Williwaw Engineering

September 1, 2015

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Subject: August 2015 Monthly Report – RCUH P.O. #Z10066105

Dear Luis,

The following constitutes my monthly report for the subject agreement for services associated with August 2015.

Work Completed under Task 3: Support HNEI in Device Performance Data Collection Throughout Development:

- Monitored the device regularly via remote connection to the NWEI host PC in Room 106, Battery French. Downloaded data from PC as necessary, and updated device control settings when necessary. See Attachment 1 for August 2015 Azura power performance data plots.

- Implemented automatic downloads of NWEI Offshore CompactRIO log files to the host PC. These files record the device control configuration for every 30 minute period. Previously these files were downloaded manually.

- Analyzed Azura float angle data using MATLAB to produce plots of 30 minute average float angle data for the deployment period. The data indicates that the Azura hull is ballasted slightly low now but probably doesn't need re-ballasting yet. It continues to settle very slowly in the water. See Attachment 2 for a plot of this data.

- Analyzed Azura power output data, control logs, and wave buoy data to create plots of output power versus hydraulic motor displacement control setting in each H_{m0} and T_e bin. See Attachment 3 for these results.

- Analyzed NREL six degree of motion data, NWEI float angle data, and Waverider data to plot Response Amplitude Operators (RAOs) that show the frequency response of the Azura hull heave, pitch, roll, and float angle with respect to the wave spectra. These results are shown in Attachment 4.

- A comparison was made between energy period (T_e) and significant wave height (H_{m0}) data that recently became available from the http://cdip.ucsd.edu web site and data calculated from wave spectra records in LabVIEW. The results showed that the Te data is identical but there is a small discrepancy in Hm0 data that will be investigated further.

Please let me know if you have any questions or comments concerning this project.

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Sincerely,

Terry Lettenmaier

Attachment 1: Azura power performance data plots for August 2015

Attachment 2: Azura 30 minute average float angle data plots

Attachment 3: Azura output power versus hydraulic motor displacement plots

Attachment 4: Azura Response Amplitude Operator analysis

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Attachment 1

Azura power performance data plots for August 2015

Summary

- Plots of August 2015 data only are shown on Slides 2-8
- Plots of cumulative data for the entire deployment period June-August 2015 are shown on Slides 9-15
- Azura was operated (output connected to grid) for approximately 687 hours in August (approximately 92% of month). Most of the down time occurred after the system shut down during momentary grid power losses of the inverters. The system requires manual re-start after these events.
- Device operation was continued throughout August the same as in July, cycling between six different constant hydraulic motor displacement settings
    - Settings changed every 30 minutes
    - Constant displacement control is the simplest method possible and is expected to be useful for comparison to computer model results.

Azura Power Performance
Monthly Data August 2015

Azura Power Performance – August 2015

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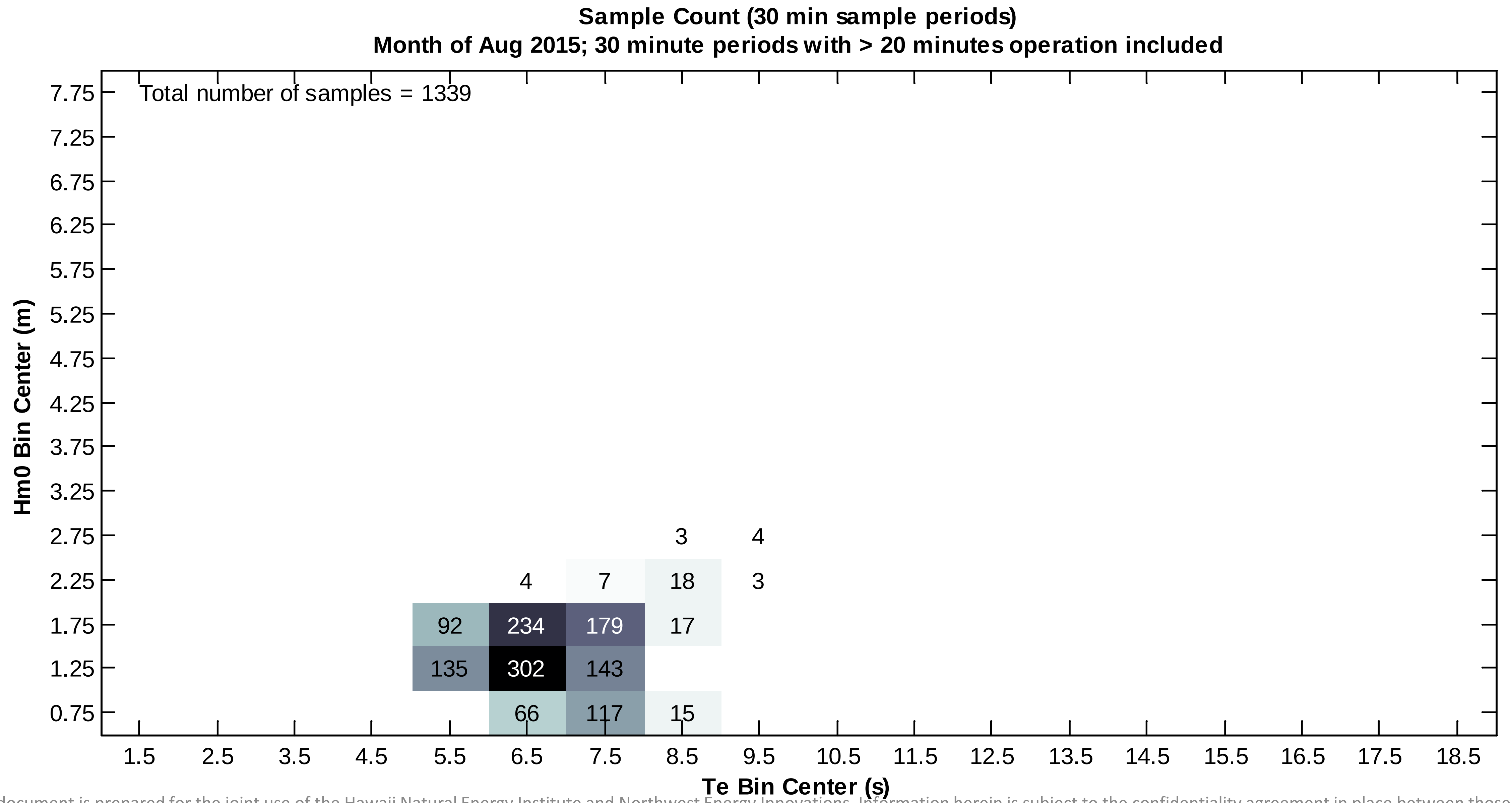
Data samples collected



Azura Power Performance – August 2015

Mean power matrix

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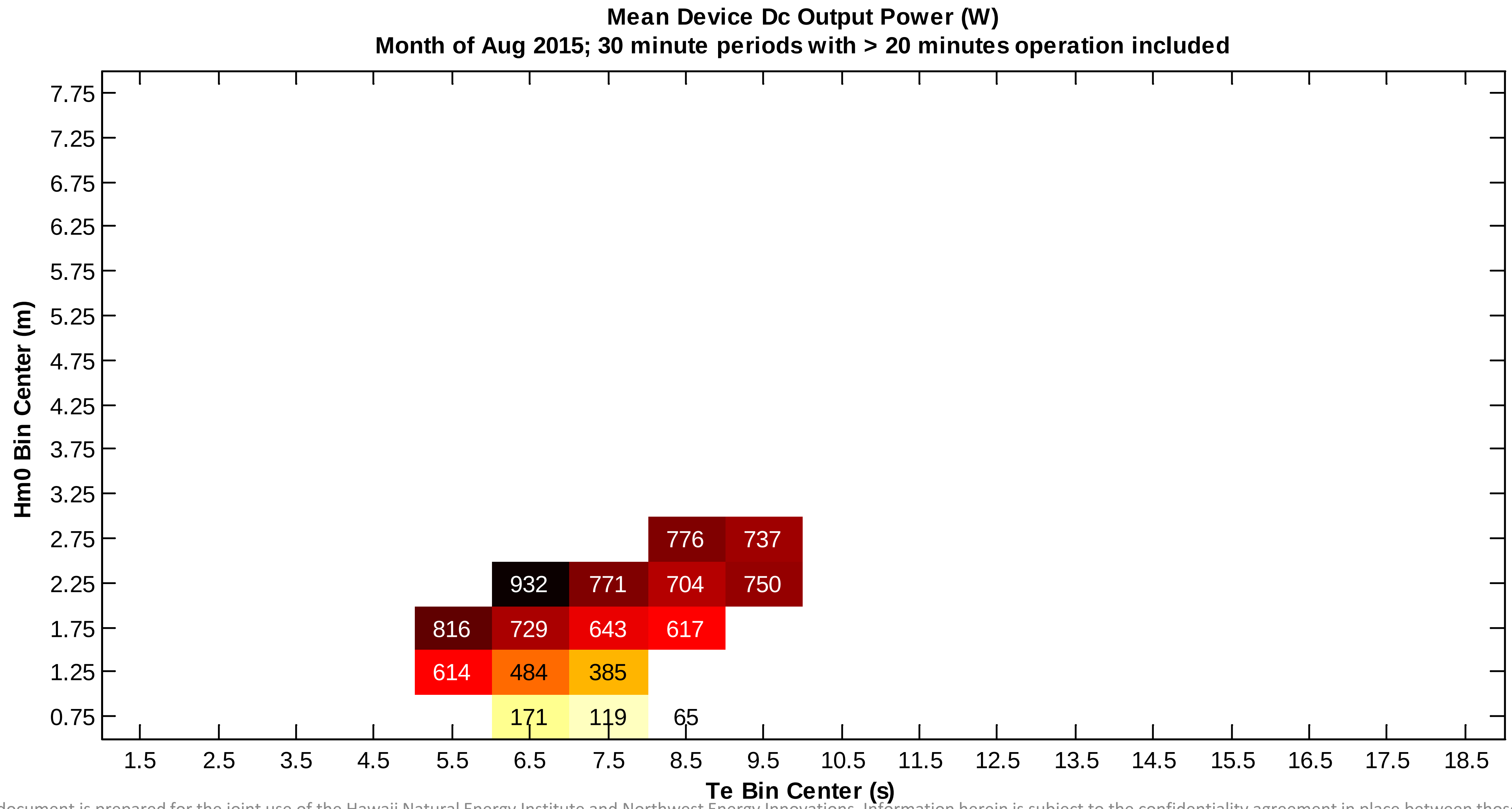

Azura Power Performance – August 2015

95th percentile power matrix

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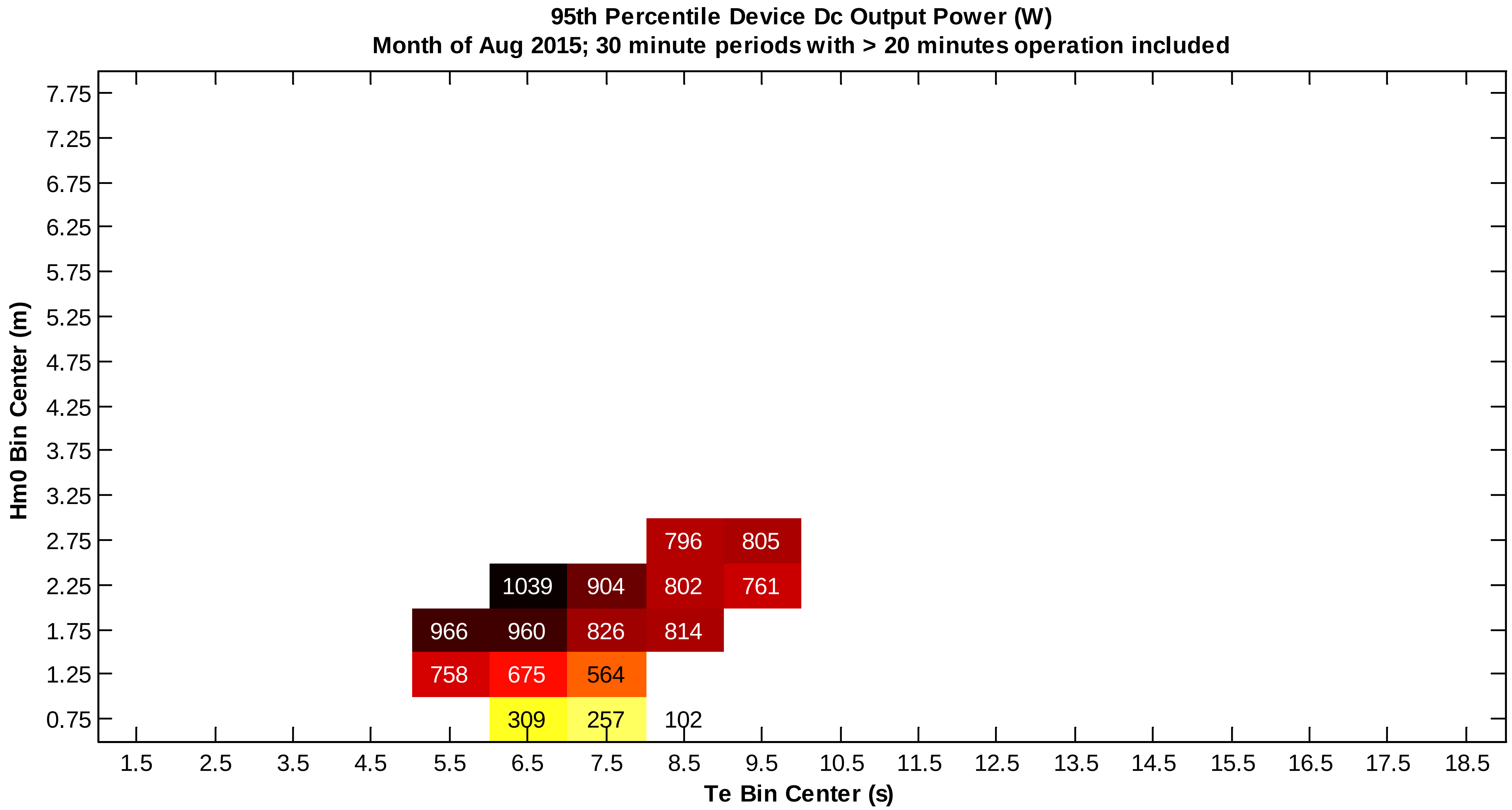

Azura Power Performance – August 2015

Standard deviation of power matrix

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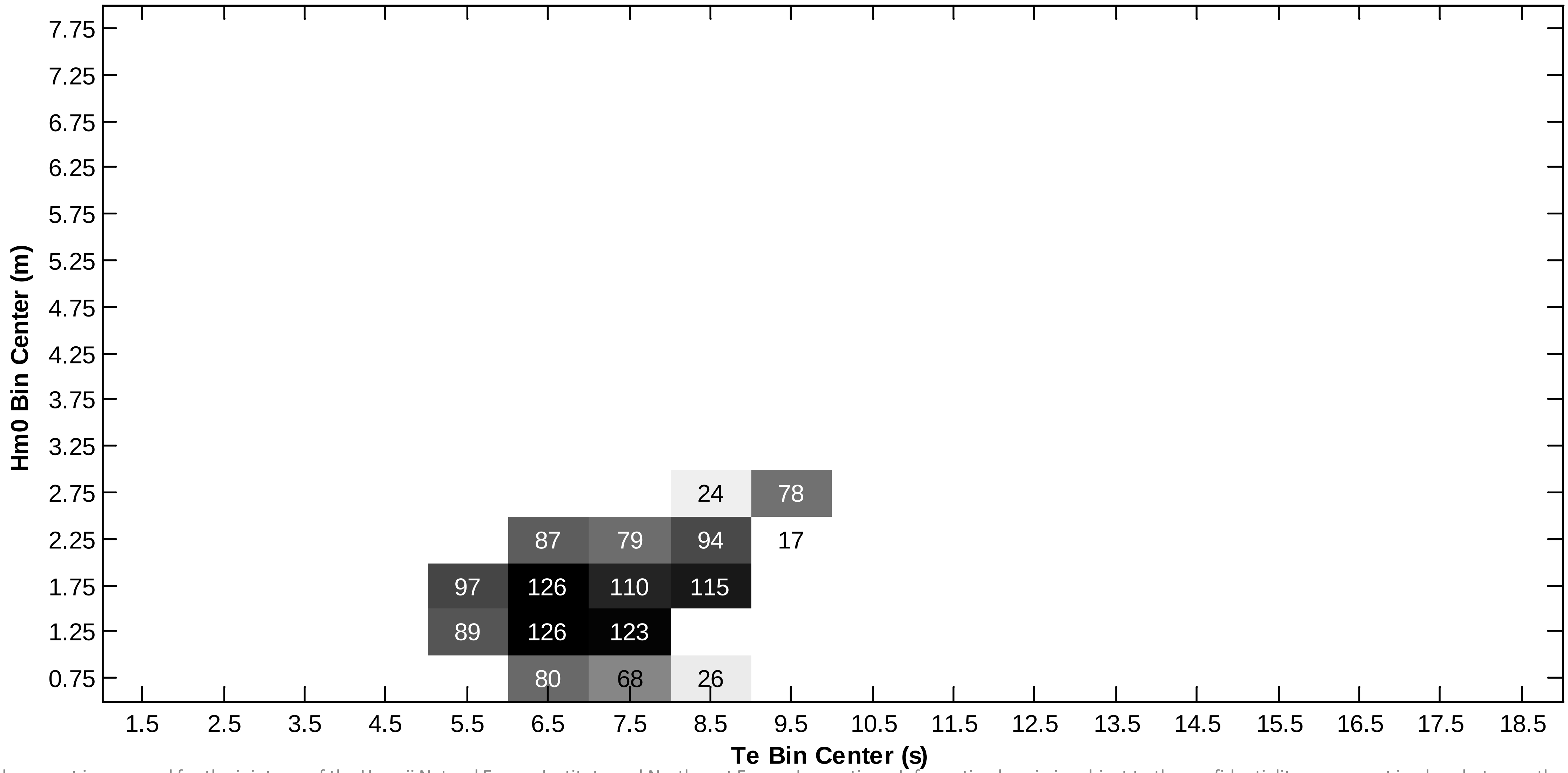
Standard Deviation of Device Dc Output Power (W)
Month of Aug 2015; 30 minute periods with > 20 minutes operation included



Azura Power Performance – August 2015

Mean capture length matrix

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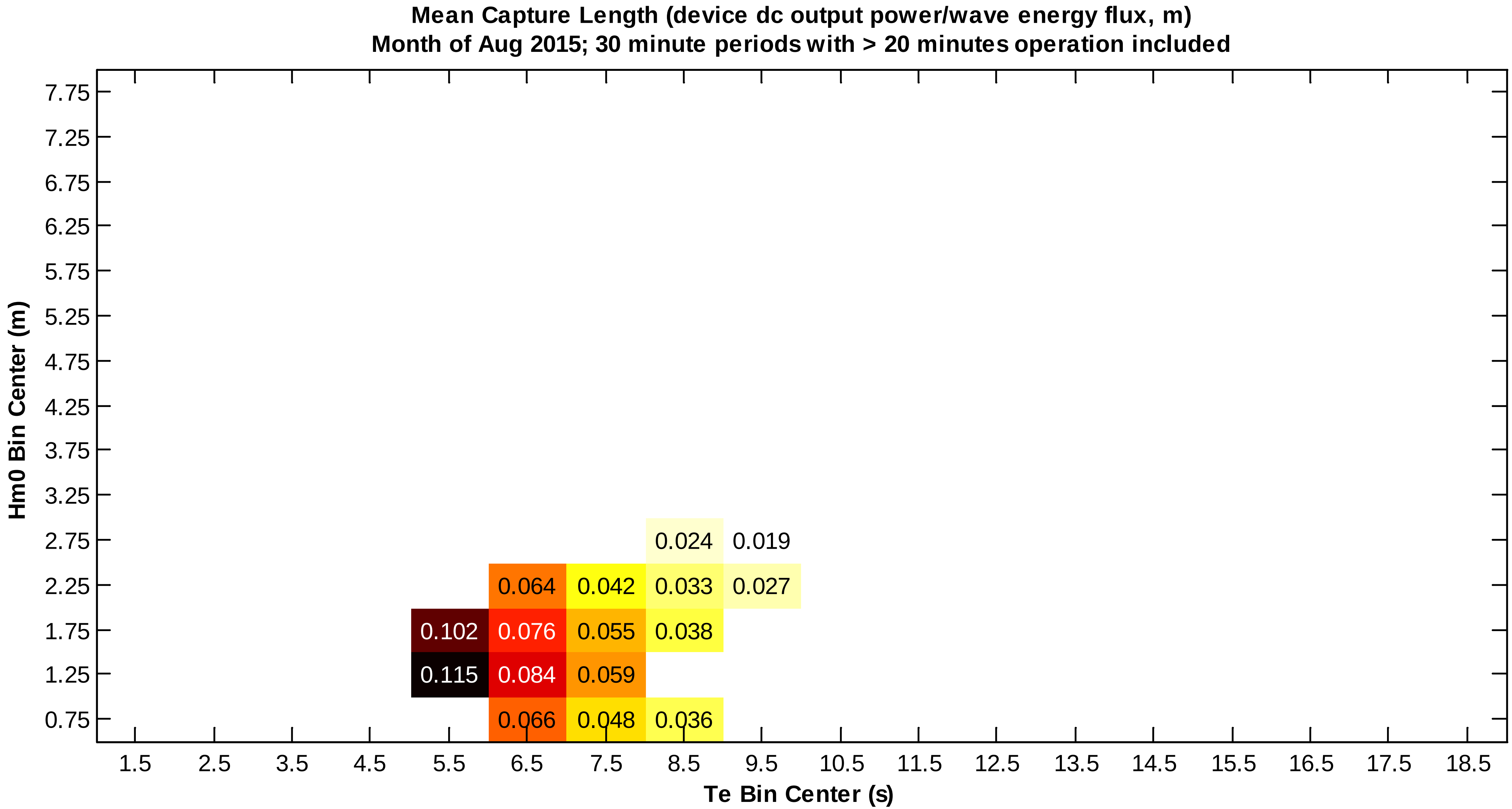

Azura Power Performance – August 2015

Standard deviation of capture length matrix

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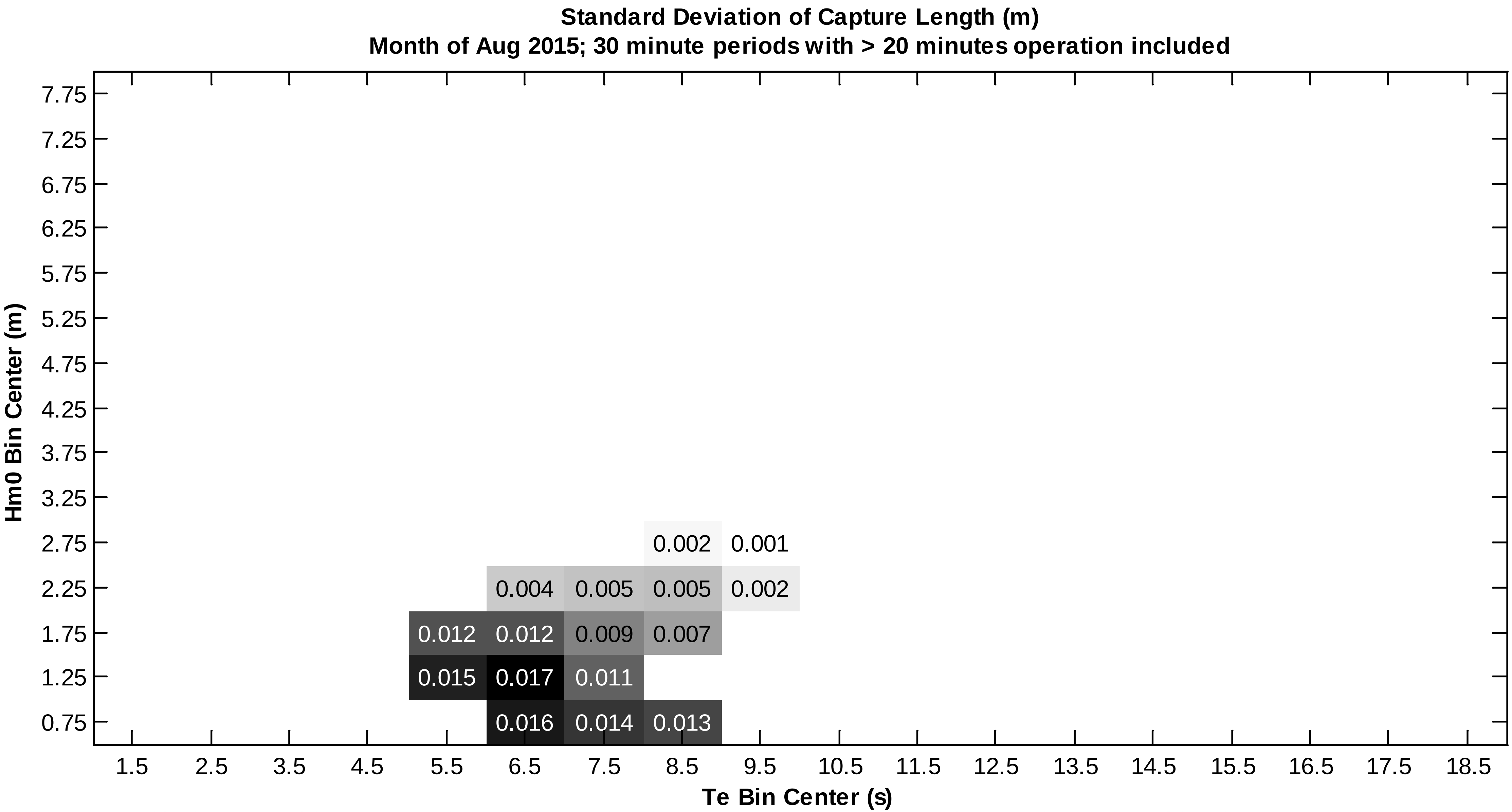

Azura Power Performance
Cumulative Data June - August 2015

Azura Power Performance – June-August 2015

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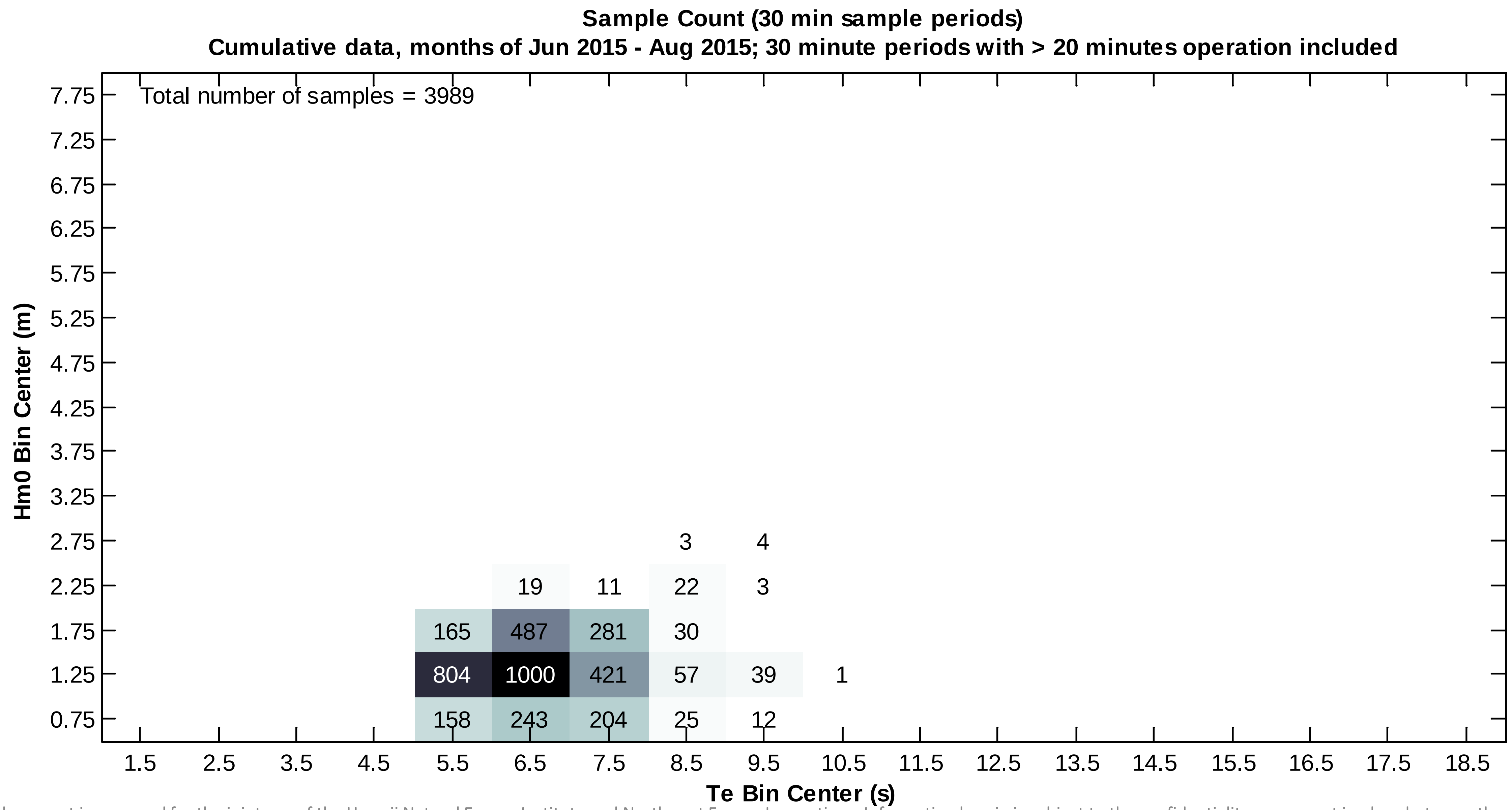
Data samples collected



Azura Power Performance – June-August 2015

Mean power matrix

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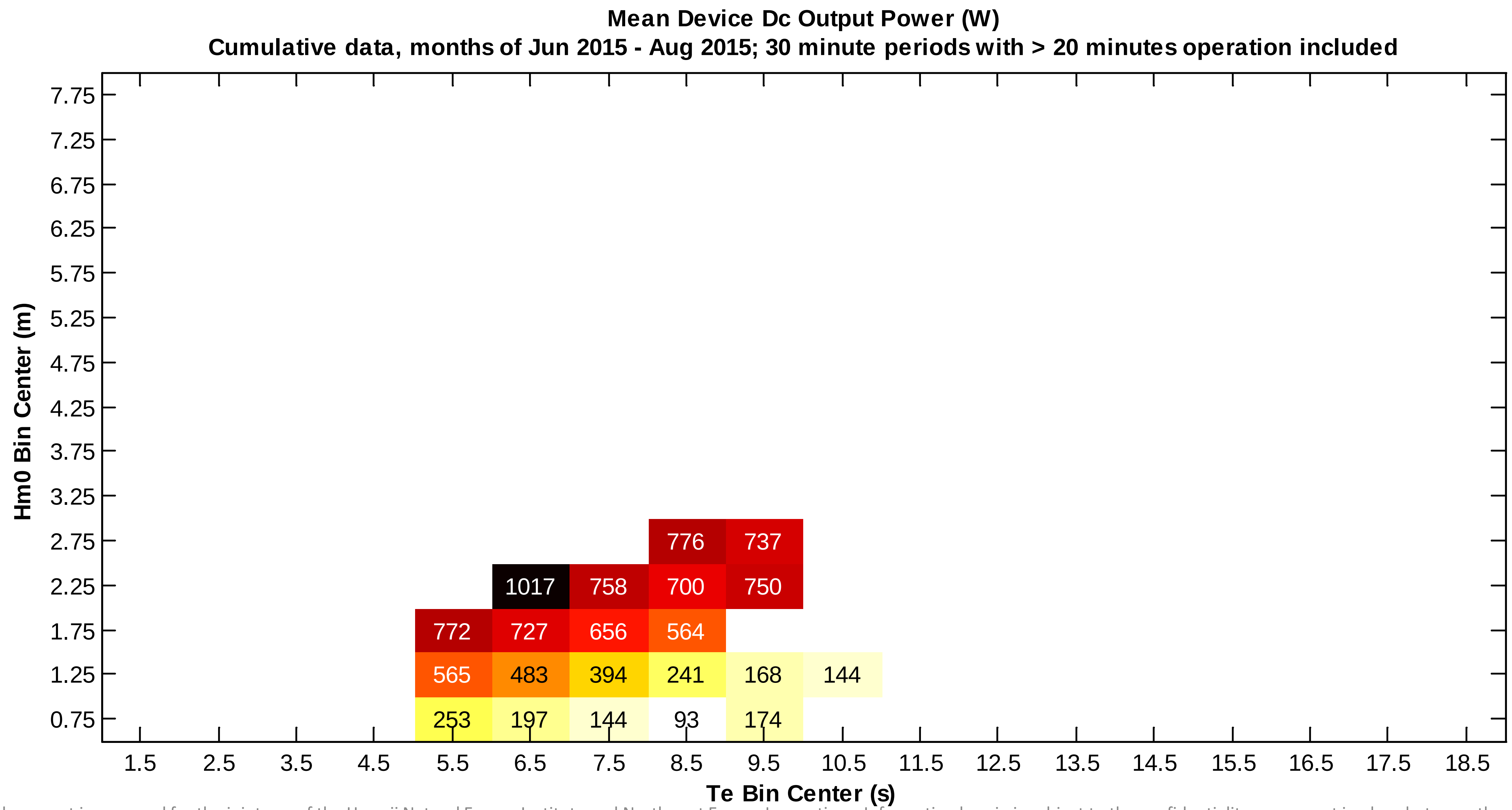

Azura Power Performance – June-August 2015

95th percentile power matrix

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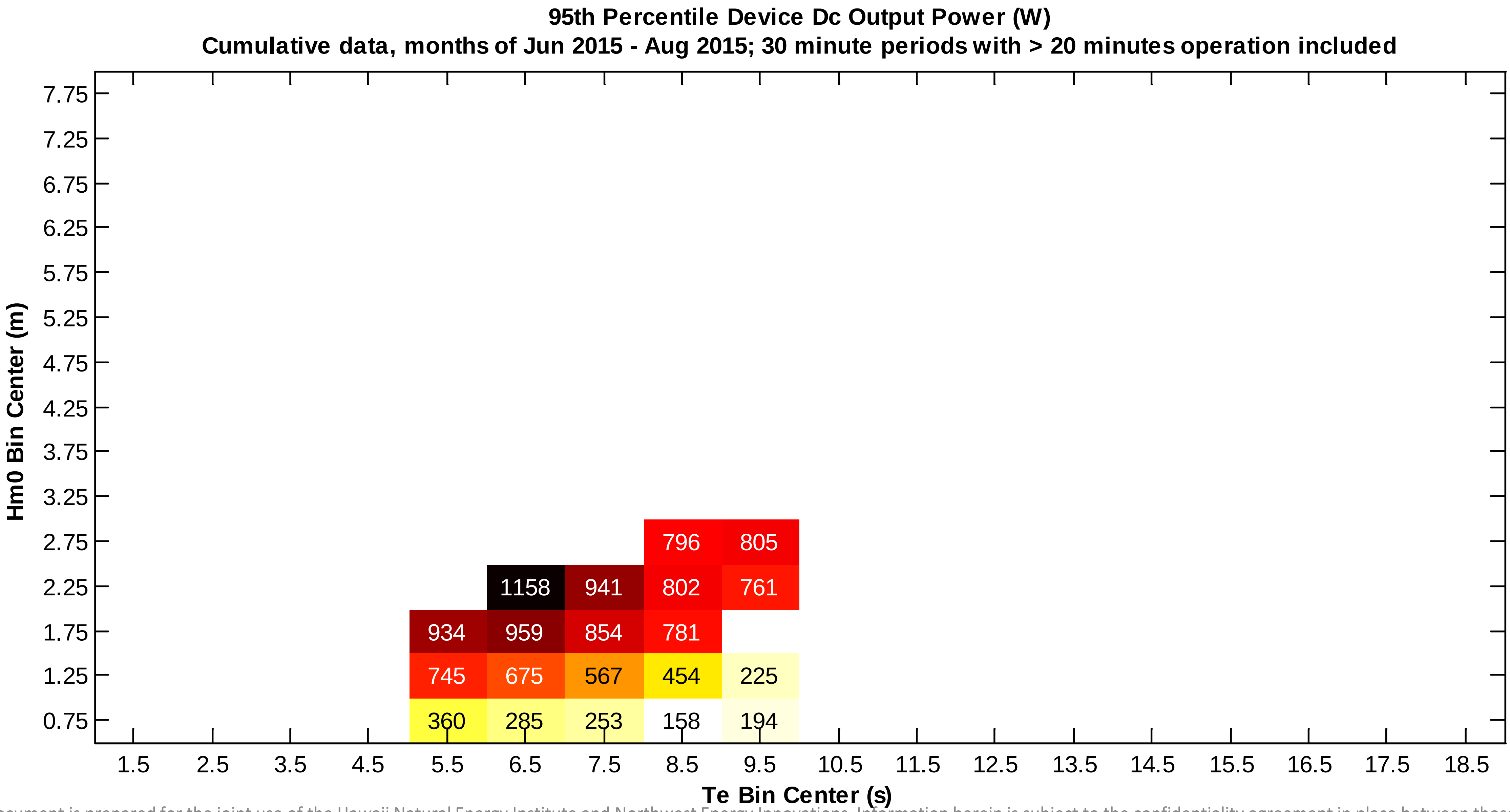
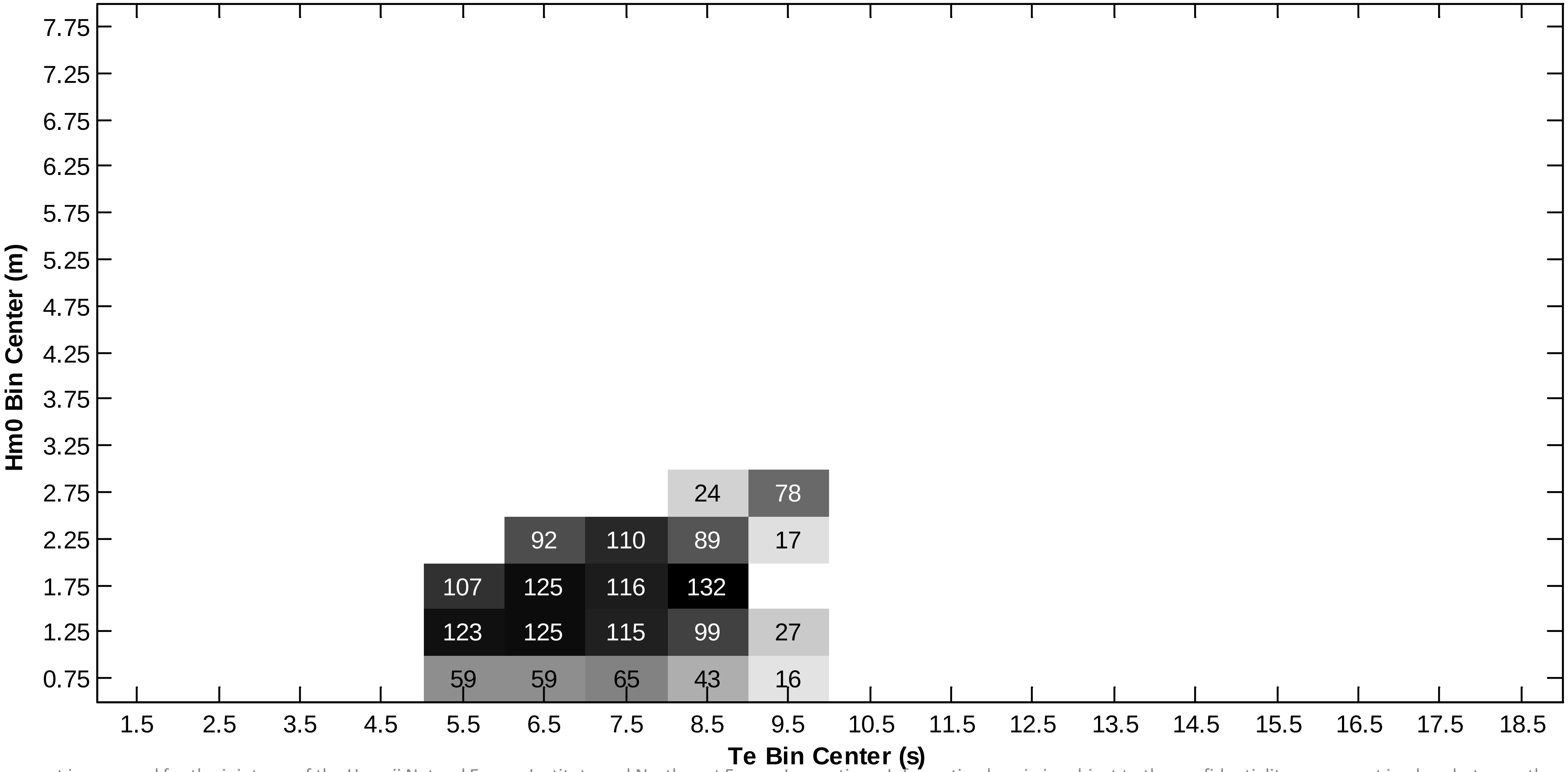


Azura Power Performance – June-August 2015

Standard deviation of power matrix

Standard Deviation of Device Dc Output Power (W)
Cumulative data, months of Jun 2015 - Aug 2015; 30 minute periods with > 20 minutes operation included



Azura Power Performance – June-August 2015

Mean capture length matrix

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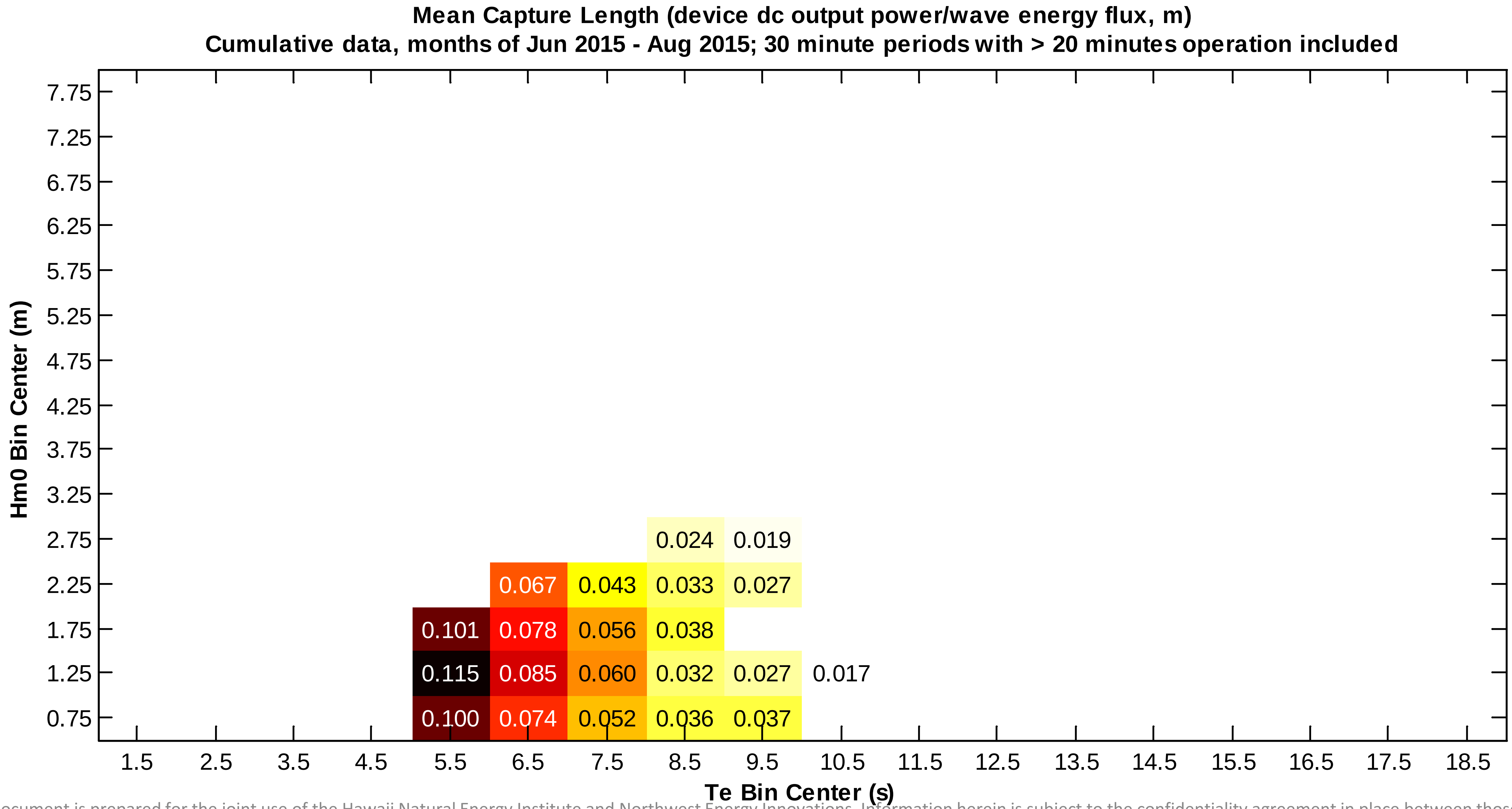

Azura Power Performance – June-August 2015

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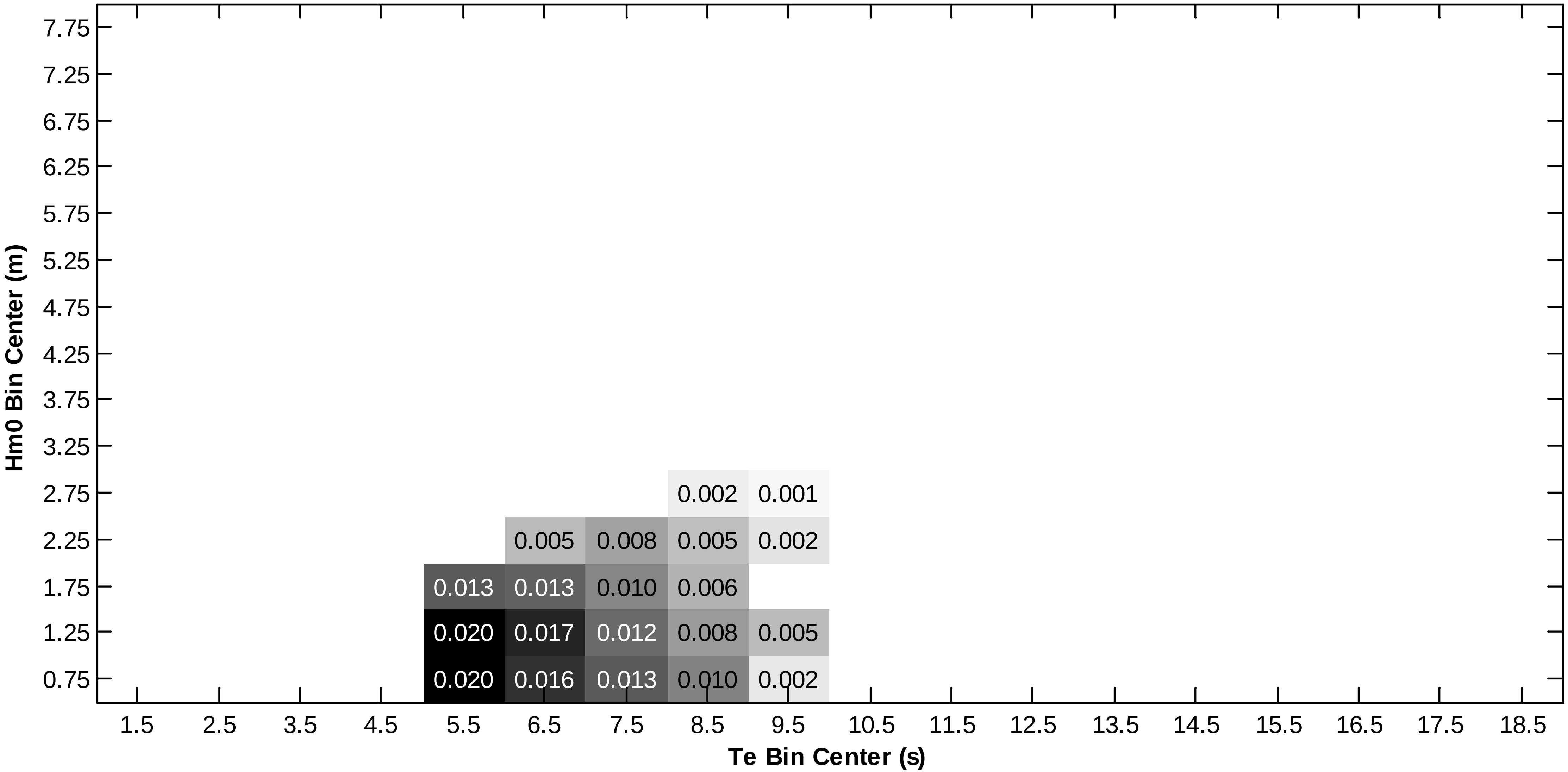
Standard deviation of capture length matrix

Standard Deviation of Capture Length (m)

Cumulative data, months of Jun 2015 - Aug 2015; 30 minute periods with > 20 minutes operation included



Attachment 2

Azura 30 minute average float angle data plots

Azura 30 min average float angle data through Aug 31

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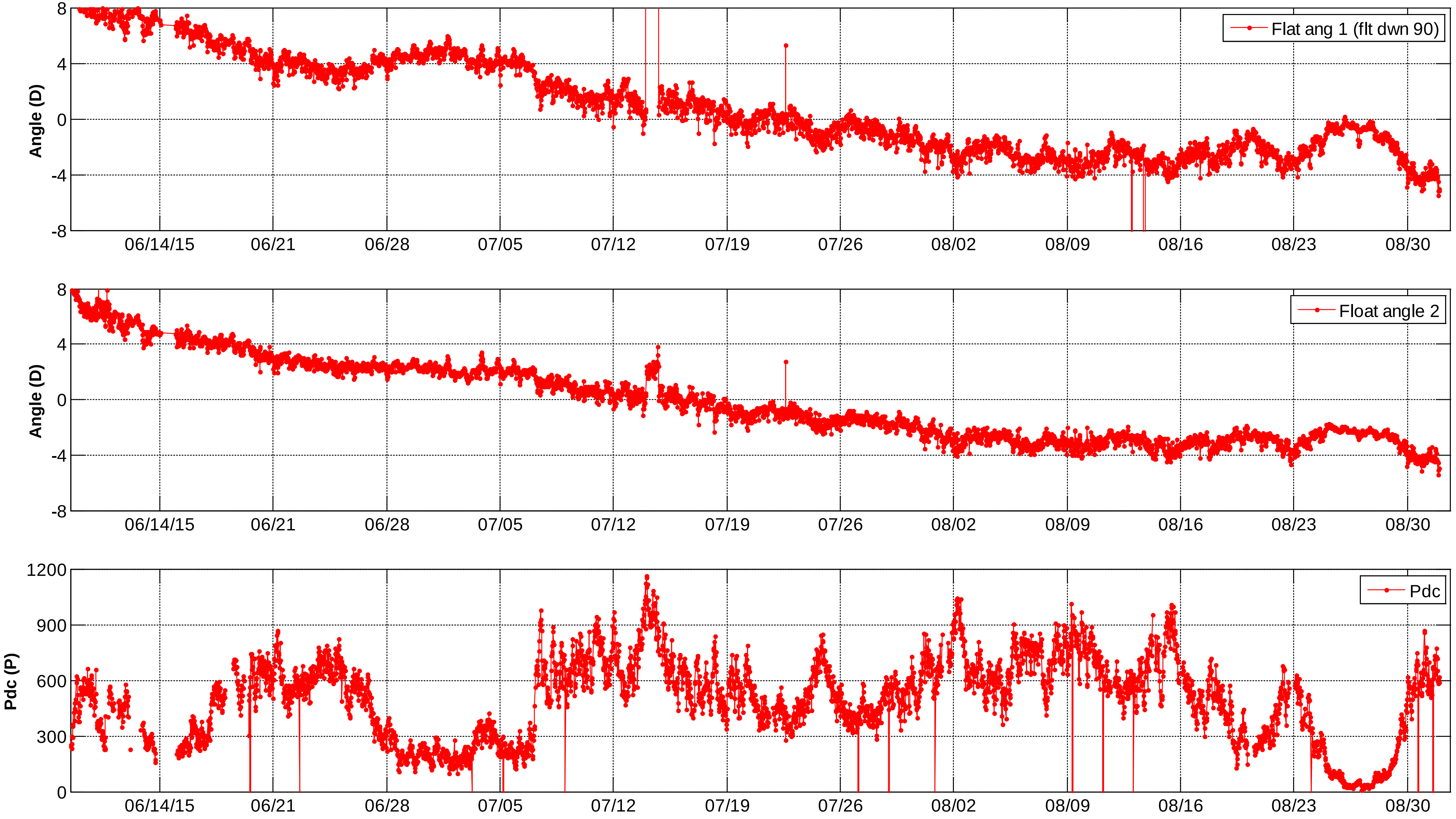
Float angle plots from file NWEI 30m avg power w float angle 201506 to 201508.txt



Attachment 3

Azura output power versus hydraulic motor displacement plots

Azura output power vs motor displacement

Data with Rdc_inv=20Ω June 1-Aug 11

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Notes:

- The Azura has been operated with the CompactRIO (cRIO) controller configured for constant hydraulic motor displacement since late June.
- In this control mode, the force applied to the float is changes inversely with motor displacement setting.
- Since early June, the cRIO controller has been configured to repeatedly alternate between six different motor displacement settings on a 30 minute basis: 30, 35, 45, 55, 65, and 80 cc/rev. At 30 cc/rev the float is very heavily loaded and at 80 cc/rev the float is very lightly loaded.
- The force applied to the float at any motor displacement setting is also affected by the load resistance setting for the inverters Rdc_inv in the cRIO controller. Since June 10, that setting has been fixed at 20 Ω.
- On the following pages are plots of Azura output power versus motor displacement setting for times when Rdc_inv = 20 Ω. The plots are binned by significant wave height H_{m0} and energy period T_e (from wave buoy data), with a large number of bins used to reduce the effects of sea state on each plot.
- The results show a slight correlation between output power and motor displacement, but less than expected.

Azura output power vs motor displacement

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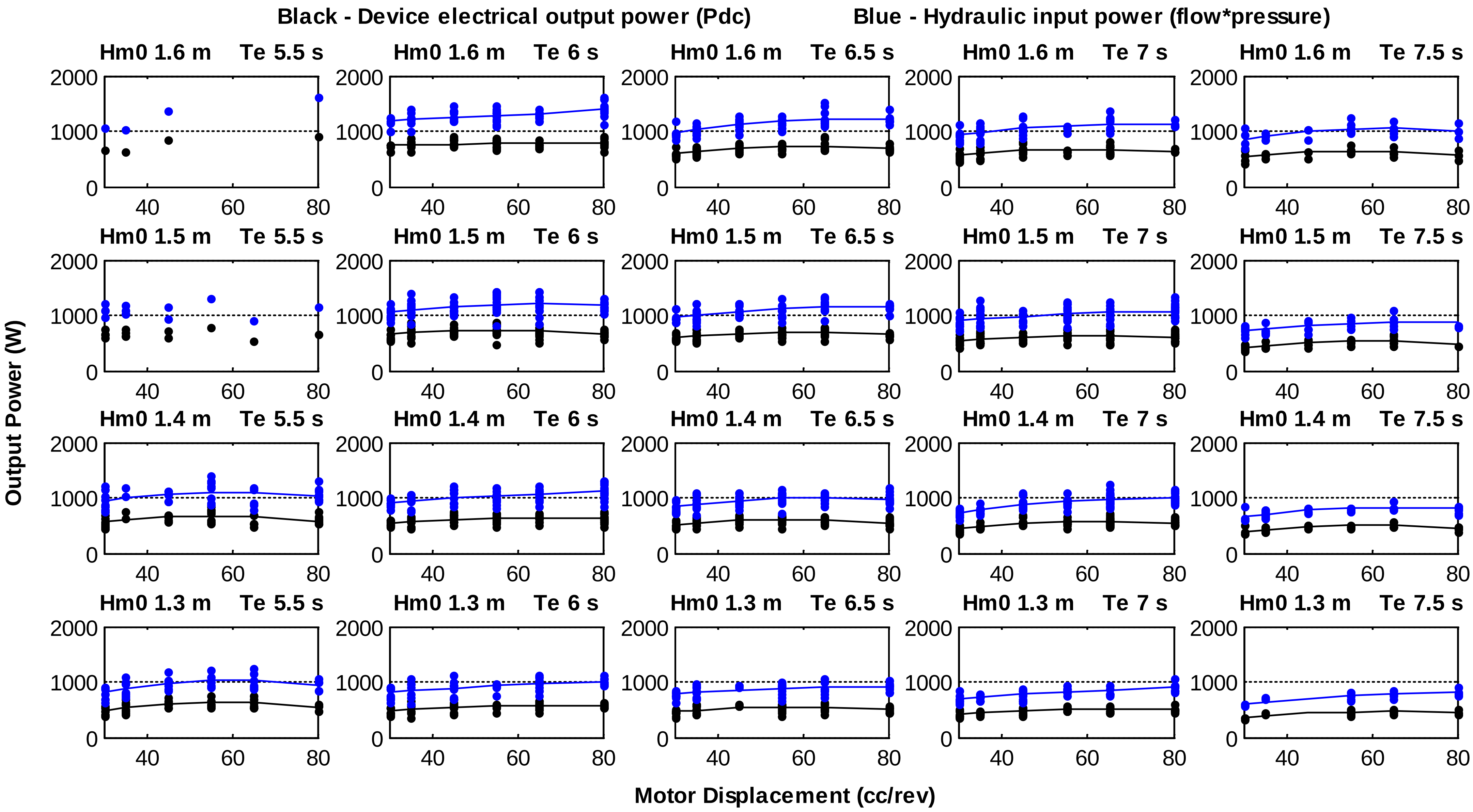
Data with Rdc_inv=20Ω June 1-Aug 11



Azura output power vs motor displacement

Data with Rdc_inv=20Ω June 1-Aug 11

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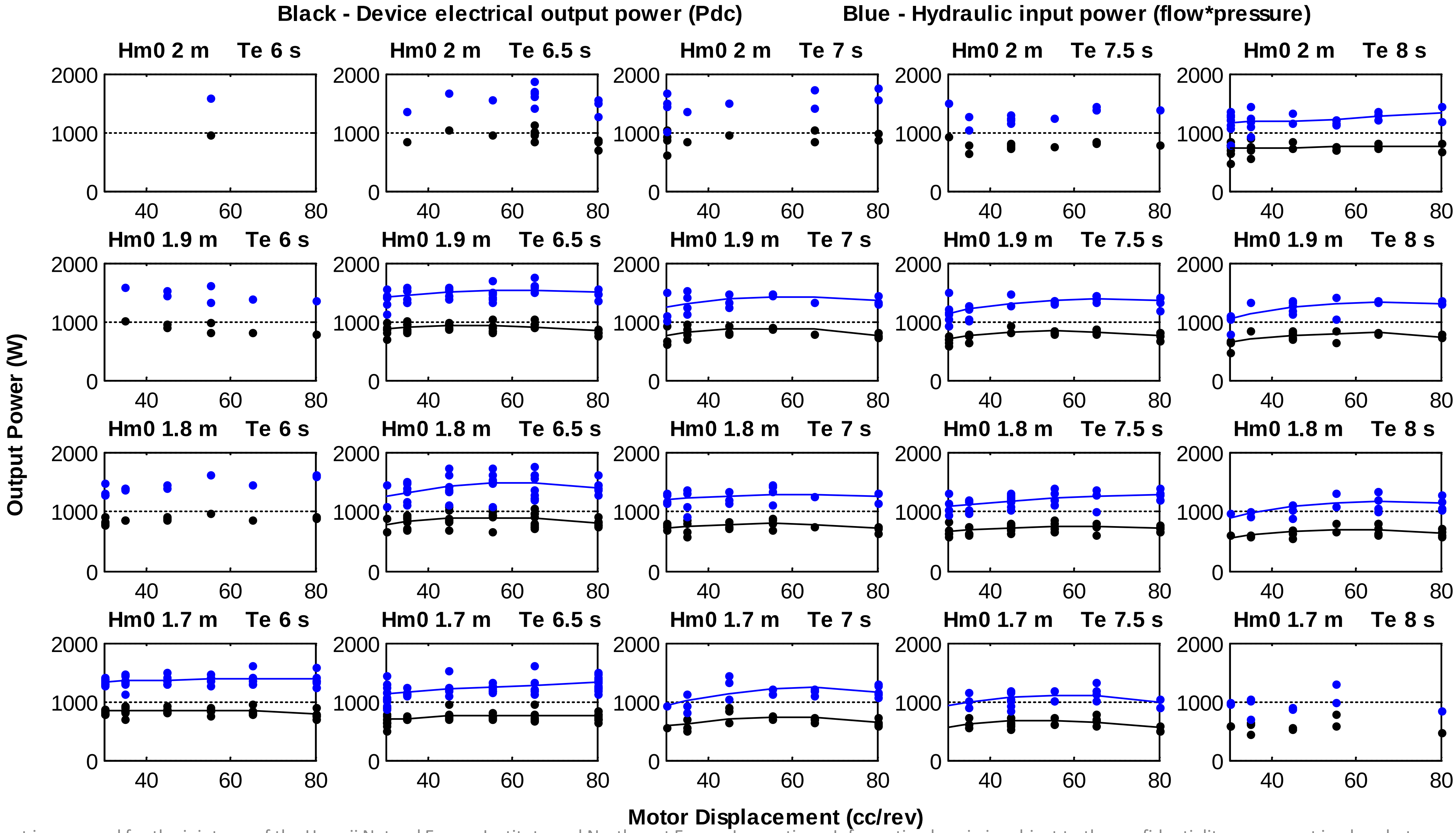

Attachment 4

Azura Response Amplitude Operator analysis

Azura Response Amplitude Operator (RAO) data analysis

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Notes:

- The Response Amplitude Operator (RAO) is defined as the modulus of H(ω) where:

$$|H(\omega)|^2 = \frac{S_{yy}(\omega)}{S_{xx}(\omega)}$$

$S_{yy}(\omega)$ is the wave spectrum at the device and $S_{yy}(\omega)$ is the measured response spectrum of device motion.

- RAOs were calculated for heave, pitch, roll, and float angle motions using data recorded on board the device and wave data recorded with the Kaneohe Bay Warerider buoy moored nearby.

- RAO spectra were calculated separately for six different PTO load settings of the Azura (hydraulic motor displacement settings; lower motor displacement gives larger PTO forces on the float).

- Each RAO spectra was calculated from the average of five different half-hour long data sets to smooth the spectra.

Data used

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Date_time	Op_min	Pdc_W	Pgen_W	Damping recorded	WR_DateTime	Te_s	Hm0_m	MotDisp	Rdc_inv
1.3m/5.5s									
20150730_0600	30	463	492	21.1	20150730_0606	5.56	1.42	30	20
20150730_0630	30	427	454	21.2	20150730_0636	5.56	1.34	35	20
20150730_0700	30	590	623	21.3	20150730_0706	5.7	1.32	45	20
20150730_0730	30	584	616	21.4	20150730_0736	5.61	1.22	55	20
20150730_0800	30	620	653	21.5	20150730_0806	5.65	1.33	65	20
20150730_0830	30	598	631	21.6	20150730_0836	5.59	1.35	80	20
1.3/6 s									
20150729_0600	30	468	497	21.1	20150729_0606	5.63	1.33	30	20
20150729_0630	30	472	501	21.2	20150729_0636	5.91	1.37	35	20
20150729_0700	30	559	590	21.3	20150729_0706	5.98	1.37	45	20
20150729_0730	30	575	606	21.4	20150729_0736	5.8	1.33	55	20
20150729_0800	30	583	615	21.5	20150729_0806	5.92	1.33	65	20
20150729_0830	30	633	667	21.6	20150729_0836	5.88	1.35	80	20
2m/6.5s									
20150714_0000	30	1052	1109	21.1	20150714_0006	6.79	2.02	30	20
20150714_0030	30	1161	1222	21.2	20150714_0036	6.93	2.16	35	20
20150714_0100	30	1154	1214	21.3	20150714_0106	6.76	2.15	45	20
20150714_0130	30	1102	1160	21.4	20150714_0136	6.78	2.1	55	20
20150714_0200	30	1120	1181	21.5	20150714_0206	6.71	2	65	20
20150714_0230	30	984	1039	21.6	20150714_0236	6.84	2.01	80	20
1.6m/7.5s									
20150807_1200	30	581	615	21.1	20150807_1206	7.59	1.64	30	20
20150807_1230	30	562	596	21.2	20150807_1236	7.67	1.65	35	20
20150807_1300	30	575	608	21.3	20150807_1306	7.63	1.67	45	20
20150807_1330	30	626	660	21.4	20150807_1336	7.51	1.69	55	20
20150807_1400	30	599	632	21.5	20150807_1406	7.61	1.75	65	20
20150807_1430	30	500	529	21.6	20150807_1436	7.55	1.67	80	20
2.5m/9s									
20150807_0000	30	764	810	21.1	20150807_0006	8.96	2.4	30	20
20150807_0030	30	713	756	21.2	20150807_0036	9.34	2.64	35	20
20150807_0100	30	805	851	21.3	20150807_0106	9.96	2.85	45	20
20150807_0130	30	792	837	21.4	20150807_0136	9.84	2.74	55	20
20150807_0200	30	750	794	21.5	20150807_0206	8.87	2.56	65	20
20150807_0230	30	796	843	21.6	20150807_0236	8.98	2.62	80	20

Notes:

- Pgen_W is measured at generator output
- Pdc_W is measured at device output and includes boost transformer & rectifier losses that may not be included in simulations.
- Te_s and Hm0_s are calculated from 30 m wave spectra; these spectra are shoaling corrections to the 80m Waverider spectral data (SP files) with half hour periods starting with WR_DateTime.
- RAO analysis was done with 1.28 Hz sampled wave elevation data from Waverider XY files. 30 min data periods starting at Date_time used. Wave spectra were calculated from time data and corrected for shoaling to 30m depth.

RAOs – average of 5 data sets

All data with Rdc_inv=20Ω June 1-Aug 11

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