POWERDRIVE LOG INTERPRETATION GUIDE

Updated August 2019

EXTREME™

INTRODUCTION

The advanced architecture of the PowerDrive rotary steerable system collects a variety of downhole data, including dynamics such as collar RPM, stick slip, shock and vibration, diagnostic channels such as steering ratio and toolface, and estimations of flow rate from the onboard turbines (torquers). This makes PowerDrive one of the best drilling mechanics optimization tools in North America. To enable advanced, near-real-time feedback on downhole drilling performance, the CRE provides a readout of PowerDrive drilling dynamics and steering performance in PDF format for every downhole run. This rich dataset provides valuable insight into maximizing drilling performance and understanding the downhole drilling environment. This report is automatically generated from downhole memory data as soon as it is downloaded from the PowerDrive to allow for rapid response to drilling conditions.

SCOPE OF GUIDE

This document serves as a how-to guide for understanding and interpreting the data and operating parameters presented in the standard NAL PowerDrive PDF log. It requires a basic understanding of how the tool functions. The log continues to evolve as more advanced analytics are created and will be updated to reflect the latest available format as it evolves. For more information, please contact the appropriate Operations Support team.

The PDF report will be presented page-by-page, under which the function of each presented channel will briefly be described, along with the potential value each measurement brings for drilling optimization.

At the end, an appendix will show “good” and “bad” logs to illustrate the diagnostic utility of the reports.

PAGE 1: SUMMARY AND TOOLSET INFORMATION

The front page contains a summary of the run and the toolset utilized. The left table shows maximum temperature, peak radial shock experienced on the run, total radial shock count, and the pumping hours recorded by the PowerDrive. The right table shows the subcomponents in the PowerDrive toolset, including bias unit and control unit. This should match the OST information provided to the rig site with the PowerDrive tool.

PowerDrive Dump Summary
Max Temp = 88.72 degC
Max Radial Shock = 144 G
Total Radial Shocks = 600 Shocks
Estimated Pumping Hours = 114.04 Hrs

SerialNo	FileCode	Description
93509	PDX9BU-RA	BU/COLLAR ASSY, 12 1/4" PDX5, 8 5/8" REG SUB CONN.
65099	PDSC9-BB	PDSC9-BB, COLLAR ASSEMBLY, PD900
22	PDCU-CA	PDCU-CA CONTROL UNIT
SLW3-98969	EQ-100707470	EXTN SUB, NECKED, PDX9, 8 5/8 REG BU CONN
TEST900-01	100707470	EXTN SUB, NECKED, PDX9/PDX1, 8 5/8 REG BU CONN
H66324	100494300	FINAL M/C ASSY, PD900 TSP PAD (HIGH ABRASION)
LPE43033-30	100494300	FINAL M/C ASSY, PD900 TSP PAD (HIGH ABRASION)
LPE43035-12	100494300	FINAL M/C ASSY, PD900 TSP PAD (HIGH ABRASION)
LPE43534-09	100107864	TREFOIL DISTRIBUTOR ASSY, 12 1/4 PDX5
LPE7552-13	100107756	FILTER/BEARING HOUSING ASSY, 12 1/4 PDX5

PAGE 2: END OF RUN SUMMARY DATA

The second page shows all data provided to the Command Center as part of the End of Run Summary (or Bit Run Summary) associated with the toolset on Page 1. This data is provided via D&M business system Field Ticket Light, or in the case of Extreme rental jobs, manually entered from ERS documentation provided by the customer utilizing the PowerDrive for that job. The completeness of this data is only as accurate as the data supplied by the rig.

JobRun	Run3 19MLR1145
DATE IN	7/27/2019 8:10:00 AM
DATE OUT	7/30/2019 8:10:00 AM
DEPTH IN	
DEPTH OUT	
ROTARY DRILLING HOURS	
PUMPING HOURS	55.8
BRT HOURS	63
DRILLING DISTANCE	
ROTARY DRILLING DISTANCE	
AVG ROP	
ON BOTTOM ROP	
Rotating ROP	
INCLINATION IN	
INCLINATION OUT	
AZIMUTH IN	
AZIMUTH OUT	
MIN SRPM	
MAX SRPM	
MIN FLOW RATE	
MAX FLOW RATE	
TVD IN	
TVD OUT	
MIN_SPP_ON_BOTTOM	
MAX SPP ON BOTTOM	
MAX BH TEMPERATURE	-459.67

PAGE 3: DOWNLINK RECORD

The third page shows a full listing of all downlinks (or potential downlinks) detected by the tool. If the command is properly decoded, the detected precursor and command (ex. 2-27) is displayed, along with the correlation percentage, showing how well the detected downlink pattern matches the expected pattern. The chart also shows the bit period used (18s, 36s, or 60s) as well as the source, either flow downlink or collar RPM downlink. Finally, the command description and downlink page indicate what the command did. The column "Page" is only relevant for runs where multipage downlink is enabled, to indicate which command list is currently active. (Multipage is currently in field test and not available commercially.)

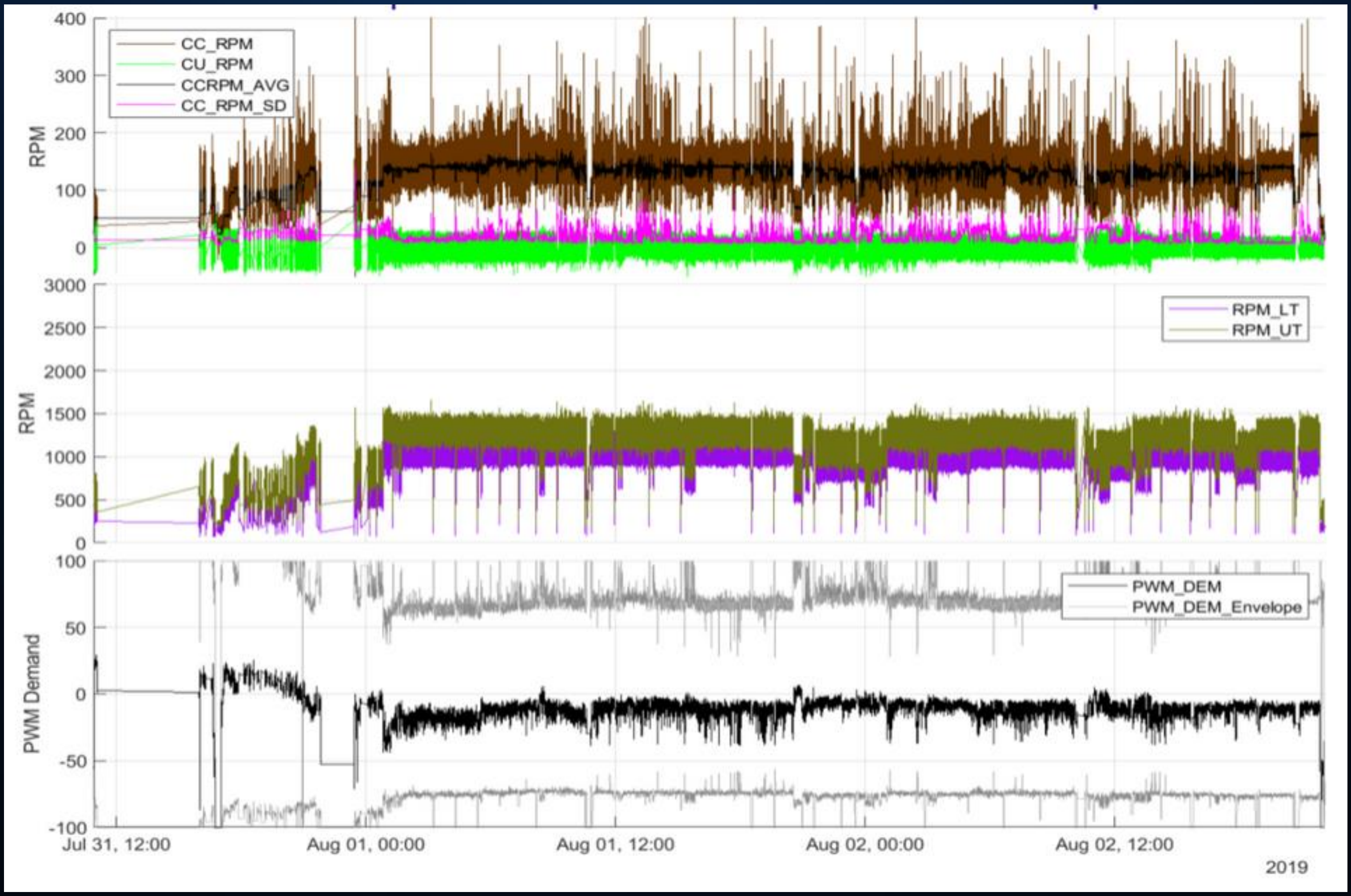
DateTime	Prec_ID	CMD_ID	PREC_CORR	CMD_CORR	BIT_PERIOD	Source	Command	Page
29-Sep-2019 16:48:41	2	28	93.40	96.40	60	CRPM	Use Magnetic Mode	0
29-Sep-2019 17:07:31	1	22	93.50	96.40	60	CRPM	Set TF = 162 degrees, SR = 75%	0
29-Sep-2019 18:59:43	2	17	93.20	94.40	60	CRPM	Inclination Hold w/ No Turn	0
30-Sep-2019 06:14:19	2	18	95.70	93.50	60	CRPM	Inclination Hold w/ Right Turn	0
01-Oct-2019 02:16:46	2	18	95.30	92.20	60	CRPM	Inclination Hold w/ Right Turn	0
01-Oct-2019 02:27:52	3302	55	93.70	0.00	60	CRPM	Unknown	0
01-Oct-2019 02:35:30	2	18	96.80	95.30	60	Flow	Inclination Hold w/ Right Turn	0
01-Oct-2019 02:47:10	3302	55	94.20	0.00	60	CRPM	Unknown	0
01-Oct-2019 02:54:50	2	22	95.00	93.90	60	Flow	Nudge Up Inclination Target	0
01-Oct-2019 11:48:43	1	0	93.40	95.00	60	CRPM	Set TF = 0 degrees, SR = 0%	0
01-Oct-2019 20:21:00	2	18	96.30	94.80	60	CRPM	Inclination Hold w/ Right Turn	0
02-Oct-2019 01:25:46	2	18	93.40	95.70	36	CRPM	Inclination Hold w/ Right Turn	0
02-Oct-2019 07:48:16	2	20	96.70	92.00	36	CRPM	Inclination Hold w/ Left Turn	0
02-Oct-2019 10:17:13	3301	55	85.00	0.00	18	Flow	Unknown	0
02-Oct-2019 13:33:38	2	18	94.30	95.40	36	CRPM	Inclination Hold w/ Right Turn	0
03-Oct-2019 05:07:05	2	18	94.20	95.50	36	CRPM	Inclination Hold w/ Right Turn	0
03-Oct-2019 19:49:32	2	5	96.60	95.60	60	CRPM	Set TF = 288 degrees, SR = 50%	0
03-Oct-2019 20:24:44	3402	55	85.70	0.00	18	Flow	Unknown	0
04-Oct-2019 06:07:38	3302	55	85.70	0.00	36	CRPM	Unknown	0
04-Oct-2019 07:05:27	1	0	94.80	97.20	36	CRPM	Set TF = 0 degrees, SR = 0%	0
05-Oct-2019 06:13:19	2	7	97.40	97.40	60	CRPM	Set TF = 306 degrees, SR = 75%	0
05-Oct-2019 12:57:41	2	6	94.70	94.20	60	CRPM	Set TF = 288 degrees, SR = 100%	0
05-Oct-2019 14:19:28	3302	55	85.60	0.00	18	Flow	Unknown	0
05-Oct-2019 16:57:15	1	0	92.60	95.80	36	CRPM	Set TF = 0 degrees, SR = 0%	0
05-Oct-2019 18:25:05	3302	55	89.40	0.00	18	Flow	Unknown	0

PAGE 4: TORQUER PERFORMANCE

The fourth page shows basic PowerDrive operational performance. The top chart shows control collar RPM (CC_RPM, red). This is the speed of the bit and all PowerDrive collars and components attached to the bit. Barring tool malfunction, any erratic behavior reflects the motion of the bit downhole. In green, the control unit RPM (CU_RPM) indicates the speed of the control unit. While biasing, this is expected to be around zero, indicating the control unit is holding a toolface to steer. For X6 and Orbit with adaptive neutral enabled, while not biasing, this should be 16RPM less than the displayed collar RPM, or as close as possible to that if the collar RPM is erratic. For Orbit without adaptive neutral, this should be 4 RPM while not biasing. Erratic motion of the control unit not explained by the drilling cycle (for example, significant negative or positive RPM, or “fuzzy” data) indicates undesired friction acting on the control unit: debris or solids in the torquers, damage or invasion of the bearing packs, debris between the CU pressure housing and the inner wall of the collar, or due to electrical malfunction of the control circuitry.

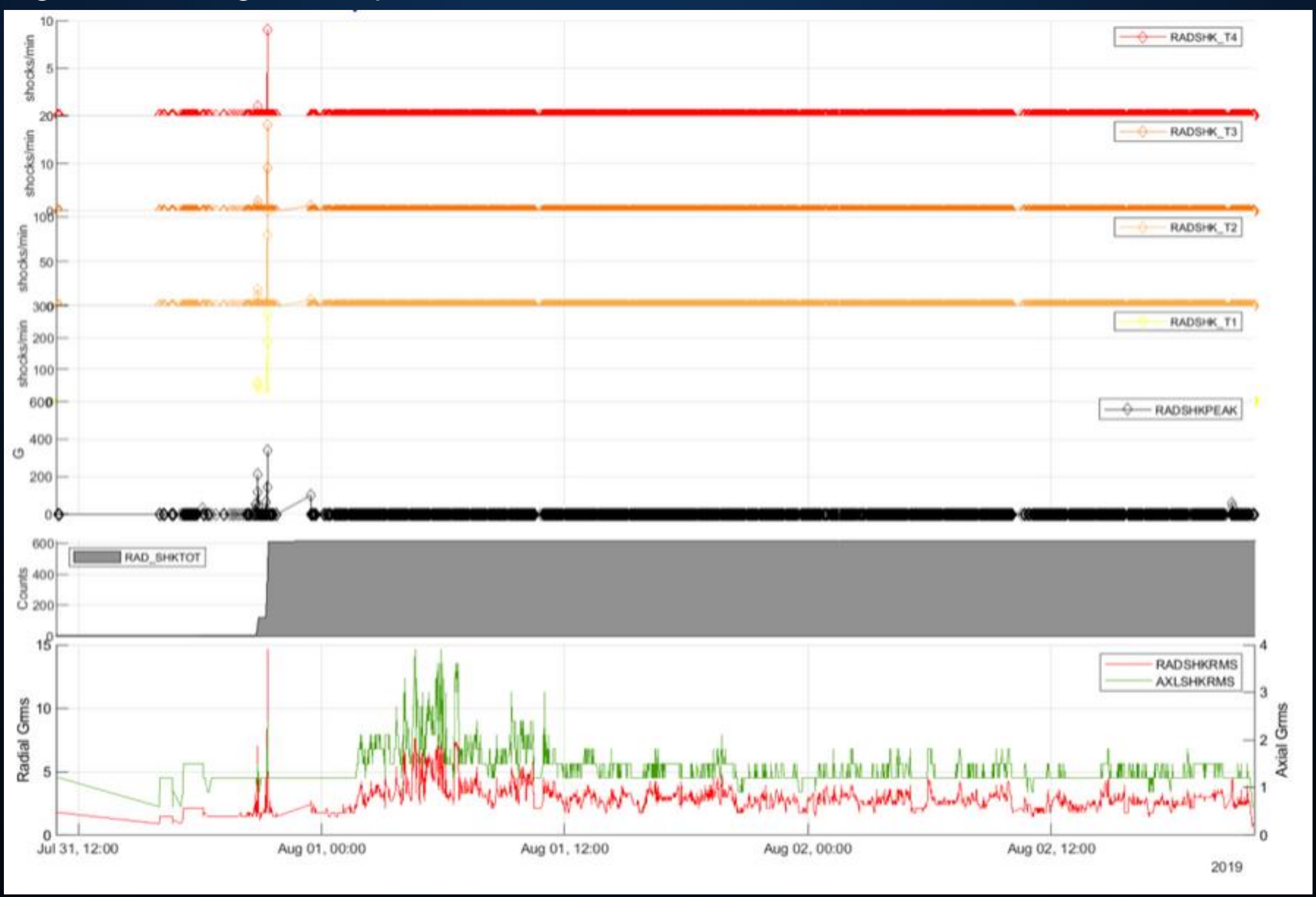
The middle chart plots the RPM of the upper (UT_RPM, grey) and lower (LT_RPM, purple) magnet housings, which each rotate around a three-phase coil to generate AC electrical power. These are called torquers. Typically, torquer RPM should be around 1500-3000rpm. The upper torquer rotates clockwise, and so imparts a clockwise torque on the control unit. The lower torquer rotates counterclockwise, and so imparts a counterclockwise torque on the control unit. Together, the torque output from both torquers is a function of electrical load, which can be varied to electronically brake either torquer, imparting a clockwise or counterclockwise rotating force on the control unit. It is important to remember this torquer RPM is measured relative to the torquer, and hence control unit itself, not the earth.

The lower chart plots the PWM demand of the control circuitry. PWM demand is the percentage of torque demanded from either the upper (positive) or lower (negative) torquer, ranging between 0 and 100%. Simply, the "fuzzier" the line, the more adjustments the control unit must make to stay steady. If the measurement pegs in either direction, something that should rotate smoothly isn't doing so. The lighter grey lines show the envelope of the PWM, indicating the extremes demanded to keep the control unit oriented in the desired place. If these reach +/- 100%, it indicates the tool is demanding maximum torque from either torquer, suggesting abnormal, intermittent friction or very high stickslip is preventing the control unit from holding a steady position or roll rate. The black line is the average value. If this reaches +/- 100, it indicates the tool is experiencing extreme consistent friction. -100% PWM indicates there is excess clockwise friction, from a jammed upper torquer, jammed bearing pack, or debris between the CU and CC. +100% PWM indicates there is excess counterclockwise friction, indicating jamming in the lower torquer, which is the only source of counterclockwise torque in the tool.



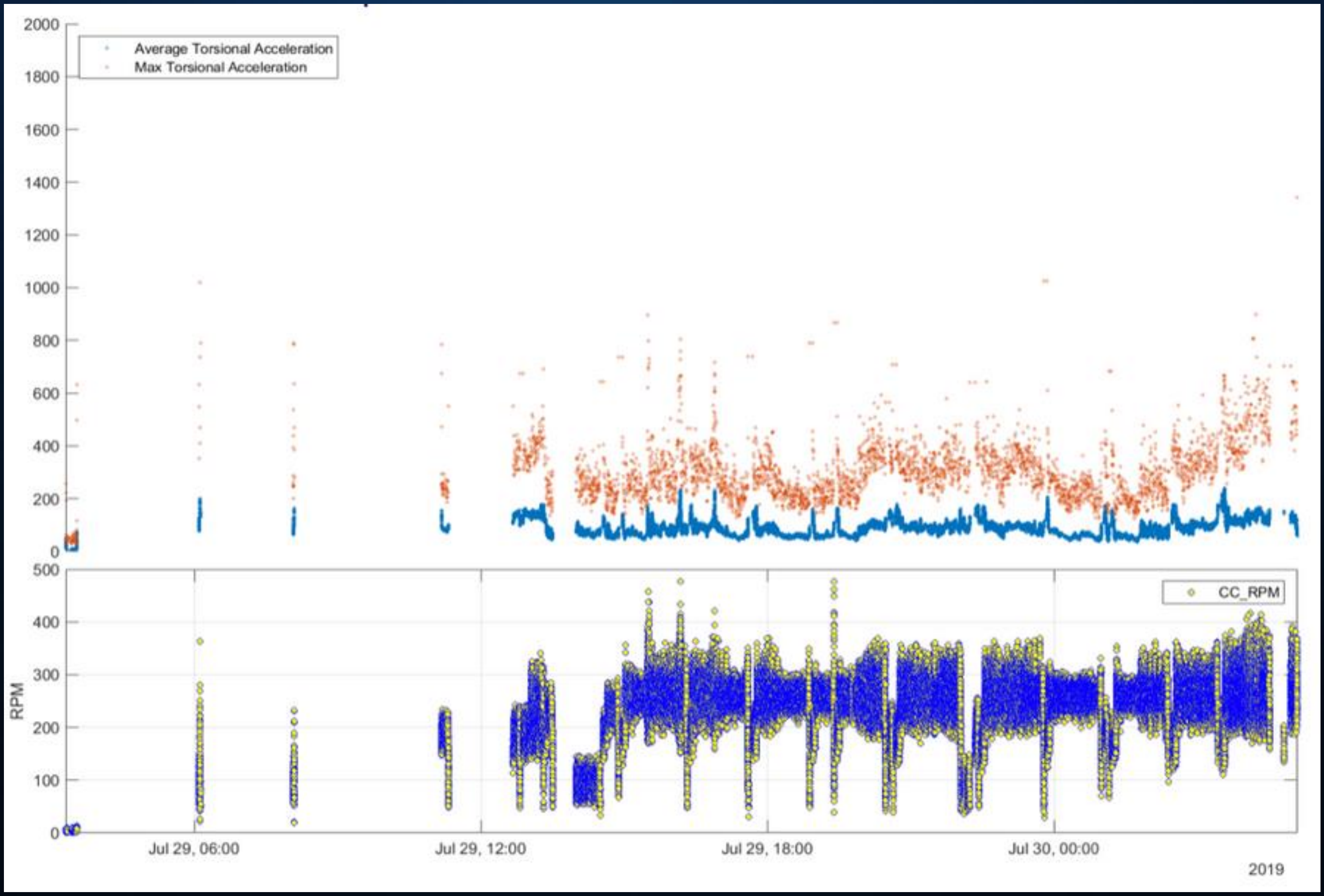
PAGE 5: RADIAL SHOCK

This page summarizes the shock environment downhole. The top four plots represent shock counts above a certain G threshold. RADSHK_T4 is counts per minute above 150G (red). RADSHK_T3 is counts per minute above 100G (orange,) RADSHK_T2 is c/min > 50G (light orange,) and RADSHK_T1 is c/min > 25G (yellow.) So, towards the top of the page, shock counts are higher G level and higher risk of damage. These represent how fast (counts) and how hard (level 1-4) the shocks are. The black track, RADSHKPEAK, is the peak amplitude in G recorded by the shock sensor, representing how hard the shock hits regardless of frequency. At 250G amplitude, even one shock can cause damage. The bottom track represents axial (AXLSHKRMS, green) and radial (RADSHKRMS, red) root-mean-square shock, which is a measure of the magnitude of the energy transmitted by vibration over time. Axial and radial rms shock can also indicate co-occurring vibration modes such as high frequency torsional oscillation (HFTO.) An increase in radial and axial RMS, when axial RMS is greater than 6grms, is a potential indicator of HFTO.



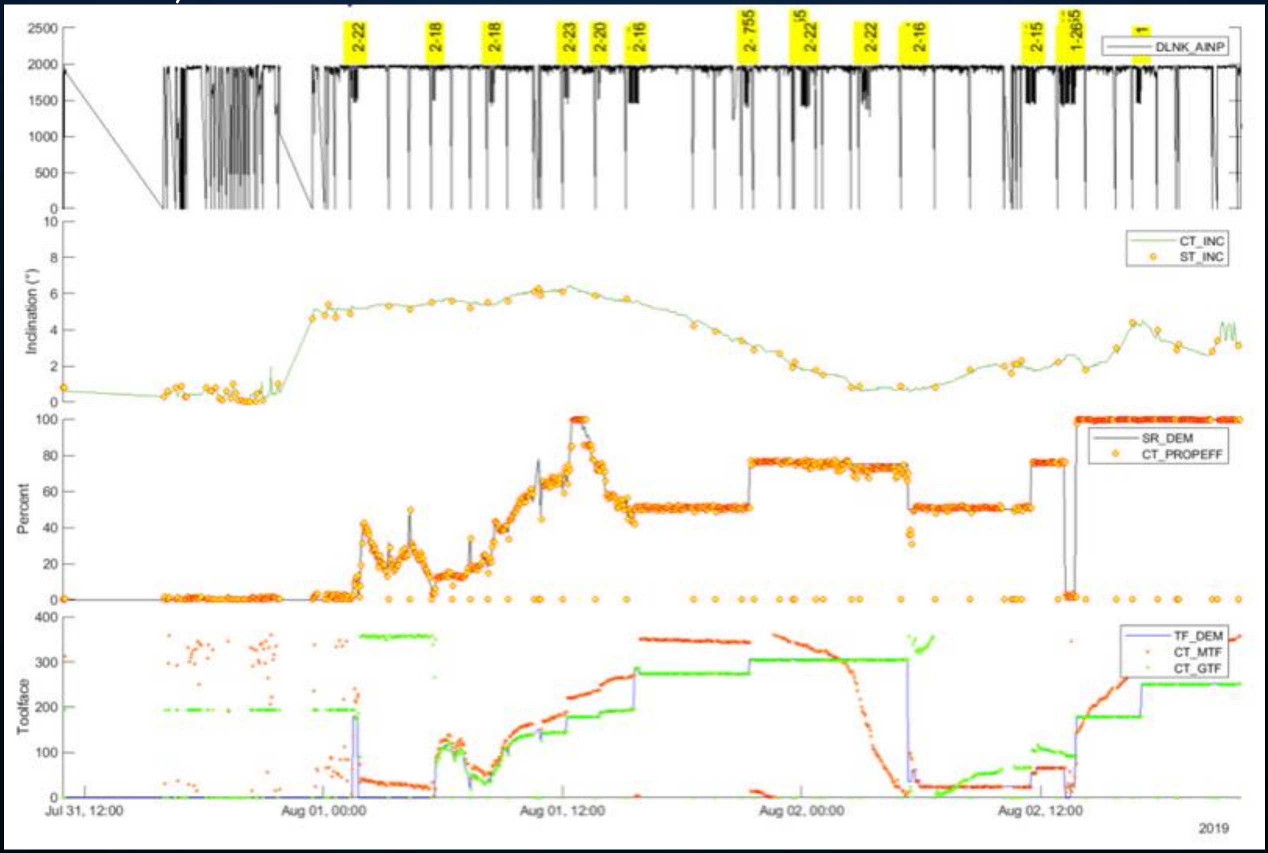
PAGE 6: TORSIONAL VIBRATION

This page is a representation of the acceleration of the control collar, bias unit, and bit. It is calculated by the slope of the line (rate of change) between collar RPM data points, and the units are delta rpm/s. It indicates the torsional load put on the control unit by torsional vibration. Historically, exceeding 1000 rpm/s is “severe.” The blue line is the average acceleration over the last 10 seconds, and the red dots are the maximum values. The bottom, blue/yellow points plot raw control collar RPM.



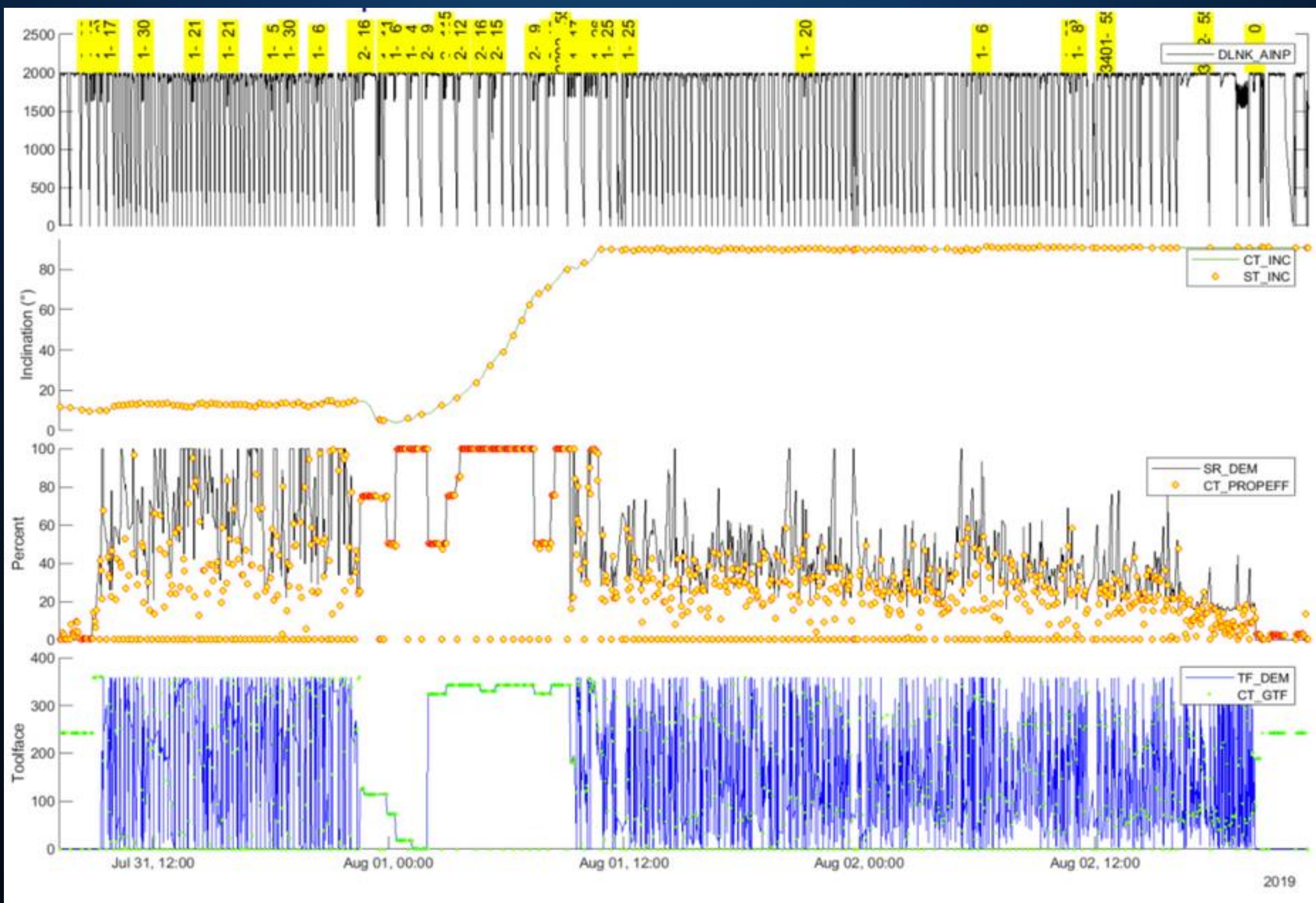
PAGE 7: BUILD RATE PERFORMANCE – VERTICAL

This page details the steering performance of the tool. The run is scaled to represent a vertical run. If the inclination exceeds 10 degrees, refer to the next plots (Curve or Lateral) to view performance. The top track indicates the downlink commands detected by the tool as yellow flags with numbers (2-30) which can be decoded on page 3. The second track down shows the continuous inclination (CT_INC, green) with static survey inclination (ST_INC, yellow/red dots.) The third track down shows the demanded steering ratio (SR_DEM, black) which varies based on tool mode. Effective steering ratio (CT_PROPEFF, yellow and red dots) is the measured ratio of time the control unit holds a consistent toolface. The effective steering ratio dots should overlay the demanded steering ratio. If they do not, further investigation is required, and steering response may be poor. The bottom track shows demanded toolface (TF_DEM, blue) and achieved toolface: CT_GTF (green dots) if the tool is in a GTF setting, and CT_MTF (red dots) if the tool is in an MTF setting. Both are included when near vertical. Actual toolface should track demanded toolface. Like steering ratio, this will vary depending on steering setting (manual or automated modes).



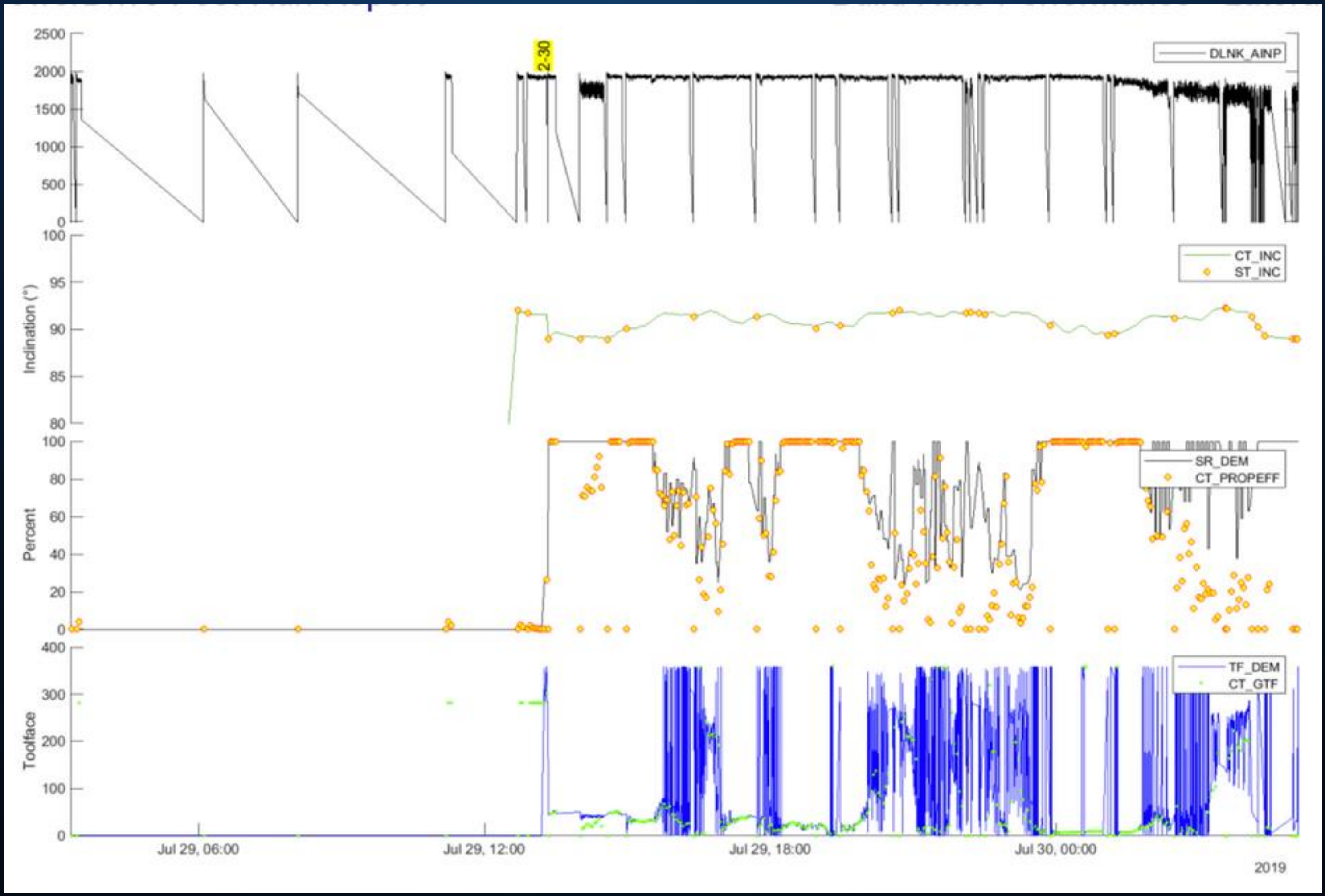
PAGE 8: BUILD RATE PERFORMANCE – CURVE

This plot is nearly identical to the prior plot, except inclination is zoomed out to show data from zero to 90 degrees. This plot is useful when kicking off from vertical. CT_MTF is removed as it is not typically used above 10 degrees inclination.



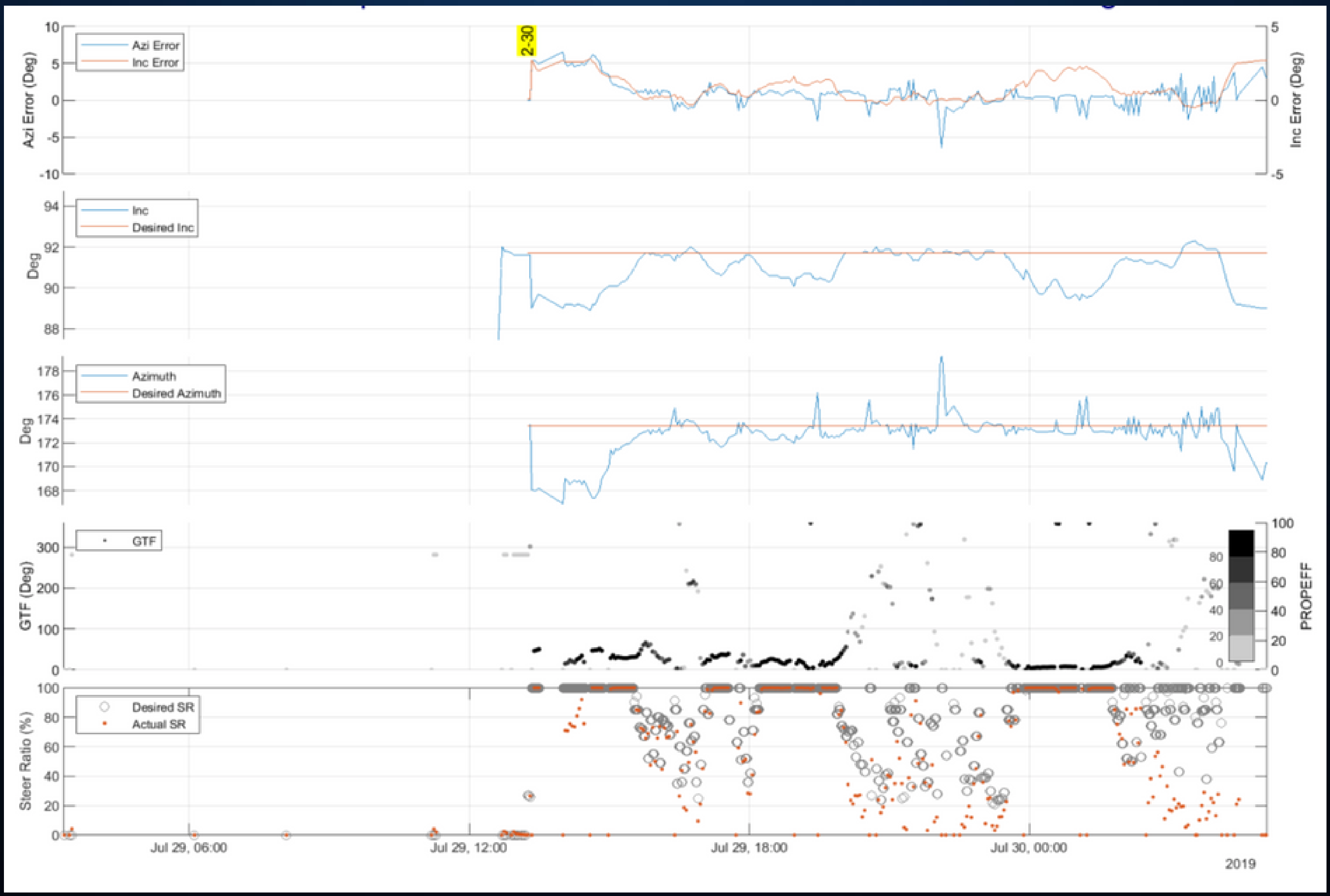
PAGE 9: BUILD RATE PERFORMANCE – LATERAL

This plot is identical to the previous, except inclination is zoomed from 80-100 to reflect typical inclinations in horizontal wells.



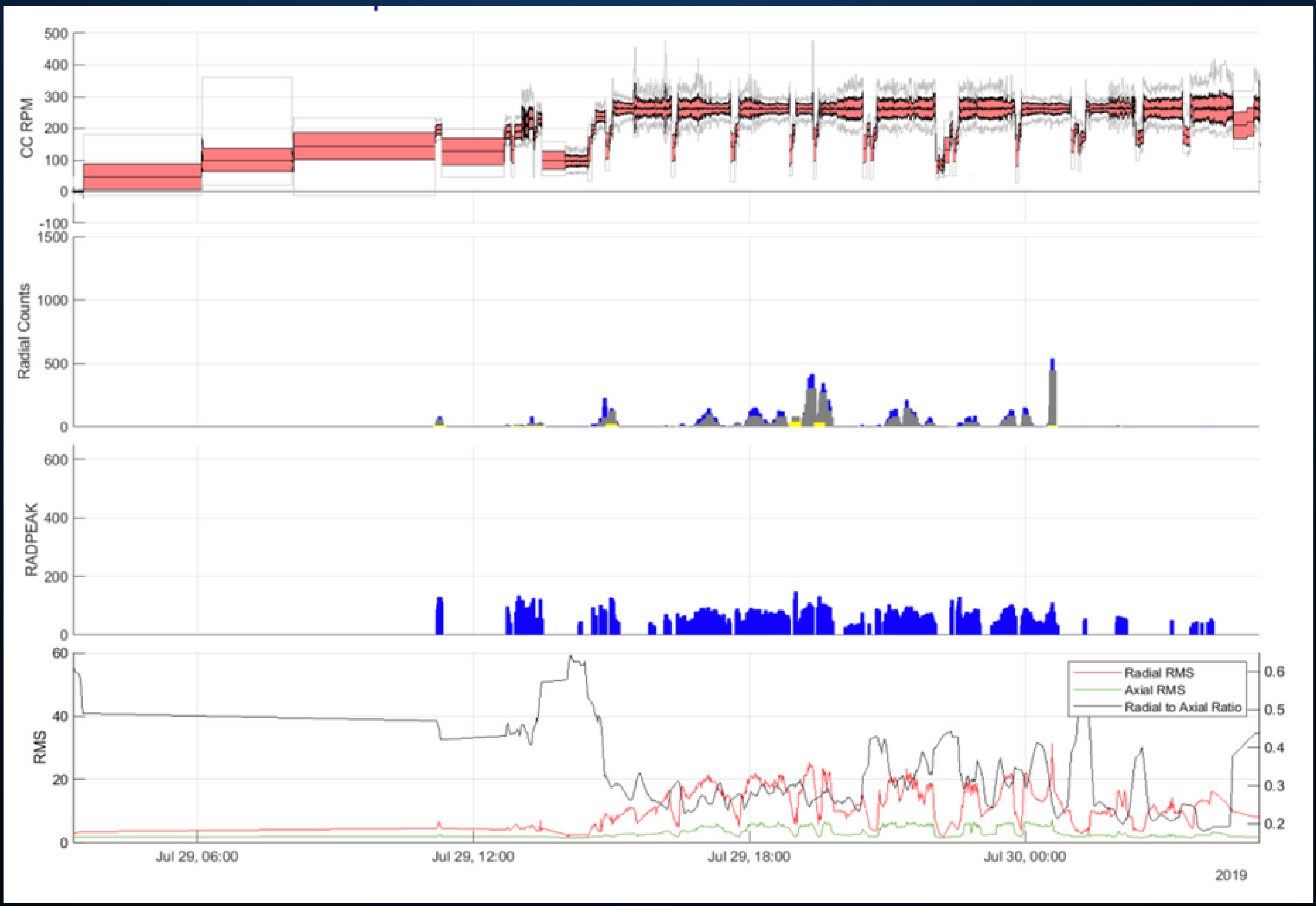
PAGE 10: STEERING PERFORMANCE

This page represents the performance of the PowerDrive in automated settings, such as inclination hold (IH) or hold inclination and azimuth (HIA). The top plot shows the error between the target and actual inclination (Inc Error, red) and the target and actual azimuth (Azi Error, blue) in degrees. The second plot down shows the measured inclination (Inc, blue) against the programmed target inclination (Desired Inc, red). The third plot shows the measured azimuth (Azimuth, blue) against the programmed target azimuth (Desired Azimuth, red). The fourth plot shows the desired toolface (GTF) plotted on the y-axis and colored by effective proportion (CT_PROPEFF.) This combines the data in pages 7-9, representing both the actual toolface and effective ratio in one plot. The bottom plot shows effective steering ratio (CT_PROPEFF, labelled Actual SR) as red dots against desired steering ratio (SR_DEM, labelled Desired SR) as grey circles. The red dots should mostly fall within the grey circles, indicating the control unit is achieving its desired steering ratio.



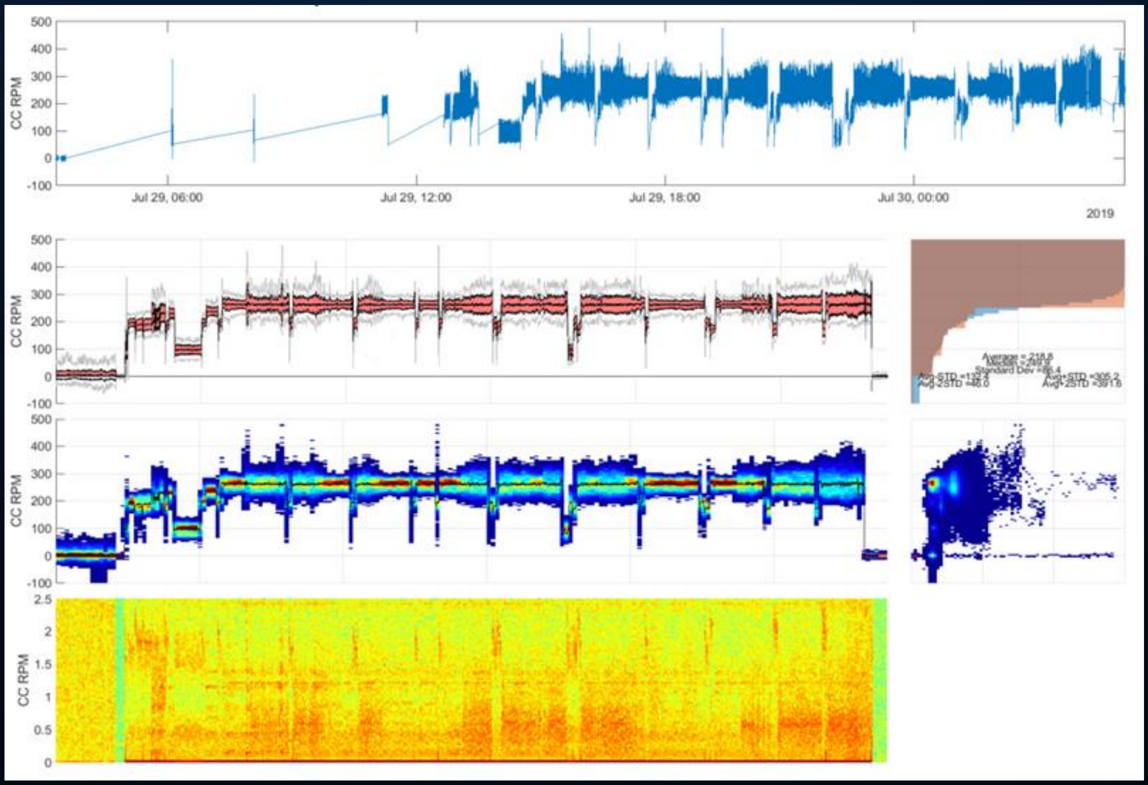
PAGE 11: SHOCKS

This page presents shock data in a slightly different format. The top chart shows control collar RPM maximum and minimum (grey lines) along with 1 standard deviation (black) with the area between the standard deviation envelope and the average filled in red. This gives a description of the envelope of RPM, as well as the statistical distribution over a rolling 10 second period. A wide envelope (grey lines) with a wide standard deviation (red area) typically indicates traditional, slow period "stick-slip." A narrow envelope with a narrow sigma indicates low torsional or stickslip vibration, as sampled at 5Hz. A wide envelope with a narrow standard deviation may indicate higher frequency modes only, without slower period stickslip. Lower envelope curves approaching zero indicate stopping of the bit.



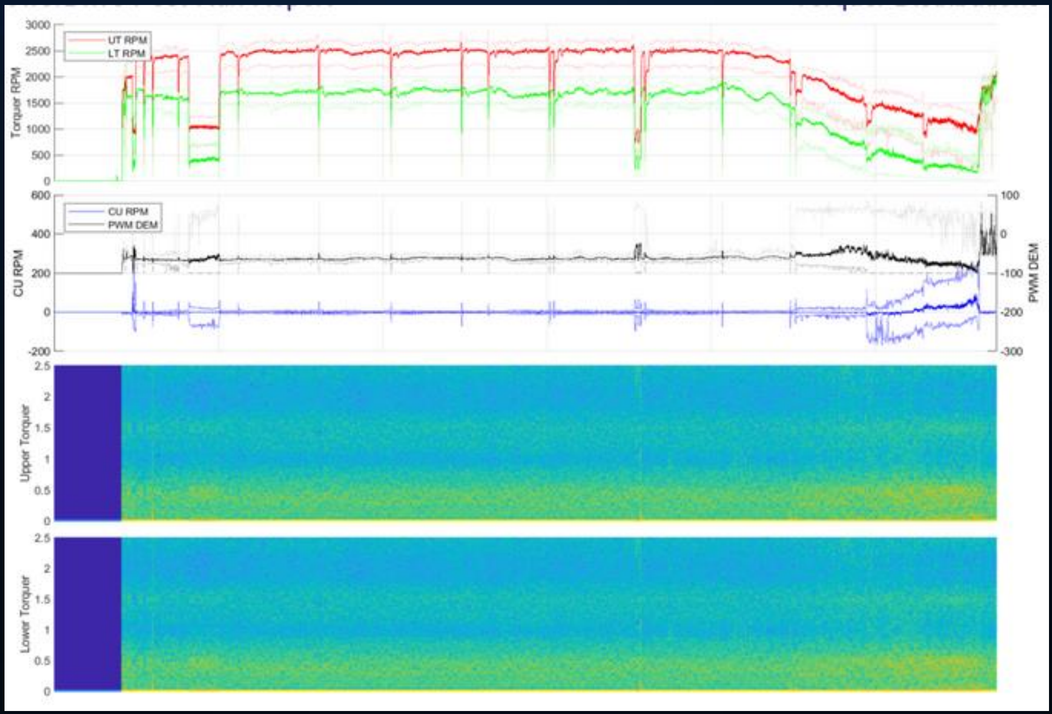
PAGE 12: CRPM DISTRIBUTIONS

This plot further expands on the collar RPM measurement. The top plot is raw CC_RPM. The second plot down is similar to the plot on page 11, but with the addition of a histogram for the entire dataset on the right – the blue bars represent the raw data, and the tan overlay represents the averaged data. The y-axis is CCRPM and the width of the bar indicates the cumulative percentage of data points at that RPM or less (cumulative distribution function). The plot third down from the top represents the standard deviation of CC_RPM, to the right of which is a condensed 2D plot of the whole run's RPM vs. standard deviation, colored by frequency. This plot is useful in describing the amount of time spent at varying RPM's and how much it varied at each RPM during the run. The bottom plot is a spectrogram waterfall plot generated by fast Fourier transform (FFT) of the collar RPM data to show frequency content of CC_RPM. The Y axis represents the frequency of vibration in the CCRPM, and the intensity of color reflects the intensity of the vibration, with redder color representing higher amplitude vibration. The 5Hz data is unfiltered, which means only signals below 2.5 Hz can be represented, and all signals above this will be aliased (Nyquist limit). As an example, a 1Hz red line would indicate the PowerDrive and bit are fluctuating at 1Hz, equaling 60 RPM. A low frequency band may indicate stickslip, which typically has a period of 3-5 seconds and a corresponding frequency under 0.5 Hz This gives richer information about the vibration modes of the BHA, which may be very complex.



PAGE 13: TORQUER DISTRIBUTIONS

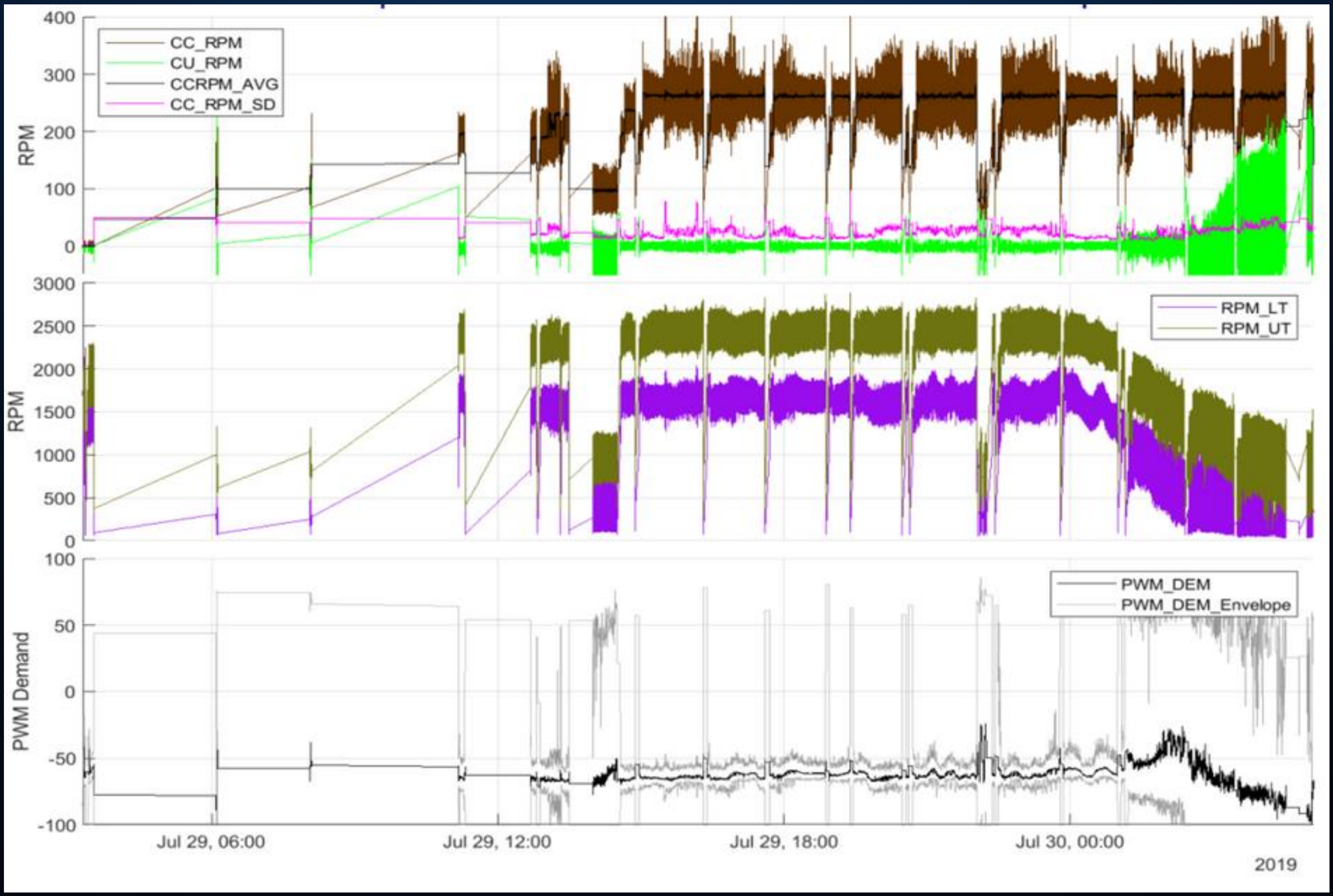
As with the collar RPM measurement, this page gives descriptive statistics to torquer performance. The top plot shows average upper (UT_RPM, red) and lower (LT_RPM, green) torquer RPMs with a fainter colored line showing the envelope. A wider envelope means more intermittent rotation of the torquer. This could indicate friction causing “sticky” rotation, or could also indicate flow interruptions, such as those from positive pulse MWD tools, or events such as motor stalls which restrict flow through the BHA. The second plot shows averages and envelopes for CU_RPM (blue) and PWM demand (black), to give context to the torquer performance, as torquer RPM is also affected by PWM_DEM from the control unit. The bottommost plots are FFT spectrograms of the torquer RPM, which typically will show drilling noise as well as MWD-induced flow variations, like any surface system spectrogram would. This is useful in determining if the MWD tool was pulsing, or if signal strength was diminishing, to help in troubleshooting downhole equipment and surface systems. The spectrograms will also reveal any cyclic motor loading, and very strong CC_RPM harmonics may cause enough load on the mud motor to be visible in the torquer spectrograms, indicating loading is severe enough to compress the drilling fluid via differential pressure above the motor. This could be correlated with a drillstring pressure measurement above the motor. This data is also sampled at 5Hz and not filtered, meaning any signal content above 2.5Hz will be aliased in the spectrogram. 2.5Hz is enough to resolve most common NAL MWD systems’ bandwidth.



APPENDIX – EXAMPLES

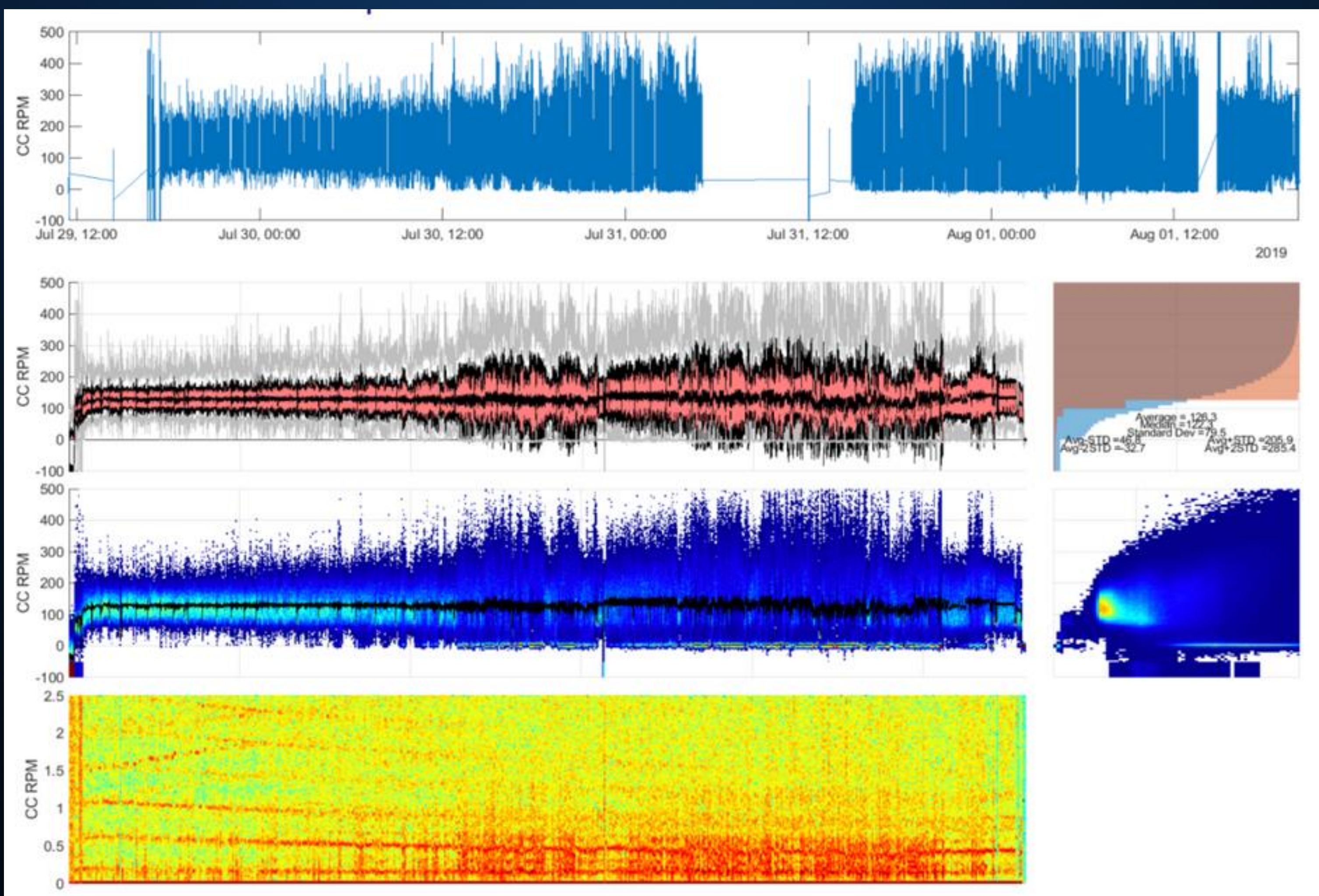
WASHOUT

This log shows progression of a washout occurring above the PowerDrive. Control collar RPM (CC_RPM, red) in the upper track is fairly consistent with no extreme dynamics present. The control unit RPM (CU_RPM, green) shows the control unit increasingly unable to hold a stable toolface or control its RPM. This is due to decreasing flow rate across the torquers as the washout progresses, as the middle track shows upper and lower torquer RPM (UT_RPM, LTRPM, grey and purple) decreasing at the same time. PWM shows a similar trend, as the control unit demands more and more torque from the lower torquer (negative PWM_DEM, black) as the flow rate across it, and thus the torque generation capability, drops.



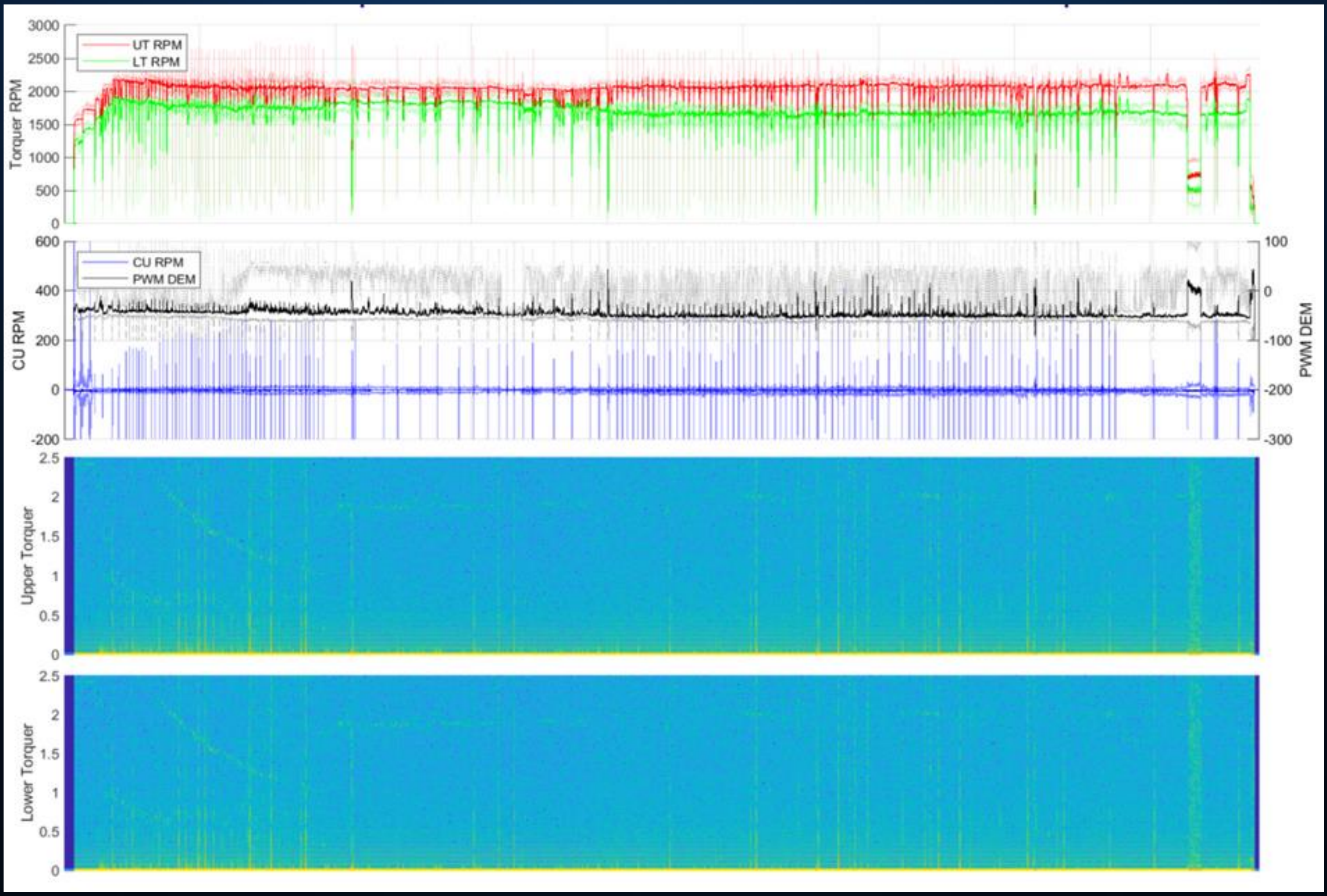
STICKSLIP AT BIT

This log shows increasingly severe bit stickslip, as CC_RPM in the top track grows erratic. The second plot shows the increase in standard deviation over time, correlating with higher peak RPM spikes. The distribution gets wider as well, with RPM of the bit frequently reaching 0 or even slightly negative. The spectrogram shows a low frequency fundamental frequency of roughly 0.2 Hz, which is a stickslip wave with a period from bit to surface of around 5 seconds, a common, but severe, first order mode vibration of the drill string.



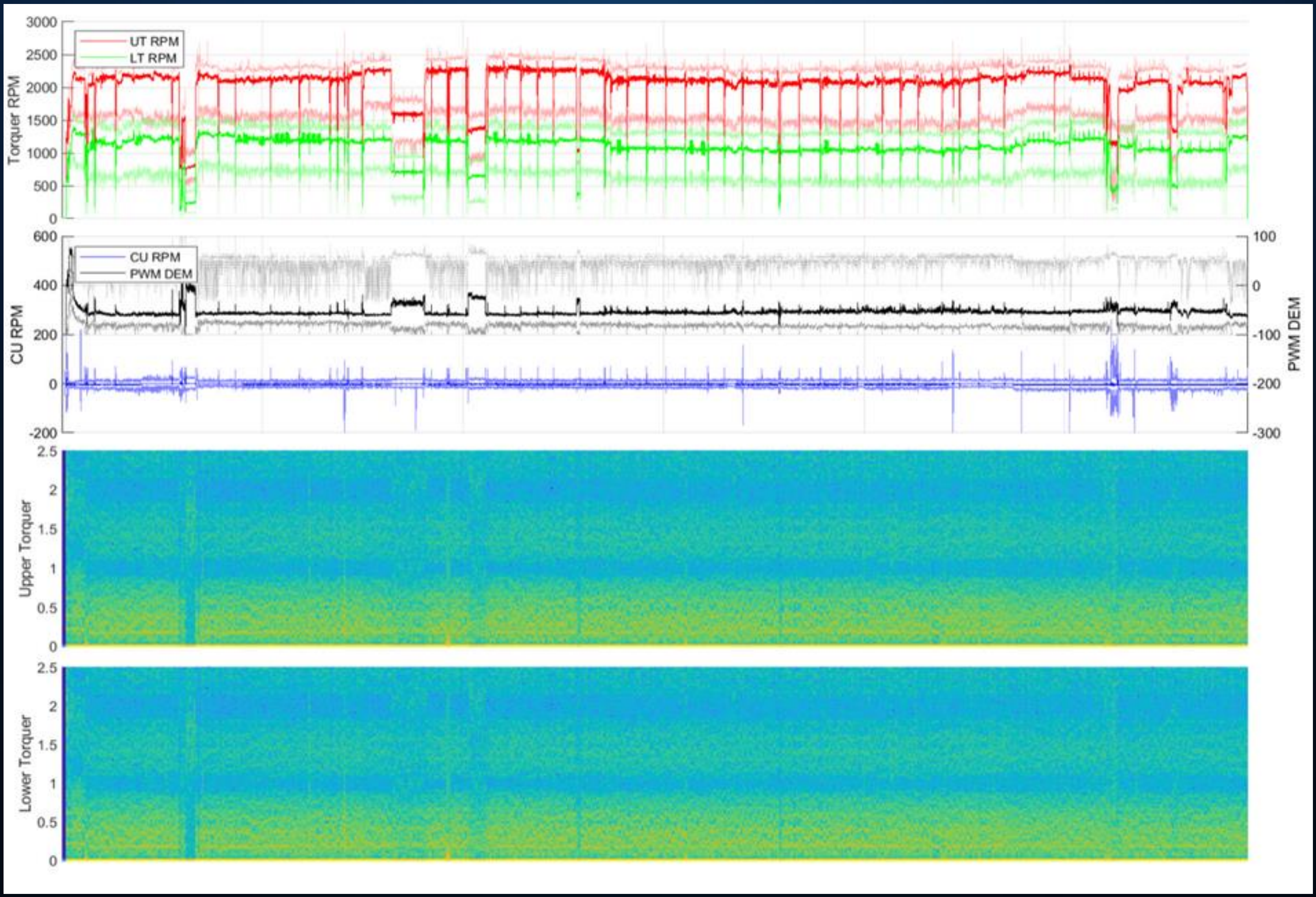
EM TELEMETRY

This log shows nearly no spread in torquer RPM envelope curves, indicating very smooth flow rate through the BHA. The frequency spectrograms do not show any MWD telemetry at all, which is understandable as this run used an EM telemetry tool and not a mud pulse system. The only harmonic present in the torquer is very low frequency drilling noise, typically due to variation in differential pressure as drilling progresses.



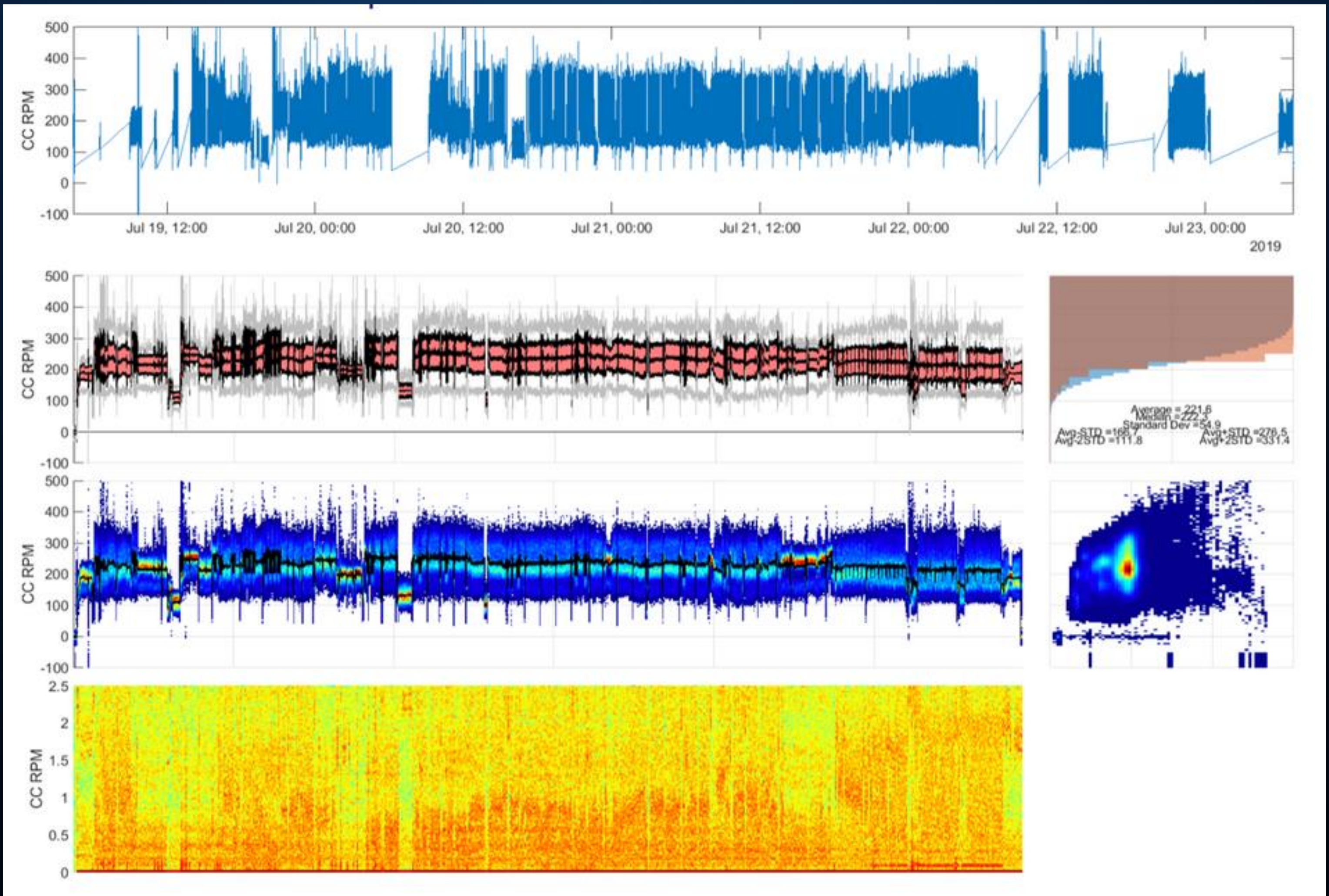
POSITIVE PULSE MWD - TORQUERS

In contrast, this log shows a wide spread in the torquer RPM envelopes, and the frequency content is characteristic of a combinatorial positive pulse MWD tool, with high pulse amplitude but no carrier frequency. Interestingly, these harmonics from the MWD tool are also apparent in the collar RPM, indicating the flow rate changes induced by the MWD pulses are affecting motor RPM output.



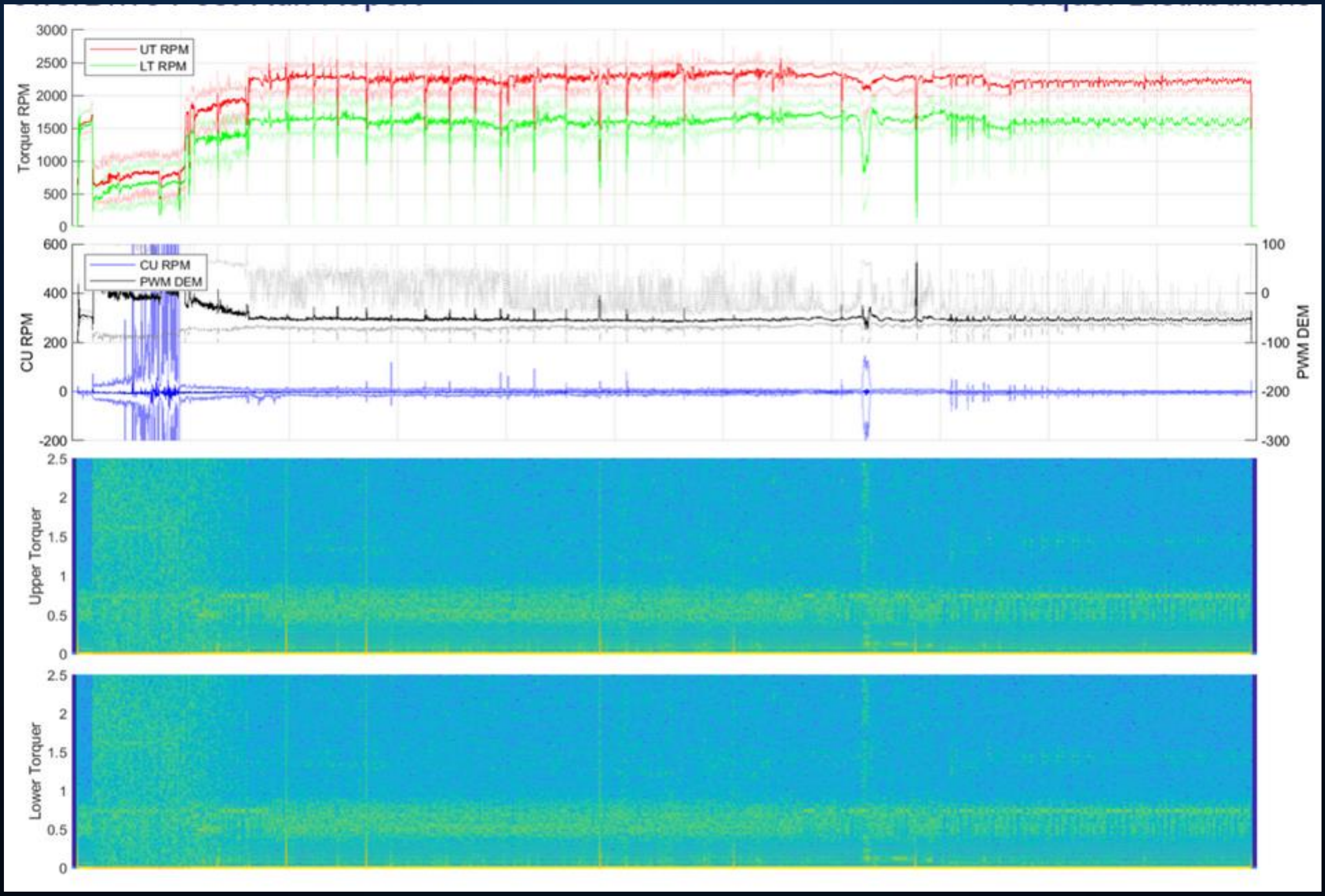
POSITIVE PULSE MWD - RPM

In this same data set, the frequency content of the torquer RPM (flow rate) and the motor RPM (also proportional to flow rate) suggests this pulse amplitude is enough to induce its own dynamics on the BHA below the motor. This can cause significant drilling dysfunction if the pulse is severe enough, especially in small holes sizes with low flow rate, which can stress motor transmissions, stators, and BHA components: see log on next page.



CONTINUOUS WAVE MWD – SLIMPULSE

This log shows the signature defined bandwidth of continuous wave (siren) MWD telemetry from a SlimPulse tool. The start of the run shows low signal amplitude and broadband noise in the torquer RPM due to low flow rate, but once flow is staged up, signal appears strong. This is very useful for determining if downhole signal amplitude is diminishing due to a tool issue, or if a surface system configuration is affecting detection of an otherwise strong signal.



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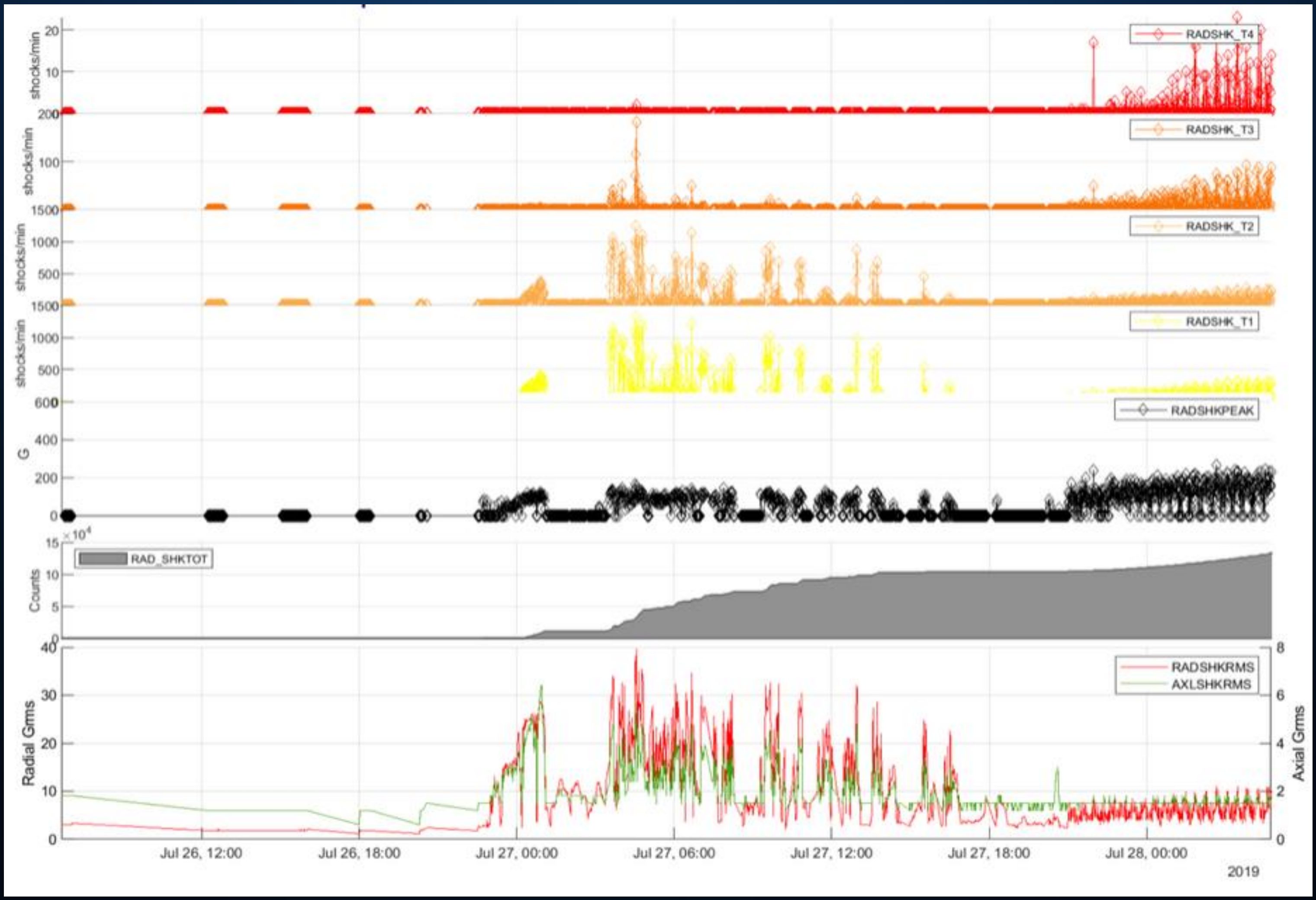
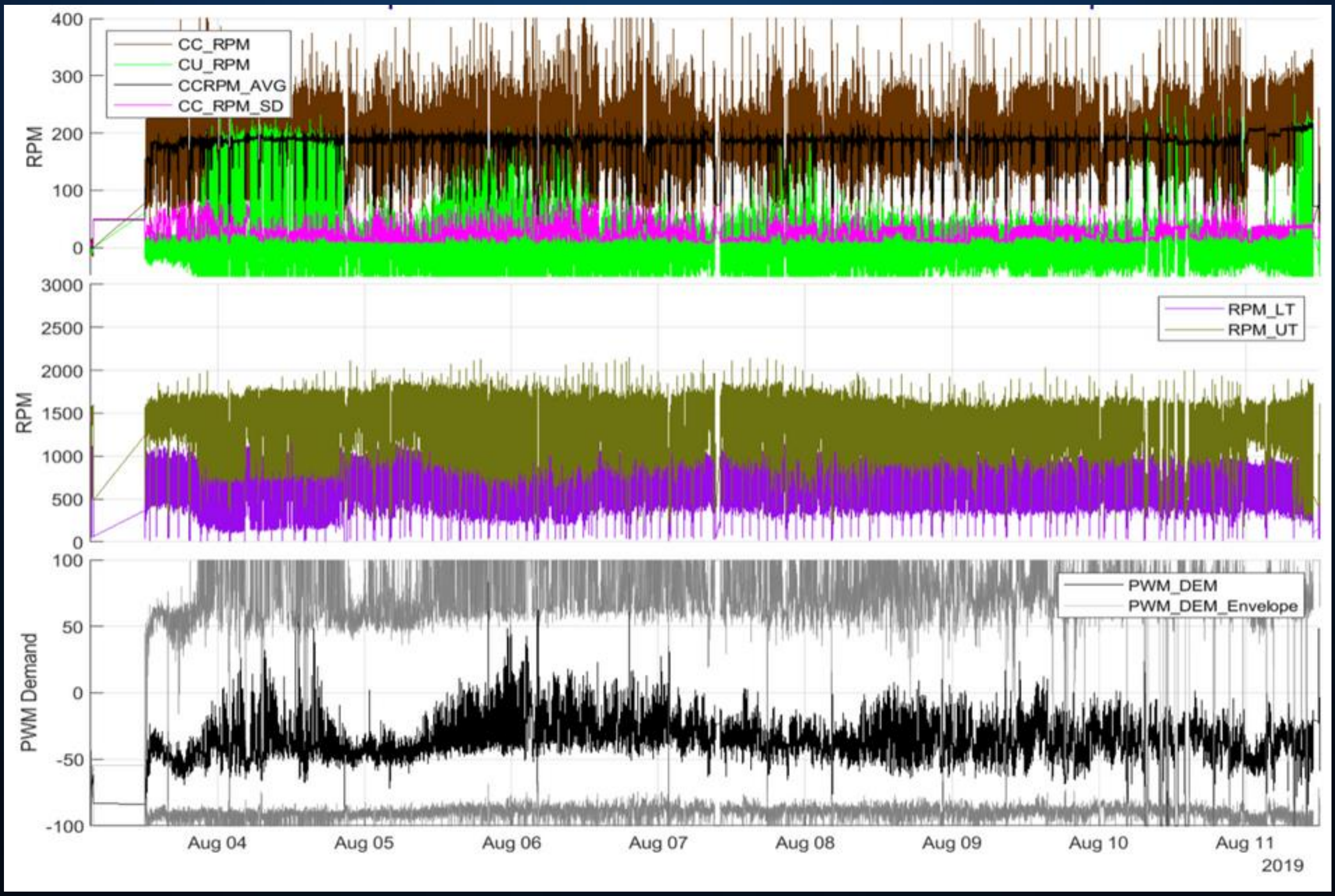
SHOCK AND VIBRATION – CLEANUP CYCLE

This log illustrates the increased severity of shock counts while off bottom reciprocating pipe. Each stroke of the pipe shows an increase and decrease in shock as the drill string moves between tension and compression. The shock amplitude grows as the cleanup cycle progresses, indicating reduction in the cuttings bed and increased freedom of movement, this could also be due to hole enlargement as well.



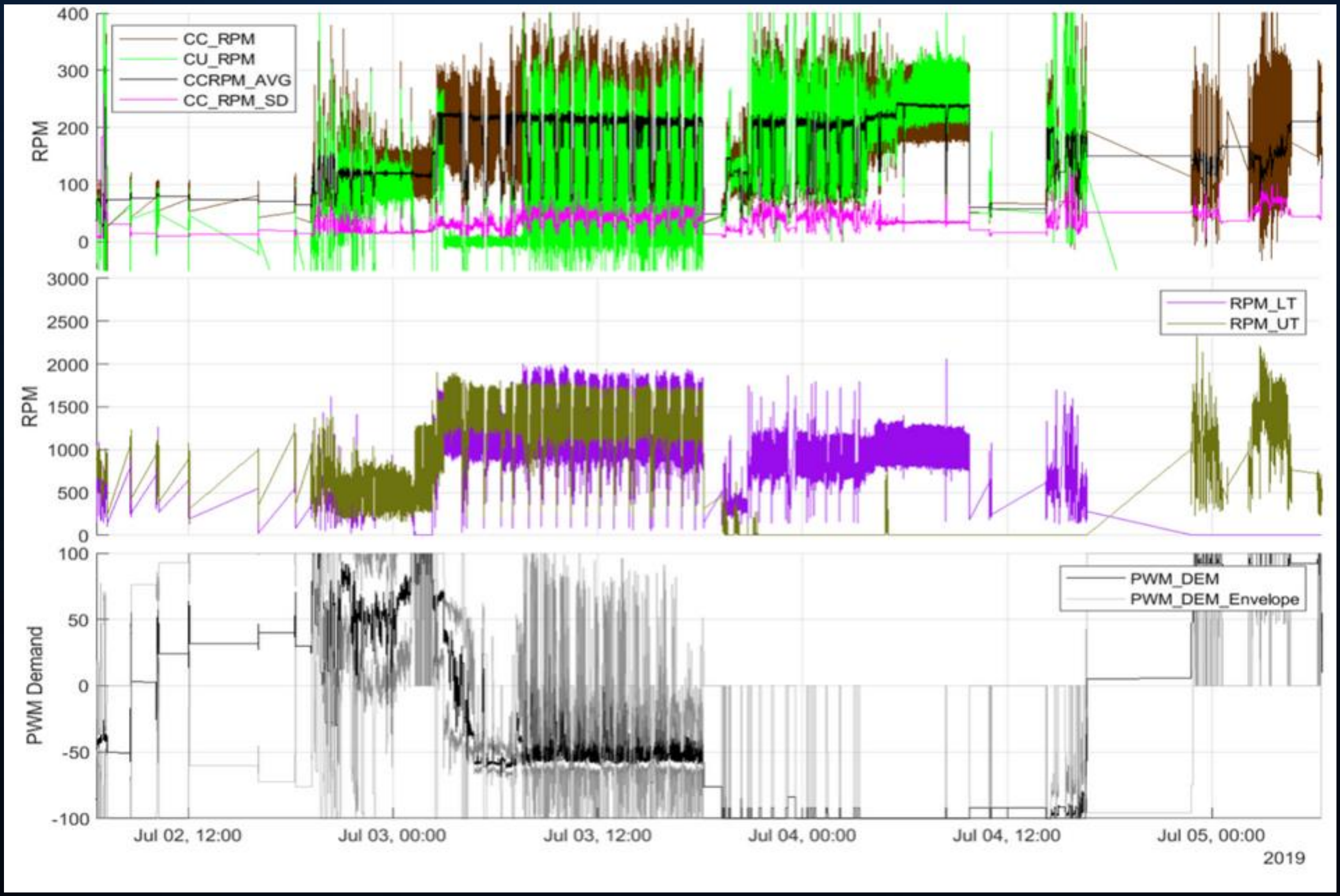
INTERMITTENT TORQUER FRICTION

In this case, torquer friction comes and goes on the run, becoming extreme in the first couple days of the run. Control unit RPM (CU_RPM, green) becomes very erratic, both torquers RPM is erratic, and PWM bounces from -100 to +100%, indicating significant torquer friction on the run.



JAMMED TORQUER – UPPER THEN LOWER

This log shows a case where debris in the mud caused rapid jamming of the upper torquer, visible in the center plot when the upper torquer RPM goes to zero (RPM_UT, grey) while the lower torquer continues spinning (RPM_LT, purple). During the period where the upper torquer is jammed, the control unit (CU_RPM, green) spins clockwise roughly with collar RPM, suggesting debris is locking the CU to the collar and stopping the upper torquer entirely. This eventually switches, as after a few pump cycles the debris moves down to the lower torquer, causing it to jam to the CU and leading the control unit to spin counterclockwise, and CU_RPM goes negative off the bottom of the page. Torque demand, in the bottom track, goes negative while the upper is jammed (PWM_DEM, black) and positive when the lower is jammed. This is correct operation of the tool as it attempts to counteract the friction from the debris. This illustrates debris moving through the tool, first appearing at the upper, then at the lower torquer.



CHANGE LOG

CHANGE	DATE	CHANGE BY
Initial draft	**7-Aug-19**	**WBlackman**
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Grammatical changes and more explanation on page 12 plot	**16-Aug-19**	**WBlackman**