Hawaii National Marine Renewable Energy Center (HINMREC)

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Task 3: Wave Resource Model, Wave Field Measurements and Data Analysis

Wave Energy Test Site Progress Report: Comparison of Wave Hindcast Model Results with Waverider Measurements

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WAVE ENERGY TEST SITE (WETS)
Progress Report:

Comparison of Wave Hindcast Model Results
with
Waverider Measurements: *November 2012 - October 2013*

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1. Introduction

SWAN version 40.85 was forced with hindcast spectral boundary conditions from WAVEWATCH III (WW3) version 4.08 to produce 11 months of spectral wave estimates from November 2012 through October 2013. The wind forcing includes the Climate Forecast System Reanalysis data set for the entire globe as well as high-resolution Weather and Forecasting (WRF) data for the Hawaii region from the UH Meteorology Department.

Model output wave parameters are compared to those derived from time history records obtained with the Kaneohe Waverider buoy located at 21.4775°N and 157.7526°W in 81 m depth at the Wave Energy Test Site (WETS) off Marine Corps Base Hawaii in Kaneohe Bay, on the east side of Oahu (Fig 1).

This projects aims at providing the wave scatter diagram required as input to estimate energy produced by a wave energy converter over a specified period. The wave scatter diagram is presented in matrix form (Tables 1-4) showing occurrence of events over binned significant wave height (Hs) and wave period (T_e or T_{02})

Figure 1. - Location of the Kaneohe Waverider Buoy (CDIP #198/NDBC 51207) deployed at the Wave Energy Test Site (WETS).

2. Wave Parameters Derived from Waverider Measurements and Hindcast Model

Figure 2 compares the wave parameters derived from the Kaneohe-Waverider records and the UH hindcast model for November 2012 to October 2013. The comparison indicates general agreement of the significant wave height (m), peak wave power period (s) and mean wave direction (°).

The scatter plot in Figure 3 shows the error in model estimates of significant wave height (Hs) in relation to those derived from Waverider measurements. The linear regression fit in the scatter plot has a slope of 0.9518 and the two blue lines delineate 90% of the data within ±0.36m of the linear regression.

The quantile-quantile (Q-Q) plot given in Figure 4 sorts the significant wave heights estimated from the model and measurements. The two datasets follow similar statistical distributions up to 3.5 m. The model, however, underestimates large swells above 3.5 m significant wave height.

The wave climate in Hawaii is composed of swells from the North and South Pacific and year-round wind waves from the northeast. A convenient way to present the occurrence, magnitude, and direction of the wave conditions are “rose” plots. Figures 5-8 show general agreement of the wave rose plots from the recorded and model wave conditions. Wind waves from the ENE are most common with typical wave heights in the 1-3 m range and typical wave period in the 6-10s range. The site also experiences north swell during the northern hemisphere winter months, but is sheltered from the south swells experienced in Hawaiian waters during the southern hemisphere winter months.

Figure 9 and 10 show examples of summer (June 2013) 2D and 1D spectra computed from the Waverider time history records and the UH model. The results provide general agreement of the peak direction and period as well as similar significant wave heights of 2.84 m (Waverider) and 2.86 m (model).

The recorded (Waverider) and computed (model) 2D and 1D spectra in Figure 11 and 12 are from January 2013 and show a distinct peak from the north-northwest as well as broad-banded signals of the wind waves from the east-northeast. North swells prevail during the winter months. Even for a multi-modal sea state, general agreement between the recorded and computed spectra is maintained.

3. Wave Scatter Matrix

The wave power flux used to quantify the wave energy resource is given by

$$P = \rho g \iint C_g(f) S(f,\theta,h)\, d\theta\, df \quad \text{(Watts/m)} \tag{1}$$

where, θ = wave direction, f = wave frequency, C_g = group speed, g = gravitational acceleration, and ρ = density of sea water.

The significant wave height Hs is defined by:

$$Hs = 4\sqrt{\iint S(f,\theta)\, d\theta\, df} \tag{2}$$

The spectrally defined periods T_e (energy period) and T_{02} (average zero-crossing wave period) are defined by

$$T_e = \frac{m_{-1}}{m_0} \tag{3}$$

$$T_{02} = \sqrt{\frac{m_2}{m_0}} \tag{4}$$

in which the *n*th spectral moment is defined as

$$m_n = \int_0^\infty f^n S(f)\, df \tag{5}$$

The occurrence of events corresponding to binned significant wave height (Hs) and wave periods (T_e or T_{02}) are presented in Tables 1-4 utilizing all 11 months of modeled and recorded data. These are in the format required by HINMREC for the estimation of energy generated by a particular wave energy converter as defined by its Power Matrix.

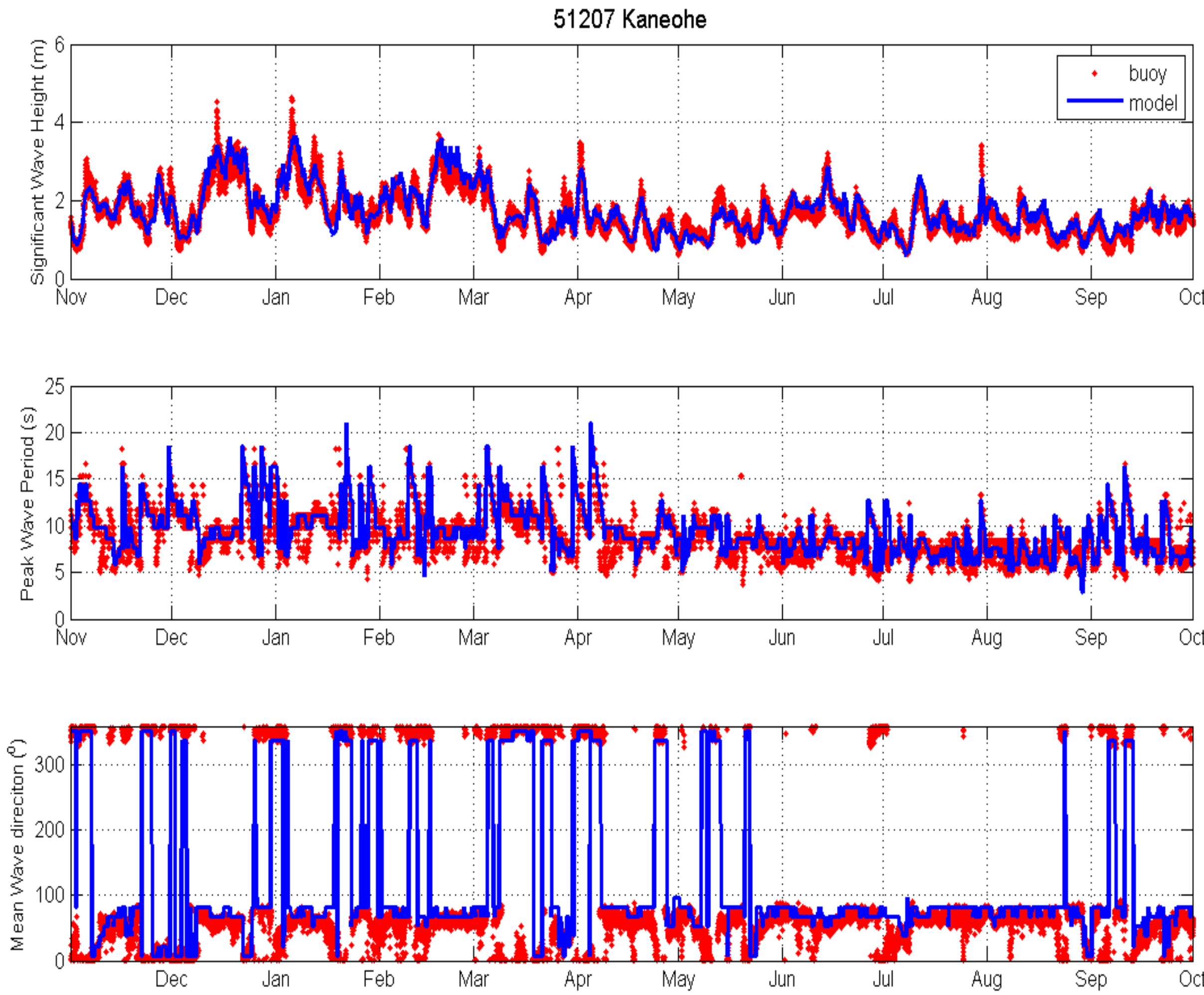

Figure 2.- Comparison of wave parameters estimated from Waverider records and hindcast model: November 2012 through October 2013.

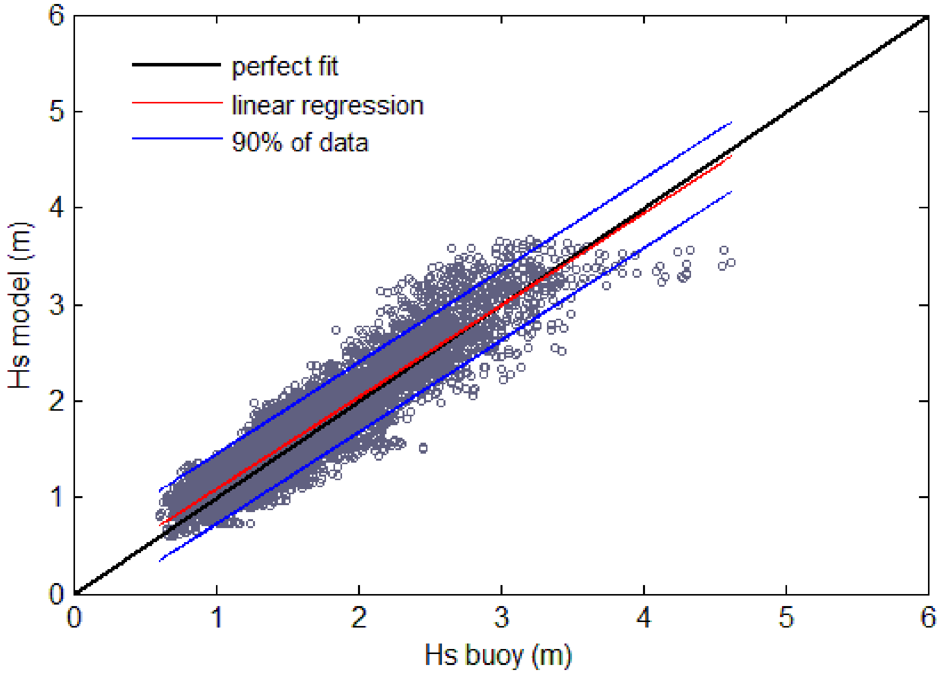

Figure 3.- Scatter plot of significant wave height estimated from Waverider records and hindcast model

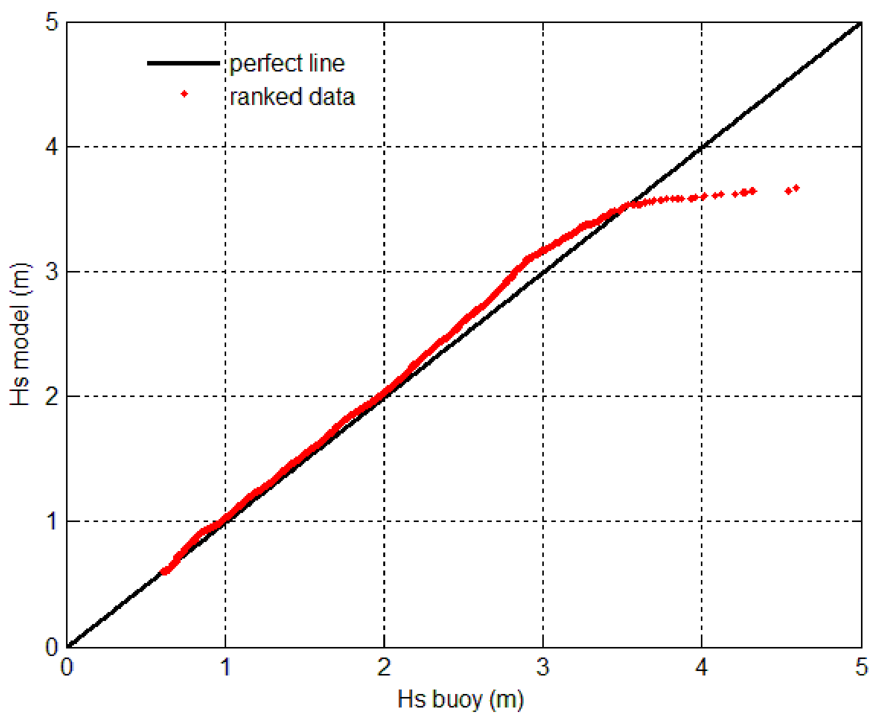

Figure 4.- Q-Q plot of significant wave height estimated from Waverider records and hindcast model

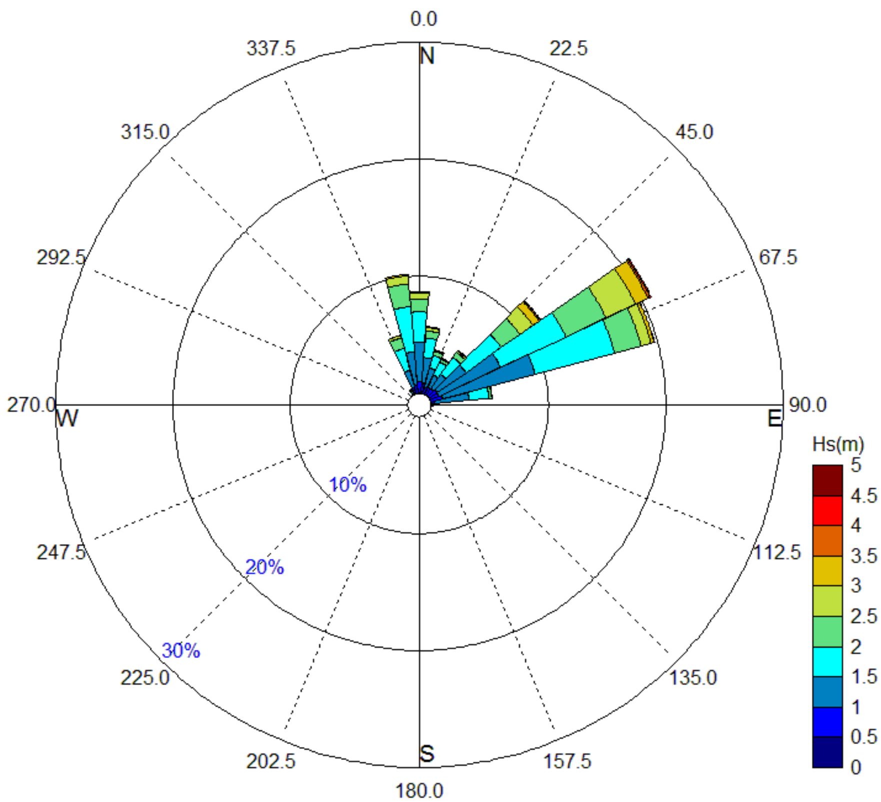

Figure 5.- Rose plot of significant wave height from Waverider records (November 2012 - October 2013)

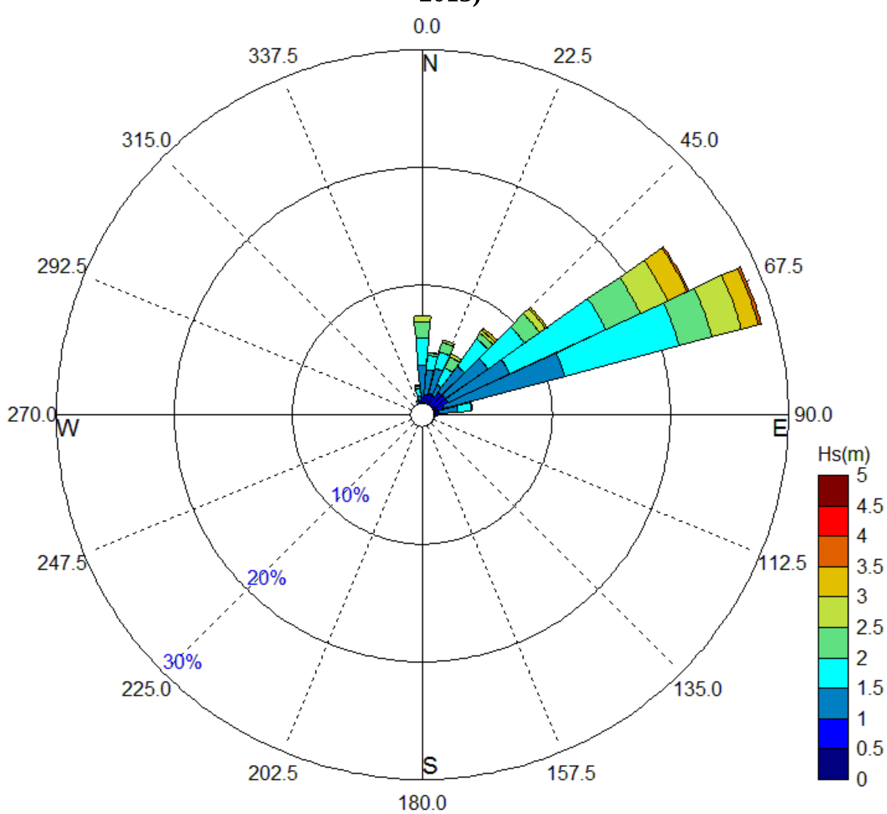

Figure 6.- Rose plot of significant wave height from hindcast model (November 2012 - October 2013)

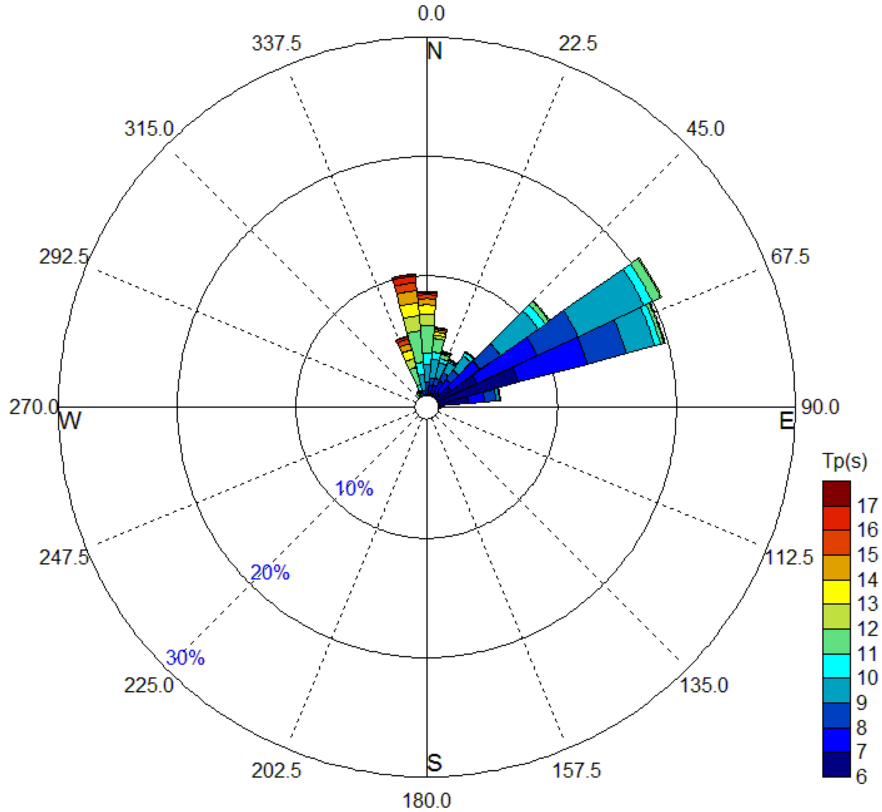

Figure 7.- Rose plot of peak wave period from Waverider records (November 2012 - October 2013)

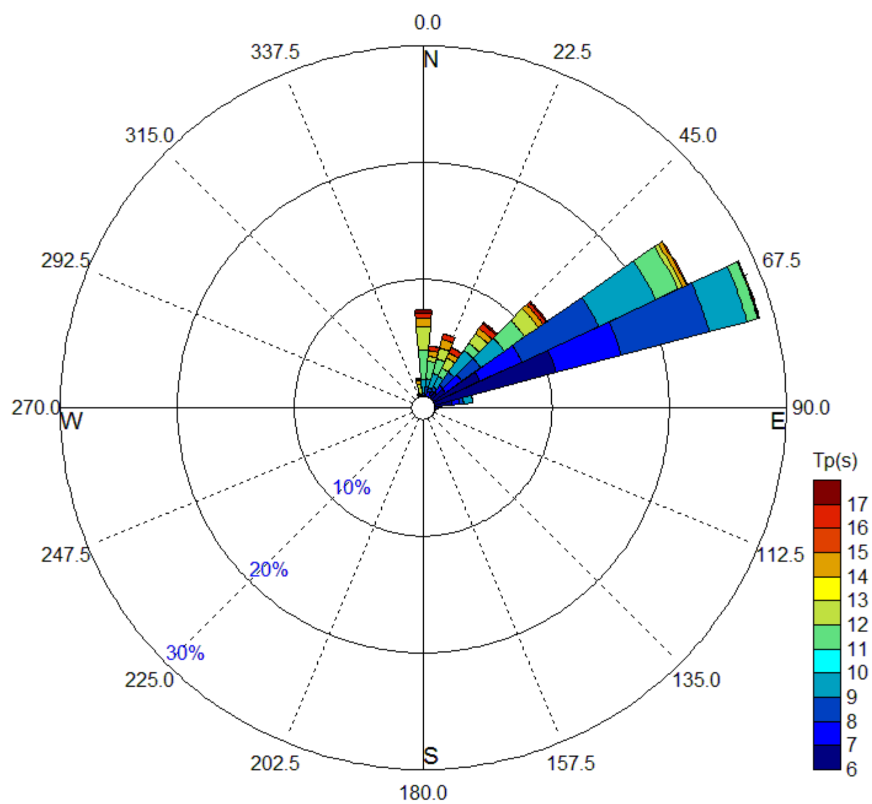

Figure 8.- Rose plot of peak wave period from hindcast model (November 2012 - October 2013)

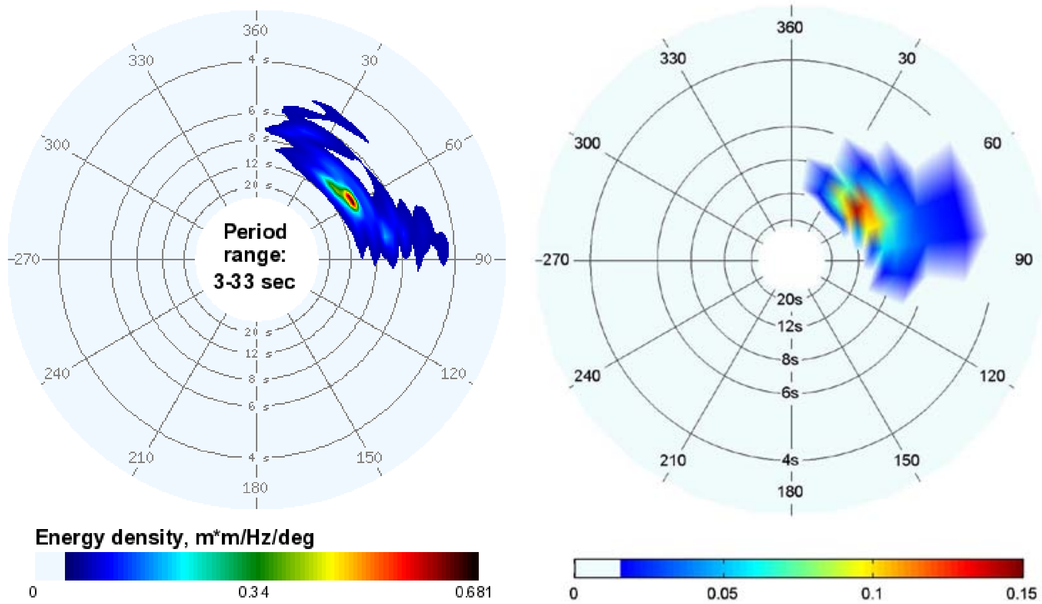

Figure 9.- 2D spectra estimated from Waverider 30-minute records centered at noon June 14, 2013 (left side) and hindcast model (right side).

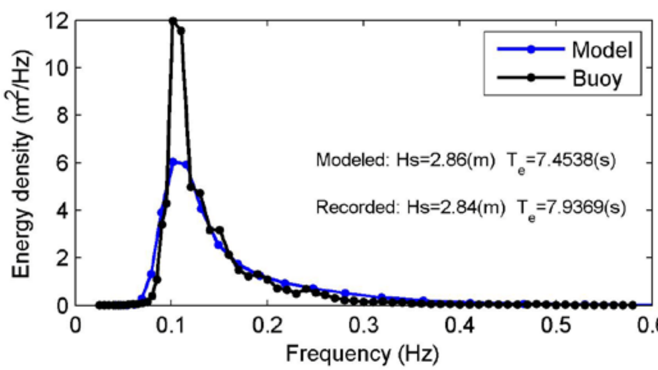

Figure 10.- 1D spectra estimated from Waverider records centered at noon June 14, 2013 and hindcast model.

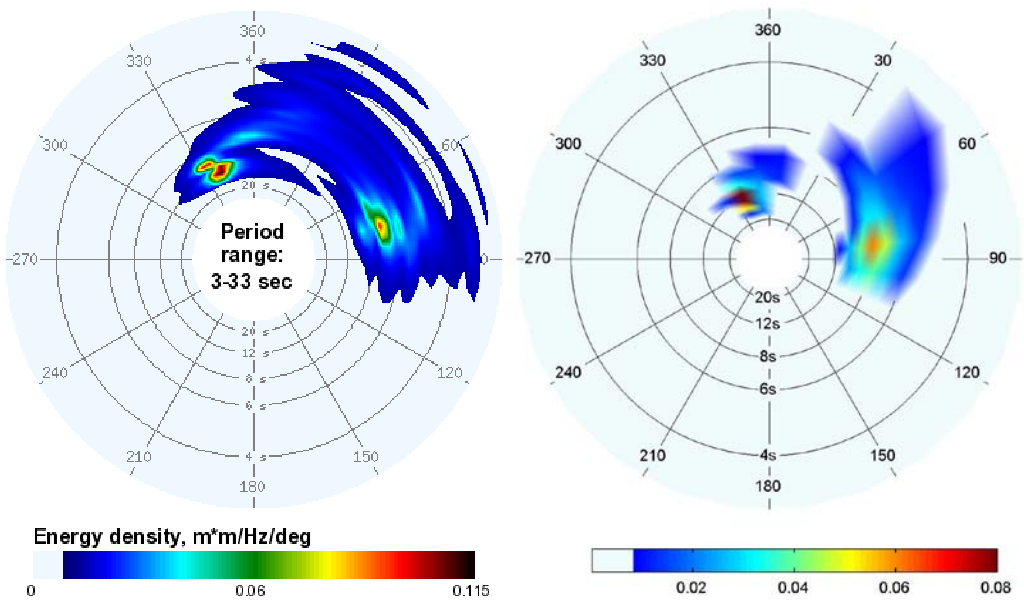

Figure 11.- 2D spectra estimated from Waverider 30-minute records centered at 0100 January 4, 2013 (left side) and hindcast model (right side).

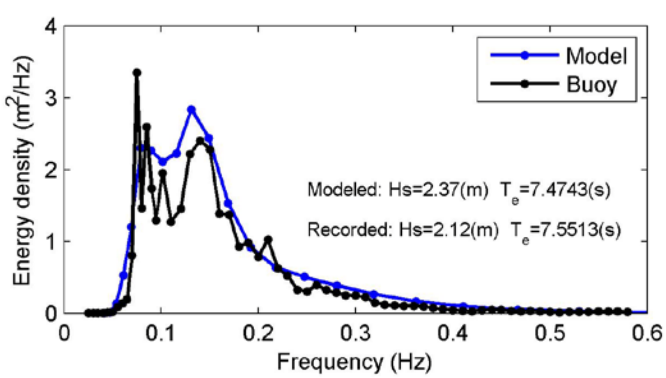

Figure 12.- 1D spectra estimated from Waverider records centered at 0100 January 4, 2013 and hindcast model.

Table 1.- Hindcast Model estimates T_e-Hs Occurrence Bins (hours): November 2012 – October 2013

		T_e (s)																		
		0.5	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**	**7.5**	**8.0.0**	**8.5**	**9.0**	**9.5**
Hs (m)	**0.5**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1.0	0	0	0	0	0	0	0	9	5	7	23	70	58	78	66	59	89	55	11
	1.5	0	0	0	0	0	0	0	3	10	56	392	422	412	287	171	247	156	86	73
	2.0	0	0	0	0	0	0	0	0	0	8	148	378	543	497	270	191	148	110	108
	2.5	0	0	0	0	0	0	0	0	0	0	0	19	92	93	236	156	106	66	49
	3.0	0	0	0	0	0	0	0	0	0	0	0	0	2	114	195	92	69	25	23
	3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	22	134	110	26	7	2
	4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	32	6	0	0
	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		T_e (s)																
		10.0	**10.5**	**11.0**	**11.5**	**12.0**	**12.5**	**13.0**	**13.5**	**14.0**	**14.5**	**15.0**	**15.5**	**16.0**	**16.5**	**17.0**	**>17.0**	
Hs (m)	**0.5**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1.0	14	23	9	0	0	0	0	0	0	0	0	0	0	0	0	0	576
	1.5	94	90	66	61	21	2	2	0	0	0	0	0	0	0	0	0	2651
	2.0	67	80	87	30	29	29	21	0	0	0	0	0	0	0	0	0	2744
	2.5	48	78	39	20	12	14	26	0	0	0	0	0	0	0	0	0	1054
	3.0	42	34	11	17	0	0	0	0	0	0	0	0	0	0	0	0	624
	3.5	3	1	11	7	4	0	0	0	0	0	0	0	0	0	0	0	327
	4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39
	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
																		8015

Table 2.- Hindcast Model estimates T_{02}-Hs Occurrence Bins (hours): November 2012 – October 2013

		T_{02} (s)																		
		0.5	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**9.0**	**9.5**
Hs (m)	**0.5**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1.0	0	0	0	0	0	15	80	94	69	81	58	42	47	38	23	18	11	0	0
	1.5	0	0	0	0	0	1	105	795	683	302	200	138	67	88	76	65	72	29	23
	2.0	0	0	0	0	0	0	0	128	915	736	295	134	183	99	77	45	26	53	30
	2.5	0	0	0	0	0	0	0	0	24	265	346	160	61	55	13	5	21	64	11
	3.0	0	0	0	0	0	0	0	0	0	32	357	122	48	29	10	7	8	7	4
	3.5	0	0	0	0	0	0	0	0	0	0	117	161	36	13	0	0	0	0	0
	4.0	0	0	0	0	0	0	0	0	0	0	0	36	3	0	0	0	0	0	0
	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		T_{02} (s)																
		10.0	**10.5**	**11.0**	**11.5**	**12.0**	**12.5**	**13.0**	**13.5**	**14.0**	**14.5**	**15.0**	**15.5**	**16.0**	**16.5**	**17.0**	**>17.0**	
Hs (m)	**0.5**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	576
	1.5	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2651
	2.0	4	6	13	0	0	0	0	0	0	0	0	0	0	0	0	0	2744
	2.5	7	5	17	0	0	0	0	0	0	0	0	0	0	0	0	0	1054
	3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	624
	3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	327
	4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39
	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
																		8015

Table 3.- Waverider Record estimates of T_e-Hs Occurrence Bins (hours): November 2012 – October 2013

		T_e (s)																		
		0.5	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**	**7.5**	**8.0.0**	**8.5**	**9.0**	**9.5**
Hs (m)	**0.5**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1.0	0	0	0	0	0	0	0	0	0	0	39.5	105	75.5	92.5	120	127.5	55	34.5	19
	1.5	0	0	0	0	0	0	0	0	0	1.5	117	653	611.5	323.5	237	345	171	122.5	83.5
	2.0	0	0	0	0	0	0	0	0	0	0	6	166	757.5	546.5	251	156	133	115.5	149.5
	2.5	0	0	0	0	0	0	0	0	0	0	0	1	51.5	190.5	298.5	215	118.5	72	52
	3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	152.5	179.5	63.5	25	23.5
	3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	18	61	42	8	2
	4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.5	11.5	7.5	0
	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	6.5	0
	5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		T_e (s)																
		10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	>17.0	
Hs (m)	**0.5**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1.0	22.5	16	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	708
	1.5	37.5	30.5	28.5	11.5	6	3	0	0	0	0	0	0	0	0	0	0	2782.5
	2.0	93	55	30	27	13	3	1.5	0	0	0	0	0	0	0	0	0	2503.5
	2.5	52	30	14	5	12.5	11	4	0	0	0	0	0	0	0	0	0	1127.5
	3.0	27.5	28.5	12.5	9.5	2	5	5	1.5	0	0	0	0	0	0	0	0	544.5
	3.5	6	11.5	6.5	8.5	5	0.5	0	0	0	0	0	0	0	0	0	0	169.5
	4.0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23
	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9.5
	5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
																	7868	

Table 4.- Waverider Record estimates of T_{02}-Hs Occurrence Bins (hours): November 2012 – October 2013

		T_{02} (s)																		
		0.5	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**	**7.5**	**8.0.0**	**8.5**	**9.0**	**9.5**
Hs (m)	**0.5**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1.0	0	0	0	0	0	0	0	15	133	162.5	110.5	89	107.5	67.5	15.5	5	2.5	0	0
	1.5	0	0	0	0	0	0	0	5.5	320	1095.5	483	282.5	242.5	177.5	86.5	42.5	35.5	11.5	0
	2.0	0	0	0	0	0	0	0	0	5	432.5	1152	349.5	160.5	162.5	103.5	67.5	32	17.5	16.5
	2.5	0	0	0	0	0	0	0	0	0	1	164	599.5	182.5	67	49	23	14	3	4
	3.0	0	0	0	0	0	0	0	0	0	0	1	161.5	237	52.5	32.5	19	18.5	10.5	2
	3.5	0	0	0	0	0	0	0	0	0	0	0	1	78	51	9	6.5	11.5	9.5	2.5
	4.0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	15	7	0	0	0.5	0
	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0.5	0	0	0
	5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		T_{02} (s)																
		10.0	**10.5**	**11.0**	**11.5**	**12.0**	**12.5**	**13.0**	**13.5**	**14.0**	**14.5**	**15.0**	**15.5**	**16.0**	**16.5**	**17.0**	**>17.0**	
Hs (m)	**0.5**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	708
	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2782.5
	2.0	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2503.5
	2.5	16	3	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	1127.5
	3.0	2.5	2	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	544.5
	3.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	169.5
	4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23
	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9.5
	5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
																		7868