Hawaii National Marine Renewable Energy Center (HINMREC)

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Task 4: Environmental Impact Monitoring at WETS

WETS Sentinel V100 ADCP Data Analysis at 70m Reports

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HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

REPORT:

Task 4G Report - ADCP Data Analysis at WETS (70m Depth)

August 2017

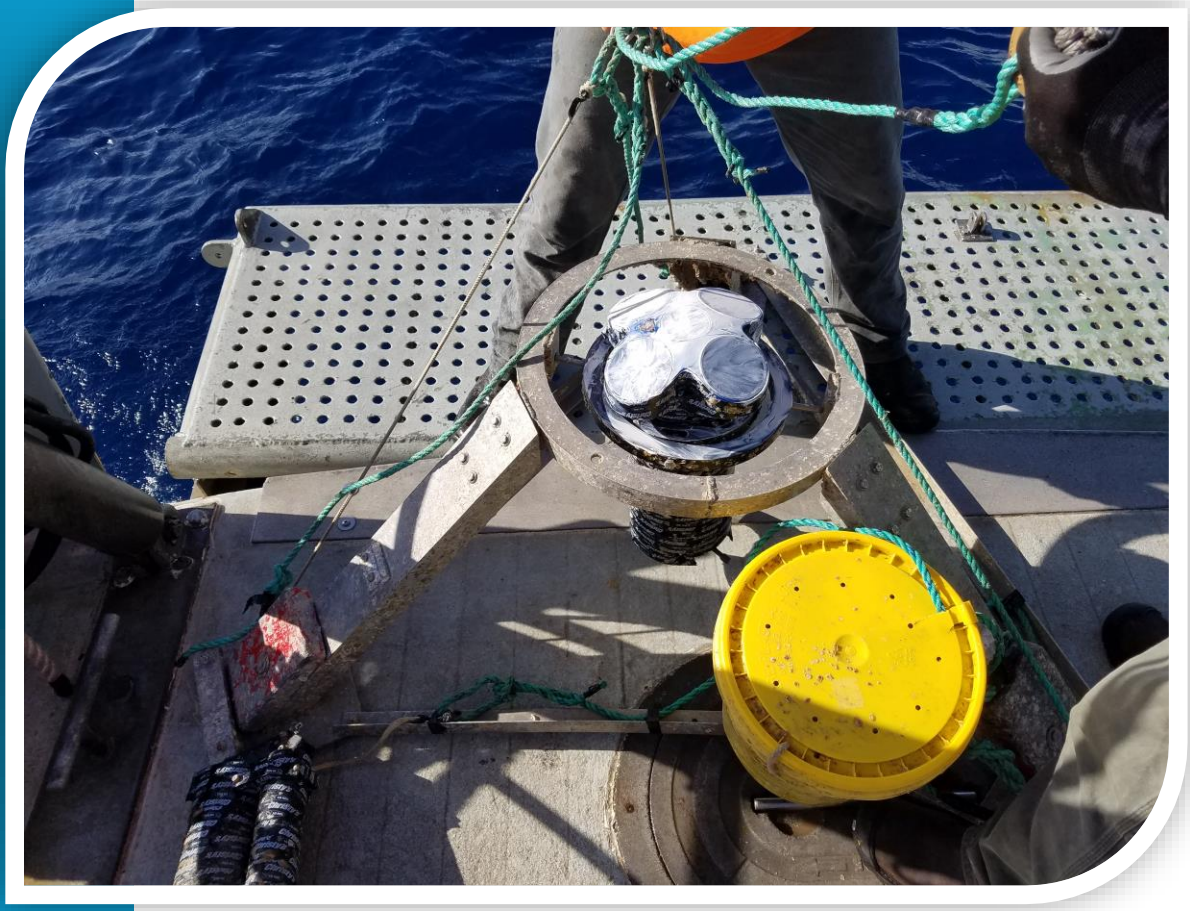

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The area north of the Mōkapu Peninsula, adjacent to Kāneʻohe Marine Corps Base Hawaiʻi (MCBH), has been utilized by the U.S. Navy for wave energy research since 2002. Prototype wave energy converters (WEC) are being tested at the 30m, 60m, and 80m berths offshore of North Beach at the MCBH. The Hawaiʻi National Marine Renewable Energy Center (HNMREC) at the University of Hawaiʻi under contract with Department of Energy and the U.S. Navy, operates the test site.

Sea Engineering has been contracted by the HNMREC to conduct site investigations in support of the test site. One of these investigations is to determine wave climate at the site and current characteristics.

The project location within the state of Hawaiʻi is shown in Figure 1-1. The test site is 1600m to 2000m wide and extends approximately 2600m offshore from the 30m depth contour to the approximate 100m depth contour.

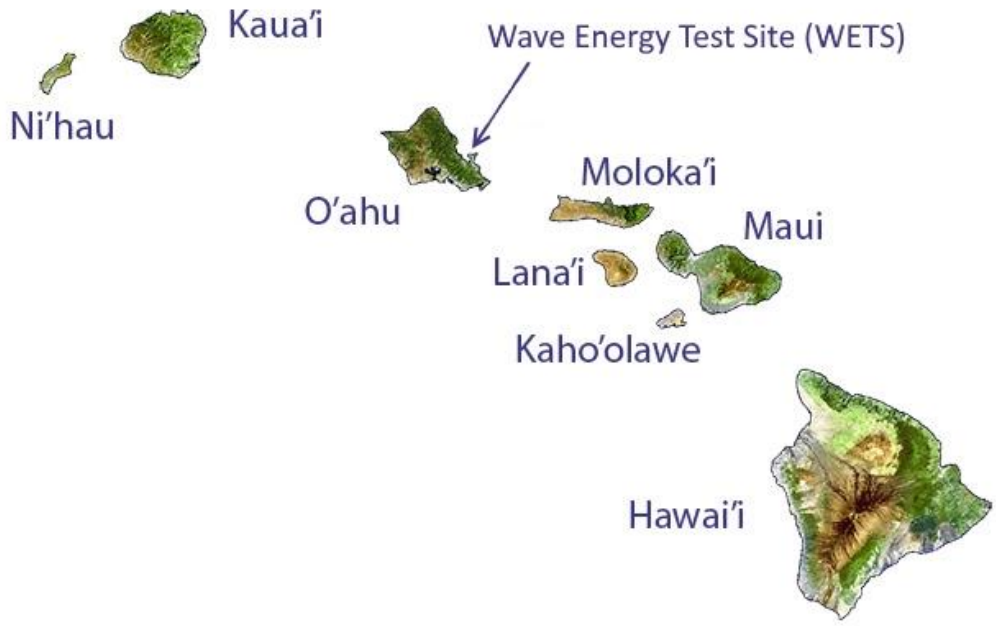

Figure 1-1 Project Location

In collaboration with HNMREC, Sea Engineering Inc. deployed a Teledyne RDI Sentinel V100 Acoustic Doppler Current Profiler (ADCP) in the Wave Energy Test Site (WETS) since November 2014. Previous deployments were at the 30m site and near the Waverider buoy. In December 2016, the ADCP was deployed at the 70m site. Figure 1-2 shows the deployment location of the ADCP. Table 1-1 shows the ADCP deployment schedule and the coordinates of the deployment. This report presents the data from the deployment of the ADCP from December 6, 2016 to April 14, 2017 at the 70m depth location between the 60m and 80m sites.

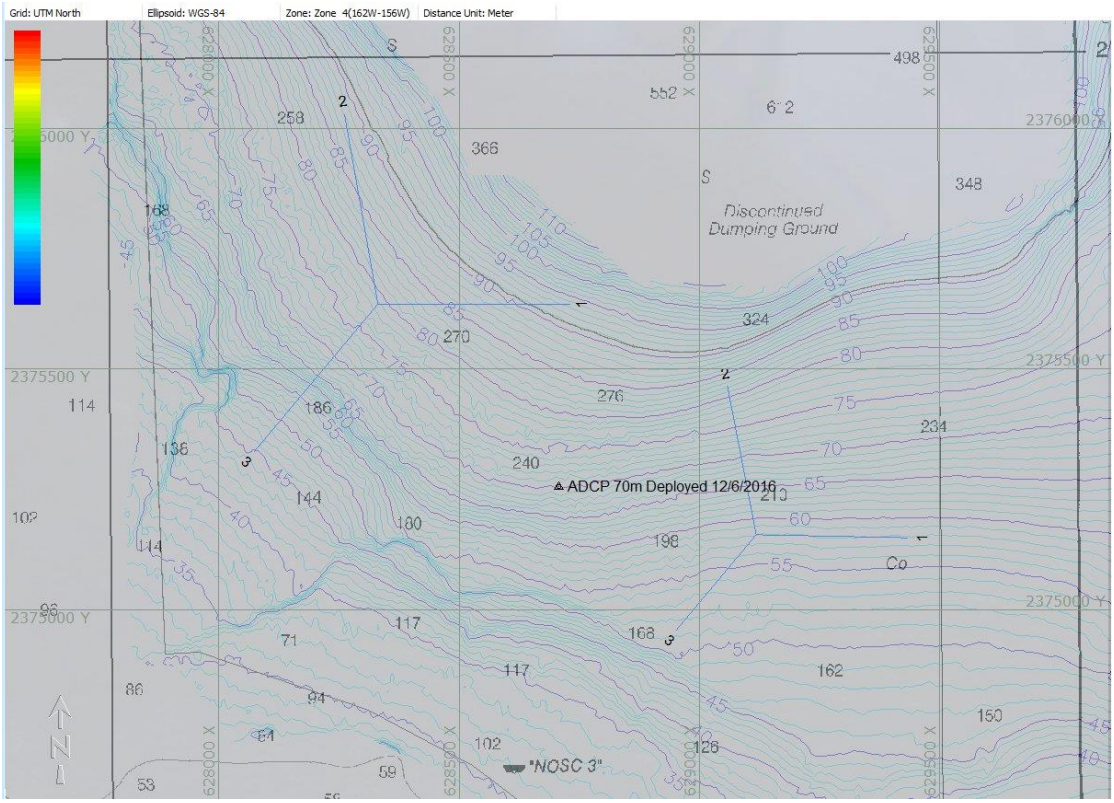

Figure 1-2 WETS 70m Depth Deployment Location

Table 1-1 ADCP Deployment Schedule and Locations

Deployment Date	Task	Retrieval Date	Task	Location	Coordinates	Depth
11/13/2014	Previous WETS Funding	2/26/2015	4A	Near Waverider	21° 28' 39.1813" N 157° 44' 56.3008" W	78m
2/26/2015	4A	6/4/2015	4B	Near Waverider	21° 28' 39.1813" N 157° 44' 56.3008" W	78m
7/6/2015	4B	10/14/2015	4C	30m Site	21° 27' 56.1738" N 157° 45' 5.0563" W	31m
10/19/2015	4C	1/13/2016	4D	30m Site	21° 27' 55.9741" N 157° 45' 4.1280" W	31m
1/14/2016	4D	8/3/2016	1H	30m Site	21° 27' 55.9801" N 157° 45' 4.9739" W	31m
12/6/2016	4E	4/14/2017	4G	Between 60m and 80m Sites	21° 28' 30.8115" N 157° 45'27.6232" W	70m

The Sentinel V100 ADCP uses a vertical acoustic beam to measure the distance to the water surface. Sound waves reflect off the water surface and the time a reflection takes to return to the ACDP is used to determine the distance to the surface. Accurate wave statistics can be computed from the measured water surface elevation record. An ADCP relies on the Doppler effect to determine the water currents through the water column. The direction of current can be determined by using three or four acoustic beams. The acoustic reflection of a beam that is up current from the ACDP will arrive before the reflection of down current acoustic reflection. With the reflection return timing of multiple beams, the direction of waves and currents can be calculated.

2. TELEDYNE RDI SENTINEL V100 SETUP

The Sentinel V100 was programmed to measure both waves and currents. ReadyV software from Teledyne RDI was used to program the Sentinel V100 ADCP. The software calculates the available battery resources and data storage for desired measurement profiles. The custom wave and current measurement profiles have the following settings:

Table 2-1 Profile Parameters

	Waves Measurement Profile	Current Measurement Profile
Ping Interval (seconds)	0.5	1
Number of Pings	2300	300
Range (meters)	75	75
Cell Size (meters)	1.0	1.0
Duration(minutes)	19.166	5

The wave measurement occurs once per hour over a 19 minute and 10 seconds period. Current measurements occur over a 5-minute period 30 minutes after the start of the wave measurements. This setup was chosen to accommodate a deployment duration of approximately 90 days.

3. SENTINEL V100 DATA

The recorded wave and current data for the deployment period required 10.6 GB of data storage; the wave data comprised 6.93 GB. Teledyne RDI provides multiple software options to display and process the data. The primary data viewing and processing software is Velocity.

The direction that the Sentinel V100 ADCP references is magnetic north. These readings were converted to a true north reference using the magnetic declination values for the location of the ADCP on Oahu. The magnetic declination for WETS is 9.55° East.

Initial processing indicated that data recorded between December 6, 2017 and February 2, 2017 was faulty. The ADCP motion sensor data for the January 10, 2017 to February 2, 2017 (Figure 3-1) reveal a roll angle of ~-50° and a pitch angle of 25°. This suggests that during the deployment the ADCP landed on top of an object such as a rock that deflected the unit from a vertical orientation, or that the tripod mount sunk into soft sediment and skewed the ADCP.

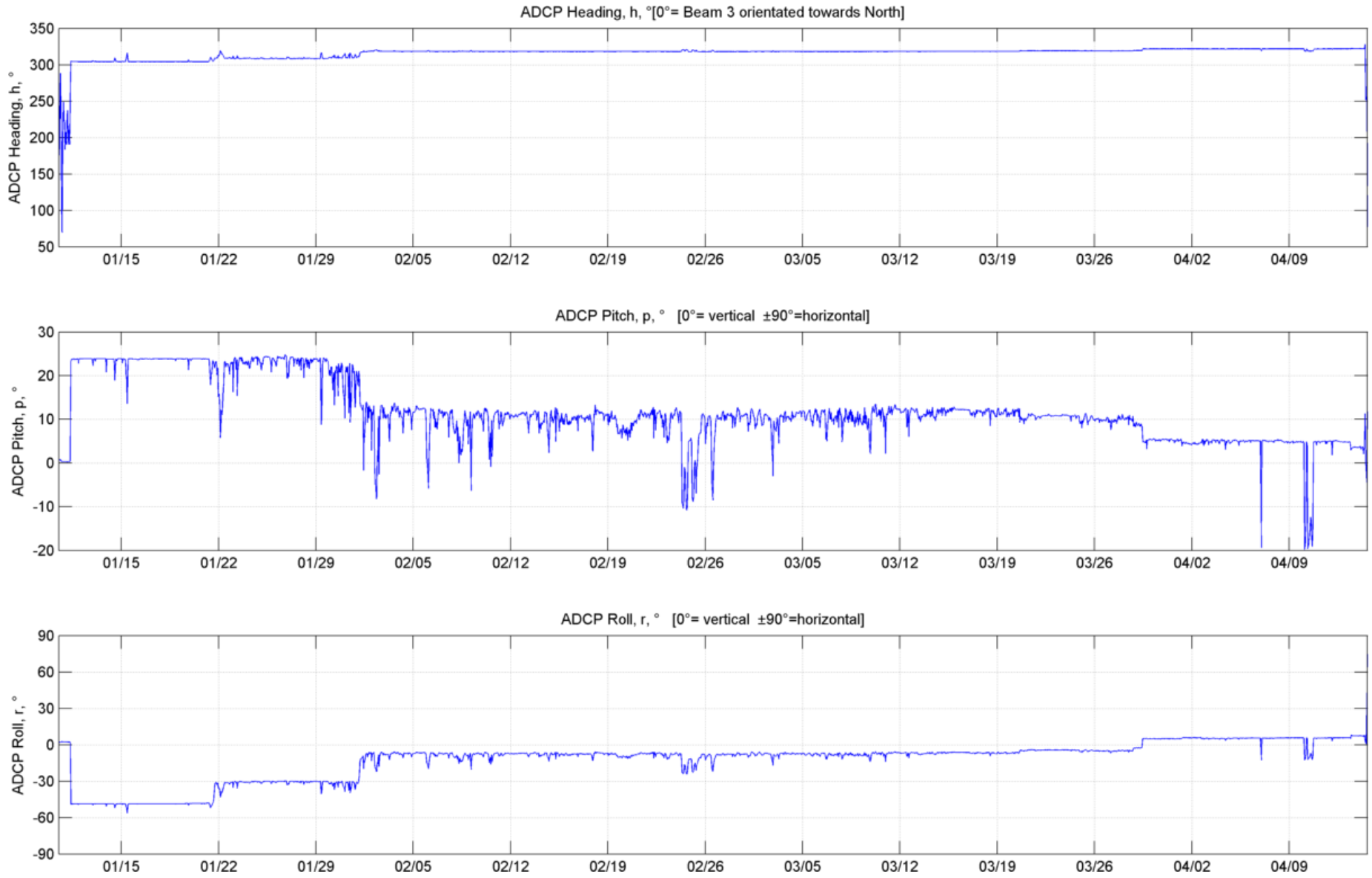

Figure 3-1 Heading, Pitch, and Roll of ADCP

3.1 Currents

Velocity software was used to average the current data into half-hour blocks. The waves profile (19min 10sec of recording) is averaged to represent the current in the bottom half of the hour and the currents profile (5min of recording) is averaged to represent the current in the top half of the hour.

The water column was divided into three layers for analysis. Table 3-1, shows the bins and associated water depths corresponding to the three layers. Near surface data is biased by side lobe interference, and is not included.

Table 3-1 Water Column Layer Divisions

	Bins	Range from ADCP, meters	Water Depth, meters
Bottom Layer	1 - 5	3.05 – 8.05	~ 61.8 – 66.8
Middle Layer	32 - 37	34.05 – 40.05	~ 28.8- 35.8
Upper Layer	53 - 58	55.05 – 60.05	~ 8.8-14.8

Figure 3-2 shows the time series current speed and direction for the three layers of water. Figure 3-3 shows the time series for current speed and direction for all the bins measured by the ADCP. The water surface is plotted as a black line on top of the current data. The measurements above the red line are biased due to side lobe interference. The gaps (white spaces) near the surface are periods of time where the orientation of the ADCP was altered so the cone of recording did not reach the surface. Figure 3-4, Figure 3-5, and Figure 3-6 are current rose plots for upper, middle, and bottom layers, respectively. Table 3-2, Table 3-3, and Table 3-4 present the percent occurrence of currents speed and direction.

Upper layer currents flow in a predominantly towards the southeast with an average speed of 0.11 m/s, and a maximum recorded speed of 0.60 m/s for the deployment (February 2, 2017 to April 14, 2016). Mid-layer currents flow predominantly east southeasterly, occurring 24% of the deployment duration. Bottom layer currents magnitudes are smaller and occur with greater occurrence in all directions. The upper layer's maximum current is almost double the middle and bottom layer's maximum current.

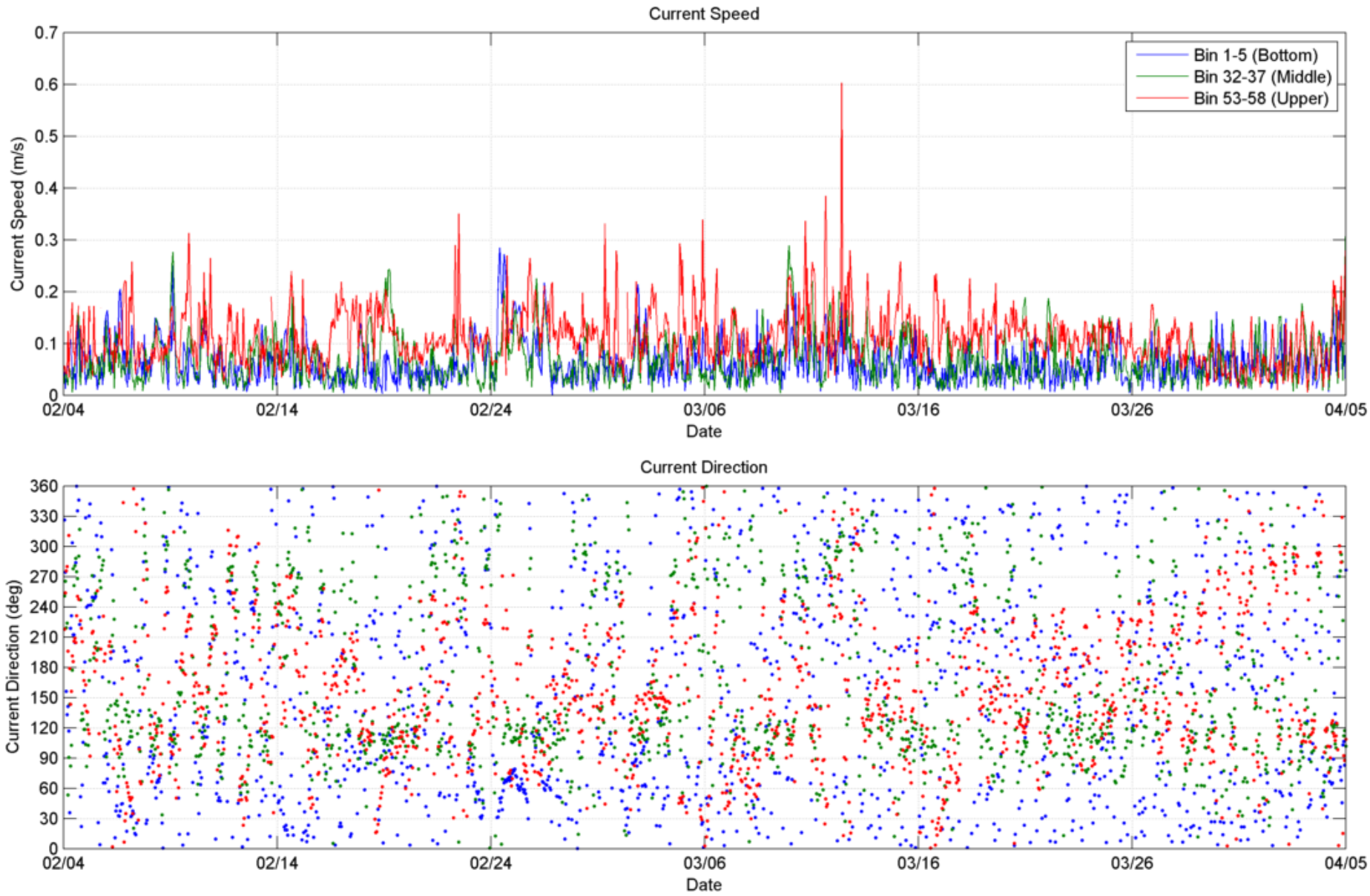

Figure 3-2 Current Speed and Direction for Each Layer

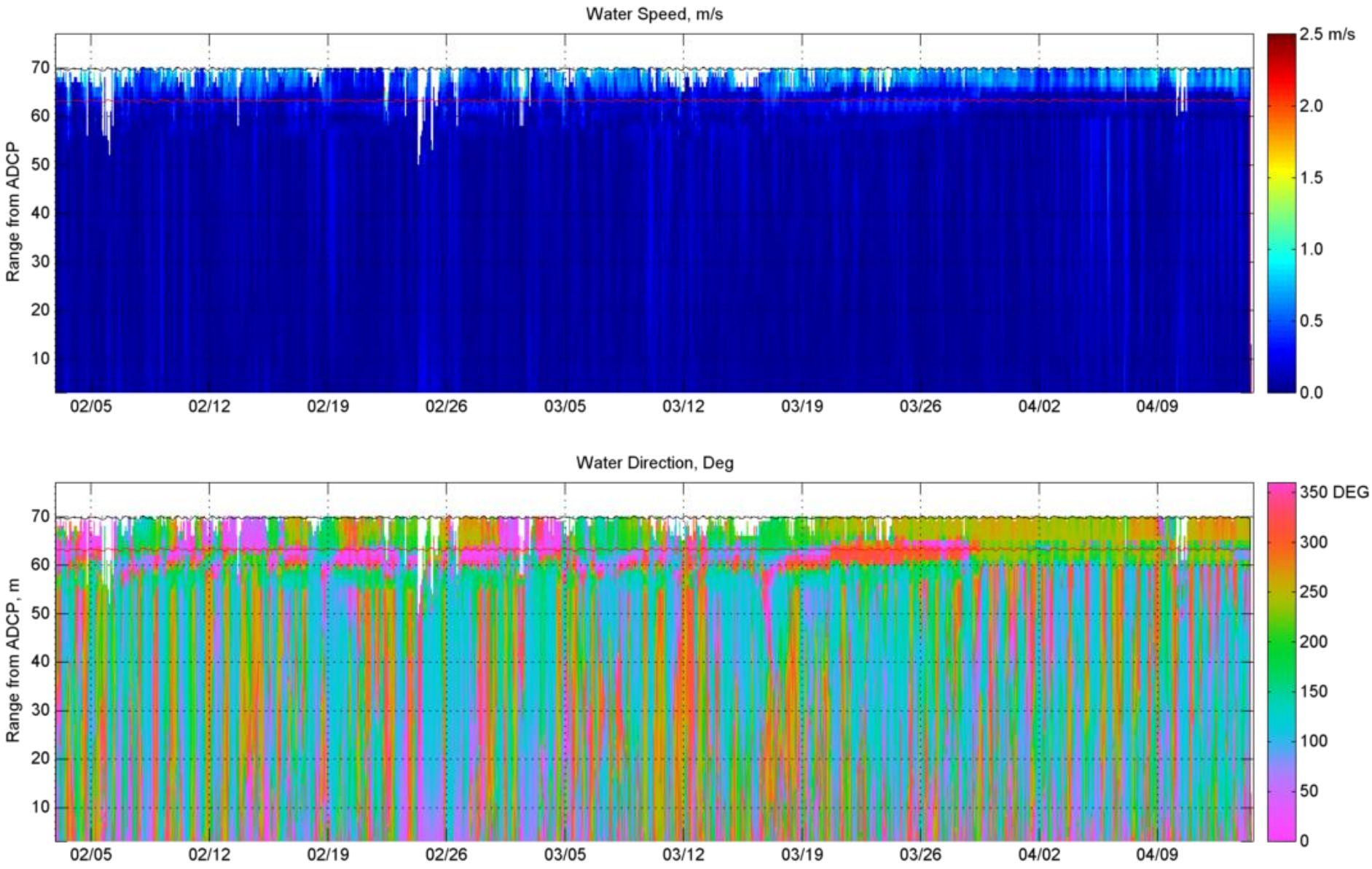

Figure 3-3 Current Speed and Direction for All Bins

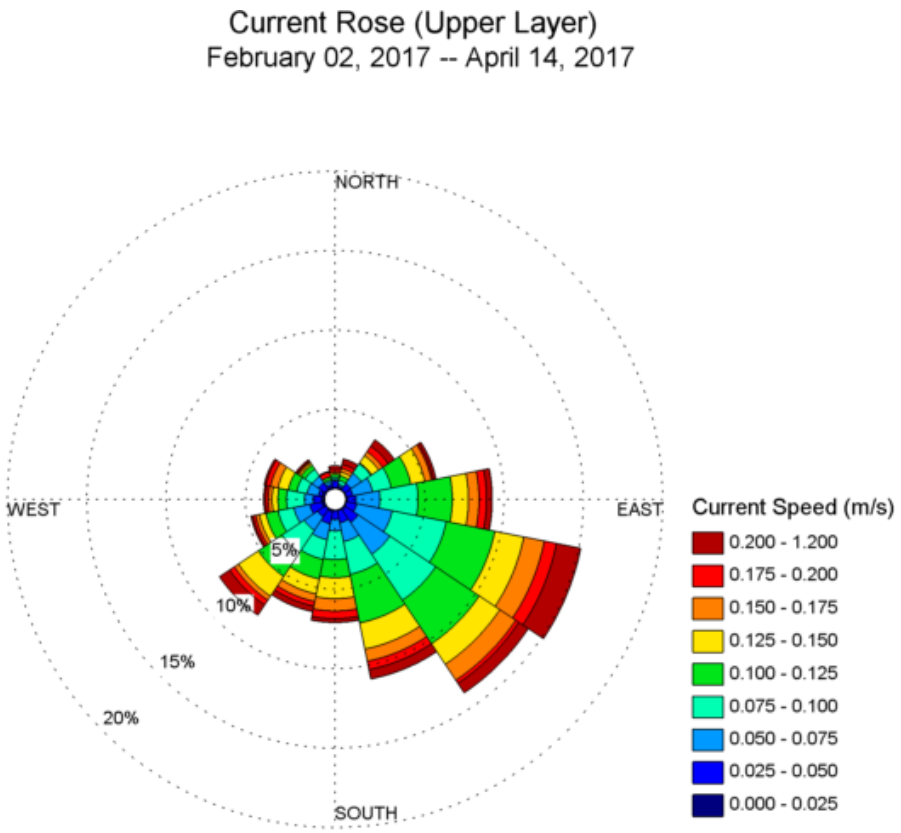

Figure 3-4 Current Rose for Upper Layer

Table 3-2 Upper Layer Current Frequency of Occurrence

Current Speed, m/s		Total % by Direction in Deg																
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.000	-0.025	0.06	0.06	0.06	0.06	0.12	0.06	0.12	0.06		0.12	0.06	0.18	0.18	0.18	0.12	0.12	1.56
0.025	-0.050	0.42	0.12	0.48	0.42	0.54	0.66	0.96	0.78	0.60	0.78	0.60	0.78	0.54	0.24	0.48	0.18	8.59
0.050	-0.075	0.12	0.12	0.78	1.26	1.50	2.28	2.40	1.20	0.72	1.02	1.02	1.02	0.54	0.72	0.48	0.18	15.38
0.075	-0.100	0.12	0.24	0.72	1.20	2.40	3.48	3.48	2.10	1.80	1.26	1.68	1.02	1.14	0.66	0.54	0.12	21.98
0.100	-0.125	0.18	0.30	0.06	1.26	2.16	3.12	3.30	3.12	1.14	1.26	1.80	0.78	0.54	0.54	0.30	0.18	20.06
0.125	-0.150	0.12	0.24	0.54	0.90	1.02	1.86	1.56	1.68	1.32	0.96	1.50	0.42	0.36	0.66	0.12		13.27
0.150	-0.175		0.24	0.30	0.42	0.66	1.32	1.20	0.78	0.78	0.48	0.30	0.24	0.24	0.48	0.12		7.57
0.175	-0.200	0.18	0.24	0.42	0.12	0.48	0.78	0.24	0.54	0.48	0.30	0.36	0.18	0.18	0.30	0.06	0.30	5.17
0.200	-1.200	0.24	0.36	0.48	0.18	0.36	1.56	0.72	0.60	0.24	0.36	0.78	0.12	0.12	0.12	0.12	0.06	6.43
Total %		**1.44**	**1.92**	**3.84**	**5.83**	**9.25**	**15.14**	**13.99**	**10.87**	**7.09**	**6.55**	**8.11**	**4.74**	**3.84**	**3.90**	**2.34**	**1.14**	**100.00**
Mean		0.12	0.14	0.12	0.10	0.11	0.12	0.11	0.11	0.11	0.11	0.12	0.09	0.10	0.11	0.09	0.10	**0.11**
StDev		0.08	0.07	0.08	0.04	0.05	0.06	0.05	0.04	0.05	0.05	0.07	0.05	0.05	0.06	0.06	0.07	**0.06**
Min		0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.01	0.01	0.02	0.02	0.02	**0.01**
Max		0.34	0.28	0.38	0.28	0.35	0.45	0.32	0.24	0.26	0.24	0.60	0.34	0.24	0.39	0.29	0.21	**0.60**

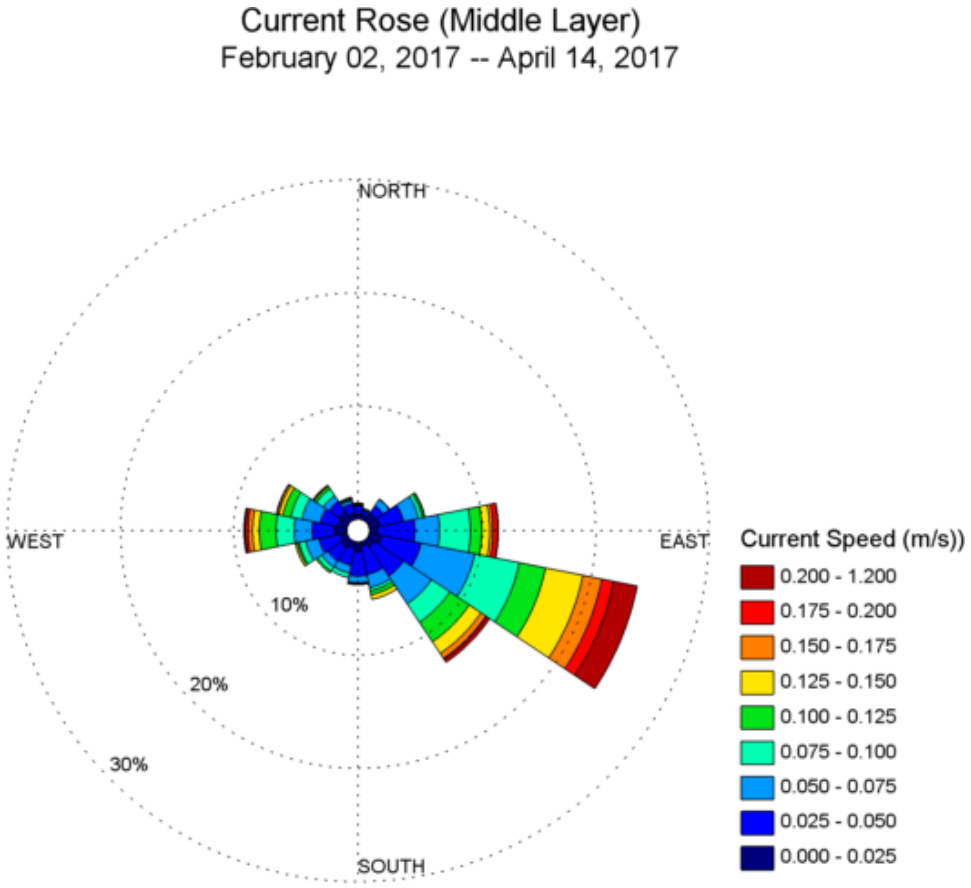

Figure 3-5 Current Rose for Middle Layer

Table 3-3 Middle Layer Current Frequency of Occurrence

Current Speed, m/s		Total % by Direction in Deg																
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.000	-0.025	0.47	0.41	0.89	0.94	0.71	1.12	0.71	0.41	0.83	0.59	0.83	0.59	1.12	0.83	1.00	0.53	11.98
0.025	-0.050	0.71	0.35	0.77	2.13	3.31	3.54	3.13	2.54	2.18	1.53	1.42	1.95	1.95	1.59	1.12	0.89	29.10
0.050	-0.075	0.06	0.12	0.65	1.36	2.18	4.84	2.95	1.18	0.59	0.71	0.65	1.18	1.59	1.65	0.59	0.30	20.60
0.075	-0.100	0.06	0.12	0.06	0.35	2.72	4.01	1.95	0.30	0.12	0.41	0.41	0.59	1.59	1.00	0.71	0.12	14.52
0.100	-0.125	0.06			0.18	1.00	2.36	2.07	0.35	0.06		0.18	0.18	1.48	0.71	0.24	0.12	8.97
0.125	-0.150	0.06			0.06	0.71	3.36	1.24	0.41				0.18	0.59	0.35		0.06	7.02
0.150	-0.175					0.30	1.71	0.53						0.41	0.18	0.12		3.25
0.175	-0.200					0.41	1.06	0.06						0.24		0.06		1.83
0.200	-1.200					0.06	2.13	0.35						0.12	0.06			2.72
Total %		**1.42**	**1.00**	**2.36**	**5.02**	**11.39**	**24.14**	**12.99**	**5.19**	**3.78**	**3.25**	**3.48**	**4.66**	**9.09**	**6.38**	**3.84**	**2.01**	**100.00**
Mean		0.04	0.04	0.04	0.05	0.08	0.11	0.08	0.06	0.04	0.04	0.05	0.05	0.08	0.07	0.05	0.04	**0.07**
StDev		0.03	0.03	0.02	0.03	0.04	0.06	0.05	0.03	0.02	0.02	0.03	0.03	0.05	0.04	0.04	0.03	**0.05**
Min		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	**0.00**
Max		0.14	0.10	0.09	0.13	0.23	0.39	0.28	0.15	0.10	0.09	0.12	0.14	0.21	0.20	0.20	0.13	**0.39**

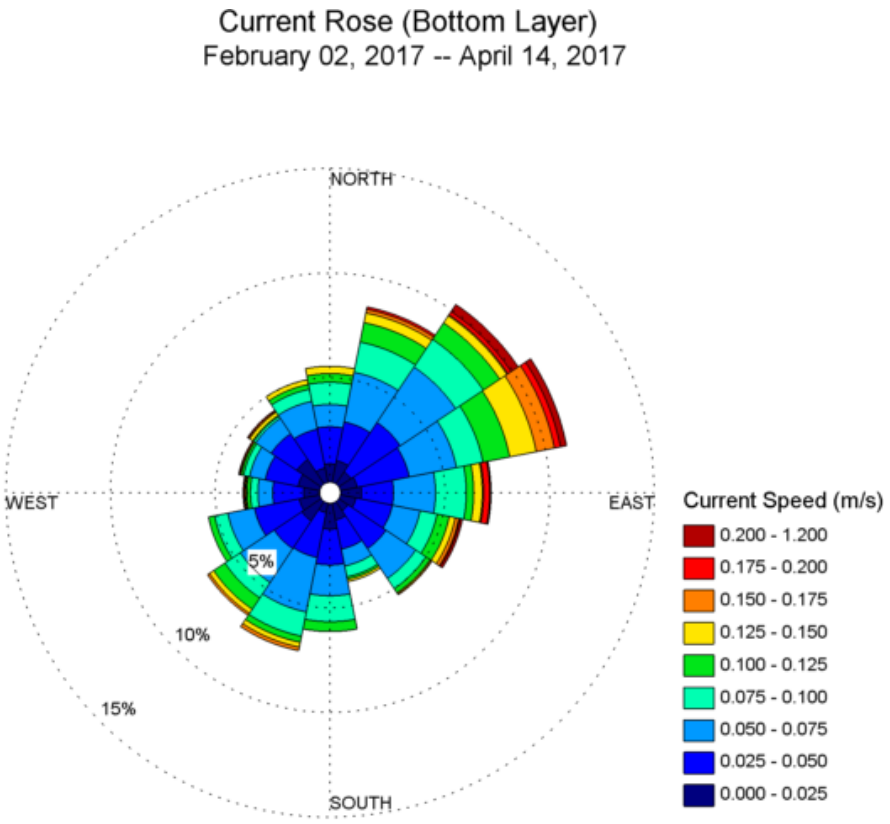

Figure 3-6 Current Rose for Bottom Layer

Table 3-4 Bottom Layer Current Frequency of Occurrence

Current Speed, m/s		Total % by Direction in Deg																
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.000	-0.025	0.88	1.06	0.71	0.83	1.00	0.77	0.53	0.83	1.24	0.47	1.12	1.00	0.77	1.06	1.42	0.71	14.40
0.025	-0.050	1.77	1.89	2.83	2.54	1.53	1.77	2.18	1.42	1.71	2.18	1.59	2.18	1.47	1.59	1.47	1.89	30.03
0.050	-0.075	1.06	2.42	3.19	2.30	2.01	1.36	1.71	0.83	1.47	2.65	1.95	1.30	0.71	0.77	0.88	1.36	25.96
0.075	-0.100	1.06	1.47	1.59	1.30	1.47	0.83	0.59	0.53	1.24	1.18	0.88	0.65	0.35	0.29	0.12	0.59	14.16
0.100	-0.125	0.41	0.94	0.94	1.30	0.35	0.59	0.24	0.12	0.47	0.29	0.65	0.29	0.18	0.12	0.06	0.24	7.20
0.125	-0.150	0.35	0.47	0.41	1.30	0.41	0.29	0.06	0.12		0.24	0.24		0.06	0.06	0.18	0.24	4.42
0.150	-0.175		0.18	0.06	0.88	0.06	0.18	0.06			0.18	0.12		0.06		0.06		1.83
0.175	-0.200		0.12	0.18	0.29	0.29	0.06							0.06	0.06			1.06
0.200	-1.200			0.41	0.29	0.06	0.12									0.06		0.94
Total %		**5.55**	**8.55**	**10.32**	**11.03**	**7.20**	**5.96**	**5.37**	**3.83**	**6.14**	**7.20**	**6.55**	**5.43**	**3.66**	**3.95**	**4.25**	**5.01**	**100.00**
Mean		0.06	0.07	0.07	0.09	0.07	0.07	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	**0.06**
StDev		0.04	0.04	0.05	0.05	0.04	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.04	0.03	**0.04**
Min		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00	**0.00**
Max		0.15	0.20	0.35	0.27	0.23	0.25	0.16	0.15	0.12	0.17	0.16	0.12	0.18	0.20	0.23	0.15	**0.35**

3.2 Waves

The WavesMon module of Velocity was used to calculate hourly wave statistics. The three statistics of most importance to wave characterization are the significant wave height (H_s), peak period (T_p), and peak direction (D_p). The direction that the Sentinel V100 ADCP references is magnetic north. These readings were converted to a true north reference using the magnetic declination values for the location of the ADCP on Oahu. The magnetic declination for WETS is 9.55° East. A second program, WavesView, is used to display the spectral data alongside the wave statistics.

A screenshot of the settings for WavesMon is presented in Figure 3-7.

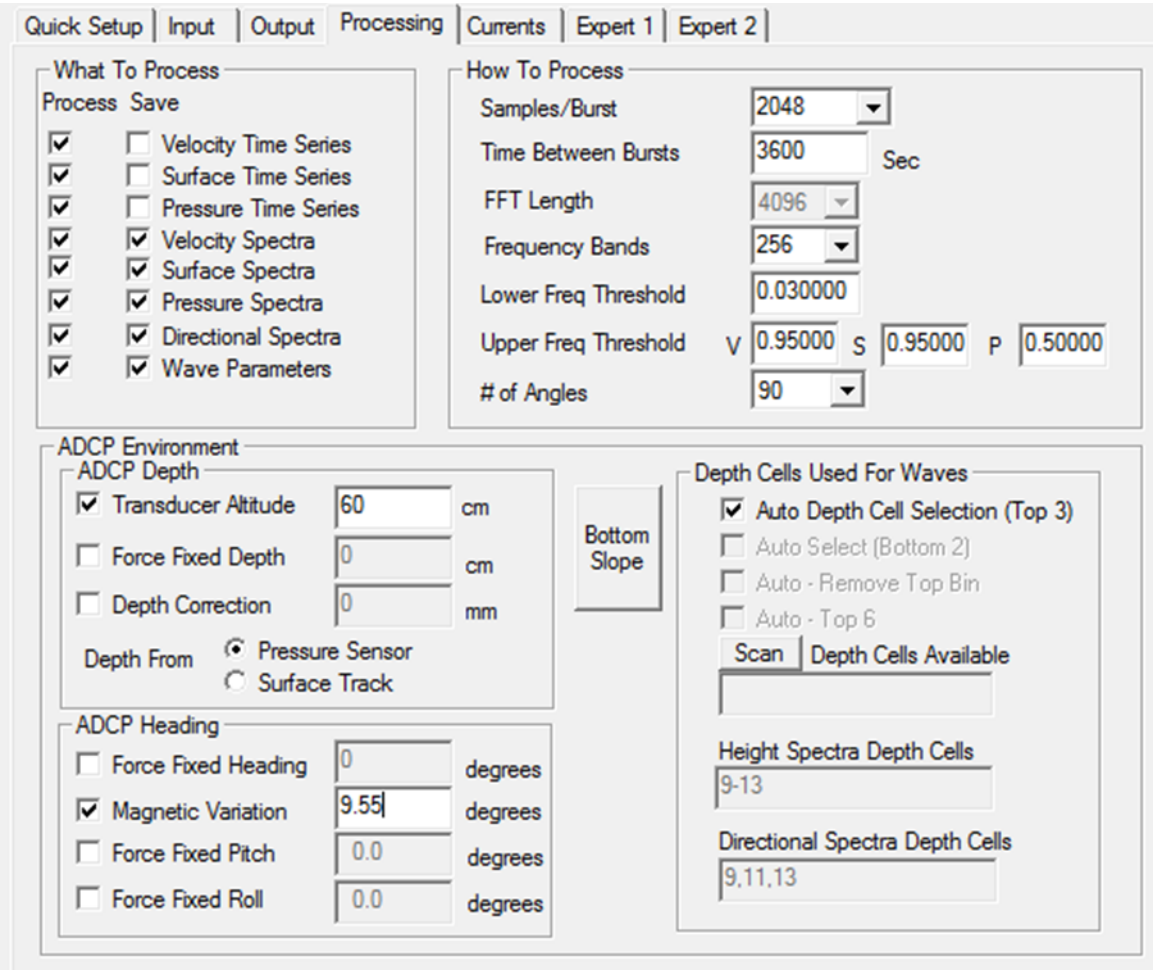

Figure 3-7 WavesMon Processing Tab

Figure 3-8 shows the time series of significant wave height, peak period, and peak direction for the deployment. Figure 3-9 shows the wave height rose which is dominated by the trade wind driven waves from the northeast with shorter periods. Table 3-5 presents the percent frequency of wave height and direction. Figure 3-9 presents the wave period rose. Table 3-6 presents the percent frequency of wave peak period and direction.

The time series, Figure 3-8, indicates typical wave heights of approximately 1.0 – 2.0m from an east-northeast direction indicative of trade wind generated swell, with a distinct peaks with wave heights greater than 3m on February 20, 2017.

The wave height rose shown in Figure 3-9, and Table 3-5, indicates waves from a northwesterly to northeasterly direction (337.5° - 67.5°) occur 79% of the time. Waves are greater than 1.0m 89% of the time. The average wave height is 1.51m and maximum wave height was 3.43m.

The period rose shown in Figure 3-10, and Table 3-6, show the mean period was 9.83 seconds and the maximum period was 15.50 seconds.

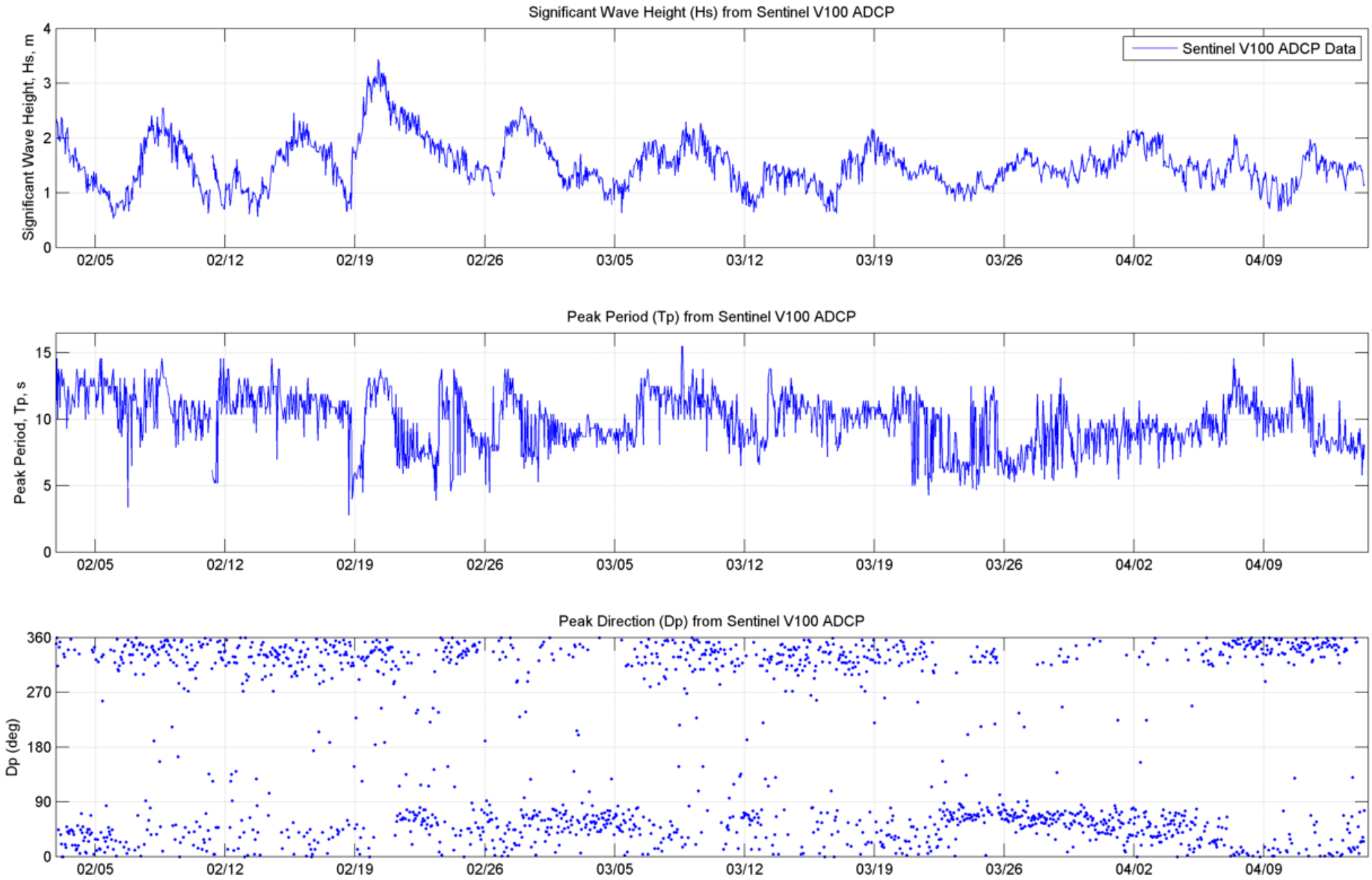

Figure 3-8 Wave Height, Peak Period, and Peak Direction

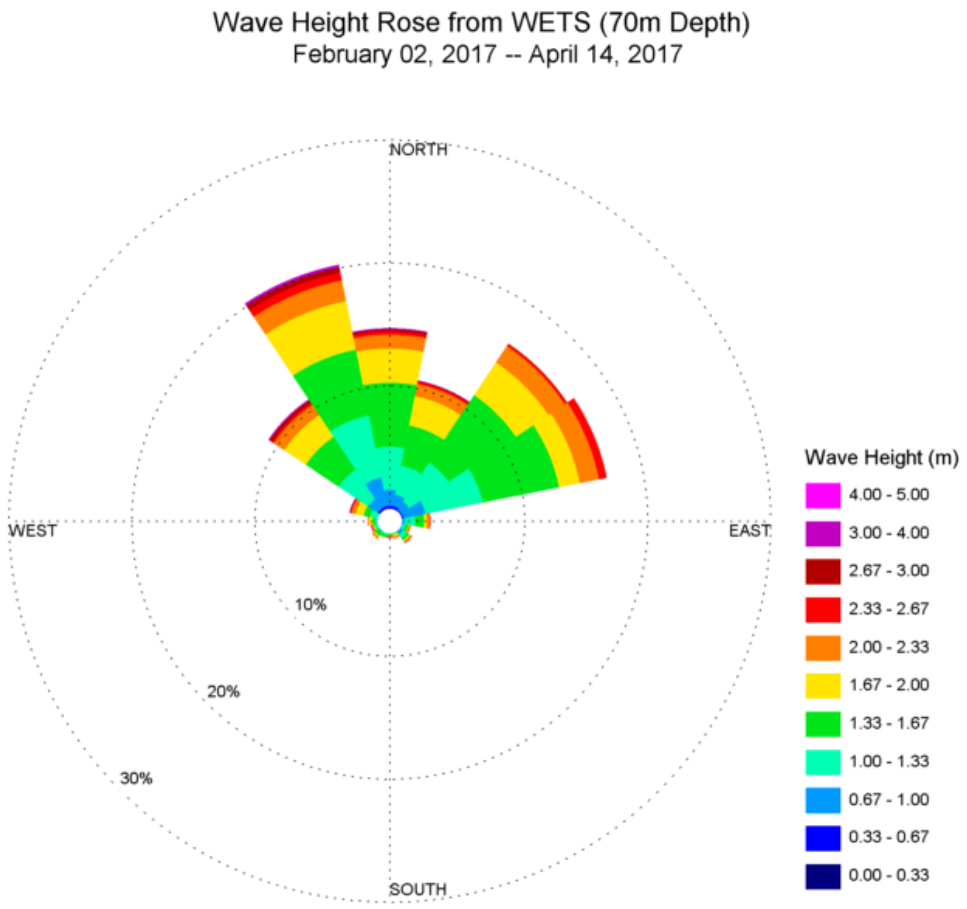

Figure 3-9 Wave Height Rose

Table 3-5 Wave Height Frequency of Occurrence

Wave Height, m	Total % by Direction in Deg															
	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.00 -0.33																	0.00
0.33 -0.67	0.24	0.24	0.12	0.12											0.18	0.24	1.13
0.67 -1.00	1.30	0.95	0.77	1.84	0.24	0.06	0.30				0.06		0.06		0.95	2.37	8.89
1.00 -1.33	3.50	2.43	3.85	4.74	0.83	0.24	0.36	0.06		0.18	0.06	0.24	0.12	0.65	2.90	5.16	25.31
1.33 -1.67	5.22	3.32	6.58	6.34	0.71	0.24	0.24	0.06	0.12	0.18	0.36	0.06	0.24	0.53	3.20	5.45	32.84
1.67 -2.00	2.79	2.43	3.20	1.72	0.24	0.06	0.12	0.18	0.06	0.06	0.12	0.12	0.36	0.65	2.13	4.03	18.26
2.00 -2.33	1.13	1.01	1.60	1.60	0.24	0.18	0.12	0.18	0.06		0.18	0.06		0.36	1.01	1.72	9.43
2.33 -2.67	0.24	0.18	0.18	0.65	0.06		0.06					0.06	0.06	0.12	0.18	0.65	2.43
2.67 -3.00	0.18	0.06	0.06						0.06						0.24	0.41	1.01
3.00 -4.00	0.12	0.06							0.06			0.06		0.06	0.12	0.24	0.71
4.00 -5.00																	0.00
Total %	14.70	10.67	16.36	17.01	2.31	0.77	1.19	0.47	0.36	0.41	0.77	0.59	0.83	2.37	10.91	20.27	100.00
Mean	1.50	1.50	1.53	1.46	1.42	1.50	1.34	1.83	2.17	1.39	1.64	1.76	1.61	1.67	1.53	1.52	1.51
StDev	0.44	0.43	0.36	0.41	0.37	0.39	0.48	0.31	0.71	0.24	0.38	0.67	0.37	0.47	0.48	0.50	0.44
Max	0.64	0.53	0.57	0.66	0.85	1.00	0.76	1.22	1.43	1.11	0.91	1.01	0.98	1.01	0.58	0.59	0.53
Min	3.02	3.09	2.75	2.58	2.35	2.13	2.40	2.14	3.13	1.73	2.30	3.19	2.53	3.19	3.43	3.36	3.43

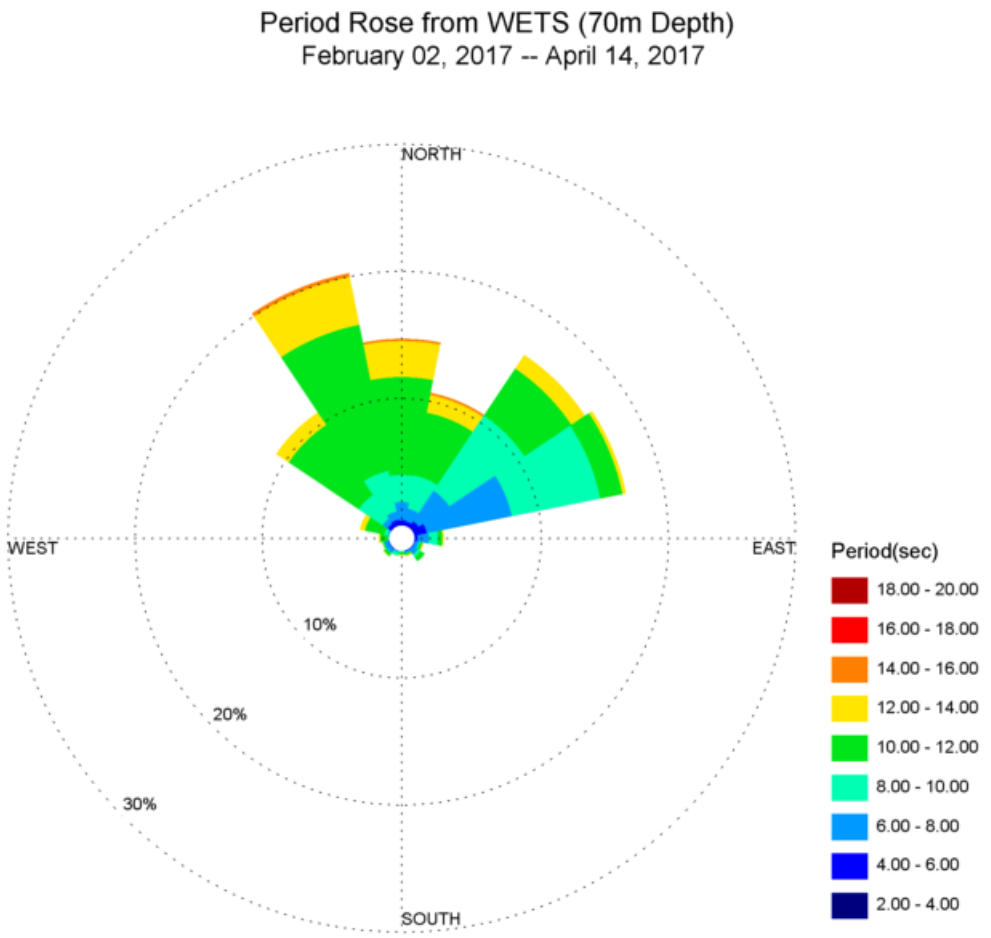

Figure 3-10 Period Rose

Table 3-6 Wave Period Frequency of Occurrence

Wave Period, s	Total % by Direction in Deg																
	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
2 -4	0.06		0.06													0.06	0.18
4 -6	0.36	0.36	0.53	1.01	0.24	0.06	0.06	0.06			0.06	0.06			0.36	0.41	3.56
6 -8	1.42	1.01	2.90	6.82	0.89	0.30	0.47	0.12		0.12	0.36	0.36	0.06	0.12	0.47	0.65	16.06
8 -10	2.13	2.67	7.11	7.11	0.71	0.12	0.24	0.06	0.12	0.24	0.06	0.06	0.06	0.30	2.25	3.26	26.50
10 -12	7.71	5.04	4.45	1.78	0.36	0.18	0.41	0.12	0.18	0.06	0.24	0.06	0.59	1.54	6.64	11.74	41.08
12 -14	2.85	1.42	1.30	0.30	0.12	0.12		0.12	0.06		0.06	0.06	0.12	0.41	1.19	3.85	11.97
14 -16	0.18	0.18														0.30	0.65
16 -18																	0.00
18 -20																	0.00
Total %	**14.70**	**10.67**	**16.36**	**17.01**	**2.31**	**0.77**	**1.19**	**0.47**	**0.36**	**0.41**	**0.77**	**0.59**	**0.83**	**2.37**	**10.91**	**20.27**	**100.00**
Mean	10.52	10.27	9.35	8.19	8.20	9.12	8.55	9.33	10.75	8.54	8.58	8.03	10.74	10.73	10.42	10.79	**9.83**
StDev	1.97	2.02	1.86	1.55	1.96	2.78	1.85	3.04	1.42	1.53	2.37	2.43	1.48	1.44	1.75	1.78	**2.07**
Min	3.40	4.30	2.80	4.70	4.50	5.30	5.60	5.90	9.00	6.20	5.80	5.60	6.50	6.50	4.30	3.90	**2.80**
Max	14.60	15.50	13.80	13.10	12.50	13.10	11.90	13.80	12.50	10.40	13.10	13.10	12.50	13.10	13.80	14.60	**15.50**

REPORT:

Task 4H Report - ADCP Data Analysis at WETS (70m Depth)

August 2017

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The area north of the Mōkapu Peninsula, adjacent to Kāneʻohe Marine Corps Base Hawaiʻi (MCBH), has been utilized by the U.S. Navy for wave energy research since 2002. Prototype wave energy converters (WEC) are being tested at the 30m, 60m, and 80m berths offshore of North Beach at the MCBH. The Hawaiʻi National Marine Renewable Energy Center (HNMREC) at the University of Hawaiʻi under contract with Department of Energy and the U.S. Navy, operates the test site.

Sea Engineering has been contracted by the HNMREC to conduct site investigations in support of the test site. One of these investigations is to determine wave climate at the site and current characteristics.

The project location within the state of Hawaiʻi is shown in Figure 1-1. The test site is 1600m to 2000m wide and extends approximately 2600m offshore from the 30m depth contour to the approximate 100m depth contour.

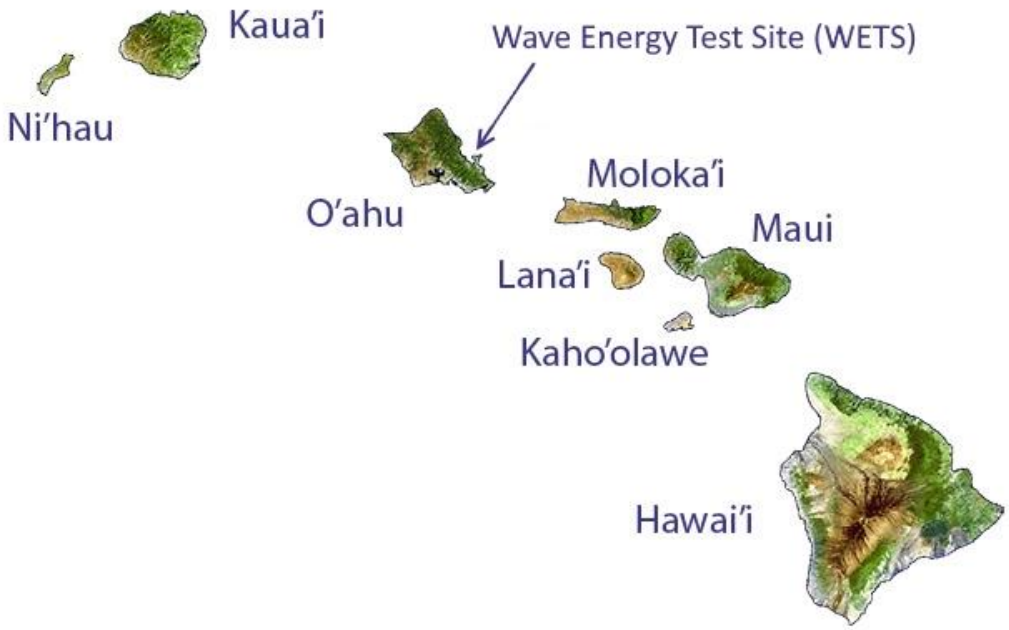

Figure 1-1 Project Location

In collaboration with HNMREC, Sea Engineering Inc. deployed a Teledyne RDI Sentinel V100 Acoustic Doppler Current Profiler (ADCP) in the Wave Energy Test Site (WETS) since November 2014. Previous deployments were at the 30m site and the Waverider buoy. In December 2016, the ADCP was deployed at the 70m depth between the 60m and 80m sites. Figure 1-2 shows the deployment location of the ADCP.

Table 1-1 shows the ADCP deployment schedule and the coordinates of the deployment. This report presents

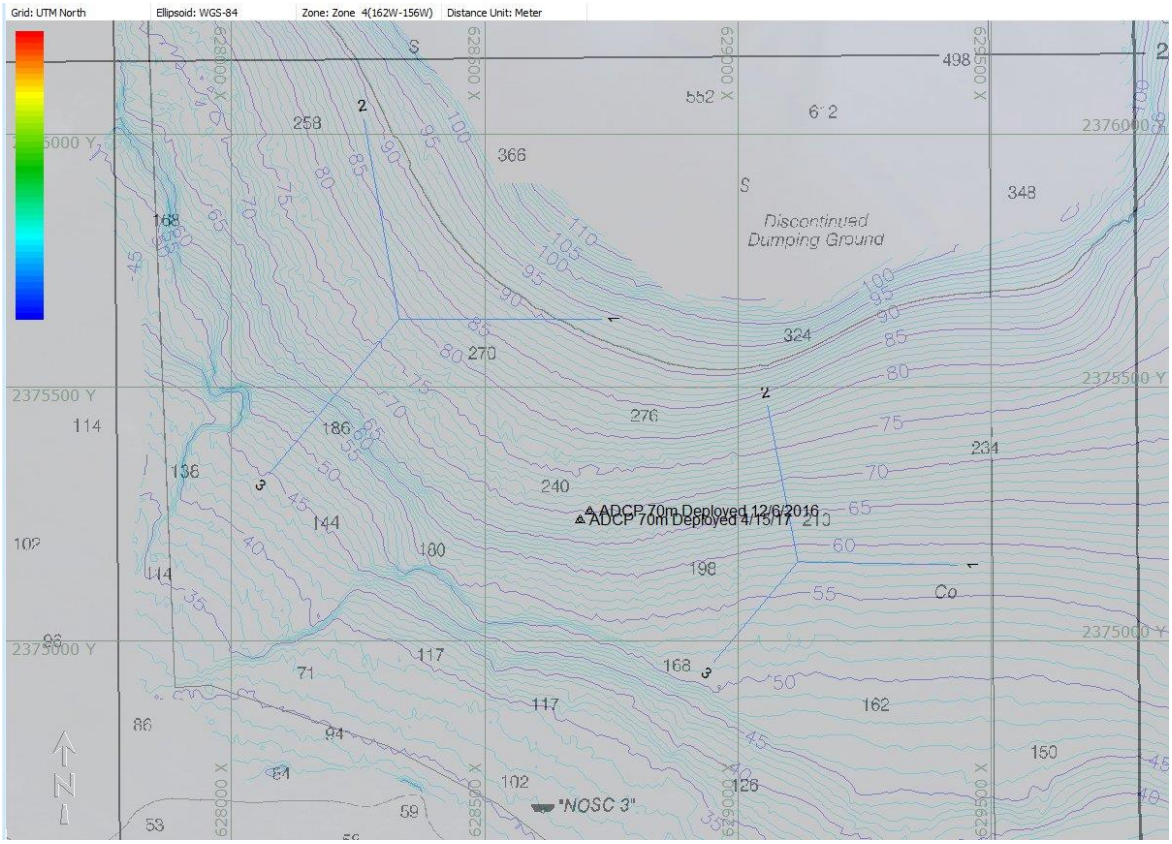

Figure 1-2 WETS 70m Depth Deployment Location

Table 1-1 ADCP Deployment Schedule and Locations

Deployment Date	Task	Retrieval Date	Task	Location	Coordinates	Depth
11/13/2014	Previous WETS Funding	2/26/2015	4A	Near Waverider	21° 28' 39.1813" N 157° 44' 56.3008" W	78m
2/26/2015	4A	6/4/2015	4B	Near Waverider	21° 28' 39.1813" N 157° 44' 56.3008" W	78m
7/6/2015	4B	10/14/2015	4C	30m Site	21° 27' 56.1738" N 157° 45' 5.0563" W	31m
10/19/2015	4C	1/13/2016	4D	30m Site	21° 27' 55.9741" N 157° 45' 4.1280" W	31m
1/14/2016	4D	8/3/2016	1H	30m Site	21° 27' 55.9801" N 157° 45' 4.9739" W	31m
12/6/2016	4E	4/14/2017	4G	Between 60m and 80m Sites	21° 28' 30.8115" N 157° 45'27.6232" W	70m
B1 secured	4F	B1 secured	4F	--	--	--
4/15/17	4G	8/2/2017	4H	Between 60m and 80m Sites	21° 28' 30.2881" N 157° 45'28.3139" W	69m
8/3/2017	4H				21° 28' 30.1335" N 157° 45'29.3408" W	69m

The Sentinel V100 ADCP uses a vertical acoustic beam to measure the distance to the water surface. Sound waves reflect off the water surface and the time a reflection takes to return to the ACDP is used to determine the distance to the surface. Accurate wave statistics can be computed from the measured water surface elevation record. An ADCP relies on the Doppler effect to determine the water currents through the water column. The direction of current can be determined by using three or four acoustic beams. The acoustic reflection of a beam that is up current from the ACDP will arrive before the reflection of down current acoustic reflection. With the reflection return timing of multiple beams, the direction of waves and currents can be calculated.

At the start of the ADCP's deployment the sensors show that the roll angle was ~-50° and the pitch angle was ~22°. The ADCP would have a roll and pitch angle of 0° if oriented vertically. Figure 3-1 shows the heading, pitch, and roll angles for the deployment. Typically, the heading is very stable with rare changes of 2-4 degrees associated with the ADCP mount settling in to the sand. The pitch and roll generally vary 2-4 degrees as the ADCP rotates in the gimble mount forced by drag from currents. From April 15 to April 21, 2017 the orientation of the ADCP made the current and wave data it collected unusable. The ADCP's roll angle varied approximately from to -32° to -20° from April 21, 2017 to June 1, 2017. Similarly, the pitch angle varied greatly from 20° to 5° from April 21, 2017 to June 1, 2017. After June 1, 2017, the pitch angle variations lessened to about 5° centered at 18°. The roll angle varies about 5° centered at -20°. Finally, the on July 2, 2017 the hourly variation in pitch and roll cease. The wave and current data presented in this report is from April 24, 2017 to July 19, 2017. The orientation of the ADCP throughout the deployment did not allow for the acoustic beams to reach the surface. Current data is generally unaffected by the angle variation and the angle variation is accounted for in the processing. Current data at the surface is out of the range of the acoustic beams and cannot be calculated. Wave parameter measurement is affected. The peak direction of the wave is not well resolved. The wave height was calculated using the orbital velocities of particles in the middle of the water column and the pressure under the passing wave and not the surface track of the wave.

2. TELEDYNE RDI SENTINEL V100 SETUP

The Sentinel V100 was programmed to measure both waves and currents. ReadyV software from Teledyne RDI was used to program the Sentinel V100 ADCP. The software calculates the available battery resources and data storage for desired measurement profiles. The custom wave and current measurement profiles have the following settings:

Table 2-1 Profile Parameters

	Waves Measurement Profile	Current Measurement Profile
Ping Interval (seconds)	0.5	1
Number of Pings	2300	300
Range (meters)	75	75
Cell Size (meters)	1.0	1.0
Duration(minutes)	19.166	5

The wave measurement occurs once per hour over a 19 minute and 10 seconds period. Current measurements occur over a 5-minute period 30 minutes after the start of the wave measurements. This setup was chosen to accommodate a deployment duration of approximately 90 days. The external battery housing was not need since the alkaline batteries have been replaced with lithium batteries. The new lithium batteries have a capacity of 2130 watt-hours.

3. SENTINEL V100 DATA

The recorded wave and current data for the deployment period required 10.2 GB of data storage; the wave data comprised 8.9 GB. Teledyne RDI provides multiple software options to display and process the data. The primary data viewing and processing software is Velocity.

The direction that the Sentinel V100 ADCP references is magnetic north. These readings were converted to a true north reference using the magnetic declination values for the location of the ADCP on Oahu. The magnetic declination for WETS is 9.55° East.

Initial processing indicated that data recorded between April 15, 2017 and April 21, 2017 was faulty. The ADCP motion sensor data for that period show that the roll angle was ~-50° and the pitch angle was ~22° (Figure 3-1). A similar initial orientation was observed on the previous deployment. This suggests that during the deployment the ADCP landed on top of an object such as a rock that deflected the unit from a vertical orientation, or that the tripod mount sunk into soft sediment and skewed the ADCP. The wave and current data presented in this report is from April 24, 2017 to July 19, 2017. The orientation of the ADCP throughout the deployment did not allow for the acoustic beams to reach the surface. Current data is generally unaffected by the angle variation and the angle variation is accounted for in the processing. Current data at the surface was out of the range of the acoustic beams and could not be calculated. Wave parameter measurement is affected. The peak direction of the wave is not well resolved. The wave height was calculated using the orbital velocities of particles in the middle of the water column and the pressure under the passing wave and not the surface track of the wave.

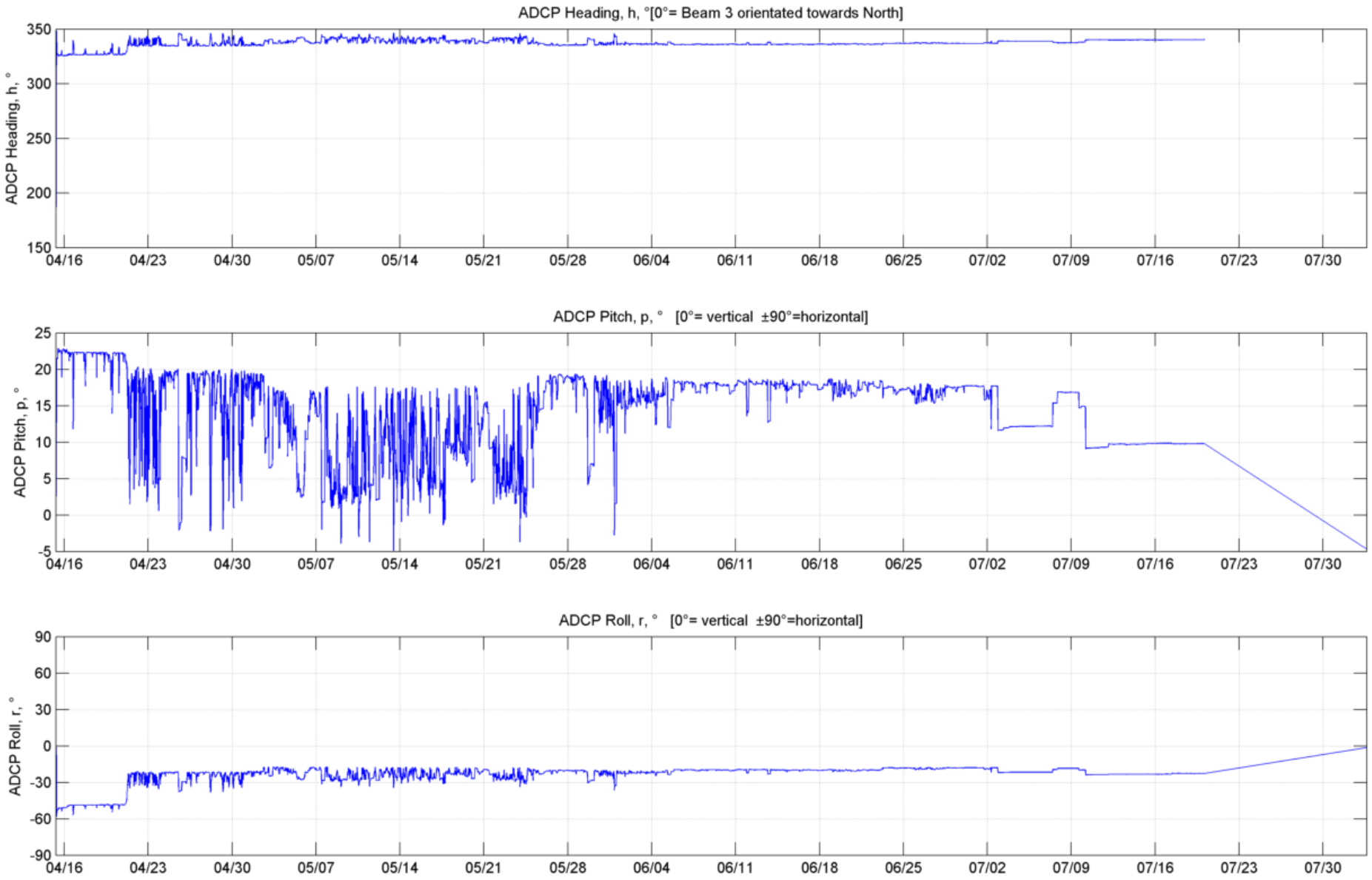

Figure 3-1 Heading, Pitch, and Roll of ADCP

3.1 Currents

Velocity software was used to average the current data into half-hour blocks. The waves profile (19min 10sec of recording) is averaged to represent the current in the bottom half of the hour and the currents profile (5min of recording) is averaged to represent the current in the top half of the hour.

The water column was divided into three layers for analysis. Table 3-1, shows the bins and associated water depths corresponding to the three layers. Near surface data is biased by side lobe interference, and is not included. The middle and bottom layers are defined to not include erroneous data at the surface due to the orientation of the ADCP.

Table 3-1 Water Column Layer Divisions

	Bins	Range from ADCP, meters	Water Depth, meters
Bottom Layer	1 - 5	3.05 – 8.05	~ 65.95 - 60.95
Middle Layer	17 -23	19.05 -26.05	~49.95 - 42.95
Upper Layer	42 -47	44.05 – 50.05	~ 24.95 – 18.95

Figure 3-2 shows the time series current speed and direction for the three layers of water. Figure 3-3 shows the time series for current speed and direction for all the bins measured by the ADCP. The water surface is plotted as a black line on top of the current data. The measurements above the red line are biased due to side lobe interference if the ADCP were oriented vertically. The orientation of the ADCP results in a larger area of water column where side lobe interference effects the data. It was assumed from observing the data that the data above 50ft range was affected by side lobe interference. The gaps (white spaces) near the surface are periods of time where the orientation of the ADCP was altered so the acoustic beams did not reach the surface. Figure 3-4, Figure 3-5, and Figure 3-6 are current rose plots for upper, middle, and bottom layers, respectively. Table 3-2, Table 3-3, and Table 3-4 present the percent occurrence of currents speed and direction.

Upper layer currents flow in a predominantly towards the southeast with an average speed of 0.13 m/s, and a maximum recorded speed of 0.50 m/s for the deployment data (April 21, 2017 – July 19, 2017). Mid-layer currents flow predominantly east southeasterly occurring 33% of the deployment duration. Bottom layer currents magnitudes are smaller and occur with greater occurrence in all directions.

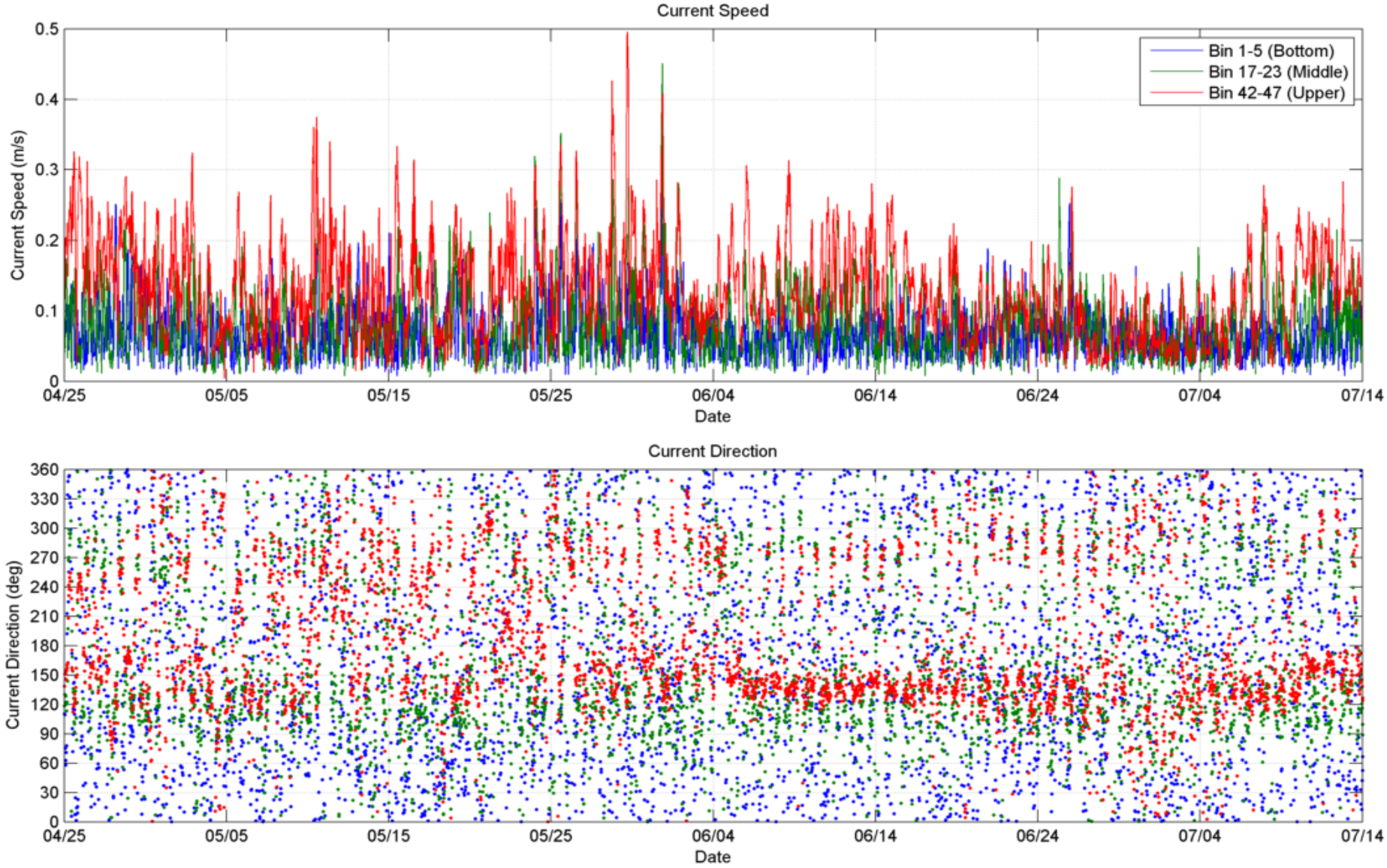

Figure 3-2 Current Speed and Direction for Each Layer

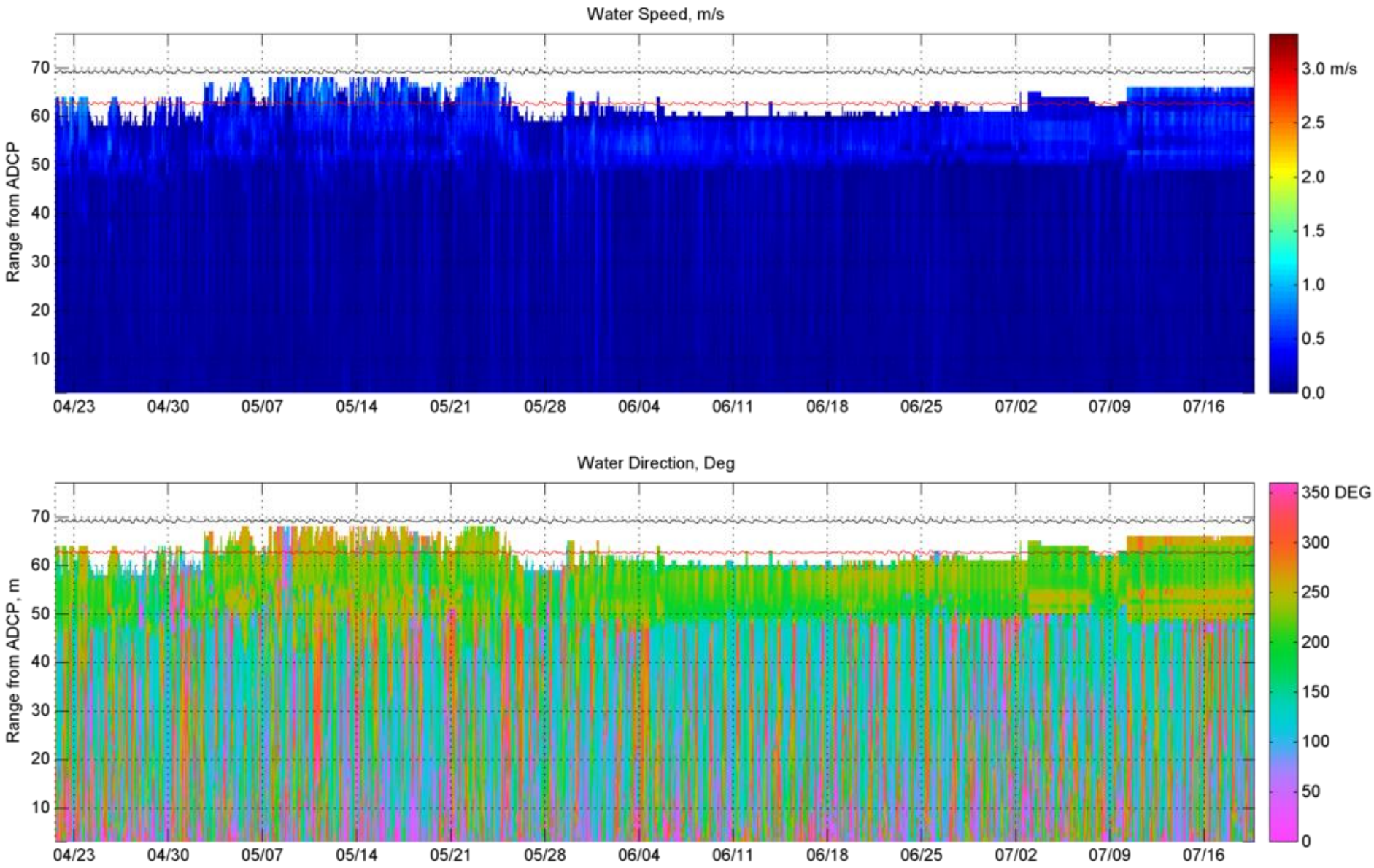

Figure 3-3 Current Speed and Direction for All Bins

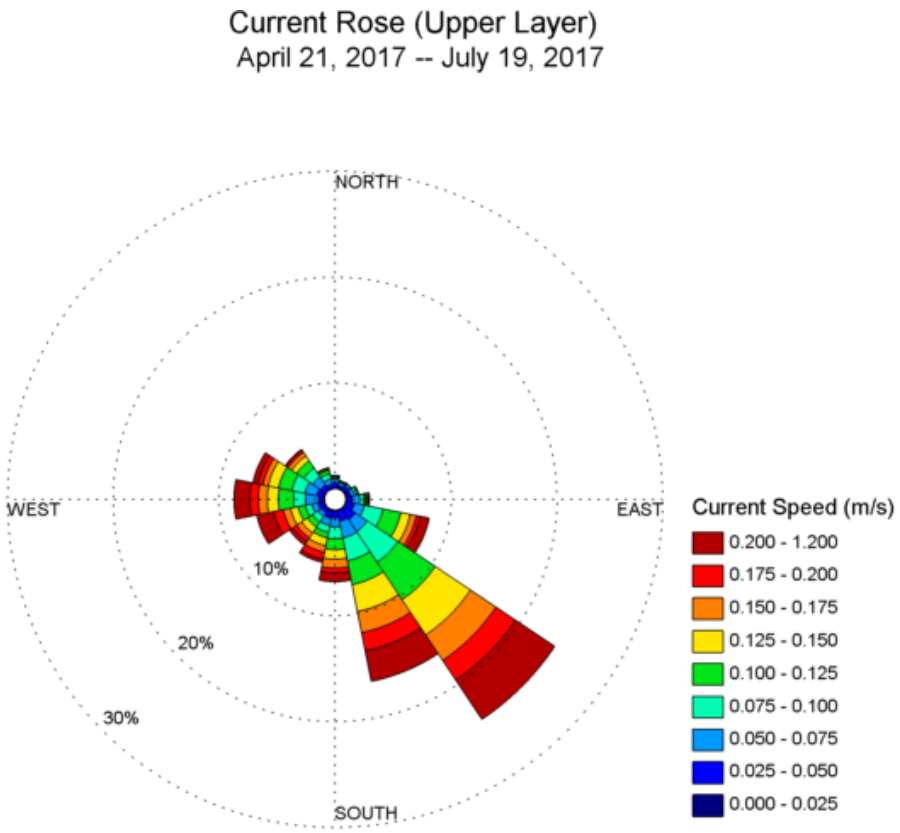

Figure 3-4 Current Rose for Upper Layer

Table 3-2 Upper Layer Current Frequency of Occurrence

Current Speed, m/s		Total % by Direction in Deg																
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.000	-0.025	0.05	0.07	0.14	0.16	0.05	0.05	0.09	0.09	0.09	0.19	0.07	0.09	0.05	0.12	0.07	0.02	1.40
0.025	-0.050	0.49	0.28	0.42	0.35	0.56	0.82	1.21	1.03	0.65	0.65	0.49	0.56	0.54	0.65	0.56	0.42	9.69
0.050	-0.075	0.40	0.28	0.21	0.35	0.72	0.96	1.35	1.59	0.84	0.68	0.40	0.61	1.24	1.14	0.93	0.51	12.21
0.075	-0.100	0.14	0.12	0.09	0.23	0.40	1.80	3.48	2.22	1.14	0.65	0.63	0.61	1.12	1.26	1.00	0.49	15.39
0.100	-0.125	0.09	0.05		0.14	0.16	1.73	4.25	2.29	1.03	0.54	0.58	0.70	1.42	1.28	0.82	0.35	15.44
0.125	-0.150	0.07	0.02	0.02		0.12	0.89	4.02	2.59	0.89	0.75	0.63	0.72	1.05	0.98	0.54	0.14	13.43
0.150	-0.175	0.02				0.16	0.58	2.90	2.03	0.84	0.63	0.56	0.70	0.84	0.51	0.42	0.09	10.30
0.175	-0.200					0.05	0.37	2.22	1.75	0.44	0.65	0.42	0.91	0.79	0.47	0.21	0.02	8.31
0.200	-1.200				0.05	0.05	0.89	4.48	2.94	0.84	0.33	0.42	1.66	1.52	0.51	0.14		13.83
Total %		**1.26**	**0.82**	**0.89**	**1.28**	**2.27**	**8.08**	**24.01**	**16.53**	**6.77**	**5.07**	**4.20**	**6.56**	**8.57**	**6.94**	**4.69**	**2.06**	**100.00**
Mean		0.06	0.06	0.05	0.07	0.08	0.12	0.14	0.14	0.12	0.12	0.12	0.15	0.14	0.11	0.10	0.08	**0.13**
StDev		0.03	0.03	0.03	0.04	0.04	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.05	0.05	0.04	**0.07**
Min		0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.02	0.03	**0.00**
Max		0.15	0.14	0.14	0.23	0.21	0.50	0.49	0.38	0.29	0.27	0.29	0.32	0.36	0.31	0.23	0.19	**0.50**

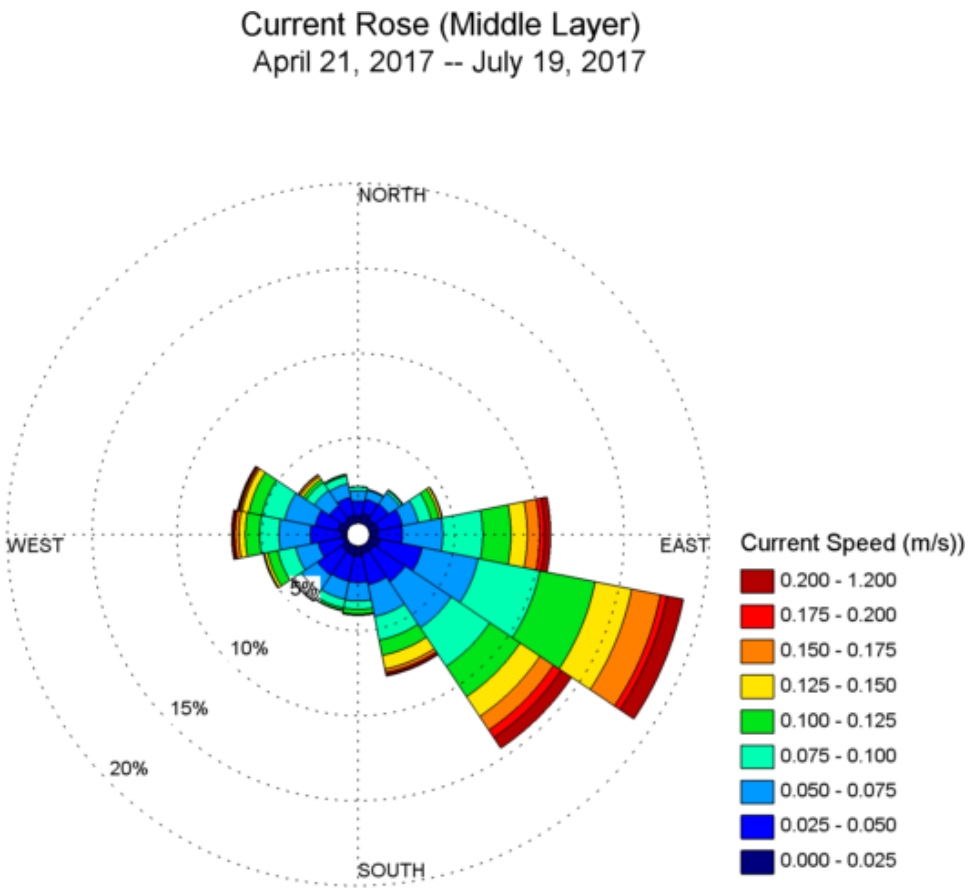

Figure 3-5 Current Rose for Middle Layer

Table 3-3 Middle Layer Current Frequency of Occurrence

Current Speed, m/s		Total % by Direction in Deg																
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.000	-0.025	0.40	0.61	0.44	0.54	0.44	0.65	0.47	0.47	0.58	0.56	0.49	0.23	0.33	0.54	0.40	0.49	7.64
0.025	-0.050	0.91	0.84	1.05	1.45	1.49	2.52	2.20	1.87	1.56	1.56	1.73	1.49	1.82	1.38	0.98	1.07	23.94
0.050	-0.075	0.61	0.54	0.79	0.96	2.38	3.36	3.27	1.91	1.10	1.10	1.14	1.35	1.84	1.82	1.07	0.82	24.08
0.075	-0.100	0.23	0.07	0.16	0.77	2.36	3.71	2.73	1.42	0.49	0.51	0.51	1.07	1.14	1.38	0.56	0.47	17.61
0.100	-0.125				0.47	1.66	3.32	2.15	0.91	0.28	0.14	0.12	0.61	0.84	0.79	0.23	0.09	11.61
0.125	-0.150	0.02			0.16	0.96	2.20	1.40	0.82	0.02	0.05	0.05	0.19	0.37	0.40	0.19	0.02	6.84
0.150	-0.175			0.02		0.72	1.73	0.96	0.21	0.02		0.02	0.05	0.23	0.12	0.12		4.20
0.175	-0.200			0.05	0.05	0.30	0.40	0.54	0.12					0.09	0.09	0.05		1.68
0.200	-1.200					0.35	0.98	0.75	0.09	0.02			0.02	0.12	0.07			2.41
Total %		**2.17**	**2.06**	**2.52**	**4.39**	**10.67**	**18.87**	**14.46**	**7.82**	**4.09**	**3.92**	**4.06**	**5.02**	**6.80**	**6.59**	**3.60**	**2.97**	**100.00**
Mean		0.05	0.04	0.05	0.06	0.09	0.10	0.10	0.08	0.06	0.05	0.05	0.07	0.08	0.07	0.07	0.05	**0.08**
StDev		0.02	0.02	0.03	0.03	0.05	0.06	0.06	0.04	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.03	**0.05**
Min		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	**0.01**
Max		0.13	0.08	0.19	0.18	0.30	0.37	0.45	0.26	0.21	0.14	0.15	0.29	0.24	0.25	0.19	0.14	**0.45**

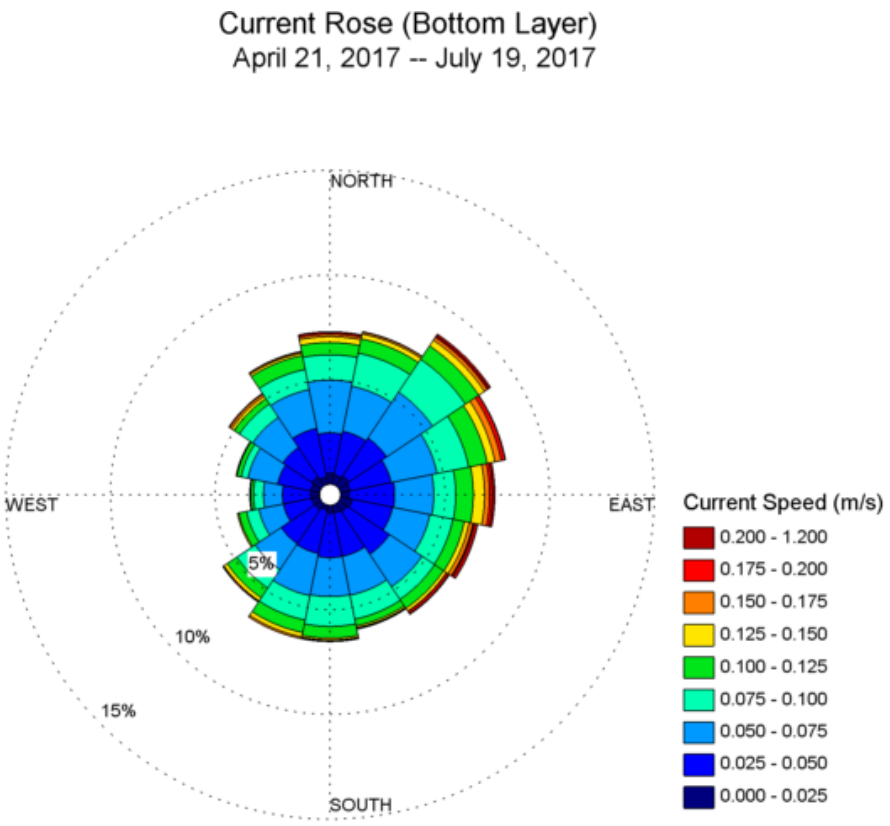

Figure 3-6 Current Rose for Bottom Layer

Table 3-4 Bottom Layer Current Frequency of Occurrence

Current Speed, m/s		Total % by Direction in Deg																
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.000	-0.025	0.54	0.47	0.58	0.47	0.42	0.58	0.49	0.40	0.35	0.23	0.37	0.40	0.40	0.44	0.54	0.37	7.05
0.025	-0.050	1.91	2.13	2.17	2.01	2.17	1.96	2.43	2.10	2.15	2.13	1.94	1.38	1.38	1.61	1.68	2.36	31.50
0.050	-0.075	2.52	2.20	2.64	2.24	1.87	1.82	1.87	1.89	1.87	2.06	1.49	1.19	0.91	1.45	1.73	1.89	29.64
0.075	-0.100	1.21	1.61	1.89	1.54	1.05	1.12	0.72	1.17	1.42	1.19	1.05	0.61	0.47	0.33	0.77	0.98	17.14
0.100	-0.125	0.58	0.70	0.77	0.91	0.84	0.56	0.51	0.33	0.56	0.61	0.56	0.37	0.14	0.21	0.30	0.68	8.64
0.125	-0.150	0.28	0.23	0.33	0.37	0.54	0.23	0.16	0.09	0.09	0.21	0.19	0.07	0.02	0.05	0.14	0.12	3.13
0.150	-0.175	0.12	0.09	0.16	0.30	0.23	0.19	0.02	0.02	0.05	0.09	0.02		0.02		0.12	0.07	1.52
0.175	-0.200	0.09	0.02	0.07	0.19	0.14	0.05	0.12		0.02		0.05				0.05	0.02	0.82
0.200	-1.200	0.02		0.12	0.02	0.12	0.19	0.05	0.05									0.56
Total %		**7.29**	**7.45**	**8.73**	**8.06**	**7.38**	**6.70**	**6.38**	**6.05**	**6.52**	**6.52**	**5.67**	**4.02**	**3.34**	**4.09**	**5.32**	**6.49**	**100.00**
Mean		0.07	0.07	0.07	0.07	0.08	0.07	0.06	0.06	0.06	0.07	0.06	0.06	0.05	0.05	0.06	0.06	**0.07**
StDev		0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	**0.04**
Min		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	**0.01**
Max		0.21	0.18	0.28	0.21	0.26	0.25	0.30	0.22	0.18	0.17	0.18	0.13	0.16	0.14	0.20	0.19	**0.30**

3.2 Waves

The WavesMon module of Velocity was used to calculate hourly wave statistics. The three statistics of most importance to wave characterization are the significant wave height (H_s), peak period (T_p), and peak direction (D_p). The direction that the Sentinel V100 ADCP references is magnetic north. These readings were converted to a true north reference using the magnetic declination values for the location of the ADCP on Oahu. The magnetic declination for WETS is 9.55° East. A second program, WavesView, is used to display the spectral data alongside the wave statistics.

A screenshot of the settings for WavesMon is presented in Figure 3-7.

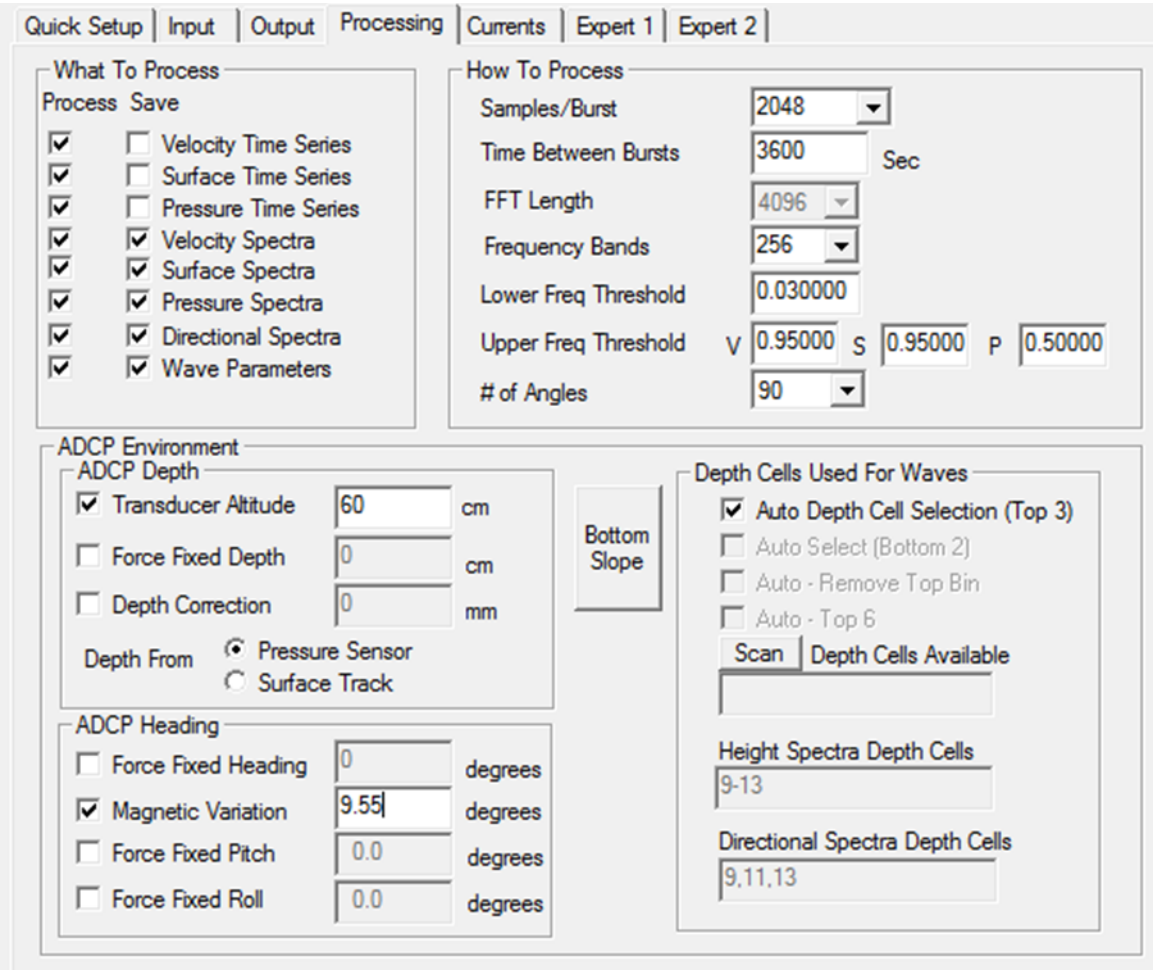

Figure 3-7 WavesMon Processing Tab

Figure 3-8 shows the time series of significant wave height, peak period, and peak direction for the deployment. Figure 3-9 shows the wave height rose which is dominated by the trade wind driven waves from the northeast with shorter periods. Table 3-5 presents the percent frequency of wave height and direction. Figure 3-9 presents the wave period rose. Table 3-6 presents the percent frequency of wave peak period and direction.

The time series, Figure 3-8, indicates typical wave heights of approximately 1.0 – 2.0m and peak periods of 6-8s from an east-northeast direction indicative of trade wind generated swell. The peak direction is of the waves is not well resolved due to the orientation of the ADCP. This is shown by the peak directions from the southern directions which are not expected. These poorly resolved peak directions will appear in the wave height rose and period rose in Figure 3-9 and Figure 3-10 respectively.

The wave height rose shown in Figure 3-9, and Table 3-5, indicates waves from an east and northeasterly direction (45° - 90°) occur 40% of the time. Waves are greater than 1.0m 84% of the time. The average wave height is 1.35m and maximum wave height was 2.47m.

The period rose shown in Figure 3-10, and Table 3-6, show the mean period was 8.07 seconds and the maximum period was 14.60 seconds.

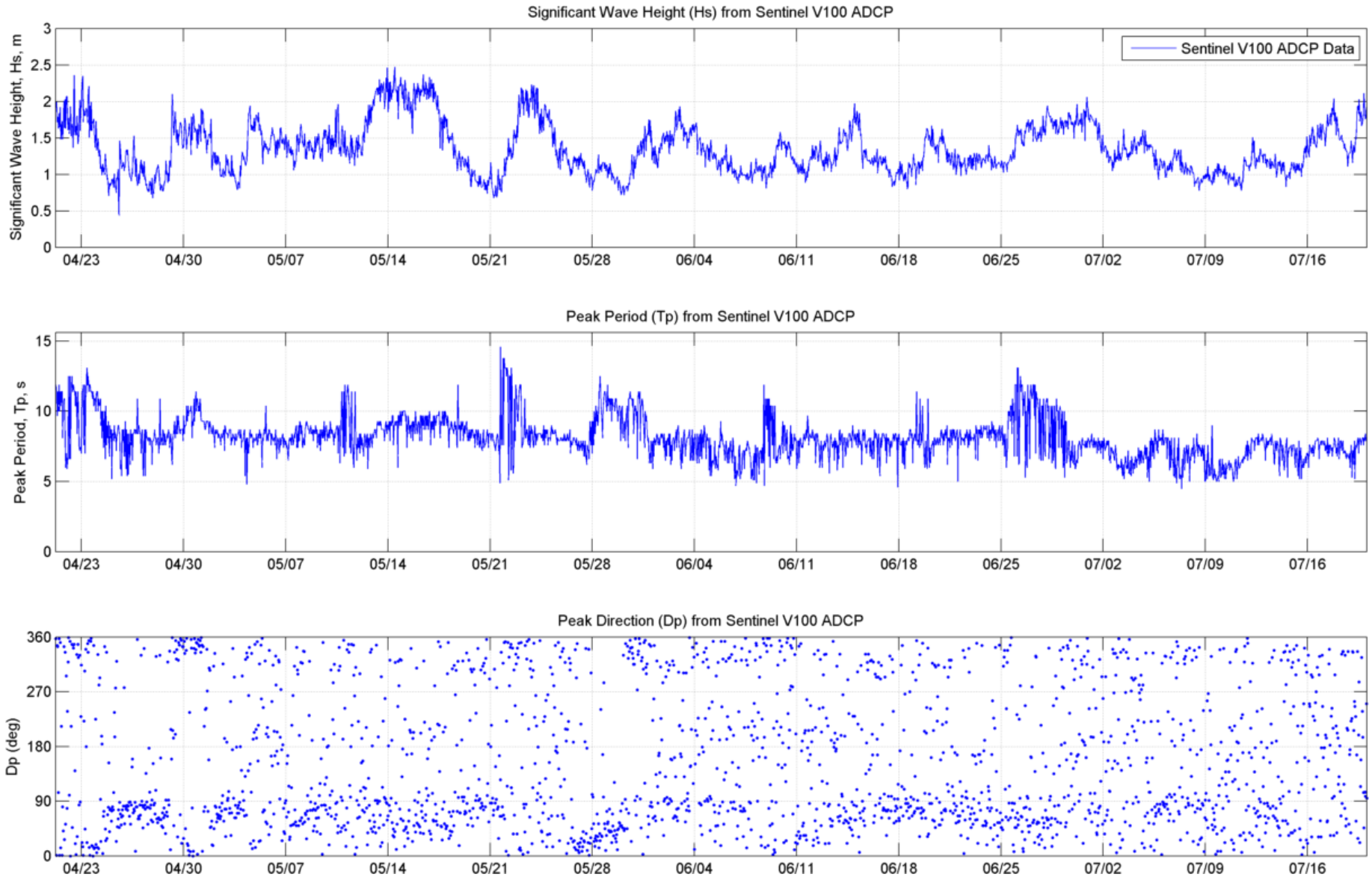

Figure 3-8 Wave Height, Peak Period, and Peak Direction

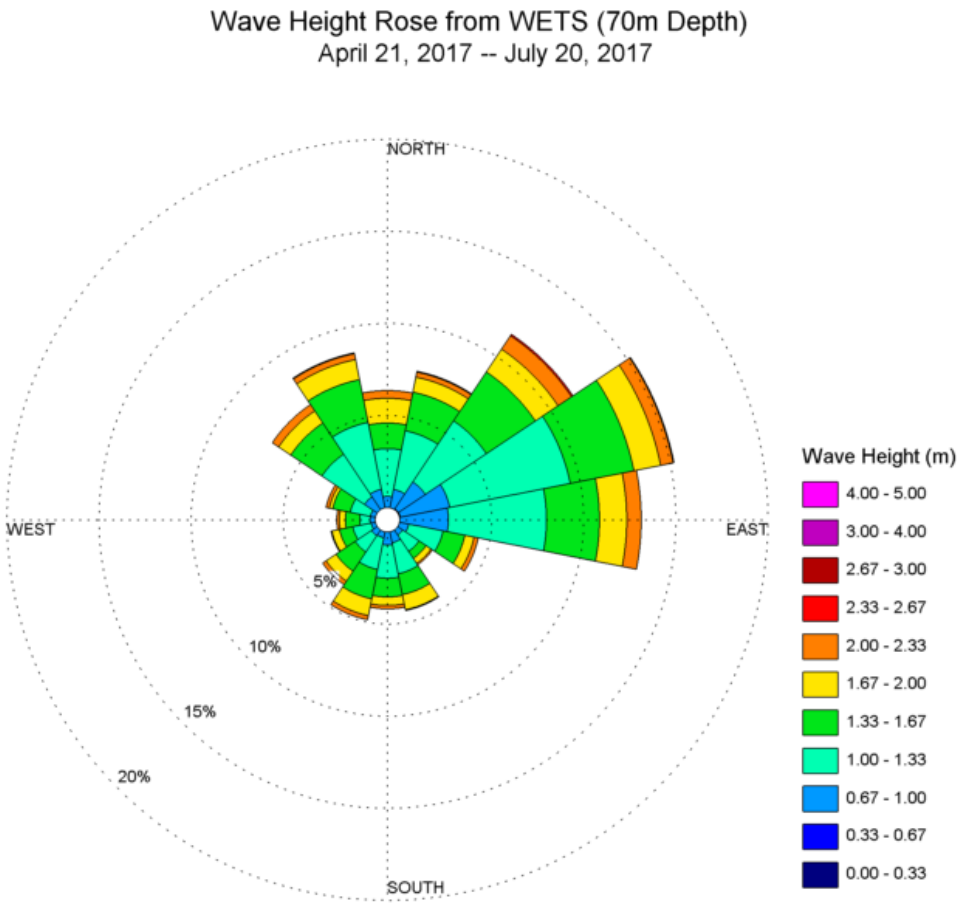

Figure 3-9 Wave Height Rose

Table 3-5 Wave Height Frequency of Occurrence

Wave Height, m	Total % by Direction in Deg																
	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.00 -0.33																	0.00
0.33 -0.67			0.05	0.05													0.09
0.67 -1.00	0.60	1.02	1.76	2.74	2.64	0.51	0.32	0.60	0.70	0.32	0.37	0.23	0.28	0.28	0.83	1.02	14.23
1.00 -1.33	2.60	3.25	3.99	6.68	5.33	1.90	1.07	1.72	1.81	1.76	1.07	1.02	0.56	1.11	2.78	3.71	40.33
1.33 -1.67	1.39	2.13	3.20	3.52	2.87	1.21	0.46	1.16	1.02	1.62	1.25	0.74	0.79	0.97	2.04	2.36	26.75
1.67 -2.00	1.34	0.83	1.48	1.48	1.48	0.51	0.32	0.83	0.46	0.93	0.65	0.42	0.32	0.19	0.79	1.11	13.17
2.00 -2.33	0.42	0.28	0.88	0.70	0.79	0.23	0.09	0.05	0.19	0.23	0.23	0.05	0.14	0.19	0.42	0.32	5.19
2.33 -2.67		0.05	0.09	0.05												0.05	0.23
2.67 -3.00																	0.00
3.00 -4.00																	0.00
4.00 -5.00																	0.00
Total %	6.35	7.56	11.45	15.21	13.12	4.36	2.27	4.36	4.17	4.87	3.57	2.46	2.09	2.74	6.86	8.58	100.00
Mean	1.42	1.34	1.38	1.30	1.30	1.35	1.32	1.35	1.31	1.42	1.43	1.37	1.41	1.36	1.34	1.34	1.35
StDev	0.36	0.33	0.39	0.34	0.36	0.33	0.34	0.32	0.32	0.32	0.36	0.30	0.33	0.32	0.33	0.32	0.34
Min	0.81	0.75	0.44	0.48	0.71	0.82	0.80	0.71	0.77	0.83	0.78	0.89	0.69	0.79	0.72	0.77	0.44
Max	2.22	2.35	2.47	2.46	2.32	2.24	2.16	2.18	2.18	2.19	2.29	2.21	2.12	2.25	2.21	2.36	2.47

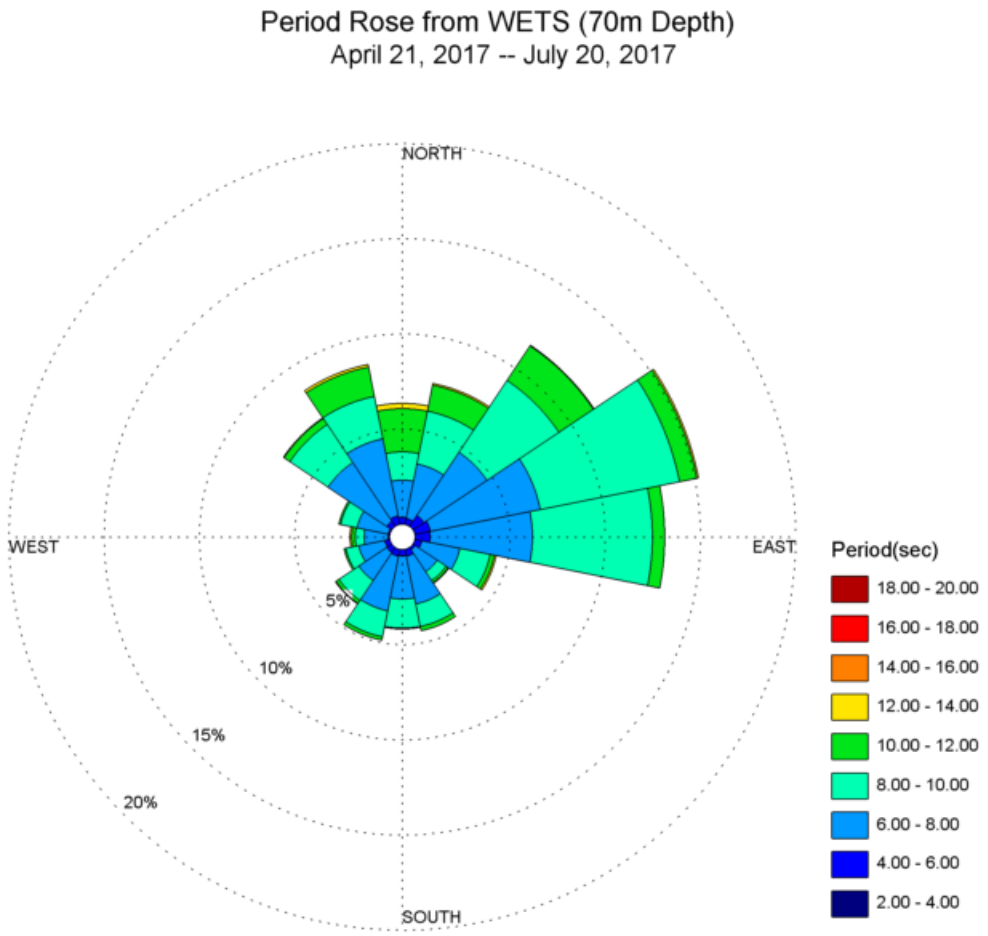

Figure 3-10 Period Rose

Table 3-6 Wave Period Frequency of Occurrence

Wave Period, s	Total % by Direction in Deg																
	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
2 -4																	0.00
4 -6	0.37	0.32	0.70	0.83	0.79	0.37	0.14	0.37	0.32	0.37	0.32	0.28	0.09	0.09	0.32	0.46	6.17
6 -8	1.95	2.92	3.99	5.89	5.38	2.04	1.39	2.55	2.27	2.92	1.76	1.39	1.25	1.67	3.71	4.13	45.20
8 -10	1.48	2.83	4.54	7.46	6.31	1.62	0.56	1.21	1.53	1.39	1.25	0.70	0.46	0.88	2.41	2.27	36.90
10 -12	2.27	1.39	2.18	0.93	0.65	0.23	0.14	0.23	0.05	0.19	0.19	0.09	0.19	0.09	0.37	1.58	10.76
12 -14	0.28	0.09	0.05	0.09		0.09					0.05		0.09		0.05	0.14	0.93
14 -16							0.05										0.05
16 -18																	0.00
18 -20																	0.00
Total %	**6.35**	**7.56**	**11.45**	**15.21**	**13.12**	**4.36**	**2.27**	**4.36**	**4.17**	**4.87**	**3.57**	**2.46**	**2.09**	**2.74**	**6.86**	**8.58**	**100.00**
Mean	9.02	8.41	8.37	8.14	7.97	7.84	7.69	7.56	7.58	7.56	7.68	7.50	7.88	7.65	8.00	8.22	**8.07**
StDev	2.07	1.62	1.57	1.18	1.08	1.43	1.68	1.28	1.08	1.16	1.28	1.29	1.68	1.02	1.26	1.72	**1.46**
Min	4.90	5.00	5.00	4.90	4.60	5.00	4.50	5.10	5.20	4.70	5.20	5.20	5.40	5.30	4.70	4.80	**4.50**
Max	13.80	13.10	13.10	13.10	11.90	13.10	14.60	11.90	11.40	11.40	12.50	11.90	12.50	10.90	13.80	12.50	**14.60**

REPORT:

Task 4I Report - ADCP Data Analysis at WETS (70m Depth)

March 2018

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The area north of the Mōkapu Peninsula, adjacent to Kāneʻohe Marine Corps Base Hawaiʻi (MCBH), has been utilized by the U.S. Navy for wave energy research since 2002. Prototype wave energy converters (WEC) are being tested at the 30m, 60m, and 80m berths offshore of North Beach at the MCBH. The Hawaiʻi National Marine Renewable Energy Center (HNMREC) at the University of Hawaiʻi under contract with Department of Energy and the U.S. Navy, operates the test site.

Sea Engineering has been contracted by the HNMREC to conduct site investigations in support of the test site. One of these investigations is to determine wave climate and current characteristics at the site.

The project location within the state of Hawaiʻi is shown in Figure 1-1. The test site is 1600m to 2000m wide and extends approximately 2600m offshore from the 30m depth contour to the approximate 100m depth contour.

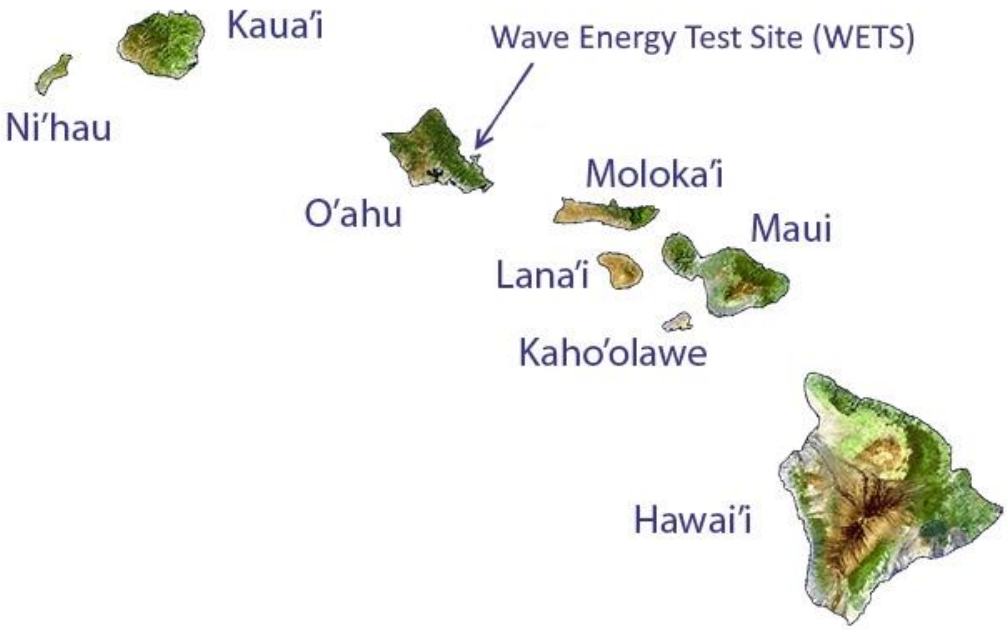

Figure 1-1 Project Location

In collaboration with HNMREC, Sea Engineering Inc. has deployed a Teledyne RDI Sentinel V100 Acoustic Doppler Current Profiler (ADCP) in the Wave Energy Test Site (WETS) since November 2014. Deployments were at the 30m site and the Waverider buoy from 2014 to 2016. In December 2016, the ADCP was deployed at the 70m depth between the 60m and 80m sites. Figure 1-2 shows the deployment location of the ADCP at 70m depth.

Table 1-1 shows the ADCP deployment schedule and the coordinates of the deployments. This report presents data recorded from August 3, 2017 to December 18, 2017.

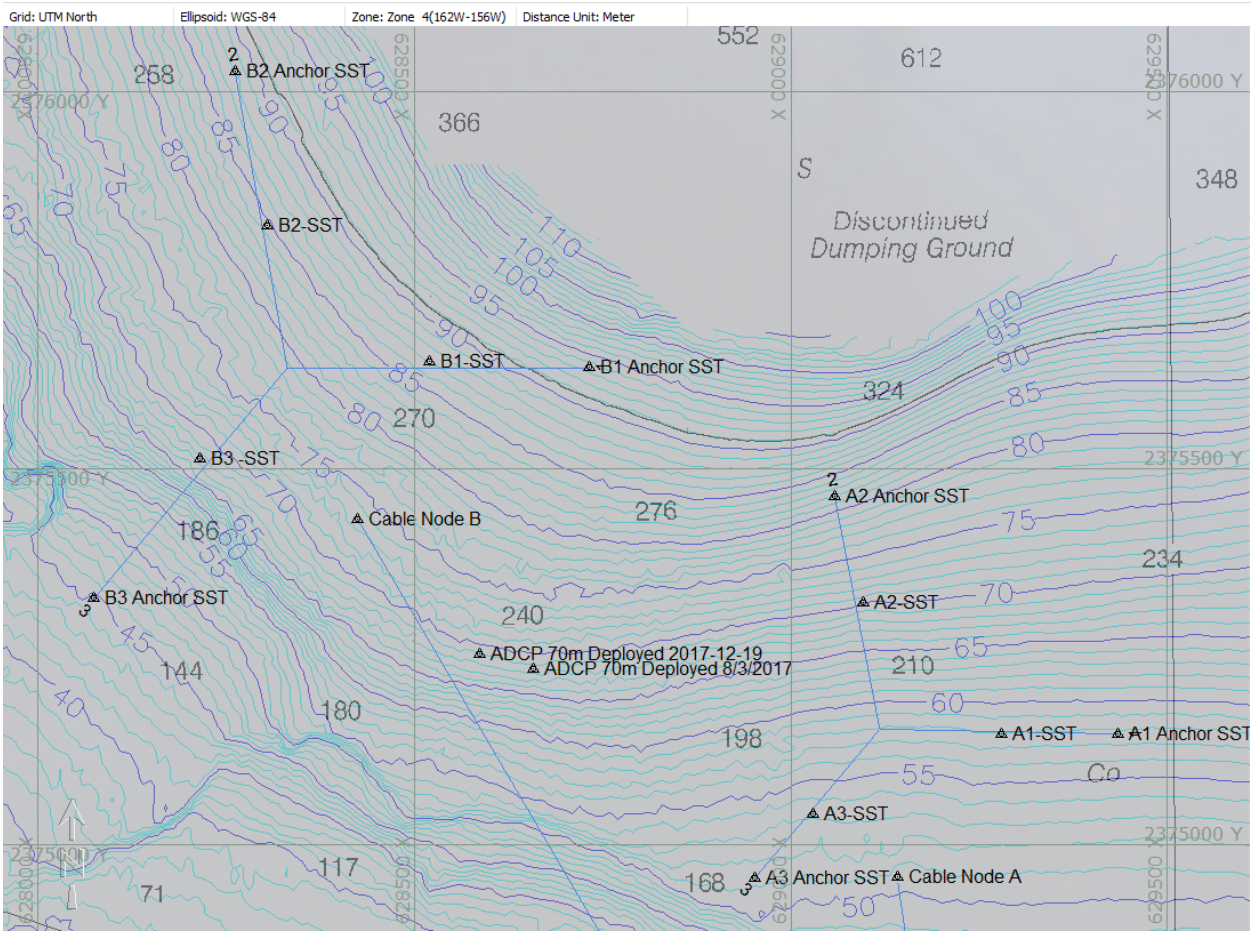

Figure 1-2 WETS 70m Depth Deployment Location

Table 1-1 ADCP Deployment Schedule and Locations

Deployment Date	Task	Retrieval Date	Task	Location	Coordinates	Depth	Comment
11/13/2014	Previous WETS Funding	2/26/2015	4A	Near Waverider	21° 28' 39.1813" N 157° 44' 56.3008" W	78m	
2/26/2015	4A	6/4/2015	4B	Near Waverider	21° 28' 39.1813" N 157° 44' 56.3008" W	78m	
7/6/2015	4B	10/14/2015	4C	30m Site	21° 27' 56.1738" N 157° 45' 5.0563" W	31m	
10/19/2015	4C	1/13/2016	4D	30m Site	21° 27' 55.9741" N 157° 45' 4.1280" W	31m	
1/14/2016	4D	8/3/2016	1H	30m Site	21° 27' 55.9801" N 157° 45' 4.9739" W	31m	Data lost to memory card failure
12/6/2016	4E	4/14/2017	4G	Between 60m and 80m Sites	21° 28' 30.8115" N 157° 45'27.6232" W	70m	New ADCP
B1 secured	4F	B1 secured	4F	--	--	--	Tug to secure unanchored B1 float
4/15/17	4G	8/2/2017	4H	Between 60m and 80m Sites	21° 28' 30.2881" N 157° 45'28.3139" W	69m	
8/3/2017	4H	12/18/2017	4I	Between 60m and 80m Sites	21° 28' 30.1335" N 157° 45'29.3408" W	69m	Adjusted mount on 9-1-2017
12/19/2017	4I			Between 60m and 80m Sites	21° 28’ 30.8004” N 157° 45’ 31.8493” W	69m	
	4K				Task remaining		
	4L				Task remaining		
	4M				Task remaining		

Task 4F was used to secure the B1 surface float.

The Sentinel V100 ADCP uses a vertical acoustic beam to measure the distance to the water surface. Sound waves reflect off the water surface and the time a reflection takes to return to the ACDP is used to determine the distance to the surface. Accurate wave statistics can be computed from the measured water surface elevation record. An ADCP relies on the Doppler effect to determine the water currents through the water column. The direction of current can be determined by using three or four acoustic beams. The acoustic reflection of a beam that is up current from the ACDP will arrive before the reflection of down current acoustic reflection. The analysis of the reflection return timing of multiple beams, allows the calculation the direction of waves and currents.

2. TELEDYNE RDI SENTINEL V100 SETUP

The Sentinel V100 was programmed to measure both waves and currents. ReadyV software from Teledyne RDI was used to program the Sentinel V100 ADCP. The software calculates the available battery resources and data storage for desired measurement profiles. The custom wave and current measurement profiles have the following settings:

Table 2-1 Profile Parameters

	Waves Measurement Profile	Current Measurement Profile
Ping Interval (seconds)	0.5	1
Number of Pings	2300	300
Range (meters)	75	75
Cell Size (meters)	1.0	1.0
Duration(minutes)	19.166	5

The wave measurement occurs once per hour over a 19 minute and 10 seconds period. Current measurements occur over a 5-minute period 30 minutes after the start of the wave measurements. This setup was chosen to accommodate a deployment duration of approximately 90 days. The external battery housing was not need since the alkaline batteries have been replaced with lithium batteries. The lithium batteries have a capacity of 2130 watt-hours.

3. SENTINEL V100 DATA

The recorded wave and current data for the deployment period required 10.9 GB of data storage; the wave data comprised 9.6 GB. Teledyne RDI provides multiple software options to display and process the data. The primary data viewing and processing software is Velocity.

The direction that the Sentinel V100 ADCP references is magnetic north. These readings were converted to a true north reference using the magnetic declination values for the location of the ADCP on Oahu. The magnetic declination for WETS is 9.55° East.

Initial processing indicated that data recorded between August 3, 2017 and September 1, 2017 was invalid because the ADCP was tilted horizontally. The data for that period shows that the roll angle was ~60° and the pitch angle was ~-55°. The ADCP was recovered and deployed on September 1, 2017 with a modified bottom mount to prevent tilt of the instrument. The wave and current data presented in this report is from September 1, 2017 to December 19, 2017 when the ADCP orientation is vertical.

3.1 Currents

Velocity software was used to average the current data into half-hour blocks. The water column was divided into three layers for analysis. Table 3-1, shows the bins and associated water depths corresponding to the three layers. Near surface data is biased by side lobe interference and is not included.

Table 3-1 Water Column Layer Divisions

	Bins	Range from ADCP, meters	Water Depth, meters
Bottom Layer	1 - 5	3.05 – 8.05	~ 66.11 – 62.11
Middle Layer	28 - 33	30.05 -35.05	~39.11 - 34.11
Upper Layer	55 - 60	57.05 – 62.05	~ 12.11 – 7.11

Figure 3-1 shows the time series of current speed and direction for the three layers of water. Figure 3-2 shows the time series for current speed and direction for all the bins measured by the ADCP. The water surface is plotted as a black line on top of the current data. The measurements above the red line are biased due to side lobe interference. Figure 3-3, Figure 3-4, and Figure 3-5 are current rose plots for upper, middle, and bottom layers, respectively. Table 3-2, Table 3-3, and Table 3-4 present the percent occurrence of currents speed and direction.

Upper layer current flow is bimodal with currents flowing predominantly towards the south and westward. The maximum recorded speed was 0.34 m/s. Mid-layer currents flow predominantly to the east southeast (occurring 39% of the deployment duration). Bottom layer currents magnitudes are weaker and occur nearly equal frequency in all directions.

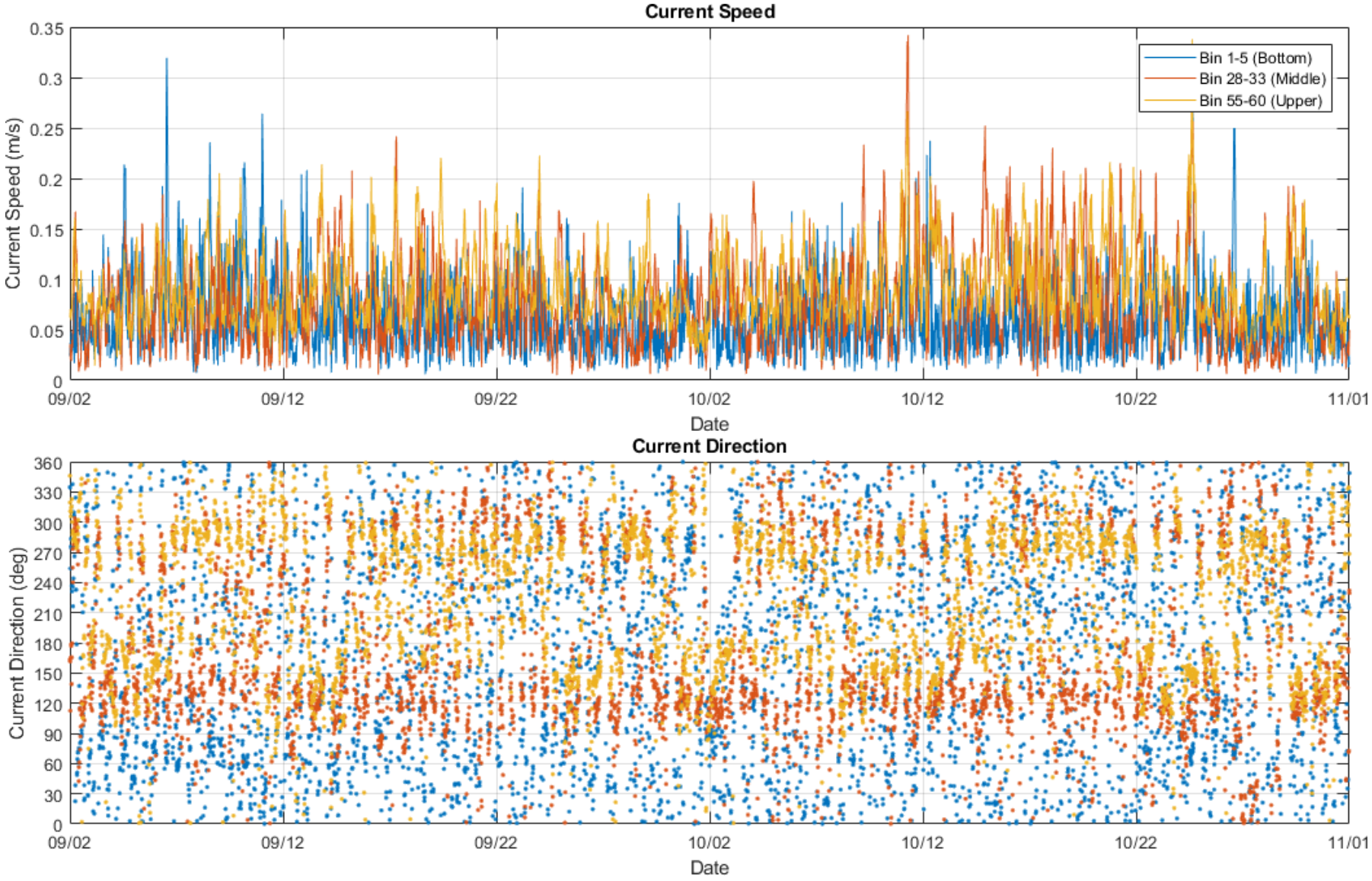

Figure 3-1 Current Speed and Direction for Each Layer

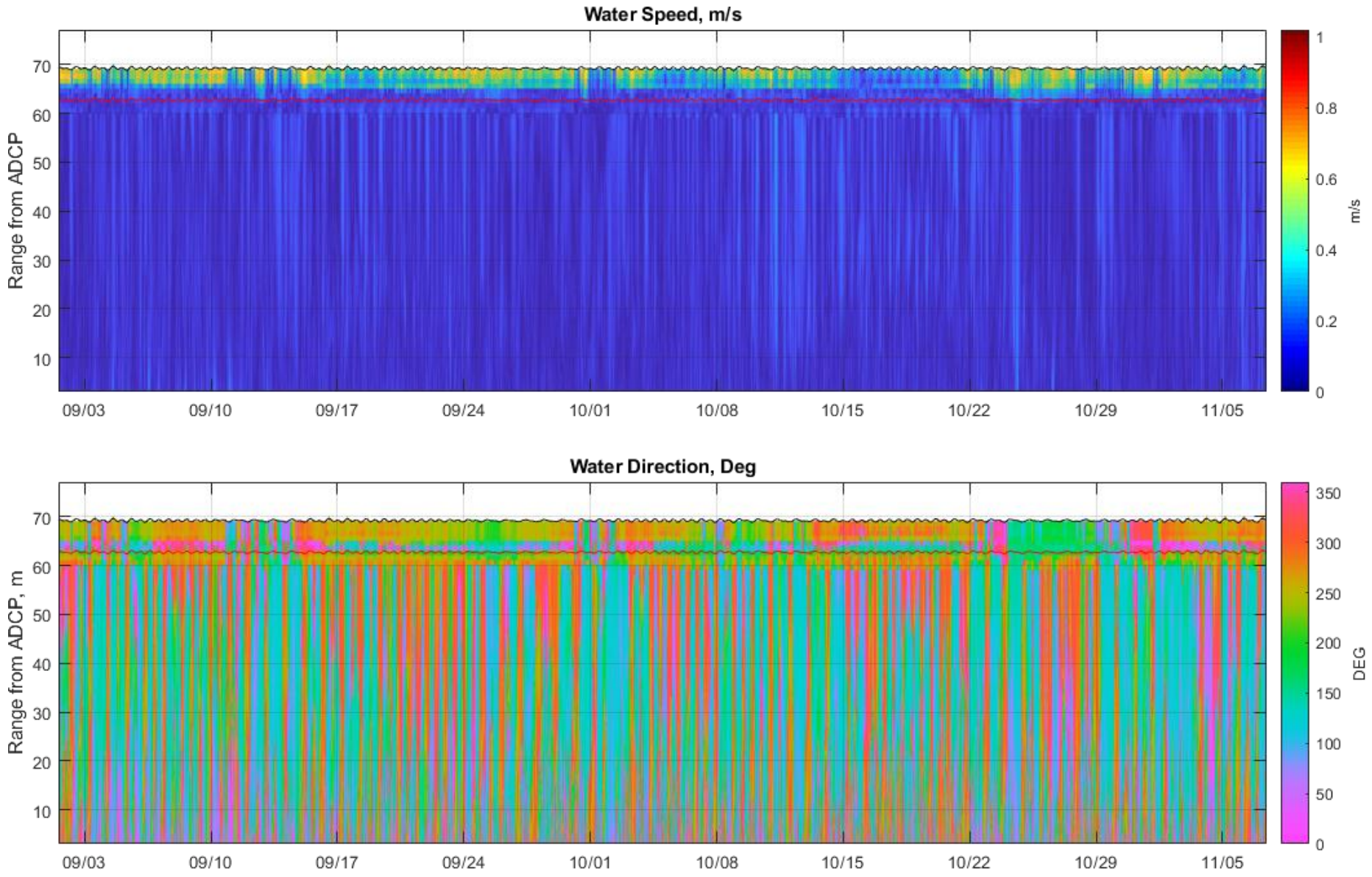

Figure 3-2 Current Speed and Direction for All Bins

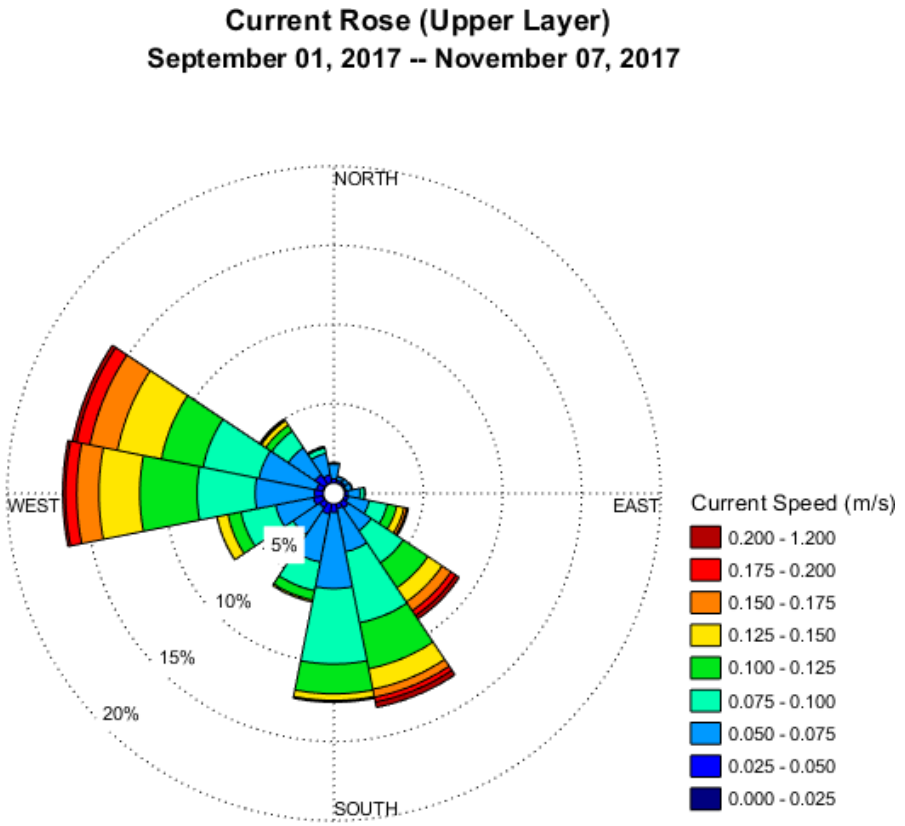

Figure 3-3 Current Rose for Upper Layer

Table 3-2 Upper Layer Current Frequency of Occurrence

Current Speed, m/s		Total % by Direction in Deg															
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.000	-0.025		0.02	0.03	0.02			0.02				0.02	0.05		0.05	0.02	0.02	0.22
0.025	-0.050	0.25	0.17	0.16	0.11	0.20	0.25	0.42	0.31	0.53	0.67	0.42	0.61	0.56	0.40	0.75	0.51	6.32
0.050	-0.075	0.93	0.23	0.26	0.36	0.78	1.37	1.73	2.77	4.81	3.08	2.01	2.43	3.75	3.71	2.04	1.37	31.64
0.075	-0.100	0.09	0.03		0.03	0.28	1.15	2.44	4.58	4.76	1.84	0.90	2.24	3.67	3.61	1.26	0.36	27.26
0.100	-0.125					0.05	0.61	1.88	2.96	1.88	0.61	0.54	0.84	3.63	2.69	0.45	0.08	16.22
0.125	-0.150				0.03		0.47	1.07	1.32	0.42	0.12	0.19	0.70	2.58	2.83	0.34		10.09
0.150	-0.175						0.19	0.67	0.51	0.08			0.02	1.40	1.77	0.03	0.03	4.70
0.175	-0.200						0.11	0.37	0.31	0.03				0.72	0.86	0.08		2.48
0.200	-1.200							0.26	0.34					0.17	0.26	0.03		1.07
Total %		**1.28**	**0.45**	**0.45**	**0.54**	**1.31**	**4.14**	**8.87**	**13.11**	**12.52**	**6.32**	**4.08**	**6.88**	**16.49**	**16.19**	**5.00**	**2.37**	**100.00**
Mean		0.06	0.05	0.05	0.06	0.07	0.09	0.11	0.10	0.08	0.07	0.08	0.08	0.11	0.11	0.08	0.06	**0.09**
StDev		0.01	0.01	0.02	0.02	0.02	0.03	0.04	0.04	0.02	0.02	0.02	0.03	0.04	0.04	0.03	0.02	**0.04**
Min		0.03	0.02	0.02	0.02	0.03	0.03	0.02	0.03	0.03	0.03	0.02	0.02	0.03	0.02	0.02	0.01	**0.01**
Max		0.09	0.09	0.07	0.14	0.11	0.18	0.27	0.34	0.19	0.15	0.14	0.15	0.22	0.22	0.21	0.15	**0.34**

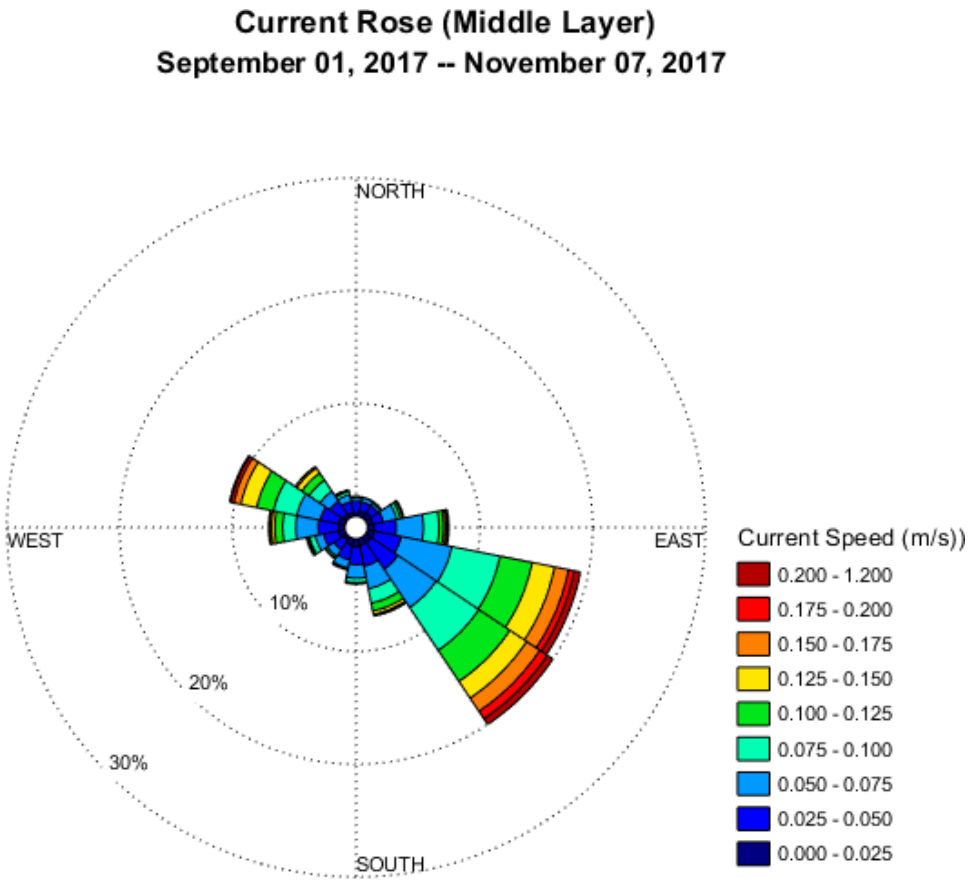

Figure 3-4 Current Rose for Middle Layer

Table 3-3 Middle Layer Current Frequency of Occurrence

Current Speed, m/s		Total % by Direction in Deg																
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.000	-0.025	0.25	0.45	0.59	0.53	0.61	0.64	0.62	0.62	0.72	0.62	0.37	0.59	0.54	0.61	0.40	0.37	8.55
0.025	-0.050	1.06	0.86	0.73	0.92	1.95	2.43	2.82	1.88	1.59	1.31	1.01	1.35	1.82	1.63	1.40	0.95	23.71
0.050	-0.075	0.30	0.37	0.28	1.20	2.41	4.59	4.09	2.02	1.20	0.73	0.70	0.75	1.99	2.12	1.06	0.62	24.44
0.075	-0.100	0.14	0.05	0.09	0.33	1.39	4.36	4.56	1.31	0.39	0.09	0.19	0.51	1.15	2.12	1.17	0.30	18.14
0.100	-0.125			0.05	0.22	0.39	2.91	3.32	0.72	0.08	0.03	0.08	0.17	0.70	1.51	0.76	0.14	11.07
0.125	-0.150	0.02	0.02		0.12	0.20	2.02	1.79	0.30	0.03	0.03		0.08	0.28	1.45	0.53		6.87
0.150	-0.175					0.17	1.26	1.40	0.08		0.03		0.03	0.19	0.62	0.19	0.03	4.00
0.175	-0.200					0.06	0.53	0.79	0.03	0.02			0.02	0.09	0.28			1.82
0.200	-1.200					0.05	0.56	0.61	0.06						0.12			1.40
Total %		**1.76**	**1.74**	**1.74**	**3.32**	**7.22**	**19.31**	**20.01**	**7.02**	**4.02**	**2.85**	**2.35**	**3.50**	**6.77**	**10.46**	**5.51**	**2.41**	**100.00**
Mean		0.04	0.04	0.04	0.06	0.07	0.09	0.10	0.07	0.05	0.04	0.05	0.05	0.07	0.09	0.08	0.05	**0.08**
StDev		0.02	0.02	0.02	0.03	0.04	0.05	0.05	0.04	0.03	0.03	0.02	0.03	0.04	0.05	0.04	0.03	**0.04**
Min		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	**0.00**
Max		0.13	0.13	0.12	0.15	0.26	0.34	0.32	0.34	0.18	0.17	0.12	0.18	0.19	0.24	0.17	0.16	**0.34**

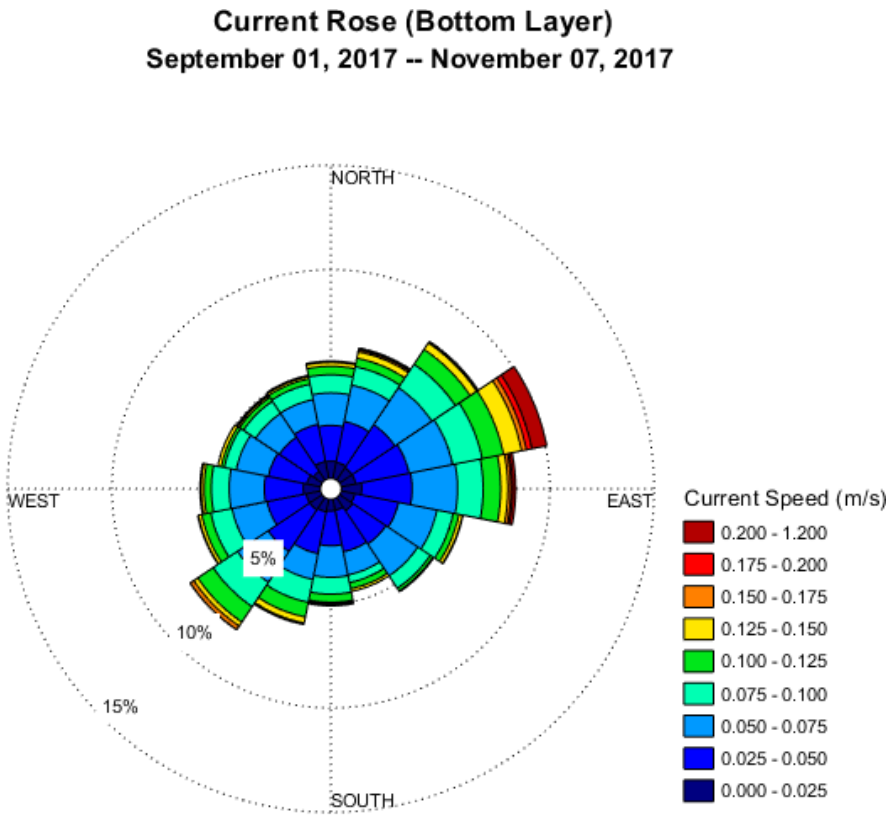

Figure 3-5 Current Rose for Bottom Layer

Table 3-4 Bottom Layer Current Frequency of Occurrence

Current Speed, m/s		Total % by Direction in Deg																
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.000	-0.025	0.83	0.79	0.72	0.72	0.98	0.67	0.76	0.54	0.56	0.62	0.72	0.72	0.83	0.67	0.51	0.84	**11.47**
0.025	-0.050	1.71	1.99	2.48	2.60	2.41	2.13	1.91	2.02	1.67	2.04	2.40	1.90	1.87	1.88	1.96	1.81	**32.79**
0.050	-0.075	1.56	1.77	2.13	2.13	2.18	1.88	1.84	1.14	1.51	1.26	1.77	1.71	1.68	1.57	1.37	1.21	**26.73**
0.075	-0.100	0.87	0.90	1.35	1.45	1.23	0.79	0.72	0.37	0.81	1.12	1.40	1.04	0.86	0.58	0.70	0.75	**14.95**
0.100	-0.125	0.40	0.42	0.86	1.04	0.84	0.28	0.16	0.30	0.39	0.72	0.89	0.44	0.34	0.16	0.22	0.26	**7.71**
0.125	-0.150	0.19	0.31	0.37	0.89	0.34	0.17	0.03	0.14	0.08	0.30	0.23	0.17	0.14	0.17	0.09	0.11	**3.74**
0.150	-0.175	0.06	0.09	0.03	0.23	0.14				0.06	0.06	0.20	0.03	0.03		0.06	0.05	**1.06**
0.175	-0.200		0.03	0.03	0.26	0.09	0.03	0.02			0.02	0.02				0.02	0.02	**0.53**
0.200	-1.200		0.06	0.03	0.73	0.14				0.03				0.03				**1.03**
Total %		**5.62**	**6.38**	**8.00**	**10.06**	**8.36**	**5.96**	**5.43**	**4.52**	**5.11**	**6.13**	**7.63**	**6.01**	**5.78**	**5.03**	**4.94**	**5.04**	**100.00**
Mean		0.06	0.06	0.07	0.09	0.07	0.06	0.05	0.05	0.06	0.06	0.07	0.06	0.06	0.05	0.06	0.05	**0.06**
StDev		0.03	0.04	0.03	0.06	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	**0.04**
Min		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	**0.01**
Max		0.17	0.23	0.26	0.32	0.26	0.18	0.18	0.14	0.20	0.18	0.18	0.15	0.22	0.15	0.18	0.19	**0.32**

3.2 Waves

The WavesMon module of Velocity was used to calculate hourly wave statistics. The three statistics of most importance for wave characterization are the significant wave height (H_s), peak period (T_p), and peak direction (D_p). The direction that the Sentinel V100 ADCP references is magnetic north. These readings were converted to a true north reference using the magnetic declination values for the location of the ADCP on Oahu. The magnetic declination for WETS is 9.55° East. A second program, WavesView, is used to display the spectral data alongside the wave statistics.

A screenshot of the settings for WavesMon is presented in Figure 3-6.

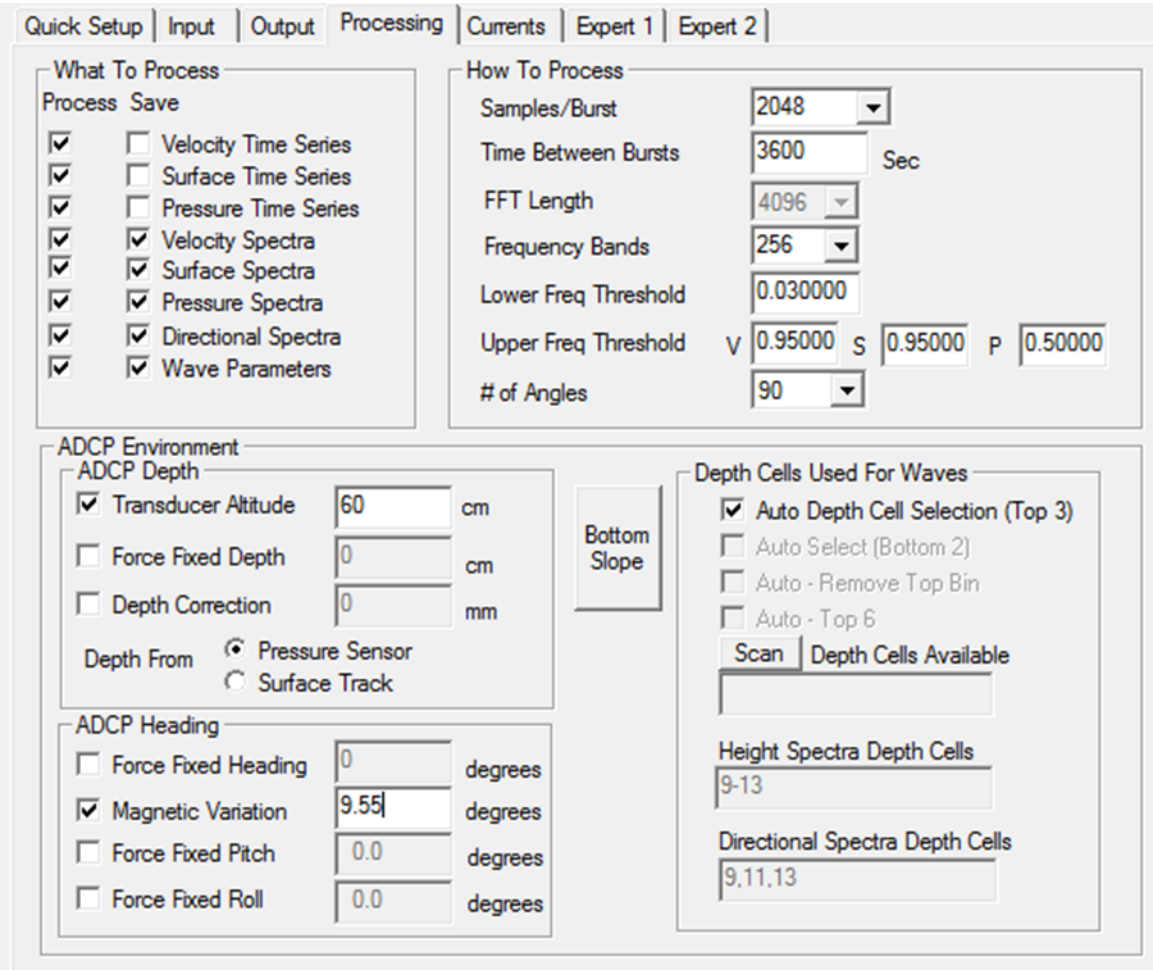

Figure 3-6 WavesMon Processing Tab

Figure 3-7 shows the time series of significant wave height, peak period, and peak direction for the deployment. Figure 3-8 shows the wave height rose which is dominated by the trade wind driven waves from the northeast with shorter periods and longer period swell from the north. Table 3-5 presents the percent frequency of wave height and direction. Figure 3-8 presents the wave period rose. Table 3-6 presents the percent frequency of wave peak period and direction.

The time series, Figure 3-7, indicates typical wave heights are approximately 1.0 – 2.0m with peak periods of 6-8s from an east-northeast direction indicative of trade wind generated swell. The wave height of 2.0 – 3.0m, peak direction from the north, and longer wave periods on October 24 and 25, 2017 are indicative of the arrival of the first north swell arriving for the winter season. The swell events from October 4 – 8 and October 15 -20, 2017 are large trade wind driven events.

The wave height rose shown in Figure 3-8, and Table 3-5, indicates waves from an east and northeasterly direction (0° - 90°) occurred 85% of the time. Waves were greater than 1.0m, 86% of the time. The average wave height was 1.55m and maximum wave height was 3.61m.

The period rose shown in Figure 3-9, and Table 3-6, show the mean peak period was 8.99 seconds and the maximum period was 20.50 seconds.

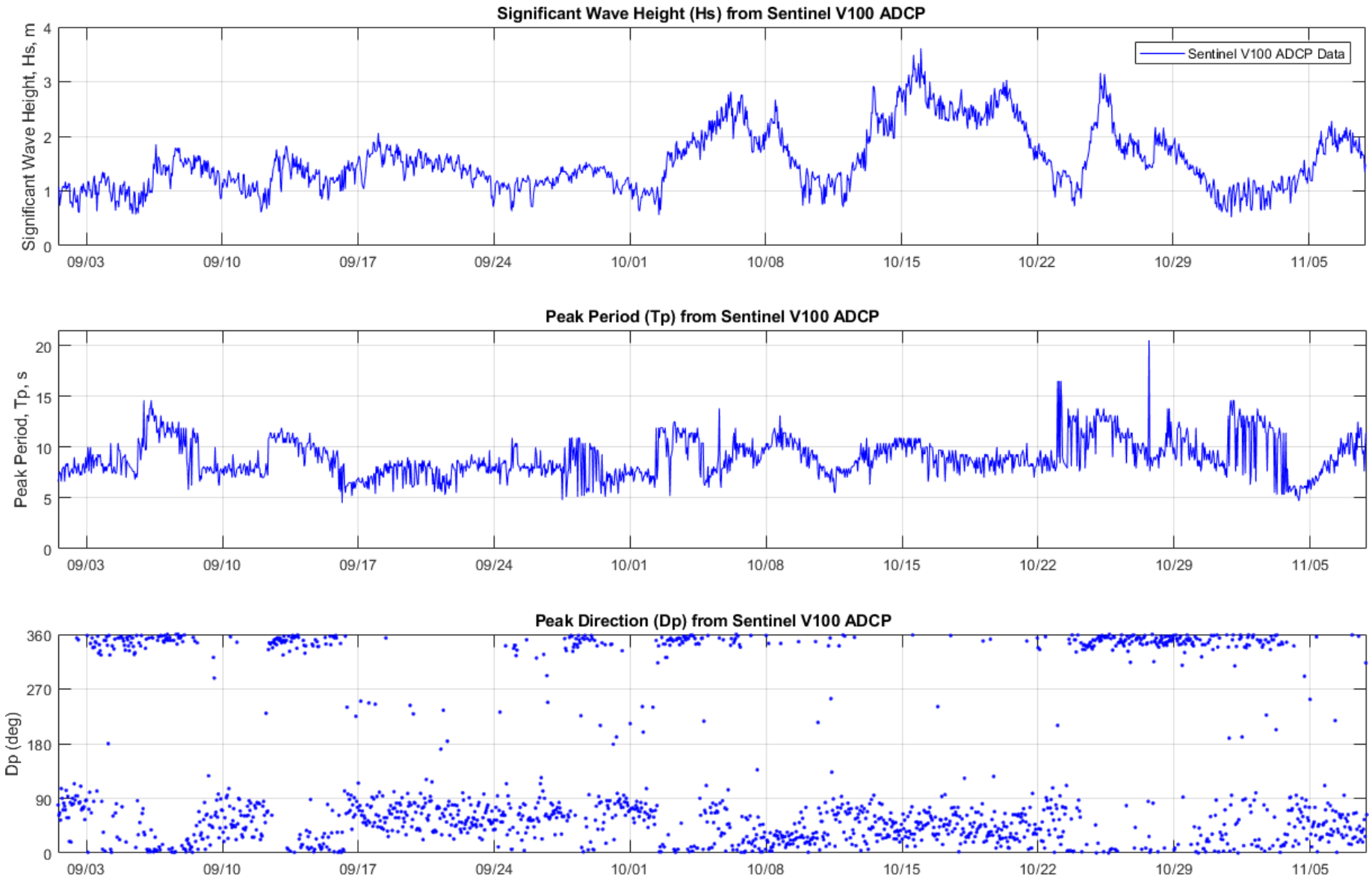

Figure 3-7 Wave Height, Peak Period, and Peak Direction

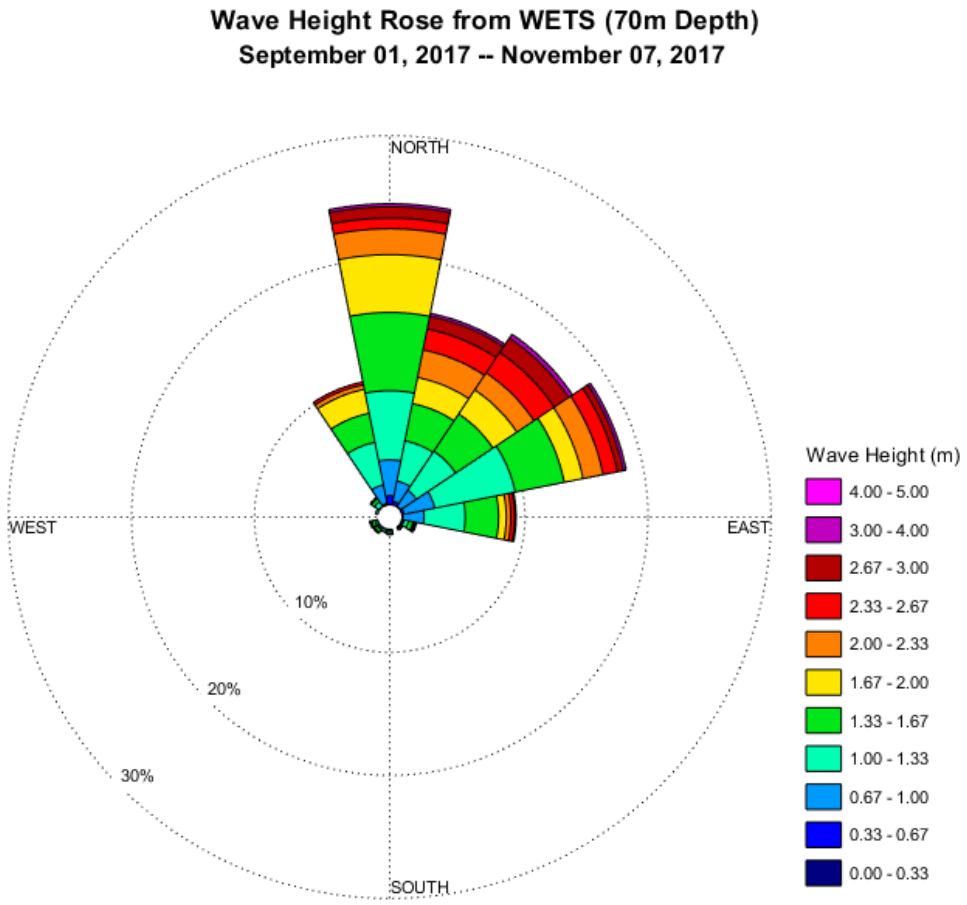

Figure 3-8 Wave Height Rose

Table 3-5 Wave Height Frequency of Occurrence

Wave Height, m	Total % by Direction in Deg																
	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.00 -0.33																	0.00
0.33 -0.67	0.74	0.31	0.06	0.19	0.06	0.06										0.12	1.55
0.67 -1.00	2.90	1.67	1.55	2.53	1.73	0.12			0.12	0.06	0.19	0.06			0.06	1.55	12.55
1.00 -1.33	5.62	3.34	3.83	6.67	3.34	0.37	0.12		0.19	0.19	0.06	0.19		0.19	0.43	3.52	28.06
1.33 -1.67	6.37	3.09	3.65	4.08	2.72	0.37	0.06		0.06	0.06	0.25	0.25			0.31	2.41	23.67
1.67 -2.00	4.70	2.16	2.35	1.55	0.62	0.12	0.06		0.06		0.12	0.12			0.06	1.98	13.91
2.00 -2.33	2.10	2.29	1.67	1.67	0.37	0.06	0.06								0.06	0.37	8.65
2.33 -2.67	0.87	1.73	1.98	1.17	0.31	0.12						0.06				0.25	6.49
2.67 -3.00	0.93	1.05	1.42	0.49	0.12												4.02
3.00 -4.00	0.25	0.25	0.37	0.25													1.11
4.00 -5.00																	0.00
Total %	24.47	15.88	16.87	18.60	9.27	1.24	0.31	0.00	0.43	0.31	0.62	0.68	0.00	0.19	0.93	10.20	100.00
Mean	1.54	1.71	1.74	1.49	1.34	1.40	1.58	0.00	1.23	1.14	1.33	1.47	0.00	1.26	1.32	1.39	1.55
StDev	0.54	0.63	0.63	0.55	0.42	0.47	0.51	0.00	0.31	0.18	0.36	0.46	0.00	0.08	0.27	0.41	0.56
Min	0.52	0.59	0.65	0.63	0.60	0.63	1.07	0.00	0.88	0.99	0.86	0.87	0.00	1.18	0.97	0.61	0.52
Max	3.22	3.61	3.24	3.34	2.92	2.45	2.32	0.00	1.69	1.43	1.87	2.58	0.00	1.33	2.00	2.66	3.61

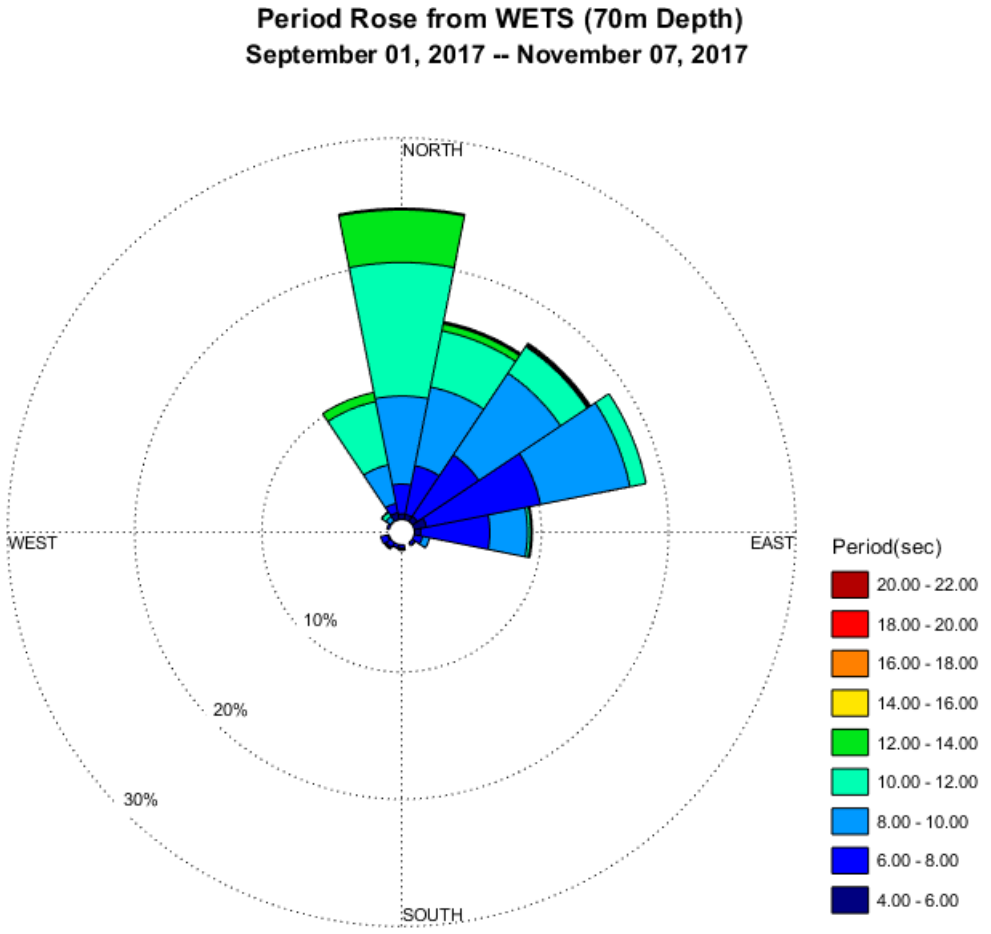

Figure 3-9 Period Rose

Table 3-6 Wave Period Frequency of Occurrence

Wave Period, s	Total % by Direction in Deg																
	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
4 -6	0.43	0.43	0.49	0.99	0.49							0.12				0.56	3.52
6 -8	2.35	3.89	5.81	9.15	5.44	0.68	0.25		0.25	0.25	0.43	0.56		0.19	0.06	0.74	30.04
8 -10	6.92	6.30	7.73	7.17	2.97	0.56	0.06		0.12		0.12				0.43	3.09	35.48
10 -12	10.51	4.51	2.53	1.30	0.25						0.06				0.37	5.07	24.60
12 -14	4.14	0.56	0.12		0.06				0.06						0.06	0.74	5.75
14 -16	0.12	0.06	0.12		0.06												0.37
16 -18		0.06	0.06							0.06							0.19
18 -20																	0.00
20 -22		0.06															0.06
Total %	**24.47**	**15.88**	**16.87**	**18.60**	**9.27**	**1.24**	**0.31**	**0.00**	**0.43**	**0.31**	**0.62**	**0.68**	**0.00**	**0.19**	**0.93**	**10.20**	**100.00**
Mean	10.31	9.16	8.48	7.91	7.84	7.79	7.80	0.00	7.91	8.86	7.54	6.58	0.00	7.00	9.61	9.89	**8.99**
StDev	1.91	1.86	1.56	1.16	1.31	0.92	0.44	0.00	2.42	4.28	1.64	0.67	0.00	0.69	1.45	1.81	**1.92**
Min	5.20	4.70	4.50	4.80	5.20	6.20	7.20	0.00	6.30	6.60	6.20	5.40	0.00	6.20	7.60	5.10	**4.50**
Max	14.60	20.50	16.50	11.40	14.60	9.70	8.40	0.00	13.10	16.50	11.40	7.60	0.00	7.40	12.50	13.10	**20.50**

REPORT:

Task 4J Report - ADCP Data Analysis at WETS (70m Depth)

June 2018

Prepared for:
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The area north of the Mōkapu Peninsula, adjacent to Kāneʻohe Marine Corps Base Hawaiʻi (MCBH), has been utilized by the U.S. Navy for wave energy research since 2002. Prototype wave energy converters (WEC) are being tested at the 30m, 60m, and 80m berths offshore of North Beach at the MCBH. The Hawaiʻi National Marine Renewable Energy Center (HNMREC) at the University of Hawaiʻi under contract with Department of Energy and the U.S. Navy, operates the test site.

Sea Engineering has been contracted by the HNMREC to conduct site investigations in support of the test site. One of these investigations is to determine wave climate and current characteristics at the site.

The project location within the state of Hawaiʻi is shown in Figure 1-1. The test site is 1600m to 2000m wide and extends approximately 2600m offshore from the 30m depth contour to the approximate 100m depth contour.

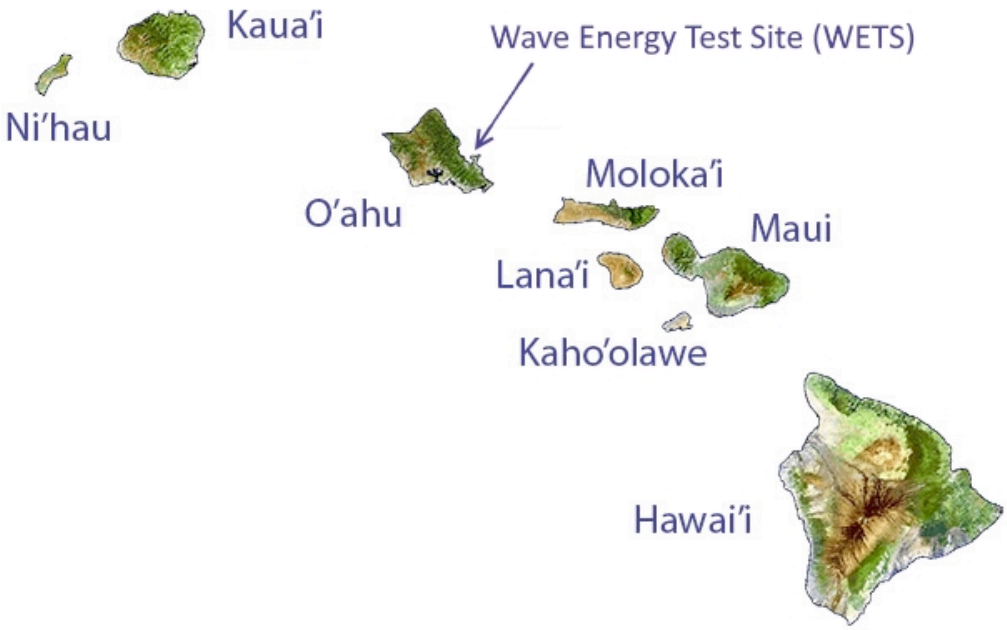

Figure 1-1 Project Location

In collaboration with HNMREC, Sea Engineering Inc. has deployed a Teledyne RDI Sentinel V100 Acoustic Doppler Current Profiler (ADCP) in the Wave Energy Test Site (WETS) since November 2014. Deployments were at the 30m site and the Waverider buoy from 2014 to 2016. In December 2016, the ADCP was deployed at the 70m depth between the 60m and 80m sites. Figure 1-2 shows the deployment location of the ADCP at 70m depth.

Table 1-1 shows the ADCP deployment schedule and the coordinates of the deployments.

Figure 1-2 WETS 70m Depth Deployment Location

Table 1-1 ADCP Deployment Schedule and Locations

Deployment Date	Task	Retrieval Date	Task	Location	Coordinates	Depth	Comment
11/13/2014	Previous WETS Funding	2/26/2015	4A	Near Waverider	21° 28' 39.1813" N 157° 44' 56.3008" W	78m	
2/26/2015	4A	6/4/2015	4B	Near Waverider	21° 28' 39.1813" N 157° 44' 56.3008" W	78m	
7/6/2015	4B	10/14/2015	4C	30m Site	21° 27' 56.1738" N 157° 45' 5.0563" W	31m	
10/19/2015	4C	1/13/2016	4D	30m Site	21° 27' 55.9741" N 157° 45' 4.1280" W	31m	
1/14/2016	4D	8/3/2016	1H	30m Site	21° 27' 55.9801" N 157° 45' 4.9739" W	31m	Data lost to memory card failure
12/6/2016	4E	4/14/2017	4G	Between 60m and 80m Sites	21° 28' 30.8115" N 157° 45'27.6232" W	70m	New ADCP
B1 secured	4F	B1 secured	4F	--	--	--	Tug to secure unanchored B1 float
4/15/17	4G	8/2/2017	4H	Between 60m and 80m Sites	21° 28' 30.2881" N 157° 45'28.3139" W	69m	
8/3/2017	4H	12/18/2017	4I	Between 60m and 80m Sites	21° 28' 30.1335" N 157° 45'29.3408" W	69m	Adjusted mount on 9-1-2017
12/19/2017	4I	3/26/2018	1N/4J	Between 60m and 80m Sites	21° 28’ 30.8004” N 157° 45’ 31.8493” W	69m	Could not reinstall do to electrical malfunction
	4J				Task remaining		
	4K				Task remaining		
	4L				Task remaining		
	4M				Task remaining		

Task 4F was used to secure the B1 surface float.

The Sentinel V100 ADCP uses a vertical acoustic beam to measure the distance to the water surface. Sound waves reflect off the water surface and the time a reflection takes to return to the ACDP is used to determine the distance to the surface. Accurate wave statistics can be

computed from the measured water surface elevation record. An ADCP relies on the Doppler effect to determine the water currents through the water column. The direction of current can be determined by using three or four acoustic beams. The acoustic reflection of a beam that is up current from the ACDP will arrive before the reflection of down current acoustic reflection. The analysis of the reflection return timing of multiple beams, allows the calculation the direction of waves and currents.

2. TELEDYNE RDI SENTINEL V100 SETUP

The Sentinel V100 was programmed to measure both waves and currents. ReadyV software from Teledyne RDI was used to program the Sentinel V100 ADCP. The software calculates the available battery resources and data storage for desired measurement profiles. The custom wave and current measurement profiles have the following settings:

Table 2-1 Profile Parameters

	Waves Measurement Profile	Current Measurement Profile
Ping Interval (seconds)	0.5	1
Number of Pings	2300	300
Range (meters)	75	75
Cell Size (meters)	1.0	1.0
Duration(minutes)	19.166	5

The wave measurement occurs once per hour over a 19 minute and 10 seconds period. Current measurements occur over a 5-minute period 30 minutes after the start of the wave measurements. This setup was chosen to accommodate a deployment duration of approximately 90 days. The lithium batteries have a capacity of 2130 watt-hours.

3. SENTINEL V100 DATA

The recorded wave and current data for the deployment period required 10.3 GB of data storage; the wave data comprised 9.2 GB. Teledyne RDI provides multiple software options to display and process the data. The primary data viewing and processing software is Velocity.

The direction that the Sentinel V100 ADCP references is magnetic north. These readings were converted to a true north reference using the magnetic declination values for the location of the ADCP on Oahu. The magnetic declination for WETS is 9.55° East.

Table 1-1 shows the ADCP deployment schedule and the coordinates of the deployment. This report presents data from the most recent deployment from December 19, 2017 to March 26, 2018.

3.1 Currents

Velocity software was used to average the current data into half-hour blocks. The water column was divided into three layers for analysis. Table 3-1, shows the bins and associated water depths corresponding to the three layers. Near surface data is biased by side lobe interference and is not included.

Table 3-1 Water Column Layer Divisions

	Bins	Range from ADCP, meters	Water Depth, meters
Bottom Layer	1 - 5	3.05 – 8.05	66 – 62
Middle Layer	28 - 33	30.05 -35.05	39- 34
Upper Layer	55 - 60	57.05 – 62.05	12 – 7

Figure 3-1 shows the time series of current speed and direction for the three layers of water. Figure 3-2 shows the time series for current speed and direction for all the bins measured by the ADCP. The water surface is plotted as a black line on top of the current data. The measurements above the red line are biased due to side lobe interference. Figure 3-3, Figure 3-4, and Figure 3-5 are current rose plots for upper, middle, and bottom layers, respectively. Table 3-2, Table 3-3, and Table 3-4 present the percent occurrence of currents speed and direction.

Upper layer current flow is bimodal with currents flowing predominantly towards the east-southeast and westward. The maximum recorded speed was 0.34 m/s and average speed was 0.1 m/s. Mid-layer currents flow predominantly to the east southeast (occurring 37% of the deployment duration). The maximum recorded speed was 0.39 m/s and average speed was 0.07 m/s. Bottom layer currents magnitudes are weaker and occur nearly equal frequency in all directions. The maximum recorded speed was 0.30 m/s and average speed was 0.07 m/s.

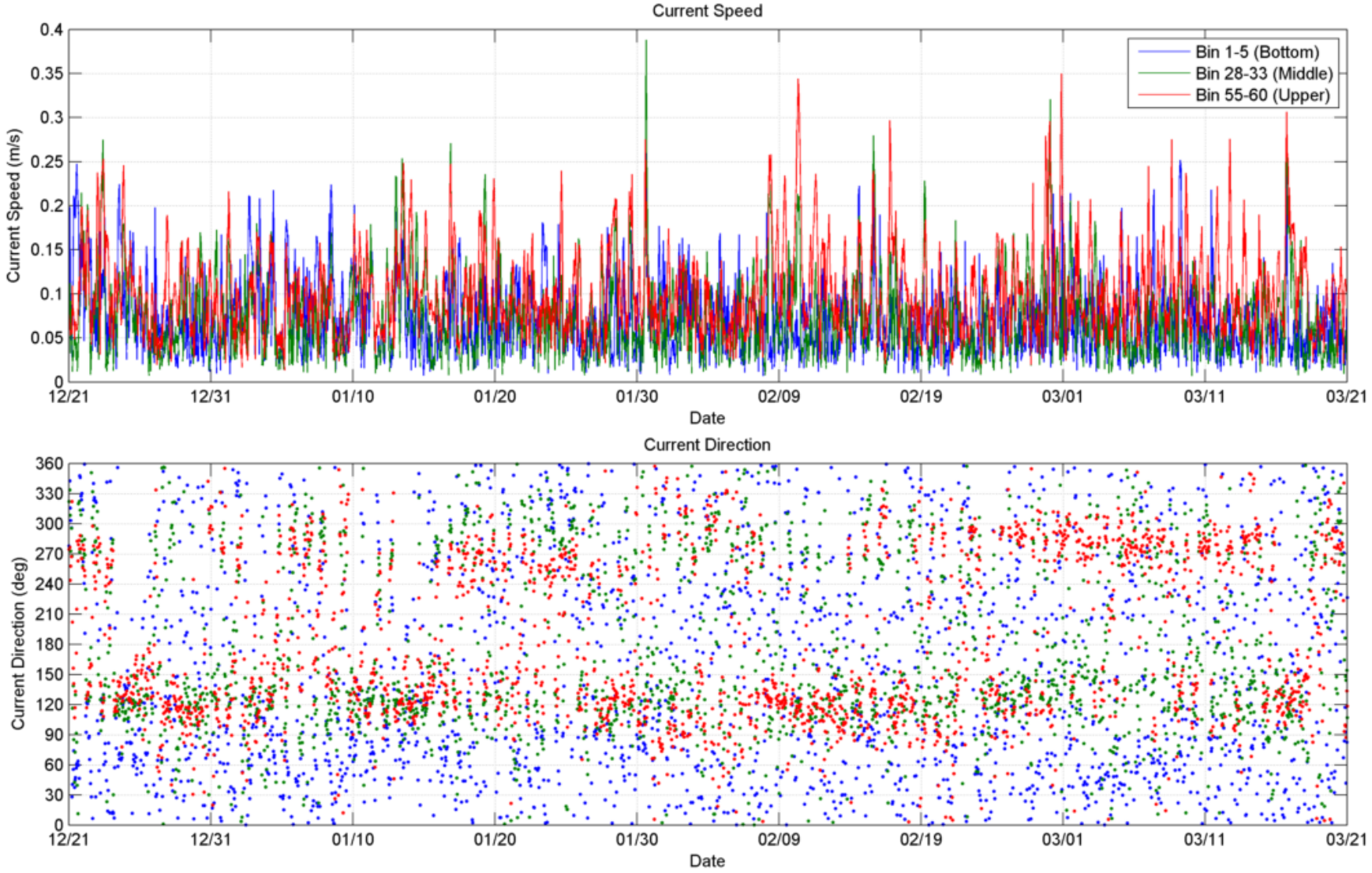

Figure 3-1 Current Speed and Direction for Each Layer

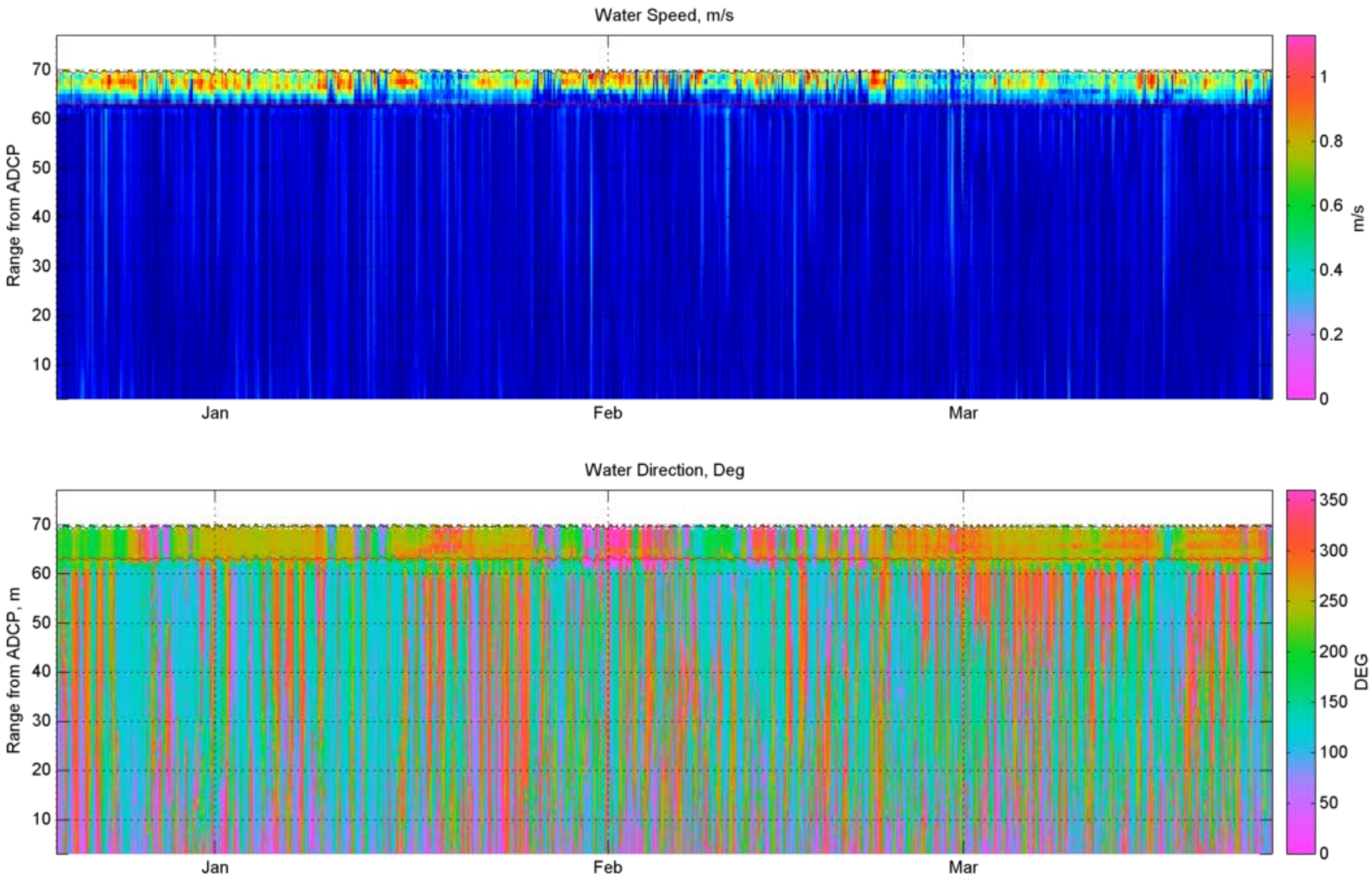

Figure 3-2 Current Speed and Direction for All Bins

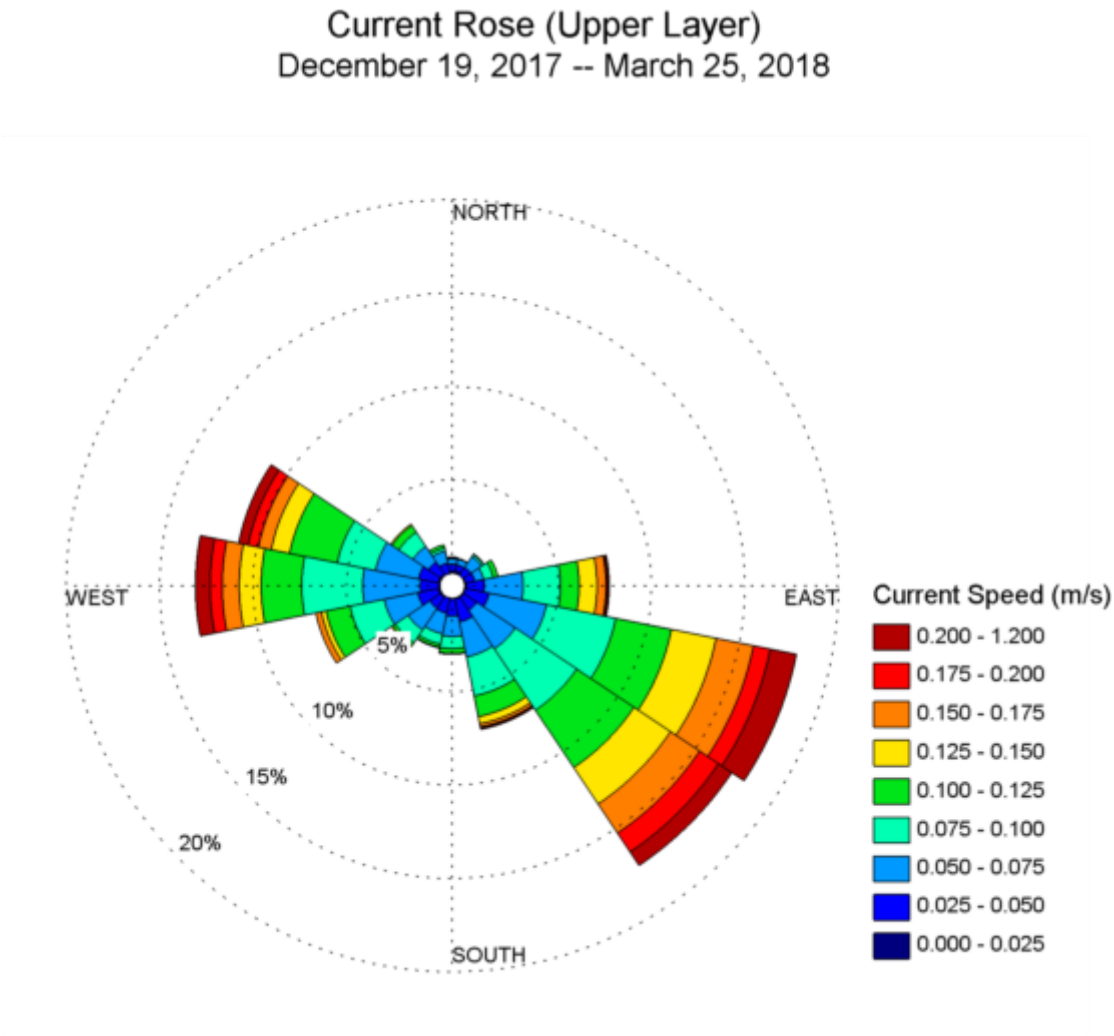

Figure 3-3 Current Rose for Upper Layer

Table 3-2 Upper Layer Current Frequency of Occurrence

Current Speed, m/s		Total % by Direction in Deg																
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.000	-0.025	0.13	0.13		0.04	0.09	0.04	0.09	0.04			0.09	0.09		0.09	0.09		0.91
0.025	-0.050	0.35	0.35	0.52	0.52	0.96	1.30	0.83	1.26	0.96	0.83	0.70	1.13	1.04	1.09	0.78	0.56	13.17
0.050	-0.075	0.30	0.30	0.70	0.48	2.09	3.13	2.48	1.91	1.09	1.13	1.39	1.83	3.09	2.35	1.00	0.65	23.90
0.075	-0.100	0.04	0.04	0.13	0.52	2.00	3.78	3.95	2.13	0.65	0.56	0.83	1.87	3.26	2.09	0.91	0.17	22.95
0.100	-0.125	0.04			0.26	1.00	3.04	3.69	1.13	0.26	0.17	0.17	1.30	2.17	2.61	0.43	0.17	16.47
0.125	-0.150					0.96	2.43	2.35	0.39	0.04	0.04	0.09	0.26	1.17	1.00	0.09		8.82
0.150	-0.175			0.04		0.48	2.04	1.87	0.17				0.30	0.91	0.70			6.52
0.175	-0.200					0.09	0.91	1.22	0.04					0.65	0.56			3.48
0.200	-1.200					0.09	1.43	0.87	0.09					0.78	0.52			3.78
Total %		**0.87**	**0.83**	**1.39**	**1.83**	**7.74**	**18.12**	**17.34**	**7.17**	**3.00**	**2.74**	**3.26**	**6.78**	**13.08**	**11.00**	**3.30**	**1.56**	**100.00**
Mean		0.05	0.05	0.06	0.07	0.09	0.12	0.12	0.08	0.07	0.06	0.07	0.08	0.11	0.10	0.07	0.06	**0.10**
StDev		0.02	0.02	0.02	0.03	0.04	0.06	0.05	0.04	0.02	0.02	0.02	0.03	0.05	0.05	0.03	0.02	**0.05**
Min		0.02	0.02	0.03	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.03	0.02	0.02	0.03	**0.01**
Max		0.11	0.08	0.16	0.12	0.28	0.34	0.31	0.31	0.14	0.14	0.13	0.17	0.35	0.31	0.14	0.12	**0.35**

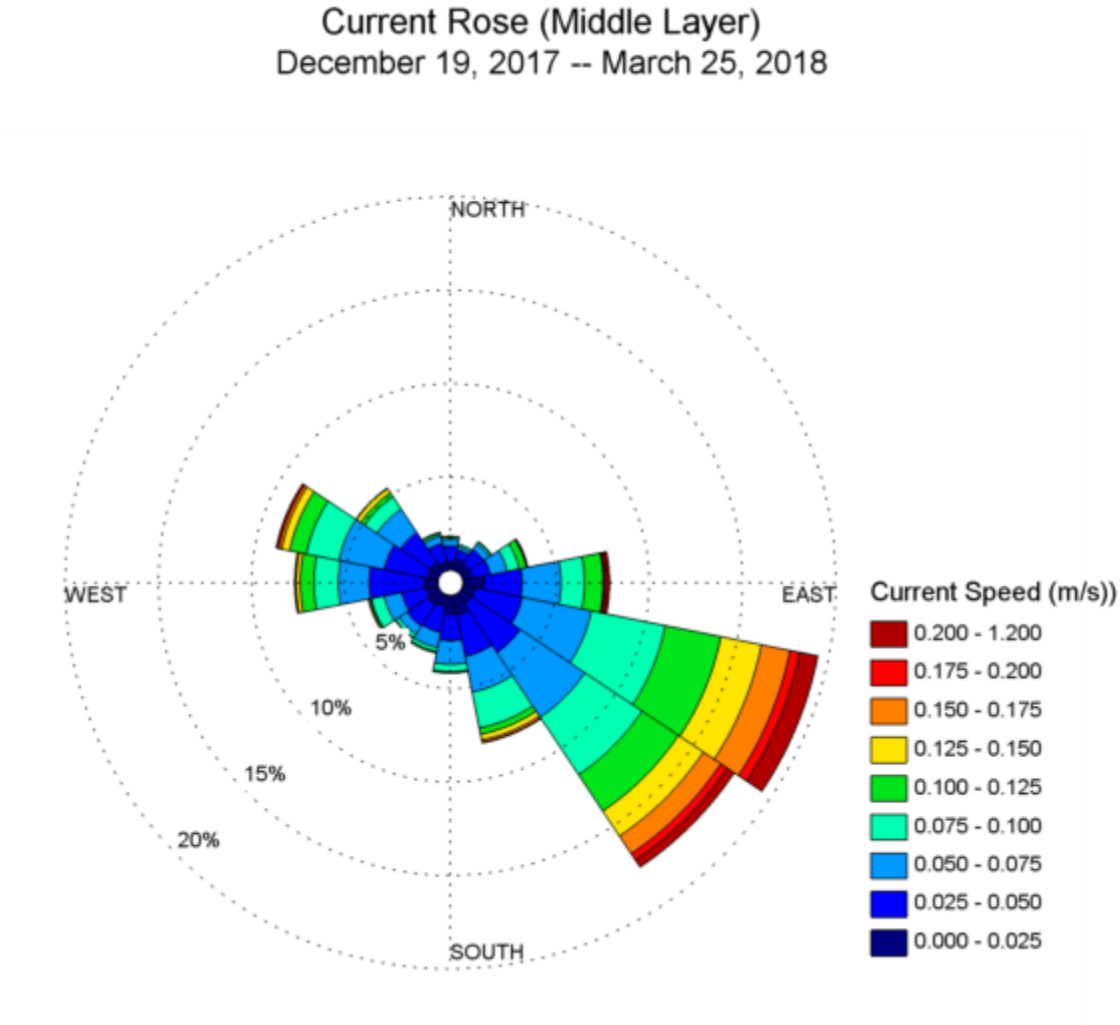

Figure 3-4 Current Rose for Middle Layer

Table 3-3 Middle Layer Current Frequency of Occurrence

Current Speed, m/s		Total % by Direction in Deg																
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.000	-0.025	0.43	0.65	0.52	0.52	1.13	0.70	0.70	1.09	1.00	0.65	0.78	0.65	0.74	0.61	0.65	0.48	**11.30**
0.025	-0.050	0.87	0.48	0.96	1.00	2.04	2.56	3.13	2.26	1.43	1.39	1.35	1.35	2.96	2.35	1.91	1.00	**27.03**
0.050	-0.075	0.35	0.17	0.35	0.91	2.09	3.78	4.17	1.96	1.26	0.83	0.52	0.96	1.65	2.48	1.52	0.39	**23.38**
0.075	-0.100	0.13	0.13	0.13	0.65	1.26	4.04	3.69	1.96	0.39	0.22	0.22	0.70	1.30	1.78	0.78	0.13	**17.51**
0.100	-0.125	0.04		0.04	0.39	1.00	3.04	2.35	0.35	0.09	0.09	0.04	0.09	0.74	0.91	0.26	0.09	**9.52**
0.125	-0.150				0.04	0.04	2.22	1.61	0.30				0.09	0.22	0.43	0.26		**5.22**
0.150	-0.175				0.04	0.04	1.56	1.13	0.13					0.09	0.17			**3.17**
0.175	-0.200					0.13	0.52	0.39	0.04							0.04		**1.13**
0.200	-1.200					0.13	1.00	0.48							0.13			**1.74**
Total %		**1.83**	**1.43**	**2.00**	**3.56**	**7.87**	**19.43**	**17.64**	**8.08**	**4.17**	**3.17**	**2.91**	**3.82**	**7.69**	**8.87**	**5.43**	**2.09**	**100.00**
Mean		0.04	0.03	0.04	0.06	0.07	0.10	0.09	0.06	0.05	0.04	0.04	0.05	0.06	0.07	0.06	0.04	**0.07**
StDev		0.02	0.02	0.02	0.03	0.04	0.05	0.05	0.03	0.02	0.02	0.02	0.03	0.03	0.04	0.03	0.02	**0.04**
Min		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	**0.01**
Max		0.12	0.09	0.11	0.16	0.24	0.29	0.39	0.18	0.11	0.11	0.11	0.15	0.17	0.27	0.18	0.11	**0.39**

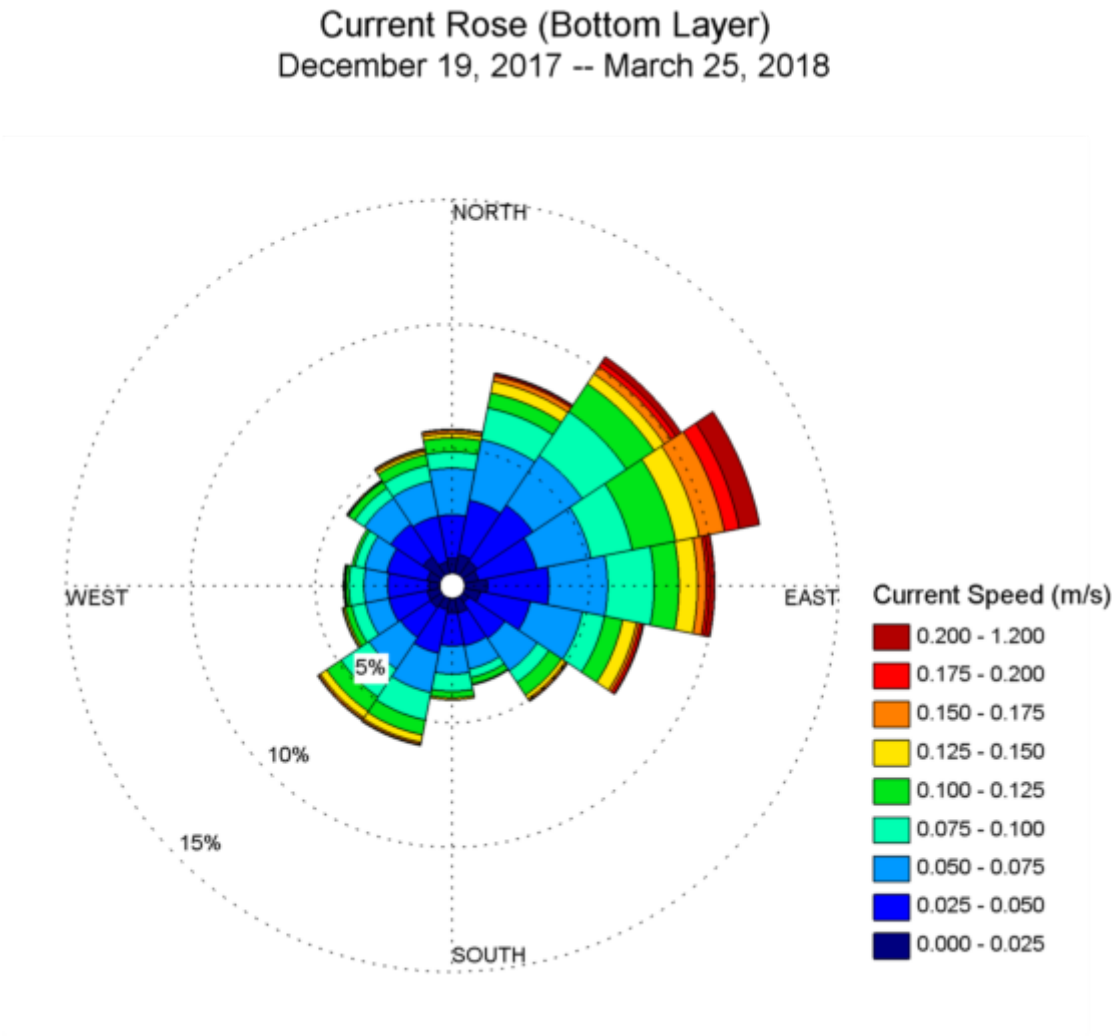

Figure 3-5 Current Rose for Bottom Layer

Table 3-4 Bottom Layer Current Frequency of Occurrence

Current Speed, m/s		Total % by Direction in Deg																
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.000	-0.025	0.61	0.78	0.70	0.56	0.91	0.65	0.30	0.61	0.61	0.48	0.56	0.52	0.43	0.52	0.91	0.48	9.65
0.025	-0.050	1.74	2.22	2.69	2.39	2.48	2.04	1.74	1.35	1.30	1.78	1.43	1.56	1.65	1.65	1.56	1.87	29.47
0.050	-0.075	1.87	2.48	2.39	2.22	2.35	2.13	1.56	0.96	1.13	1.61	1.52	0.96	0.96	0.91	1.26	1.43	25.73
0.075	-0.100	0.65	1.30	2.13	1.69	1.87	0.91	0.56	0.35	0.70	1.13	1.35	0.56	0.61	0.39	0.48	0.65	15.34
0.100	-0.125	0.56	0.61	1.35	1.78	1.00	0.74	0.61	0.26	0.26	0.61	0.70	0.26	0.13	0.13	0.30	0.43	9.73
0.125	-0.150	0.17	0.48	0.48	0.96	0.74	0.56	0.17	0.04	0.09	0.30	0.30	0.09	0.04		0.04	0.13	4.61
0.150	-0.175	0.13	0.22	0.35	1.04	0.35	0.13	0.09			0.09	0.09	0.04	0.04		0.04	0.09	2.69
0.175	-0.200		0.09	0.22	0.61	0.13	0.13	0.04			0.04	0.04					0.04	1.35
0.200	-1.200	0.04	0.04	0.26	0.83	0.22	0.04											1.43
Total %		**5.78**	**8.21**	**10.56**	**12.08**	**10.04**	**7.34**	**5.08**	**3.56**	**4.09**	**6.04**	**6.00**	**4.00**	**3.87**	**3.61**	**4.61**	**5.13**	**100.00**
Mean		0.06	0.07	0.08	0.10	0.08	0.07	0.06	0.05	0.06	0.07	0.07	0.06	0.05	0.05	0.05	0.06	**0.07**
StDev		0.04	0.04	0.05	0.06	0.05	0.04	0.03	0.03	0.03	0.04	0.04	0.03	0.03	0.02	0.03	0.03	**0.04**
Min		0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	**0.01**
Max		0.21	0.21	0.27	0.27	0.30	0.22	0.19	0.13	0.14	0.20	0.19	0.17	0.16	0.12	0.16	0.20	**0.30**

3.2 Waves

The WavesMon module of Velocity was used to calculate hourly wave statistics. The three statistics of most importance for wave characterization are the significant wave height (H_s), peak period (T_p), and peak direction (D_p). The direction that the Sentinel V100 ADCP references is magnetic north. These readings were converted to a true north reference using the magnetic declination values for the location of the ADCP on Oahu. The magnetic declination for WETS is 9.55° East. A second program, WavesView, is used to display the spectral data alongside the wave statistics.

A screenshot of the settings for WavesMon is presented in Figure 3-6.

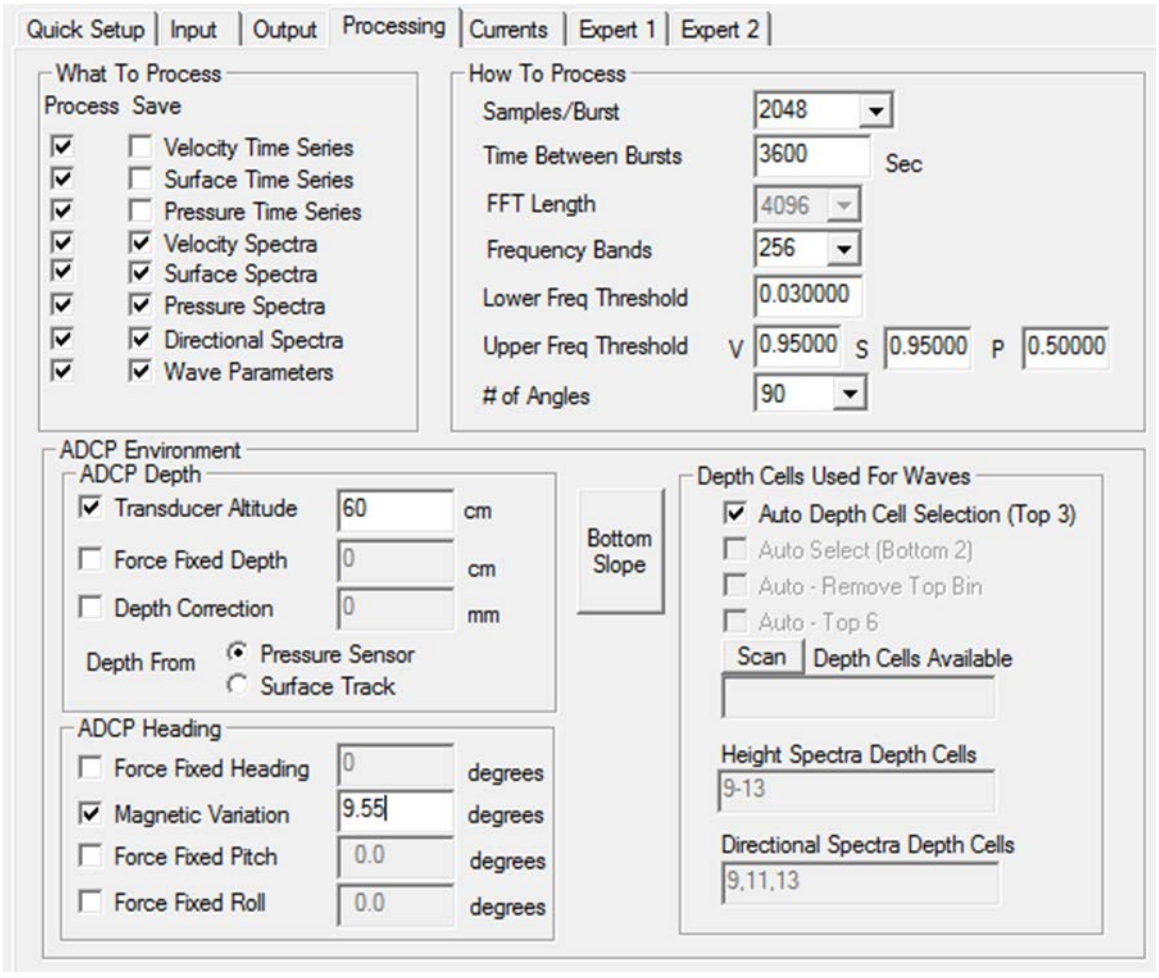

Figure 3-6 WavesMon Processing Tab

Figure 3-7 shows the time series of significant wave height, peak period, and peak direction for the deployment. Figure 3-8 shows the wave height rose which is dominated by the trade wind driven waves from the northeast with shorter periods and longer period swell from the north.

Table 3-5 presents the percent frequency of wave height and direction. Figure 3-8 presents the wave period rose.

Table 3-6 presents the percent frequency of wave peak period and direction.

The time series, Figure 3-7, indicates typical wave heights are approximately 1.0 – 2.0m with peak periods of 6-8s from an east-northeast direction indicative of trade wind generated swell. The wave height of 2.0 – 3.0m, and peak direction from the east, and shorter wave periods are indicative of a strong trade wind period from January 17 -20, 2018. A north swell event is recorded December 19 – 21, 2018 with waves from the north and longer period waves.

The wave height rose shown in Figure 3-8, and Table 3-5, indicates waves from an east and northeasterly direction (0° - 90°) occurred 86% of the time. Waves were greater than 1.0m, 95% of the time. The average wave height was 1.77m and maximum wave height was 3.72m.

The period rose shown in Figure 3-9, and Table 3-6, show the mean peak period was 9.77 seconds and the maximum period was 19.0 seconds.

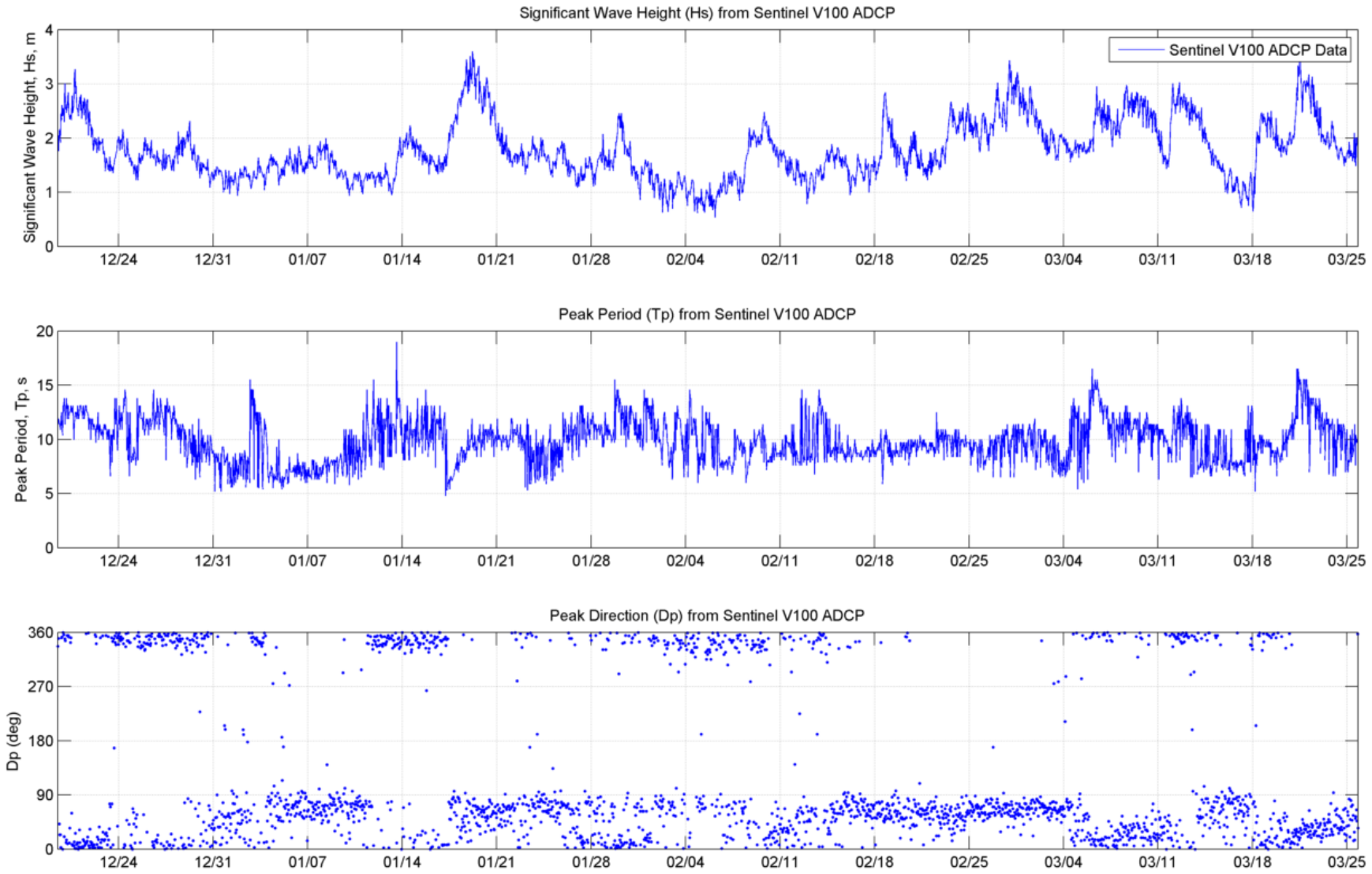

Figure 3-7 Wave Height, Peak Period, and Peak Direction

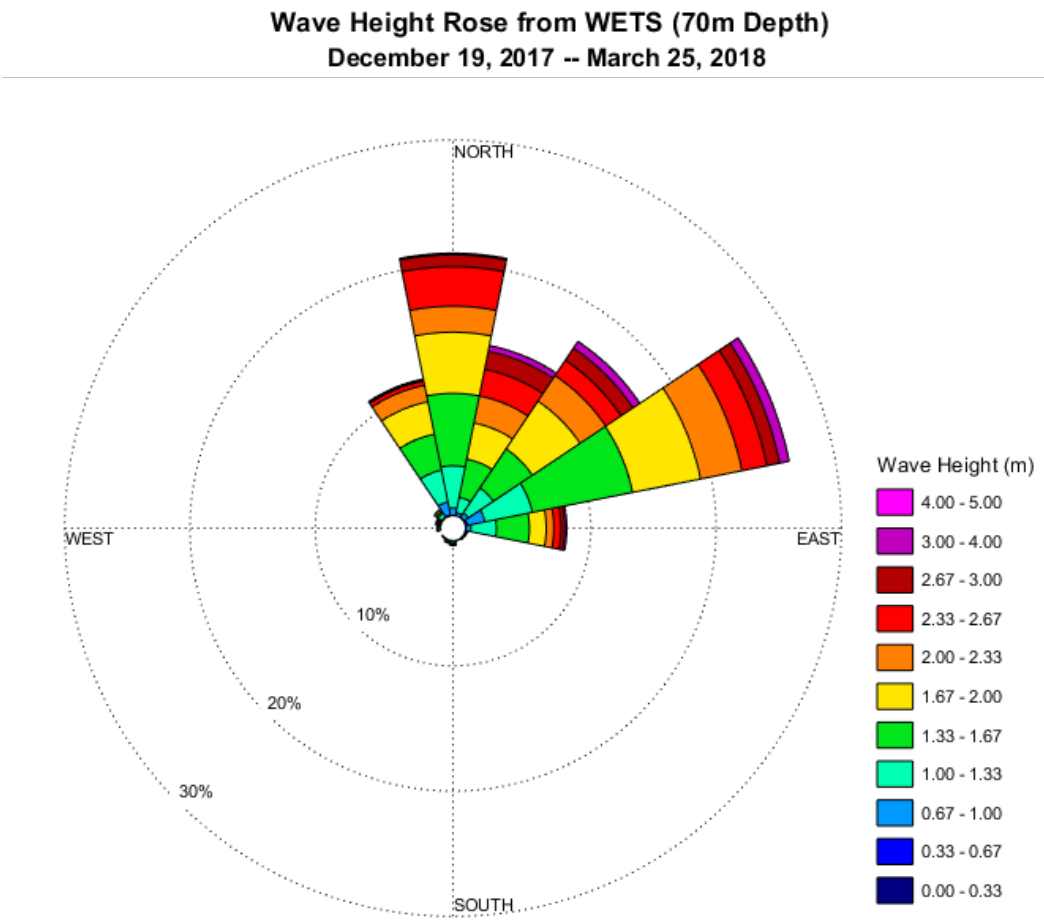

Figure 3-8 Wave Height Rose

Table 3-5 Wave Height Frequency of Occurrence

Wave Height, m	Total % by Direction in Deg																
	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.00 -0.33																	0.00
0.33 -0.67			0.04	0.17	0.04											0.09	0.35
0.67 -1.00	0.61	0.26	0.43	1.43	0.39										0.09	1.04	4.24
1.00 -1.33	3.37	1.25	2.38	3.85	2.03	0.04	0.04		0.17	0.13	0.04			0.13	0.35	2.59	16.38
1.33 -1.67	5.79	3.11	3.76	8.17	2.64	0.09	0.04	0.04	0.09	0.04	0.04		0.17	0.09	0.17	2.94	27.18
1.67 -2.00	4.88	2.94	4.58	5.53	1.34		0.04		0.09	0.04			0.09	0.09	0.17	2.64	22.43
2.00 -2.33	2.07	2.20	2.46	3.37	0.61	0.04			0.04	0.04			0.04			1.34	12.23
2.33 -2.67	3.15	2.16	1.47	2.03	0.56									0.13		0.35	9.85
2.67 -3.00	0.95	1.47	1.17	1.04	0.30										0.04	0.09	5.06
3.00 -4.00	0.13	0.48	0.65	0.78	0.17											0.09	2.29
4.00 -5.00																	0.00
Total %	20.96	13.87	16.94	26.36	8.08	0.17	0.13	0.04	0.39	0.26	0.09	0.00	0.30	0.43	0.82	11.15	100.00
Mean	1.79	1.98	1.85	1.74	1.66	1.62	1.53	1.52	1.47	1.54	1.31	0.00	1.70	1.77	1.41	1.56	1.77
StDev	0.50	0.55	0.55	0.55	0.52	0.34	0.29	0.00	0.30	0.51	0.07	0.00	0.20	0.49	0.47	0.45	0.54
Min	0.68	0.76	0.54	0.62	0.66	1.31	1.22	1.52	1.06	1.05	1.26	0.00	1.53	1.23	0.86	0.64	0.54
Max	3.27	3.72	3.35	3.60	3.45	2.09	1.79	1.52	2.04	2.31	1.36	0.00	2.07	2.44	2.83	3.01	3.72

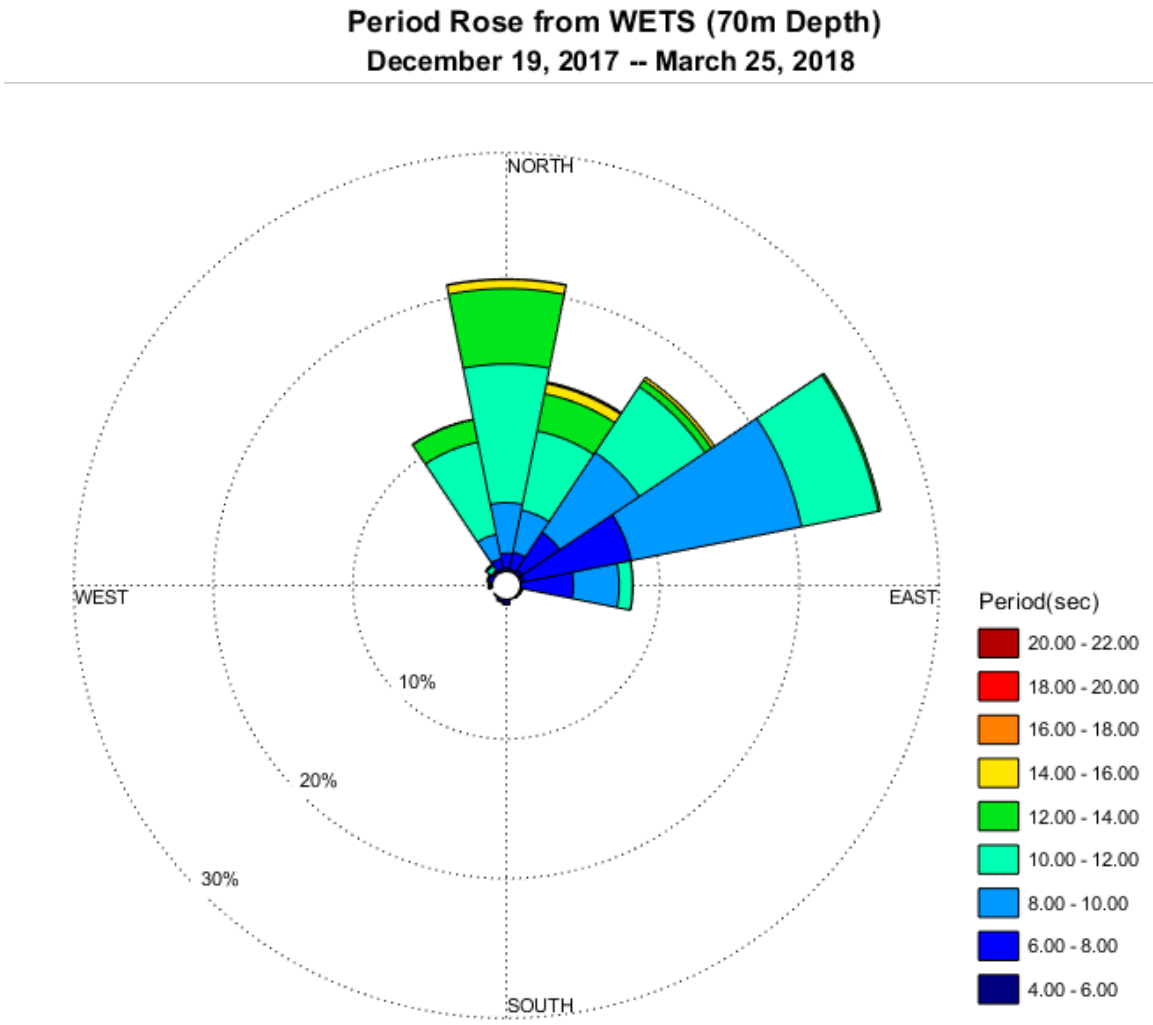

Figure 3-9 Period Rose

Table 3-6 Wave Period Frequency of Occurrence

Wave Period, s	Total % by Direction in Deg															
	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
4 -6	0.26	0.17	0.35	0.30	0.04				0.09				0.04			0.17	1.43
6 -8	1.04	1.25	3.24	7.82	3.76	0.13	0.09		0.22	0.17	0.09		0.09	0.30	0.17	0.78	19.14
8 -10	3.63	3.07	6.87	12.45	3.28	0.04	0.04		0.04	0.09			0.04	0.04	0.13	1.77	31.50
10 -12	9.94	5.79	5.66	5.62	0.95			0.04	0.04				0.13	0.04	0.39	6.74	35.35
12 -14	5.40	2.72	0.56	0.17	0.04									0.04	0.13	1.64	10.72
14 -16	0.65	0.73	0.26													0.04	1.69
16 -18		0.13															0.13
18 -20	0.04																0.04
20 -22																	0.00
Total %	**20.96**	**13.87**	**16.94**	**26.36**	**8.08**	**0.17**	**0.13**	**0.04**	**0.39**	**0.26**	**0.09**	**0.00**	**0.30**	**0.43**	**0.82**	**11.15**	**100.00**
Mean	11.06	10.81	9.34	8.71	8.26	7.53	7.30	10.00	6.98	7.33	7.05	0.00	8.47	7.89	10.23	10.63	**9.77**
StDev	1.92	2.19	1.76	1.39	1.27	1.23	2.08	0.00	1.90	0.94	0.78	0.00	2.10	2.38	1.91	1.64	**2.04**
Min	4.80	5.20	5.40	5.20	5.90	6.60	6.00	10.00	5.40	6.50	6.50	0.00	5.50	6.30	7.20	5.40	**4.80**
Max	19.00	16.50	15.50	13.80	12.50	9.30	9.70	10.00	11.40	8.70	7.60	0.00	11.40	12.50	12.50	14.60	**19.00**

REPORT:

Task 4K Report - ADCP Data Analysis at WETS (70m Depth)

Report Date: December 19, 2018

Prepared for:
Hawai‘i National Marine Renewable Energy Center
1680 East West Road, POST 112A
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Job No. 25419

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The area north of the Mōkapu Peninsula, adjacent to Kāneʻohe Marine Corps Base Hawaiʻi (MCBH), has been utilized by the U.S. Navy for wave energy research since 2002. Prototype wave energy converters (WEC) are being tested at the 30m, 60m, and 80m berths offshore of North Beach at the MCBH. The Hawaiʻi National Marine Renewable Energy Center (HNMREC) at the University of Hawaiʻi, under contract with Department of Energy and the U.S. Navy, operates the test site.

Sea Engineering has been contracted by the HNMREC to conduct site investigations in support of the test site. One of these investigations is to determine wave climate and current characteristics at the site.

The project location within the state of Hawaiʻi is shown in Figure 1-1. The test site is 1600m to 2000m wide and extends approximately 2600m offshore from the 30m depth contour to the approximate 100m depth contour.

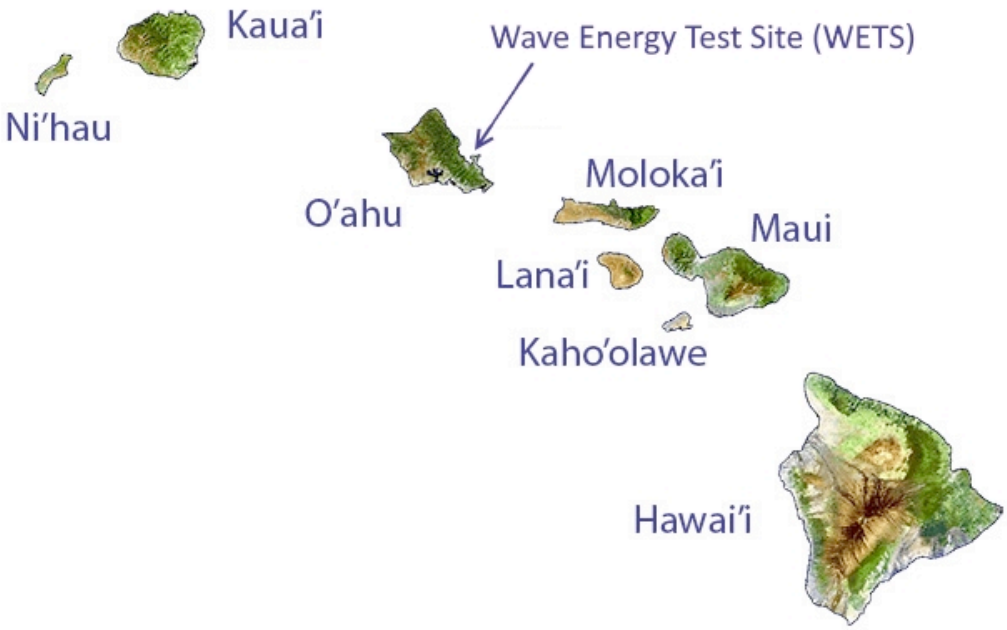

Figure 1-1 Project Location

In collaboration with HNMREC, Sea Engineering Inc. has deployed a Teledyne RDI Sentinel V100 Acoustic Doppler Current Profiler (ADCP) in the Wave Energy Test Site (WETS) since November 2014. Deployments were located at the 30m site and the Waverider buoy from 2014 to 2016. In December 2016, the ADCP was deployed at the 70m water depth between the 60m and 80m sites. Figure 1-2 shows the deployment location of the ADCP at 70m depth.

Table 1-1 shows the ADCP deployment schedule and the coordinates of the deployments.

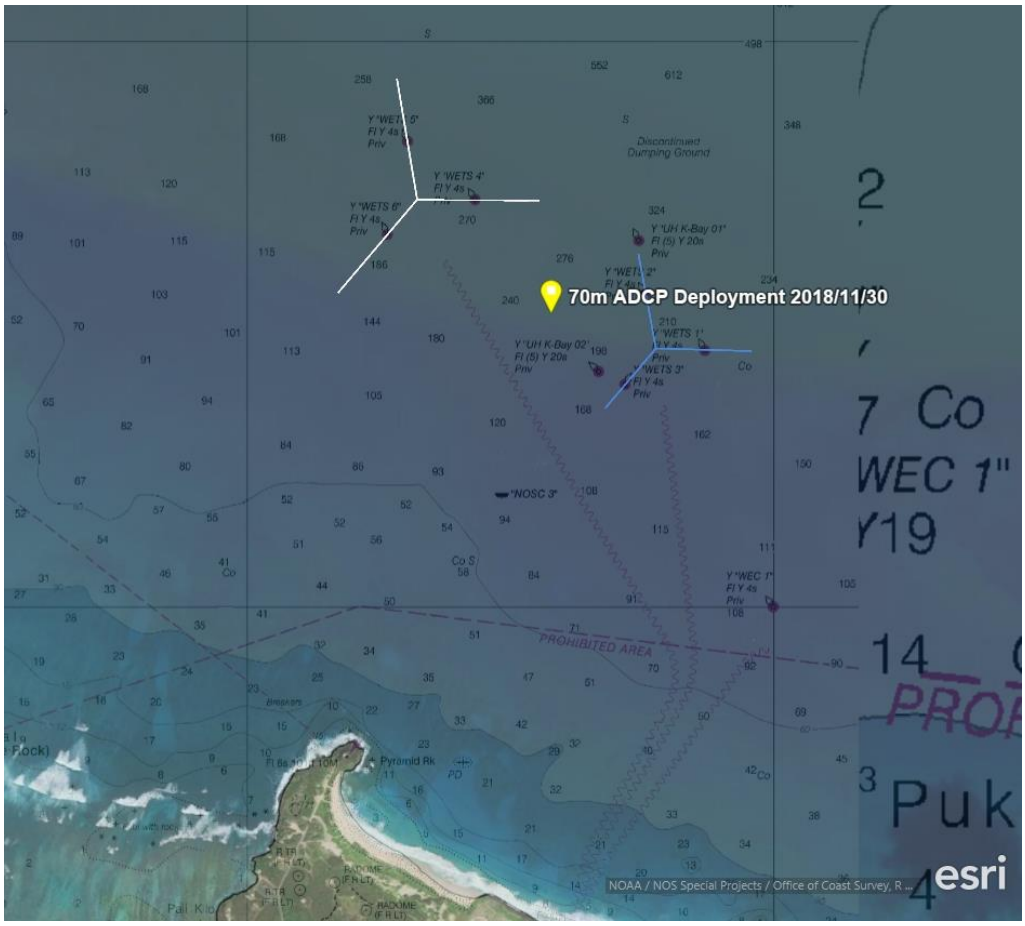

Figure 1-2 WETS 70m Depth Deployment Location

Table 1-1 ADCP Deployment Schedule and Locations

Deployment Date	Task	Retrieval Date	Task	Location	Coordinates	Depth	Comment
11/13/2014	Previous WETS Funding	2/26/2015	4A	Near Waverider	21° 28' 39.1813" N 157° 44' 56.3008" W	78m	
2/26/2015	4A	6/4/2015	4B	Near Waverider	21° 28' 39.1813" N 157° 44' 56.3008" W	78m	
7/6/2015	4B	10/14/2015	4C	30m Site	21° 27' 56.1738" N 157° 45' 5.0563" W	31m	
10/19/2015	4C	1/13/2016	4D	30m Site	21° 27' 55.9741" N 157° 45' 4.1280" W	31m	
1/14/2016	4D	8/3/2016	1H	30m Site	21° 27' 55.9801" N 157° 45' 4.9739" W	31m	Data lost to memory card failure
12/6/2016	4E	4/14/2017	4G	Between 60m and 80m Sites	21° 28' 30.8115" N 157° 45'27.6232" W	70m	New ADCP
B1 secured	4F	B1 secured	4F	--	--	--	Tug to secure unanchored B1 float
4/15/17	4G	8/2/2017	4H	Between 60m and 80m Sites	21° 28' 30.2881" N 157° 45'28.3139" W	69m	
8/3/2017	4H	12/18/2017	4I	Between 60m and 80m Sites	21° 28' 30.1335" N 157° 45'29.3408" W	69m	Adjusted mount on 9-1-2017
12/19/2017	4I	3/26/2018	1N/4J	Between 60m and 80m Sites	21° 28’ 30.8004” N 157° 45’ 31.8493” W	69m	Could not reinstall due to electrical malfunction
6/18/2018	4J	11/29/2018	4K	Between 60m and 80m Sites	21° 28' 31.0428" N 157° 45' 25.3122"W	70m	
	4L				Task remaining		
	4M				Task remaining		

Task 4F was used to secure the B1 surface float.

The Sentinel V100 ADCP uses a vertical acoustic beam to measure the distance to the water surface. Sound waves reflect off the water surface and the time a reflection takes to return to the ACDP is used to determine the distance to the surface. Accurate wave statistics can be computed from the measured water surface elevation record. An ADCP relies on the Doppler effect to determine the water currents through the water column. The direction of current can be

determined by using three or four acoustic beams. The acoustic reflection of a beam that is up current from the ACDP will arrive before the reflection of down current acoustic reflection. The analysis of the reflection return timing of multiple beams, allows the calculation the direction of waves and currents.

2. TELEDYNE RDI SENTINEL V100 SETUP

The Sentinel V100 was programmed to measure both waves and currents. ReadyV software from Teledyne RDI was used to program the Sentinel V100 ADCP. The software calculates the available battery resources and data storage for desired measurement profiles. The custom wave and current measurement profiles have the following settings:

Table 2-1 Profile Parameters

	Waves Measurement Profile	Current Measurement Profile
Ping Interval (seconds)	1.3	1
Number of Pings	2300	300
Range (meters)	75	75
Cell Size (meters)	1.0	1.0
Duration(minutes)	28	5

The wave measurement occurs once per hour over a 28 minute period. The ping interval parameter changed from 0.5s. The result of this change are that the minimum included wave period is 1.5s. Current measurements occur over a 5-minute period 30 minutes after the start of the wave measurements. This setup was chosen to accommodate a deployment duration of approximately 90 days. The lithium batteries have a capacity of 2130 watt-hours.

3. SENTINEL V100 DATA

Teledyne RDI provides multiple software options to display and process the data. The primary data viewing and processing software is Velocity.

The direction that the Sentinel V100 ADCP references is magnetic north. These readings were converted to a true north reference using the magnetic declination values for the location of the ADCP on Oahu. The magnetic declination for WETS is 9.55° East.

3.1 Currents

Velocity software was used to average the current data into half-hour blocks. The water column was divided into three layers for analysis. Table 3-1, shows the bins and associated water depths corresponding to the three layers. Near surface data is biased by side lobe interference and is not included.

Table 3-1 Water Column Layer Divisions

	Bins	Range from ADCP, meters	Water Depth, meters
Bottom Layer	1 -5	3.05 -7.05	64.69 -60.69
Middle Layer	27 -32	29.05 -34.05	38.69 -33.69
Upper Layer	54 -59	56.05 -61.05	11.69 -6.69

Figure 3-1 shows the time series of current speed and direction for the three layers of water. Figure 3-2 shows the time series for current speed and direction for all the bins measured by the ADCP. The water surface is plotted as a black line on top of the current data. The measurements above the red line are biased due to side lobe interference. Figure 3-3, Figure 3-4, and Figure 3-5 are current rose plots for upper, middle, and bottom layers, respectively. Table 3-2, Table 3-3, and Table 3-4 present the percent frequency of occurrence of currents speed and direction.

Upper layer current flow is predominantly westward. The maximum recorded speed was 0.32 m/s and average speed was 0.12 m/s. Mid-layer currents flow predominantly to the east southeast (occurring 40% of the deployment duration). The maximum recorded speed was 0.34 m/s and average speed was 0.08 m/s. Bottom layer currents magnitudes are weaker and occur at nearly equal frequency in all directions. The maximum recorded speed was 0.25 m/s and average speed was 0.06 m/s.

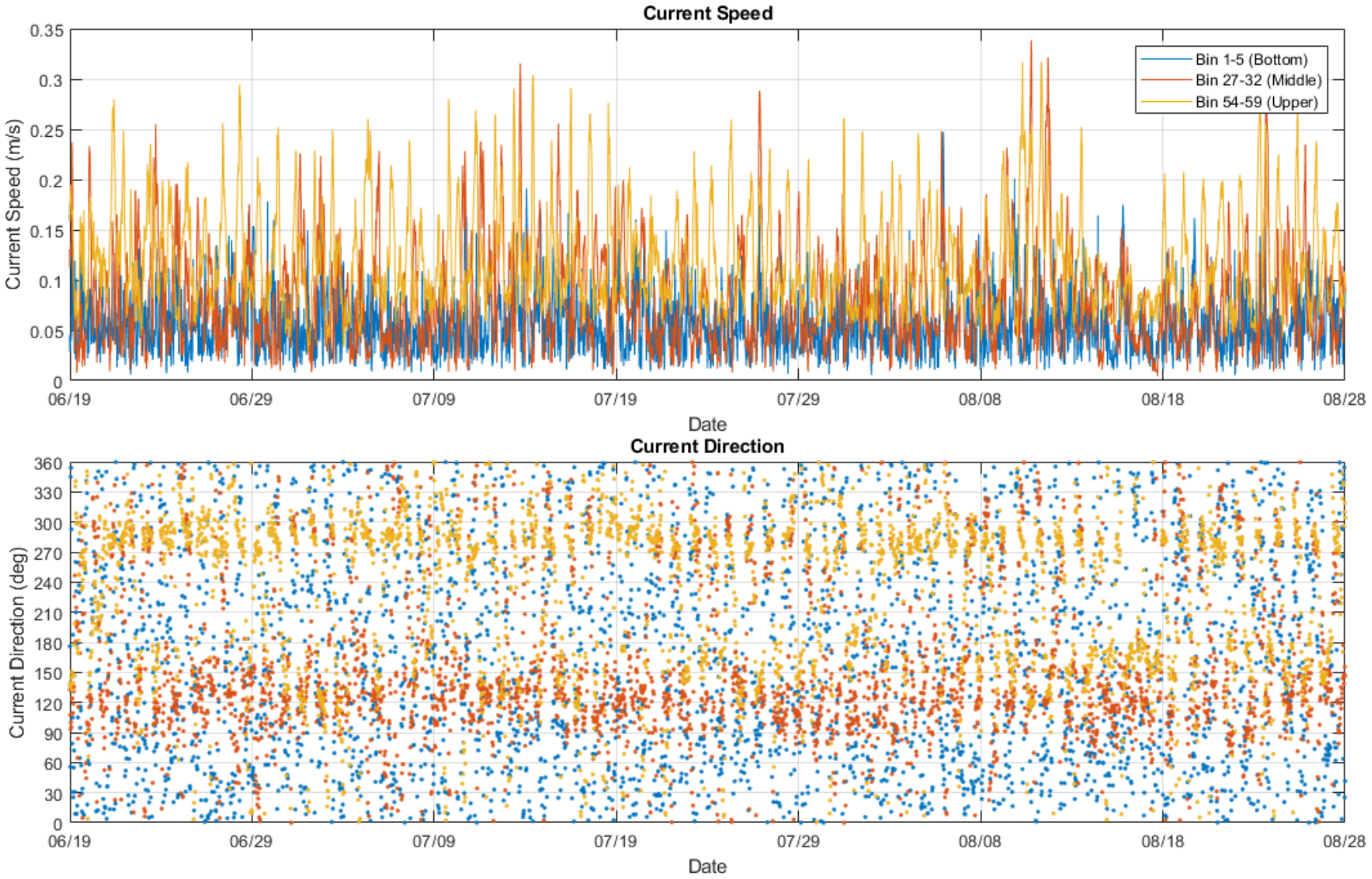

Figure 3-1 Current Speed and Direction for Each Layer

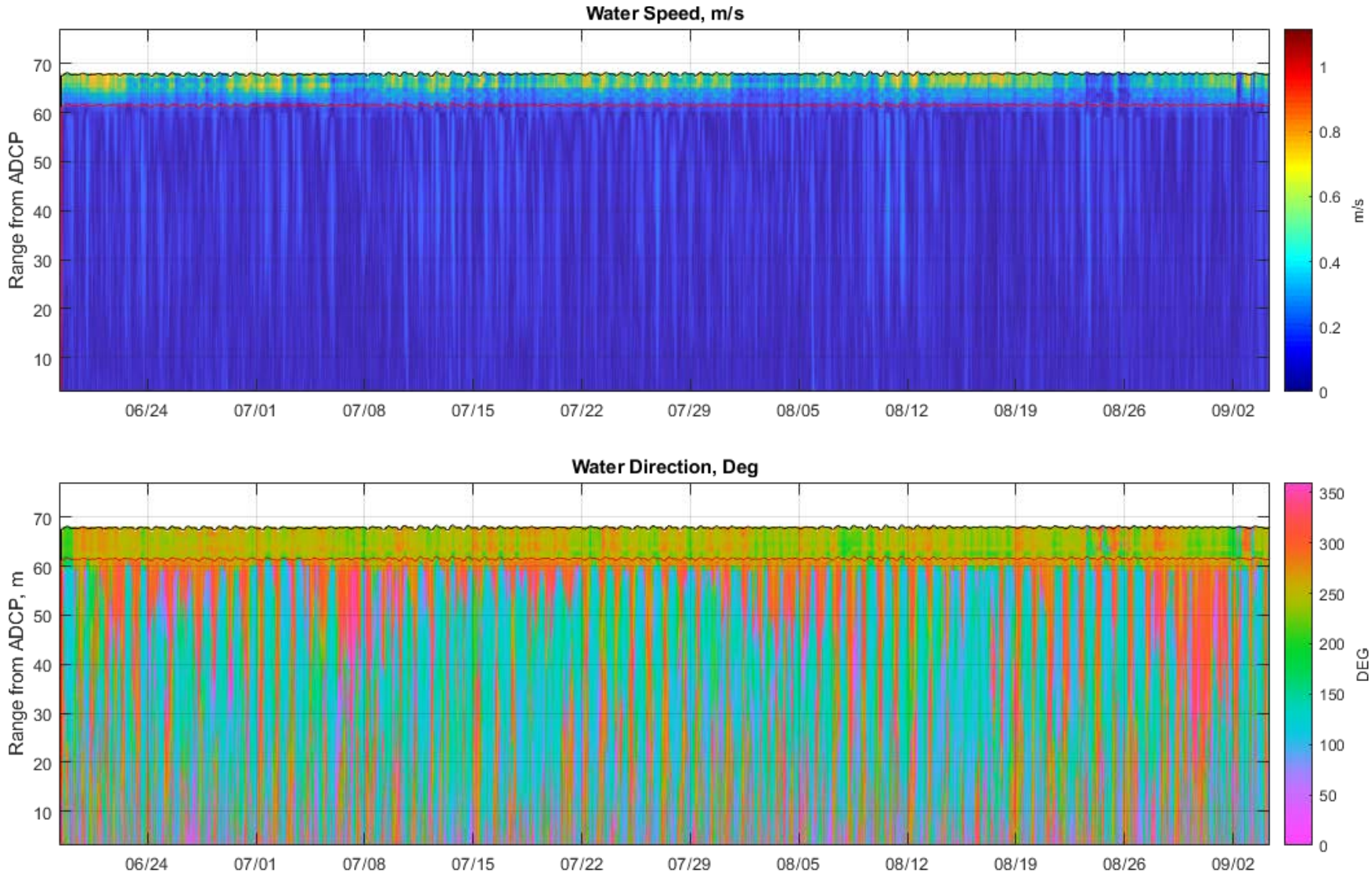

Figure 3-2 Current Speed and Direction for All Bins

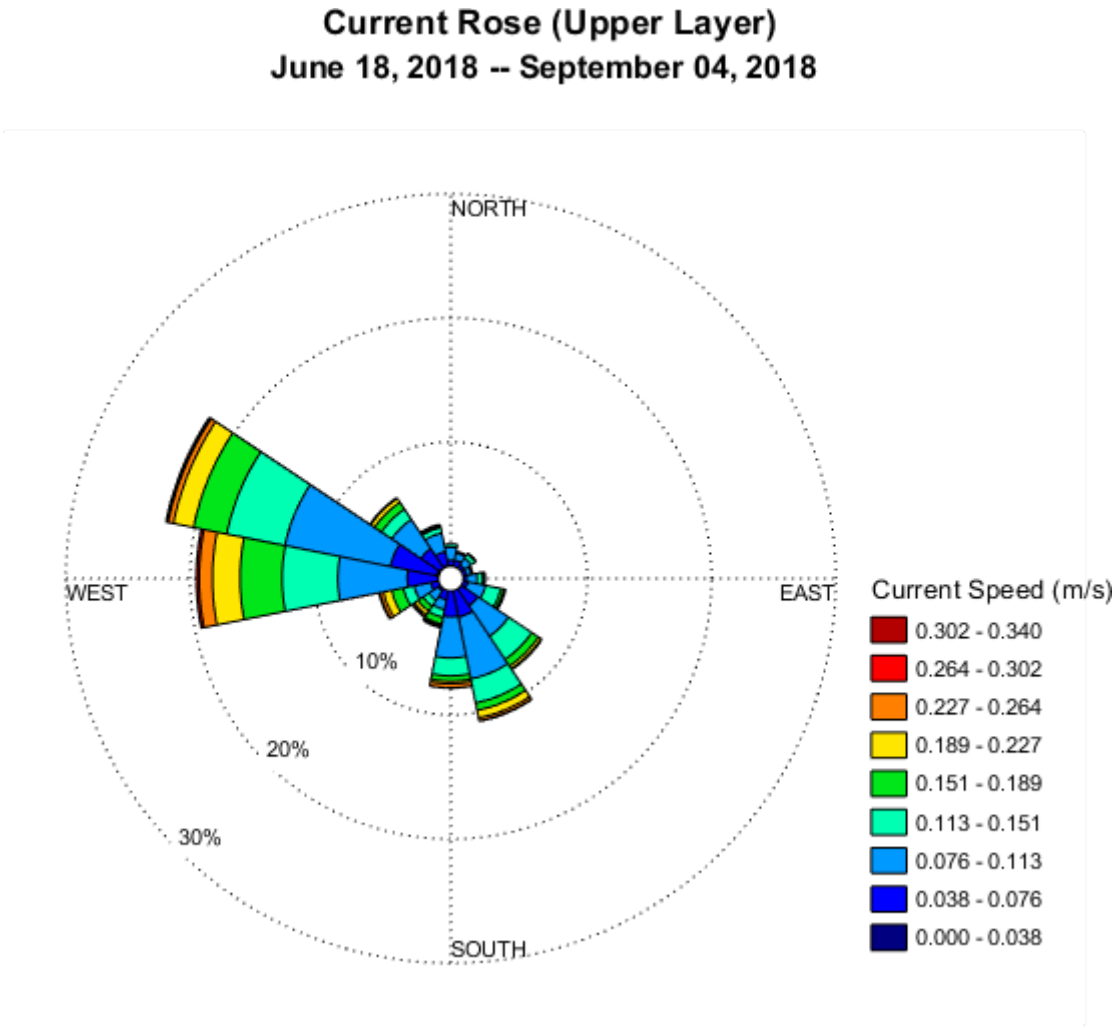

Figure 3-3 Current Rose for Upper Layer

Table 3-2 Upper Layer Current Frequency of Occurrence

Current Speed, m/s		Total % by Direction in Deg																
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.000	-0.038	0.03	0.11	0.03					0.05	0.05						0.03	0.05	0.35
0.038	-0.076	1.02	0.64	0.61	0.35	0.51	0.53	1.15	2.46	3.37	1.79	1.23	0.94	0.72	0.96	1.34	1.42	19.02
0.076	-0.113	0.75	0.43	0.77	0.40	1.10	1.52	3.34	5.53	3.55	0.91	1.07	2.24	5.08	5.58	3.77	1.87	37.91
0.113	-0.151		0.05	0.05	0.08	0.13	0.83	2.08	2.03	0.51	0.35	0.37	1.02	5.16	6.71	1.50	0.11	20.97
0.151	-0.189					0.03	0.32	0.48	0.59	0.27		0.08	0.48	4.30	4.27	0.21		11.03
0.189	-0.227						0.16	0.56	0.08	0.08			0.05	2.40	3.53			6.87
0.227	-0.264						0.13	0.21					0.08	1.39	1.18			2.99
0.264	-0.302												0.11	0.32	0.27			0.69
0.302	-0.340													0.16				0.16
Total %		**1.79**	**1.23**	**1.47**	**0.83**	**1.76**	**3.50**	**7.83**	**10.74**	**7.83**	**3.05**	**2.75**	**4.92**	**19.53**	**22.50**	**6.84**	**3.45**	**100.00**
Mean		0.07	0.07	0.08	0.08	0.09	0.12	0.12	0.10	0.08	0.08	0.09	0.11	0.15	0.15	0.10	0.08	**0.12**
StDev		0.01	0.02	0.02	0.02	0.02	0.05	0.04	0.03	0.03	0.02	0.03	0.04	0.05	0.05	0.03	0.02	**0.05**
Min		0.04	0.03	0.03	0.05	0.04	0.04	0.04	0.03	0.03	0.04	0.04	0.04	0.05	0.04	0.04	0.03	**0.03**
Max		0.10	0.12	0.12	0.12	0.17	0.25	0.26	0.21	0.20	0.15	0.16	0.28	0.32	0.29	0.19	0.13	**0.32**

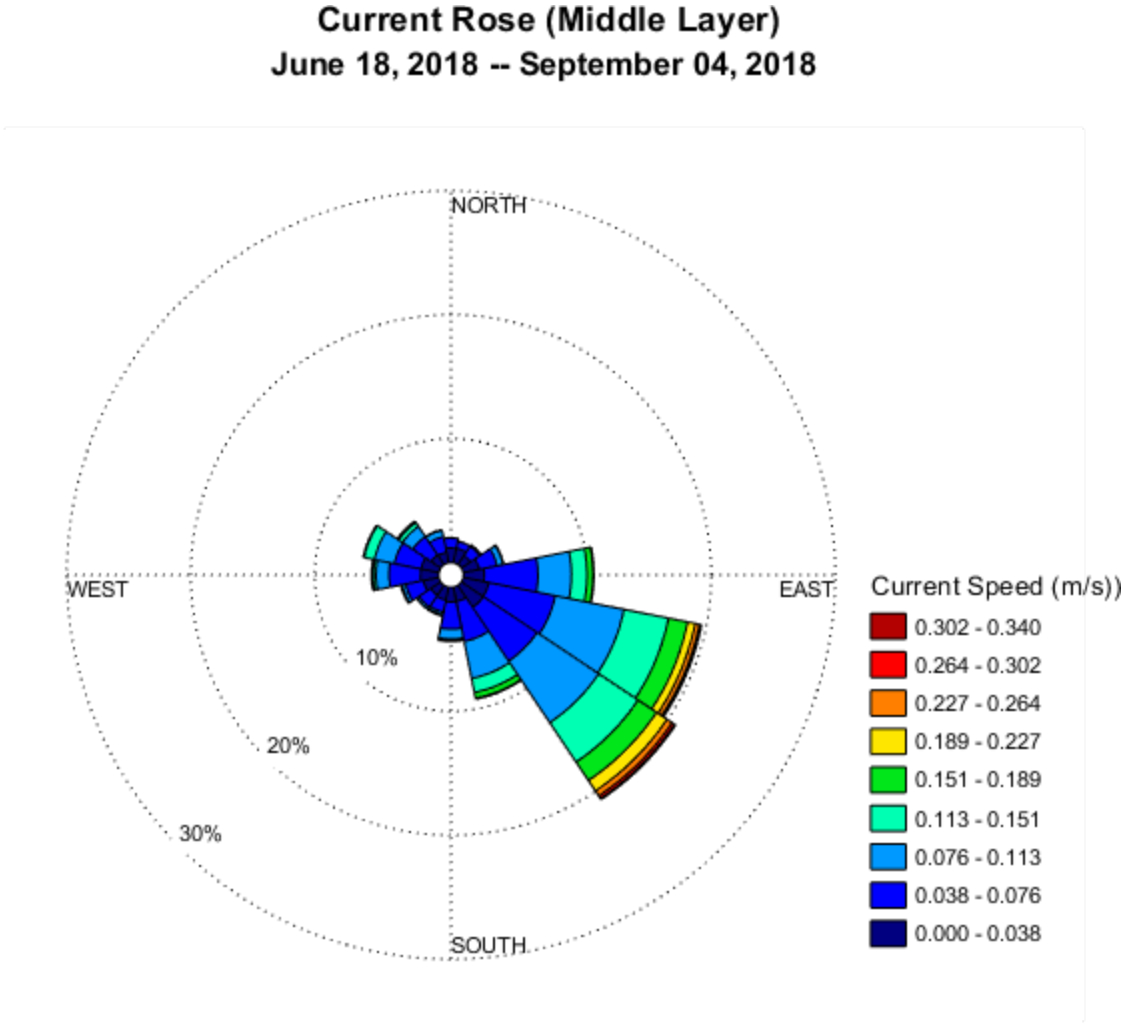

Figure 3-4 Current Rose for Middle Layer

Table 3-3 Middle Layer Current Frequency of Occurrence

Current Speed, m/s		Total % by Direction in Deg																
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.000	-0.038	1.18	1.20	0.88	1.31	1.68	2.11	2.14	1.18	1.18	1.07	0.96	1.28	1.47	1.47	0.94	0.88	20.92
0.038	-0.076	0.80	0.56	0.91	1.47	4.33	5.45	5.21	3.29	2.19	0.99	1.15	1.44	2.54	2.19	1.79	1.26	35.56
0.076	-0.113		0.03	0.13	0.48	2.70	5.66	5.98	3.05	0.80	0.21	0.21	0.29	1.04	1.63	0.99	0.53	23.75
0.113	-0.151	0.03			0.05	1.26	3.66	3.82	1.15	0.13	0.11	0.03	0.11	0.21	0.85	0.37	0.05	11.84
0.151	-0.189				0.03	0.48	1.58	1.79	0.48	0.05				0.16	0.08	0.13		4.78
0.189	-0.227					0.08	0.61	1.02	0.08									1.79
0.227	-0.264						0.35	0.48										0.83
0.264	-0.302						0.16	0.24										0.40
0.302	-0.340						0.03	0.11										0.13
Total %		**2.00**	**1.79**	**1.92**	**3.34**	**10.53**	**19.61**	**20.79**	**9.22**	**4.35**	**2.38**	**2.35**	**3.13**	**5.42**	**6.22**	**4.22**	**2.73**	**100.00**
Mean		0.04	0.03	0.04	0.05	0.08	0.10	0.10	0.08	0.06	0.05	0.04	0.05	0.06	0.07	0.07	0.05	**0.08**
StDev		0.02	0.02	0.02	0.03	0.04	0.05	0.06	0.04	0.03	0.03	0.02	0.03	0.03	0.04	0.04	0.03	**0.05**
Min		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	**0.00**
Max		0.11	0.08	0.09	0.17	0.22	0.33	0.34	0.22	0.16	0.15	0.13	0.15	0.19	0.19	0.16	0.14	**0.34**

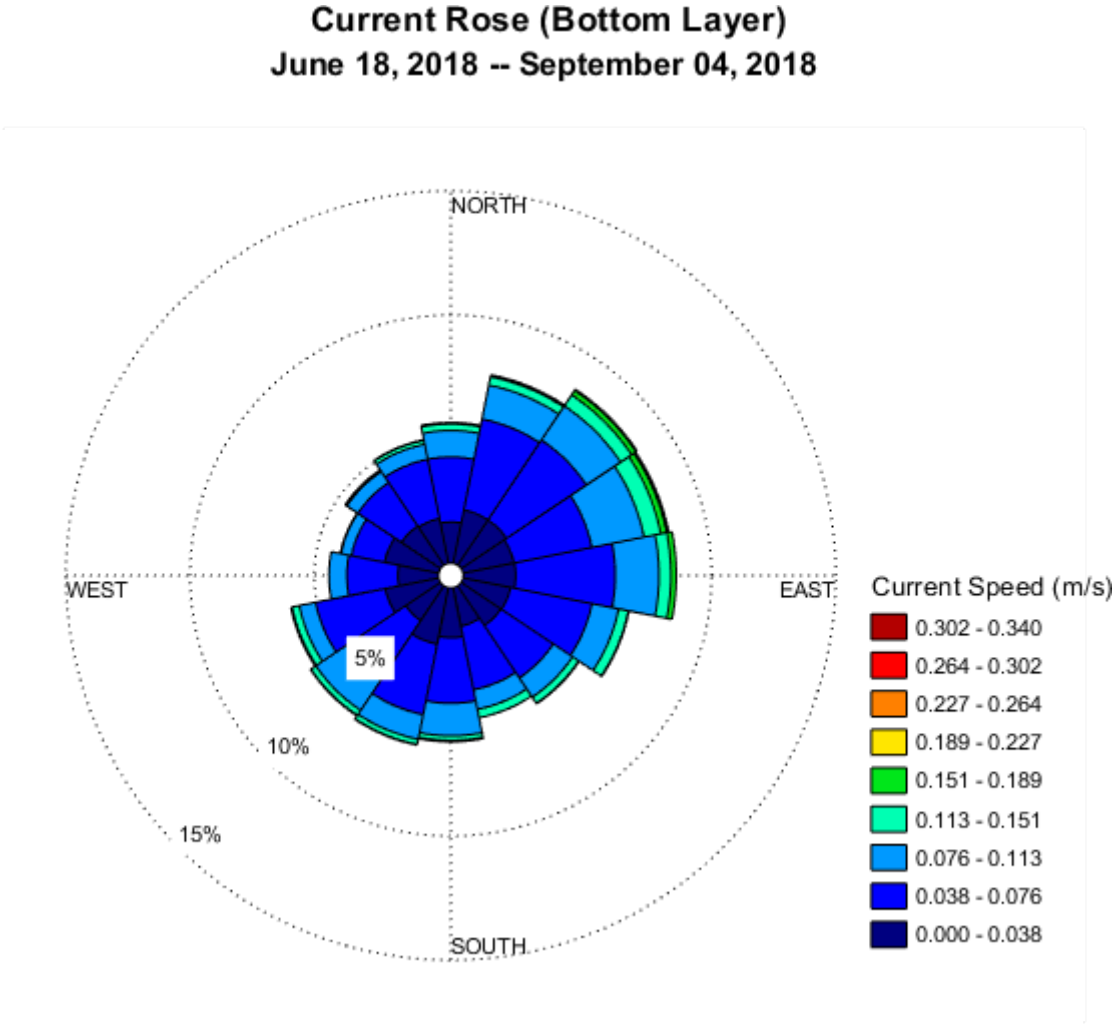

Figure 3-5 Current Rose for Bottom Layer

Table 3-4 Bottom Layer Current Frequency of Occurrence

Current Speed, m/s		Total % by Direction in Deg																
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.000	-0.038	1.66	2.19	2.19	2.08	2.11	1.95	1.92	1.58	2.00	2.32	1.68	2.19	1.63	2.22	1.90	1.84	31.47
0.038	-0.076	2.62	3.74	3.87	3.21	4.01	3.34	2.54	2.62	2.64	2.89	2.86	2.86	2.06	1.36	2.11	2.43	45.15
0.076	-0.113	1.07	1.39	1.66	2.14	1.76	1.10	0.94	0.80	1.31	1.02	1.50	0.67	0.72	0.43	0.53	0.61	17.63
0.113	-0.151	0.27	0.35	0.53	0.69	0.48	0.40	0.29	0.35	0.19	0.21	0.24	0.29		0.03	0.08	0.16	4.57
0.151	-0.189	0.05	0.08	0.21	0.24	0.21	0.03	0.03		0.05	0.03		0.05				0.03	1.02
0.189	-0.227			0.05	0.03							0.03						0.11
0.227	-0.264				0.05													0.05
0.264	-0.302																	0.00
0.302	-0.340																	0.00
Total %		5.66	7.75	8.52	8.44	8.58	6.81	5.72	5.34	6.20	6.47	6.31	6.06	4.41	4.03	4.62	5.08	100.00
Mean		0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.05	0.05	0.04	0.05	0.05	0.06
StDev		0.03	0.03	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03
Min		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Max		0.18	0.18	0.22	0.25	0.17	0.16	0.18	0.15	0.16	0.16	0.20	0.17	0.11	0.11	0.13	0.15	0.25

3.2 Waves

The WavesMon module of Velocity was used to calculate hourly wave statistics. The three statistics of most importance for wave characterization are the significant wave height (H_s), peak period (T_p), and peak direction (D_p). The direction that the Sentinel V100 ADCP references is magnetic north. These readings were converted to a true north reference using the magnetic declination values for the location of the ADCP on Oahu. The magnetic declination for WETS is 9.55° East. A second program, WavesView, is used to display the spectral data alongside the wave statistics.

A screenshot of the settings for WavesMon is presented in Figure 3-6. The peak direction of the processed wave data had a lot of variation with 256 frequency bands. The data was reprocessed with 128 frequency bands allow more averaging in each band as opposed to the 246 bands show in Figure 3-6.

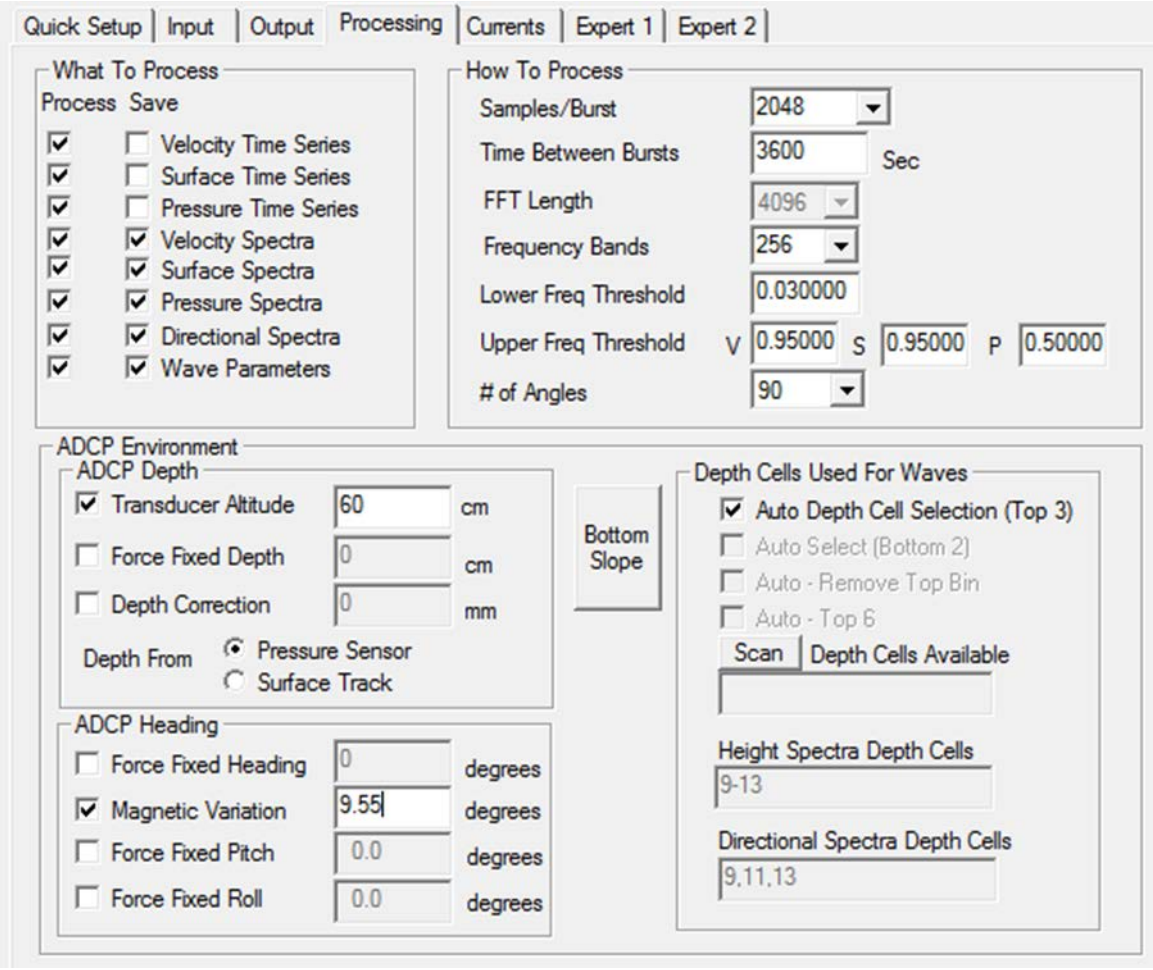

Figure 3-6 WavesMon Processing Tab

Figure 3-7 shows the time series of significant wave height, peak period, and peak direction for the deployment. Figure 3-8 shows the wave height rose which is dominated by the trade wind waves from the northeast with periods of 6 to 10 seconds.

Table 3-5 presents the percent frequency of wave height and direction. Figure 3-8 presents the wave period rose. Table 3-6 presents the percent frequency of wave peak period and direction.

The time series (Figure 3-7) indicates typical wave heights are approximately 1.0 – 2.0m with peak periods of 6-8s from an east-northeast direction indicative of trade wind generated swell. The wave height of 2.0 – 3.0m, and peak direction from the east, and shorter wave periods are indicative of a strong trade wind periods.

The wave height rose shown in Figure 3-8, and Table 3-5, indicate waves from an east and north direction (0° - 90°) occurred 87% of the time. Waves were greater than 1.0m, 87% of the time. The average wave height was 1.44m and maximum wave height was 2.83m.

The period rose shown in Figure 3-9, and Table 3-6, show the mean peak period was 7.78 seconds and the maximum period was 16.70 seconds.

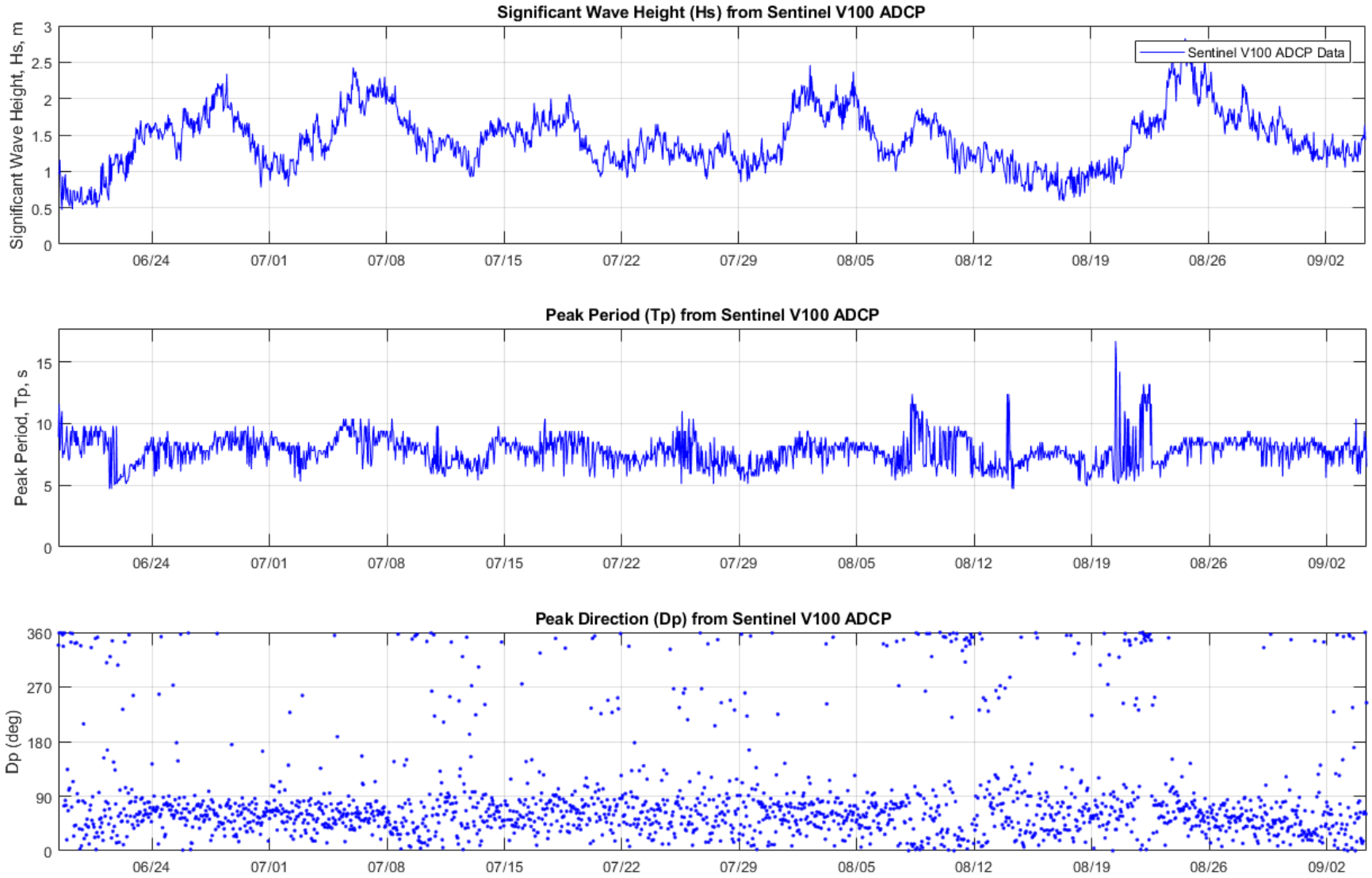

Figure 3-7 Wave Height, Peak Period, and Peak Direction

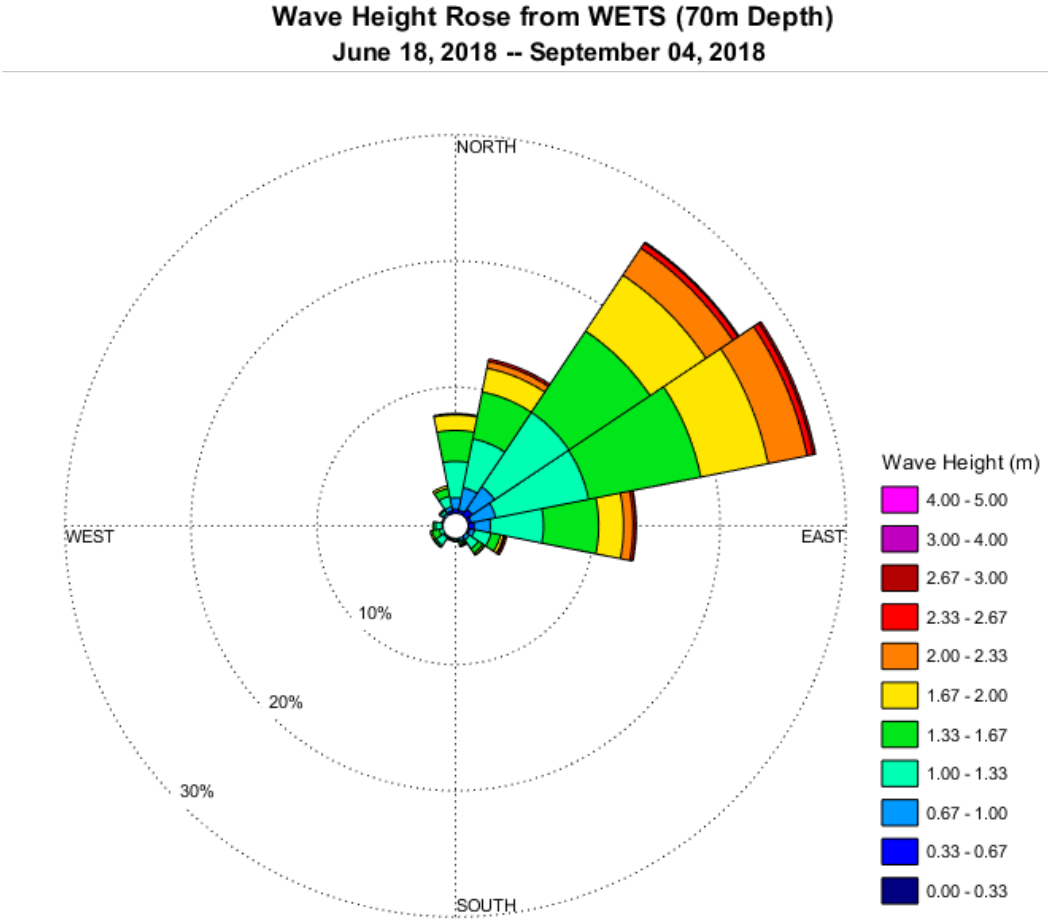

Figure 3-8 Wave Height Rose

Table 3-5 Wave Height Frequency of Occurrence

Wave Height, m	Total % by Direction in Deg																
	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
0.00 -0.33																	0.00
0.33 -0.67	0.32	0.27	0.59	0.27	0.48	0.16				0.05						0.21	2.35
0.67 -1.00	0.91	1.82	2.14	1.98	1.28	0.37	0.32	0.21		0.05	0.16		0.05		0.21	0.32	9.83
1.00 -1.33	2.88	3.95	7.10	7.53	4.22	1.34	0.85	0.16	0.16	0.05	0.69	0.32	0.53	0.11	0.27	0.85	31.04
1.33 -1.67	2.46	3.79	7.75	9.08	4.38	0.75	0.43	0.16		0.05	0.16	0.59	0.21		0.11	0.64	30.56
1.67 -2.00	1.23	1.92	5.34	5.45	1.98	0.27	0.16	0.05	0.11		0.05	0.16				0.21	16.93
2.00 -2.33	0.11	0.53	2.56	3.15	0.75	0.11		0.05									7.26
2.33 -2.67		0.21	0.48	0.48	0.21	0.16		0.05									1.60
2.67 -3.00			0.11	0.21	0.05		0.05										0.43
3.00 -4.00																	0.00
4.00 -5.00																	0.00
Total %	7.91	12.50	26.07	28.15	13.35	3.15	1.82	0.69	0.27	0.21	1.07	1.07	0.80	0.11	0.59	2.24	100.00
Mean	1.33	1.37	1.49	1.52	1.41	1.34	1.28	1.38	1.41	1.07	1.22	1.41	1.27	1.08	1.09	1.23	1.44
StDev	0.34	0.38	0.41	0.40	0.39	0.44	0.39	0.50	0.39	0.39	0.19	0.22	0.20	0.00	0.23	0.33	0.40
Min	0.47	0.50	0.54	0.57	0.54	0.52	0.72	0.70	1.09	0.55	0.92	1.02	0.95	1.08	0.79	0.59	0.47
Max	2.15	2.60	2.76	2.83	2.67	2.57	2.76	2.34	1.90	1.45	1.67	1.76	1.65	1.08	1.49	1.81	2.83

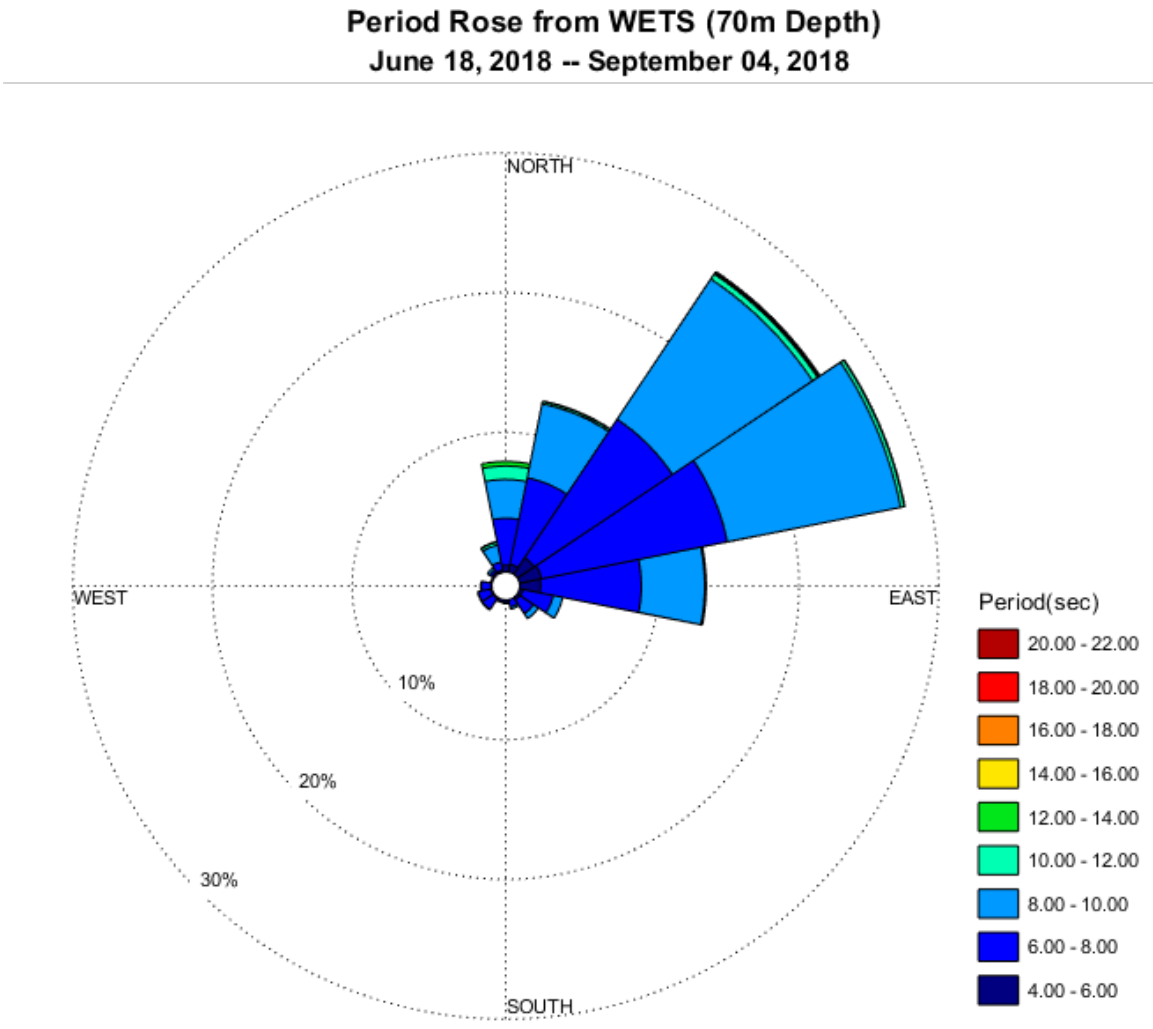

Figure 3-9 Period Rose

Table 3-6 Wave Period Frequency of Occurrence

Wave Period, s	Total % by Direction in Deg																
	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	Total %
4 -6	0.48	0.59	1.44	1.60	1.50	0.27	0.21				0.11	0.11	0.05		0.16	0.16	6.68
6 -8	3.37	6.30	11.91	13.57	7.21	2.19	1.18	0.53	0.16	0.16	0.91	0.91	0.69	0.11	0.21	0.59	50.00
8 -10	2.78	5.40	12.07	12.66	4.54	0.69	0.43	0.16	0.11	0.05	0.05	0.05	0.05		0.21	1.23	40.49
10 -12	0.96	0.16	0.43	0.27	0.11											0.21	2.14
12 -14	0.32	0.05	0.11													0.05	0.53
14 -16			0.05	0.05													0.11
16 -18			0.05														0.05
18 -20																	0.00
20 -22																	0.00
Total %	**7.91**	**12.50**	**26.07**	**28.15**	**13.35**	**3.15**	**1.82**	**0.69**	**0.27**	**0.21**	**1.07**	**1.07**	**0.80**	**0.11**	**0.59**	**2.24**	**100.00**
Mean	8.37	7.82	7.90	7.83	7.47	7.15	7.32	7.58	8.02	7.28	6.53	6.51	6.54	7.25	7.32	8.54	**7.78**
StDev	1.72	1.14	1.23	1.07	1.13	0.99	0.97	0.79	0.45	1.69	0.58	0.48	0.55	0.35	1.47	1.51	**1.23**
Min	5.60	4.70	5.00	4.70	4.70	5.30	4.70	6.10	7.50	6.30	5.70	5.70	5.70	7.00	5.30	5.40	**4.70**
Max	13.20	13.20	16.70	14.20	11.00	9.40	9.40	8.90	8.50	9.80	8.20	8.20	8.20	7.50	9.40	12.40	**16.70**