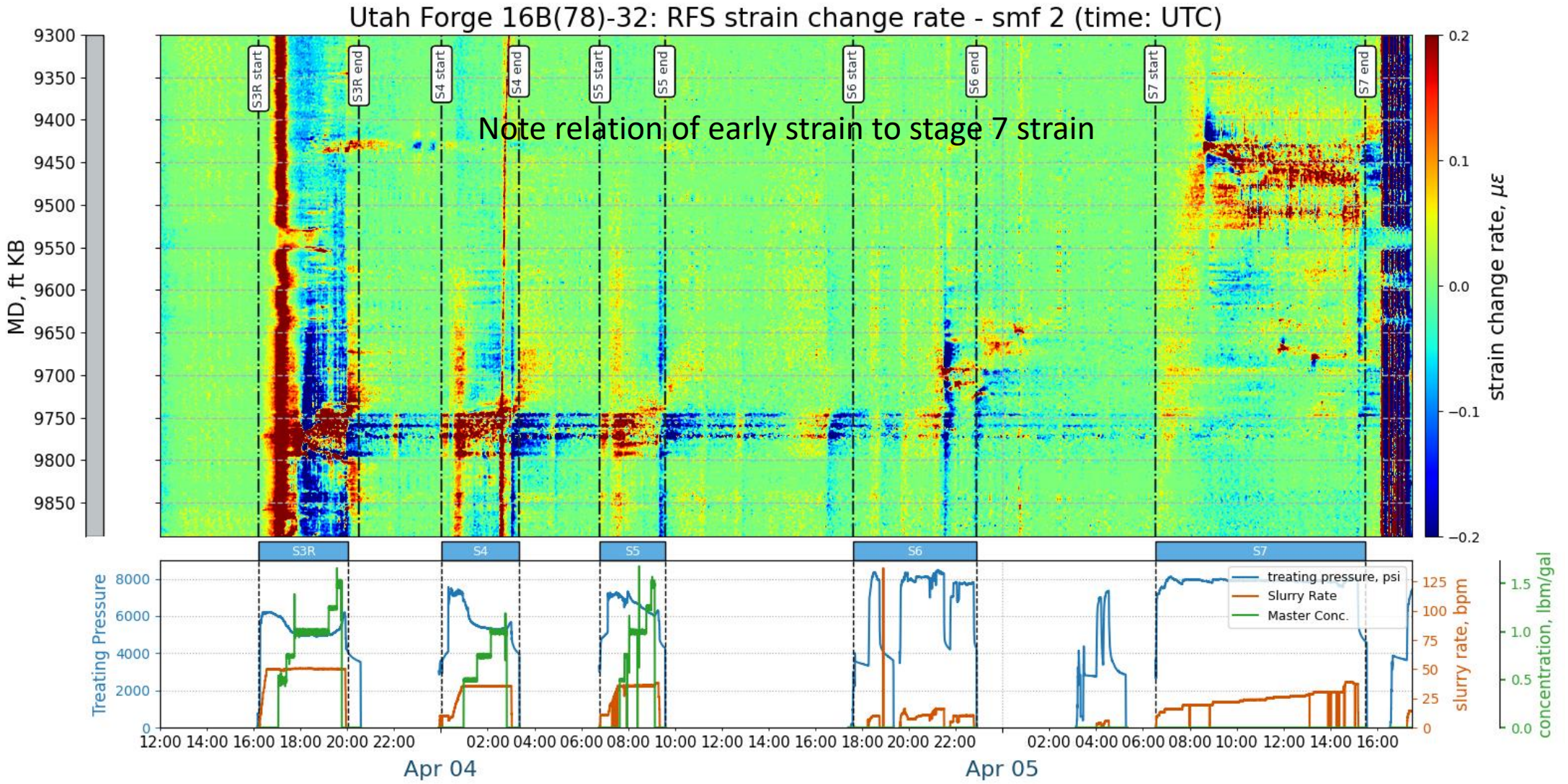
Well 16B – RFS DSS strain rate – FDI raw picks on data



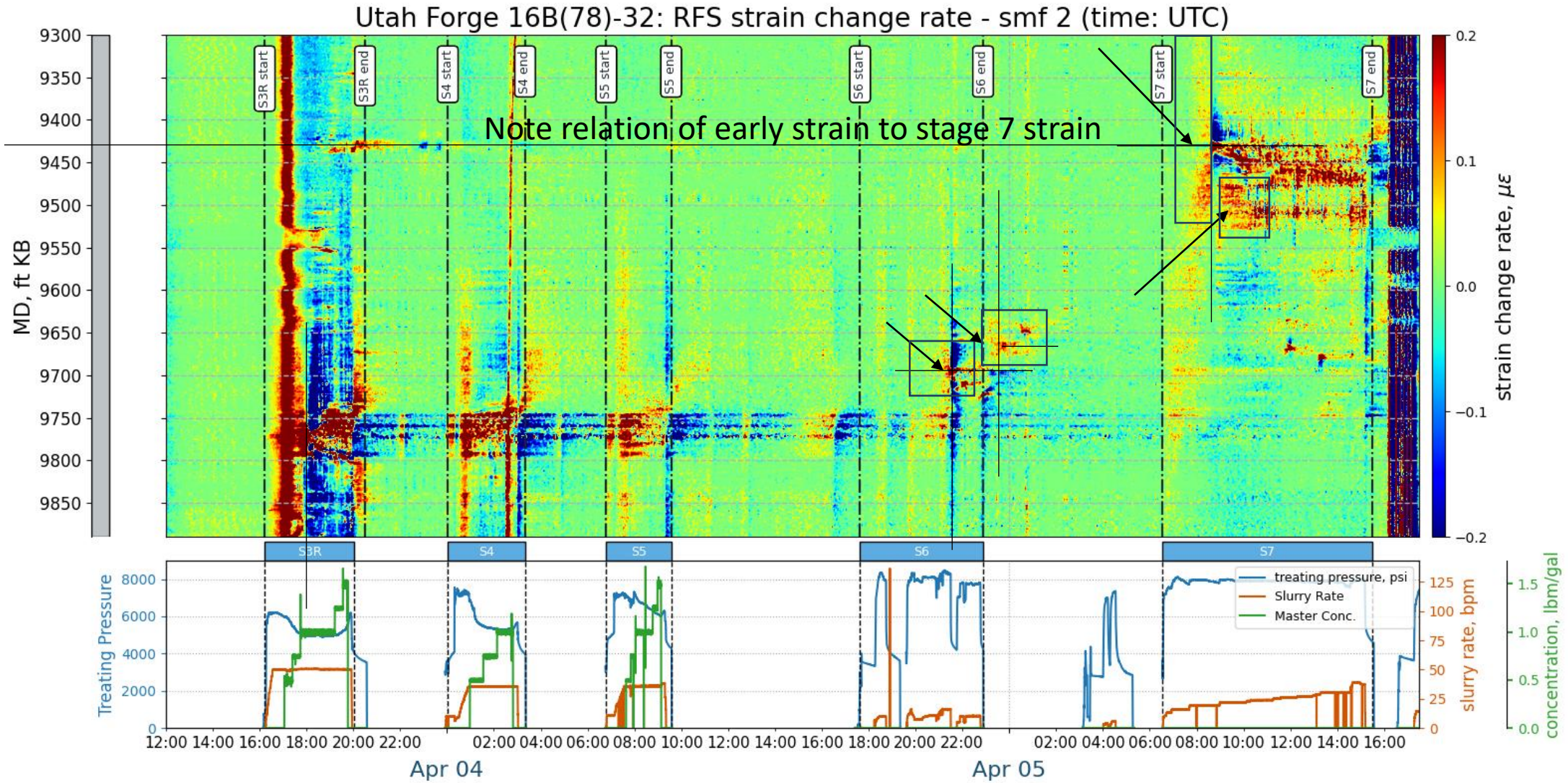
Well 16B – RFS DSS strain rate – 16A stimulated stages 3-7



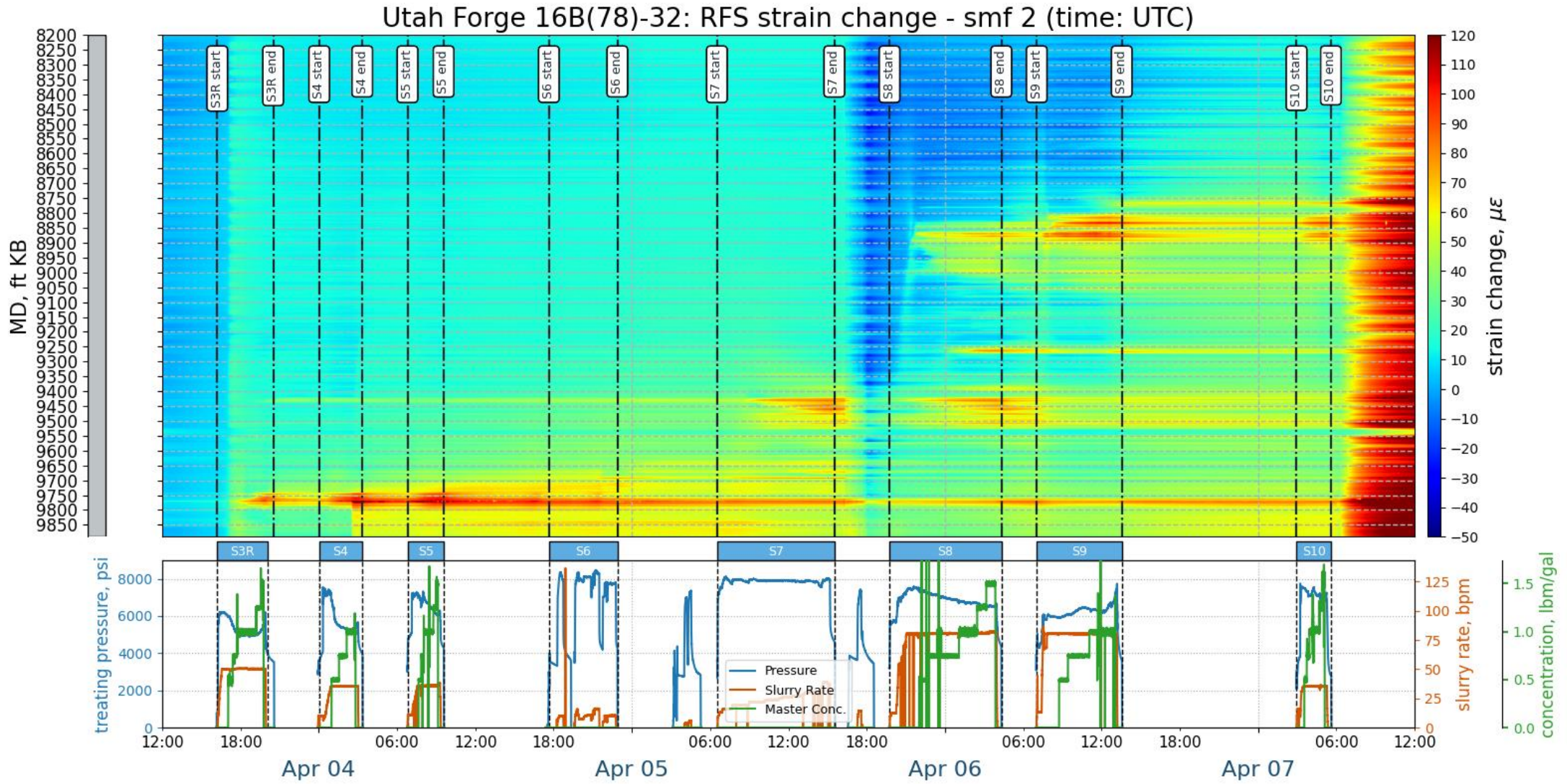
Well 16B – RFS DSS strain rate – stimulated stages 3-7 on 16A



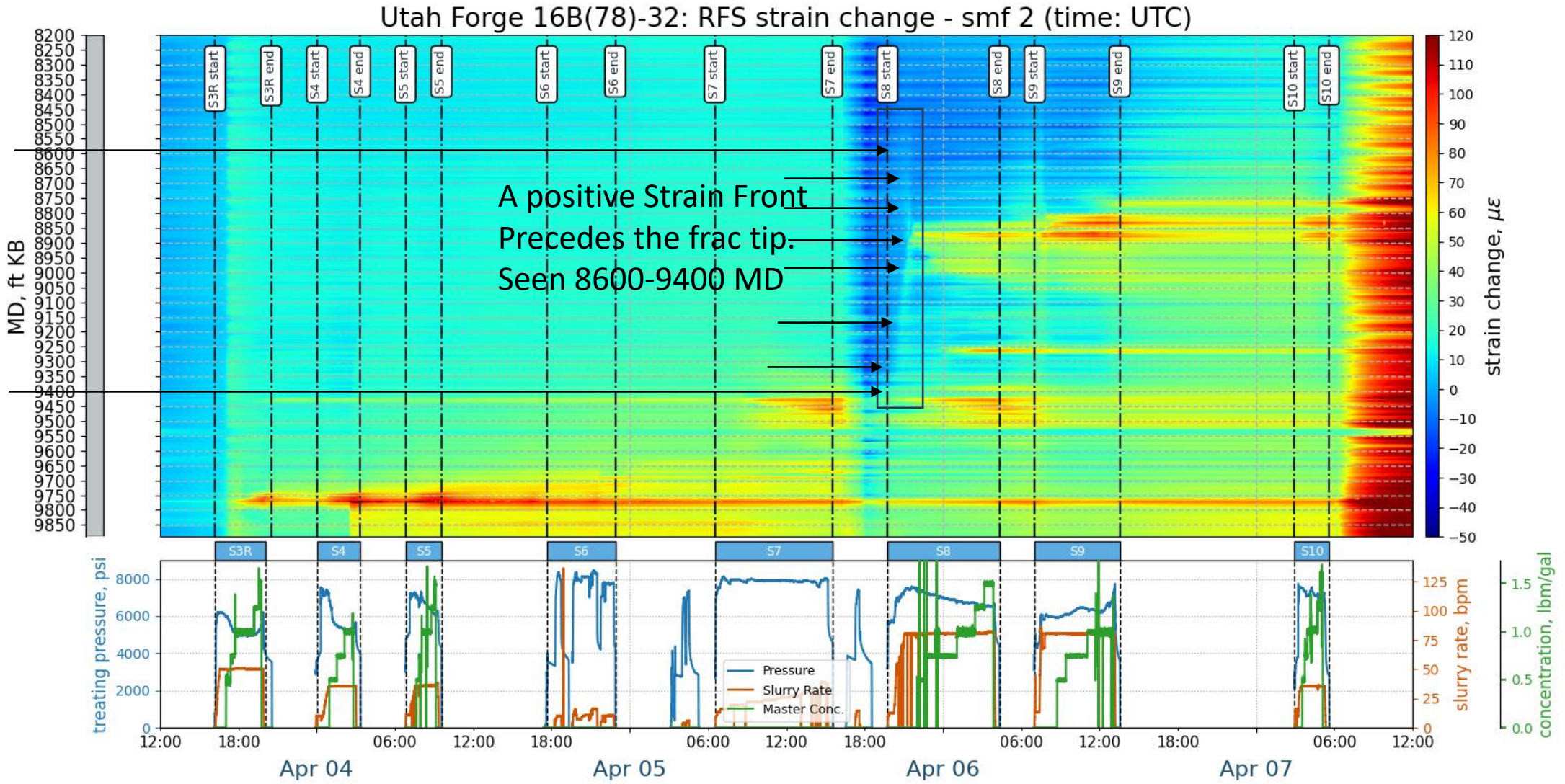
Well 16B – RFS DSS strain rate – Pre Tip Heart Shaped Features



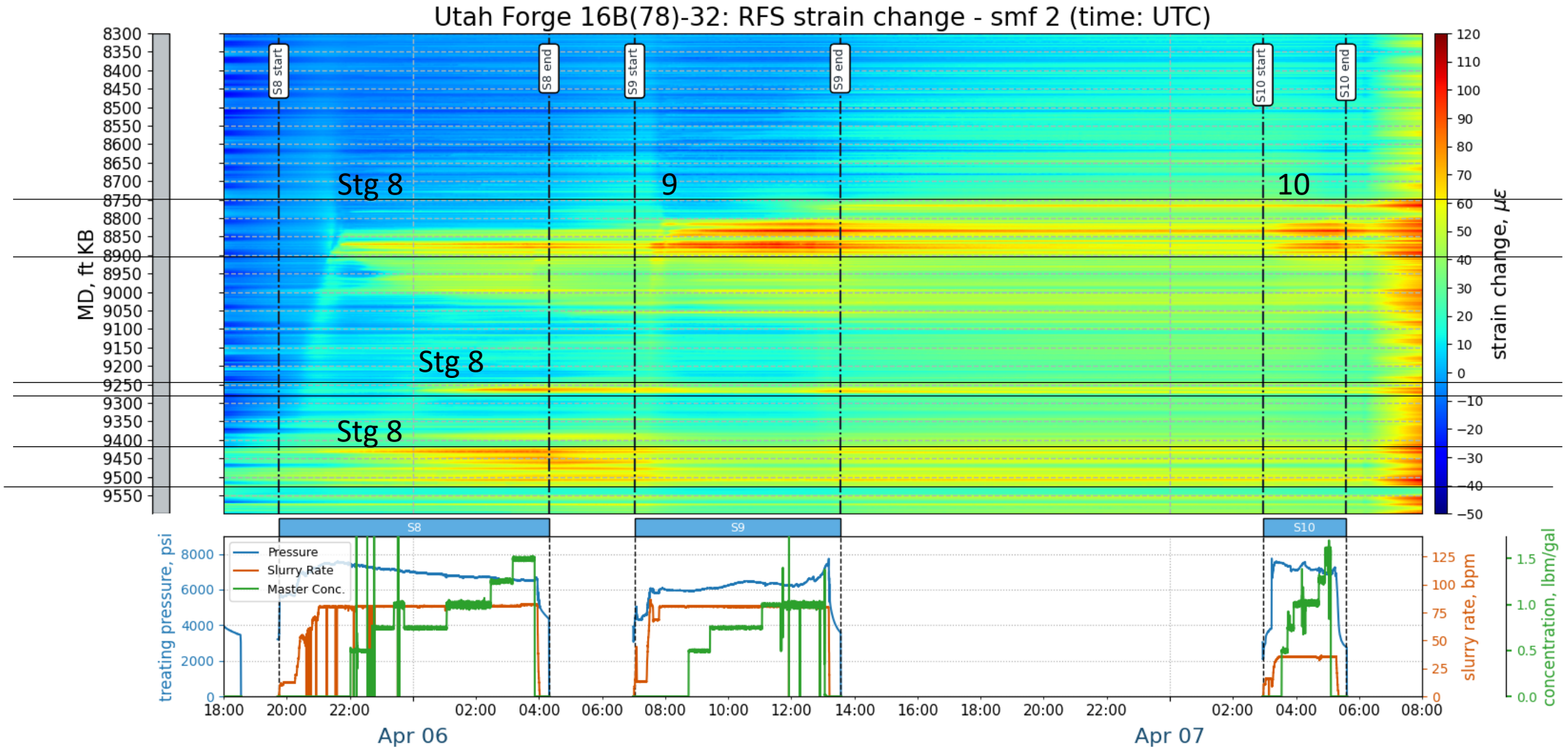
Well 16B – RFS DSS strain change – stimulated stages 3-10 on 16A



Well 16B – RFS DSS strain change – stimulated stages 3-10 on 16A

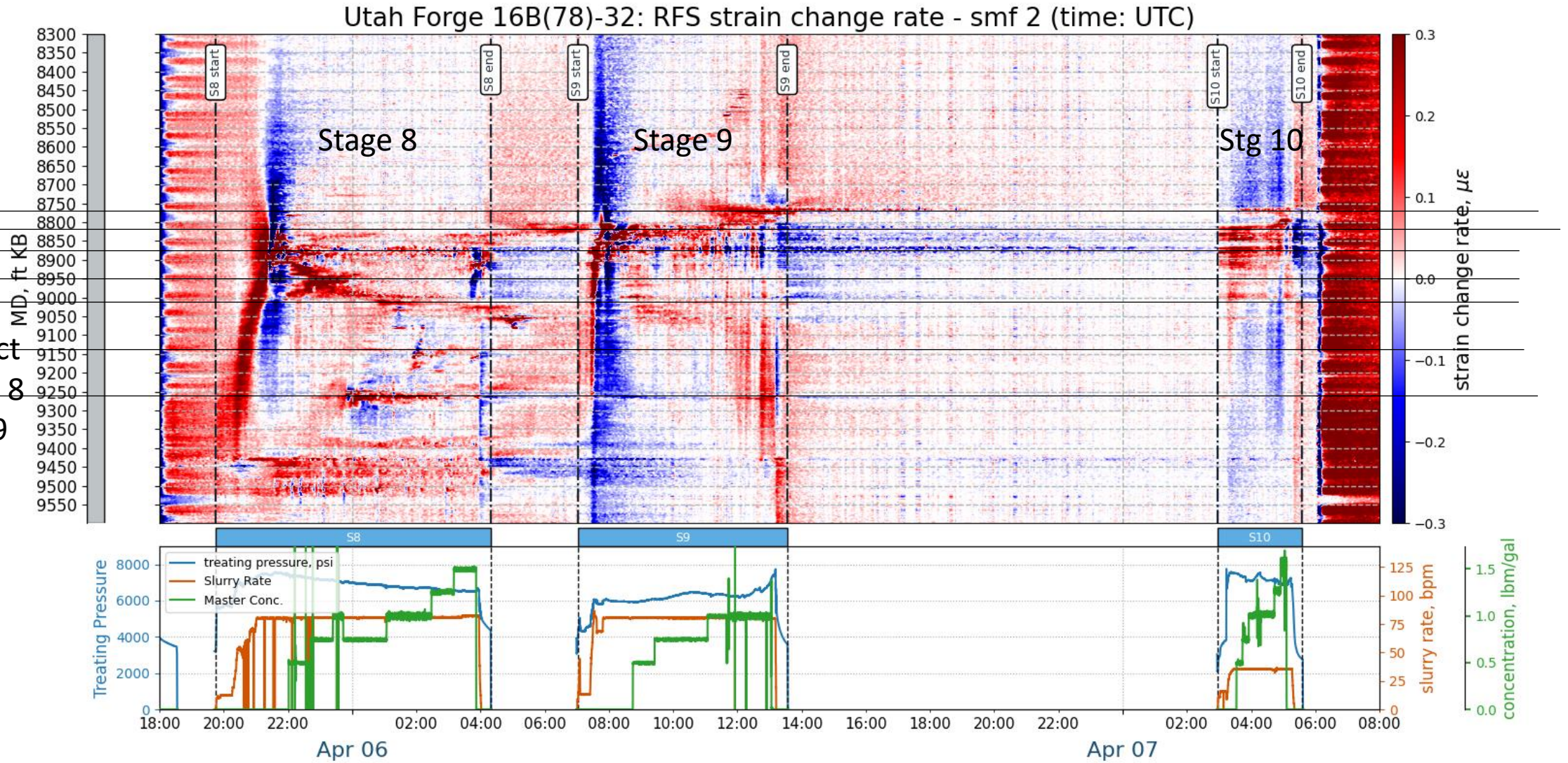


Well 16B – RFS DSS strain change – stimulated stages 8-10 on 16A

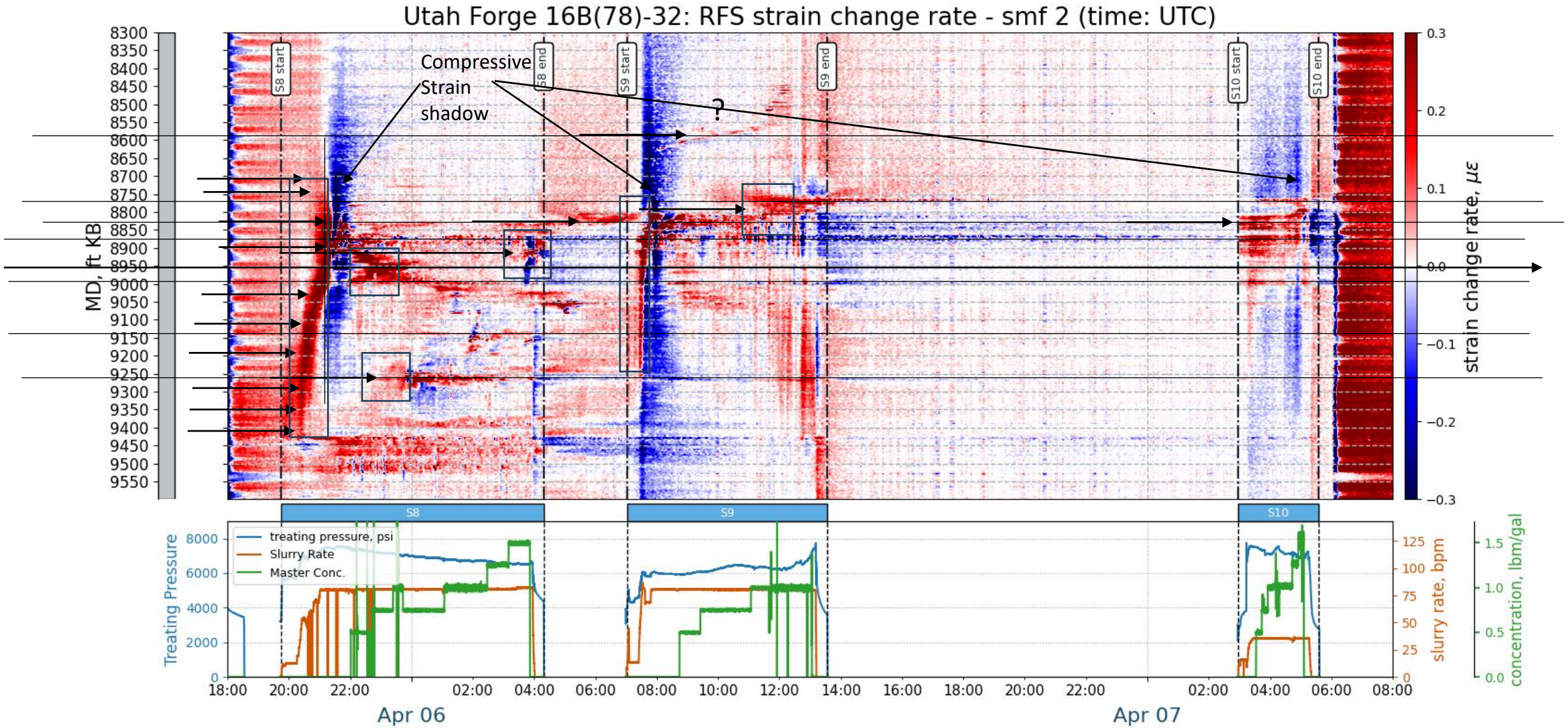


Well 16B – RFS DSS strain rate – stimulated stages 8-10 on 16A

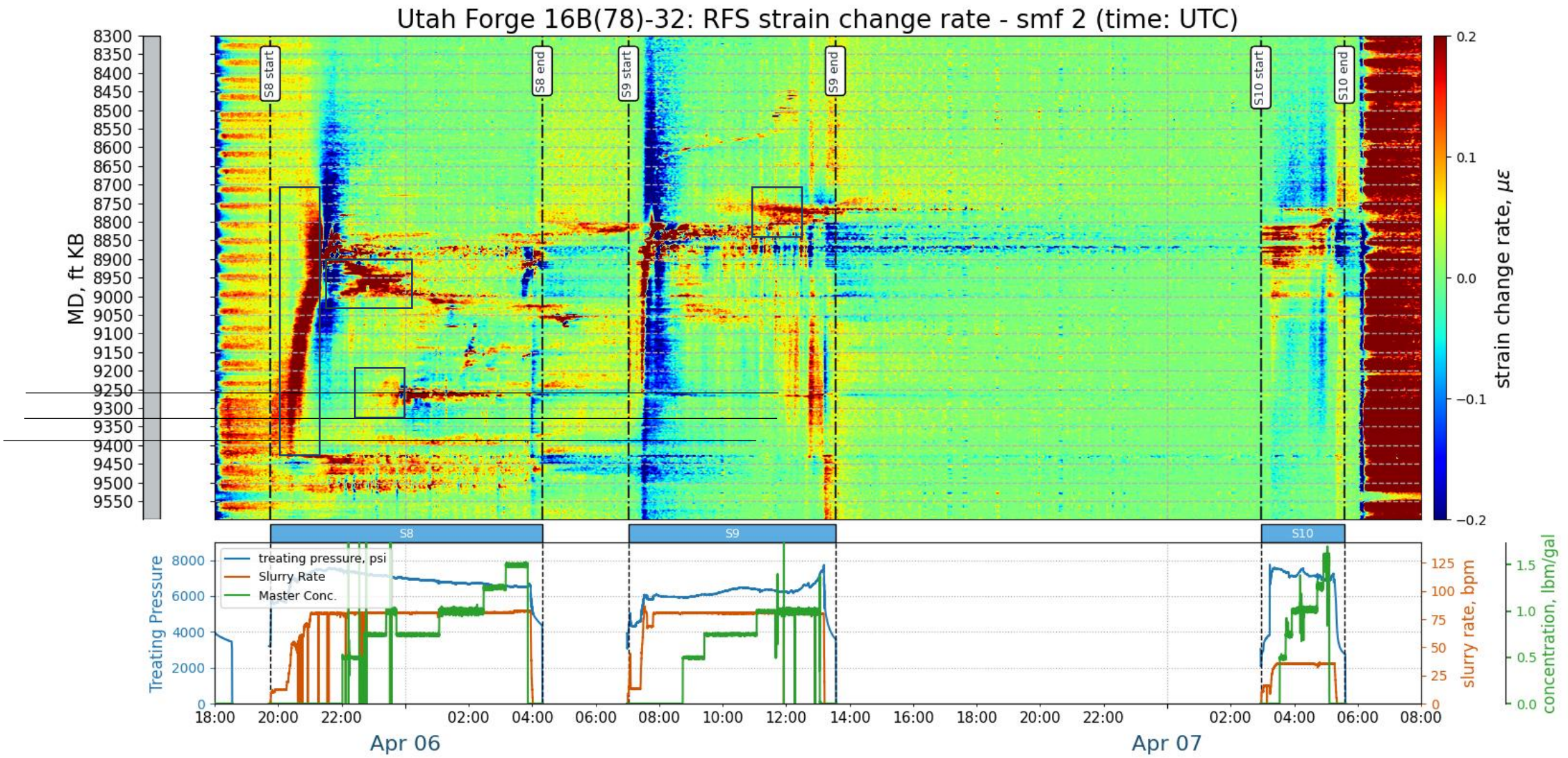
A series
Of FDI
Events
Are detect
From Stg 8
And Stg 9
16A frac



Well 16B – RFS DSS strain rate – Stgs 8-10 “heart shaped features”



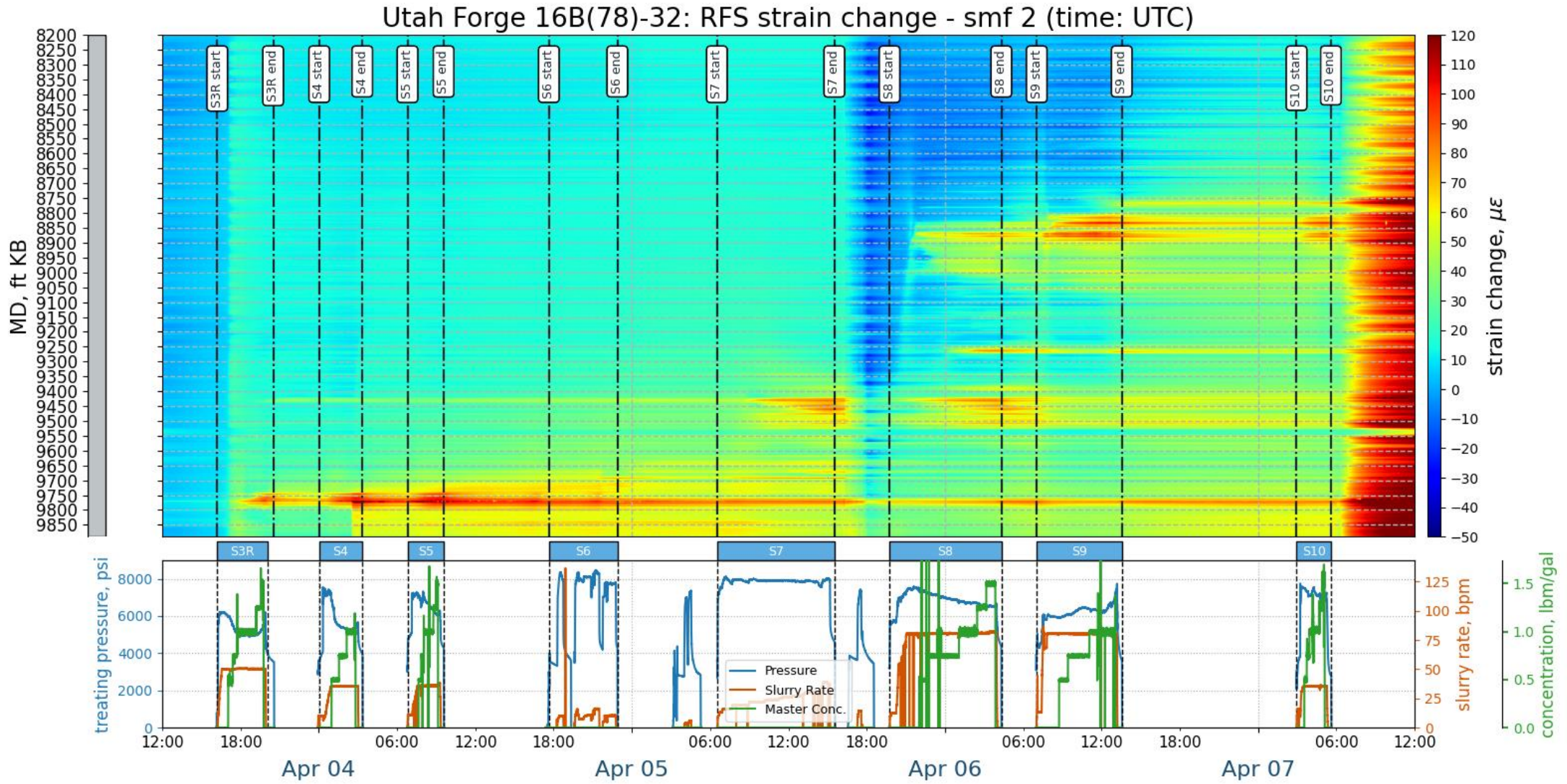
Well 16B – RFS DSS strain rate –stages 8-10 Heart Shaped Features



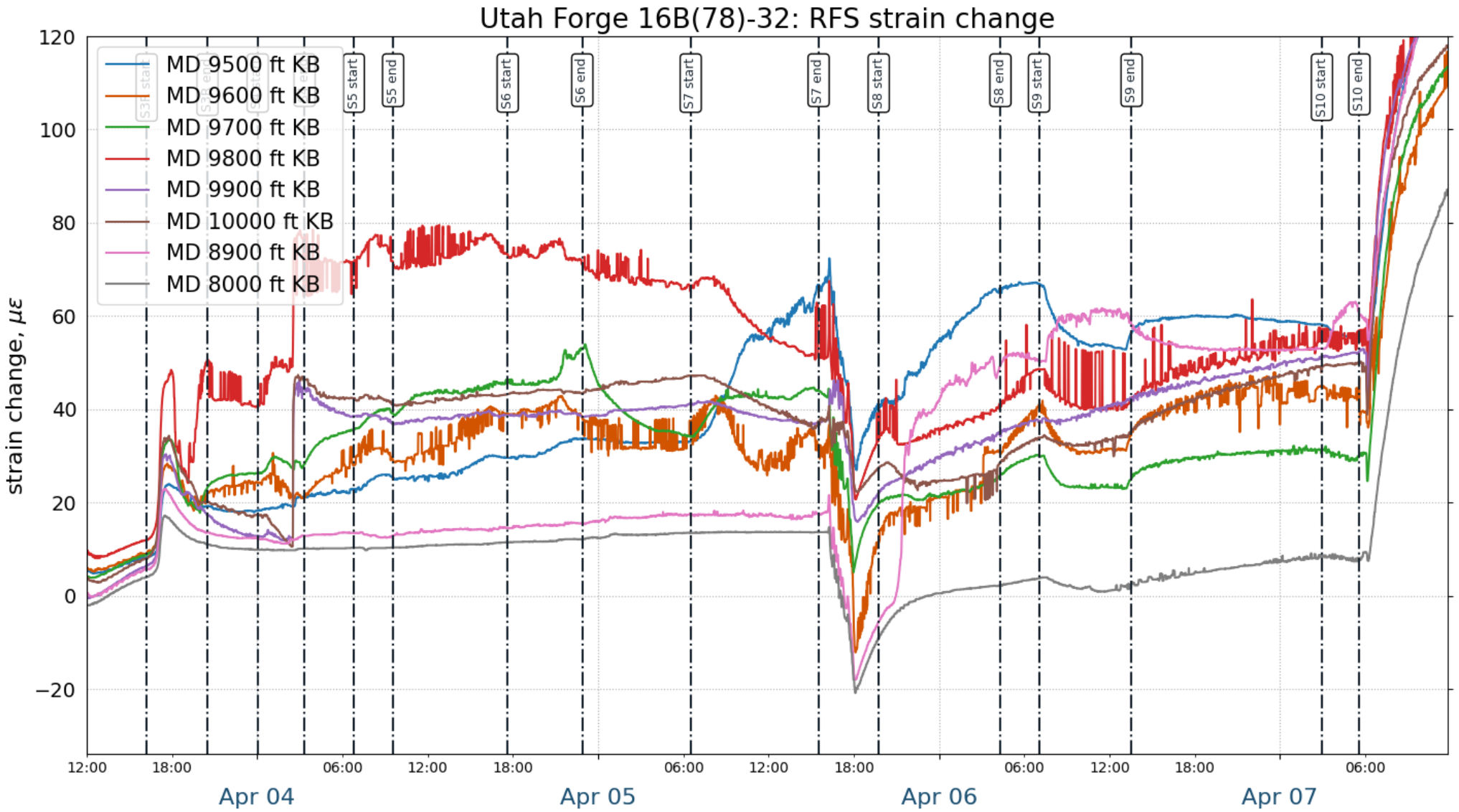
RFS DSS – strain change displays

-- first trace: Apr 01, 2024, 19:24:44
-- last trace: Apr 07, 2024, 22:30:34
-- number of traces: 10,680
-- number of samples per trace: 39,175
-- average temporal interval (sec): 50

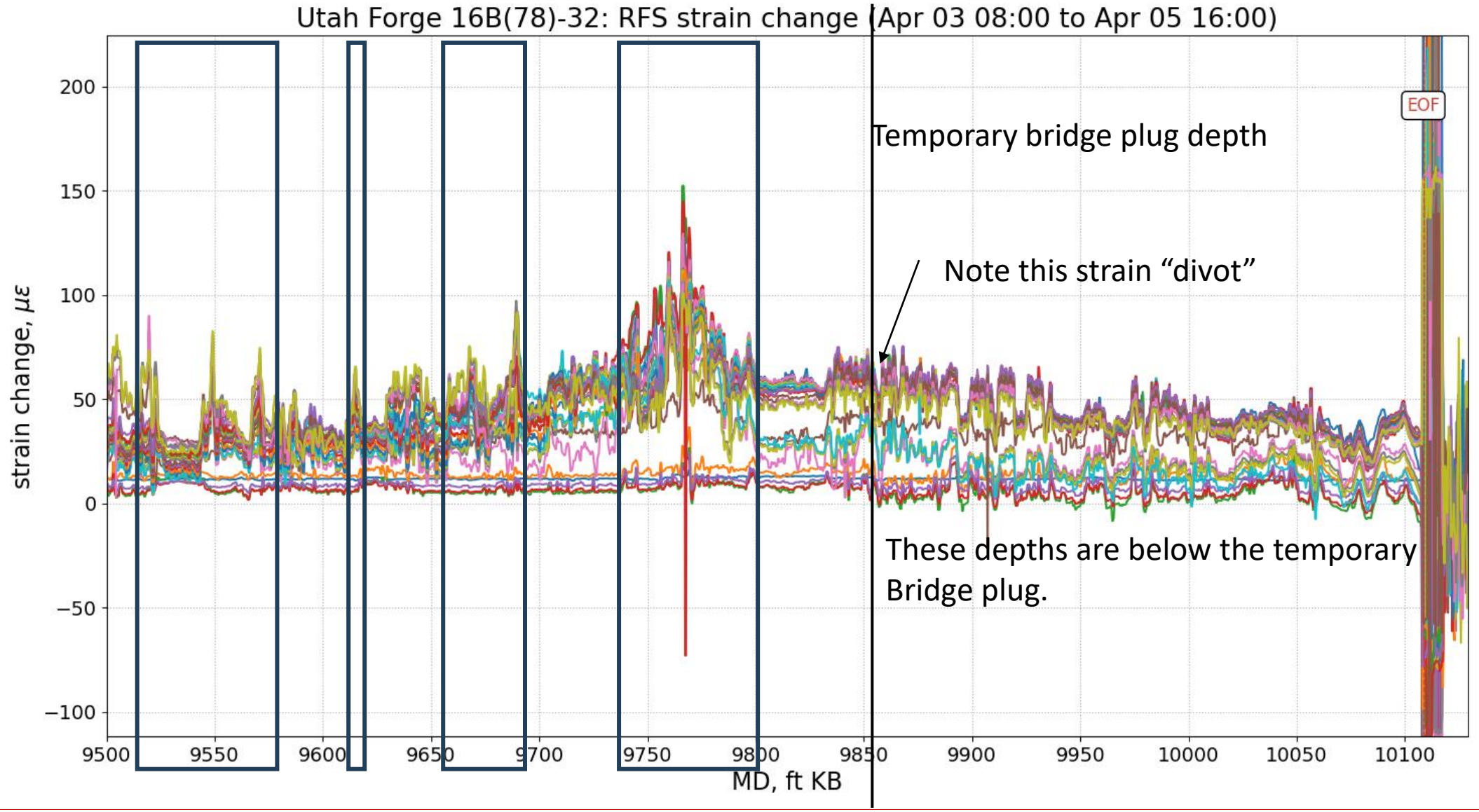
Well 16B – RFS DSS strain change – stimulated stages 3-10 on 16A



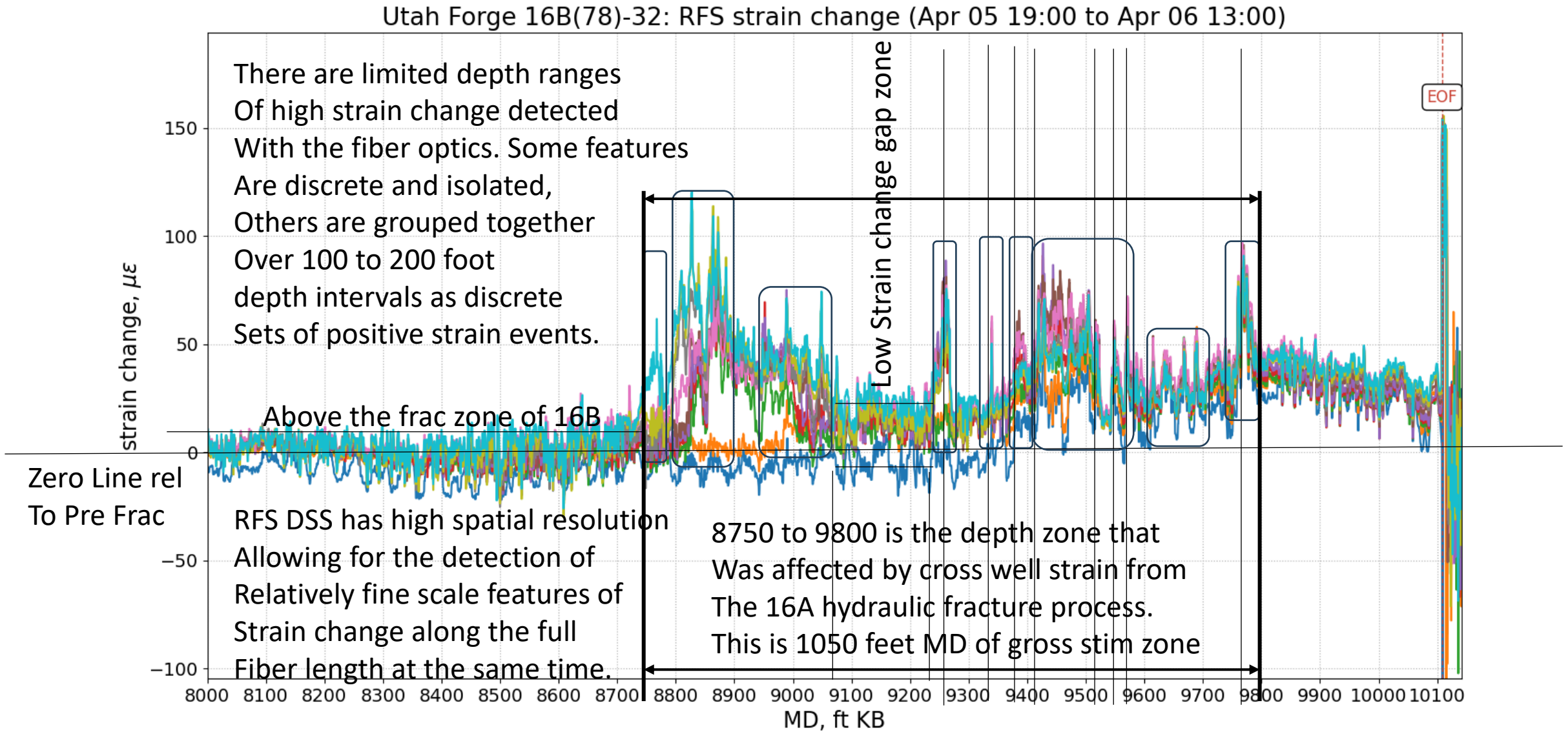
Well 16B – RFS DSS strain change – stimulated stages 3-10 on 16A



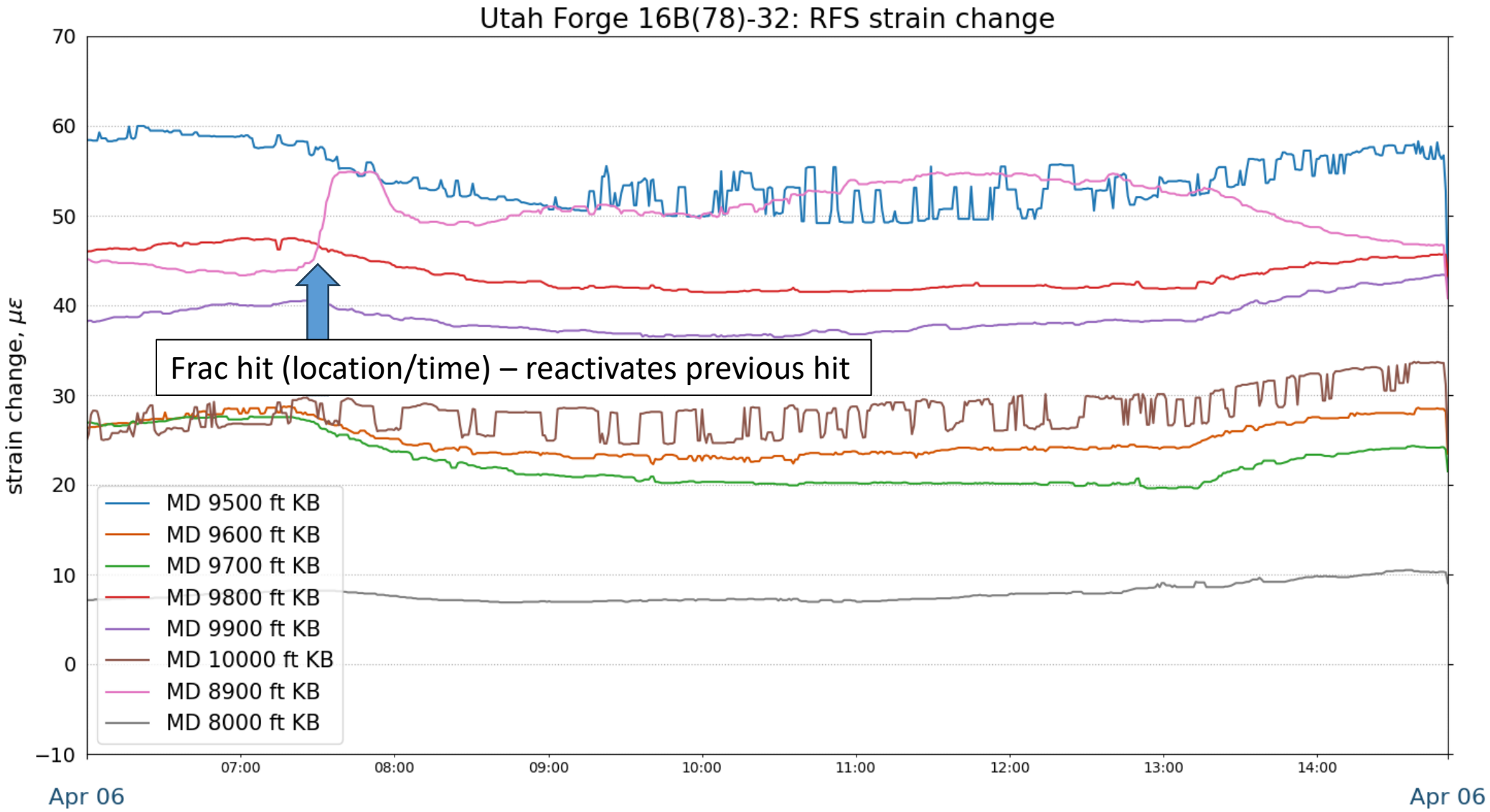
Well 16B – RFS DSS strain change – selected traces, limited depth



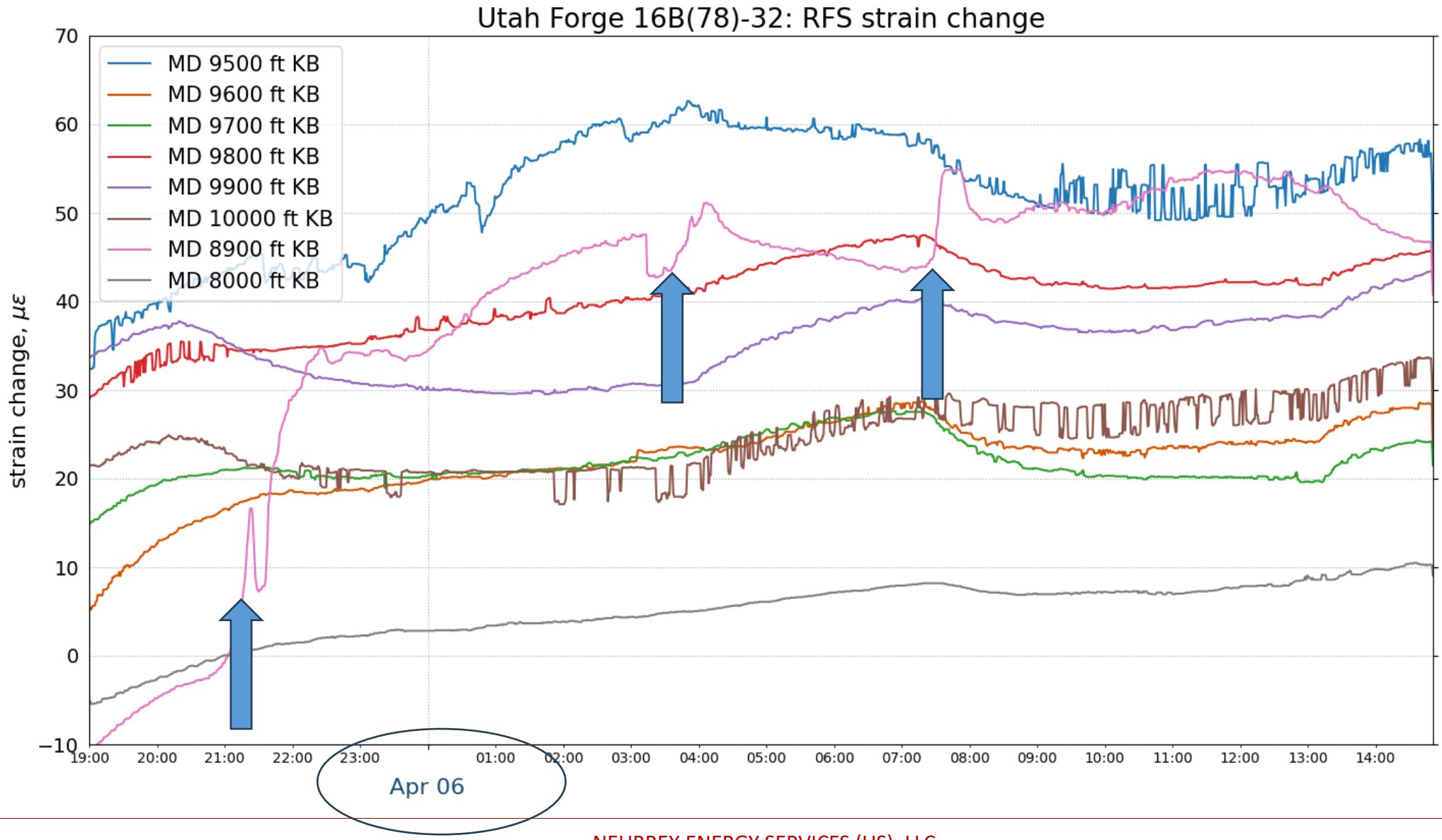
Well 16B – RFS DSS strain change – select traces over time



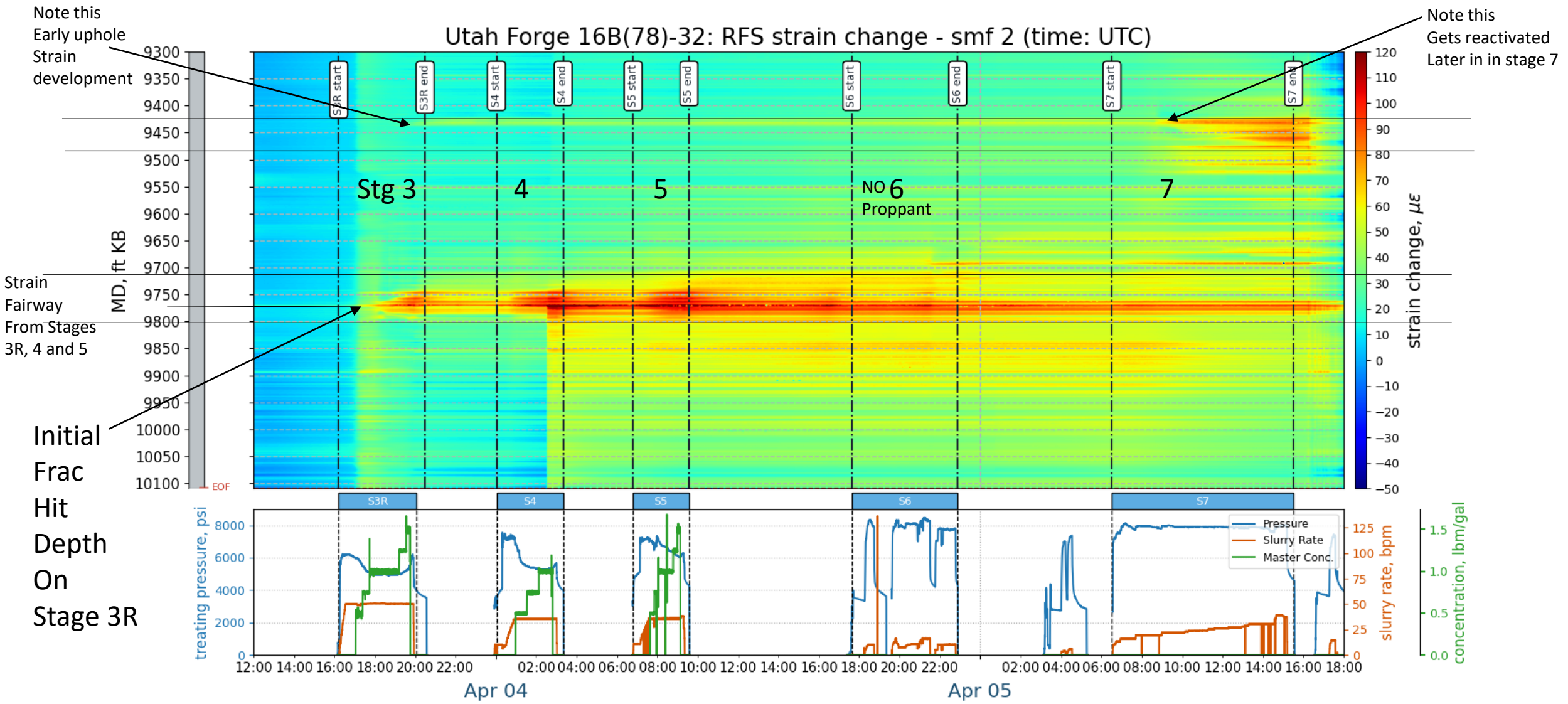
Well 16B – RFS DSS strain change – selected depths



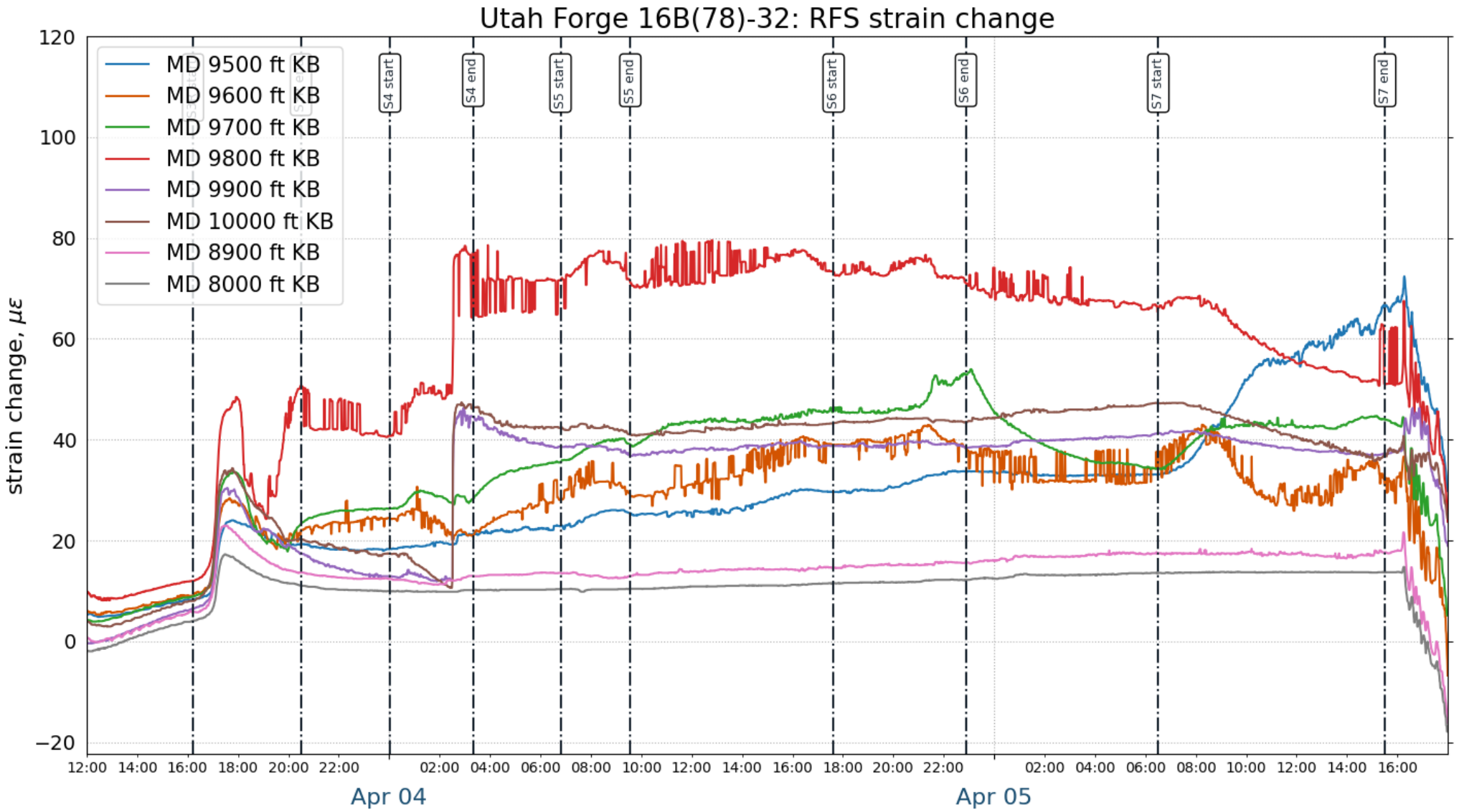
Well 16B – RFS DSS strain change – selected depths



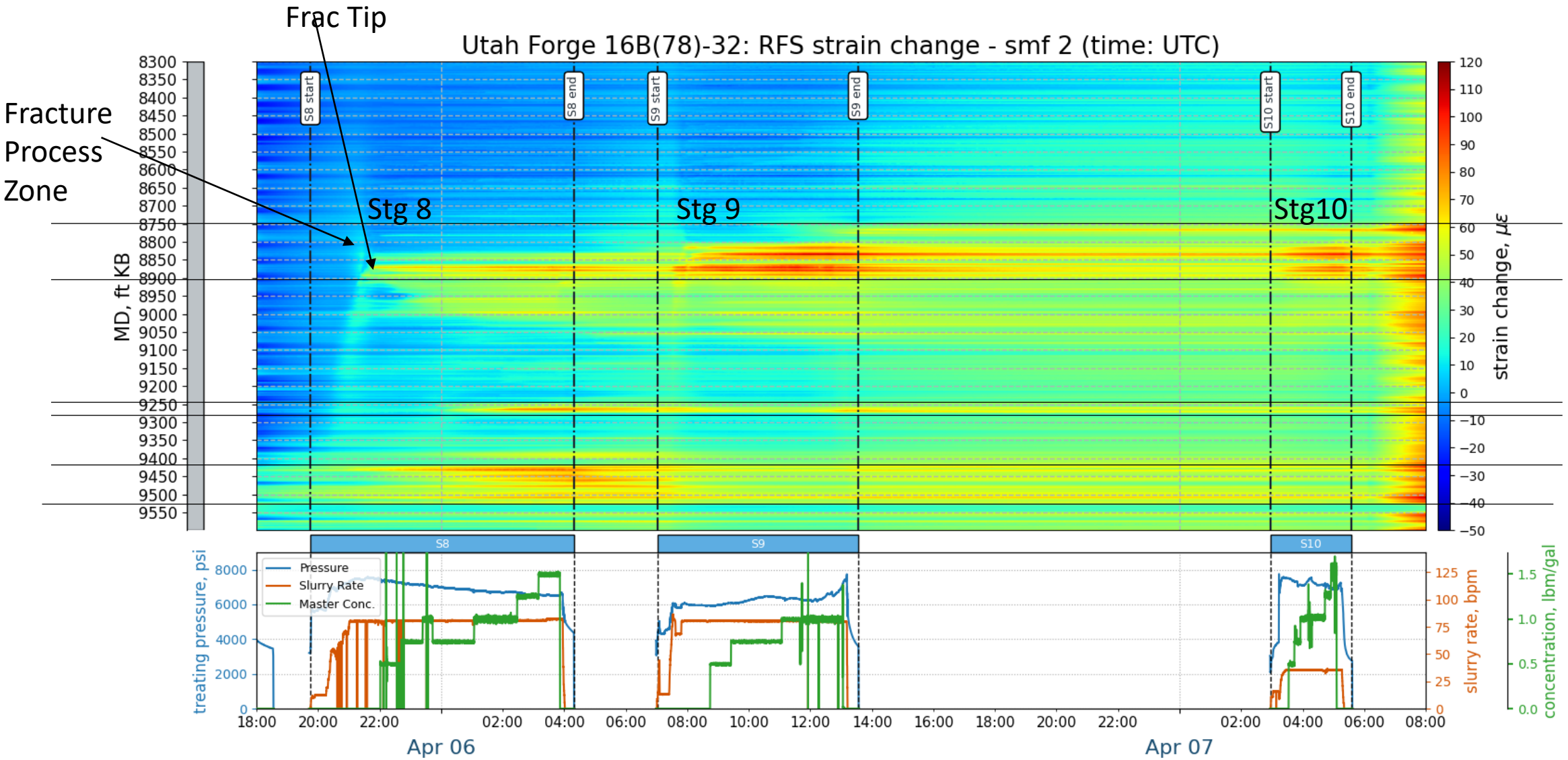
Well 16B – RFS DSS Strain Change – stim 16A stg 3R thru 7



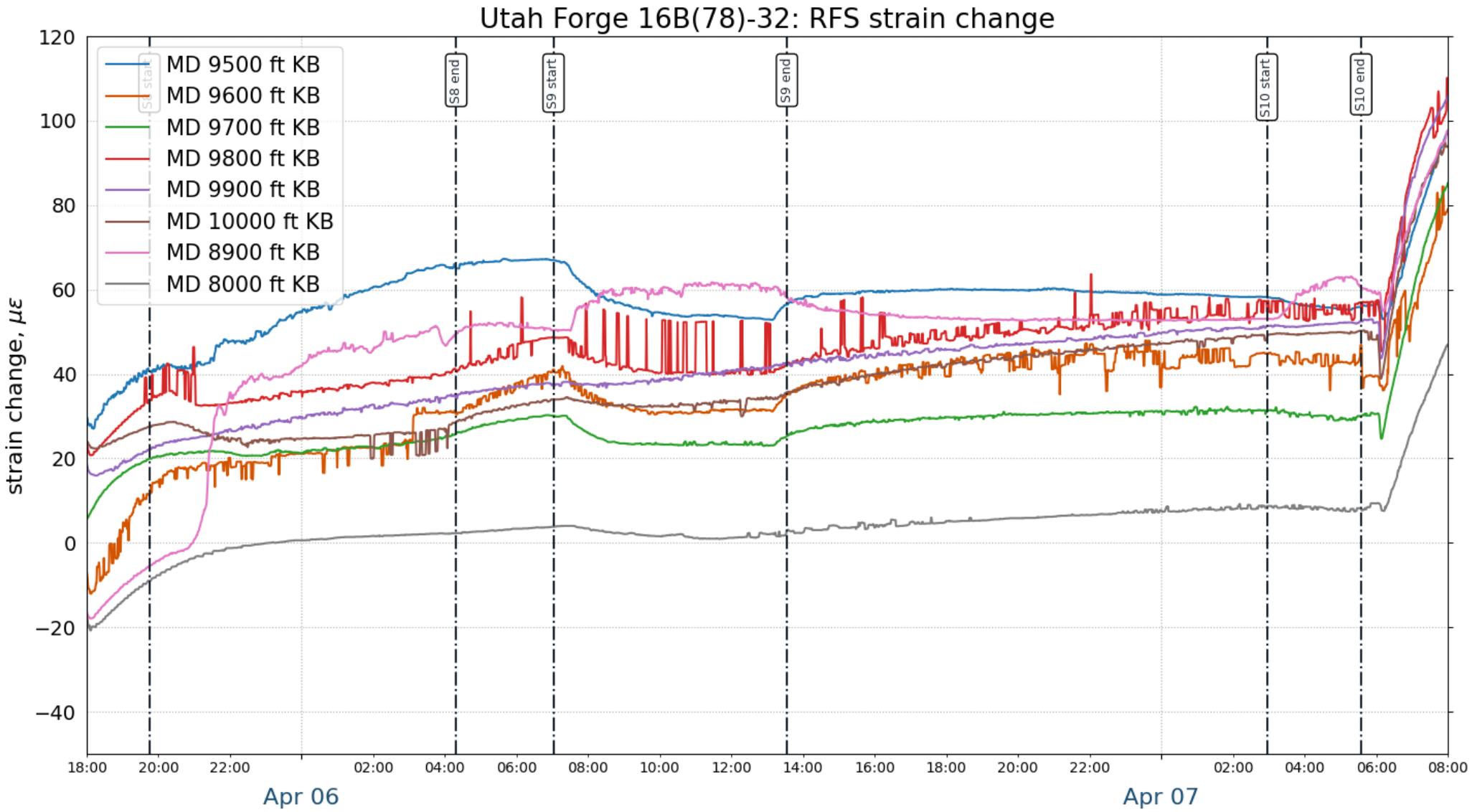
Well 16B – RFS DSS strain – stimulated stages 3-7 on 16A



Well 16B – RFS DSS strain change – stimulated stages 8-10 on 16A



Well 16B – RFS DSS strain change – stimulated stages 8-10 on 16A



Selected Interpretations of FDI frac hits interpreted by Neubrex

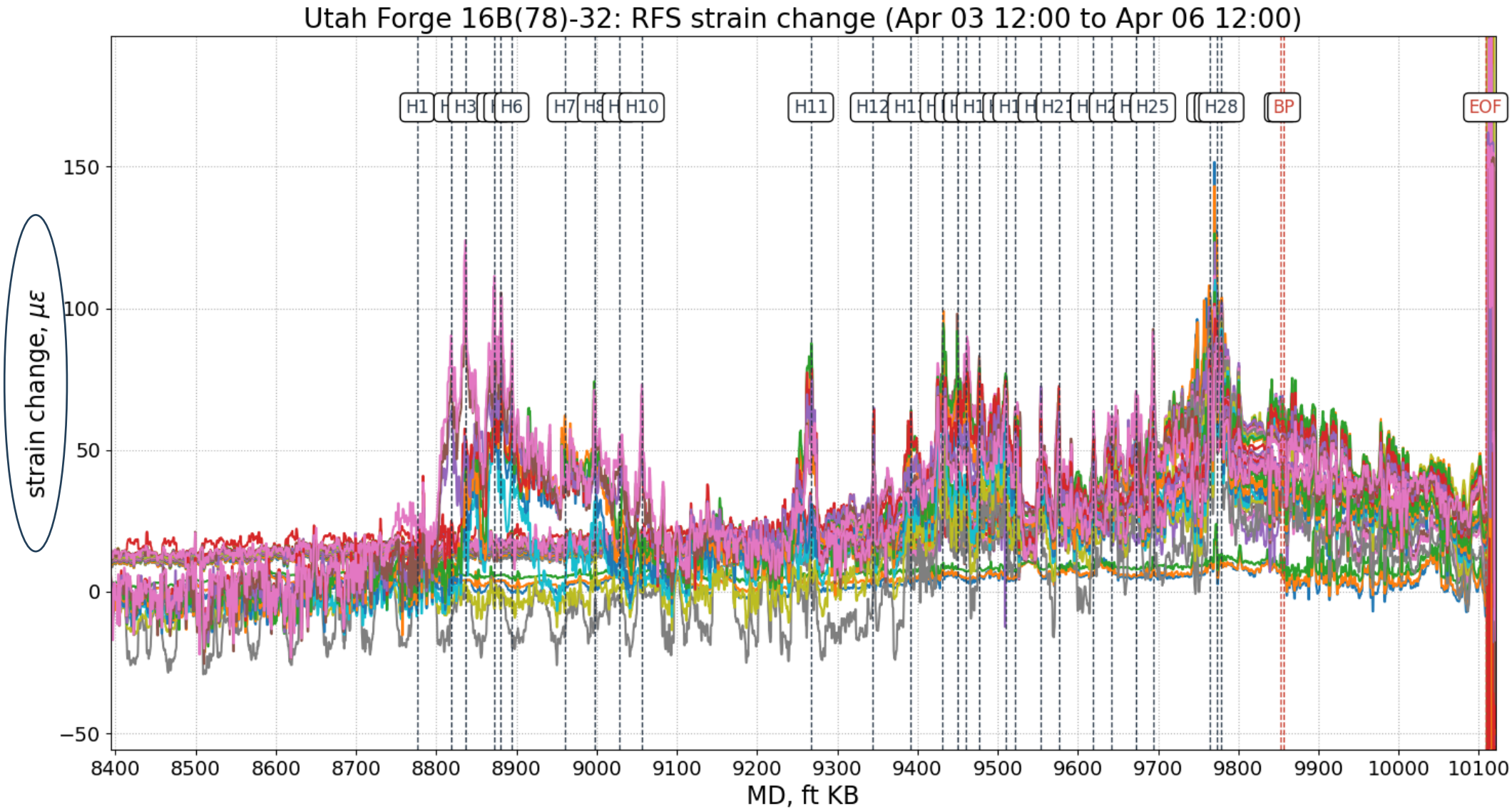
Interpreted by Neubrex (D Jurick)

Selected locations on 16B from 16A Stimulation

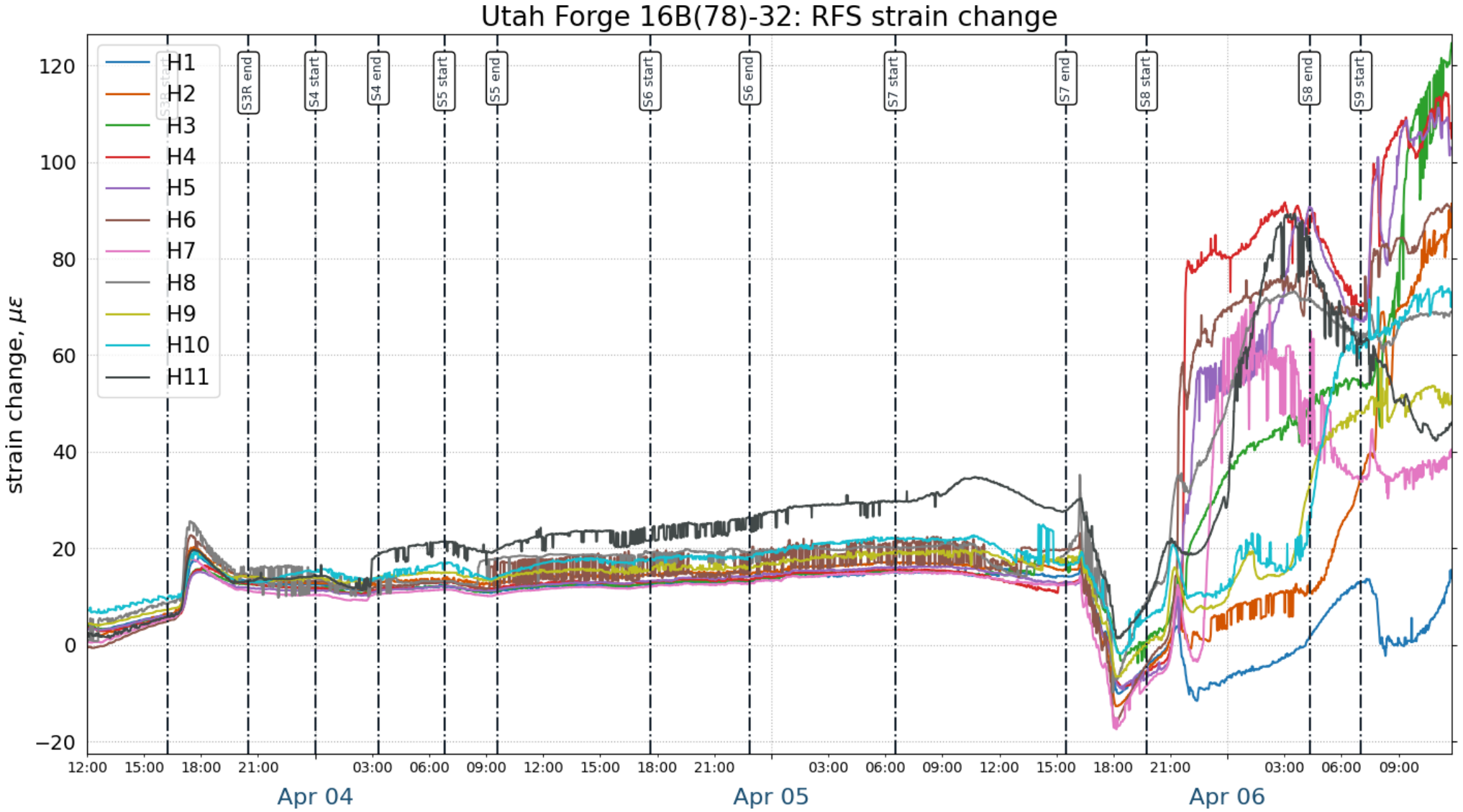
- The following locations were selected for potential frac perf locations on future 16B frac
- Total of 28 locations picked
- These were picked on location during field operations

Label	Depth, MD ft KB
H1	8776.265
H2	8818.477
H3	8836.065
H4	8872.024
H5	8880.622
H6	8894.151
H7	8959.965
H8	8997.487
H9	9028.365
H10	9056.115
H11	9267.093
H12	9344.577
H13	9391.146
H14	9431.453
H15	9449.455
H16	9460.804
H17	9476.848
H18	9509.721
H19	9522.243
H20	9553.550
H21	9576.247
H22	9618.903
H23	9642.383
H24	9672.516
H25	9693.648
H26	9763.903
H27	9773.289
H28	9778.827

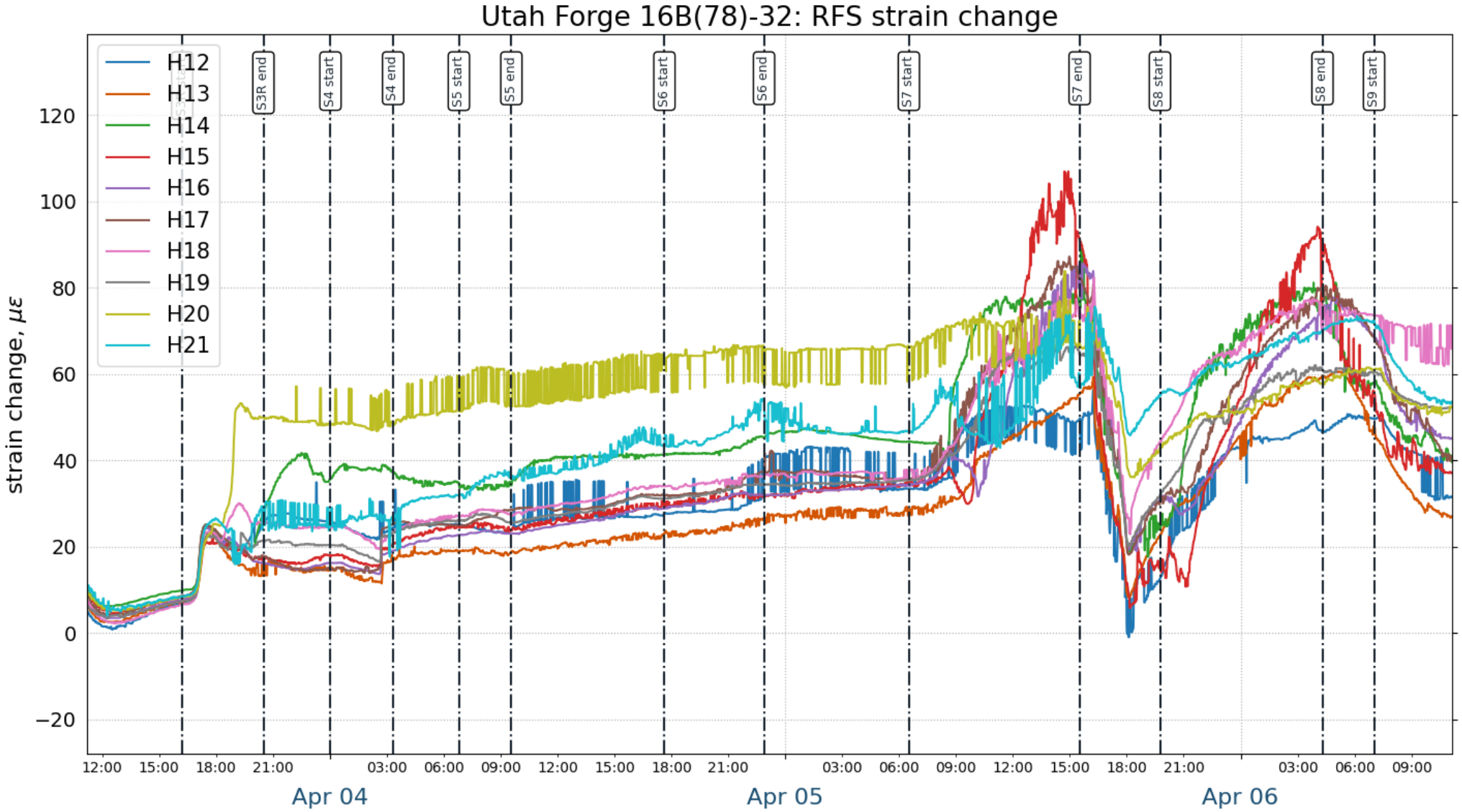
Well 16B – selected FDI locations picked on RFS DSS data



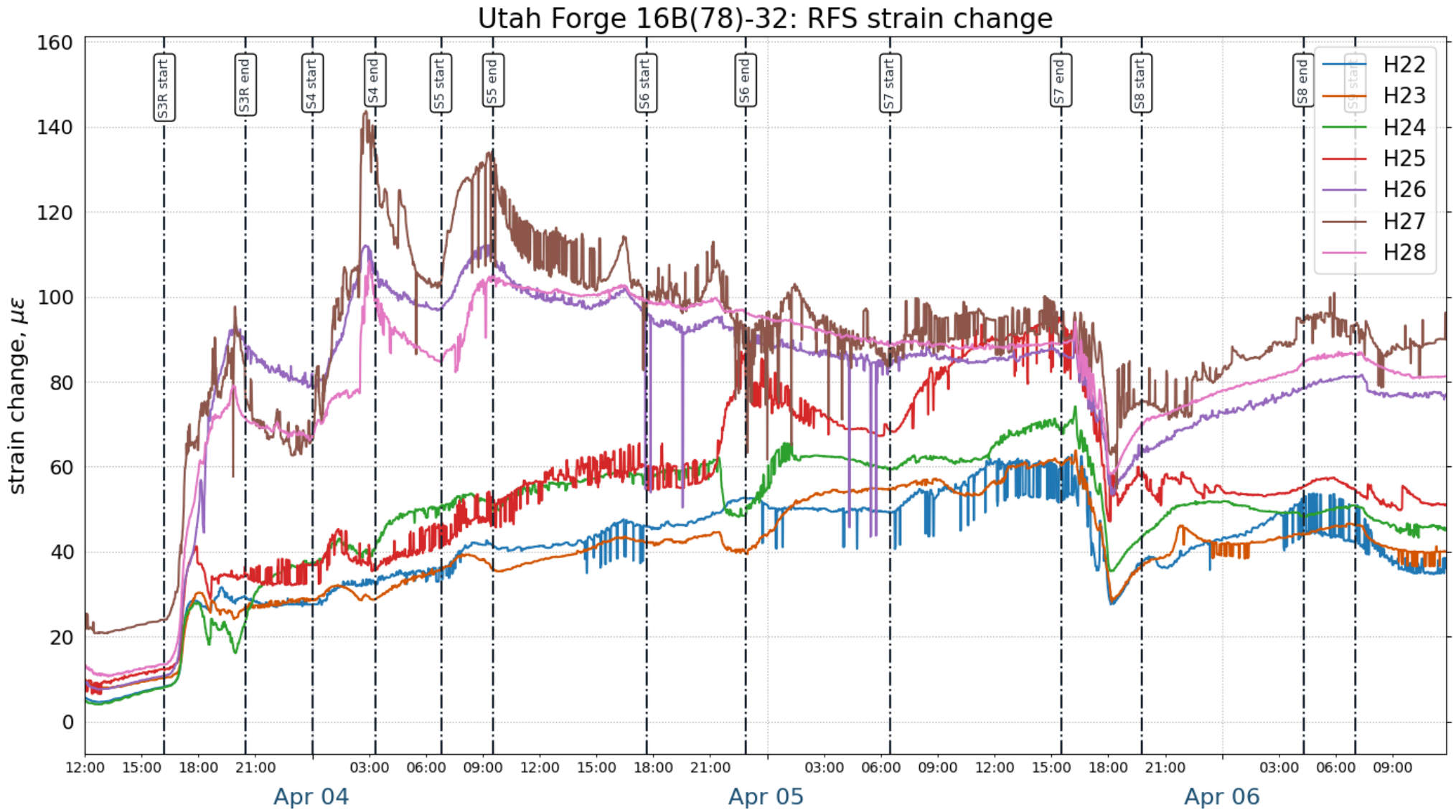
Well 16B – RFS DSS selected locations time series



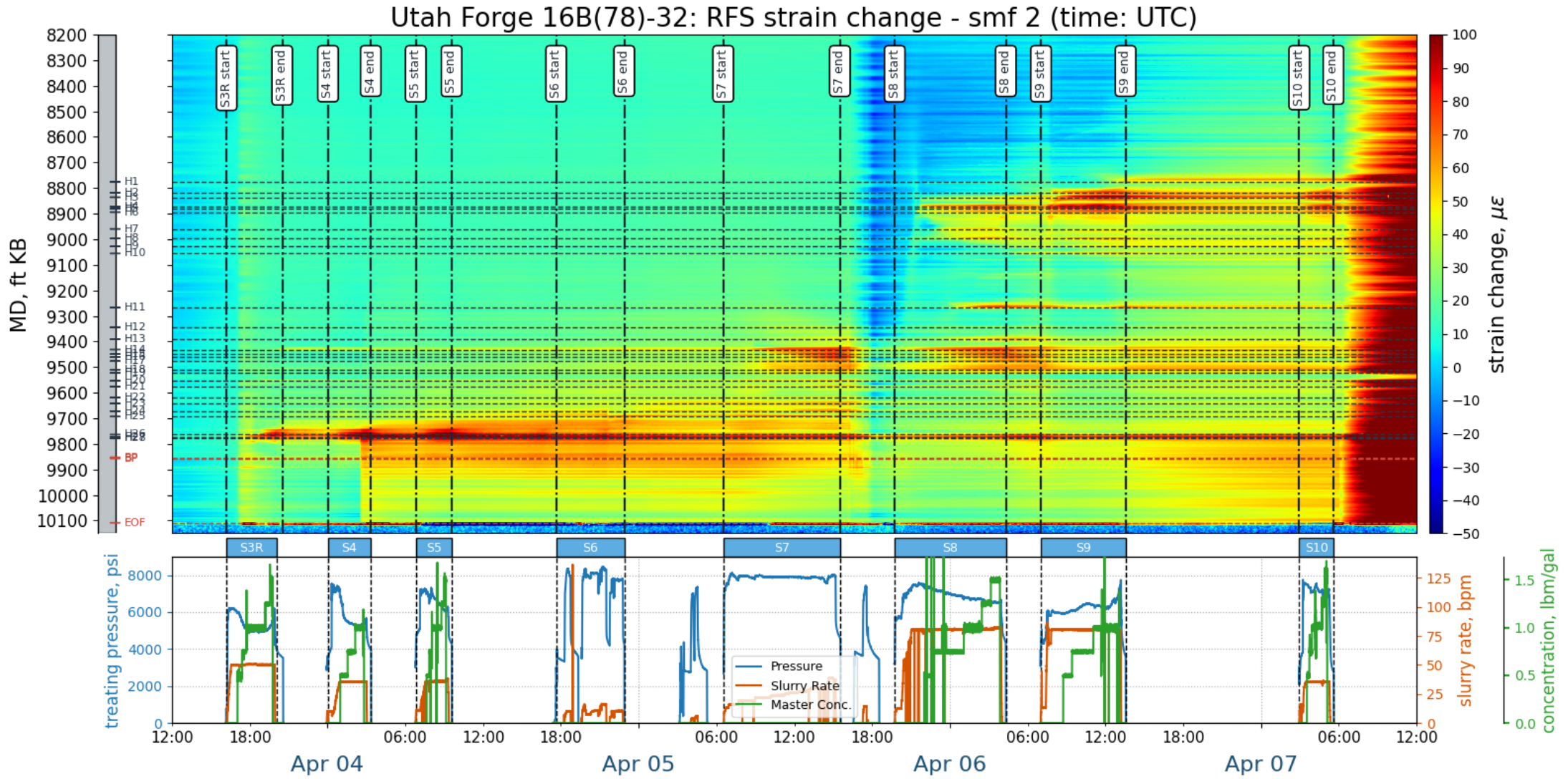
Well 16B – RFS DSS selected locations time series



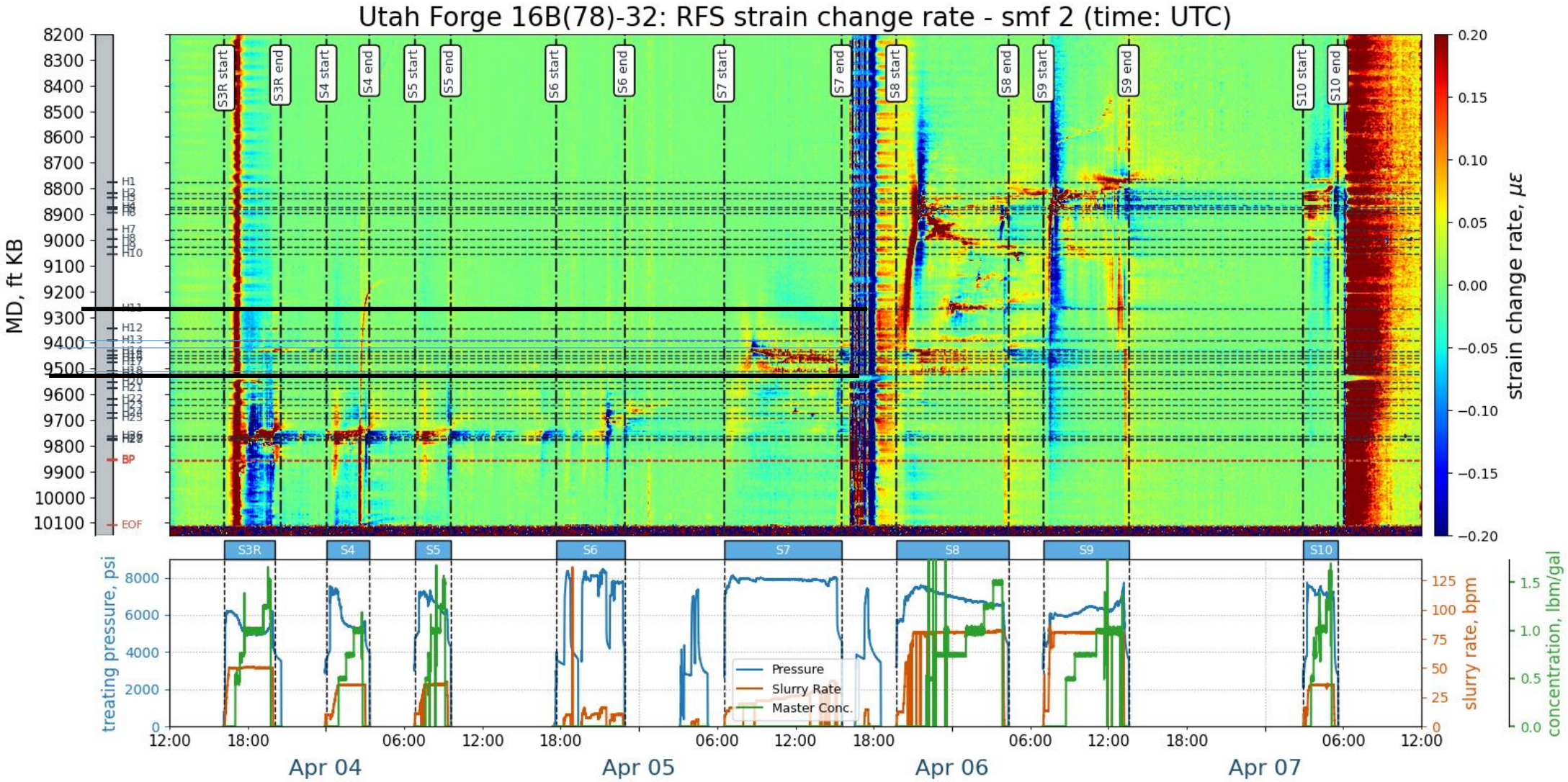
Well 16B – RFS DSS selected locations time series



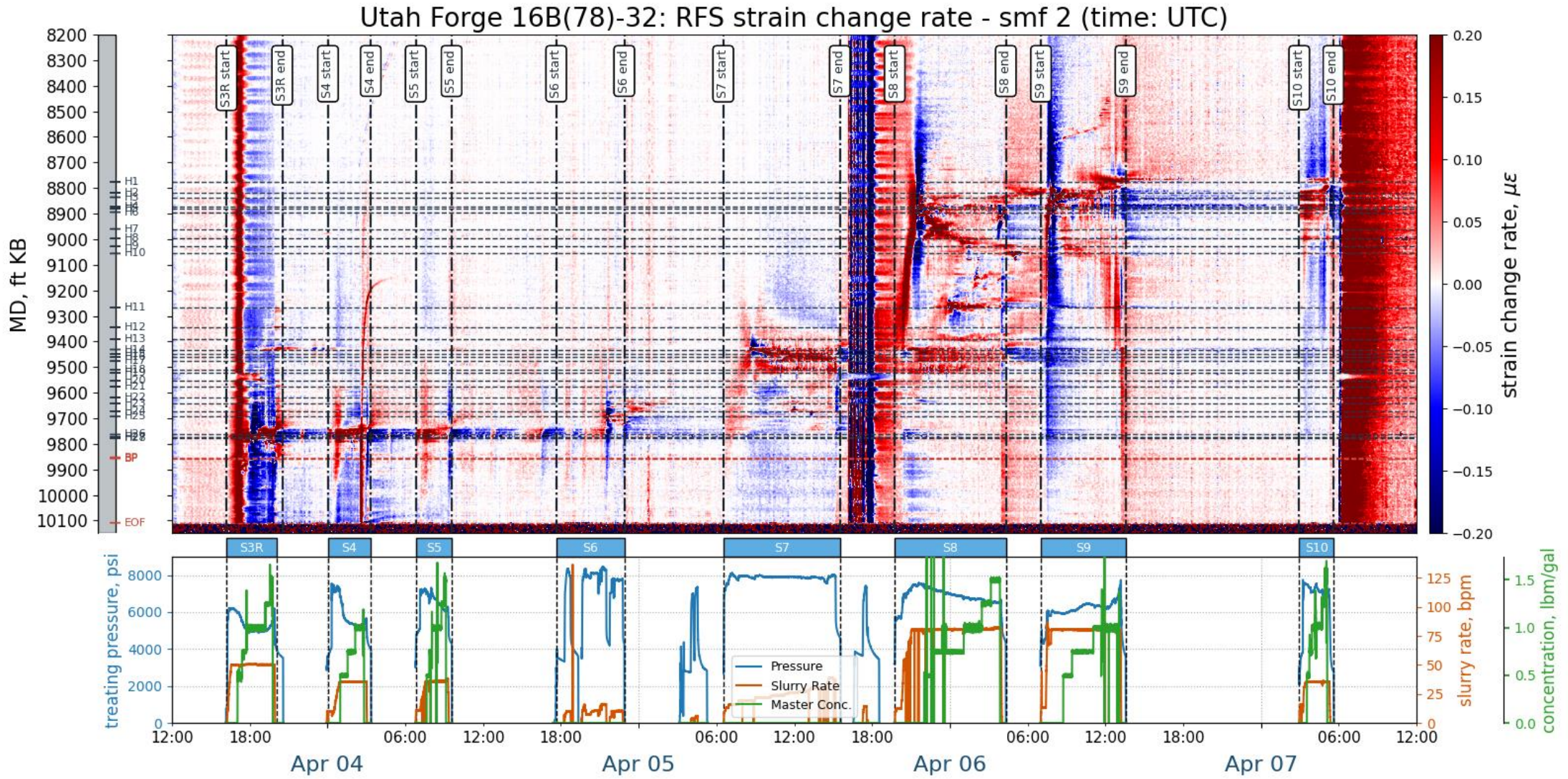
Well 16B – RFS DSS strain change – overlay selected locations



Well 16B – RFS DSS strain rate – overlay selected locations



Well 16B – RFS DSS strain rate – overlay selected locations



End of Technical Report and Contact Information

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