Hawaii National Marine Renewable Energy Center (HINMREC)

U.S. Department of Energy Award Number: DE-FG36-08GO18180

Task 4: Environmental Impact Monitoring at WETS

WETS Sentinel V100 ADCP Data Analysis at 30m Reports

Prepared by:
Sea Engineering, Inc.

Prepared for:
Hawaii Natural Energy Institute, University of Hawaii

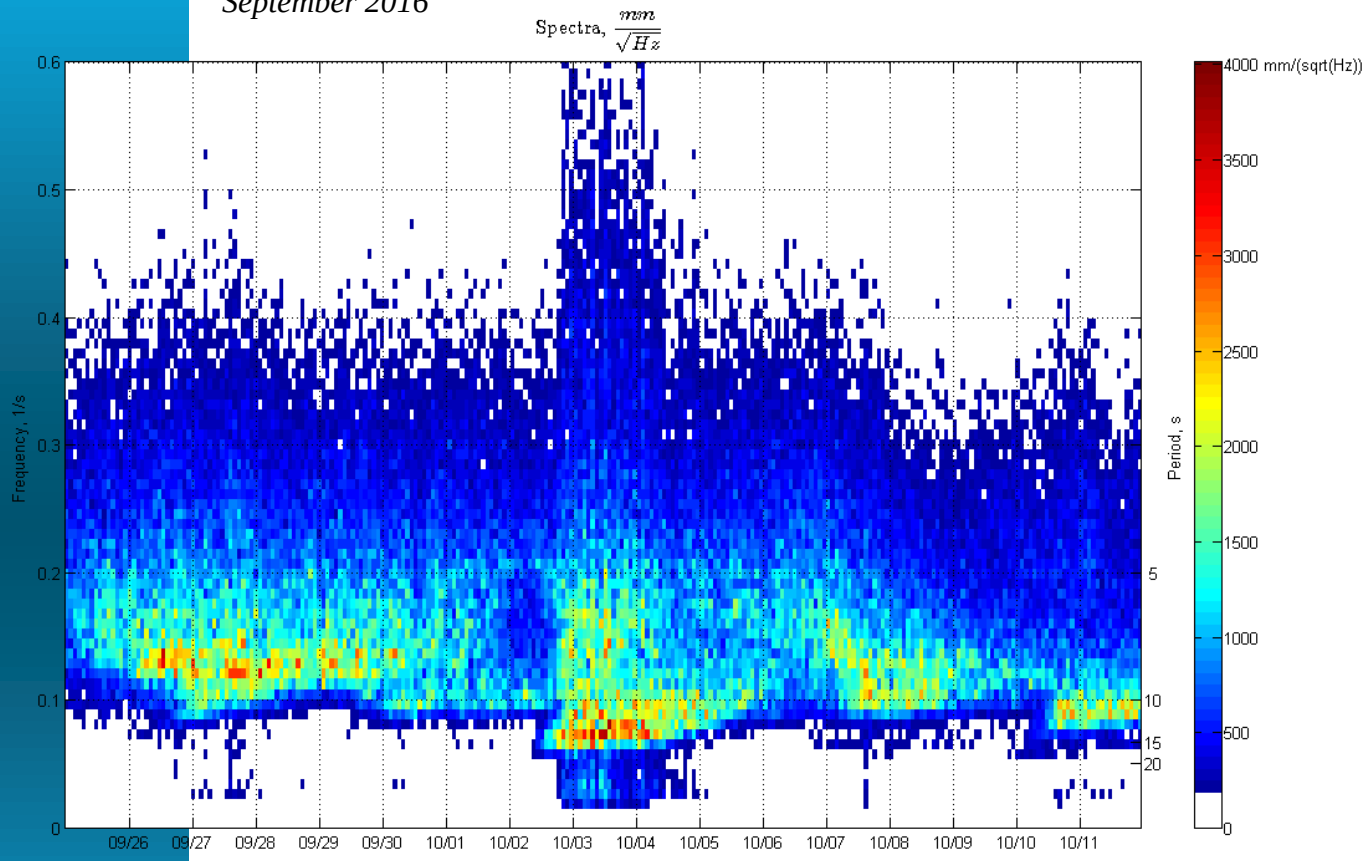
2016 - 2017

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

REPORT:

Task 4C Wave Energy Test Site Sentinel V100 ADCP Data Analysis at 30m Site

September 2016



Prepared for:
Hawaii National Marine Renewable Energy Center
1680 East West Road, POST 112A
Honolulu, HI 96822

Prepared by:
Sea Engineering, Inc.
Makai Research Pier
Waimanalo, HI 96795

Job No. 25419

This page intentionally left blank

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The area north of the Mokapu Peninsula, adjacent to Kaneohe Marine Corps Base Hawaii (MCBH), has been utilized by the U.S. Navy for wave energy research since 2002. Two prototype wave energy converters (WEC) are currently being tested at the 30 m and 60 m berths offshore of North Beach at the MCBH. The Hawaii National Marine Renewable Energy Center (HNMREC) at the University of Hawaii, under contract with Department of Energy and the U.S. Navy, has expanded the test site to water depths of 100 m to allow for the testing of other wave energy devices.

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

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

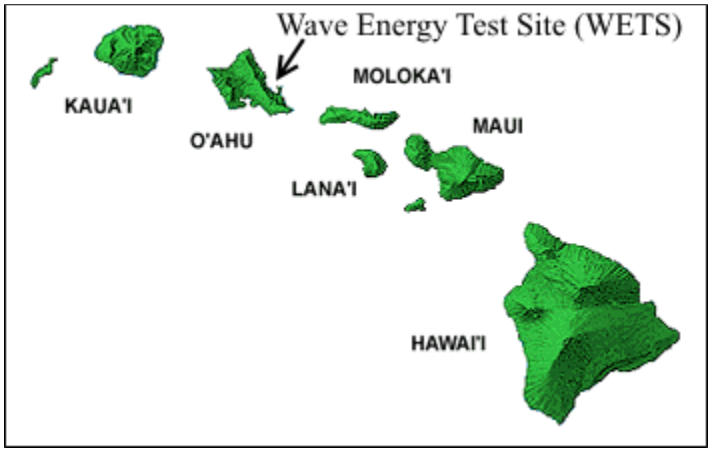


Figure 1-1 Project Location

In collaboration with HNMREC, Sea Engineering Inc. deployed a Teledyne RDI Sentinel V100 Acoustic Doppler Current Profiler (ADCP) at 4:54 PM on July 6th, 2015 at coordinates 21° 27' 56.1738" N and 157° 45' 5.0563" W in the Wave Energy Test Site (WETS) 30m berth. One of the features of the Sentinel V100 is its ability to measure wave statistics using a fifth vertical beam to improve the accuracy of the measurements and provide high-resolution surface tracking. Figure 1-2 shows the deployment location of the ADCP.

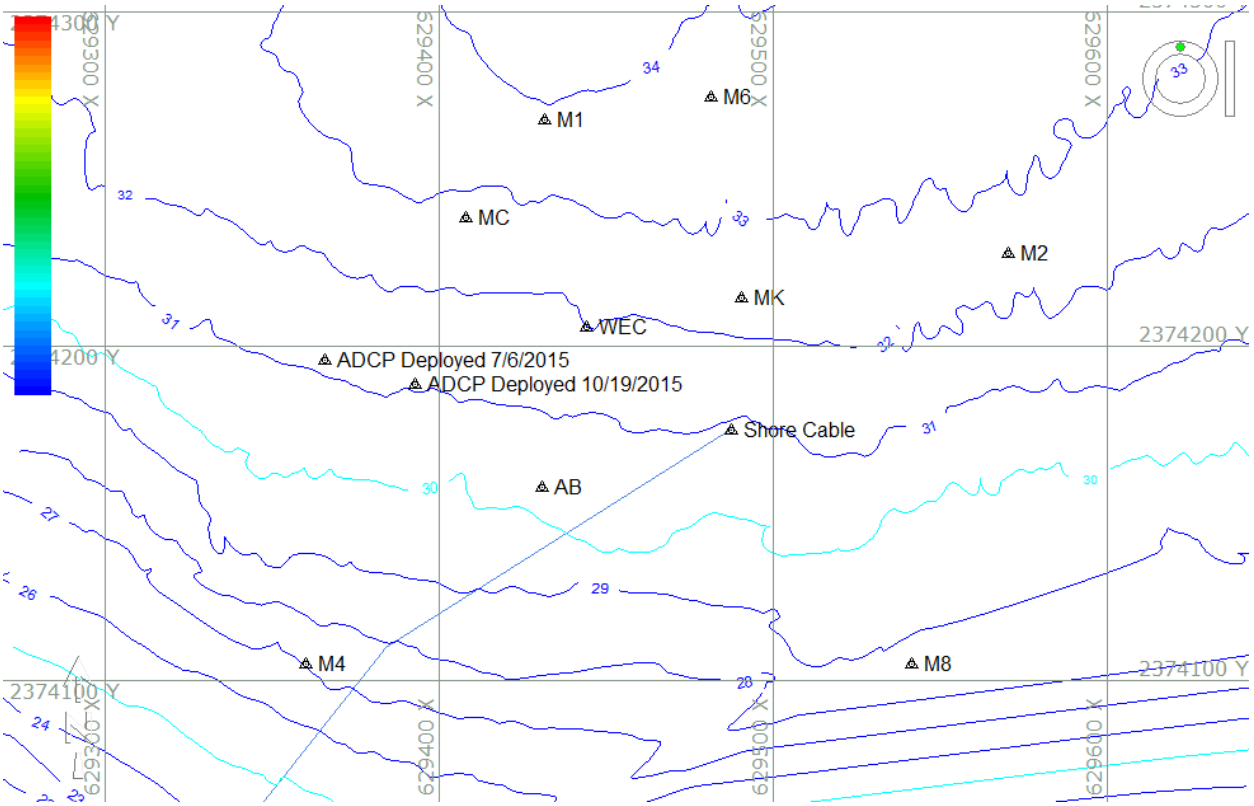


Figure 1-2 WETS Wave Measurement Instrumentation

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 current. 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)	36	36
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 90 days. An external battery housing was used with two additional battery packs rated at 540 watt-hours. In total three battery packs were used, one in the Sentinel V100 ADCP and two in the external housing, providing 1,620 watt-hours of energy.

The Sentinel V100 ADCP was deployed on 4:54 PM on July 6th, 2015 and recovered at 5:35 PM on October 14th, 2015, a 100-day deployment.

3. SENTINEL V100 DATA

The data file for the deployment of the Sentinel V100 was 6.4 GB. The waves profile was 5.6 GB. Only the data from the wave profiles was used to calculate the wave statistics. 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 Current processing

Velocity was used to average the current data into half-hour blocks. The result of this is that 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 averaged data was then exported to Matlab for further processing. The water column was divided into three layers for analysis. Table 3-1, below shows the bins and associated water depths that make of the three layers

Table 3-1 Layer Divisions

	Bins	Range from ADCP, meters	Water Depth, meters
Bottom Layer	1 - 4	3.04 - 8.04	24-27
Middle Layer	13 - 18	15.04 - 20.4	10-15
Surface Layer	23 - 28	25.04 - 30.04	0-5

Figure 3-1 shows the time series 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. Figure 3-3, Figure 3-4, and Figure 3-5 are current rose plots for each layer, surface, middle, and bottom, respectively. Table 3-2, Table 3-3, and Table 3-4 are the statistics that make up the current rose plots.

The current distribution for the surface, middle, and bottom water layers compare well with a previous current study at WETS (Kaneohe Wave Energy Test Site Acoustic Doppler Current Profiler Data Report 2012). This report uses magnetic north as its reference direction instead of true North used here. Surface currents flow in a predominantly westerly direction with an average speed of 0.24 m/s, and a maximum recorded speed of 0.67 m/s. Mid-layer currents flow in a predominantly southeast, with less frequent flow to the northeast. Average speed is 0.10 m/s and the maximum current speed is 0.52 m/s. Bottom layer currents

also flow predominantly to the southeast direction, but with greater occurrence in all directions. Currents are significantly weaker with an average speed of 0.07 m/s, and a maximum recorded speed of 0.37 m/s.

The predominant direction of the surface current is centered at 292.5°. The average speed for this direction is 0.27 m/s and the max current speed is 0.67m/s.

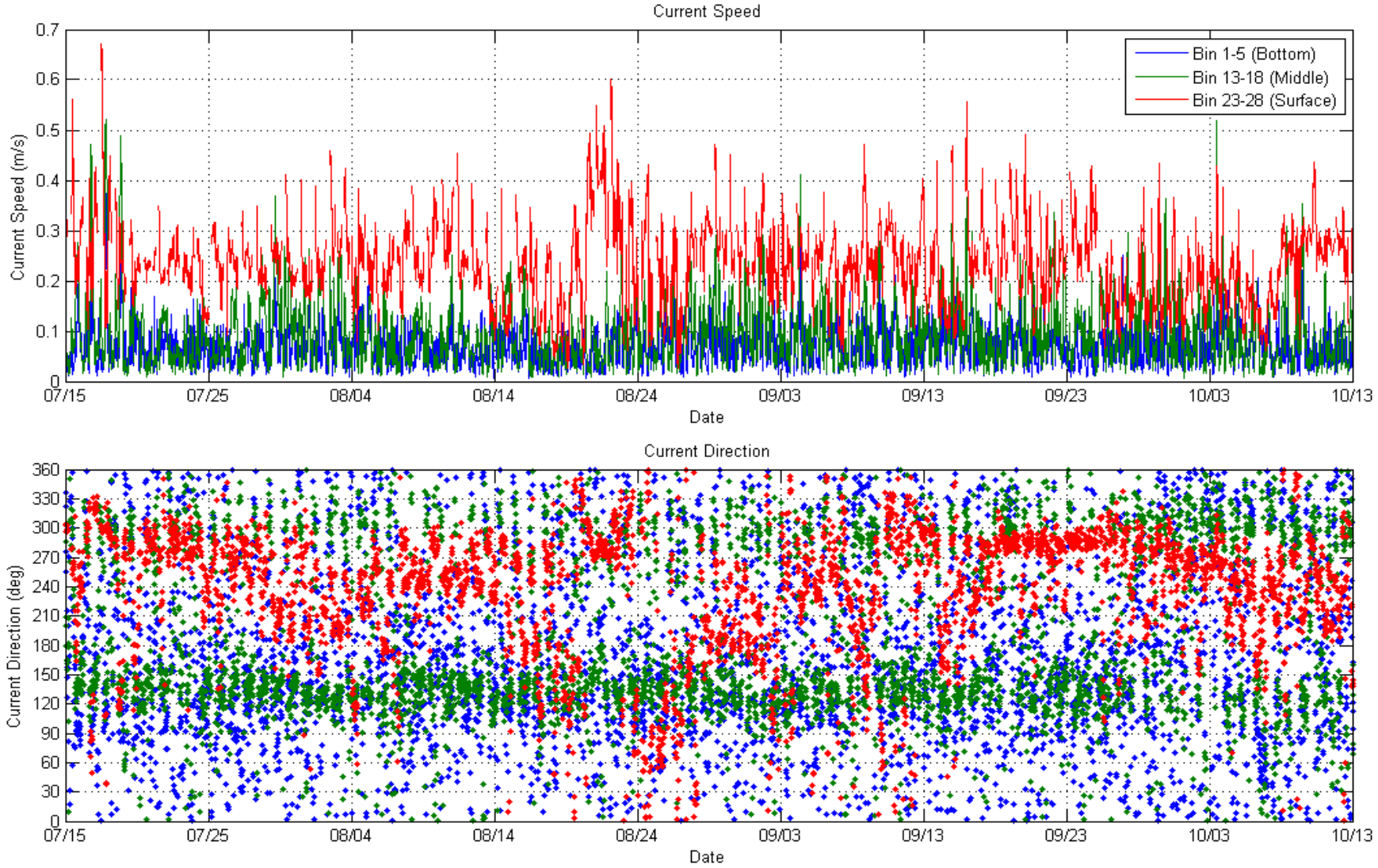


Figure 3-1 Current Speed and Direction for Each Layer

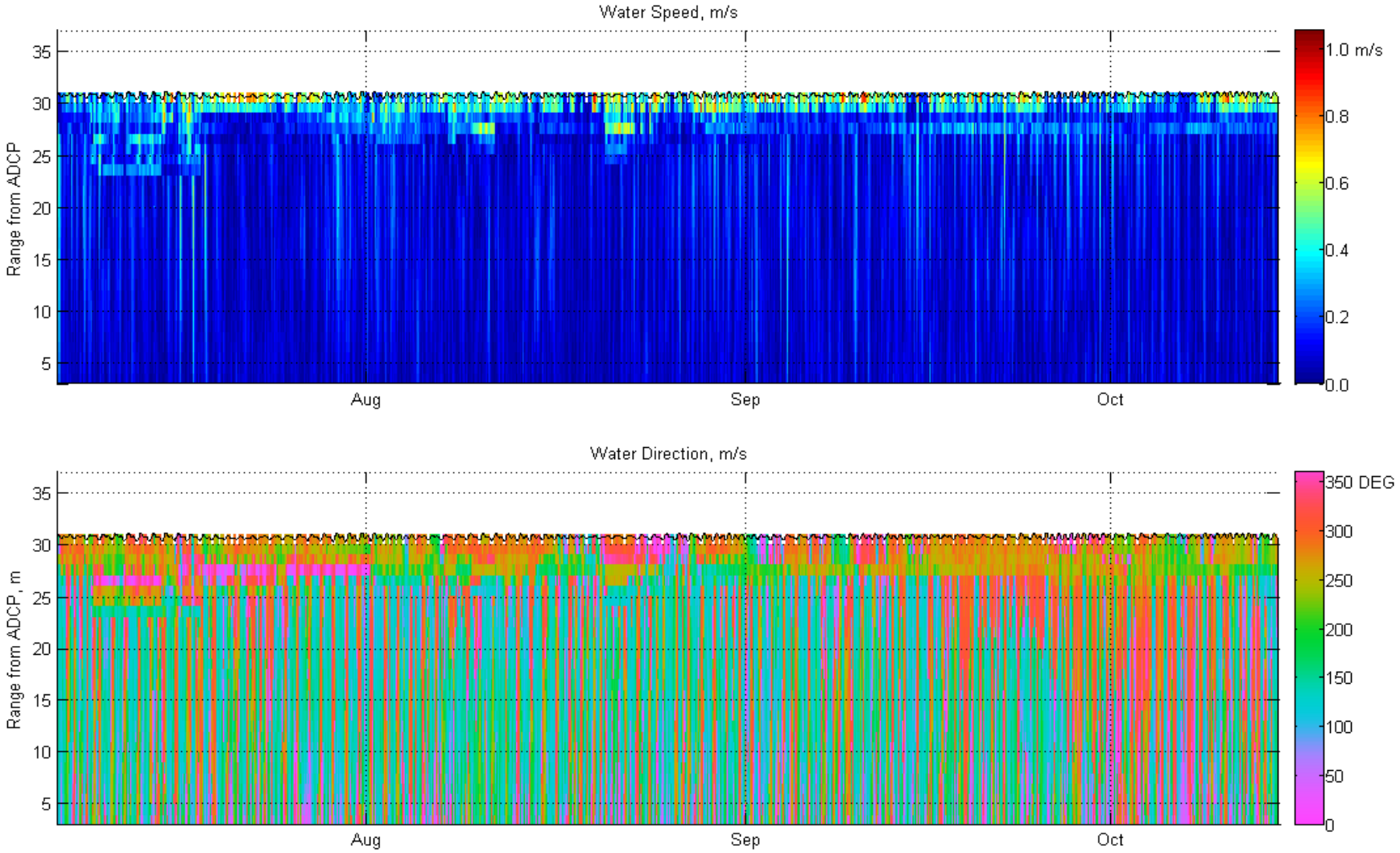


Figure 3-2 Current Speed and Direction for All Bins

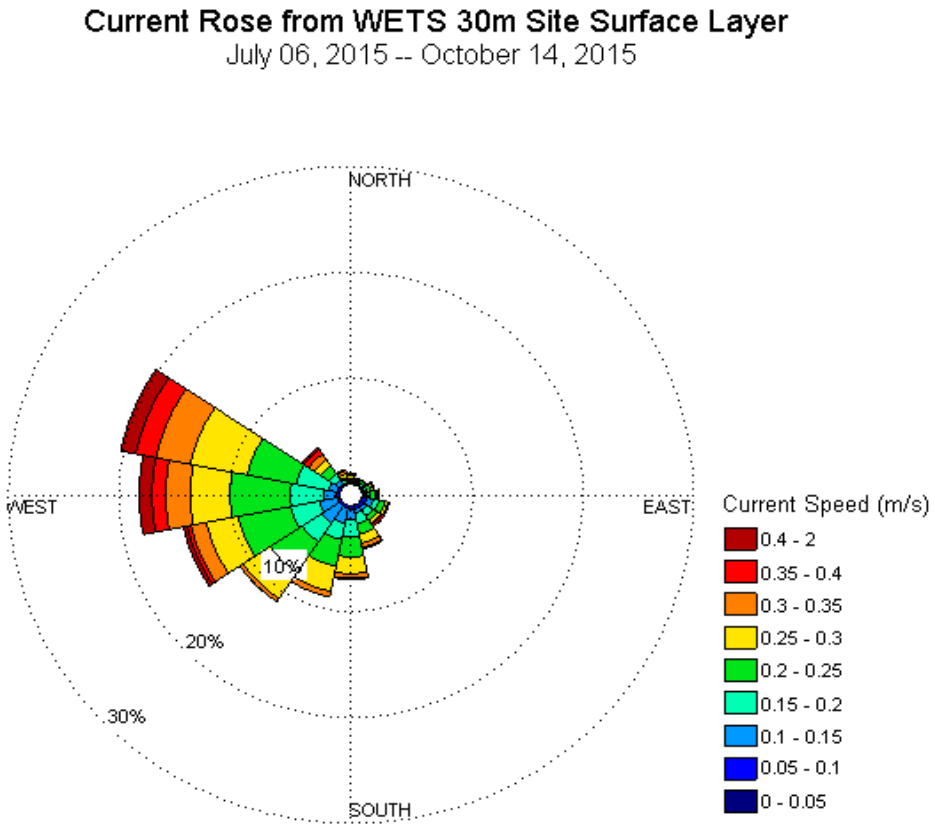


Figure 3-3 Current Rose for Surface Layer

Table 3-2 Surface Layer Current Statistics

Current Speed,	Direction, deg																
m/s	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 -0.05	0.03	0.03	0.05			0.03			0.03			0.03	0.03		0.03	0.03	0.25
0.05 -0.1	0.10	0.05	0.05	0.10	0.18	0.46	0.35	0.38	0.33	0.25	0.20	0.23	0.30	0.25	0.15	0.10	3.49
0.1 -0.15	0.03	0.08	0.10	0.13	0.20	0.56	0.40	0.38	0.96	1.47	2.00	1.67	1.09	0.84	0.56	0.10	10.55
0.15 -0.2	0.15	0.13	0.18	0.20	0.35	0.53	0.61	1.01	1.70	1.57	2.10	2.66	3.09	2.99	0.66	0.25	18.17
0.2 -0.25	0.23	0.13	0.20	0.40	0.48	0.58	0.51	1.01	1.82	2.58	3.49	4.83	5.44	4.51	0.94	0.20	27.36
0.25 -0.3	0.30	0.15	0.13	0.23	0.20	0.25	0.38	0.86	1.59	2.40	2.94	2.91	3.59	5.24	0.66	0.35	22.20
0.3 -0.35	0.10	0.08	0.03	0.10	0.15	0.13	0.10	0.38	0.43	0.53	0.35	1.42	2.23	3.16	0.63	0.28	10.10
0.35 -0.4	0.08				0.03		0.20	0.10	0.13		0.03	0.35	1.24	1.87	0.53	0.05	4.61
0.4 -0.7							0.05	0.05				0.35	1.16	1.39	0.20	0.05	3.26
Total %	1.01	0.63	0.73	1.16	1.59	2.53	2.61	4.18	6.99	8.81	11.11	14.45	18.17	20.25	4.35	1.42	100.00
Mean, m/s	0.23	0.21	0.18	0.21	0.20	0.18	0.21	0.22	0.21	0.22	0.21	0.23	0.26	0.27	0.25	0.24	0.24
StDev, m/s	0.08	0.08	0.08	0.07	0.07	0.07	0.09	0.08	0.07	0.06	0.06	0.07	0.08	0.09	0.09	0.09	0.08
Min, m/s	0.05	0.04	0.03	0.06	0.06	0.04	0.06	0.06	0.04	0.06	0.06	0.04	0.04	0.07	0.03	0.03	0.03
Max, m/s	0.37	0.34	0.31	0.33	0.36	0.34	0.47	0.41	0.39	0.35	0.38	0.48	0.60	0.67	0.45	0.43	0.67

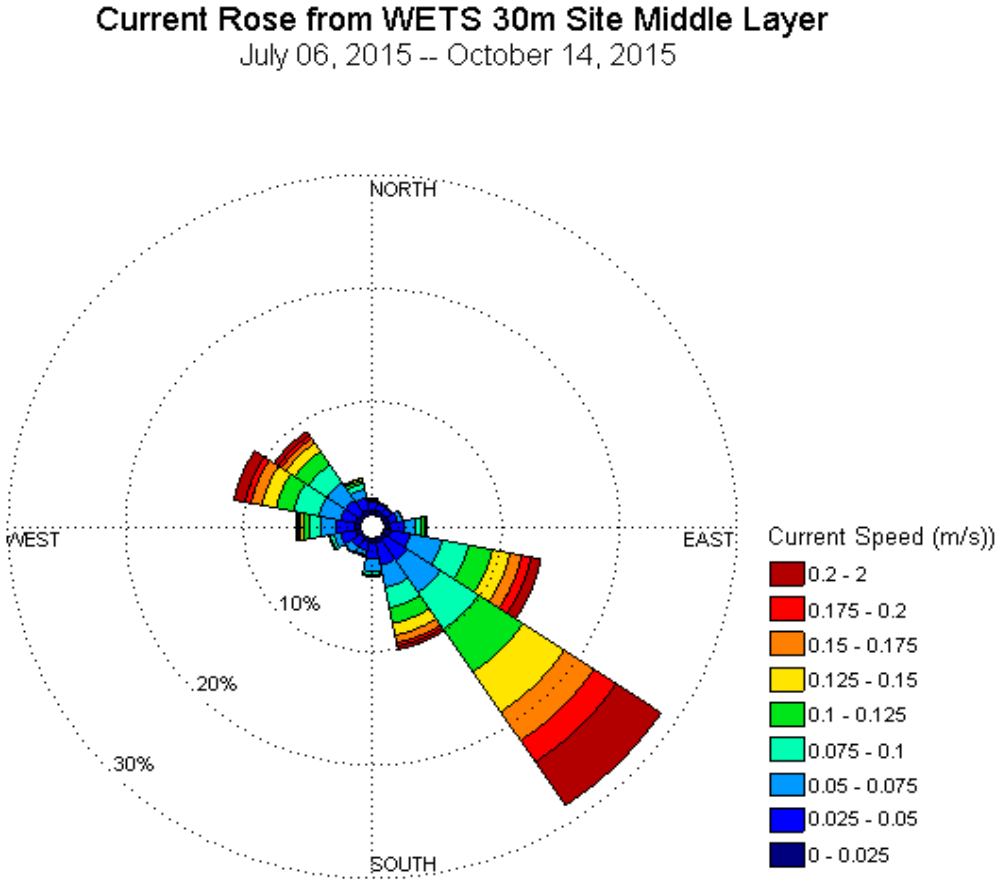


Figure 3-4 Current Rose for Middle Layer

Table 3-3 Middle Layer Current Statistics

Current Speed, m/s		Direction, 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	-0.025	0.42	0.46	0.33	0.46	0.42	0.61	0.40	0.48	0.44	0.36	0.25	0.52	0.56	0.48	0.40	0.50	**7.08**
0.025	-0.05	0.79	0.58	0.67	0.71	1.25	1.65	2.17	1.96	1.38	0.81	0.90	1.23	1.52	1.27	1.38	1.07	**19.36**
0.05	-0.075	0.19	0.10	0.08	0.38	1.00	2.76	3.38	2.01	1.09	0.38	0.63	0.58	1.32	1.88	1.88	0.79	**18.45**
0.075	-0.1	0.08	0.04		0.06	0.52	2.30	3.91	1.84	0.31	0.15	0.06	0.33	0.96	2.21	1.88	0.50	**15.17**
0.1	-0.125	0.04				0.27	2.09	4.53	1.40	0.08	0.02	0.04	0.08	0.54	1.50	1.42	0.27	**12.30**
0.125	-0.15					0.10	1.50	4.24	1.07	0.04				0.27	1.23	0.88	0.17	**9.50**
0.15	-0.175	0.02				0.04	1.02	3.03	0.67	0.04			0.02	0.19	0.94	0.48	0.02	**6.48**
0.175	-0.2						0.81	2.28	0.29					0.13	0.52	0.31	0.04	**4.39**
0.2	-0.6						0.88	4.60	0.31					0.06	0.98	0.44		**7.27**
Total %		**1.55**	**1.19**	**1.09**	**1.61**	**3.61**	**13.62**	**28.54**	**10.03**	**3.38**	**1.71**	**1.88**	**2.78**	**5.56**	**11.03**	**9.07**	**3.36**	**100.00**
Mean, m/s		0.04	0.03	0.03	0.04	0.06	0.10	0.14	0.09	0.05	0.04	0.05	0.05	0.07	0.11	0.10	0.06	**0.10**
StDev, m/s		0.03	0.02	0.01	0.02	0.03	0.06	0.08	0.05	0.03	0.02	0.02	0.03	0.04	0.07	0.06	0.04	**0.07**
Min, m/s		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, m/s		0.16	0.08	0.05	0.08	0.17	0.31	0.52	0.25	0.15	0.12	0.12	0.17	0.26	0.52	0.44	0.20	**0.52**

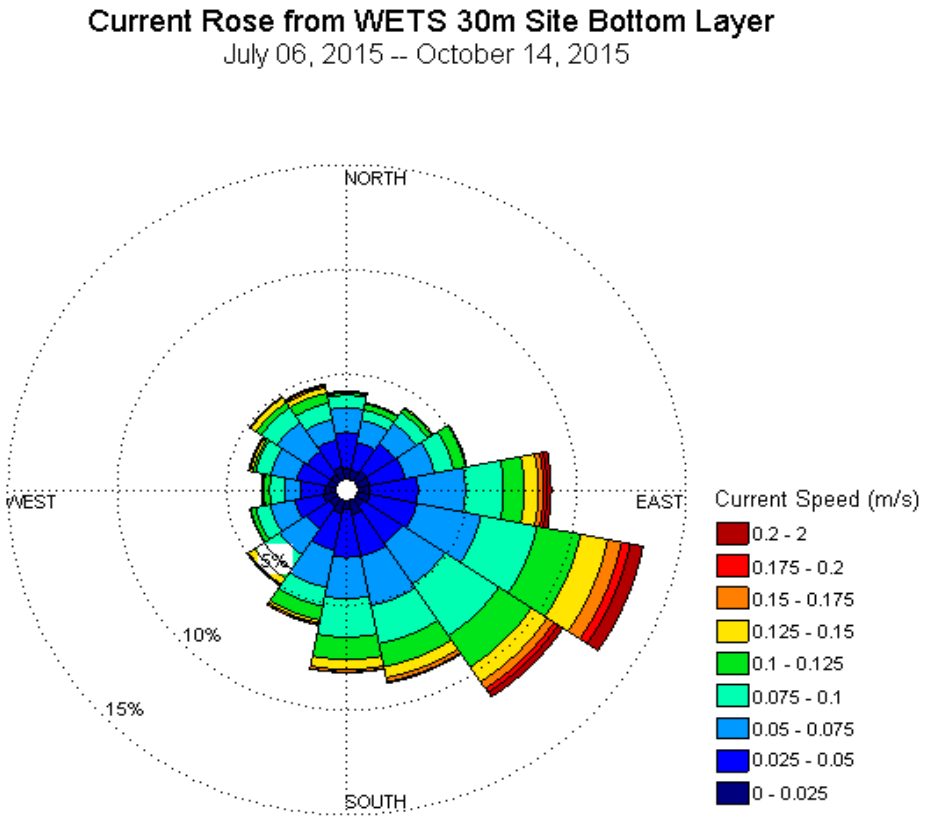


Figure 3-5 Current Rose for Bottom Layer

Table 3-4 Bottom Layer Current Statistics

Current Speed, m/s		Direction, 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	-0.025	0.48	0.46	0.61	0.56	0.52	0.58	0.44	0.71	0.46	0.65	0.48	0.61	0.48	0.38	0.38	0.63	8.42
0.025	-0.05	1.75	1.34	1.55	1.65	2.21	2.17	2.11	2.01	2.26	1.78	1.25	1.32	1.13	1.46	1.32	1.30	26.59
0.05	-0.075	1.17	1.09	1.15	1.36	2.17	2.99	2.34	2.40	1.96	1.82	1.46	1.15	0.75	1.21	1.65	0.98	25.65
0.075	-0.1	0.61	0.50	0.63	0.90	1.75	2.61	2.97	1.86	1.84	0.90	0.86	0.69	0.67	0.71	0.86	0.81	19.16
0.1	-0.125	0.10	0.29	0.23	0.56	0.94	2.03	1.80	1.13	1.07	0.69	0.52	0.23	0.27	0.13	0.29	0.48	10.76
0.125	-0.15	0.04	0.06	0.08	0.02	0.65	1.27	0.86	0.52	0.48	0.15	0.33	0.04	0.08	0.13	0.29	0.27	5.29
0.15	-0.175	0.04			0.02	0.23	0.65	0.38	0.21	0.13	0.08	0.02			0.04	0.02	0.08	1.90
0.175	-0.2				0.02	0.17	0.40	0.23	0.04	0.02	0.02	0.04			0.02	0.02	0.04	1.02
0.2	-0.4					0.19	0.61	0.27	0.02			0.02		0.02	0.02	0.02	0.04	1.21
Total %		4.20	3.74	4.24	5.10	8.84	13.31	11.39	8.90	8.21	6.08	4.99	4.03	3.41	4.09	4.85	4.64	100.00
Mean, m/s		0.05	0.06	0.05	0.06	0.08	0.09	0.09	0.07	0.07	0.06	0.07	0.05	0.06	0.06	0.07	0.07	0.07
StDev, m/s		0.03	0.03	0.03	0.03	0.05	0.05	0.04	0.04	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.04	0.04
Min, m/s		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, m/s		0.16	0.15	0.14	0.18	0.32	0.37	0.26	0.21	0.20	0.19	0.24	0.15	0.21	0.24	0.24	0.22	0.37

3.2 Wave Processing

The Velocity software also calculates many different 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.

The waves data was measured hourly. Only the waves profile was used for wave statistics. The waves profile data was processed in a subprogram called WavesMon. The settings for the processing are quite complex. A brief summary of the settings is presented below along with a screenshot of the processing tab in WavesMon, Figure 3-6.

The "What to Process" window shows all the parameters to be calculated from the data. The "How to Process" has many of the settings concerning the calculation of the wave spectra. The Sample/Bursts is the number of samples that are used in the Fast Fourier Transform (FFT). The frequency bands setting is the number of frequency to use in the FFT. The lower frequency threshold is the lowest frequency wave that will be considered in the processing . The value of 0.03 corresponds to a 33.3 second wave period. The Upper Frequency Threshold is the highest frequency considered for each of the spectra calculated by the velocity, water surface, and pressure parameters. The number of angles is the count of angles used in the calculation of the directional spectra. The ADCP Environment window has a setting for the ADCP height off the seafloor. The ADCP Heading window has a setting to account for the magnetic declination of the deployment location.

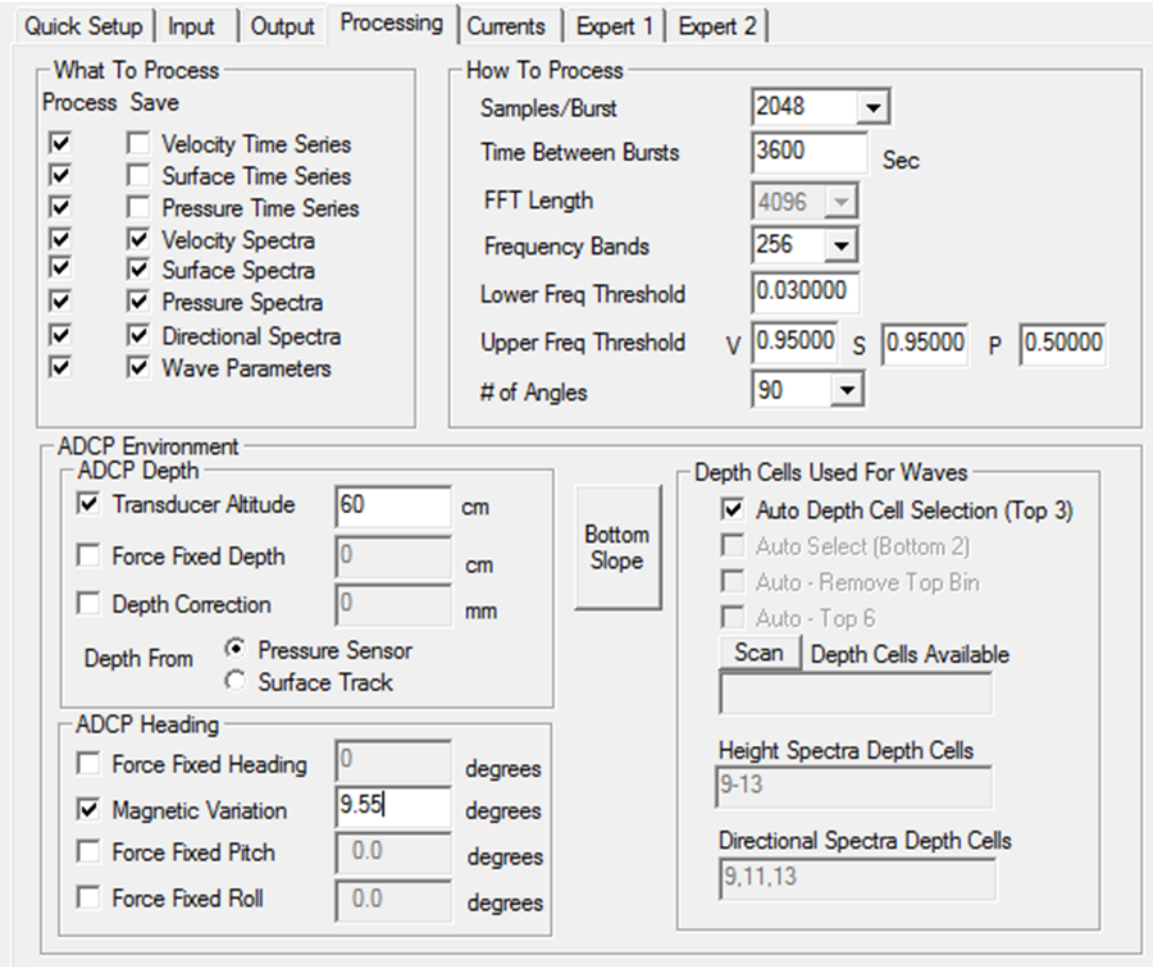


Figure 3-6 WavesMon Processing Tab

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 for the northeast with shorter periods. Table 3-5 shows the wave height statistics associated with the wave height rose. Figure 3-8 presents the wave period rose. Table 3-6 shows the wave period statistics associated with the wave period rose. Finally, Figure 3-10 shows the wave spectra measured by the ADCP.

The time series, Figure 3-7, shows typical wave heights of approximately 1.5m from an east-northeast direction, with distinct peaks with wave heights greater than 3m on September 3, 2015, and October 3, 2015.

The wave height rose, Figure 3-8 and Table 3-5, shows waves from a northeasterly direction (22.5° - 67.5°) occur 80.87 % of the time. Waves are greater than 1.25m 67.5% of the time. The average wave height is 1.42m and max wave height was 3.57m.

The period rose, Figure 3-9 and Table 3-6, show the mean period was 8.33 seconds and the max period was 16.80 seconds.

The cover of this report shows the Wave Spectra from 09/25/2015 to 10/12/2015. The large wave event on the 10/02/2015 coincides with 3.5 m waves and a 16.5 period.

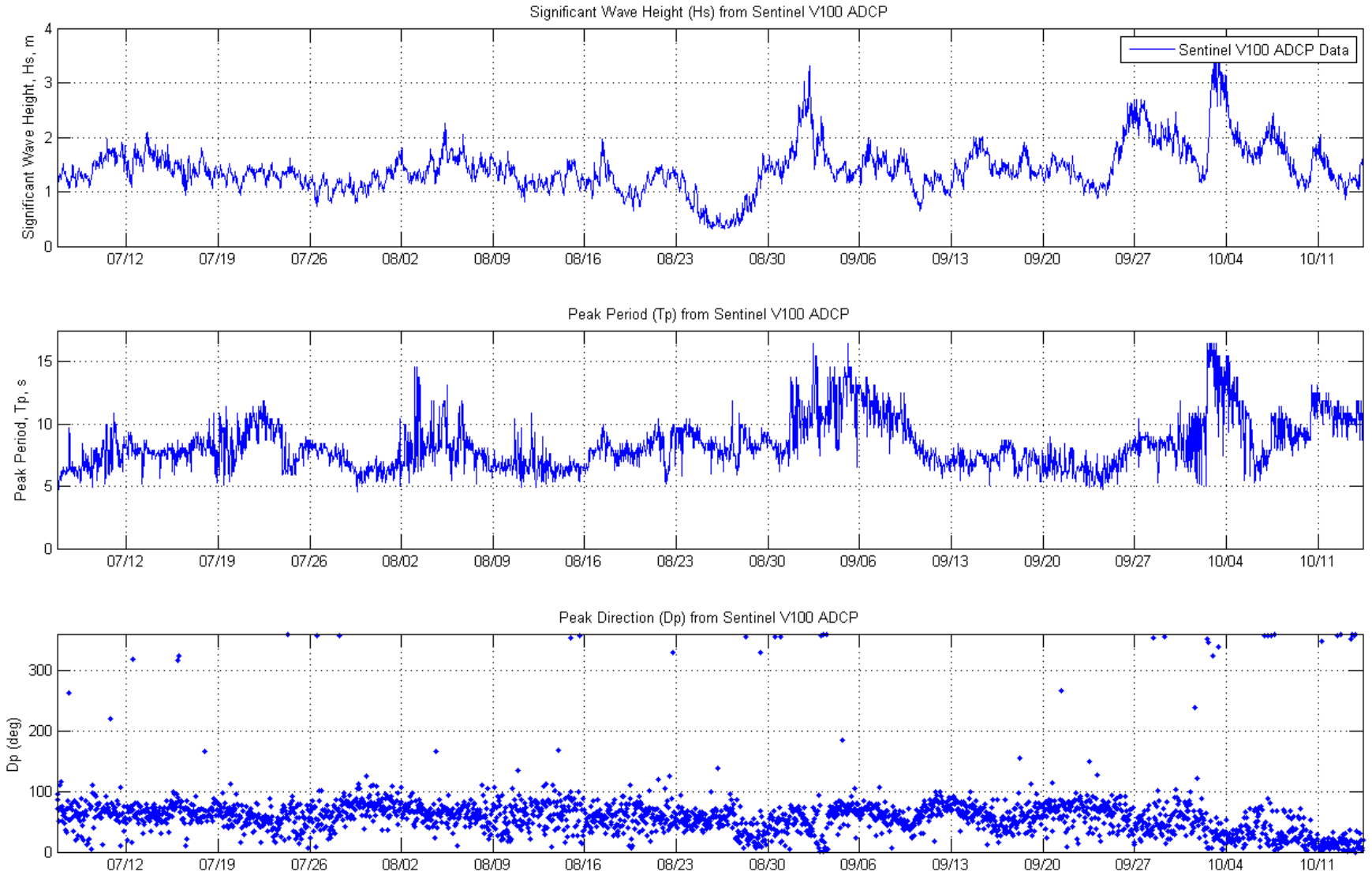


Figure 3-7 Wave Height, Peak Period, and Peak Direction

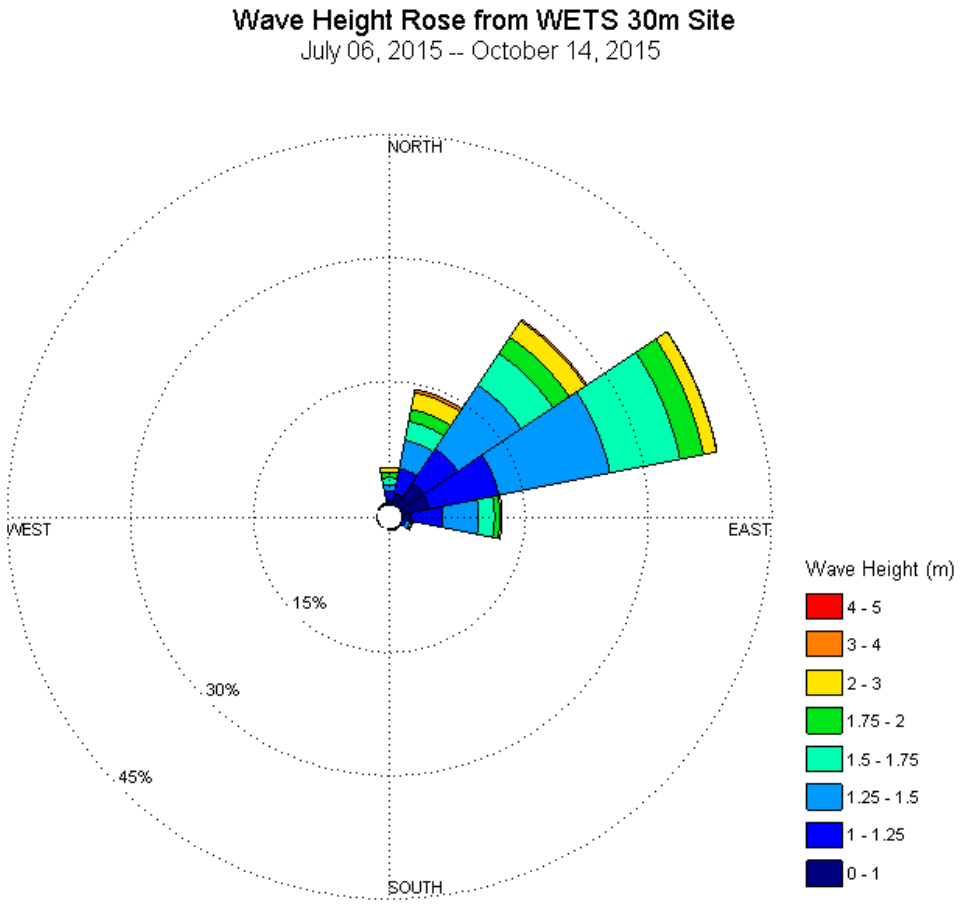


Figure 3-8 Wave Height Rose

Table 3-5 Wave Height Statistics

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 -1	0.46	1.42	3.47	3.38	1.09	0.04	0.13	0.04									10.03
1 -1.25	1.13	3.09	5.01	8.65	3.88	0.50	0.08	0.04					0.04			0.04	22.47
1.25 -1.5	0.88	3.51	9.31	####	4.39	0.46		0.13	0.04						0.08	0.04	32.66
1.5 -1.75	0.79	2.34	4.64	8.69	1.92	0.29						0.04	0.04		0.04	0.08	18.88
1.75 -2	0.67	1.50	2.38	2.92	0.67	0.04					0.04						8.23
2 -3	0.58	2.05	2.34	1.63	0.25	0.04											6.89
3 -4	0.04	0.42	0.25	0.04											0.04	0.04	0.84
4 -5																	
Total %	**4.55**	**####**	**####**	**####**	**####**	**1.38**	**0.21**	**0.21**	**0.04**		**0.04**	**0.04**	**0.08**		**0.17**	**0.21**	**######**
Mean	1.50	1.55	1.42	1.39	1.32	1.35	0.91	1.26	1.44	0.00	1.75	1.58	1.31	0.00	1.91	1.80	**1.42**
StDev	0.46	0.56	0.47	0.36	0.28	0.30	0.26	0.19	0.00	0.00	0.00	0.00	0.34	0.00	0.90	0.79	**0.43**
Min	0.57	0.39	0.31	0.31	0.37	0.81	0.52	0.98	1.44	0.00	1.75	1.58	1.07	0.00	1.38	1.07	**0.31**
Max	3.14	3.57	3.53	3.02	2.12	2.46	1.22	1.45	1.44	0.00	1.75	1.58	1.55	0.00	3.25	3.14	**3.57**

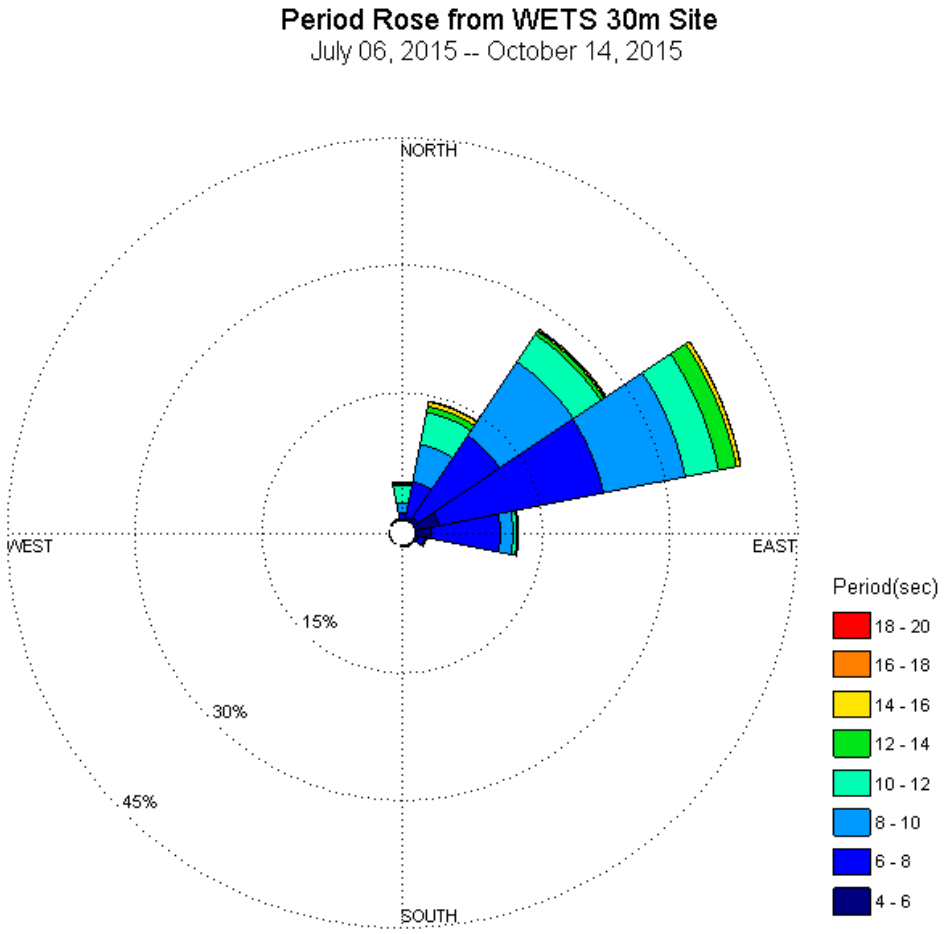


Figure 3-9 Period Rose

Table 3-6 Wave Period Statistics

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	0.17	0.42	0.75	2.92	1.96	0.46							0.04				**6.73**
6 -8	0.75	4.22	11.53	19.67	8.06	0.67	0.17	0.13				0.04			0.04		**45.28**
8 -10	1.09	4.51	10.44	9.86	1.50	0.13	0.04	0.08			0.04		0.04		0.08	0.08	**27.90**
10 -12	2.13	3.84	3.88	4.01	0.46	0.13			0.04							0.04	**14.54**
12 -14	0.21	0.71	0.46	2.13	0.21												**3.72**
14 -16	0.17	0.54	0.17	0.50											0.04	0.08	**1.50**
16 -18	0.04	0.08	0.17	0.04													**0.33**
18 -20																	
Total %	**4.55**	**14.33**	**27.40**	**39.14**	**12.20**	**1.38**	**0.21**	**0.21**	**0.04**		**0.04**	**0.04**	**0.08**		**0.17**	**0.21**	**######**
Mean	9.85	9.20	8.38	8.20	7.15	6.83	7.34	7.16	11.40	0.00	9.70	6.20	7.55	0.00	10.13	12.10	**8.33**
StDev	2.22	2.28	1.74	2.08	1.47	1.67	1.18	0.88	0.00	0.00	0.00	0.00	3.04	0.00	3.60	3.28	**2.07**
Min	5.40	5.00	4.70	4.70	4.80	4.60	6.50	6.30	11.40	0.00	9.70	6.20	5.40	0.00	7.90	8.40	**4.60**
Max	16.50	16.50	16.50	16.50	13.80	11.90	9.30	8.10	11.40	0.00	9.70	6.20	9.70	0.00	15.50	15.50	**16.50**

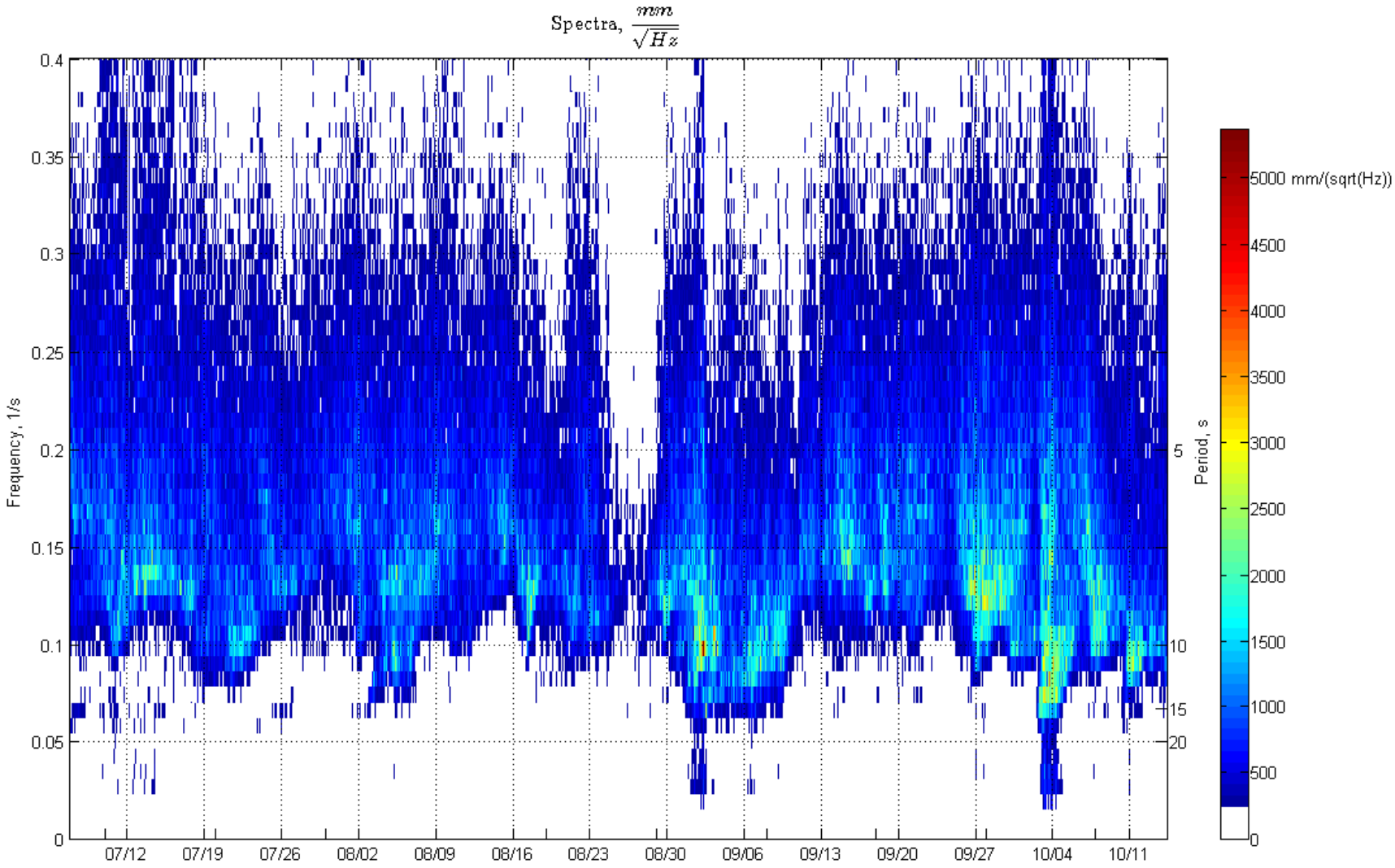
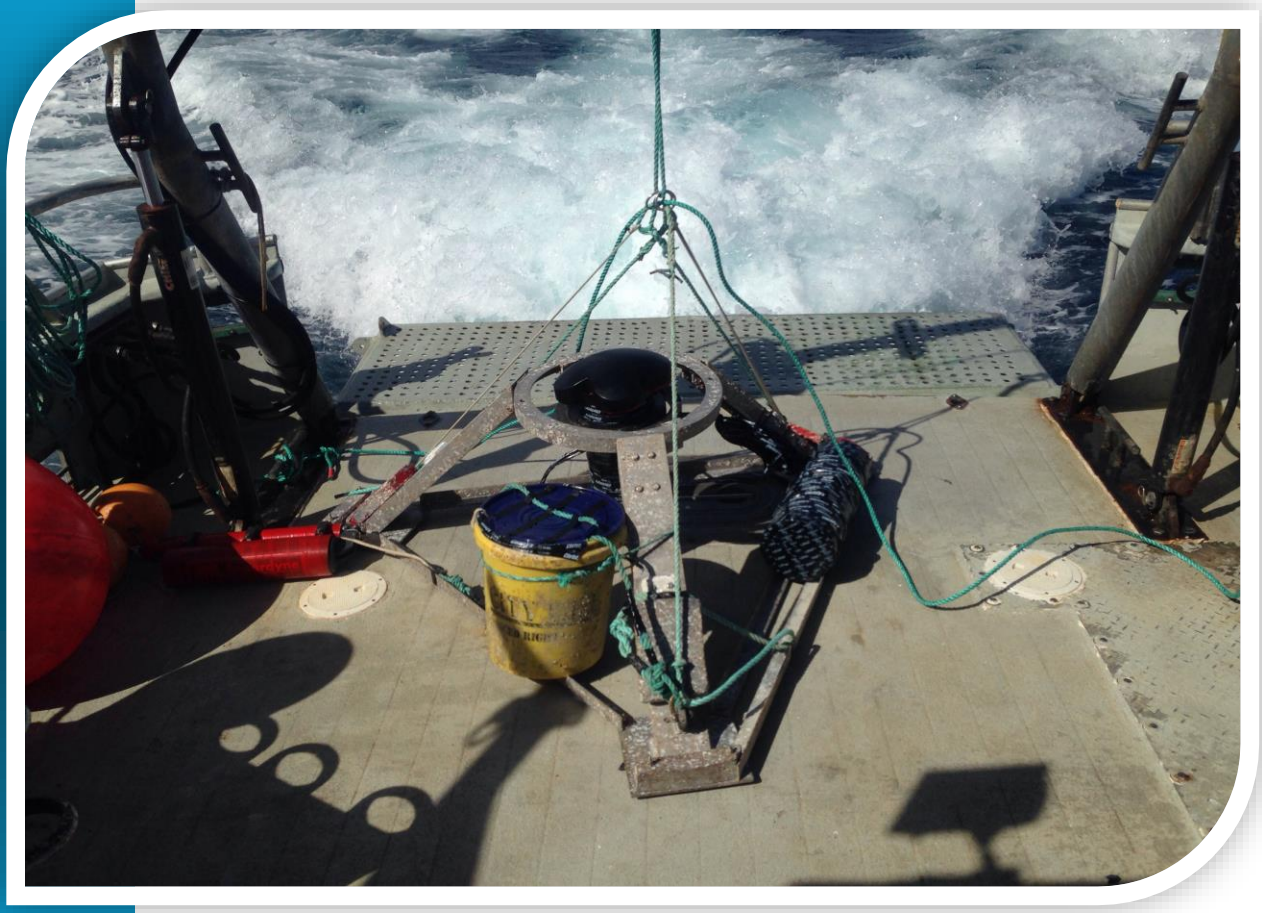


Figure 3-10 Wave Spectra

REPORT:

Task 4D Report - ADCP Data Analysis at WETS 30m Site

August 2017



Prepared for:
Hawai‘i National Marine Renewable Energy Center
1680 East West Road, POST 112A
Honolulu, HI 96822

Prepared by:
Sea Engineering, Inc.
Makai Research Pier
Waimānalo, HI 96795

Job No. 25419

This page intentionally left blank

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.

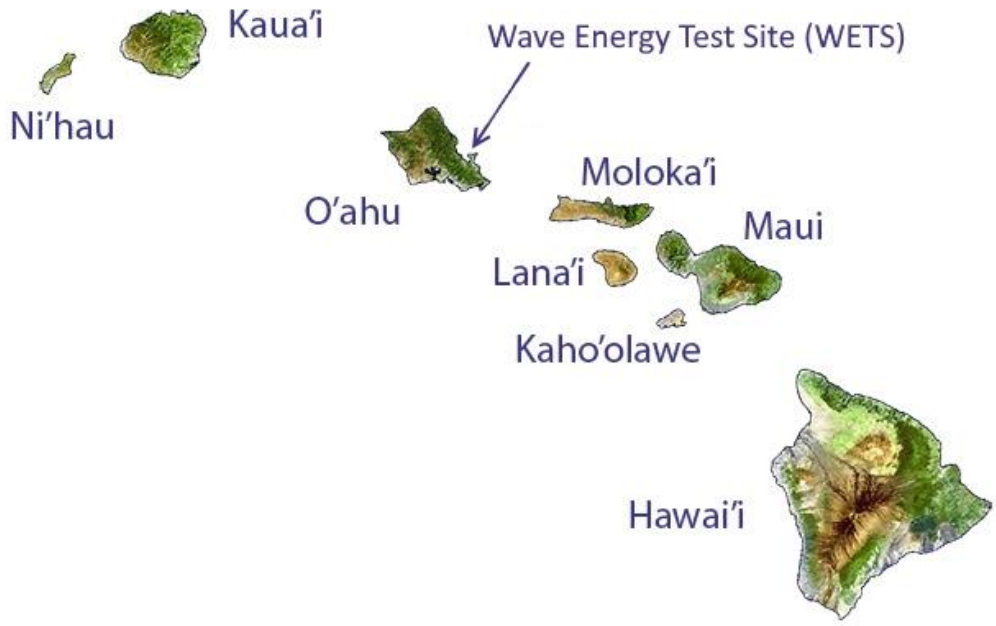


Figure 1-1 Project Location

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) 30m Site. This was the second deployment of the ADCP at the 30m 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 October 19, 2015 to January 13, 2016.

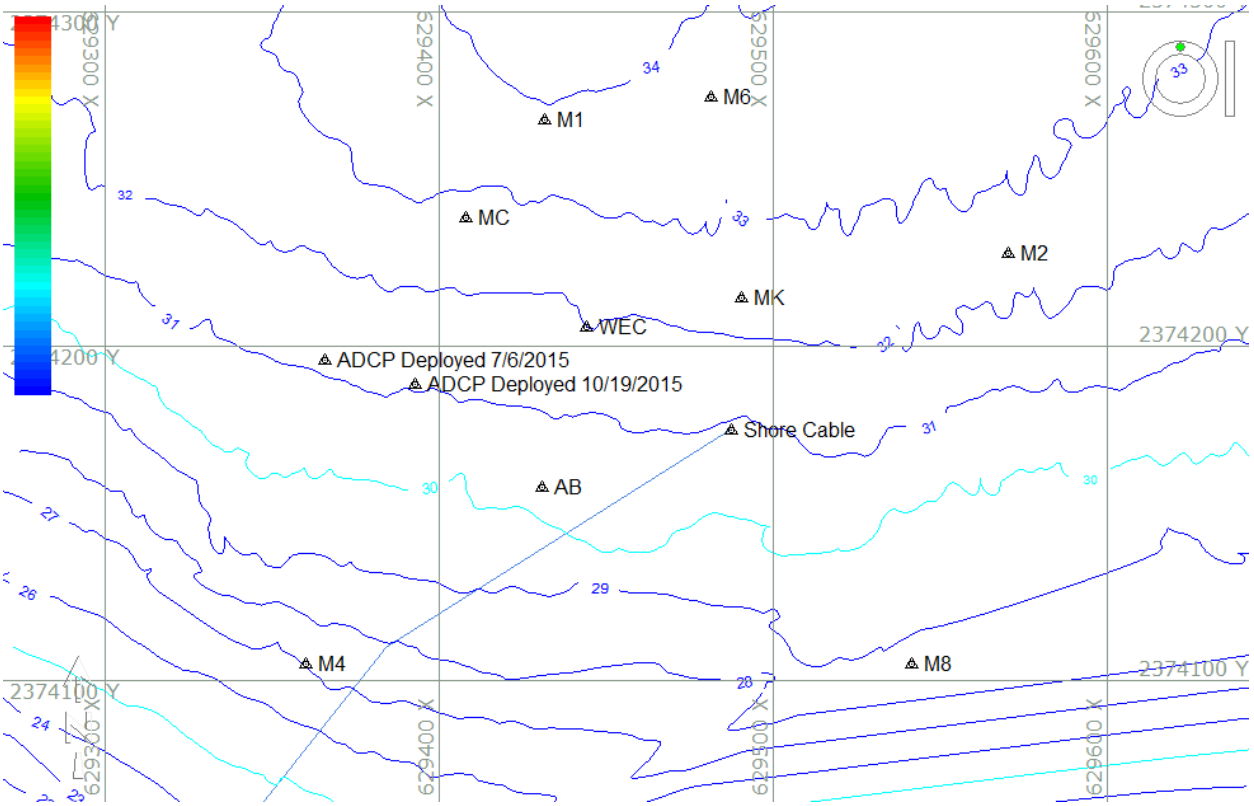


Figure 1-2 WETS Wave Measurement Instrumentation

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

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)	36	36
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. An external battery housing was used with two additional battery packs rated at 540 watt-hours. In total three battery packs were used, one in the Sentinel V100 ADCP and two in the external housing, providing 1,620 watt-hours of energy.

3. SENTINEL V100 DATA

The recorded wave and current data for the 87 day deployment period required 5.2 GB of data storage; the wave data comprised 4.6 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.

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 data was then exported to Matlab for further processing. The water column was divided into three layers for analysis. Table 3-1, shows the bins and associated water depths corresponding to three layers. Near surface data is bias 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	3.04 - 8.04	~ 24-28
Middle Layer	13 - 18	15.04 - 20.4	~ 10-15
Upper Layer	21 - 25	25.04 - 30.04~	~ 4-8

Figure 3-1 shows the time series 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 each layer, upper, middle, and bottom, 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 westerly direction with an average speed of 0.11 m/s, and a maximum recorded speed of 0.55 m/s for the duration of the deployment (October 19, 2015 to January 13, 2016). Mid-layer currents flow has a bimodal distribution, predominantly westerly and easterly. Current is either westerly or easterly 80% of the time. Bottom layer currents also flow predominantly to the east direction, but with greater occurrence in all directions. Currents are significantly weaker, less than 0.10 m/s with an average speed of 0.07 m/s, and a maximum recorded speed of 0.32 m/s.

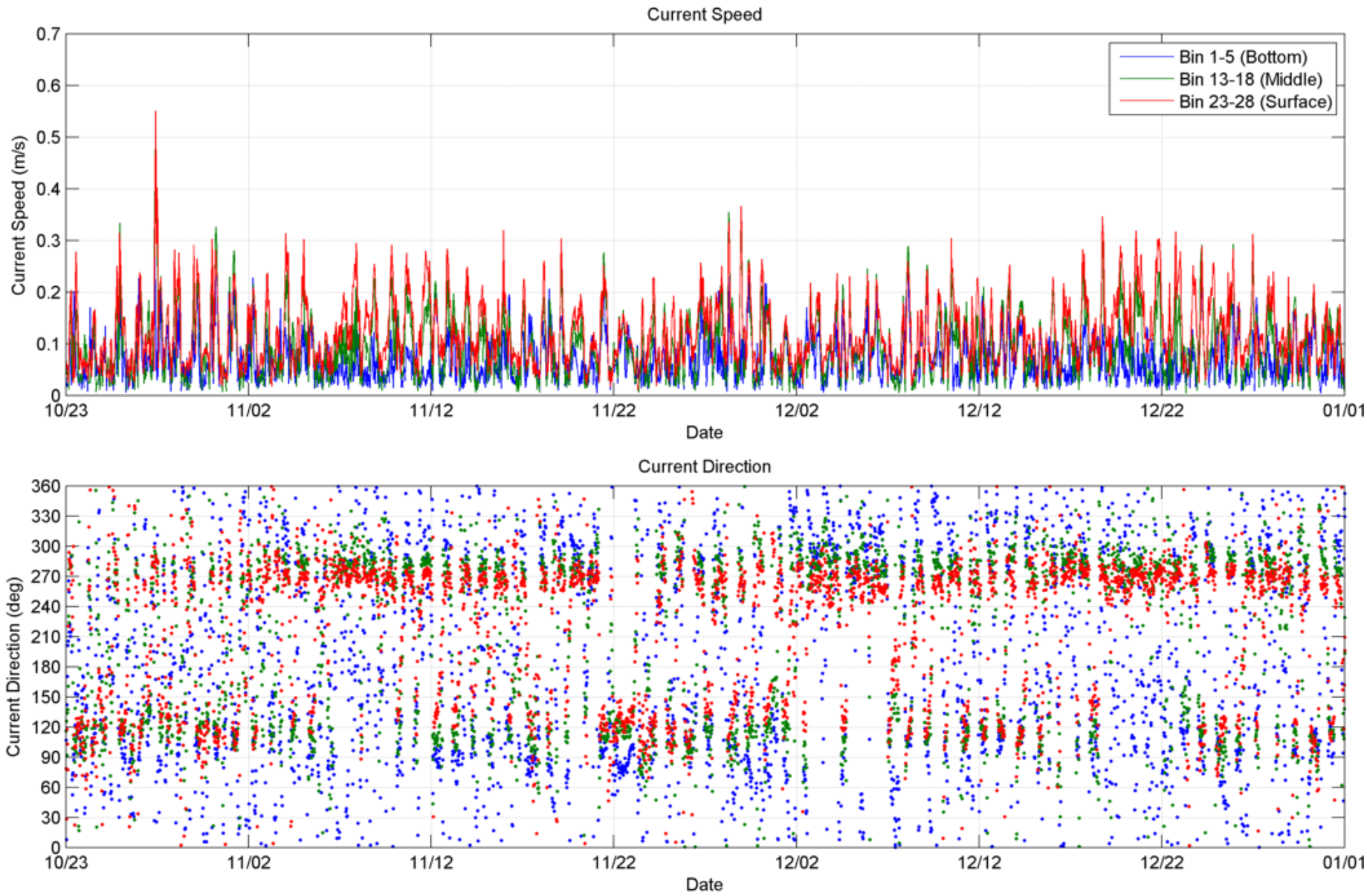


Figure 3-1 Current Speed and Direction for Each Layer

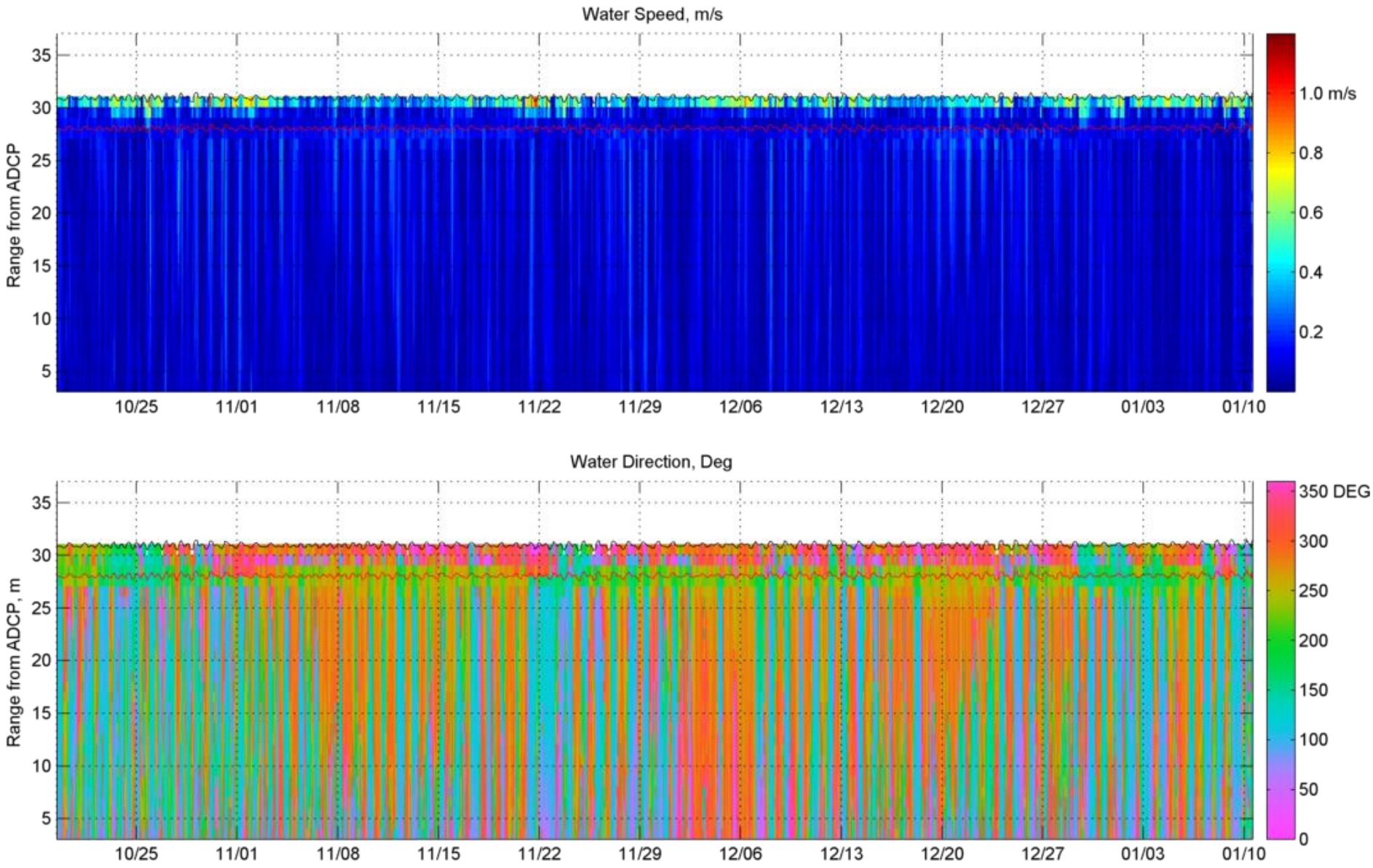


Figure 3-2 Current Speed and Direction for All Bins

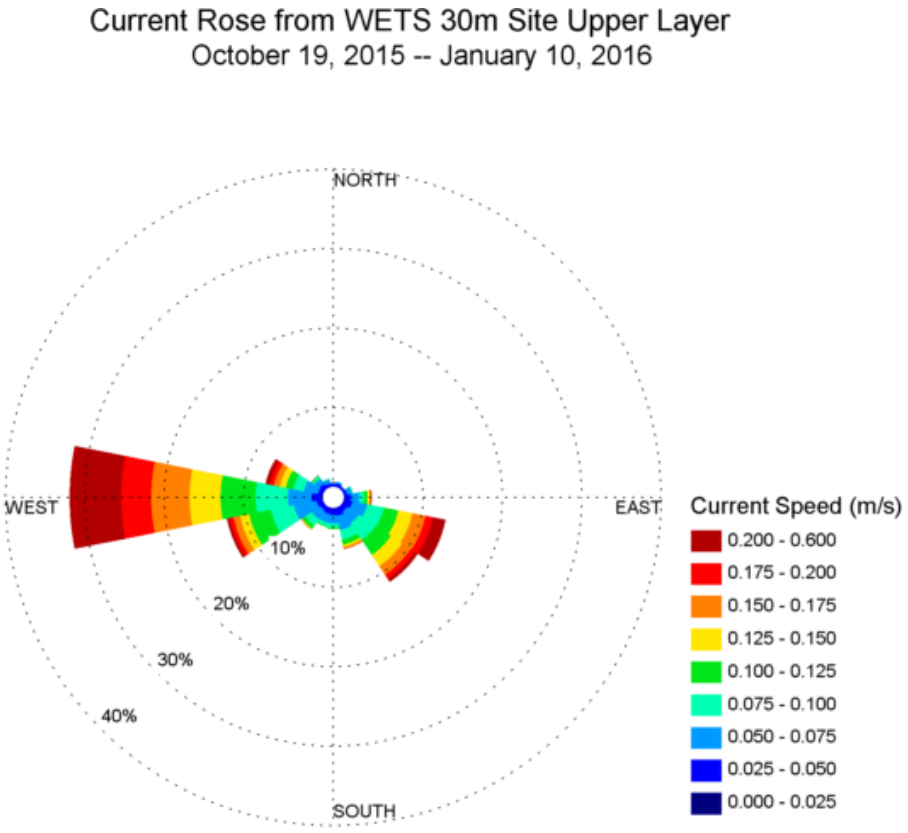


Figure 3-3 Current Rose for Upper Layer

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	0.03	0.05	0.05		0.08	0.13	0.05	0.08	0.03	0.13		0.03	0.05	0.08		0.05	0.80
0.025	-0.050	0.33	0.40	0.25	0.43	0.78	1.00	0.73	0.95	0.88	0.68	0.63	0.80	1.33	0.58	0.73	0.38	10.88
0.050	-0.075	0.15	0.23	0.10	0.63	1.06	1.91	1.78	1.83	1.06	1.11	1.31	2.89	2.99	1.81	0.83	0.53	20.20
0.075	-0.100	0.05	0.03	0.03	0.13	0.68	2.14	2.56	1.26	0.50	0.45	1.00	2.96	4.09	1.33	0.30	0.13	17.63
0.100	-0.125				0.03	0.38	1.83	2.26	0.63	0.20	0.13	0.48	2.79	4.42	0.98	0.15		14.27
0.125	-0.150				0.03	0.35	1.83	1.71	0.30	0.03	0.03	0.13	1.16	3.92	0.78		0.03	10.27
0.150	-0.175					0.05	1.66	1.28	0.23			0.03	0.88	4.82	0.75	0.03		9.72
0.175	-0.200					0.03	0.98	0.63	0.03			0.03	0.50	3.79	0.55			6.53
0.200	-0.600	0.03				0.13	1.63	0.48	0.03				0.35	6.51	0.53	0.03		9.70
Total %		**0.58**	**0.70**	**0.43**	**1.23**	**3.52**	**13.11**	**11.48**	**5.33**	**2.69**	**2.51**	**3.59**	**12.36**	**31.93**	**7.39**	**2.06**	**1.11**	**100.00**
Mean		0.07	0.05	0.05	0.06	0.08	0.13	0.11	0.08	0.06	0.06	0.08	0.10	0.15	0.11	0.06	0.06	**0.11**
StDev		0.08	0.01	0.01	0.02	0.04	0.06	0.05	0.03	0.02	0.02	0.03	0.04	0.06	0.06	0.03	0.02	**0.06**
Min		0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.01	0.03	0.02	**0.01**
Max		0.44	0.08	0.08	0.13	0.24	0.34	0.31	0.20	0.14	0.15	0.18	0.25	0.40	0.55	0.28	0.15	**0.55**

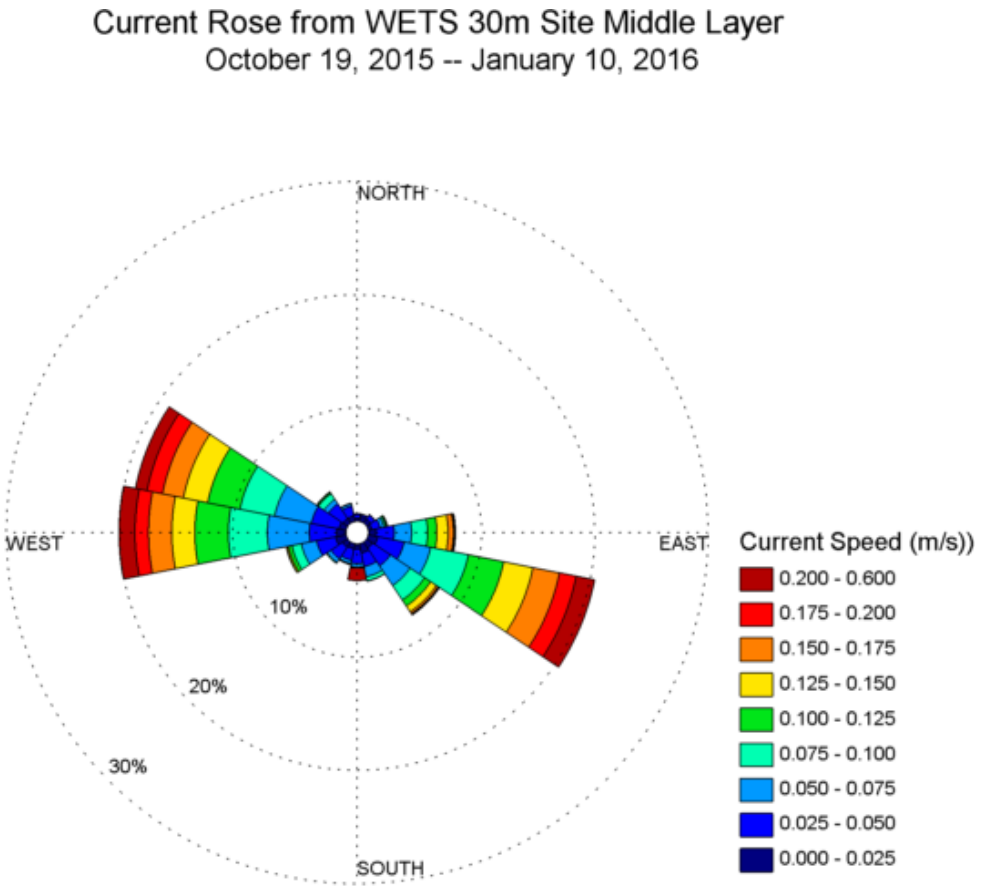


Figure 3-4 Current Rose for Middle Layer

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	0.27	0.45	0.45	0.32	0.65	0.87	0.65	0.84	0.45	0.47	0.57	0.94	0.80	0.65	0.52	0.50	9.39
0.025	-0.050	0.35	0.17	0.42	0.75	1.61	2.36	1.89	1.22	1.29	1.02	1.22	1.71	2.43	2.48	1.54	0.89	21.37
0.050	-0.075	0.02	0.05	0.02	0.32	1.54	2.39	2.09	0.92	0.30	0.30	0.40	1.37	3.70	3.30	0.47	0.20	17.39
0.075	-0.100			0.02	0.17	1.42	3.40	1.54	0.37	0.02	0.05	0.10	0.84	3.45	3.13	0.60	0.02	15.16
0.100	-0.125				0.12	0.82	3.18	0.65	0.02	0.07	0.02		0.32	2.96	2.91	0.12		11.20
0.125	-0.150				0.05	0.99	2.63	0.60			0.02		0.15	2.04	2.19	0.05		8.72
0.150	-0.175					0.47	2.39	0.20					0.02	2.06	1.89			7.03
0.175	-0.200					0.07	1.52	0.07						1.19	1.39	0.02		4.27
0.200	-0.600	0.02				0.10	1.66	0.07		1.09			0.02	1.42	1.04		0.02	5.47
Total %		**0.67**	**0.67**	**0.92**	**1.74**	**7.68**	**20.40**	**7.75**	**3.38**	**3.23**	**1.89**	**2.29**	**5.39**	**20.05**	**18.98**	**3.33**	**1.64**	**100.00**
Mean		0.03	0.02	0.03	0.05	0.08	0.11	0.07	0.05	0.14	0.04	0.04	0.06	0.11	0.11	0.05	0.04	**0.09**
StDev		0.04	0.01	0.02	0.03	0.05	0.06	0.04	0.02	0.14	0.02	0.02	0.04	0.06	0.06	0.03	0.04	**0.06**
Min		0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	**0.00**
Max		0.20	0.07	0.09	0.14	0.35	0.33	0.29	0.12	0.34	0.13	0.09	0.36	0.32	0.54	0.18	0.31	**0.54**

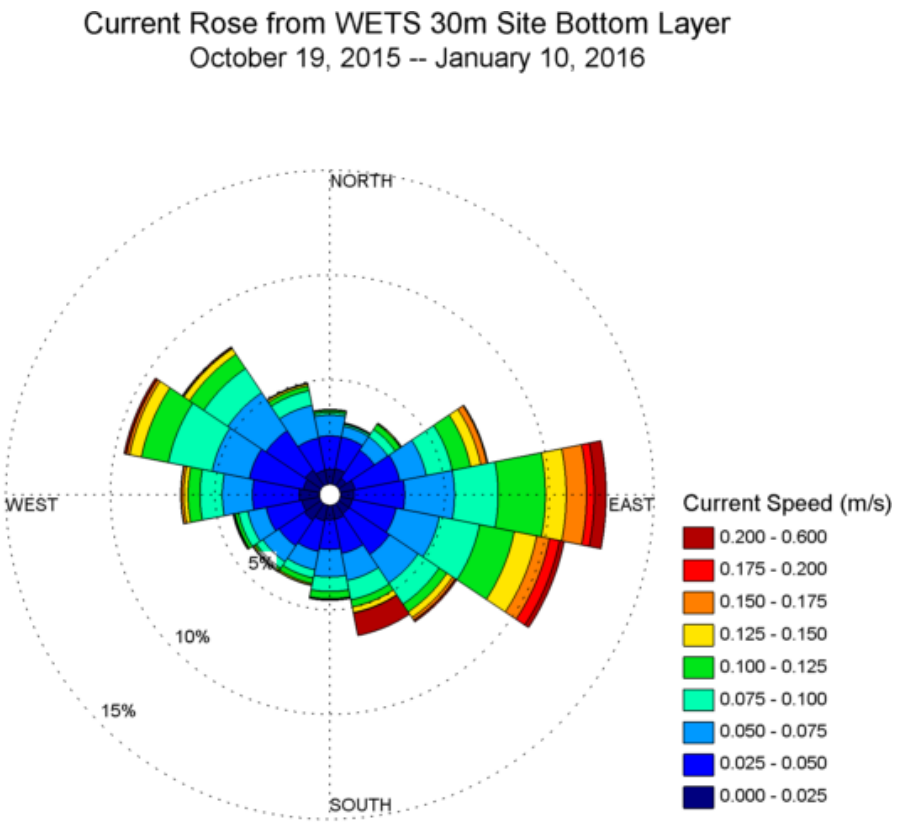


Figure 3-5 Current Rose for Bottom Layer

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	0.72	0.77	0.45	0.72	0.65	0.60	0.60	0.70	0.70	0.77	0.97	0.87	0.97	0.80	0.92	0.70	11.88
0.025	-0.050	1.59	1.54	1.61	2.19	2.43	2.14	2.34	1.66	1.42	1.49	1.47	1.74	2.24	2.63	2.26	1.57	30.31
0.050	-0.075	0.99	0.52	0.77	1.29	2.39	2.11	1.64	1.32	1.32	0.89	0.92	0.89	1.44	1.81	2.19	1.59	22.09
0.075	-0.100	0.12	0.10	0.42	1.27	2.09	1.96	1.22	0.94	0.70	0.40	0.37	0.45	1.07	2.14	1.39	0.72	15.35
0.100	-0.125	0.10	0.05	0.30	0.89	2.26	1.69	0.45	0.35	0.35	0.27	0.10	0.17	0.57	1.32	0.82	0.22	9.91
0.125	-0.150	0.02		0.05	0.50	0.99	1.09	0.32	0.27		0.07	0.07	0.05	0.20	0.57	0.32	0.10	4.65
0.150	-0.175			0.02	0.30	0.97	0.62	0.15	0.02	0.05		0.02	0.05	0.12	0.15	0.02	0.02	2.53
0.175	-0.200		0.02		0.02	0.37	0.50	0.02			0.02	0.02			0.02	0.05		1.07
0.200	-0.600	0.02			0.02	0.57	0.22	0.07	1.09	0.02				0.02	0.10	0.02	0.02	2.21
Total %		**3.58**	**3.01**	**3.63**	**7.20**	**12.72**	**10.93**	**6.81**	**6.36**	**4.55**	**3.93**	**3.95**	**4.22**	**6.63**	**9.54**	**8.00**	**4.94**	**100.00**
Mean		0.04	0.04	0.05	0.07	0.09	0.09	0.07	0.09	0.06	0.05	0.05	0.05	0.06	0.07	0.06	0.06	**0.07**
StDev		0.03	0.02	0.03	0.04	0.05	0.05	0.04	0.08	0.03	0.03	0.03	0.03	0.04	0.04	0.03	0.03	**0.05**
Min		0.01	0.00	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	**0.00**
Max		0.25	0.18	0.17	0.22	0.27	0.24	0.23	0.26	0.20	0.18	0.20	0.16	0.20	0.32	0.21	0.25	**0.32**

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.

Only the waves profile was used for wave statistics. The waves profile data was processed in a subprogram called WavesMon. The settings for the processing are quite complex. A screenshot of the settings for WavesMon is presented in Figure 3-6.

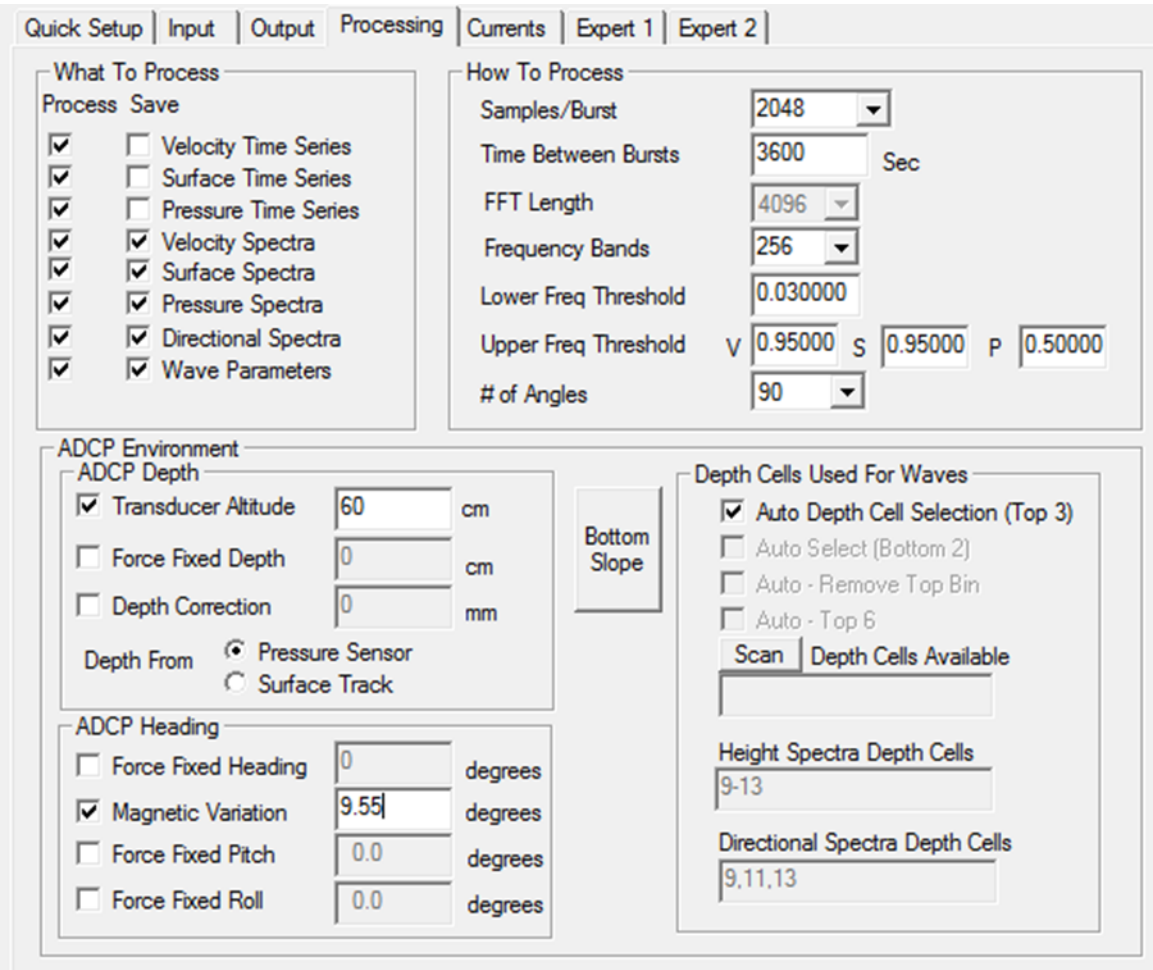


Figure 3-6 WavesMon Processing Tab

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. Table 3-5 present the percent frequency of

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

The time series, Figure 3-7, indicates typical wave heights of approximately 1.0 - 1.5m from an east-northeast direction indicative of trade wind generated swell, with distinct peaks with wave heights greater than 3m on October 27, 2015 and December 20, 2015.

The wave height rose shown in Figure 3-8, and Table 3-5, indicates waves from a northeasterly direction (0° - 67.5°) occur 86% of the time. Waves are greater than 1.25m 76% of the time. The average wave height is 1.67m and maximum wave height was 3.42m.

The period rose shown in Figure 3-9, and Table 3-6, show the mean period was 10.05 seconds and the maximum period was 20.5 seconds.

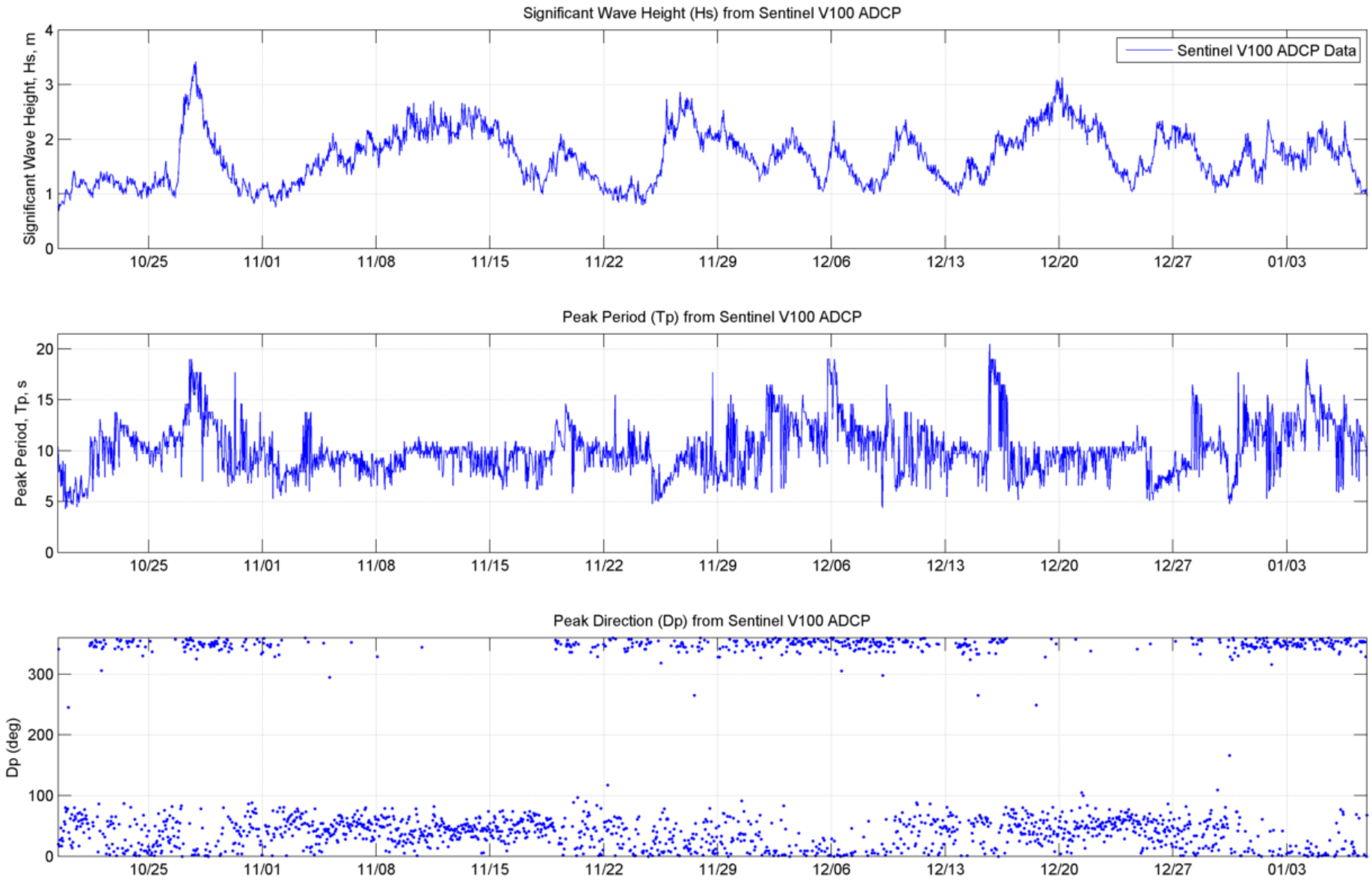


Figure 3-7 Wave Height, Peak Period, and Peak Direction

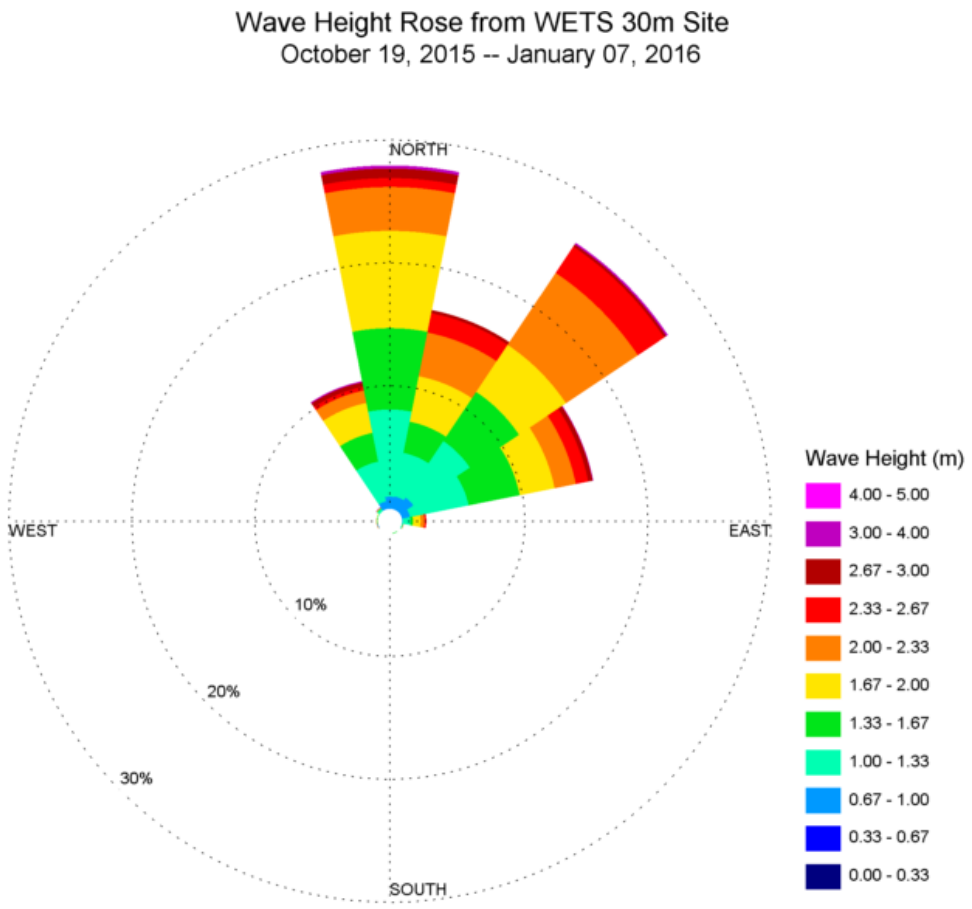


Figure 3-8 Wave Height Rose

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																	0.00
0.67	-1.00	0.98	1.03	1.29	0.67	0.05							0.05				0.62	4.71
1.00	-1.33	7.09	3.62	5.54	4.86	0.62	0.10								0.05	0.21	3.31	25.40
1.33	-1.67	6.62	2.59	4.81	4.24	0.21			0.05					0.05		0.05	2.38	21.00
1.67	-2.00	7.92	3.78	4.60	2.90	0.62									0.05	0.05	2.48	22.40
2.00	-2.33	3.57	3.62	7.04	1.76	0.31	0.05						0.05	0.05			1.03	17.49
2.33	-2.67	0.72	1.60	2.59	1.03	0.16											0.31	6.41
2.67	-3.00	0.78	0.26	0.21	0.36												0.36	1.97
3.00	-4.00	0.26		0.16	0.05											0.05	0.10	0.62
4.00	-5.00																	0.00
Total %		27.94	16.50	26.23	15.88	1.97	0.16	0.00	0.05	0.00	0.00	0.00	0.10	0.10	0.10	0.36	10.61	100.00
Mean		1.64	1.72	1.76	1.61	1.65	1.45	0.00	1.35	0.00	0.00	0.00	1.62	1.81	1.64	1.69	1.59	1.67
StDev		0.46	0.49	0.50	0.47	0.47	0.65	0.00	0.00	0.00	0.00	0.00	0.88	0.56	0.43	0.65	0.47	0.48
Max		0.80	0.76	0.76	0.81	0.95	1.00	0.00	1.35	0.00	0.00	0.00	0.99	1.41	1.33	1.25	0.69	0.69
Min		3.42	2.82	3.09	3.13	2.53	2.19	0.00	1.35	0.00	0.00	0.00	2.24	2.20	1.94	3.04	3.37	3.42

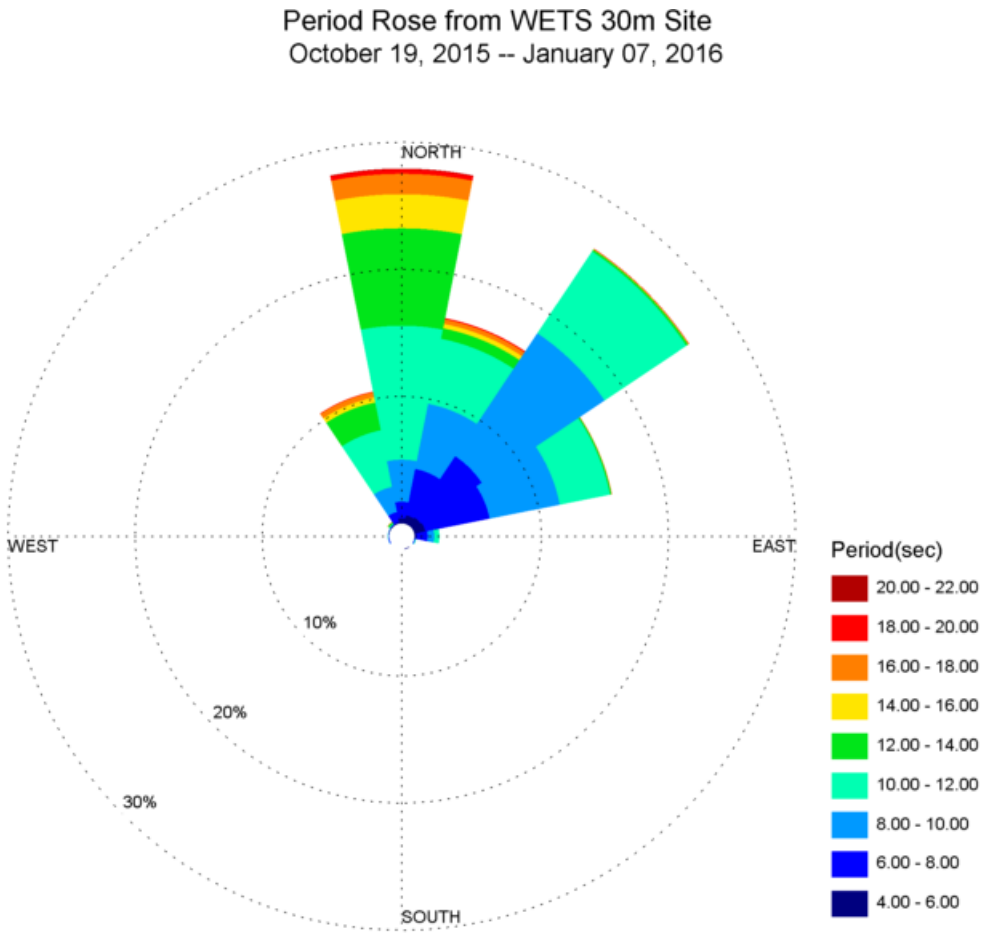


Figure 3-9 Period Rose

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	0.41	0.67	0.78	0.88	0.16			0.05						0.05	0.05	0.10	3.16
6 -8	1.29	3.72	5.79	5.17	0.88	0.05						0.05	0.05		0.05	0.83	17.90
8 -10	3.31	5.23	11.64	5.64	0.52	0.05						0.05		0.05		2.02	28.50
10 -12	10.55	5.23	7.76	4.04	0.41	0.05							0.05		0.10	4.55	32.75
12 -14	7.66	0.83	0.16	0.10											0.10	2.22	11.07
14 -16	2.69	0.36	0.05													0.41	3.52
16 -18	1.60	0.36		0.05											0.05	0.41	2.48
18 -20	0.36	0.10	0.05													0.05	0.57
20 -22	0.05																0.05
Total %	**27.94**	**16.50**	**26.23**	**15.88**	**1.97**	**0.16**	**0.00**	**0.05**	**0.00**	**0.00**	**0.00**	**0.10**	**0.10**	**0.10**	**0.36**	**10.61**	**100.00**
Mean	11.96	9.55	8.93	8.61	8.05	8.47	0.00	4.80	0.00	0.00	0.00	7.85	8.95	6.55	11.16	11.15	**10.05**
StDev	2.61	2.43	1.49	1.67	1.80	1.90	0.00	0.00	0.00	0.00	0.00	2.62	3.46	3.04	4.18	2.36	**2.57**
Min	4.80	4.70	4.50	4.50	4.30	6.60	0.00	4.80	0.00	0.00	0.00	6.00	6.50	4.40	5.90	5.30	**4.30**
Max	20.50	19.00	19.00	17.70	11.40	10.40	0.00	4.80	0.00	0.00	0.00	9.70	11.40	8.70	17.70	19.00	**20.50**