



Utah Forge

Monitored Well: 16B(78)-32

Fiber Optic Distributed Temperature Sensing Thermal Data Processing and Analysis Report Field Operations: April 2024

Neubrex Energy Services (US), LLC

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Last update: July 5, 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.

Timeline – this report is Evolution 2 and 3



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
Evolution 3	Frac on well 16B and circulation test	Apr 7, 2024, 16:00	May 2, 2024, 16:00

This Report

Notes about Data Source and Measurement Units



- All times shown in this document are in UTC time coordinates.
- All depths are in MD Relative to Kelly Bushing Height.
- Temperatures are in degrees Fahrenheit.
- All DTS measurements were made using a Yokogawa 3000DTSX Distributed Temperature Sensing Interrogator Unit.
- Spatial sampling interval on all DTS measurements were at 3.28 feet.
- Temporal sampling rate on all DTS measurements was 129 seconds.
- **The third-party Pressure – Temperature Gauge data should be used with caution after about April 20, 2024, as performance of the gauge after this time in question and not considered reliable.**

Project and reporting period timeframe



- This Report period:
 - **Apr 01, 2024, 19:25 (UTC)**
 - **May 02, 2024, 22:30 (UTC)**

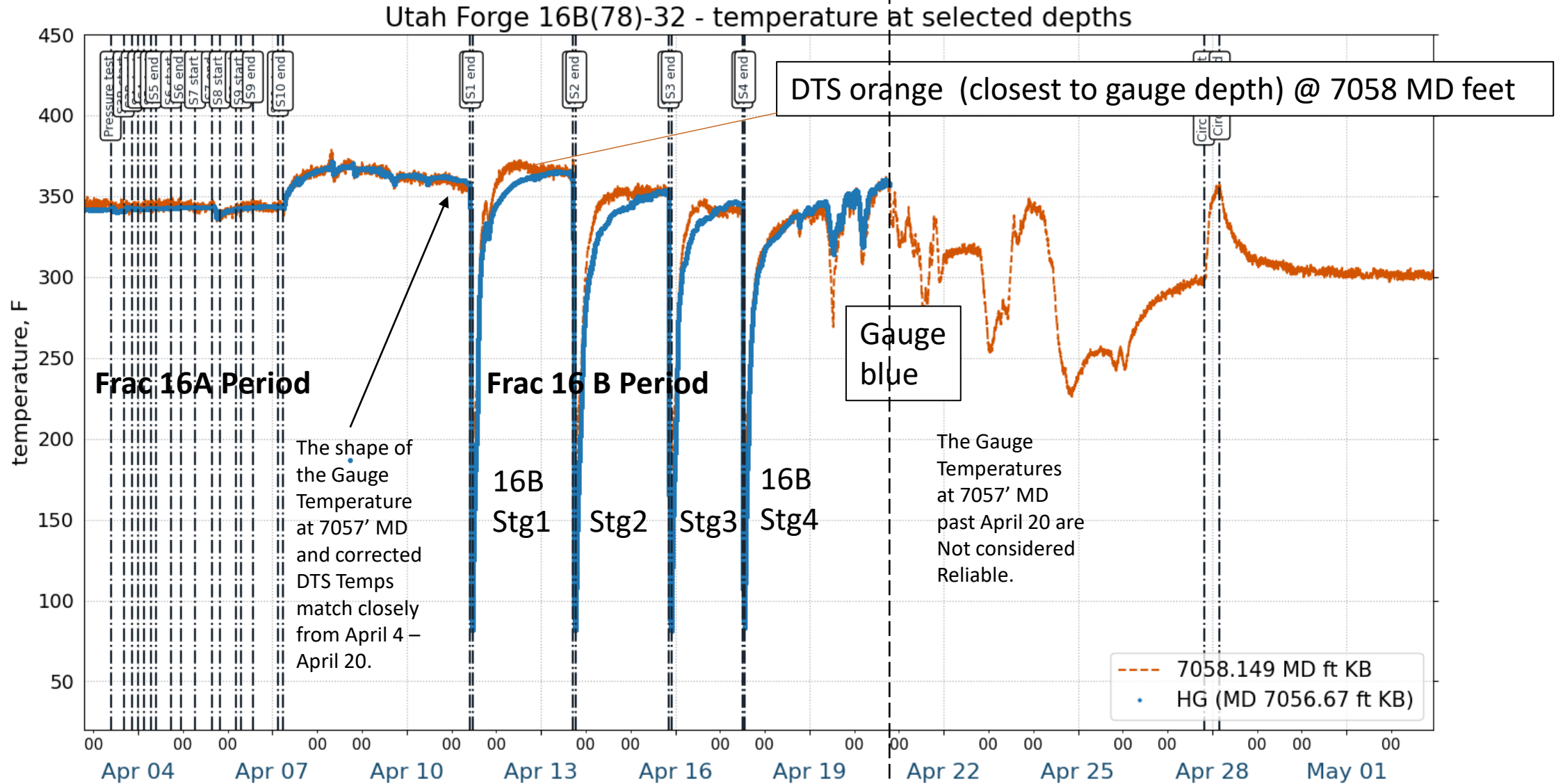
- This covers:
 - Hydraulic Fracture stimulation on **well 16A stages 3R through 10**
 - Hydraulic Fracture Stimulation on **well 16B stages 1 – 4**
 - **Perforations only shot on well 16B stage 5**
 - Short 9-hour duration **circulation test performed from 16A to 16B wells**

Key Slides that follow



- 4 Key Technical Slides of the DTS Temperature Data that are Corrected for non-linear optical power loss on cemented behind pipe Multi-Mode Fiber and calibrated to one downhole, behind pipe and cemented in place, Temperature Gauge follow.
- The slides that follow these 4 slides are the technical work that support the findings of the 4 key slides.
- Temperature data acquired on the “UT Fiber Optic Cable Multi-mode Fiber” are only reliable after processing methods that account for nonlinear optical transmission and backscatter loss of the Stokes and Anti-Stokes wavelength data acquired on a Yokogawa 3000DTSX Interrogator Unit by Neubrex Energy Services (US), LLC. Neubrex has applied a methodology to the data processing that includes utilization of independent Brillouin wavelength backscattered data acquired on the single mode fiber in the same cable, at the same time as DTS data, but prior to strain perturbations caused by Hydraulic Fracturing operations.

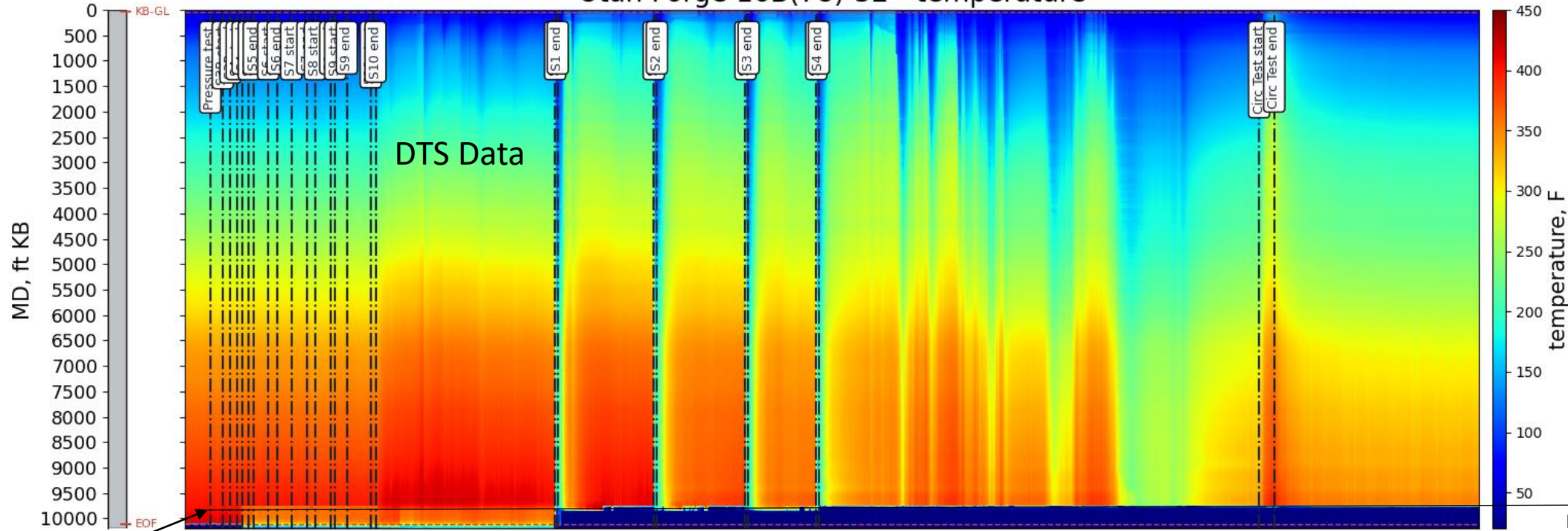
Well 16B – Brillouin corrected DTS in Orange. Gauge in Blue



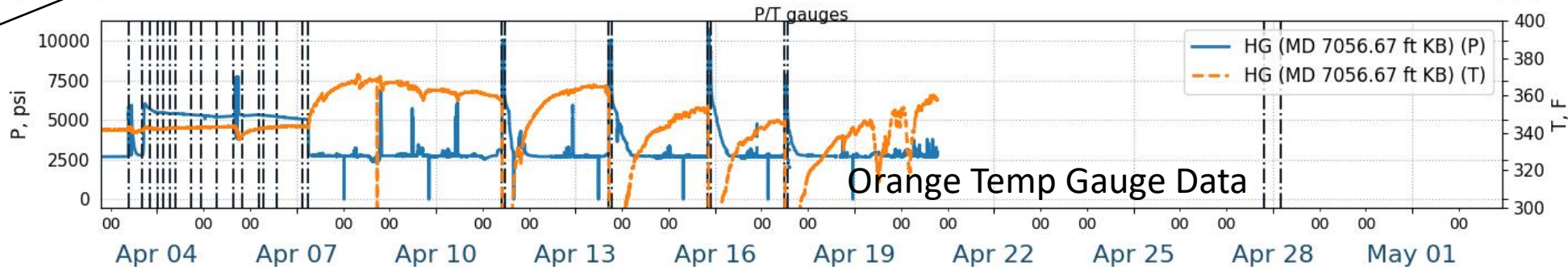
Well 16B – Brillouin corrected DTS final adjusted waterfall plot



Utah Forge 16B(78)-32 - temperature

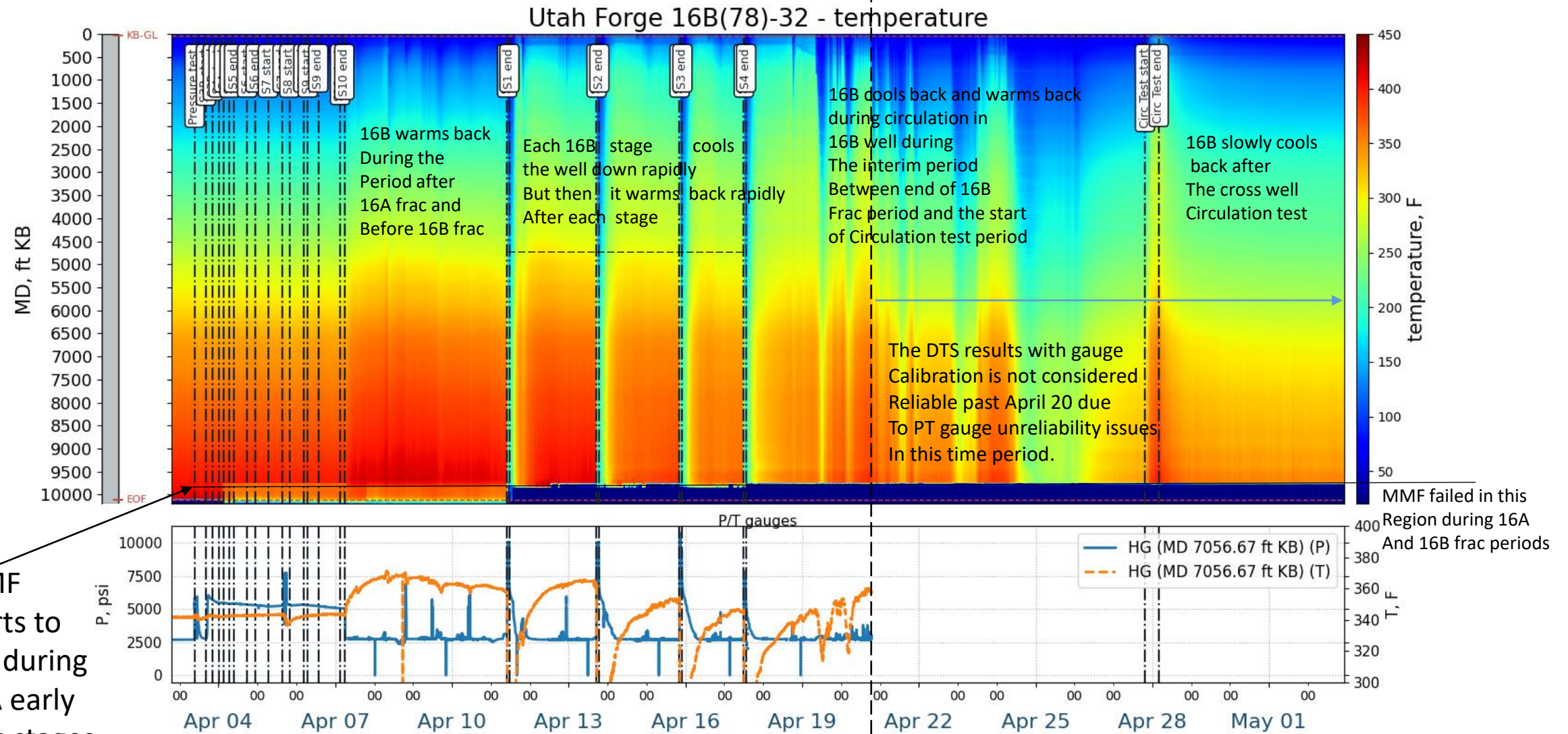


MMF Failing



MMF failed in this Region during 16A And 16B frac periods

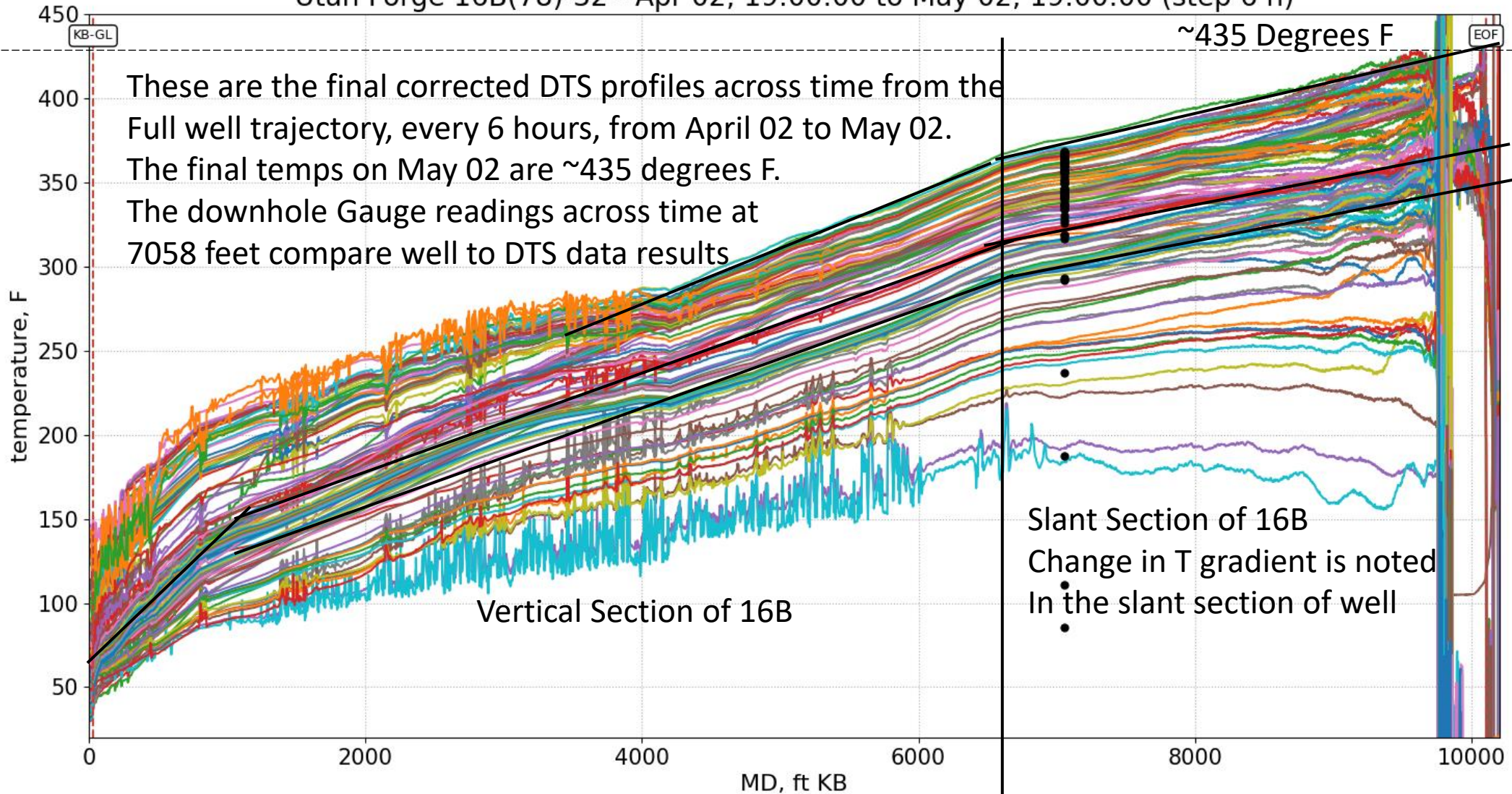
Well 16B – Brillouin corrected DTS – annotated waterfall plot



Well 16B –Brillouin corrected DTS– selected time profiles



Utah Forge 16B(78)-32 - Apr 02, 19:00:00 to May 02, 19:00:00 (step 6 h)





Pressure/Temperature gauge data

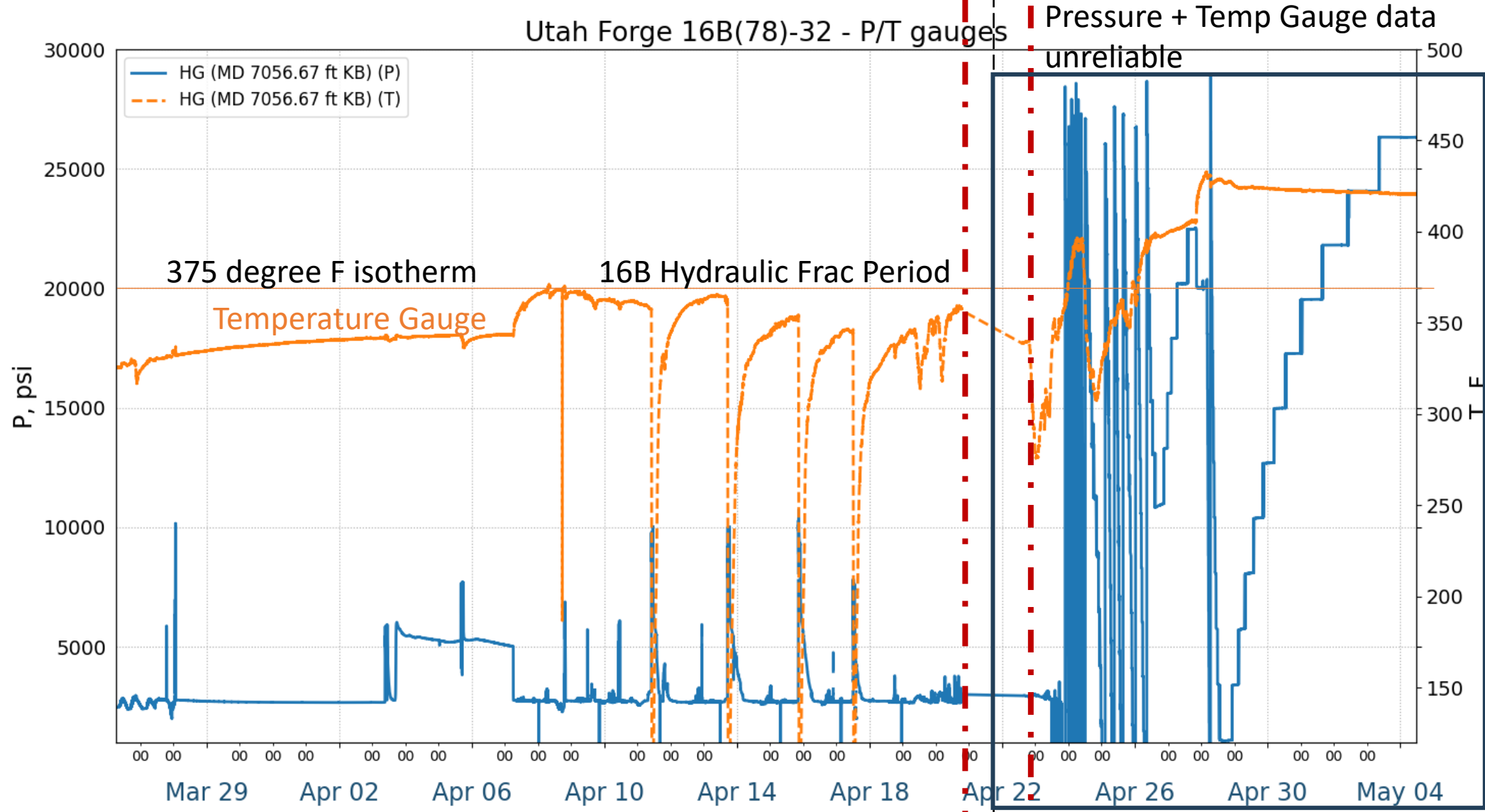
Obtained from A. Reynolds (Consultant)

Downhole Baker PT Gauge Data.

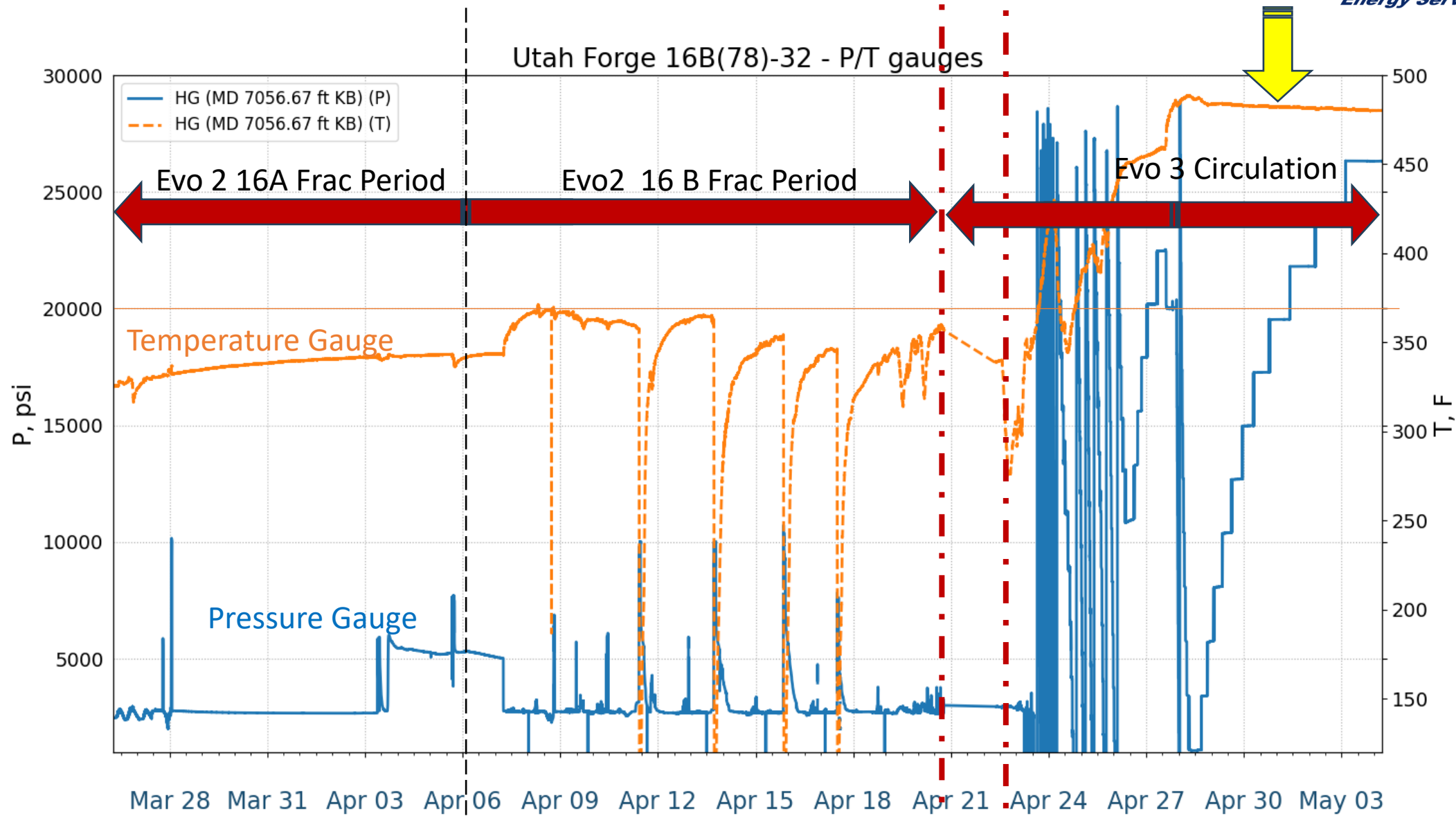
Gauge data was checked and corrected “whenever required” as per Alan Reynolds.

Author notes that there is some skepticism that Baker Gauge is providing accurate downhole temperature readings throughout the duration of the survey, especially after April 20th 2024.

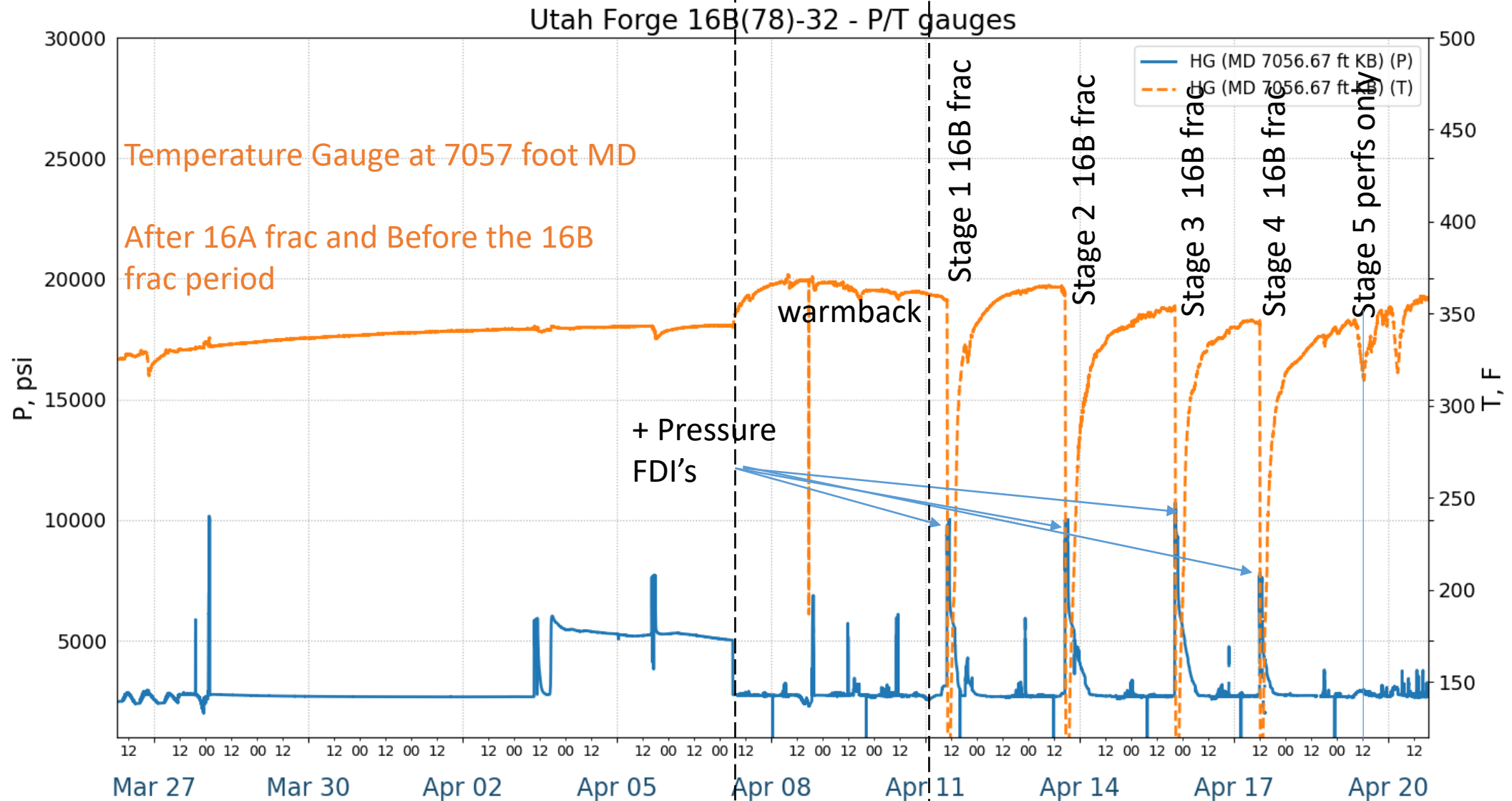
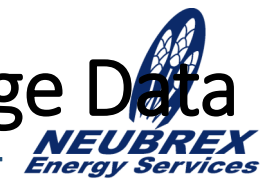
Well 16B – P/T gauge data – Evo 2 & 3 (uncorrected data)



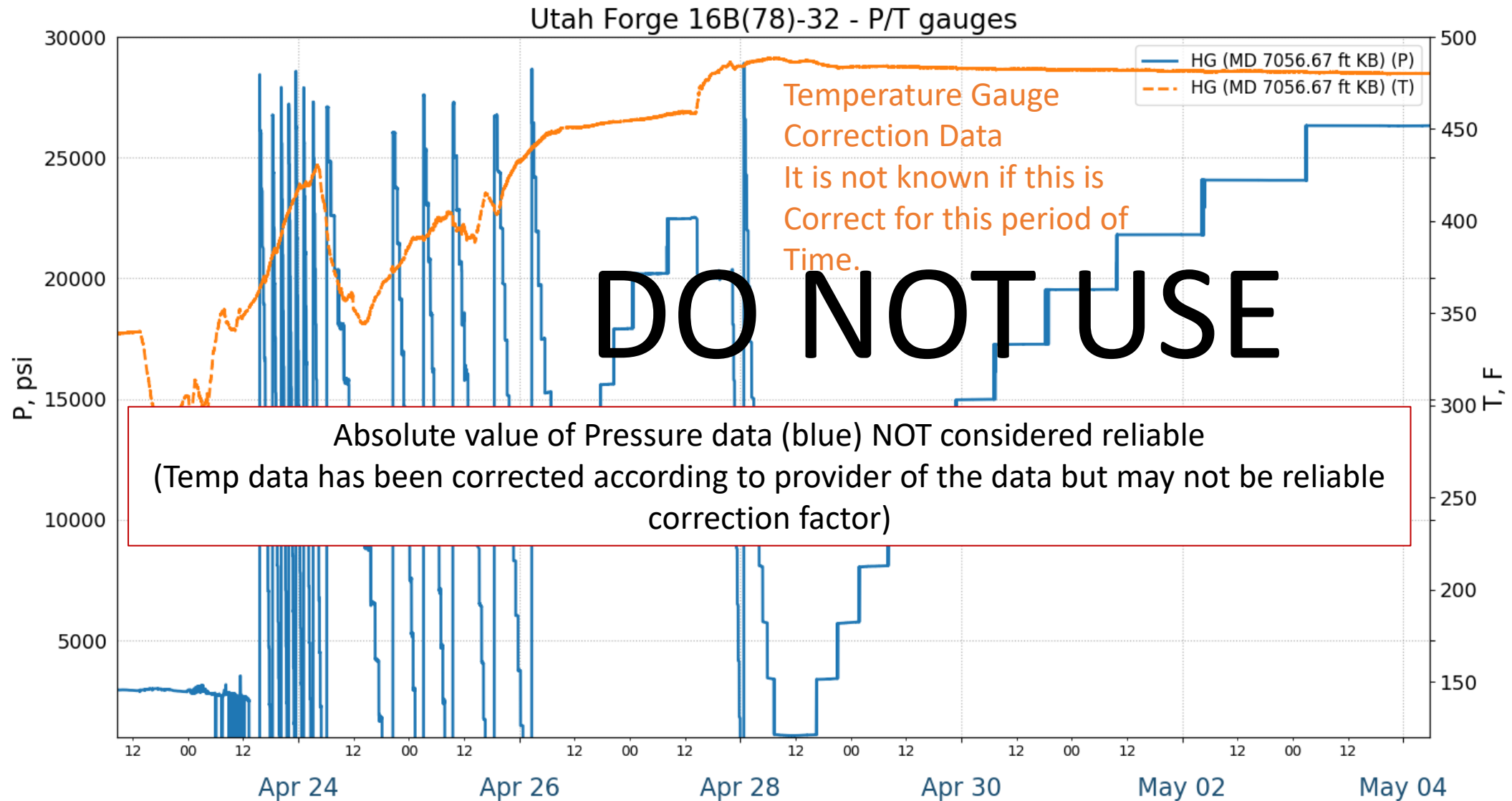
Well 16B – P/T gauge data – From FORGE Evo 2 & 3 (corrected)



P/T gauge data –16A and 16B Frac Periods show 16B Gauge Data



Well 16B – P/T gauge Evo 3 16B Circulation – DO NOT USE

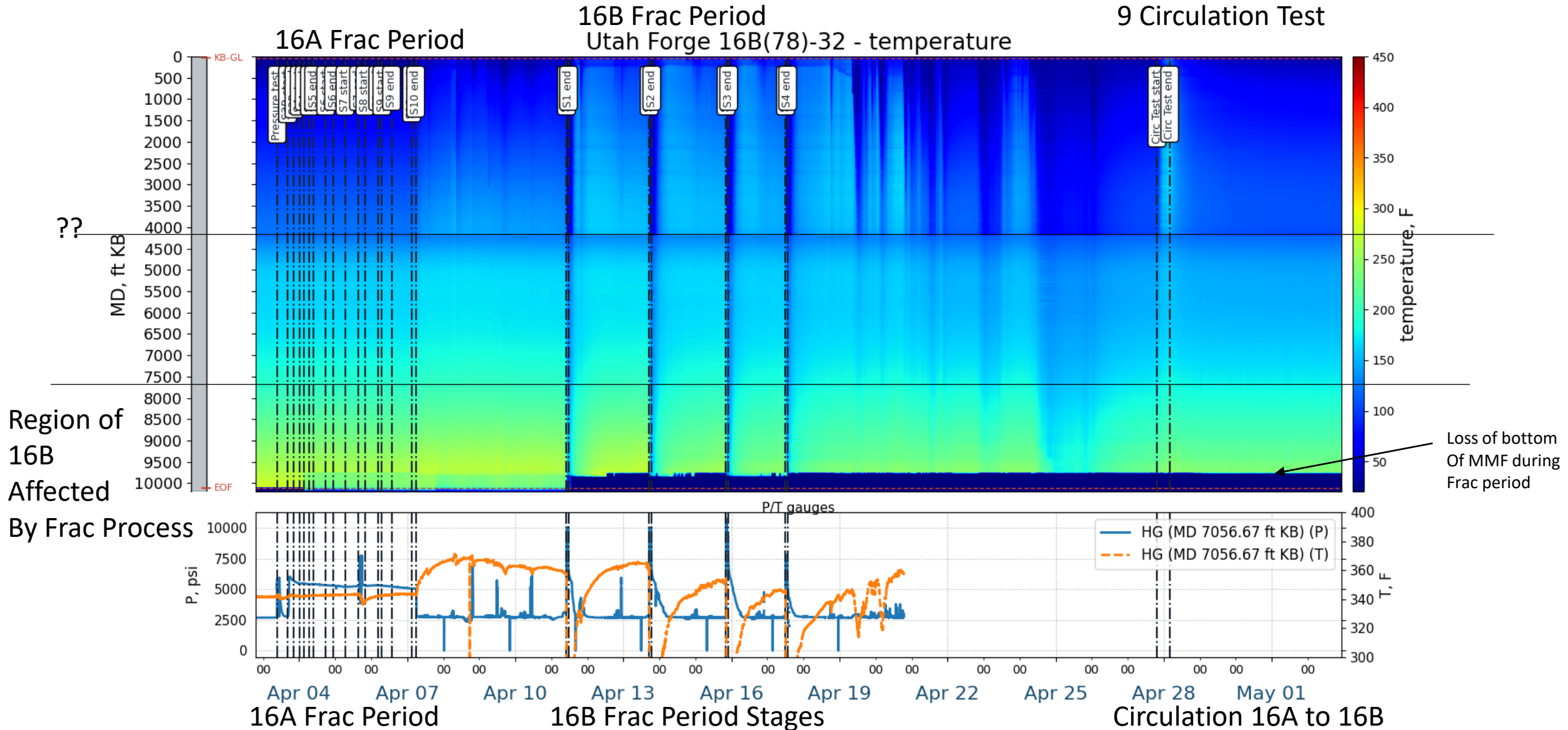




Fiber Optic DTS Data Distributed Temperature Sensing

- first trace: Apr 02, 2024, 17:56:09
 - last trace: May 02, 2024, 22:29:48
 - number of traces: 20231
 - number of samples per trace: 4348
 - average temporal interval (sec): 129 seconds between each DTS profile during monitoring period
-

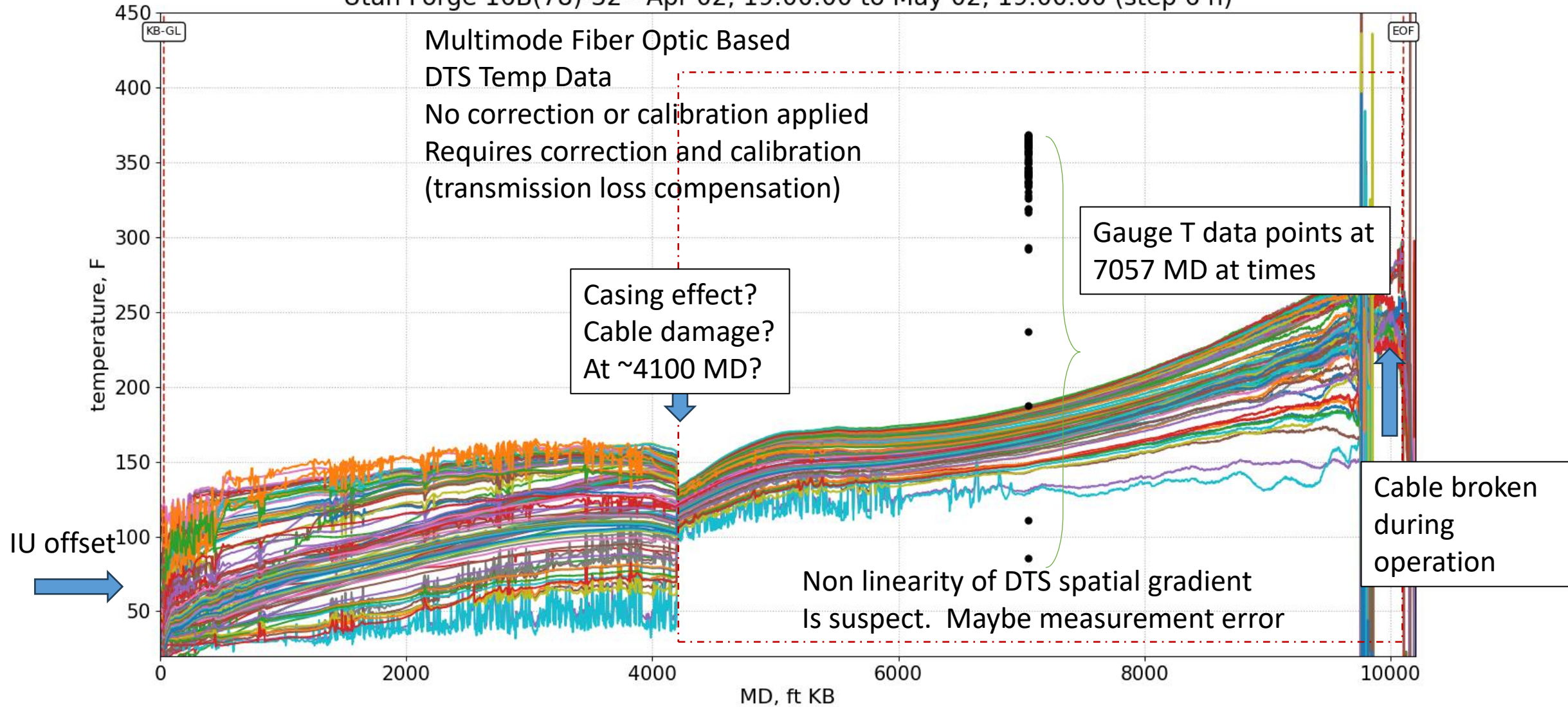
Well 16B – DTS temperature overview – raw original uncorrected T



Well 16B – Multi-Mode Fiber DTS select traces – original data



Utah Forge 16B(78)-32 - Apr 02, 19:00:00 to May 02, 19:00:00 (step 6 h)



Well 16B – Note: DTS MMF Fiber and gauge issues

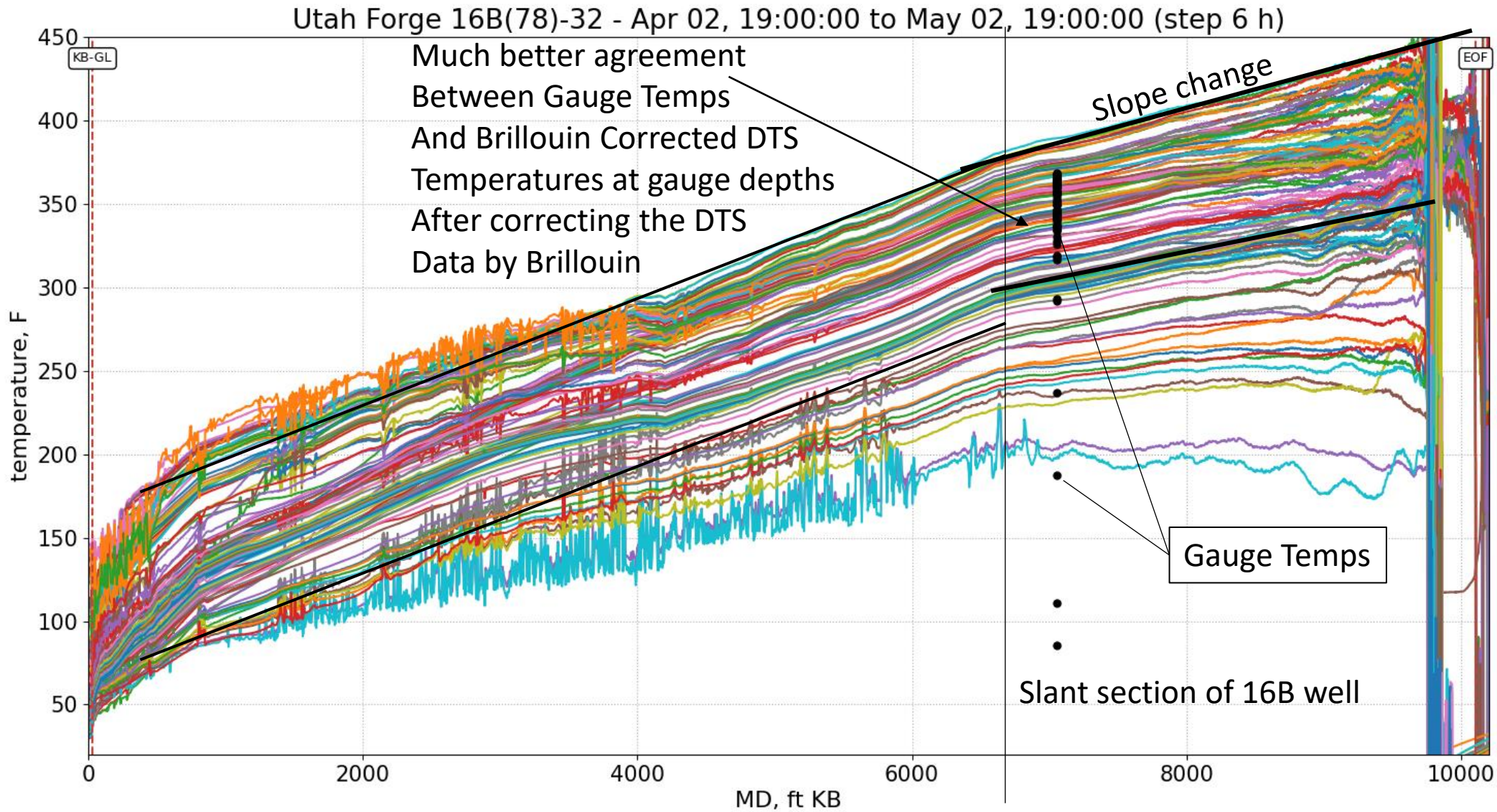


- **PT Gauge Data is NOT CONSIDERED RELIABLE PAST APRIL 20 2024 DATE.**
- Several damaged or high optical loss points in MMF fiber suspected
- In portion of the fiber below 4100, the raw DTS data has some nonlinear spatial gradient character which is not expected in this setting
- It is expected that there would be a near linear spatial temp gradient through the vertical section of well, then another near linear spatial gradient, with different slope, in slant section of the well.
 - This was not observed in the raw DTS data from this Multimode Fiber
- There are temperature “differences” or “offsets” between downhole gauge data values and raw DTS temperature data values the Multimode Fiber. These two datasets are independent, but are not in agreement
- During frac operations, the MMF fiber termination at end of cable was compromised, as evidence by loss of deep readings. This affects the last ~100 meters of the multi mode fiber in the 16B well.
- A variety of data driven Correction and Calibration methods have been applied to Fiber Optic DTS data in order to make it more reliable.

Brillouin based (optical loss) correction to DTS results

A profile reading of the single mode fiber in the same cable as the multimode fiber is made using a Brillouin based interrogation interrogator unit. This is a BOTDR interrogator made by Neubrex LTD. In the absence of dynamic strain conditions, such as present prior to hydraulic fracturing operations, the spatial gradient of the Brillouin backscattered total absolute strain is indicative of geothermal gradient. This data was used as a means to map the geothermal gradient conditions using different means and then correct the Raman wavelength interrogation of the Multimode fiber, and the DTS temperatures derived from it. This is a means of correcting the multimode fiber readings that suffer from non linear loss characteristics.

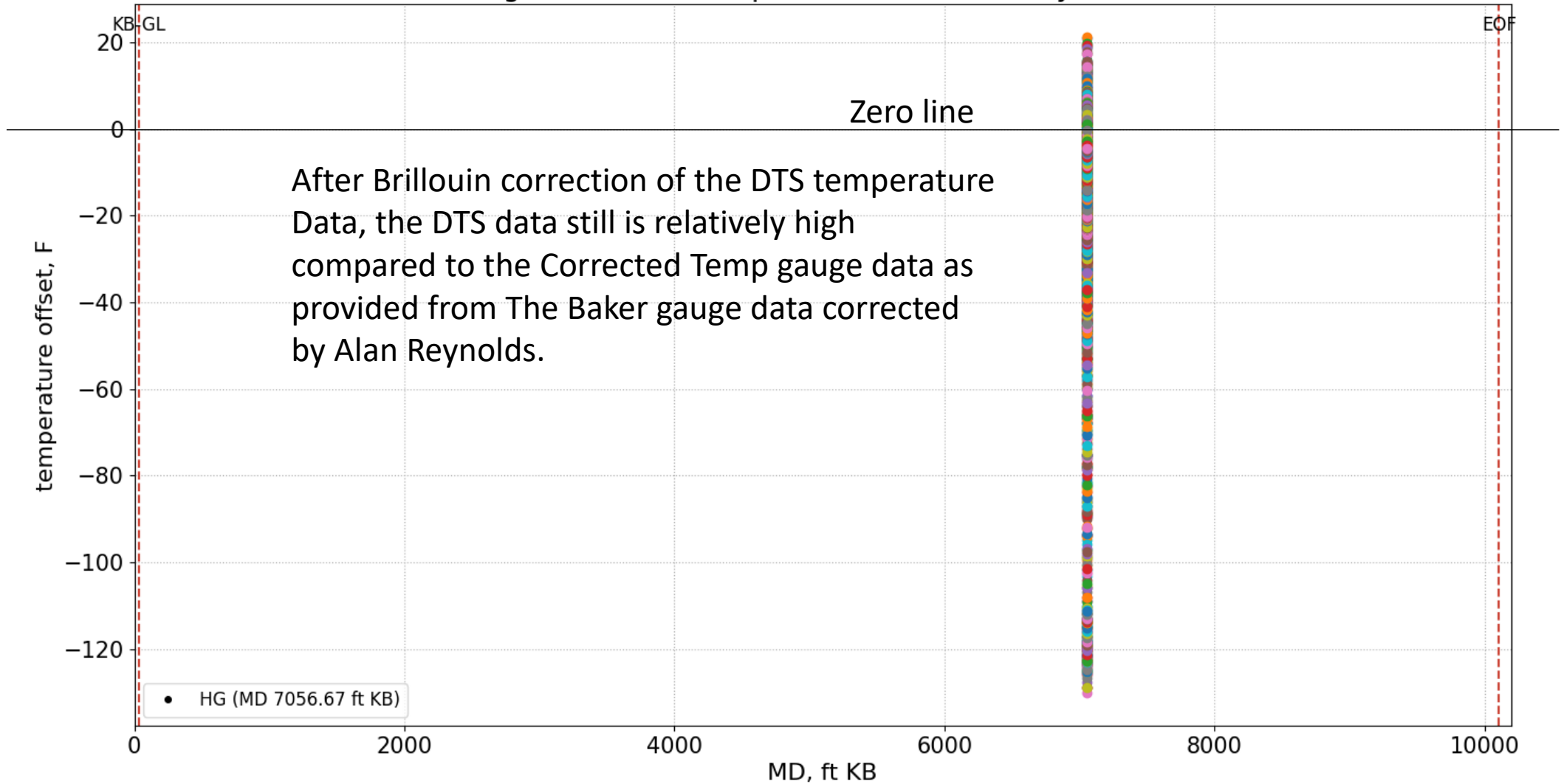
Well 16B –Neubrex Brillouin corrected DTS– select traces thru time



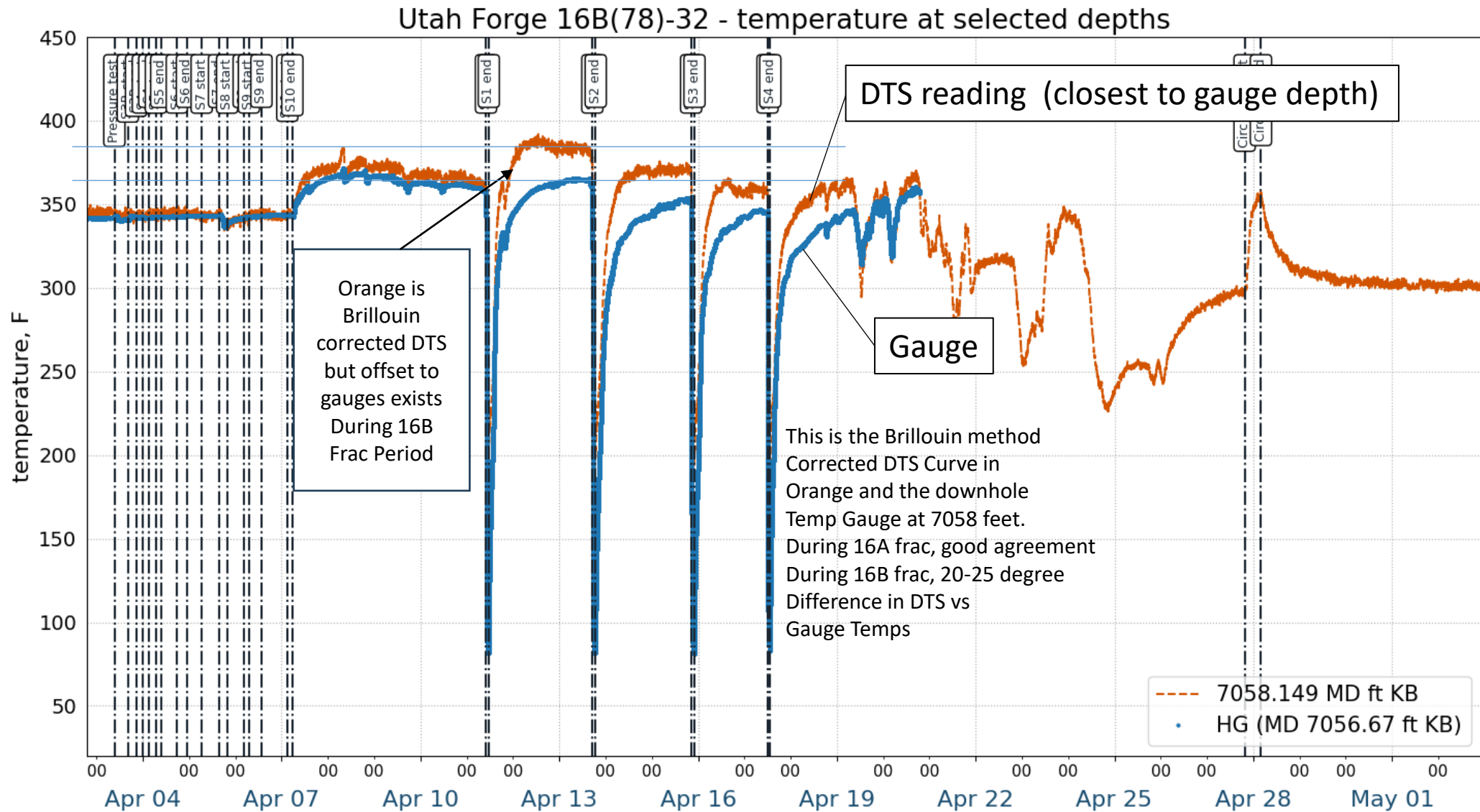
Well 16B – Brillouin corrected DTS – difference values to gauges



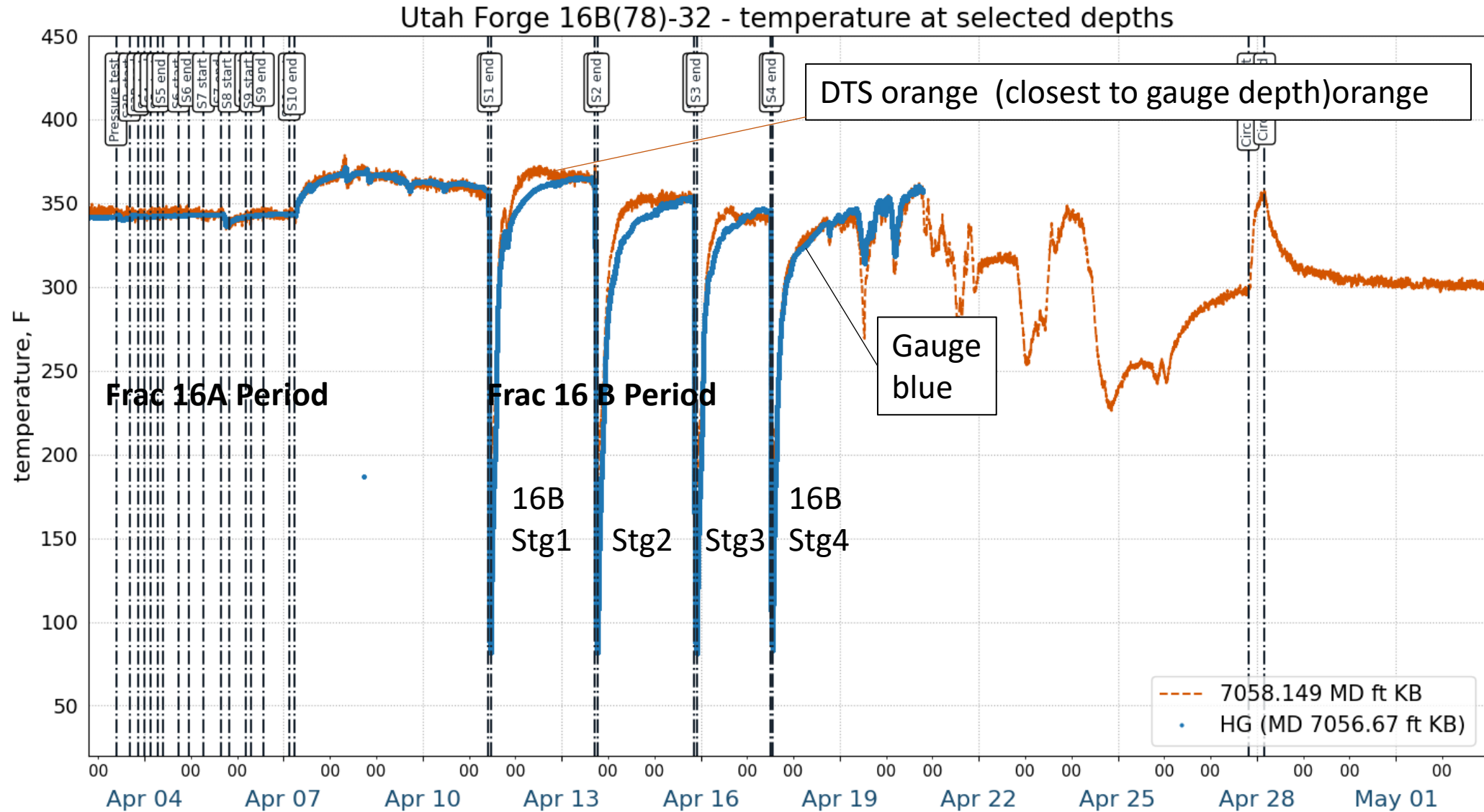
Utah Forge 16B(78)-32 - Apr 02, 17:56:09 to May 02, 22:29:48



Well 16B – Brillouin corrected DTS & gauge data comparison



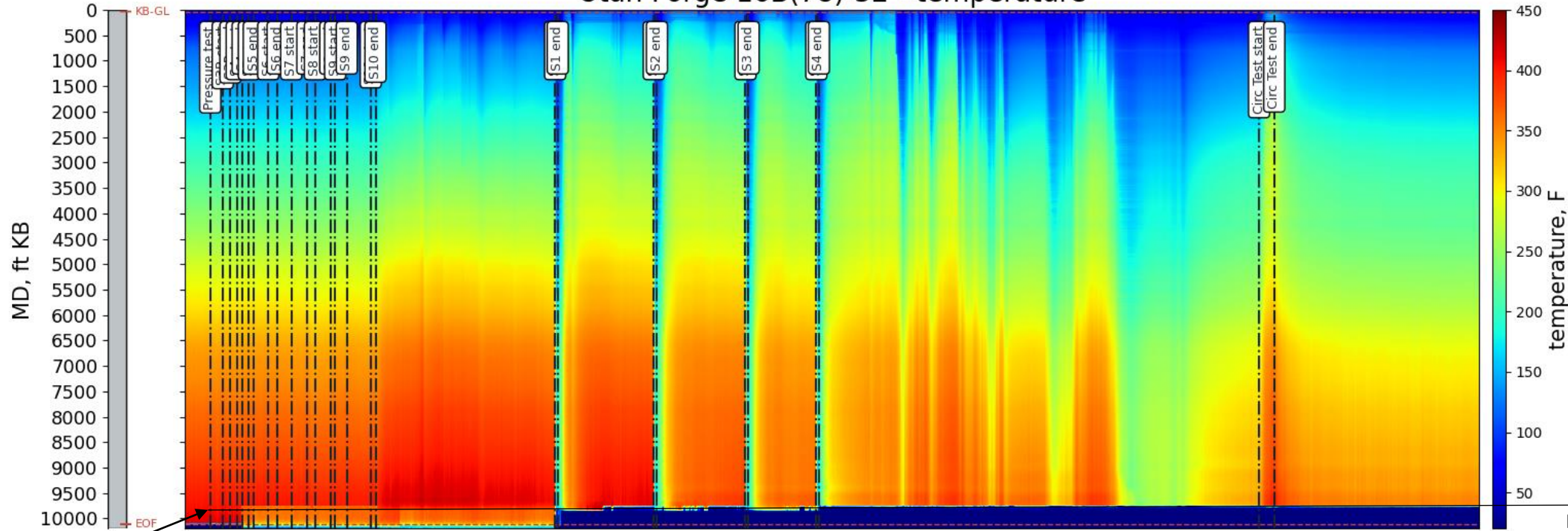
Well 16B – Brillouin corrected and Gauge Calibrated DTS in Orange with reliability through end of April 20 2024.



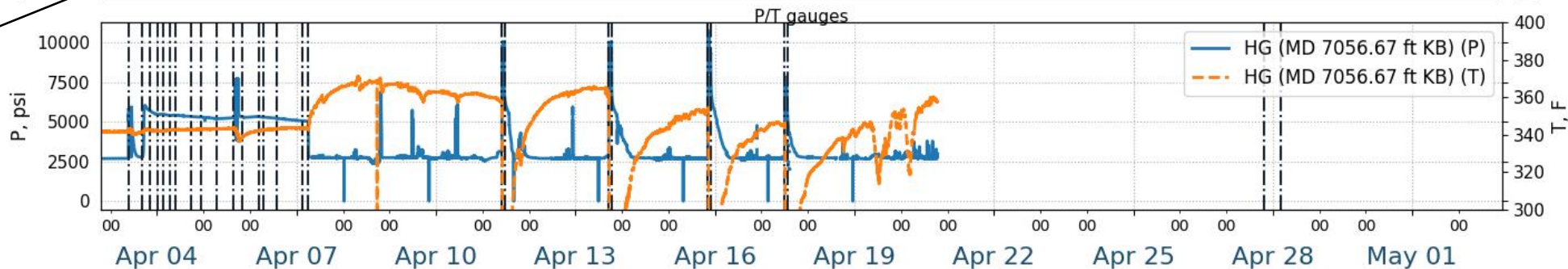
Well 16B – Brillouin corrected and gauge calibrated DTS data



Utah Forge 16B(78)-32 - temperature

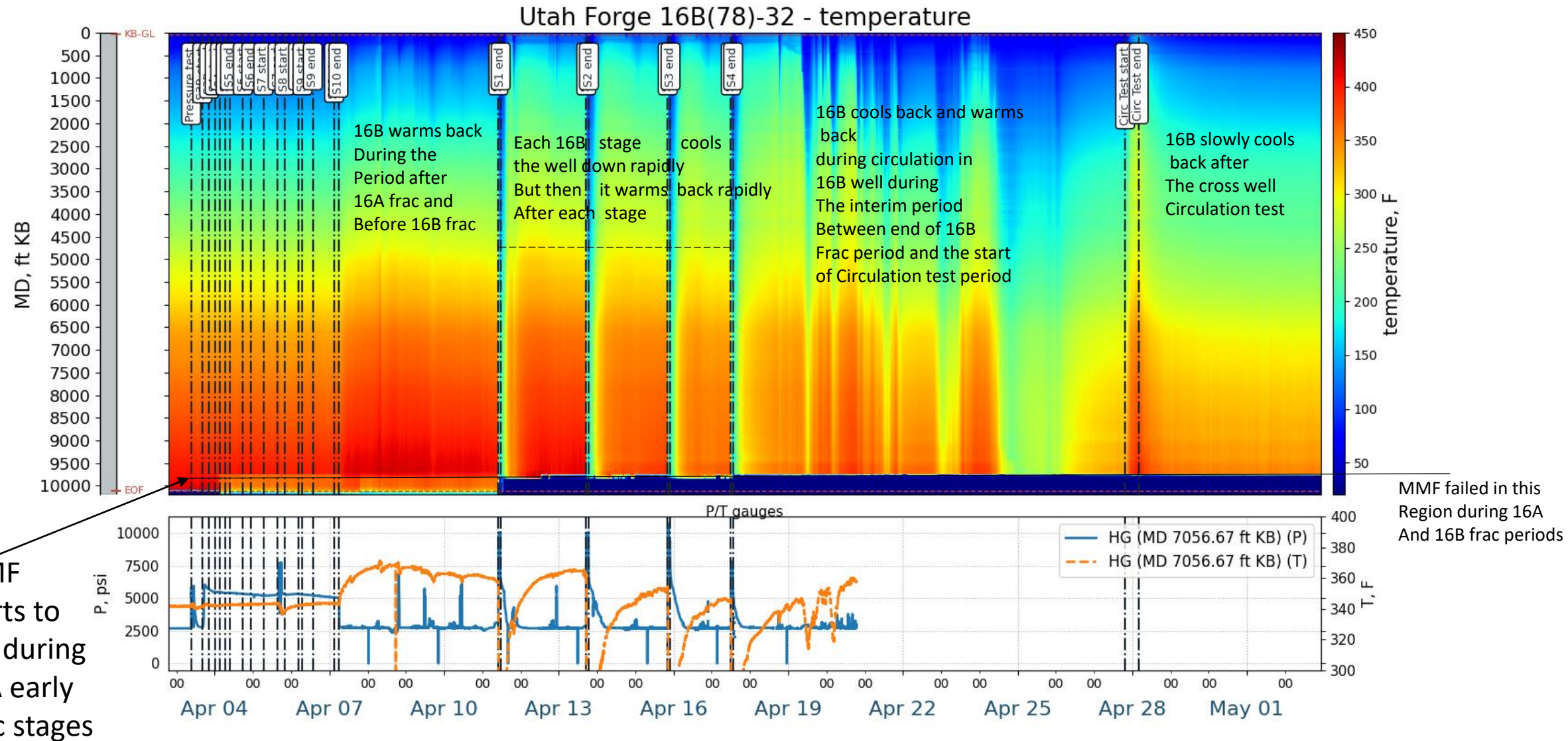


MMF Failing



MMF failed in this Region during 16A And 16B frac periods

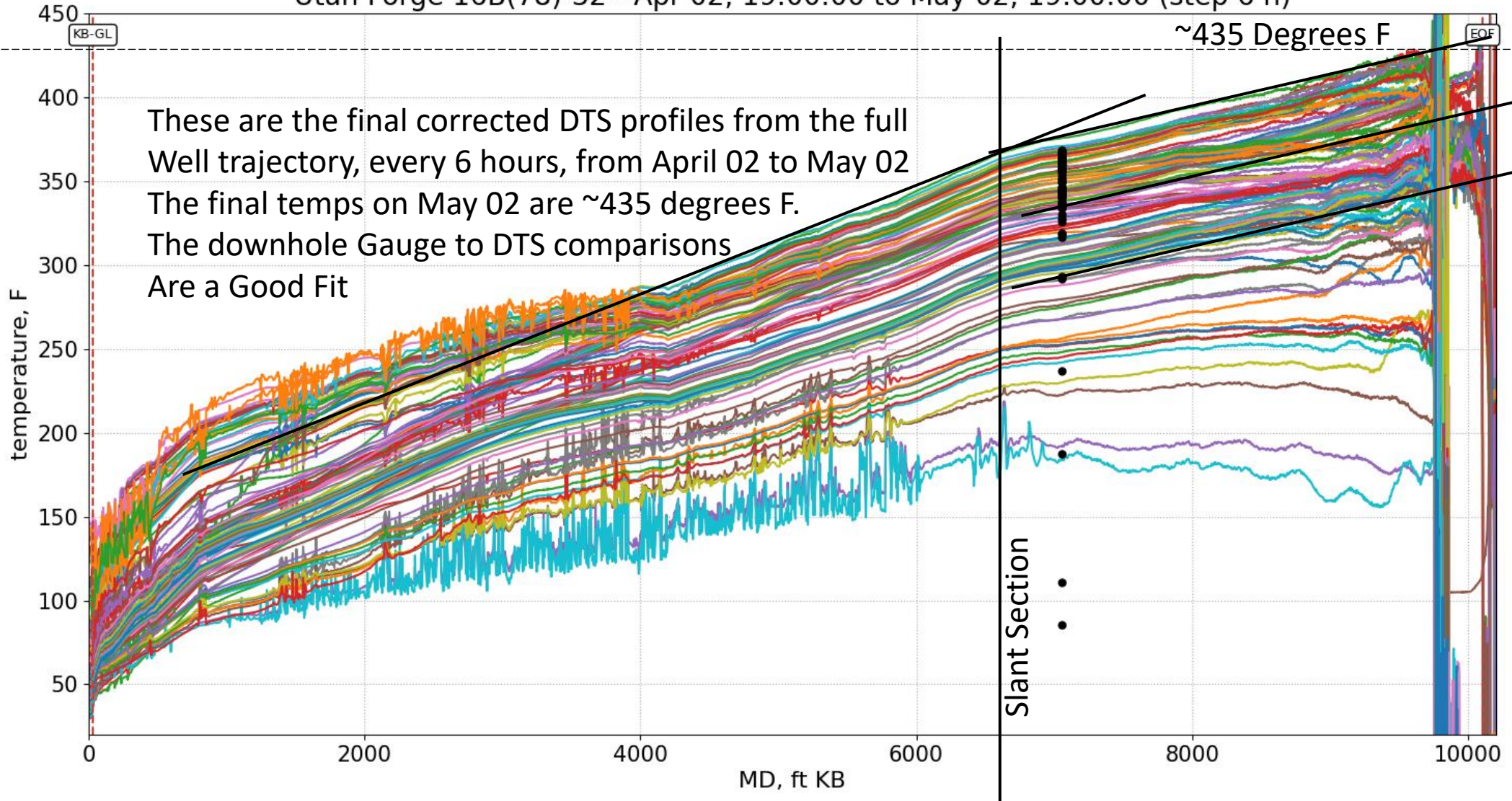
Well 16B – Brillouin corrected and gauge calibrated DTS – annotated



Well 16B –Brillouin corrected DTS (FINAL) – selected traces

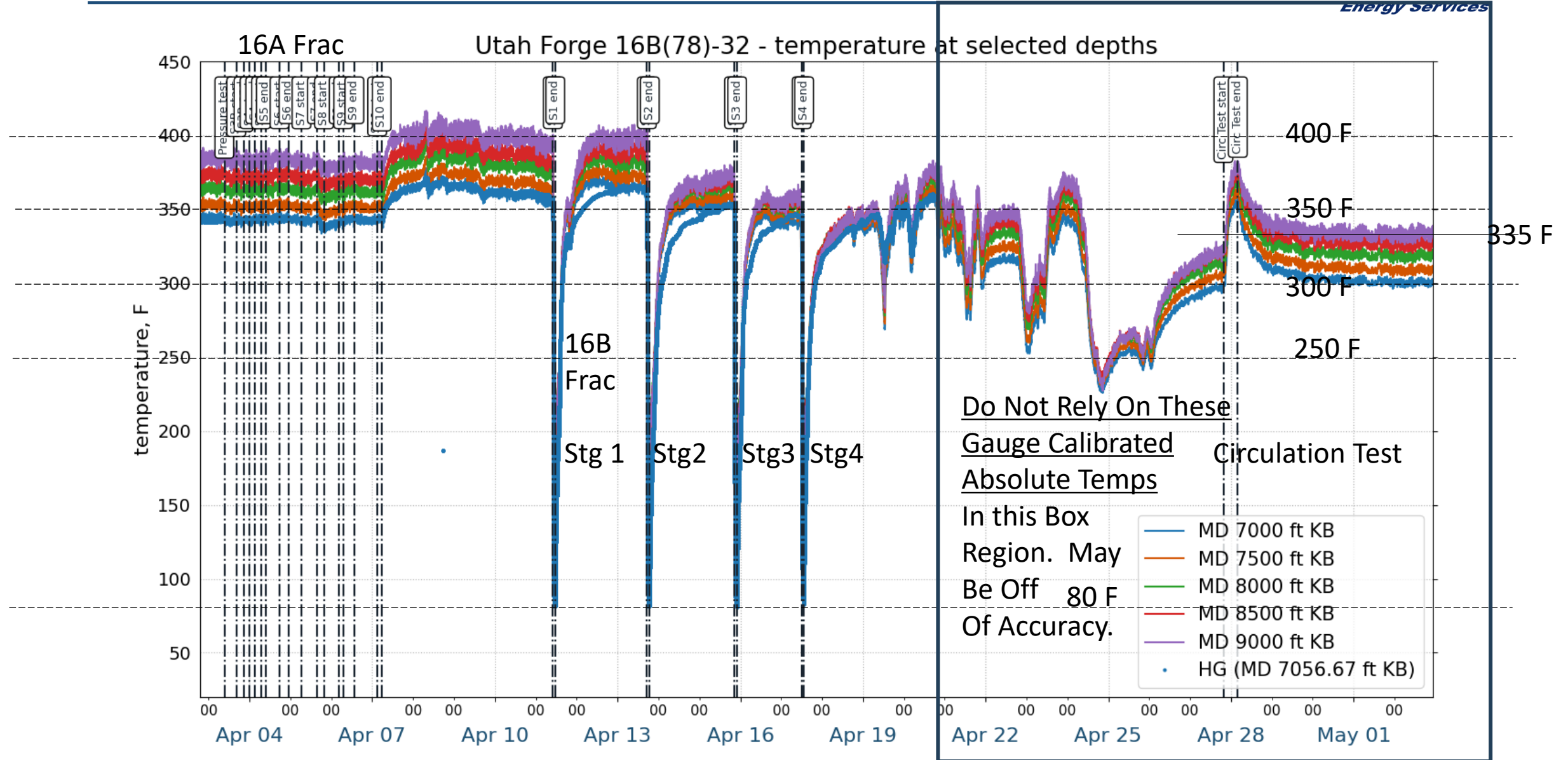


Utah Forge 16B(78)-32 - Apr 02, 19:00:00 to May 02, 19:00:00 (step 6 h)



These are the final corrected DTS profiles from the full Well trajectory, every 6 hours, from April 02 to May 02
The final temps on May 02 are ~435 degrees F.
The downhole Gauge to DTS comparisons
Are a Good Fit

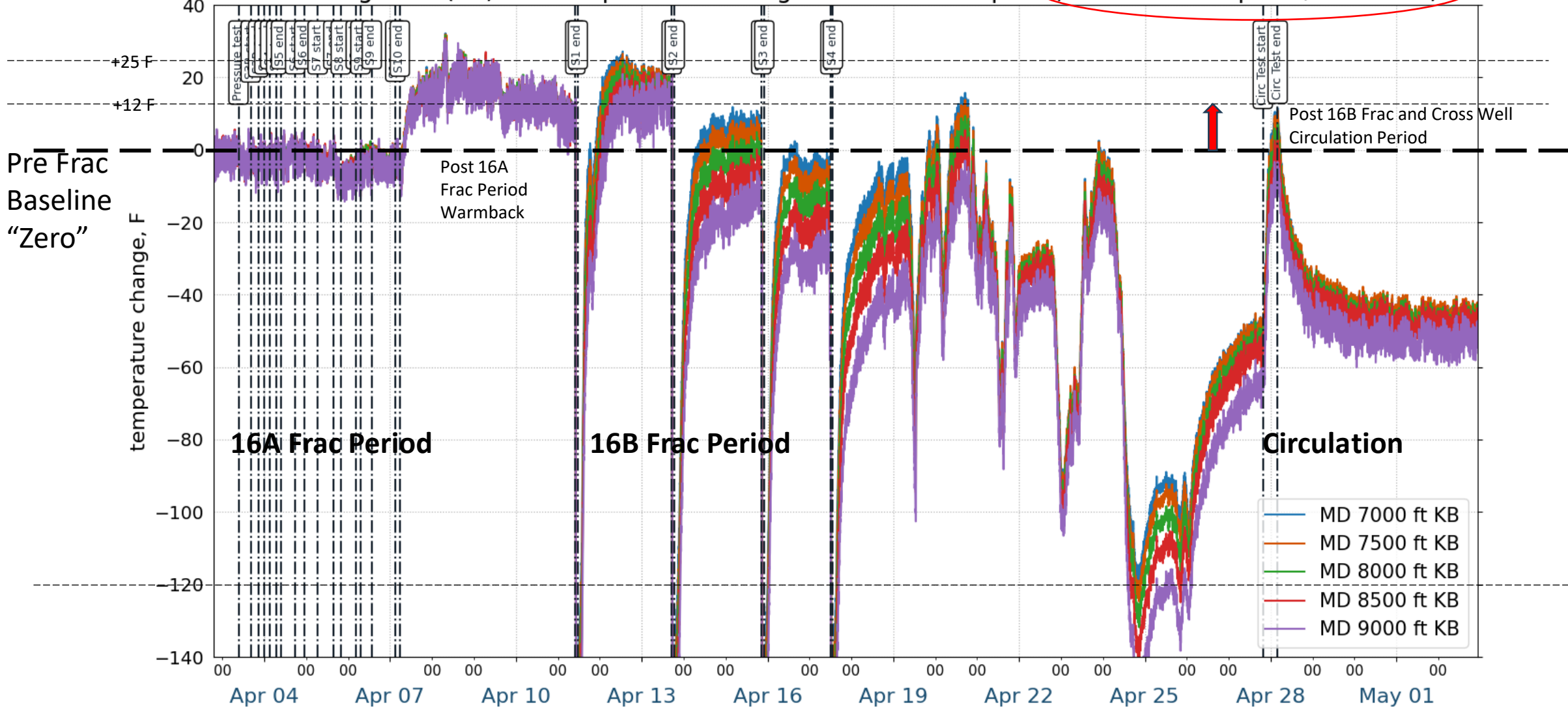
Well 16B – Brillouin corrected DTS (Final) – @ select depths in 16B



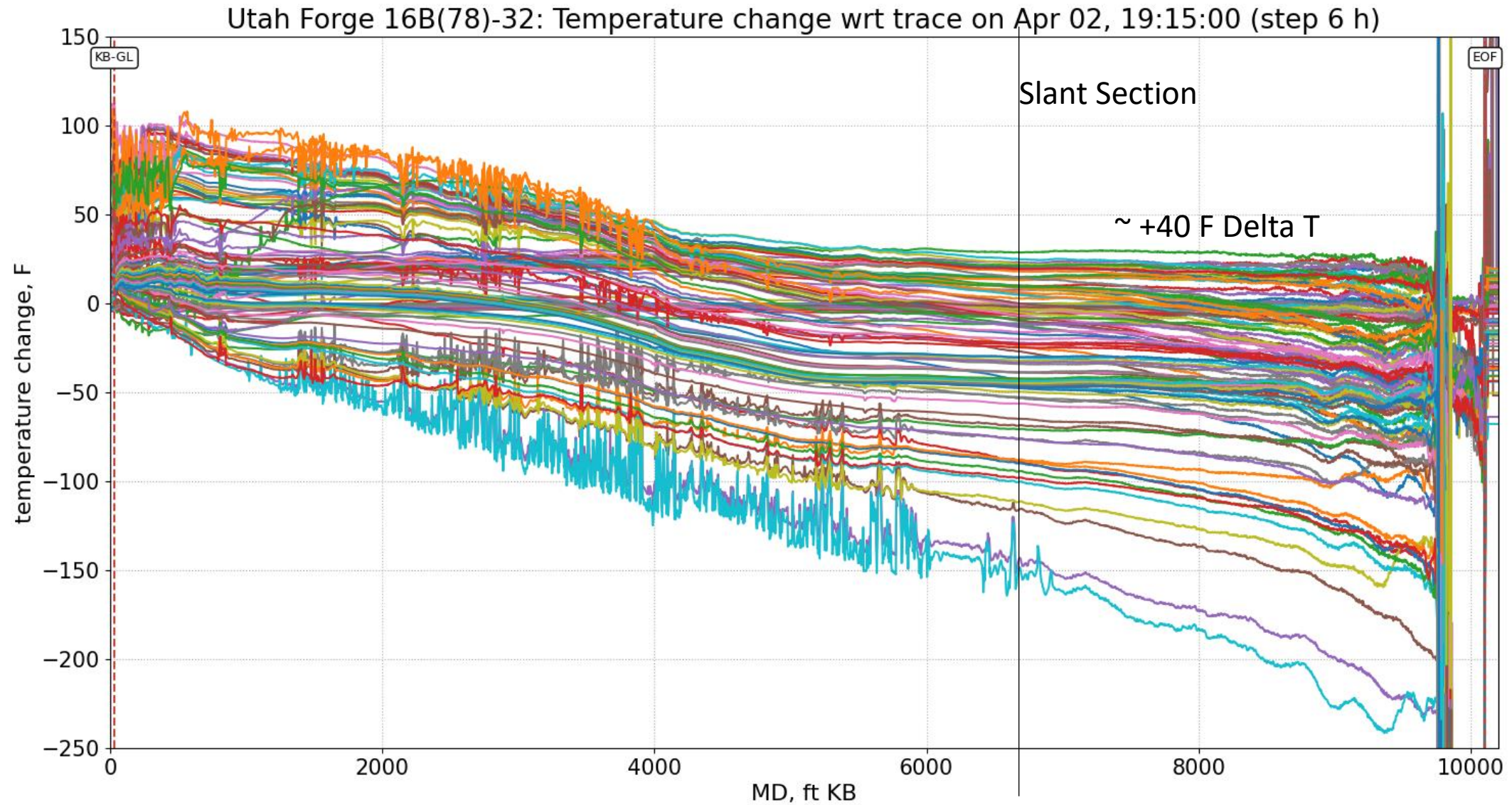
Well 16B – Brillouin corrected DTS – T change @ selected depths



Utah Forge 16B(78)-32: Temperature change at selected depths (wrt trace on Apr 02, 19:15:00)



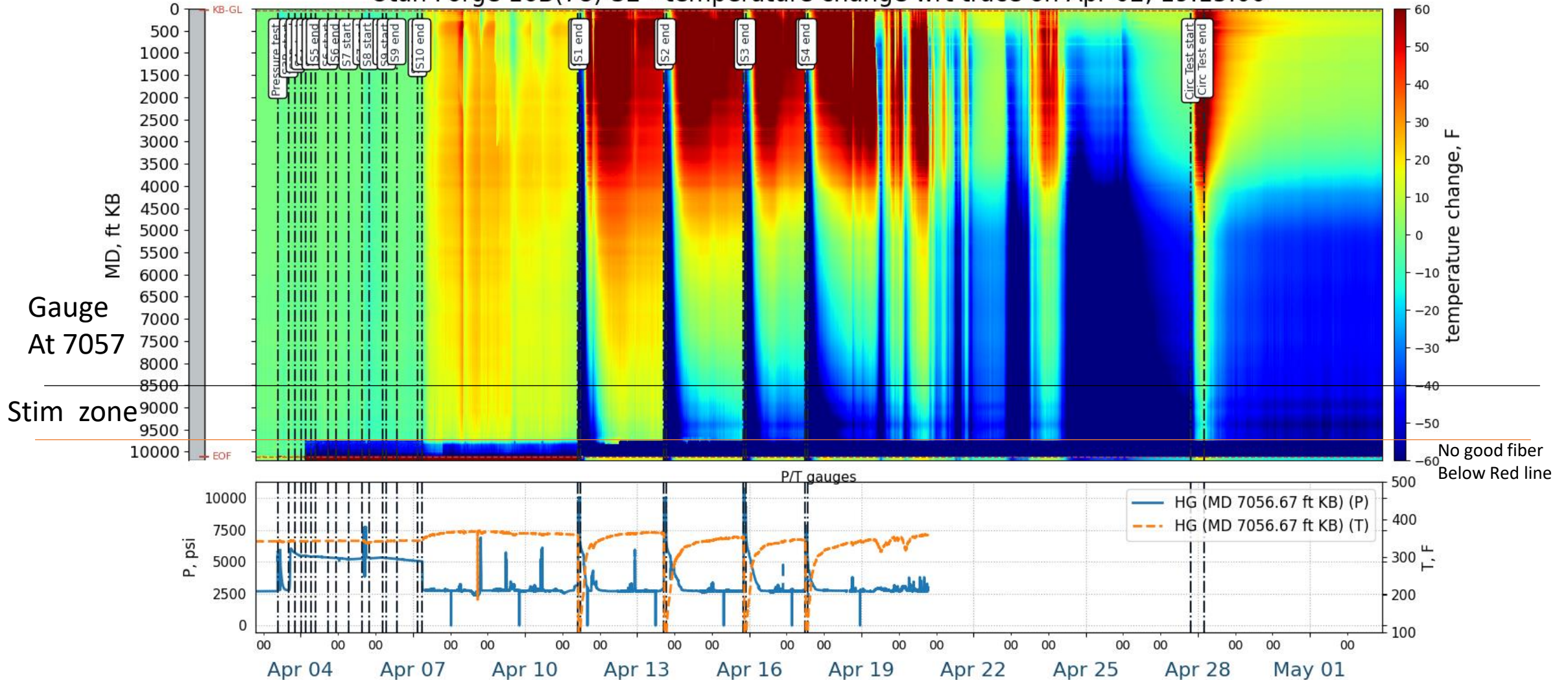
Well 16B – Brillouin corrected DTS – T change – selected traces



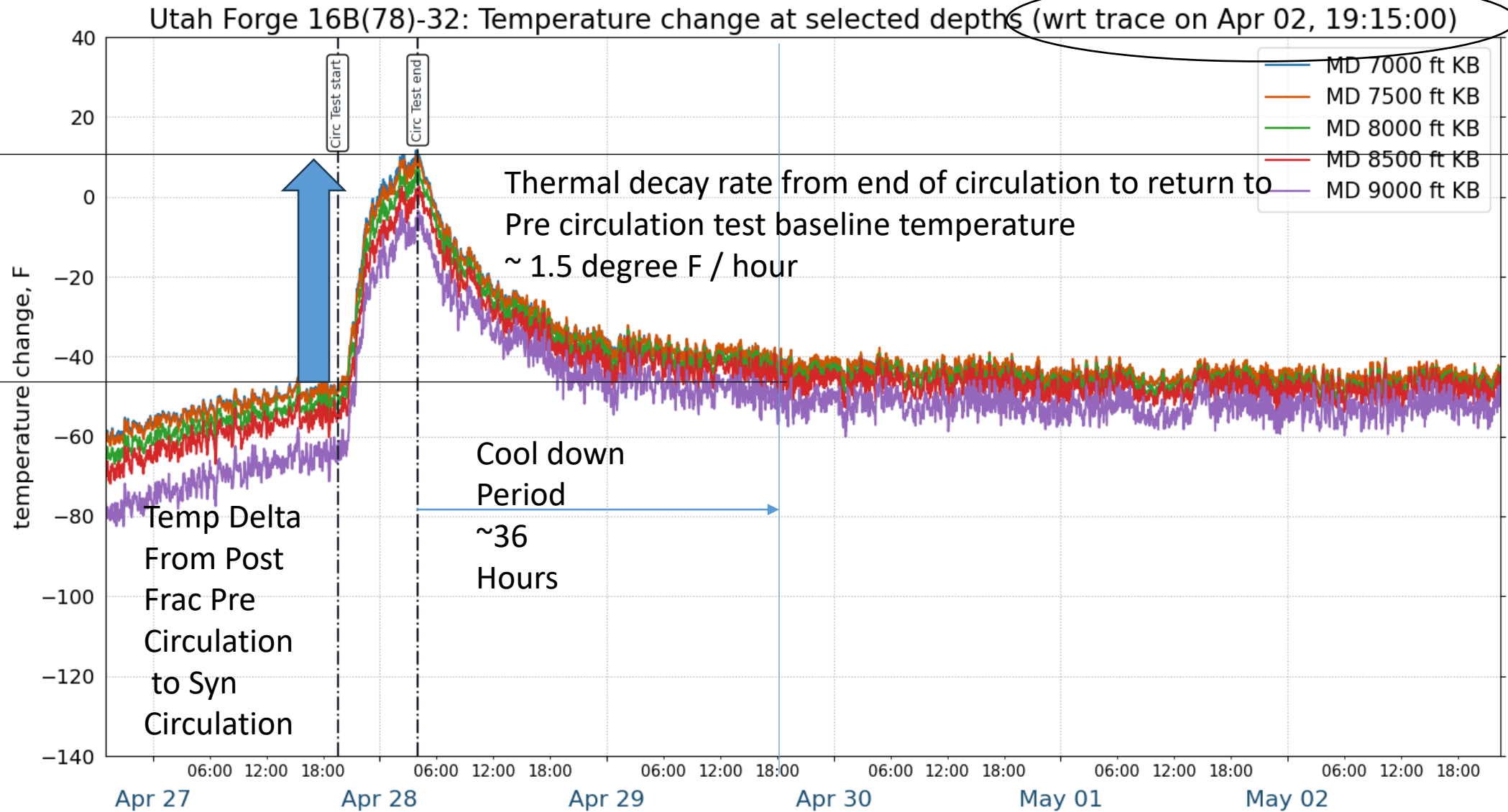
Well 16B – Brillouin corrected DTS – T change waterfall plot



This is a critical data plot. Temperature change from Baseline on April 02, 2024; 1915pm
 Utah Forge 16B(78)-32 - temperature change wrt trace on Apr 02, 19:15:00



Well 16B – DTS Temp change – select depths – @ circulation

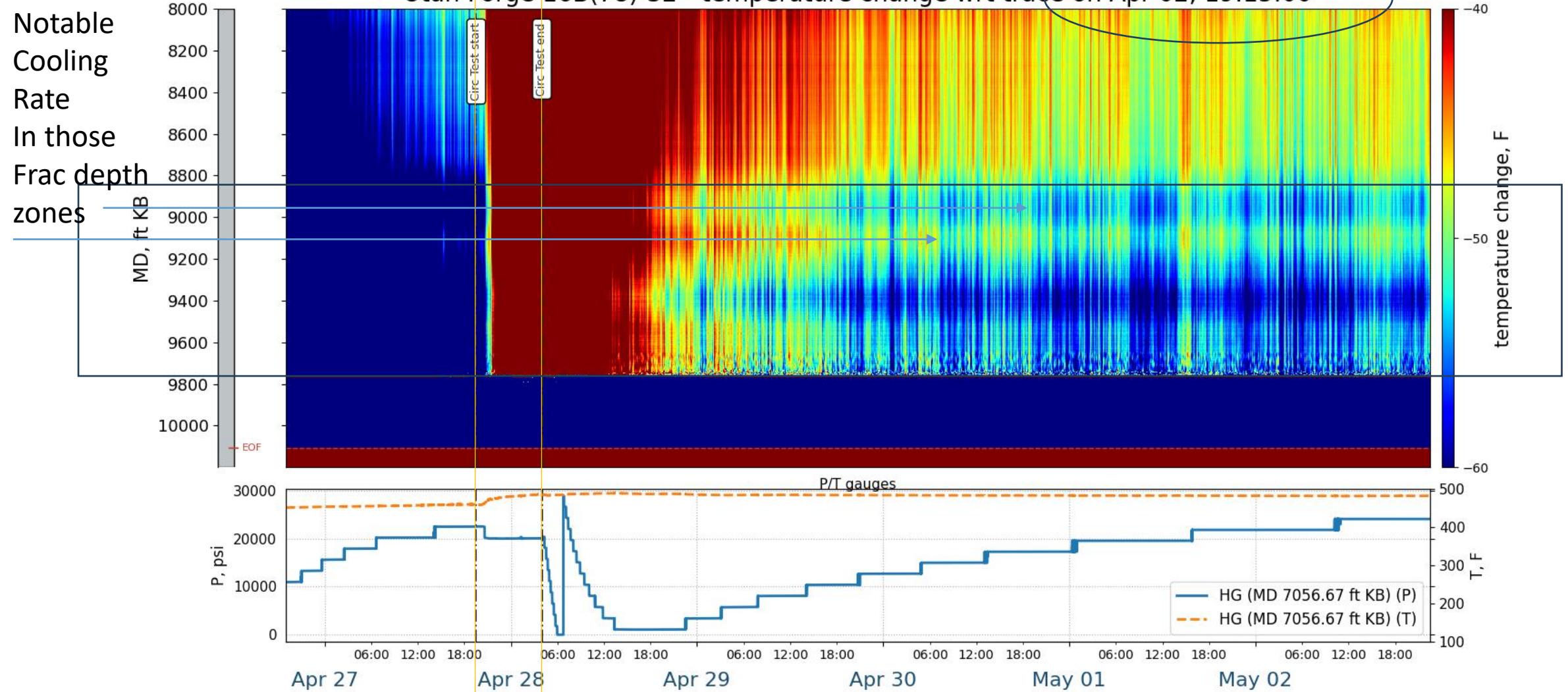


Well 16B – DTS temperature change – post frac circulation



Circulation Period

Utah Forge 16B(78)-32 - temperature change wrt trace on Apr 02, 19:15:00



Summary of corrections



- SMF based Brillouin wavelength Absolute Total Strain (temperature and mechanical strain properties) measurement profiles of geothermal gradient were taken in Well 16B prior to frac operations. These were used for correcting MMF optical loss as a depth-based correction factor that was applied to all MMF DTS profiles during the entire operation. This is a correction factor method based on measurements from two different fibers in same cable structure, namely the MMF and SMF2.
- At first, no direct use of gauge data
 - If used to offset DTS, then an incorrect gradient/temperature at surface was attained in the DTS data
- Correction with Brillouin Depth Geothermal Gradient improved gradient of DTS data and made surface temps at wellhead realistic.
- Forcing match of DTS data to the gauge data at 7057 MD produces very high absolute temperature values in the deeper part of the well and these may not be realistic, especially during the post frac circulation period
- The validity of the Baker Gauge T gauge data may be in question during the 16B frac period and the post 16B 9-hour circulation test. Use Temps during those periods of time with caution. The calibration factor required during 16B frac period, to match Gauge with DTS was much smaller than during Post 16B frac.

Contact



- This work was acquired, data processed and analyzed by Neubrex Energy Services (US), LLC.
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