Williwaw Engineering

December 1, 2015

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Honolulu, HI 96822

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

Dear Luis,

The following constitutes my monthly report for the subject agreement for services associated with November 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. Coordinated with team members during two events that occurred during the month of November:
    1. The loss of the AB subsurface float on Nov 16 and its retrieval
    2. Loss of hydraulic pressure on Nov 26

- Uploaded Azura data to the Department of Energy MHK repository as time permitted.

- Analyzed output power data to produce monthly power performance data plots; see Attachment 1 for results.

- Analyzed Azura float angle data using MATLAB to produce plots of 30 minute average float angle data for the deployment period. The Azura settled a little further in the water before it was re-ballasted by adding air to the hull tanks on Nov 23. The average float angle was very close to zero after re-ballasting. See Attachment 2 for results.

- Plotted daily humidity sensor data for the cRIO enclosure and drybox on board the Azura. The results continue to show that the drybox, which is entirely sealed from the Azura hull, has maintained very low humidity throughout the deployment period while humidity has slowly increased inside the cRIO enclosure since the June deployment. To date the humidity inside the cRIO enclosure is still well below levels that would cause condensing moisture and equipment damage. See Attachment 3 for a plot of these results.

- Analyzed data to compare performance of the Azura in terms of Relative Capture Width (RCW) with respect to wave frequency under the following conditions:
    1. Leading versus trailing float. See Attachment 4 for these results, which indicate that the RCW is about 10% higher with the float leading versus float trailing over a wide range of wave periods.

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2. Device heading. See Attachment 5 for these results, which indicated that RCW is about 10% higher when the device heading is very close to the wave direction than it is when wave direction is approximately 45 degrees different than the device heading.
3. AB subsurface float. See Attachment 6 for these results. These results show that the RCW was significantly lower after the AB float was no longer connected. These results may be misleading, however, because the hull was ballasted quite low when operating without the AB float and this may also have affected the Azura output.

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

Sincerely,

Terry Lettenmaier

Attachment 1: Azura power performance data plots

Attachment 2: Azura 30 minute average float angle data plots

Attachment 3: Azura cRIO enclosure and drybox humidity

Attachment 4: Azura Relative Capture Width (RCW) Comparison for Leading vs. Trailing Float

Attachment 5: Azura Relative Capture Width (RCW) Comparison for Different Wave Headings

Attachment 6: Azura Relative Capture Width (RCW) Comparison for AB Float

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Attachment 1

Azura power performance data plots

Azura Power Performance – November 2015

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Summary

- Plots of Nov 2015 data only are shown on Slides 2-8.
- Plots of cumulative data for the entire deployment period June-Nov 2015 are shown on Slides 9-15.
- Azura was operated (output connected to grid) for 586 hours in November (81% of month). Most of the down time was from November 26 through the end of the month when the device was not producing power after a hydraulic failure. A repair is planned in December.
- During about 50% of November, experimentation was carried out with proportional-integral (PI) control of hydraulic pressure per request from NWEI partner Energy Hydraulics Limited (EHL). Otherwise constant displacement control, as used in previous months, was in place. The PI control did not generally increase power output with respect to constant displacement control but allowed EHL to gain a better understanding of device operation.
- On November 16, the AB subsurface mooring float was lost from the mooring system. This float had been on the surface due to an installation problem, so while in place this float changed the surface wave loading on the mooring system. There are plans to re-install this float in December.

Azura Power Performance
Monthly Data November 2015

Azura Power Performance – November 2015

Data samples collected

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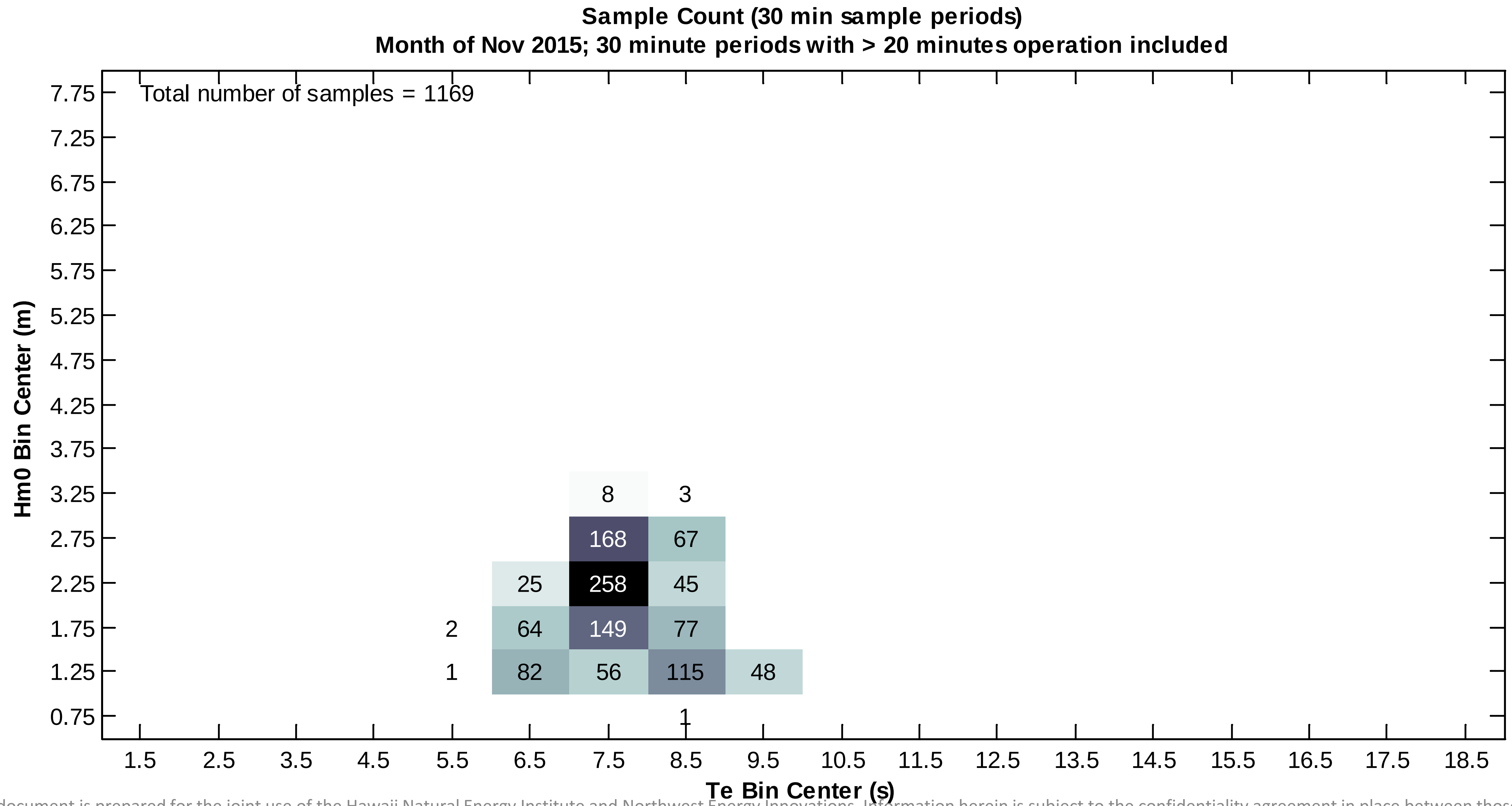

Azura Power Performance – November 2015

Mean power matrix

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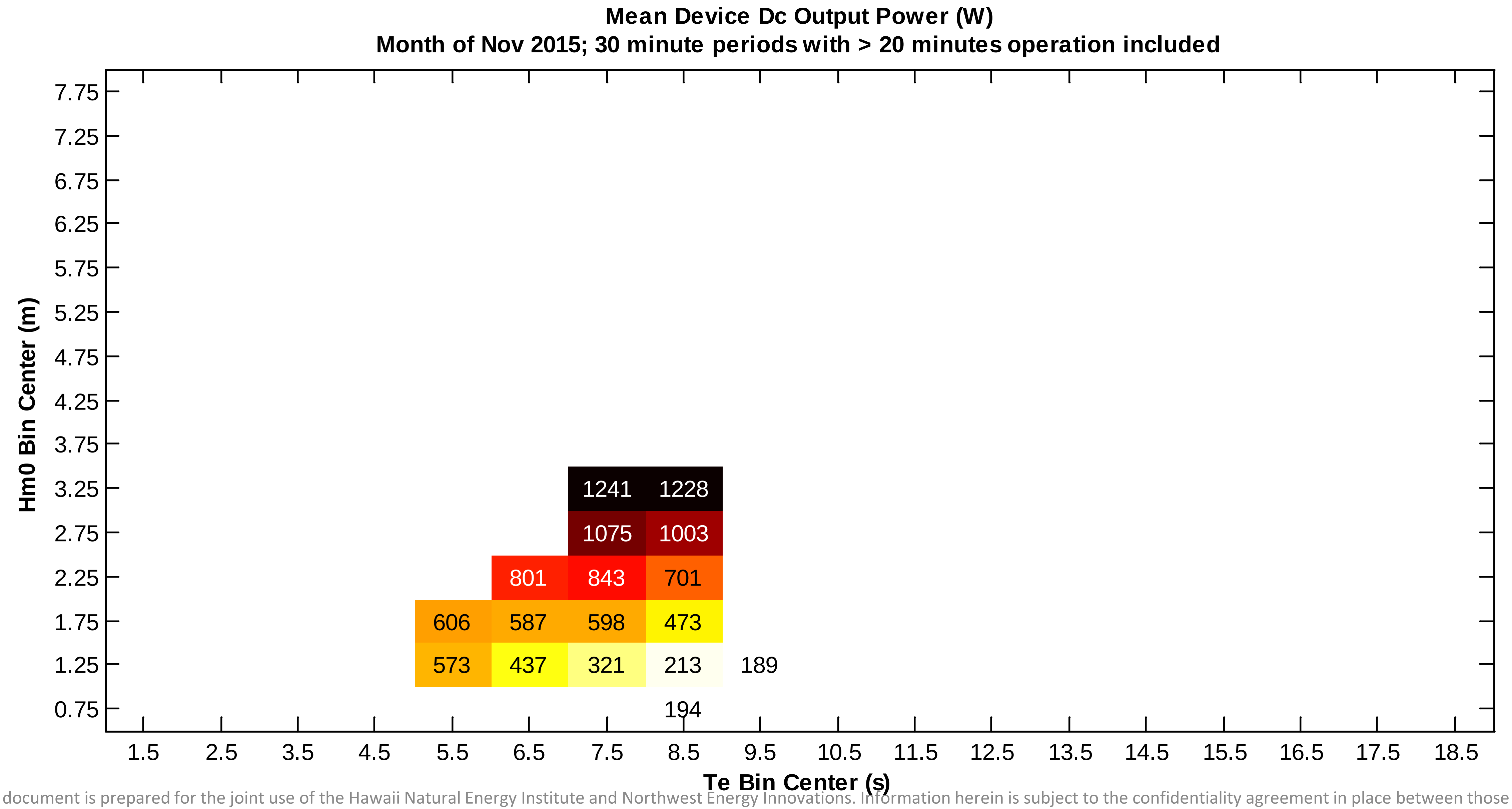

Azura Power Performance – November 2015

95th percentile power matrix

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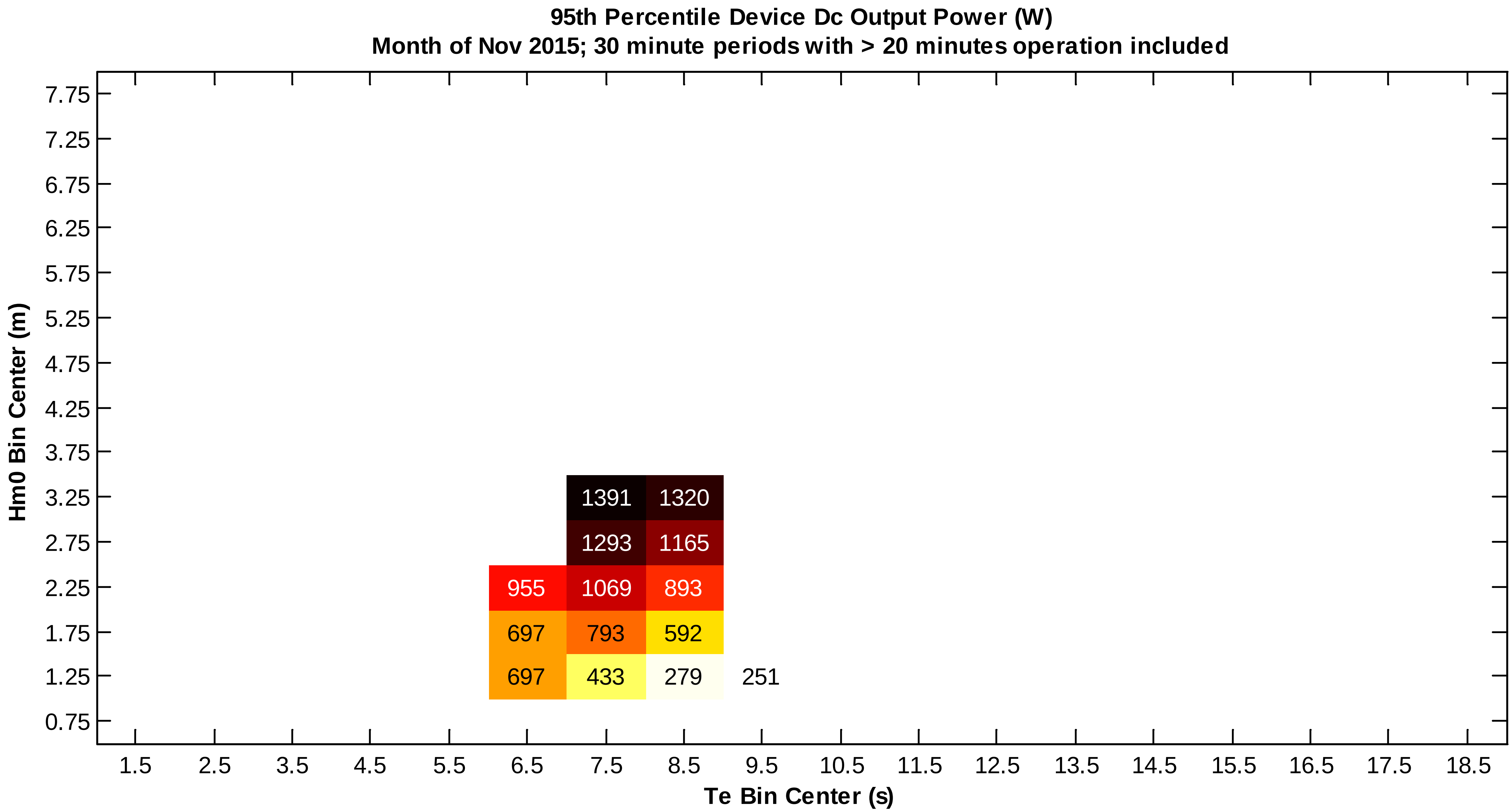

Azura Power Performance – November 2015

Standard deviation of power matrix

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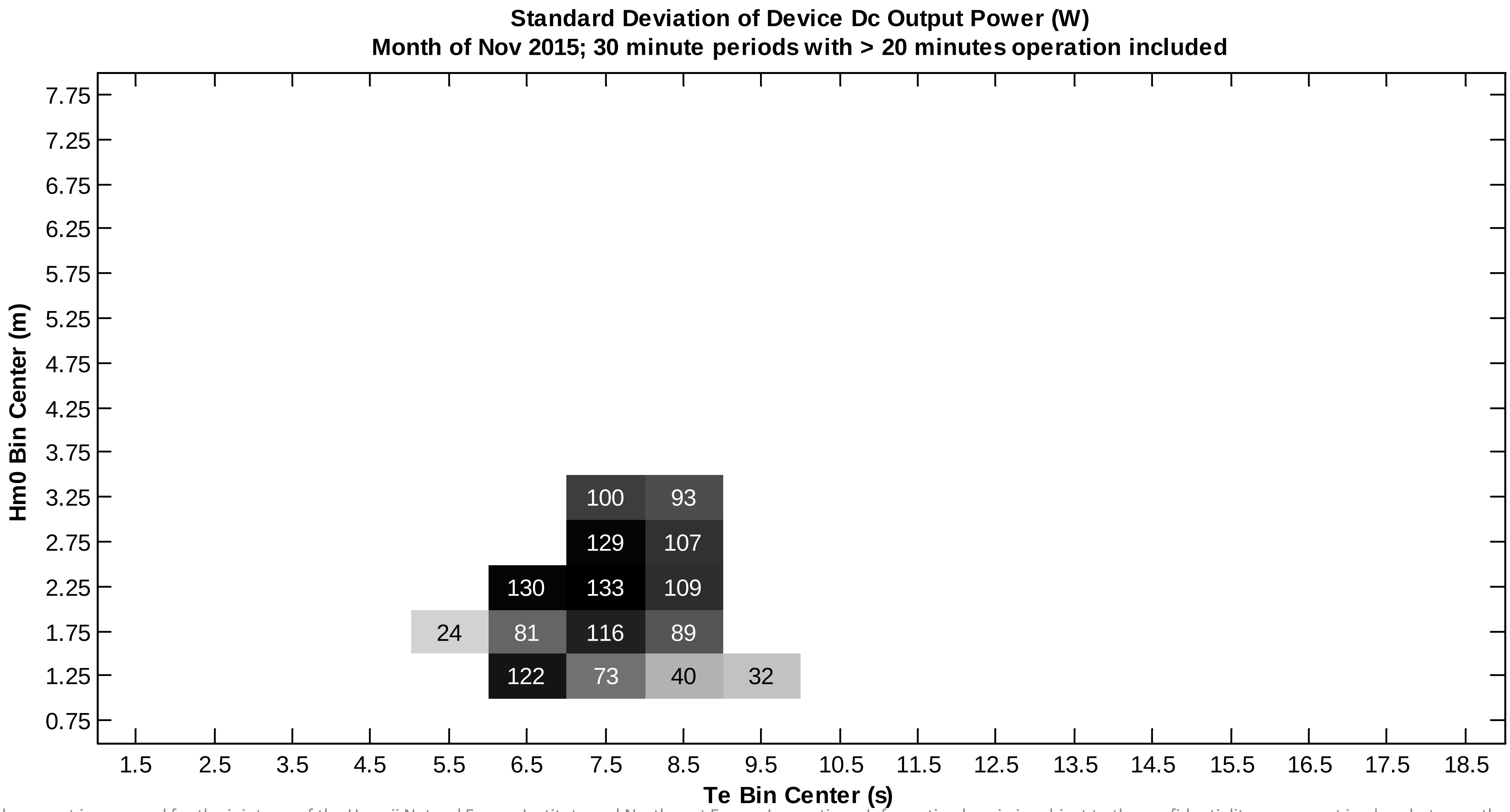

Azura Power Performance – November 2015

Mean capture length matrix

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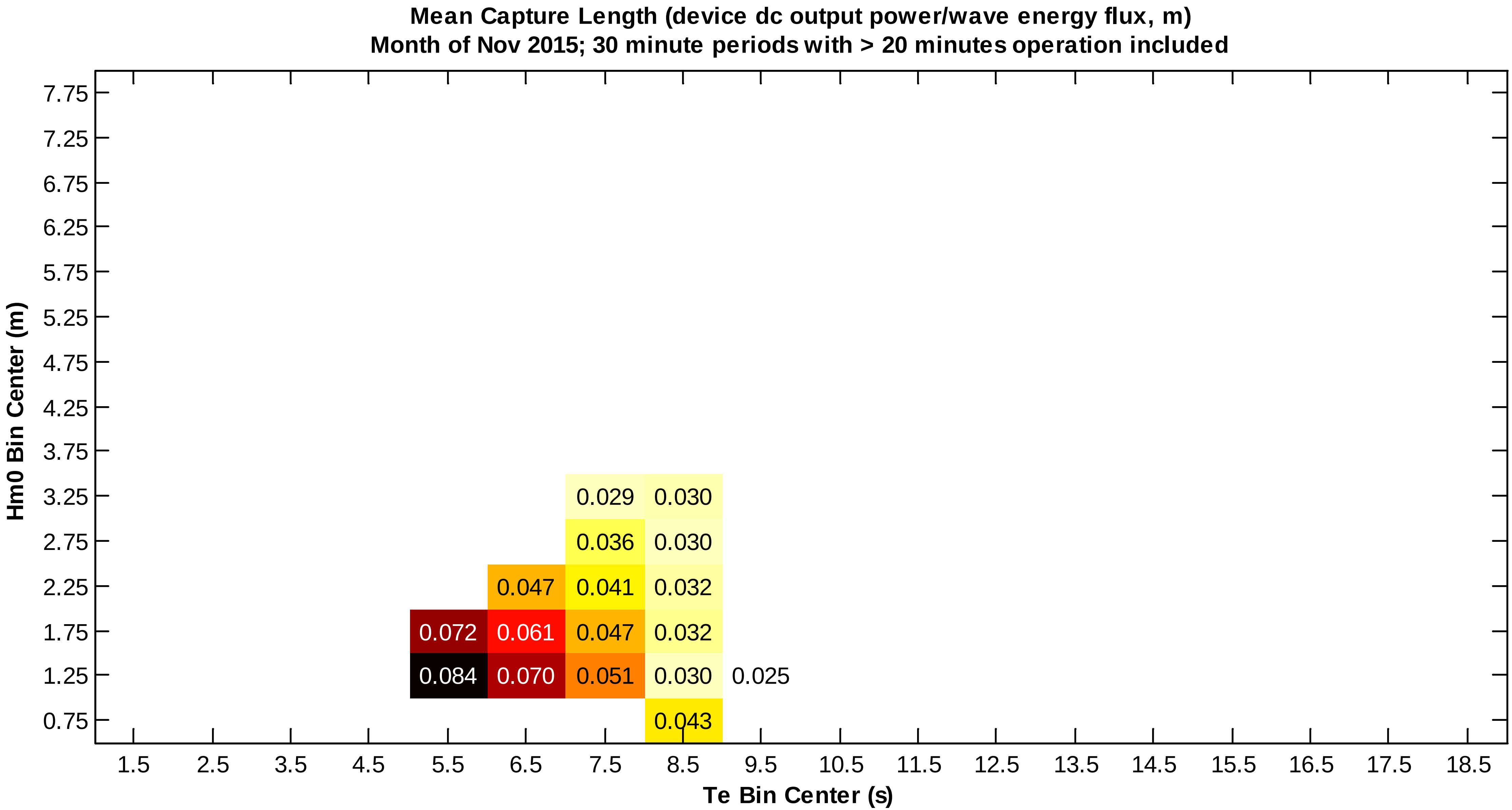

Azura Power Performance – November 2015

Standard deviation of capture length matrix

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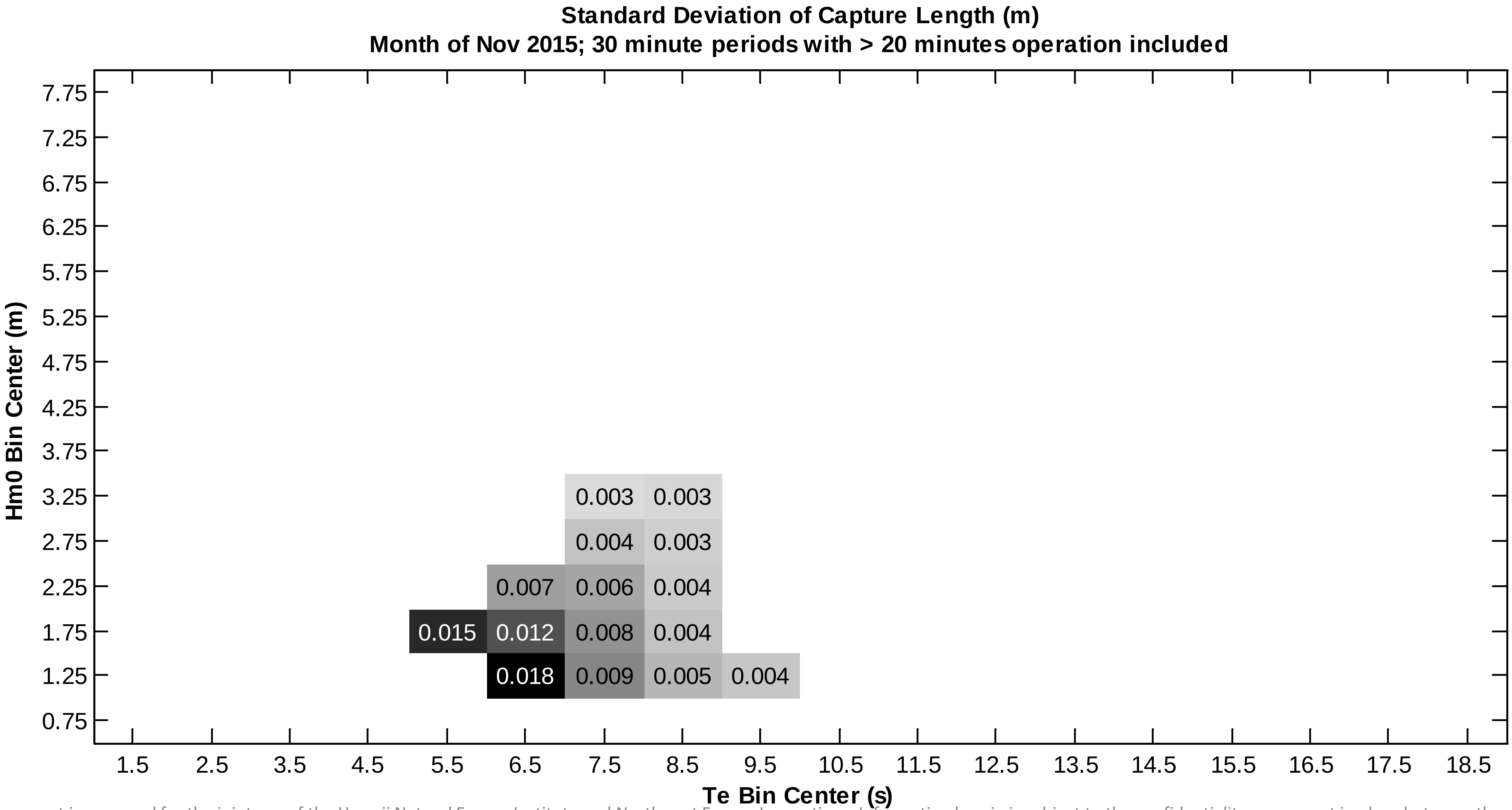

Azura Power Performance
Cumulative Data June - November 2015

Azura Power Performance – June-November 2015

Data samples collected

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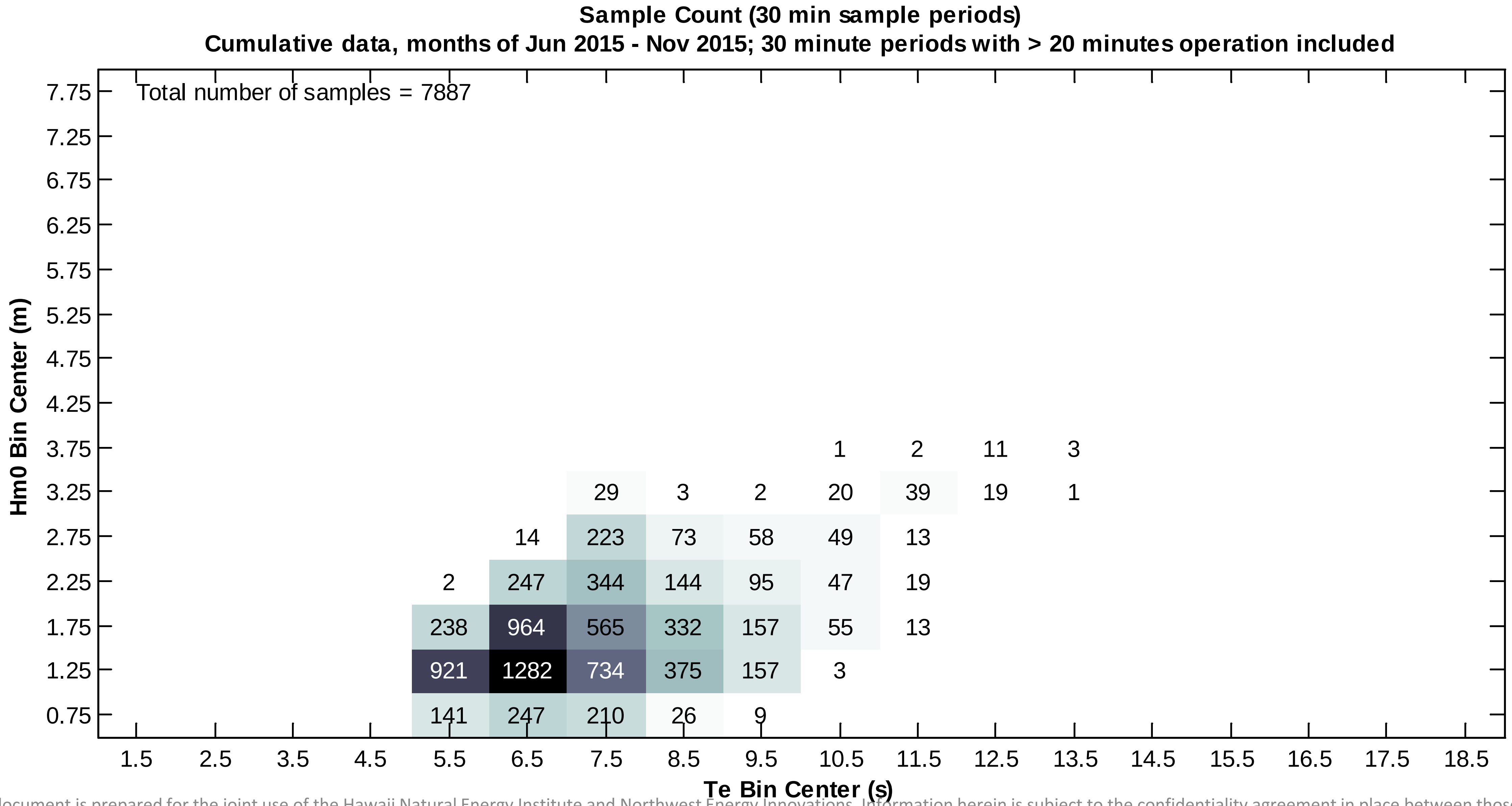

Azura Power Performance – June-November 2015

Mean power matrix

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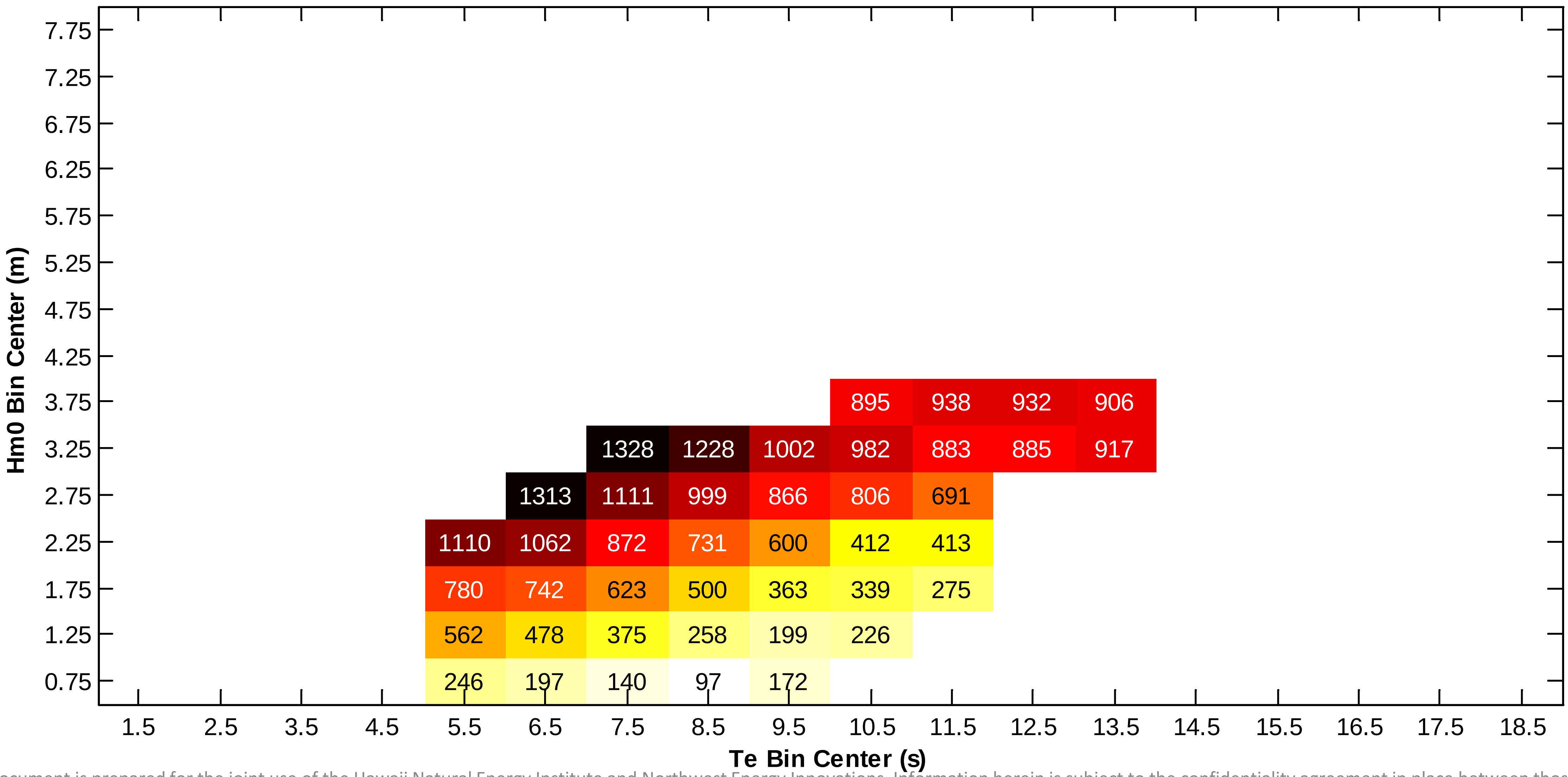
Mean Device Dc Output Power (W)

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



Azura Power Performance – June-November 2015

95th percentile power matrix

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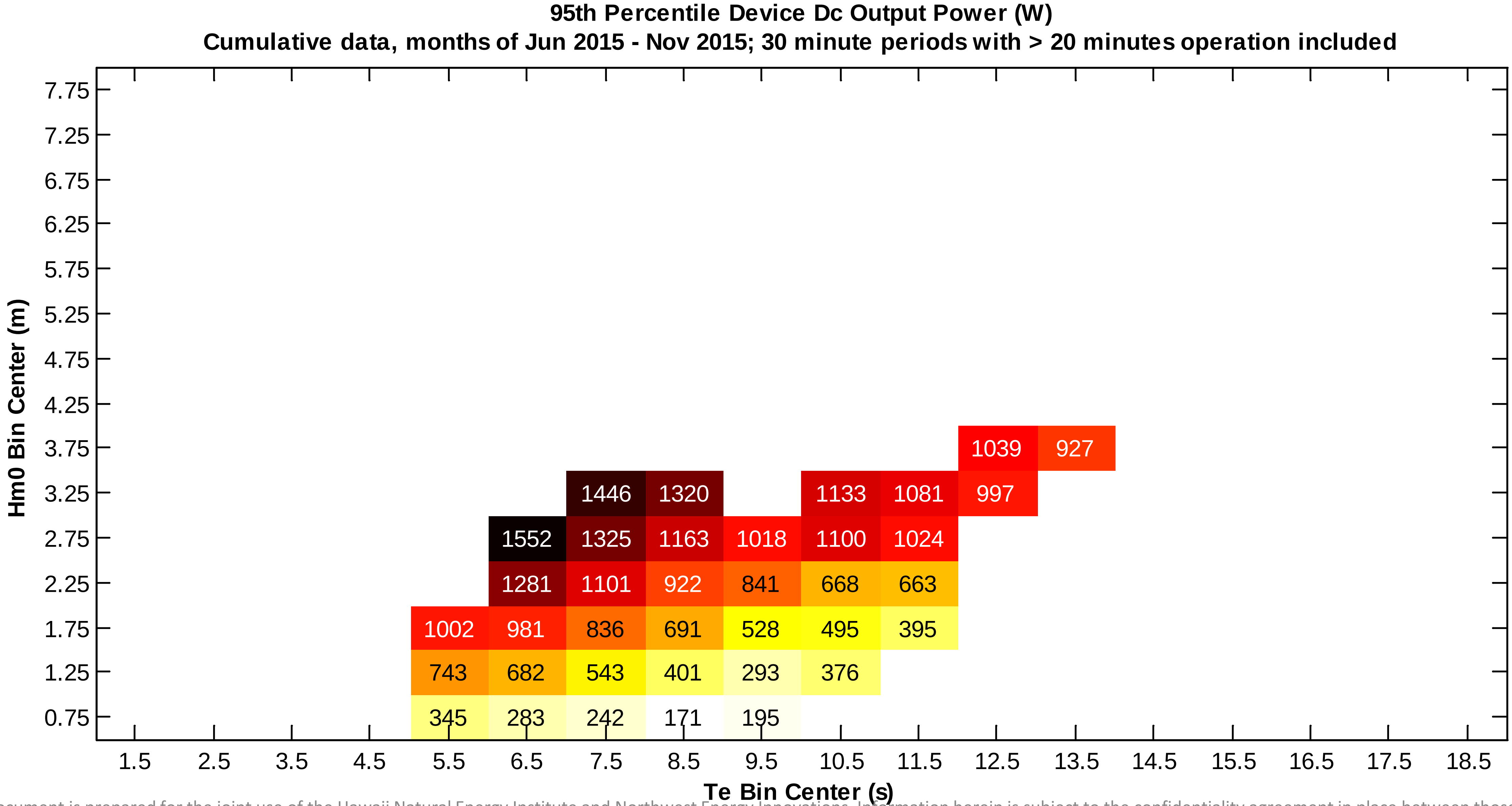

Azura Power Performance – June-November 2015

Standard deviation of power matrix

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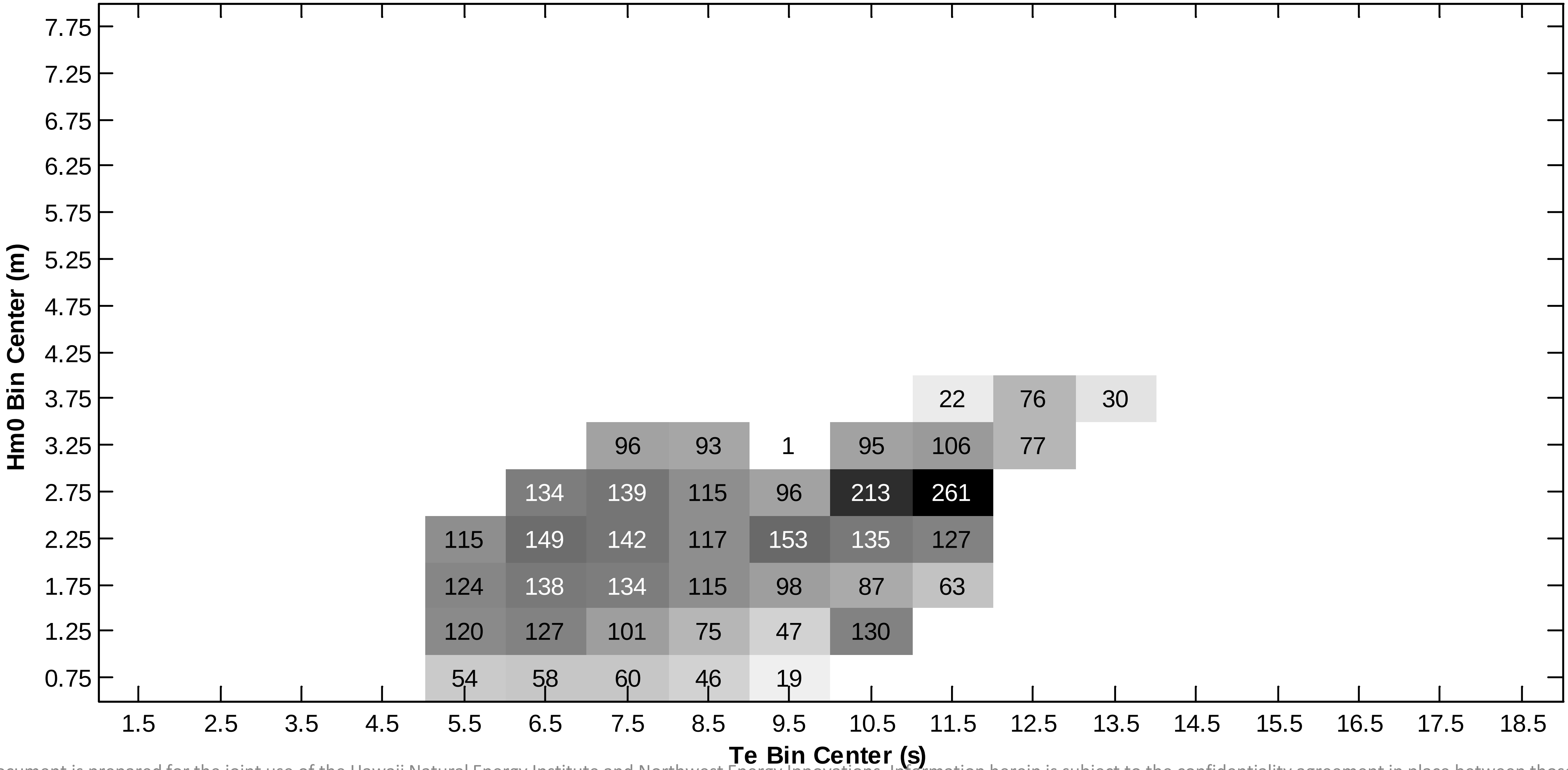
Standard Deviation of Device Dc Output Power (W)
Cumulative data, months of Jun 2015 - Nov 2015; 30 minute periods with > 20 minutes operation included



Azura Power Performance – June-November 2015

Mean capture length matrix

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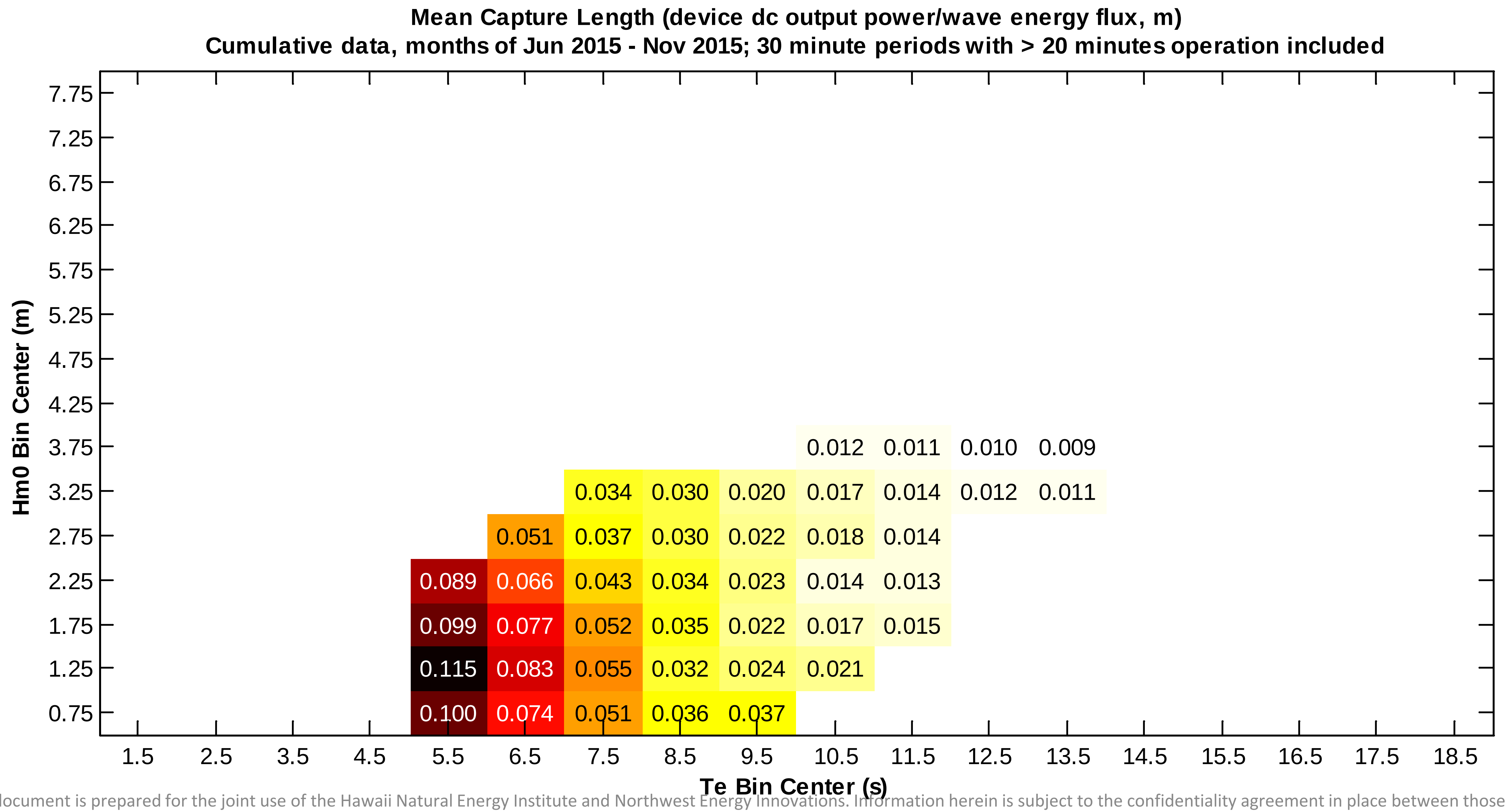

Azura Power Performance – June-November 2015

Standard deviation of capture length matrix

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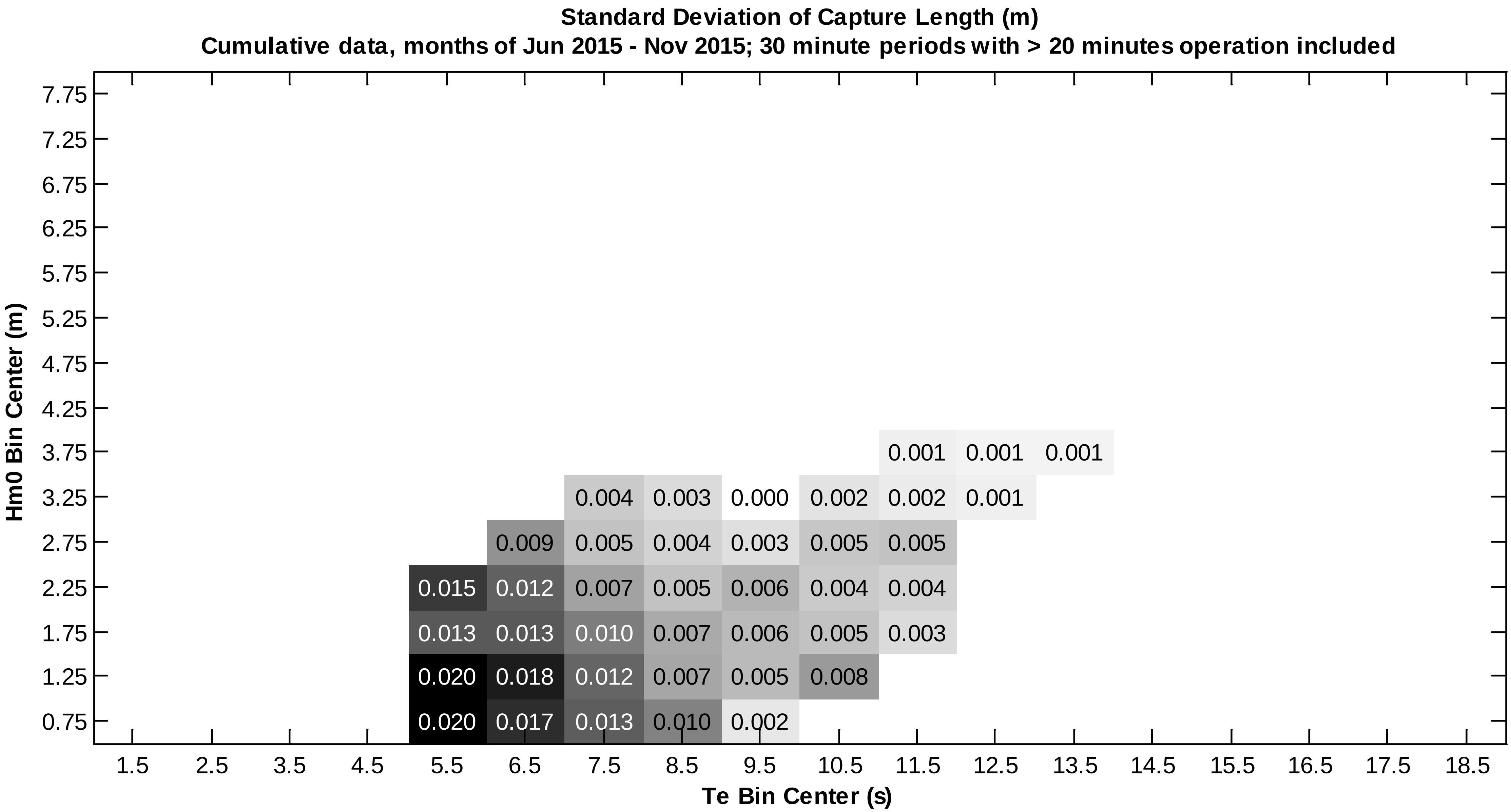

Attachment 2

Azura 30 minute average float angle data plots

Azura 30 minute average float angle data – November 2015

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Summary

- See Slide2 for plot of June-Nov 2015 data; see Slide 3 for Nov 2015 data
- Average float angle was at approximately 8-14° above horizontal until November 23 when Sea Engineering added air to the Azura hull to re-ballast. The re-ballasting raised the hull by approximately 1.5 m.
- After the November 23 re-ballast, average float angle was very close to zero.
- The float went over the top and the device continued to operate with the float on the offshore side of the hull for extended periods of time on Oct. 30 – Nov. 16 and also Nov. 21-24.
- The loading on the float changes the average angle; see results for Nov 8-15 when PI control was used with very heavy loading (motor displacement often 20 cc/rev).

Azura 30 min average float angle data through Nov 2015

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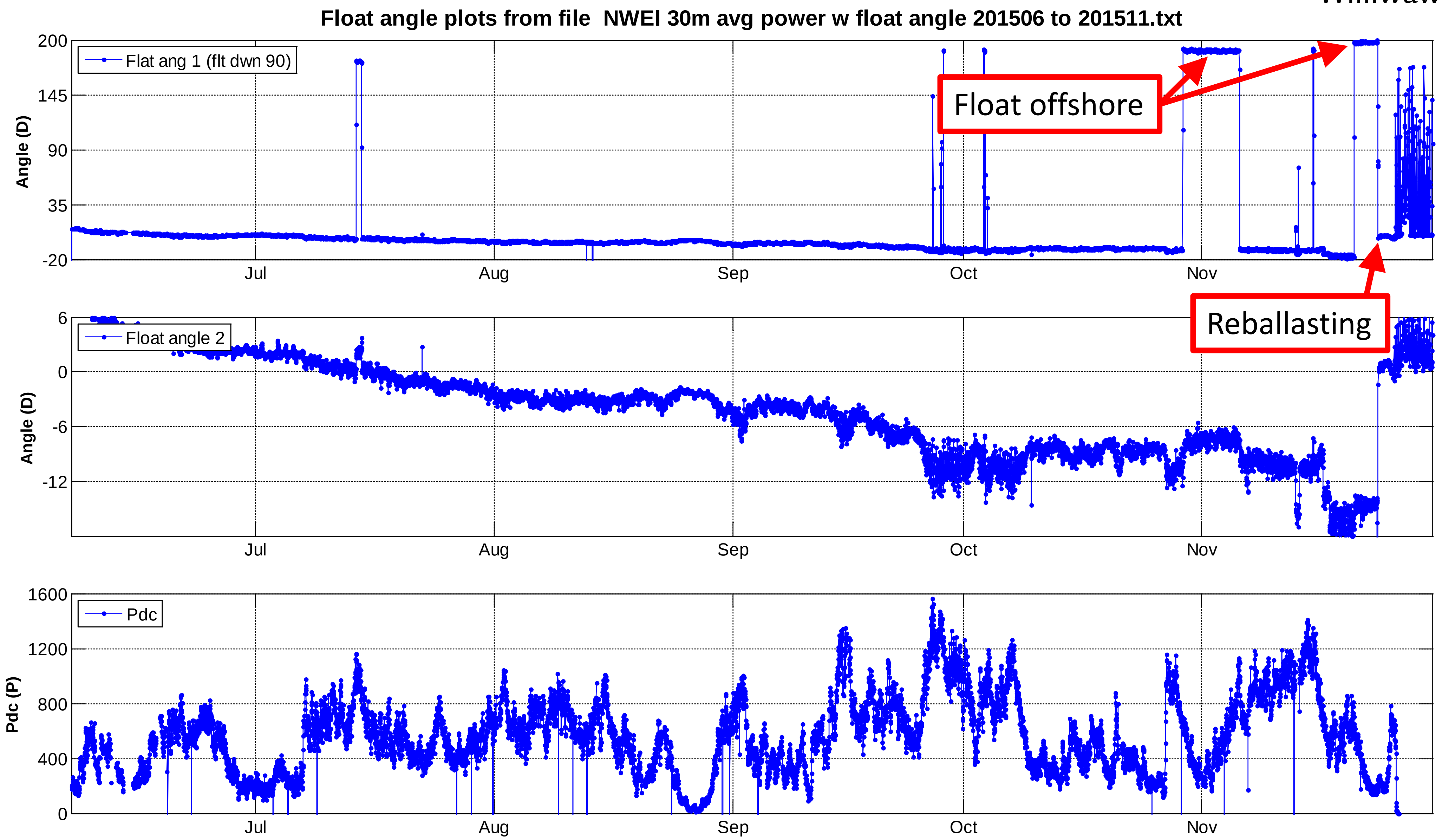

Azura 30 min average float angle data Nov 2015

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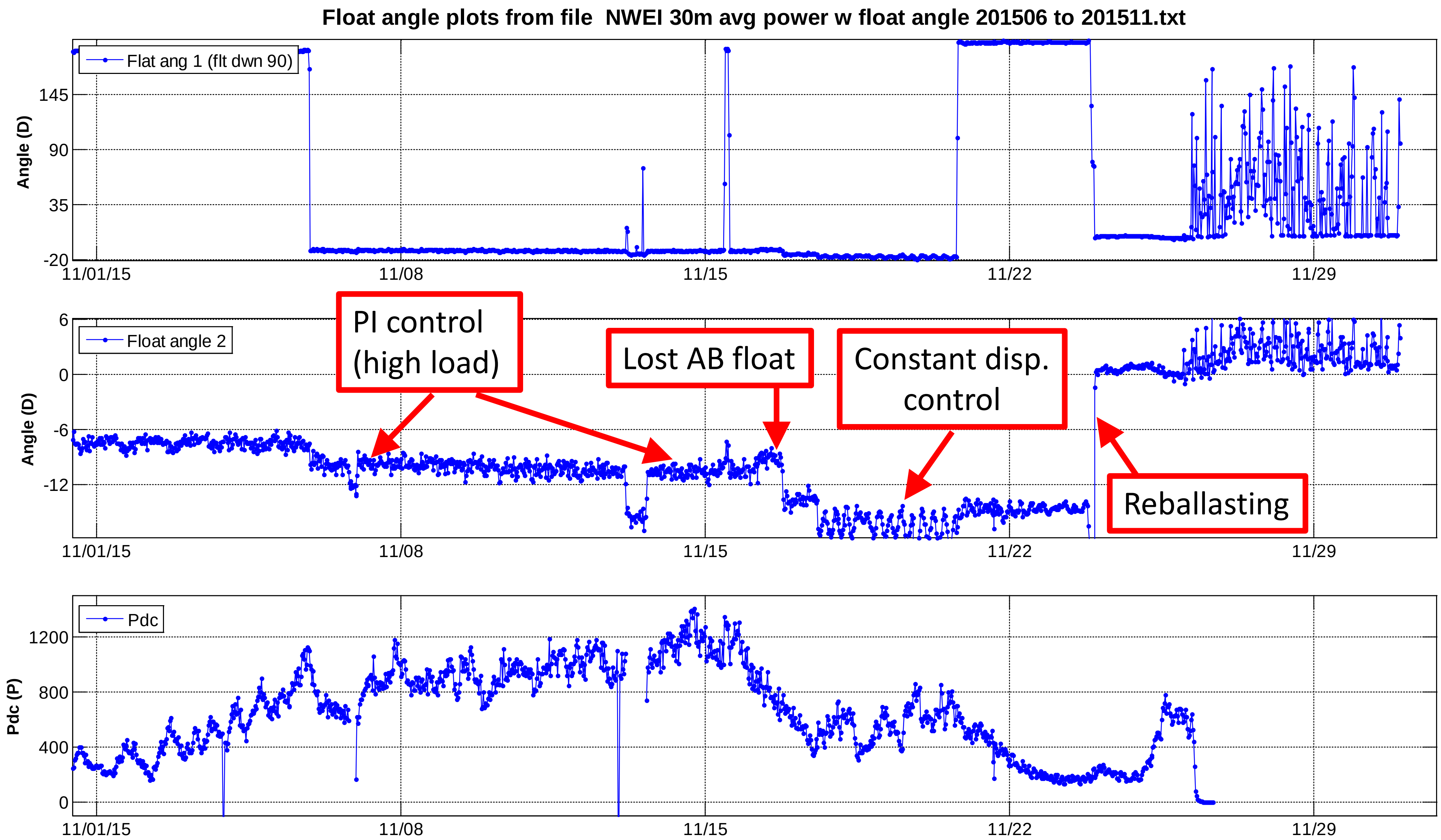

Attachment 3

Azura cRIO enclosure and drybox humidity plots

Azura cRIO enclosure and drybox humidity Nov 2015

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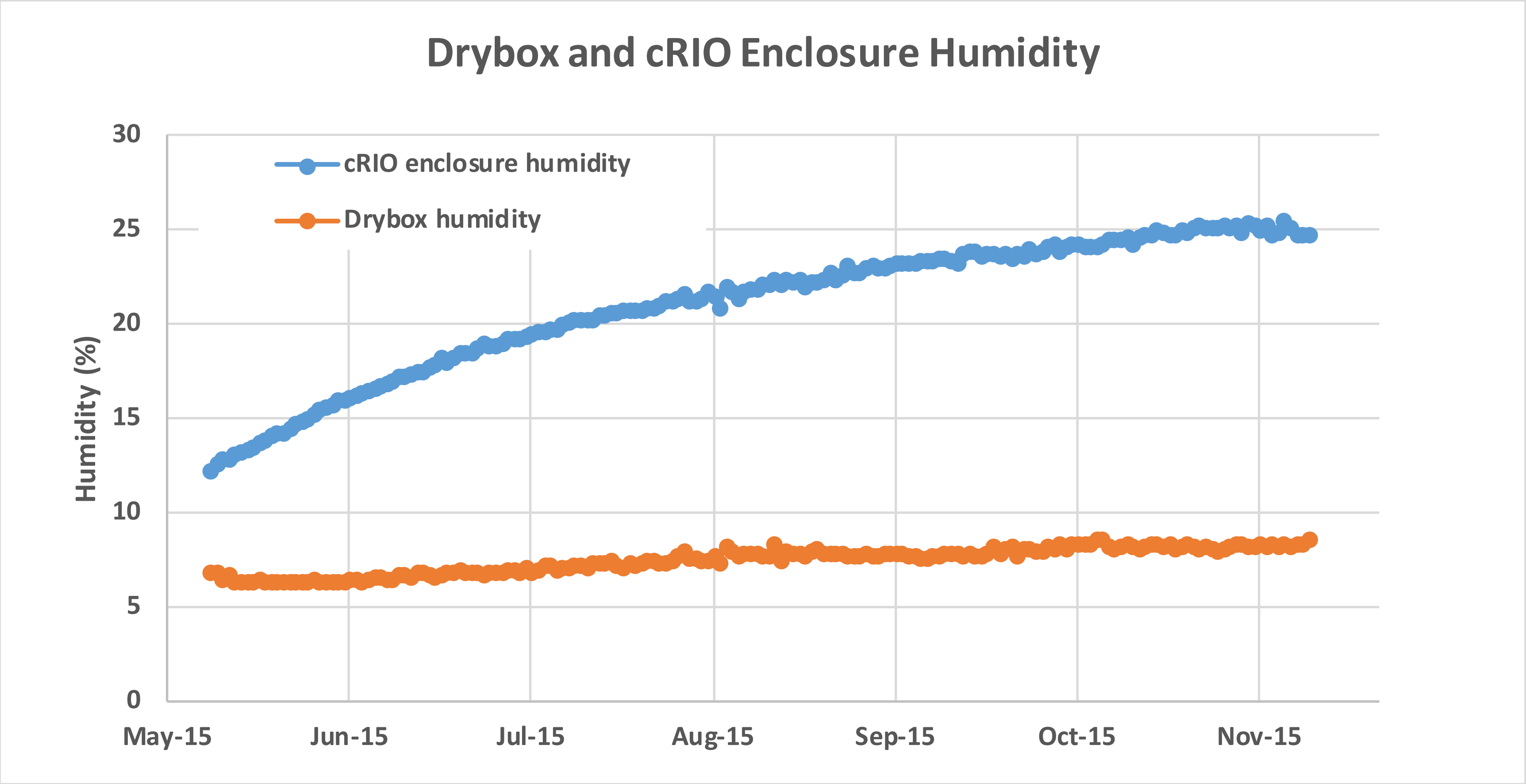

Attachment 4

Azura Relative Capture Width (RCW) Comparison
Leading vs. Trailing Float

Azura leading vs trailing float comparison
PTO motor disp 65 & 80 cc/rev

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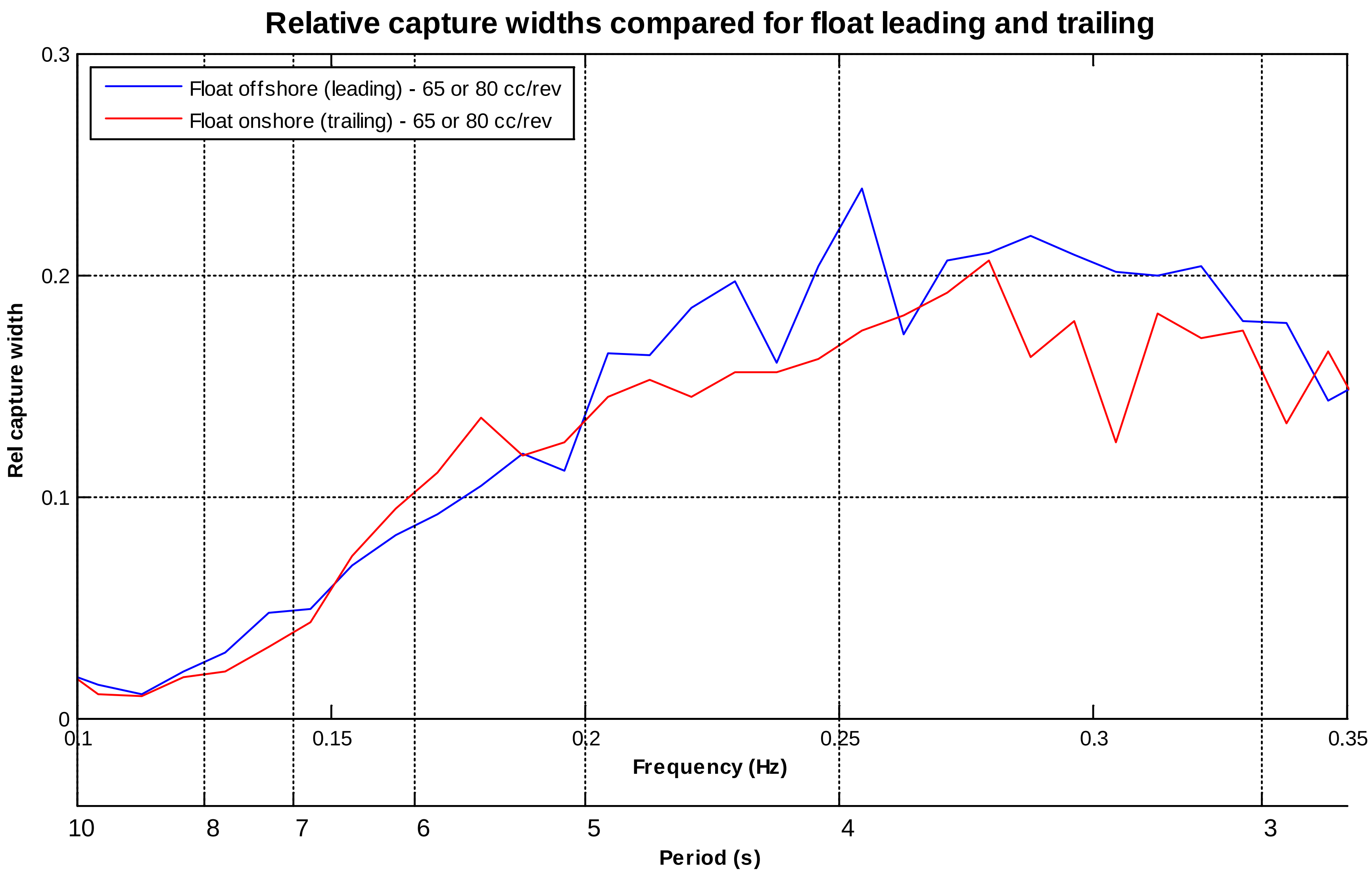

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Azura leading vs trailing float comparison
PTO motor disp 65 & 80 cc/rev

Date_time	Op_min	Pdc_W	Pgen_W	Damping recorded	WR_DateTime	Te_s	Hm0_m	MotDisp	Rdc_inv		Mean wave direction 4-7s (degrees true)	Mean Azura heading (degrees true)
Leading float												
20150714_0200	30	1120	1181	21.5	20150714_0206	6.71	2.00	65	20		53	26
20150714_0230	30	984	1039	21.6	20150714_0236	6.84	2.01	80	20		58	25
20150714_0300	30	1027	1084	21.6	20150714_0306	6.9	2.15	80	20		58	24
20150714_0330	30	1031	1087	21.5	20150714_0336	6.83	2.01	65	20		55	24
20150714_0800	30	929	978	21.5	20150714_0806	6.43	1.83	65	20		57	24
20150714_0830	30	891	939	21.6	20150714_0836	6.1	1.65	80	20		53	25
20150714_0900	30	896	944	21.6	20150714_0906	6.22	1.74	80	20		52	24
20150714_0930	30	970	1019	21.5	20150714_0936	6.52	1.75	65	20		56	25
20150714_1500	30	833	876	21.6	20150714_1506	6.44	1.73	80	20		57	26
20150714_1530	30	1046	1099	21.5	20150714_1536	6.53	1.84	65	20		59	25
Trailing float												
20150713_0800	30	688	724	21.5	20150713_0806	6.44	1.58	65	20		53	24
20150713_0830	30	764	804	21.6	20150713_0836	6.38	1.69	80	20		51	25
20150713_0900	30	747	787	21.6	20150713_0906	6.36	1.71	80	20		55	24
20150713_0930	30	786	827	21.5	20150713_0936	6.35	1.54	65	20		55	25
20150713_1400	30	869	913	21.5	20150713_1406	6.3	1.62	65	20		56	25
20150713_1430	30	814	857	21.6	20150713_1436	6.21	1.58	80	20		57	25
20150713_1500	30	770	810	21.6	20150713_1506	6.05	1.56	80	20		57	26
20150713_1530	30	800	841	21.5	20150713_1536	6.25	1.54	65	20		59	25
20150713_2000	30	990	1039	21.5	20150713_2006	6.53	2.01	65	20		49	27
20150713_2030	30	891	937	21.6	20150713_2036	6.54	2.07	80	20		51	26

Azura leading vs trailing float comparison
PTO motor disp 30 cc/rev

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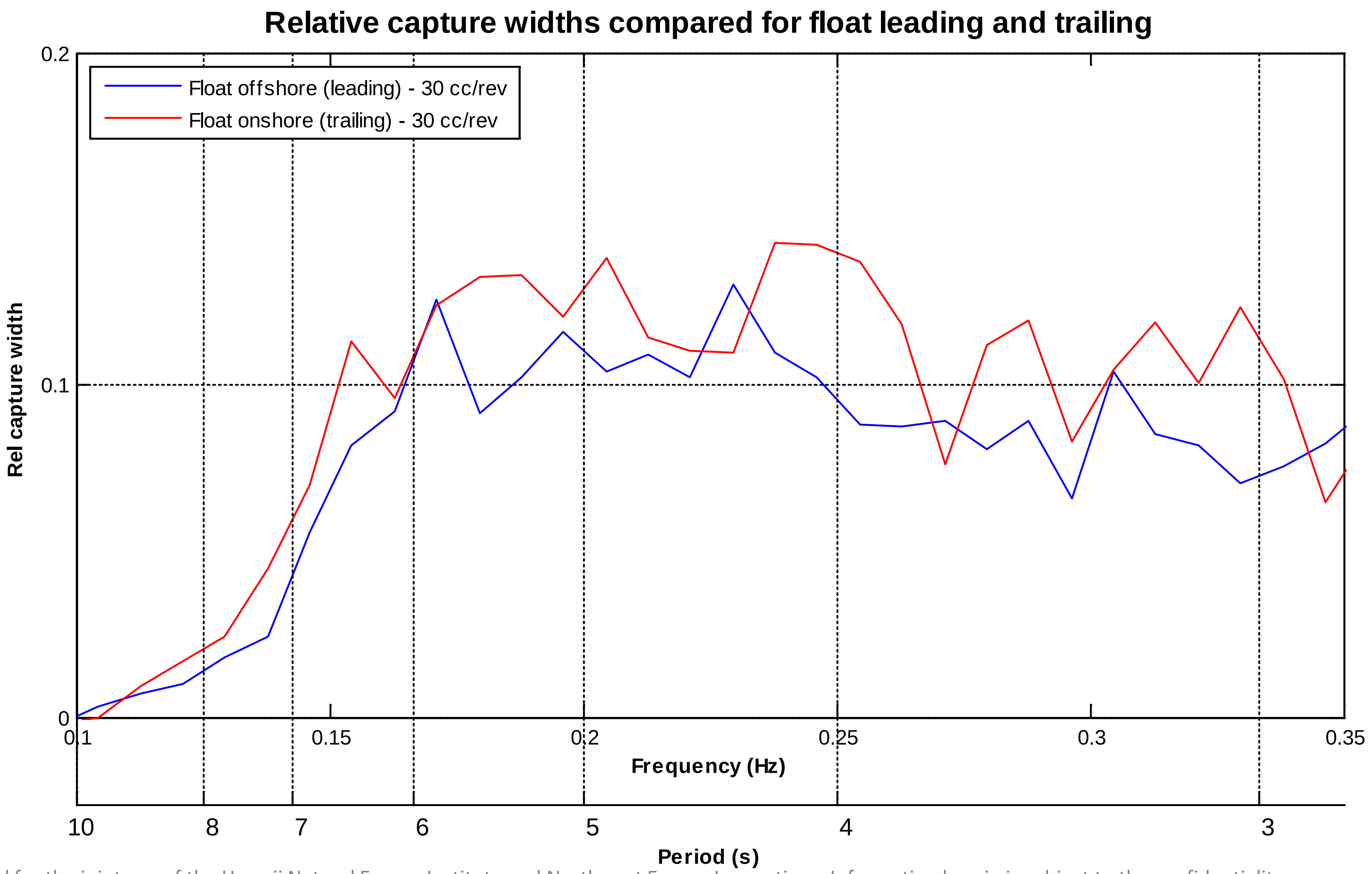

Azura leading vs trailing float comparison
PTO motor disp 30 cc/rev

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Date_time	Op_min	Pdc_W	Pgen_W	Damping recorded	WR_DateTime	Te_s	Hm0_m	MotDisp	Rdc_inv		Mean wave direction 4-7s (degrees true)	Mean Azura heading (degrees true)
Leading float												
20151103_0230	30	390	417	4.5	20151103_0239	6.57	1.43	30	20		69	25
20151103_0300	30	366	393	4.5	20151103_0309	6.63	1.45	30	20		74	25
20151103_0330	30	370	396	4.5	20151103_0339	6.67	1.46	30	20		73	25
20151103_0400	30	363	389	4.5	20151103_0409	6.65	1.37	30	20		73	25
20151103_0430	30	384	411	4.5	20151103_0439	6.31	1.43	30	20		74	25
20151103_0500	30	437	466	4.5	20151103_0509	6.28	1.43	30	20		75	25
20151103_0530	30	507	539	4.5	20151103_0539	6.22	1.54	30	20		76	25
20151103_0600	30	541	575	4.5	20151103_0609	6.44	1.49	30	20		76	25
20151103_0630	30	526	559	4.5	20151103_0639	6.43	1.55	30	20		78	25
20151103_0700	30	521	554	4.5	20151103_0709	6.23	1.51	30	20		80	26
Trailing float												
20150917_1800	30	607	644	21.1	20150917_1806	6.08	1.52	30	20		45	25
20150917_2330	30	433	464	21.1	20150917_2336	6.35	1.4	30	20		51	26
20150918_0000	30	554	591	21.1	20150918_0006	6.23	1.32	30	20		46	26
20150918_0600	30	609	646	21.1	20150918_0606	5.71	1.46	30	20		53	26
20150918_1130	30	693	734	21.1	20150918_1136	6.16	1.43	30	20		50	28
20150918_1200	30	711	753	21.1	20150918_1206	6.02	1.42	30	20		48	29
20150918_1730	30	867	916	21.1	20150918_1736	6.08	1.74	30	20		57	26
20150918_1800	30	897	947	21.1	20150918_1806	6.14	1.68	30	20		63	25
20150919_1130	30	540	574	21.1	20150919_1136	6.44	1.49	30	20		50	28
20150919_1200	30	595	632	21.1	20150919_1206	6.46	1.53	30	20		48	28

Attachment 5

Azura Relative Capture Width (RCW) Comparison
Different Wave Headings

Azura relative capture width for different wave directions

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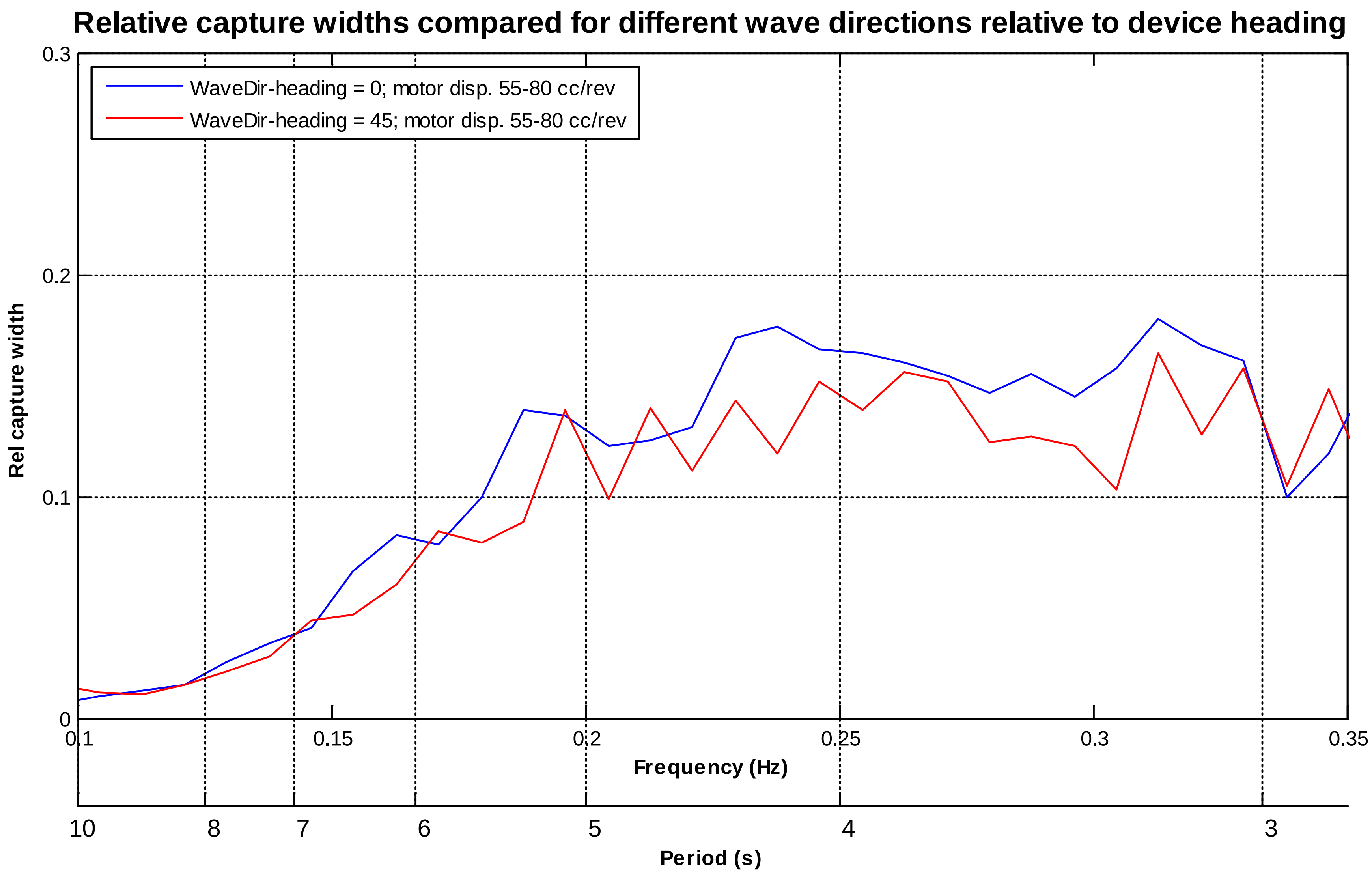

Azura relative capture width for different wave directions

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Date_time	Op_min	Pdc_W	Pgen_W	Damping recorded	WR_DateTime	Te_s	Hm0_m	MotDisp	Rdc_inv		Mean wave direction 4-7s (degrees true)	Mean Azura heading (degrees true)
Wave direction minus heading -5 to 5 degrees												
20151002_2000	30	622	657	21.5	20151002_2006	6.6	1.40	65	20		26	27
20151007_0230	30	1038	1097	21.6	20151007_0236	6.3	2.00	80	20		28	25
20151007_0300	30	993	1050	21.6	20151007_0306	6.4	2.00	80	20		29	25
20151007_0330	30	993	1048	21.5	20151007_0336	6.3	2.00	65	20		29	25
20151007_0400	30	1046	1102	21.4	20151007_0406	6.4	1.90	55	20		28	25
20151007_0730	30	1204	1266	21.4	20151007_0736	6.4	2.20	55	20		30	26
20151007_0800	30	1126	1185	21.5	20151007_0806	6.4	2.10	65	20		28	25
20151007_0830	30	1121	1182	21.6	20151007_0836	6.5	2.30	80	20		26	25
20151007_0930	30	1141	1200	21.5	20151007_0936	6.6	2.20	65	20		26	26
20151013_2000	30	452	478	21.5	20151013_2009	6.4	1.30	65	20		27	26
Wave direction minus heading 40 to 50 degrees												
20150808_0900	30	768	811	21.6	20150808_0906	6.4	1.90	80	20		69	26
20150808_1000	30	855	900	21.4	20150808_1006	6.3	1.90	55	20		69	26
20150922_0830	30	787	832	21.6	20150922_0836	6.3	1.90	80	20		66	25
20150913_2000	30	819	866	21.5	20150913_2006	6.3	1.80	65	20		73	26
20150911_2030	30	573	608	21.6	20150911_2036	6.1	1.60	80	20		73	26
20150914_0330	30	723	766	21.5	20150914_0336	6.1	1.70	65	20		69	25
20150923_0730	30	656	694	21.4	20150923_0736	5.7	1.50	55	20		69	25
20150808_0830	30	776	819	21.6	20150808_0836	6.1	1.90	80	20		74	26
20150912_0730	30	657	694	21.4	20150912_0736	6.3	1.60	55	20		71	26
20150912_0800	30	597	632	21.5	20150912_0806	6.2	1.60	65	20		72	27

Attachment 6

Azura Relative Capture Width (RCW) Comparison
AB Float

Azura RCW comparison with and without AB float comparison
PTO motor disp 65 & 80 cc/rev

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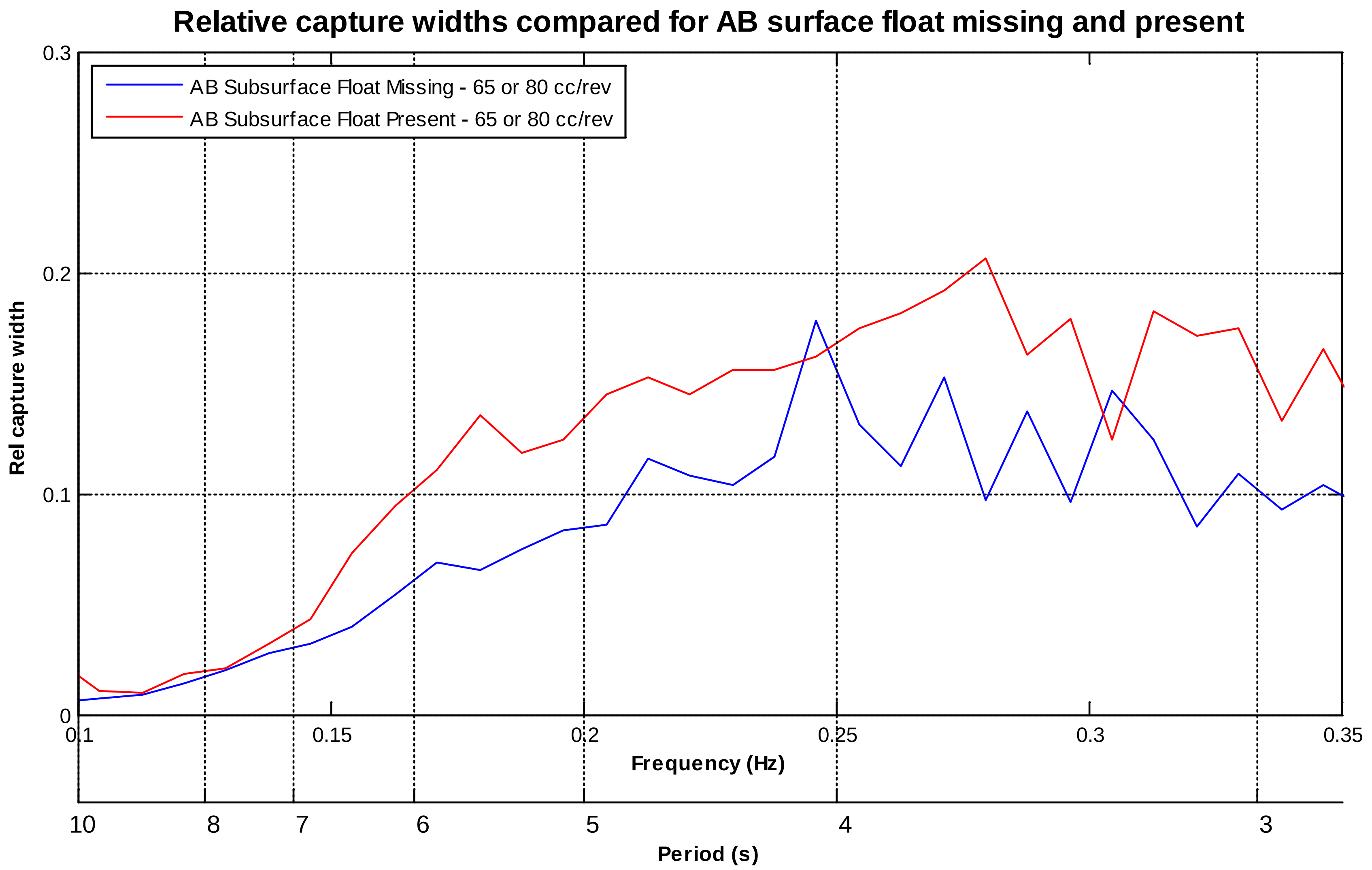

Azura AB float present/missing comparison
PTO motor disp 65 & 80 cc/rev

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Date_time	Op_min	Pdc_W	Pgen_W	Damping recorded	WR_DateTime	Te_s	Hm0_m	MotDisp	Rdc_inv		Mean wave direction 4-7s (degrees true)	Mean Azura heading (degrees true)
AB subsurface float missing												
20151118_0300	30	512	510	21.6	20151118_0309	7.18	1.66	80	20		65	25
20151118_0330	30	628	627	21.5	20151118_0339	6.75	1.65	65	20		69	26
20151118_0800	30	654	652	21.5	20151118_0809	6.47	1.79	65	20		77	28
20151118_0830	30	614	612	21.6	20151118_0839	6.29	1.7	80	20		77	27
20151118_0900	30	580	578	21.6	20151118_0909	6.47	1.79	80	20		79	28
20151118_0930	30	653	651	21.5	20151118_0939	6.33	1.67	65	20		77	28
20151118_1400	30	364	361	21.5	20151118_1409	7.31	1.35	65	20		66	30
AB subsurface float present on surface												
20150713_0800	30	688	724	21.5	20150713_0806	6.44	1.58	65	20		53	24
20150713_0830	30	764	804	21.6	20150713_0836	6.38	1.69	80	20		51	25
20150713_0900	30	747	787	21.6	20150713_0906	6.36	1.71	80	20		55	24
20150713_0930	30	786	827	21.5	20150713_0936	6.35	1.54	65	20		55	25
20150713_1400	30	869	913	21.5	20150713_1406	6.3	1.62	65	20		56	25
20150713_1430	30	814	857	21.6	20150713_1436	6.21	1.58	80	20		57	25
20150713_1500	30	770	810	21.6	20150713_1506	6.05	1.56	80	20		57	26
20150713_1530	30	800	841	21.5	20150713_1536	6.25	1.54	65	20		59	25
20150713_2000	30	990	1039	21.5	20150713_2006	6.53	2.01	65	20		49	27
20150713_2030	30	891	937	21.6	20150713_2036	6.54	2.07	80	20		51	26

Note: the hull was approximately 0.5 m low in the water when the 11/18 data was recorded and this could have affected output power. There is no comparable data with similar ballasting, device control, and wave heights/periods from before the AB float was lost that can be used for comparison.