FTN Associates Ltd.
water resources / environmental consultants
7648 Picardy Ave, Suite 100 • Baton Rouge, LA 70808 • (225) 766-0586 • Fax (225) 766-0561

TECHNICAL MEMORANDUM

STATE OF LOUISIANA
RANJIT S. JADHAV
License No. 29984
PROFESSIONAL ENGINEER
IN
CIVIL ENGINEERING

DATE: May 22, 2018

TO: **Mr. Lee Forbes, PE, D.WRE**
SWCA Environmental Consultants

FROM: **Ranjit Jadhav, PhD, PE, D.WRE** RSJ
FTN Associates, Ltd.

SUBJECT: LA-0016 Non-Rock Alternatives to Shoreline Protection Demonstration Project, Iberia Parish, Louisiana
Wave Monitoring Data Processing and Calculation of Wave Transmission Coefficients.
FTN No. R11659-1144-001

1.0 INTRODUCTION

FTN Associates (FTN), through a subcontract with SWCA Environmental Consultants (SWCA), provided professional engineering services to the Coastal Protection and Restoration Authority (CPRA). The services pertain to wave monitoring data analysis for the LA-0016 Non-Rock Alternatives to Shoreline Protection Demonstration Project (the Project).

The overall goal of CPRA for this project is to identify and test non-rock alternative method(s) of shoreline protection that can be used in areas having one or more limiting factors which preclude the use of currently adopted standards. Four types of shoreline protection structures (Products) are already installed at four sites in the study area (Figure 1). They are as follows:

- Site 1: Wave Attenuation Devices by Living Shoreline Solutions, Inc.;
- Site 2: Wave Screen System by Royal Engineers & Consultants, Inc.;
- Site 3: EcoSystems Units by Walter Marine; and
- Site 4: Buoyancy Compensated Erosion Control Modular System by Jansen, Inc.

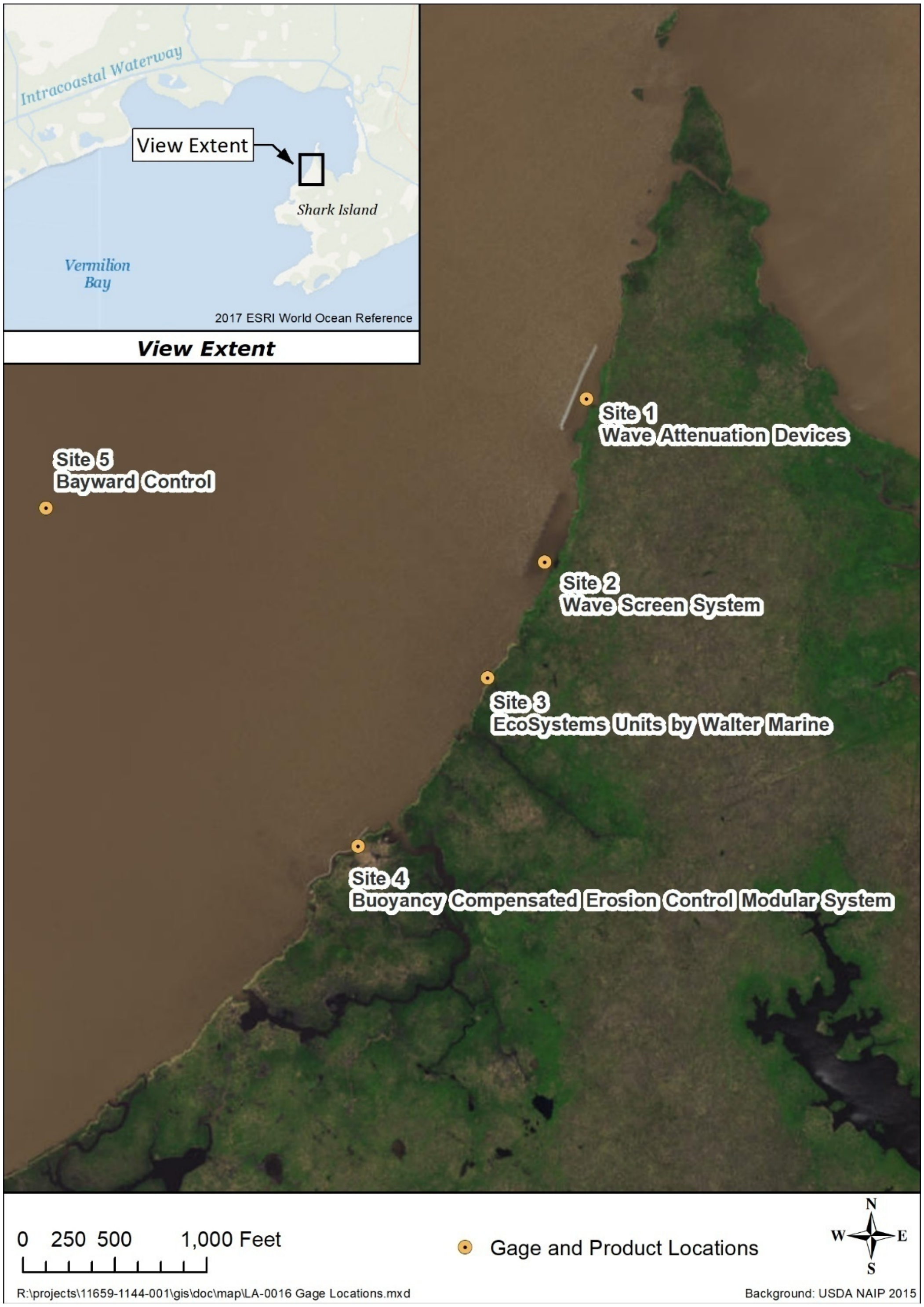


Figure 1. LA-0016 shoreline protection products and wave monitoring locations.

The objective of the task order is to quantify wave attenuation at each of the four product installments. In a parallel effort, CPRA, with the help of the NRCS, also measured shoreline change and topographic/ bathymetric elevation at the site. The following are the crest elevations for the four products:

- 5.0 ft, NAVD88 for Wave Attenuation Devices (Site 1);
- 2.1 ft, NAVD88 for Wave Screen System (Site 2);
- 3.0 ft, NAVD88 for EcoSystems Units (Site 3); and
- 3.5 ft, NAVD88 for Buoyancy Compensated Erosion Control Modular System (Site 4).

2.0 OBJECTIVE

The objective of the study is to measure Significant Wave Height (H_s), Peak Wave Period (T_p), and Water Surface Elevation (NAVD88) on the protected (leeward) and unprotected (bayward) side of the four shoreline protection products and determine the Wave Transmission Coefficients (K) for each product.

3.0 STUDY AREA

The Project is located in Iberia Parish, Louisiana, along the northeastern shoreline of Vermilion Bay. Four non-rock structures (Products) are installed to protect the marsh shoreline that is generally oriented north-south along Shark Island (Figure 1). From north to south, these structures are called: (1) Wave Attenuation Devices (WADs), (2) Wave Screen Systems, (3) EcoSystems Units, and (4) Buoyancy Compensated Erosion Control Modular Systems. Each structure is about 500 ft in length and the distance between them is about 300 ft except between Product 3 and 4 where it is about 700 ft.

The Project is located in the northeast region of Vermilion Bay where the shoreline is exposed to the incident waves coming from the southwest and northwest quadrants. The maximum wind fetch length (the length of the open water over which the wind blows) in the west to east direction is approximately 8 mi. The general water depth in the upper bay is approximately 6 to 10 ft.

4.0 DATA AND METHODS

The general approach was to measure hourly waves on the bayward and leeward side of the structures over a period of about 6 months, select weather events that produced generally shore-normal waves, and calculate the wave attenuation coefficients.

4.1 Wave Gage Deployment

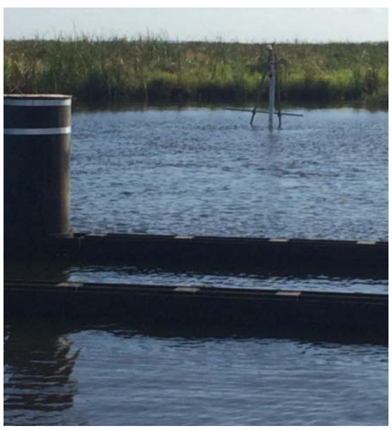
At the beginning of the study, FTN reconnoitered the site by a boat with CPRA, NRCS, SWCA, and ENCOS, Inc. on September 20, 2016. During the visit, water depths in the vicinity were assessed using a measuring staff and locations for the wave gages were identified.

Due to the shallow depths and low-energy wave environment behind the structures, wave staff gages (as opposed to the wave pressure gages) were recommended. Pressure gages provide less accurate wave measurements in shallow low-energy wave conditions. The wave heights measured by the pressure gages and wave staffs are equivalent. They differ only in the way the recorded raw data is processed to arrive at the wave height magnitudes. The staff gages are referred to as Sites 1 through 4 corresponding to Products 1 through 4, respectively. A wave pressure gage was installed at Site 5 which sampled at a 10 Hz frequency. Additionally, a gage to measure water level and barometric pressure was also installed at Site 5. Figure 2 shows the photographs of the gage installations. The details can be found in the installation report prepared by ENCOS (ENCOS 2017). Table 1 summarizes details of the wave gage deployment.

Table 1. Wavegage, data type, and sampling parameters.

Site	Gage	Location	Measured Parameter	Sampling Frequency and Interval	Parameter Obtained After FTN analysis
1	Wave staff	Leeward of Wave Attenuation Devices	Water level	15 min burst at 10 Hz every hour	Hourly H_s and T_p
2	Wave staff	Leeward of Wave Screen System	Water level	15 min burst at 10 Hz every hour	Hourly H_s and T_p
3	Wave staff	Leeward of EcoSystems Units	Water level	15 min burst at 10 Hz every hour	Hourly H_s and T_p
4	Wave staff	Leeward of Buoyancy Compensated Erosion Control Modular System	Water level	15 min burst at 10 Hz every hour	Hourly H_s and T_p
5	Wave pressure sensor	Bayward of structures	Water pressure	15 min burst at 10 Hz every hour	Hourly Significant Wave Height and Peak Wave Period
5	Atmospheric pressure sensor	Bayward of structures	Atmospheric pressure	2 min, continuously	No further processing
5	Vented Water Level Sensor	Bayward of structures	Water Level	15 min, continuously	Convert Water Depths to NAVD88

Site 1. Wave attenuation devices.



Site 2. Wave screen system.

Site 3. EcoSystems units.

Site 4. Buoyancy compensated erosion control modular system.

Site 5. Bayward control.

Figure 2. LA-0016 Photographs of gages installations (Source: ENCOS, 2017).

4.2 Wave Gage Data Quality and Analysis Methods

4.2.1 Data Quality

At all five sites, the wave data were recorded from November 3, 2016, through May 16, 2017. However, there were periods of missing or invalid (negative water levels) data for Sites 1 through 4. Data for all 4 gages was missing during the period from January 3, 2017, through January 17, 2017, because a gage deployment error caused the data to be overwritten. Site 2 recorded invalid data from January 31, 2017, until the end of the data collection period, May 16, 2017. This is likely due to the sediment building up at this gage. The following table shows the time intervals when data was missing or bad data was recorded due to instrument malfunction.

Table 2.Data non-availability periods.

Site	Missing Data Period	Bad Data Period
1	January 3, 2017 - January 17, 2017	N/A
2	January 3, 2017 - January 17, 2017	January 31, 2017 - End of period
3	January 3, 2017 - January 17, 2017	N/A
4	January 3, 2017 - January 17, 2017	N/A
5	N/A	N/A

4.2.2 Sites 1-4: Wave Staff Gages Data Processing

The raw data collected from the staff gages (Sites 1-4) were processed using a series of codes written in MATLAB (vR2016b). For the staff gages the process involved the following steps:

1. Read the raw data signal from the .csv files generated from the wave staff data logger.
2. Convert the raw data signal to depth values (h) using the calibration relation (provided in Ocean Sensor Systems Wave Logger Manual) below:

   Depth = RawData*StaffLength/4096

   Where StaffLength=2 m, length of the wave staff.
3. Use the zero-down crossing method (Sorensen, 2006) to calculate wave statistics, i.e., significant wave height (H_s) and peak period (T_p) from the depth (h) data. The Matlab code zero_crossing.m of Professor Urs Neumier, PhD. (http://neumeier.perso.ch/matlab/waves.html) was used for the zero crossing step.
4. Calculate mean hourly depth (h_{mean}) for each burst by averaging over the 15 min available data window for each hour.

4.2.3 Site 5: Wave Pressure Gage Data Processing

The raw data collected from the pressure gage (Site 5) was also processed using a series of codes written in MATLAB (vR2016b). For the pressure gage the process involved the following steps:

1. Read raw pressure data (recorded in bars) from the .csv files generated from the pressure gage data logger.
2. The presence of waves at the free surface affects the pressure (p) at the instrument sensor located under water (at depth z) according to the following relation (Sorensen, 2006):

$$p=\rho gz+\frac{\rho gH}{2}[\frac{\cosh(k(h-z))}{\cosh(kh)}]\cos(kx-\omega t)$$

where

p=pressure at the sensor (Pa),

ρ=1012 kg/m^3 density of water,

g=9.81m/s^2 acceleration due to gravity,

z=distance of sensor from mean water level (m),

h=mean water depth calculated from the hourly averaged mean water level (m),

H=wave height (m),

k=2π/L=wavenumber (m^{-1}) evaluated from the wavelength, L (m) using the following wave dispersion relationship: $L=L_0\tanh(kh)$

Where, $L_0 = gT^2/(2\pi)$ is the deepwater wavelength whereT=wave time period (s).

Note that the dispersion relation is an implicit equation and requires an iterative solution method.

Thus, the raw pressure readings (p) from step 1 have to be corrected for wave attenuation of pressure variation. This is typically done by first converting the raw pressure data to (uncorrected) depth (of the instrument sensor, h_{uncorr}) using the following equation:

$$h_{uncorr}=p/\rho g$$

3. Convert the uncorrected depth values (h_{uncorr}) to power spectrum $S_{h,uncorr}$ using a Fast Fourier Transform method.
4. Use the wave attenuation factor $K_p=\frac{\cosh(k(h-z))}{\cosh(kh)}$ to convert the uncorrected depth spectrum to the corrected depth spectrum:

$$S_{h,corr}= S_{h,}uncorr/K_p$$

5. Reconvert the corrected depth spectrum ($S_{h,corr}$) to the corrected depth values (h_{corr}) by an Inverse Fast Fourier Transform.
6. Compute wave characteristics, significant wave height (H_s), peak period (T_p) and 15-min averaged hourly mean corrected depth from the corrected depth values using the zero-crossing method.

Steps 2 to 5 were executed using the Matlab code pr_corr.m by Professor Urs Neumier, PhD. (http://neumeier.perso.ch/matlab/waves.html).

4.2.4 Wave Transmission Coefficients

When waves impinge on a structure, they are partly reflected, dissipated and transmitted through the structure. The wave transmission depends on the geometry of the structure. If the crest of the structure is submerged, the incident wave will simply propagate over the structure. On the other hand, if the crest is above the water level, the wave may generate flow over the structure which will regenerate waves in the protected area. Additionally, if the structure is sufficiently permeable, wave energy may transmit through the structure. The degree of wave transmission is defined by a wave transmission coefficient (K) as defined below.

$$K=H_t/H_i$$

Where H_t is the transmitted significant wave height on the protected (leeward) side, and
H_i is the incident significant wave height on the unprotected (bayward) side of the structure.

The lower the coefficient K, the more effective is the shoreline protection structure. Figure 3 defines the commonly used parameters to relate the wave transmission coefficient to the shoreline protection structure geometry and incident wave characteristics. These definitions allow a convenient way of relating K to the structure crest elevation and incident wave height. The figure shows the structure as a trapezoidal structure but it can be of any shape similar to any one of the four structures considered.

To determine wave transmission coefficients correctly, only those incident waves that are generally normal (perpendicular) to the protection structures are required. Such wave events were identified by using wind directions recorded at the USGS Gage at Vermilion Bay near Cypremort Point, LA (USGS Gage No. 07387040). The waves were considered shore-normal when the wave or wind came out of the southwest and the northwest quadrants (i.e., wind angles of 270°±90° or from 180° to 360°). Such a relaxed definition of shore-normal conditions was adopted so that a sufficient number of wave records would be available for analysis from a variety of directions.

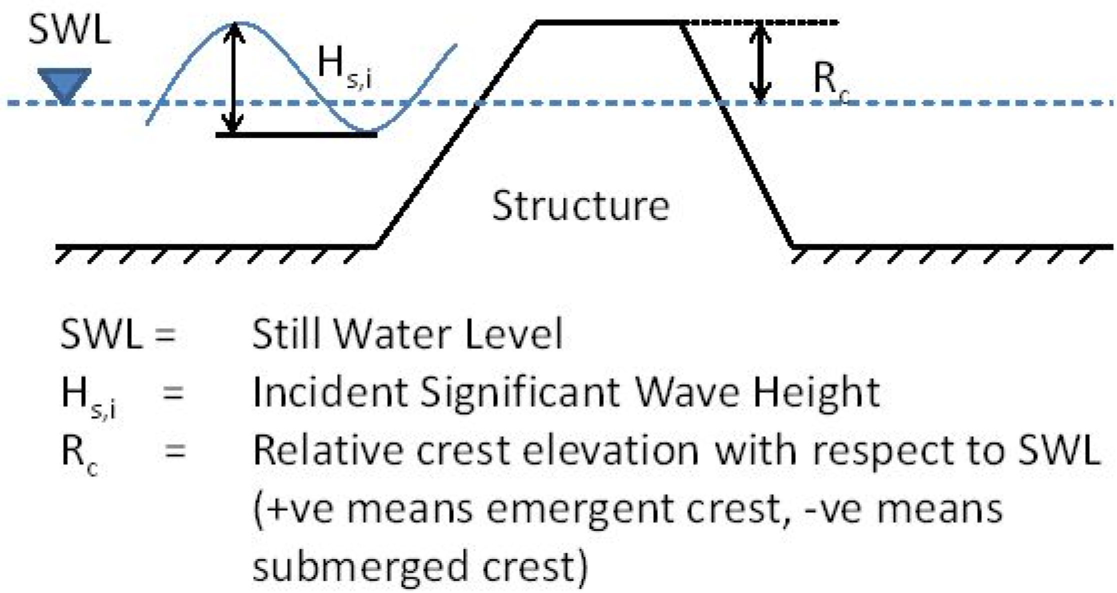


Figure 3. Definition of shoreline protection structure parameters.

R_c is defined as the relative crest elevation of the structure with respect to the Still Water Level (SWL) and $H_{s,i}$ the incident significant wave height bayward of the structure.

5.0 RESULTS AND DISCUSSION

The overall statistics of observed significant wave heights and peak periods are summarized in Table 3. All recorded data from gages behind structures (Sites 1-4) are considered. For Site 5 only the waves which have significant height greater than 0.1 ft are considered as wave measurements smaller than this are less reliable. Additionally, at Site 5 only, waves with peak period greater than 5.0 s are ignored as they represent swells of very low energy. Swells are long waves that enter coastal basins from remote offshore areas as opposed to the wind waves that are generated within the basin. An analysis of swell energy revealed that waves with peak period (T_p) greater than 5.0 s had an average significant wave height (H_s) of 0.0325 ft (0.4 in) at Site 5 and less than 0.004 ft (0.05 in) at Sites 1-4. Swells with such a small wave height are not expected to contribute to shoreline erosion and are ignored in the analysis. It has been shown that even in open, unsheltered bays, most wave-induced erosion is caused by locally generated wind waves (Karimpour et al, 2013).

Table 3. Statistics of observed significant wave height and peak period.

Wave Gage	Parameter	Number of Observations	Minimum	Mean	Median	Maximum
Site 1	H_s (ft)≥ 0.001 ft	4294	0.001	0.07	0.06	0.61
	T_p (s)≤ 5.0 s	4294	0.61	1.27	1.31	5.00
Site 2	H_s (ft)≥ 0.001 ft	2263	0.001	0.04	0.02	0.62
	T_p (s)≤ 5.0 s	2263	0.60	1.29	1.27	5.00
Site 3	H_s (ft)≥ 0.001 ft	4507	0.001	0.06	0.04	0.77
	T_p (s)≤ 5.0 s	4507	0.72	1.38	1.29	5.00
Site 4	H_s (ft)≥ 0.001 ft	4297	0.001	0.04	0.02	0.47
	T_p (s)≤ 5.0 s	4297	0.86	2.07	1.48	5.00
Site 5	H_s (ft)≥ 0.1 ft	1457	0.10	0.29	0.23	3.63
	T_p (s)≤ 5.0 s	1457	1.77	2.60	2.28	5.00

The time series charts of observed wind speed, wind direction, water level, and wave heights, wave period and transmission coefficients for the months of November 2016 through May 2017 are shown in Attachment A. The purpose of these figures is to provide an overall synoptic picture of the collected data on consistent scales. The observations with a significant wave height less than 0.1 ft at Site 5 (bayward) are eliminated from all analysis as measurements of waves smaller than this threshold are considered unreliable. Additionally, records that resulted in K greater than 1 are also eliminated from the tables and figures. These, approximately 4% of the total records, correspond to waves that are less than 0.5 ft in height. Half of these records are found at Site 1 likely due to the fact that this site has no other product on its north/west side and is therefore exposed to waves that circumvent the structure adding to the transmitted waves.

Results for individual products are presented in the following sub-sections. The statistics of the attenuated wave height and transmission coefficient are summarized by wave height and water level of the incoming wave (Site 5, Bayward Control) in a table followed by two plots. The first is a scatter plot of incoming wave heights (as recorded at control Site 5) versus the attenuated wave heights behind the structure. The second plot shows variation of wave transmission coefficient with the non-dimensional relative crest height ratio of $R_c/H_{s,i}$, where R_c and $H_{s,i}$ are as defined in Figure 3. Note that a negative $R_c/H_{s,i}$ ratio indicates a submerged crest while a positive value indicates an emergent structure. In the wave transmission plots, panel (a) on the left shows waves of at least 0.1 ft height at Site 5, the bayward control. To reduce the scatter in the data, Panel (b) on the right shows waves with height 0.5 ft or greater at Site 5. Wave transmission decreases with increasing ratio $R_c/H_{s,i}$. In all plots, the scatter near the smaller wave heights is seen to be generally larger. This can be explained as follows. The wave energy on the protected side is a result of the transmitted wave energy and the local wind wave energy albeit from small local ripples behind the structure. For small wave heights, the contribution from local ripples forms a larger proportion of the total wave height making it more evident for smaller incident waves compared to the larger waves. On the other hand, at larger wave heights, one is essentially looking at transmitted waves as the contribution of local ripples is relatively small. The result is a reduced data scatter and a noticeable trend. The gray line on the scatter plot represents a line of slope 1:1 indicating no energy reduction in the transmitted waves. The closer the points are to this line, the smaller the wave energy reduction. The dashed line is a linear regression fit to the observed data. The flatter the line, the lower is the wave transmission coefficient indicating higher effectiveness of the structure in attenuation of incident waves.

(Remainder of Page Intentionally Left Blank)

5.1 Site 1: Wave Attenuation Devices Results

The attenuated wave height (H_s) and transmission coefficient (K) statistic for the Wave Attenuation Devices is summarized in Table 4. N is the number of observations and SD is the standard deviation. The scatter plot of incoming wave heights (as recorded at Site 5) versus the attenuated wave heights is shown Figure 4. Figure 5 shows the variation of wave transmission coefficient with the non-dimensional relative crest height ratio of $R_c/H_{s,i}$. Overall the structure shows effectiveness in reducing wave heights. Based on the K values in Table 4, it appears that the structure was more effective in reducing wave energy during the times of lower water surface elevations than during the higher water surface elevations.

Table 4. Site 1 Wave Attenuation Devices: Mean attenuated H_s and K with SD categorized by the range of water surface elevation and control wave height.

Water Surface Elevation, h (ft, NAVD88)	Statistic at Site 1	H_s (ft) Site 5 (Bayward control)			
		0.1 - 0.5	0.5 - 1.0	1.0 - 1.5	1.5 - 2.0
-2.5 to -0.5	N	168	31	0	0
	H_s (ft) Mean±SD	0.09±0.05	0.14±0.06	N/A	N/A
	K Mean±SD	0.33±0.18	0.23±0.09	N/A	N/A
-0.5 to 0.0	N	109	14	0	0
	H_s (ft) Mean±SD	0.1±0.03	0.18±0.03	N/A	N/A
	K Mean±SD	0.51±0.19	0.31±0.05	N/A	N/A
0.0 to 0.5	N	137	7	4	0
	H_s (ft) Mean±SD	0.12±0.04	0.21±0.04	0.13±0.15	N/A
	K Mean±SD	0.61±0.19	0.3±0.03	0.11±0.12	N/A
0.5 to 1.0	N	134	11	4	1
	H_s (ft) Mean±SD	0.12±0.05	0.21±0.05	0.12±0.02	0.1±0
	K Mean±SD	0.6±0.21	0.34±0.08	0.09±0.01	0.07±0
1.0 to 1.5	N	113	12	4	1
	H_s (ft) Mean±SD	0.13±0.05	0.26±0.08	0.16±0.09	0.15±0
	K Mean±SD	0.58±0.22	0.35±0.1	0.14±0.09	0.1±0
1.5 to 2.0	N	79	10	3	0
	H_s (ft) Mean±SD	0.12±0.06	0.27±0.09	0.3±0.07	N/A
	K Mean±SD	0.6±0.22	0.43±0.19	0.25±0.01	N/A
2.0 to 4.5	N	73	13	3	0
	H_s (ft) Mean±SD	0.16±0.08	0.3±0.1	0.47±0.12	N/A
	K Mean±SD	0.67±0.19	0.45±0.13	0.45±0.1	N/A

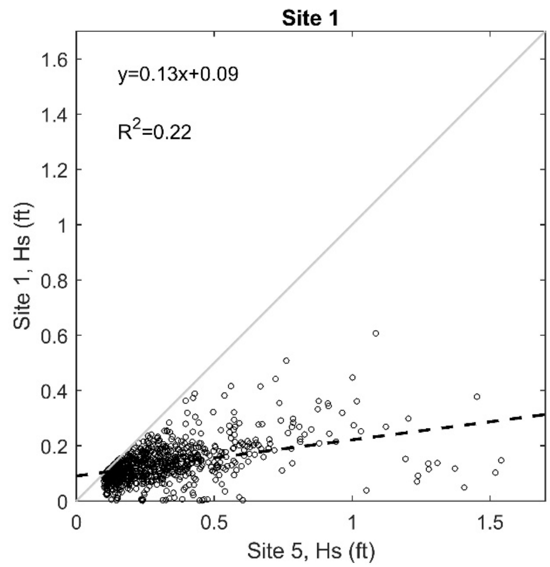


Figure 4. Scatter plot of significant wave heightsat Site 5, Bayward Control, ($H_s \geq 0.1$ ft) versus those behind Site 1, Wave Attenuation Devices.

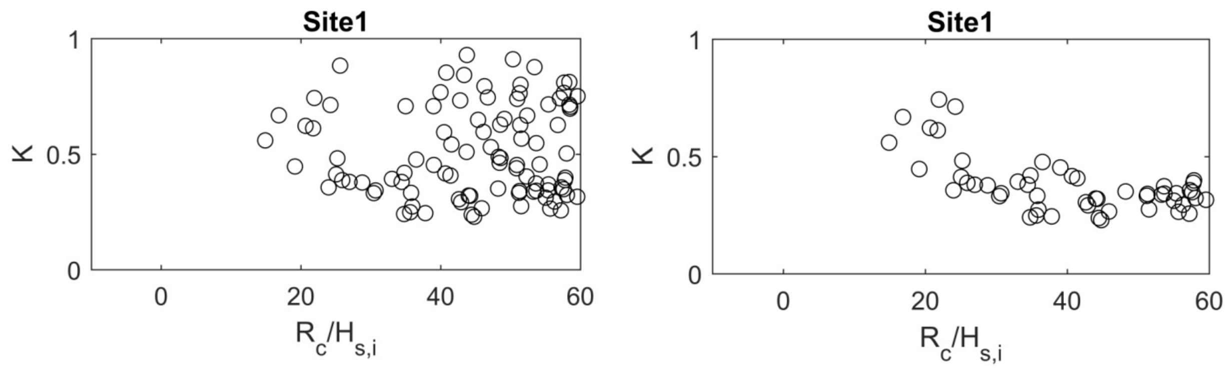


Figure 5. Wave transmission coefficient (K) at Site 1, Wave Attenuation Devices when Site 5 significant wave heightis (a) $H_s \geq 0.1$ ft and (b) $H_s \geq 0.5$ ft.

5.2 Site 2: Wave Screen System Results

The attenuated wave height (H_s) and transmission coefficient (K) statistic for the Wave Screen System is summarized in Table 5. N is the number of observations and SD is the standard deviation. The scatter plot of incoming wave heights (as recorded at Site 5) versus the attenuated wave heights is shown Figure 6. Figure 7 shows variation of wave transmission coefficient with the non-dimensional relative crest height ratio of $R_c/H_{s,i}$. A negative $R_c/H_{s,i}$ ratio indicates a submerged crest while a positive value indicates an emergent structure. Overall the structure shows effectiveness in reducing wave heights. Based on the K values in Table 5, for low incident waves, the structure appears to be slightly more effective for water levels in the range from 1.5 to 2.0 ft, NAVD88 which happens to be the approximate extent of the physical wave screen.This site showed sediment accumulation in the lee of the structure, the mechanism of which cannot be explained by the wave height alone and may need additional investigation using sediment transport and velocity measurements coupled with numerical modeling. The accumulation resulted in reduced water depth which limited wave heights in the lee.

Table 5. Site 2 Wave Screen System: Mean attenuated H_s and K with SD categorized by the range of water surface elevation and control wave height.

Water Surface Elevation (ft, NAVD88)	Statistic at Site 2	H_s (ft) Site 5 (Bayward control)			
		0.1 - 0.5	0.5 - 1.0	1.0 - 1.5	1.5 - 2.0
-2.5 to -0.5	N	147	30	0	0
	H_s (ft) Mean±SD	0.01±0.02	0.01±0.03	N/A	N/A
	K Mean±SD	0.04±0.05	0.02±0.04	N/A	N/A
-0.5 to 0.0	N	83	13	0	0
	H_s (ft) Mean±SD	0.03±0.02	0.06±0.03	N/A	N/A
	K Mean±SD	0.14±0.12	0.09±0.05	N/A	N/A
0.0 to 0.5	N	120	5	4	0
	H_s (ft) Mean±SD	0.07±0.03	0.1±0.05	0.11±0.1	N/A
	K Mean±SD	0.42±0.2	0.13±0.07	0.09±0.09	N/A
0.5 to 1.0	N	114	8	4	1
	H_s (ft) Mean±SD	0.06±0.04	0.17±0.07	0.06±0.01	0.11±0
	K Mean±SD	0.4±0.25	0.28±0.11	0.04±0.01	0.07±0
1.0 to 1.5	N	103	6	3	1
	H_s (ft) Mean±SD	0.06±0.05	0.21±0.13	0.09±0.02	0.11±0
	K Mean±SD	0.32±0.23	0.29±0.12	0.08±0.02	0.07±0
1.5 to 2.0	N	64	5	2	0
	H_s (ft) Mean±SD	0.06±0.06	0.25±0.19	0.34±0.2	N/A
	K Mean±SD	0.29±0.24	0.3±0.18	0.29±0.21	N/A
2.0 to 4.5	N	45	10	3	0
	H_s (ft) Mean±SD	0.17±0.1	0.41±0.2	0.56±0.09	N/A
	K Mean±SD	0.56±0.25	0.54±0.23	0.56±0.09	N/A

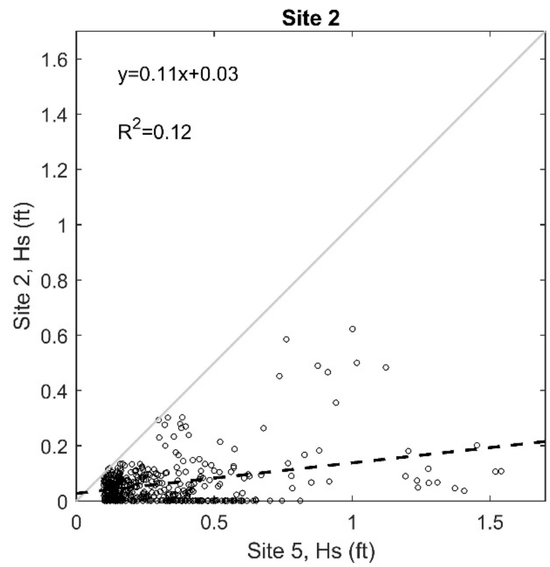


Figure 6. Scatter plot of significant wave heights at Site 5, Bayward Control ($H_s \geq 0.1$ ft) versus those behind Site 2, Wave Screen System.

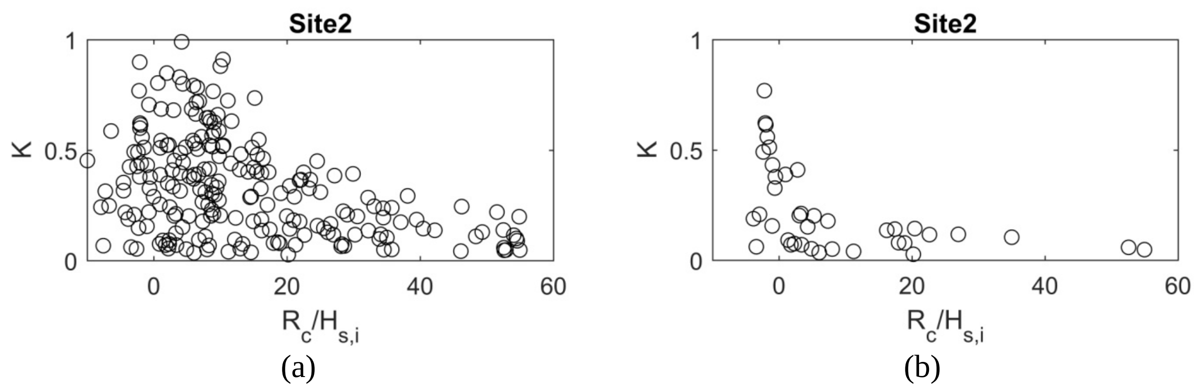


Figure 7. Wave transmission coefficient (K) at Site 2, Wave Screen System when Site 5 significant wave height is (a) $H_s \geq 0.1$ ft and (b) $H_s \geq 0.5$ ft.

5.3 Site 3: EcoSystems Units Results

The attenuated wave height (H_s) and transmission coefficient (K) statistic for the EcoSystems Units is summarized in Table 6. N is the number of observations and SD is the standard deviation. The scatter plot of incoming wave heights (as recorded at Site 5) versus the attenuated wave heights is shown Figure 8. Figure 9 shows variation of wave transmission coefficient with the non-dimensional relative crest height ratio of $R_c/H_{s,i}$. Overall the structure shows effectiveness in reducing wave heights though it is less effective compared to other structures. For smaller waves, the effectiveness in reducing wave energy is relatively uniform across the range of water level.

Table 6. Site 3 EcoSystems Units: Mean attenuated H_s and K with SD categorized by the range of water surface elevation and control wave height.

Water Surface Elevation (ft, NAVD88)	Statistic at Site 3	H_s (ft) Site 5 (Bayward control)			
		0.1 - 0.5	0.5 - 1.0	1.0 - 1.5	1.5 - 2.0
-2.5 to -0.5	N	168	31	0	0
	H_s (ft) Mean±SD	0.11±0.04	0.17±0.03	N/A	N/A
	K Mean±SD	0.41±0.18	0.28±0.05	N/A	N/A
-0.5 to 0.0	N	106	14	0	0
	H_s (ft) Mean±SD	0.11±0.04	0.17±0.04	N/A	N/A
	K Mean±SD	0.5±0.15	0.29±0.07	N/A	N/A
0.0 to 0.5	N	139	7	4	0
	H_s (ft) Mean±SD	0.12±0.04	0.23±0.05	0.4±0.1	N/A
	K Mean±SD	0.57±0.17	0.33±0.07	0.33±0.1	N/A
0.5 to 1.0	N	148	11	4	1
	H_s (ft) Mean±SD	0.09±0.04	0.21±0.05	0.48±0.1	0.49±0
	K Mean±SD	0.46±0.18	0.33±0.07	0.37±0.08	0.32±0
1.0 to 1.5	N	142	12	4	1
	H_s (ft) Mean±SD	0.1±0.04	0.31±0.16	0.35±0.21	0.63±0
	K Mean±SD	0.48±0.2	0.42±0.23	0.3±0.16	0.41±0
1.5 to 2.0	N	87	10	3	0
	H_s (ft) Mean±SD	0.09±0.06	0.26±0.12	0.39±0.13	N/A
	K Mean±SD	0.48±0.23	0.4±0.21	0.32±0.04	N/A
2.0 to 4.5	N	74	12	3	0
	H_s (ft) Mean±SD	0.14±0.07	0.36±0.13	0.49±0.13	N/A
	K Mean±SD	0.6±0.2	0.52±0.15	0.48±0.14	N/A

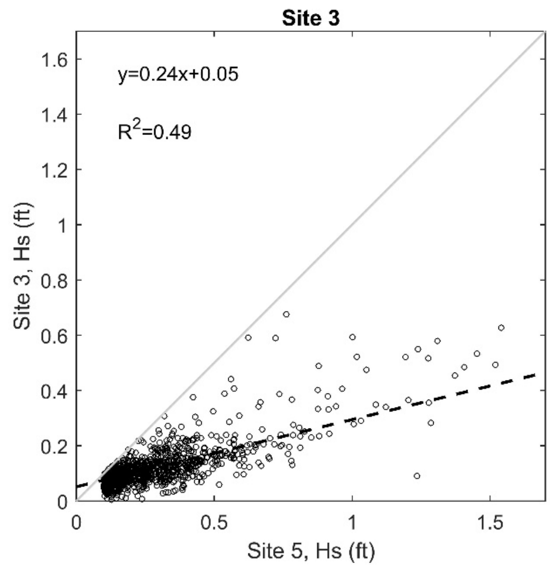


Figure 8. Scatter plot of significant wave heights at Site 5, Bayward Control ($H_s \geq 0.1$ ft) versus those behind Site 3, EcoSystems Units.

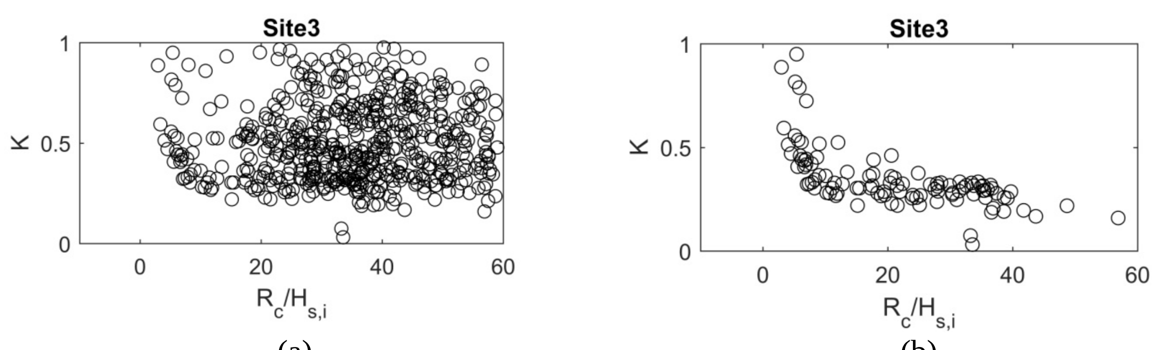


Figure 9. Wave transmission coefficient (K) at Site 3, EcoSystems Units when Site 5 significant wave height is (a) $H_s \geq 0.1$ ft and (b) $H_s \geq 0.5$ ft.

5.4 Site 4: Buoyancy Compensated Erosion Control Modular System Results

The attenuated wave height (H_s) and transmission coefficient (K) statistic for this shoreline protection structure is summarized in Table 7. N is the number of observations and SD is the standard deviation. The scatter plot of incoming wave heights (as recorded at Site 5) versus the attenuated wave heights is shown Figure 10. Figure 11 shows variation of wave transmission coefficient with the non-dimensional relative crest height ratio of $R_c/H_{s,i}$. Overall the structure shows effectiveness in reducing wave heights. Based on the K values, this structure appears to be the most effective of the four structures. The effectiveness of reducing wave energy generally appears to be uniform over the range of the water levels encountered in the study.

Table 7. Site 4 Buoyancy Compensated Erosion Control: Mean attenuated H_s and K with SD categorized by the range of water surface elevation and control wave height.

Water Surface Elevation (ft, NAVD88)	**Statistic at Site 4**	**H_s (ft) Site 5 (Bayward control)**			
		0.1 - 0.5	**0.5 - 1.0**	**1.0 - 1.5**	**1.5 - 2.0**
-2.5 to -0.5	N	168	31	0	0
	H_s (ft) Mean±SD	0.08±0.03	0.12±0.02	N/A	N/A
	K Mean±SD	0.29±0.1	0.21±0.04	N/A	N/A
-0.5 to 0.0	N	111	14	0	0
	H_s (ft) Mean±SD	0.07±0.02	0.13±0.03	N/A	N/A
	K Mean±SD	0.37±0.15	0.21±0.03	N/A	N/A
0.0 to 0.5	N	144	7	4	0
	H_s (ft) Mean±SD	0.07±0.03	0.14±0.04	0.12±0.11	N/A
	K Mean±SD	0.4±0.22	0.2±0.07	0.1±0.09	N/A
0.5 to 1.0	N	149	11	4	1
	H_s (ft) Mean±SD	0.06±0.04	0.15±0.04	0.11±0.01	0.1±0
	K Mean±SD	0.34±0.24	0.24±0.07	0.08±0.01	0.07±0
1.0 to 1.5	N	141	12	4	1
	H_s (ft) Mean±SD	0.06±0.04	0.17±0.08	0.11±0.07	0.12±0
	K Mean±SD	0.3±0.24	0.22±0.11	0.1±0.08	0.08±0
1.5 to 2.0	N	92	10	3	0
	H_s (ft) Mean±SD	0.04±0.04	0.12±0.06	0.19±0.04	N/A
	K Mean±SD	0.24±0.2	0.18±0.12	0.15±0.01	N/A
2.0 to 4.5	N	92	13	3	0
	H_s (ft) Mean±SD	0.03±0.03	0.13±0.09	0.32±0.14	N/A
	K Mean±SD	0.18±0.14	0.18±0.1	0.31±0.12	N/A

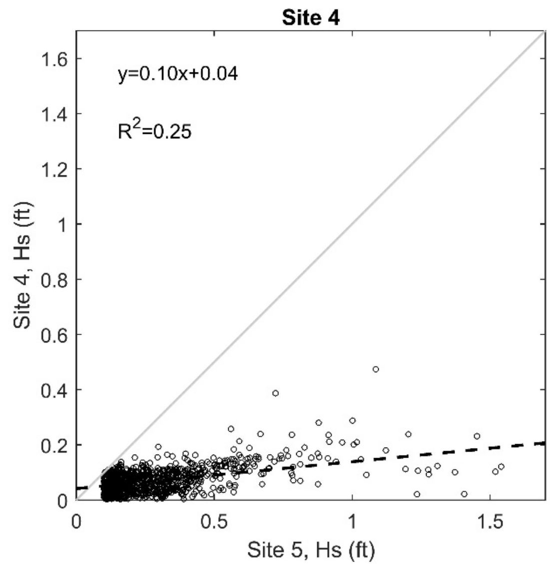
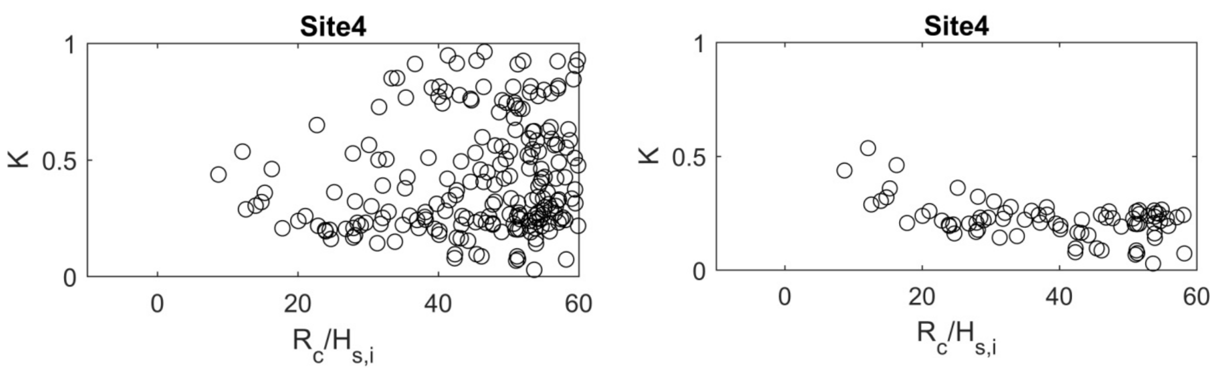


Figure 10. Scatter plot of significant wave heights at Site 5, Bayward Control, ($H_s \geq 0.1$ ft) versus those behind Site 4, Buoyancy Compensated Erosion Control Modular System.



(a) (b)

Figure 11. Wave transmission coefficient (K) at Site 4, Buoyancy Compensated Erosion Control Modular System when Site 5 significant wave height (a) $H_s \geq 0.1$ ft and (b) $H_s \geq 0.5$ ft.

6.0 CONCLUSION

Overall, Product 4 (Site 4), the Buoyancy Compensated Erosion Control Modular System, produced the lowest wave transmission coefficients. For lower water surface elevations, Product 2 (Site 2), the Wave Screen System, had the lowest transmission coefficients while Product 3 (Site 3), the EcoSystems Units, had the highest transmission coefficients among the four products. For the higher water surface elevations, Product 4, the Buoyancy Compensated Erosion Control Modular System, had the lowest wave transmission coefficients while Product 2, the Wave Screen System, had the highest transmission coefficients. This is because the Product 2 crest is the lowest among the four products making it more prone to wave overtopping. There was sediment accumulation in the lee side of Product 2, the mechanism of which cannot be explained by the wave height alone and may need additional investigation using sediment transport and velocity measurements coupled with numerical modeling.

7.0 REFERENCES

ENCOS (2017) Non-Rock Alternatives to Shoreline Protection Demonstration Project (LA-16), Field Installation Report, ENCOS, Baton Rouge, Louisiana. 2017.

Karimpour, K., Chen, Q., and Jadhav, R. (2013) Turbidity dynamics in upper Terrebonne Bay, Louisiana. Sediment Transport: Monitoring, Modeling and Management, Khan, A. and Wu, W. (ed.), Nova Science Publishers. ISBN-13: 9781626186835, 339-360.

NRCS (2016) Non-Rock Alternatives to Shoreline Protection Demonstration Project (LA-16), Information Packet, USDA Natural Resources Conservation Service, Lafayette, Louisiana. March 17, 2016.

Sorensen, R.M., (2006) Basic Coastal Engineering, 3rd Edition, Springer, USA.

USACE (2008), Coastal Engineering Manual (CEM), Engineer Manual 1110-2-1100, US Army Corps of Engineers, Washington, D.C.

Thank you very much for the opportunity to present this analysis. Please do not hesitate to call me at (225) 766-0586 or Marc Johnson, PE, CFM, at (501) 225-7779.

RSJ/tas

Attachment

T:\WP_FILES\11659-1144-001\CORRESPONDENCE\2018-05-22 TM-L FORBES\2018-05-22 TM-L FORBES.DOCX

ATTACHMENT

Time Series Charts of Observed Wind Speed, Wind Directions, Water Surface Elevations, Wave Heights, Peak Periods, and Calculated Wave Transmission Coefficients

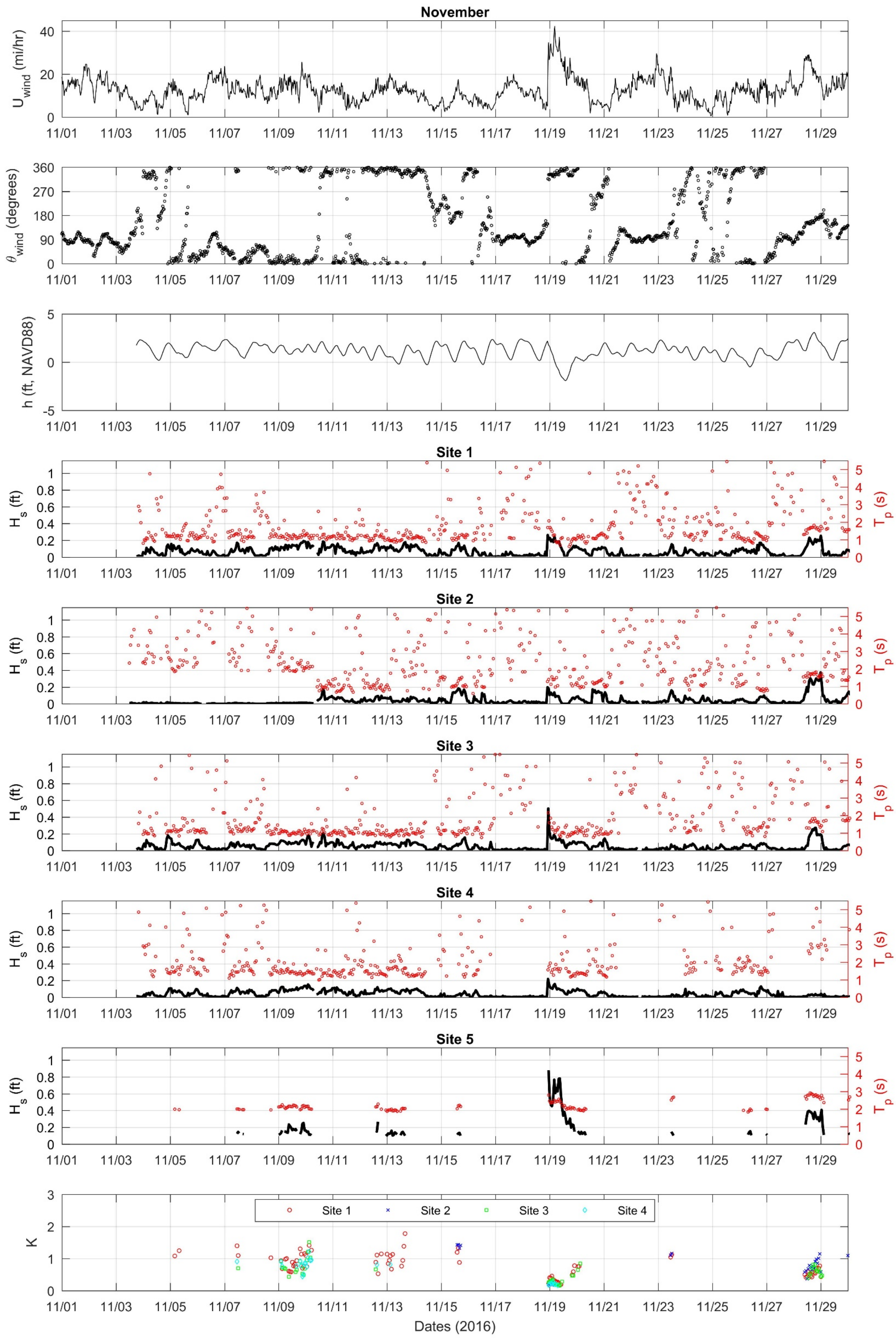


Figure A1. Significant Wave Height (Hs), Peak Wave Period (Tp), Water Surface Elevation (h), Wind Speed and Direction observed during November 2016. Bottom panel shows corresponding Wave Transmission Coefficient (K).

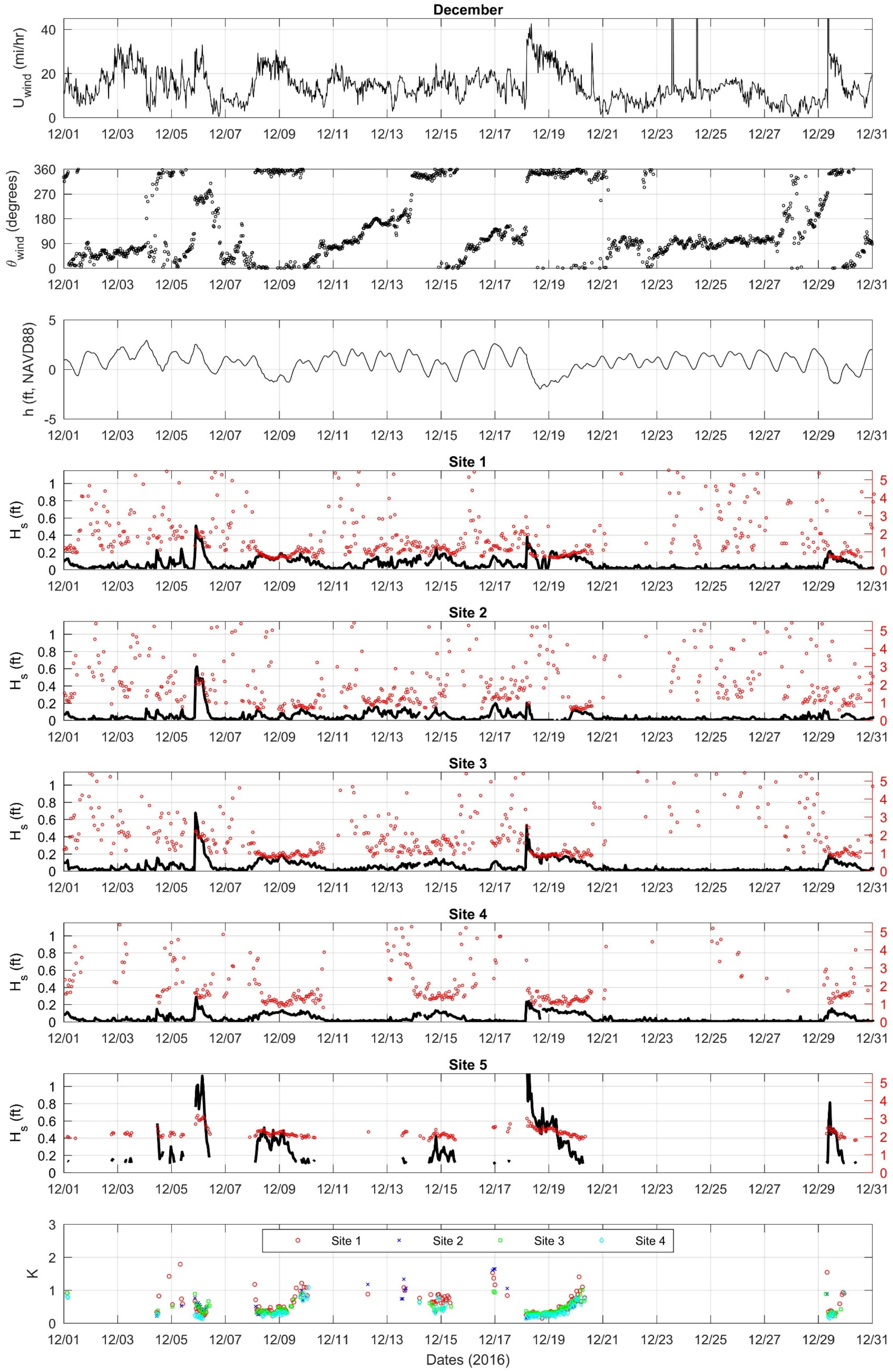


Figure A2. Significant Wave Height (Hs), Peak Wave Period (Tp), Water Surface Elevation (h), Wind Speed and Direction observed during December 2016. Bottom panel shows corresponding Wave Transmission Coefficient (K).

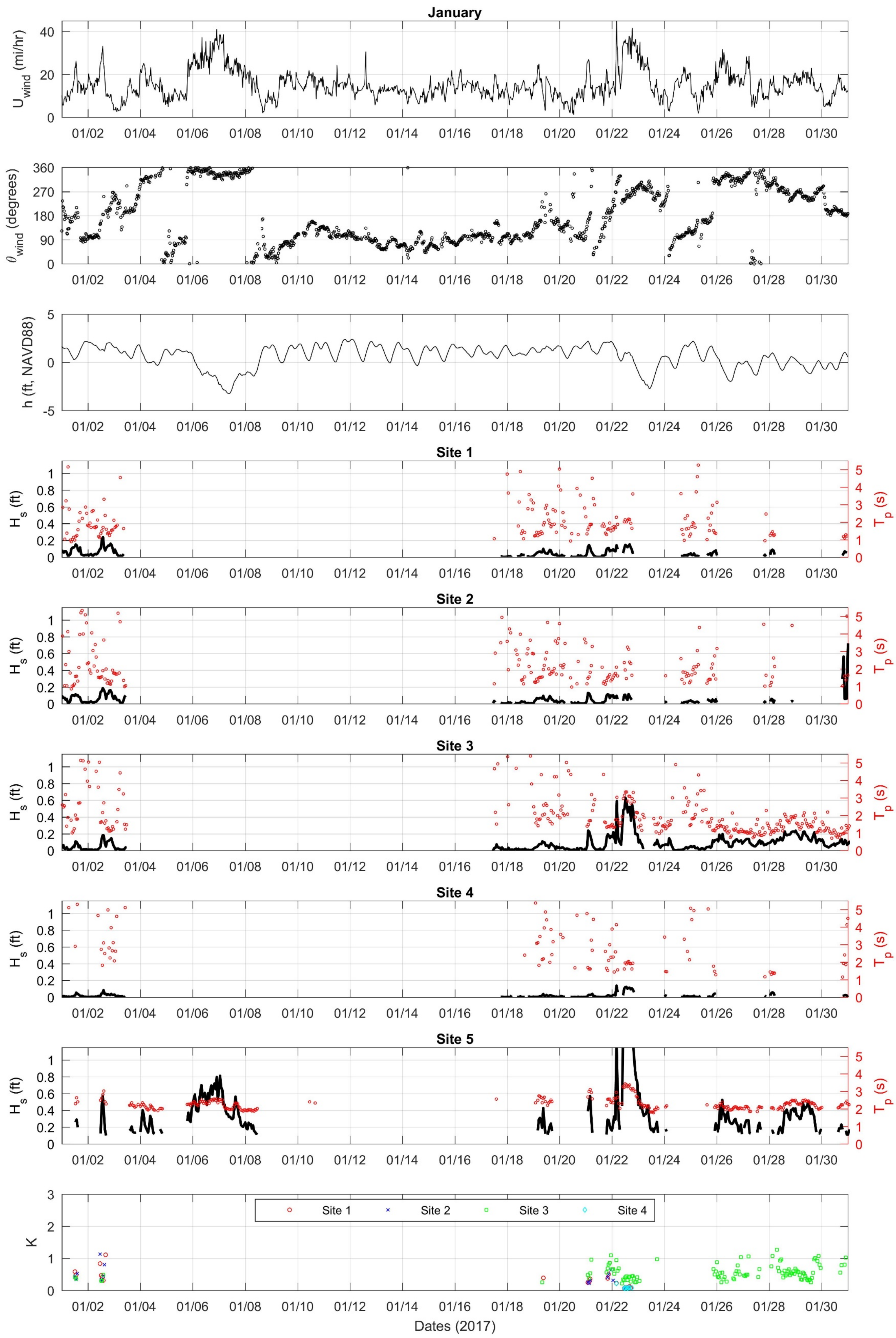


Figure A3. Significant Wave Height (Hs), Peak Wave Period (Tp), Water Surface Elevation (h), Wind Speed and Direction observed during January 2017. Bottom panel shows corresponding Wave Transmission Coefficient (K).

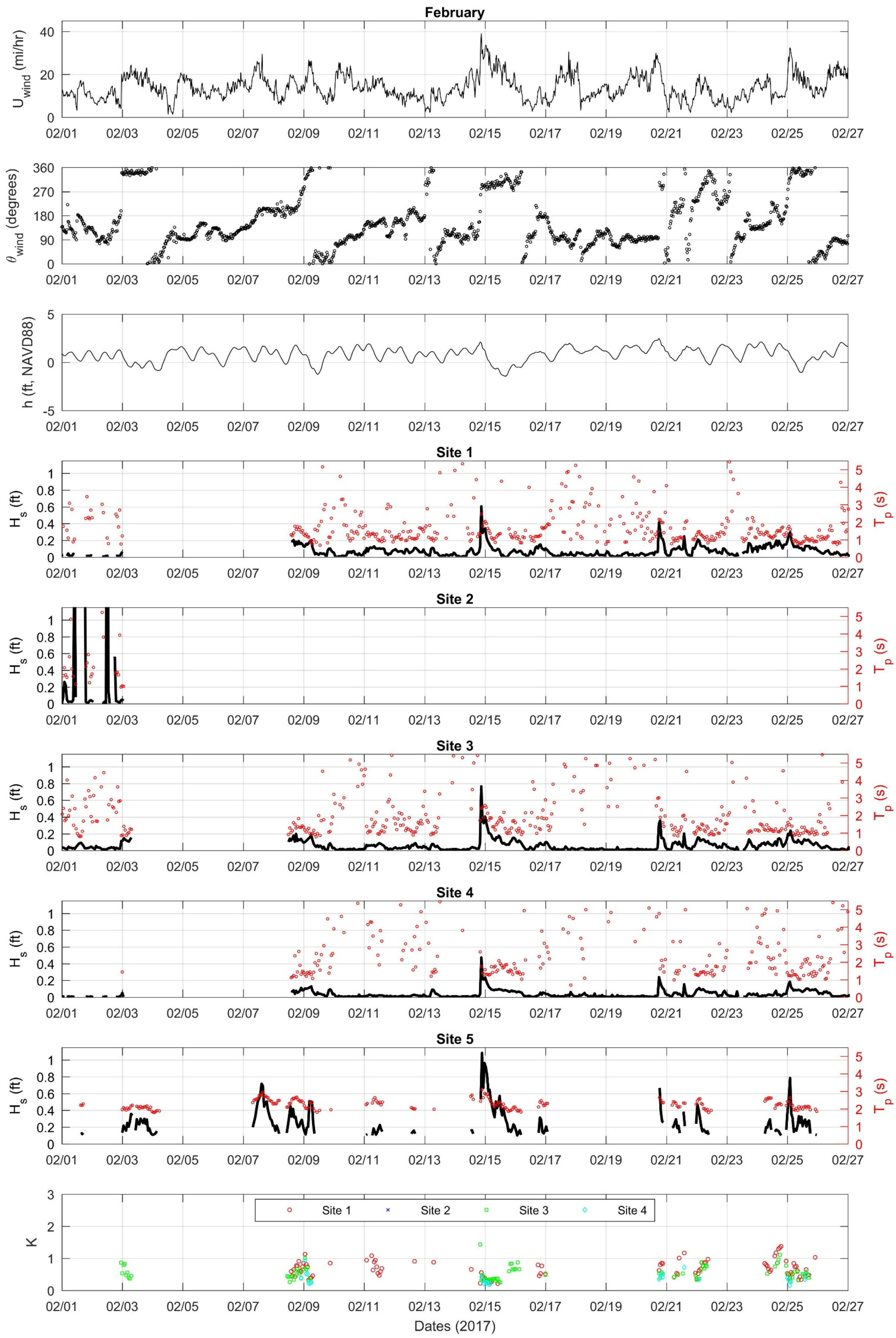


Figure A4. Significant Wave Height (Hs), Peak Wave Period (Tp), Water Surface Elevation (h), Wind Speed and Direction observed during February 2017. Bottom panel shows corresponding Wave Transmission Coefficient (K).

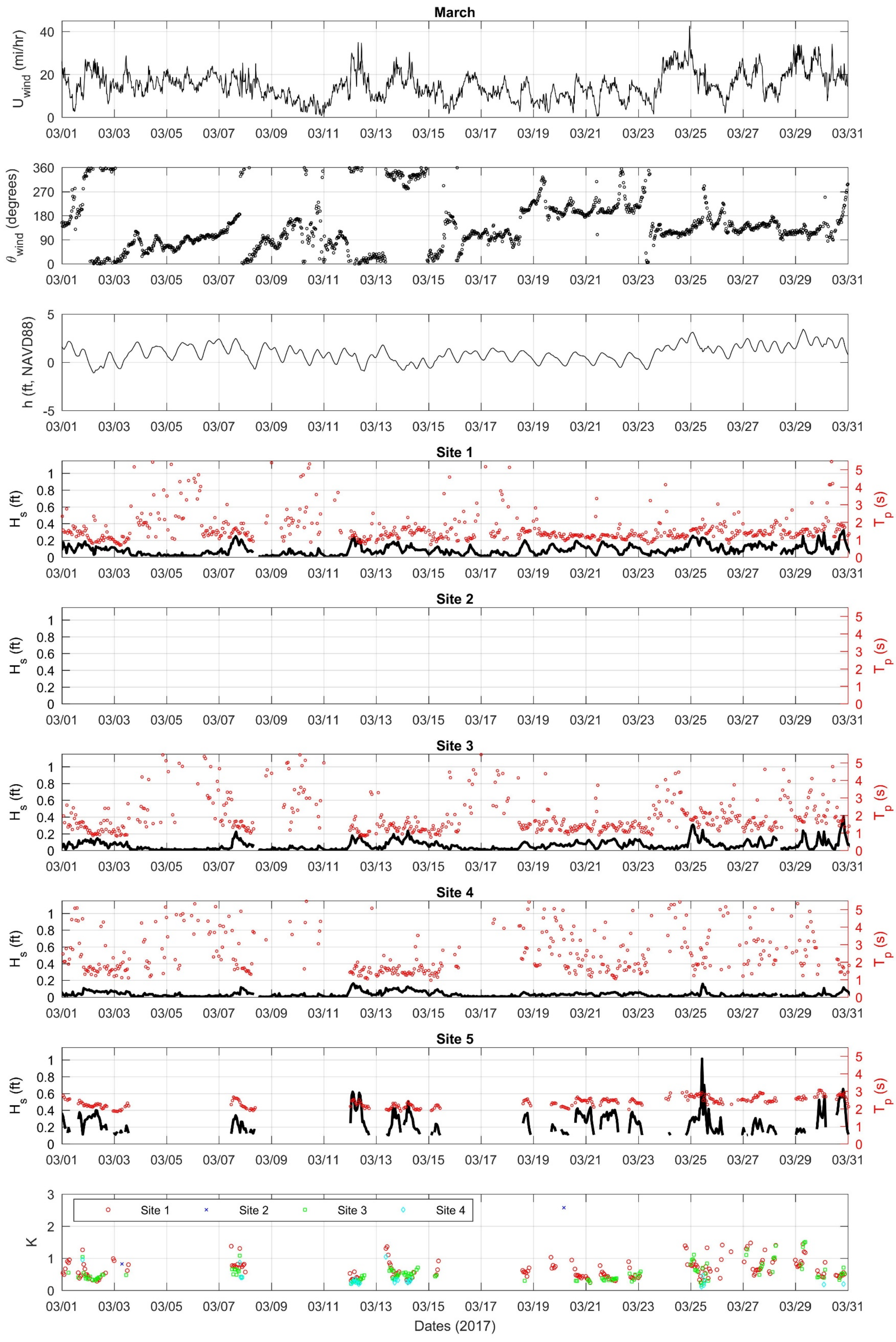


Figure A5. Significant Wave Height (Hs), Peak Wave Period (Tp), Water Surface Elevation (h), Wind Speed and Direction observed during March 2017. Bottom panel shows corresponding Wave Transmission Coefficient (K).

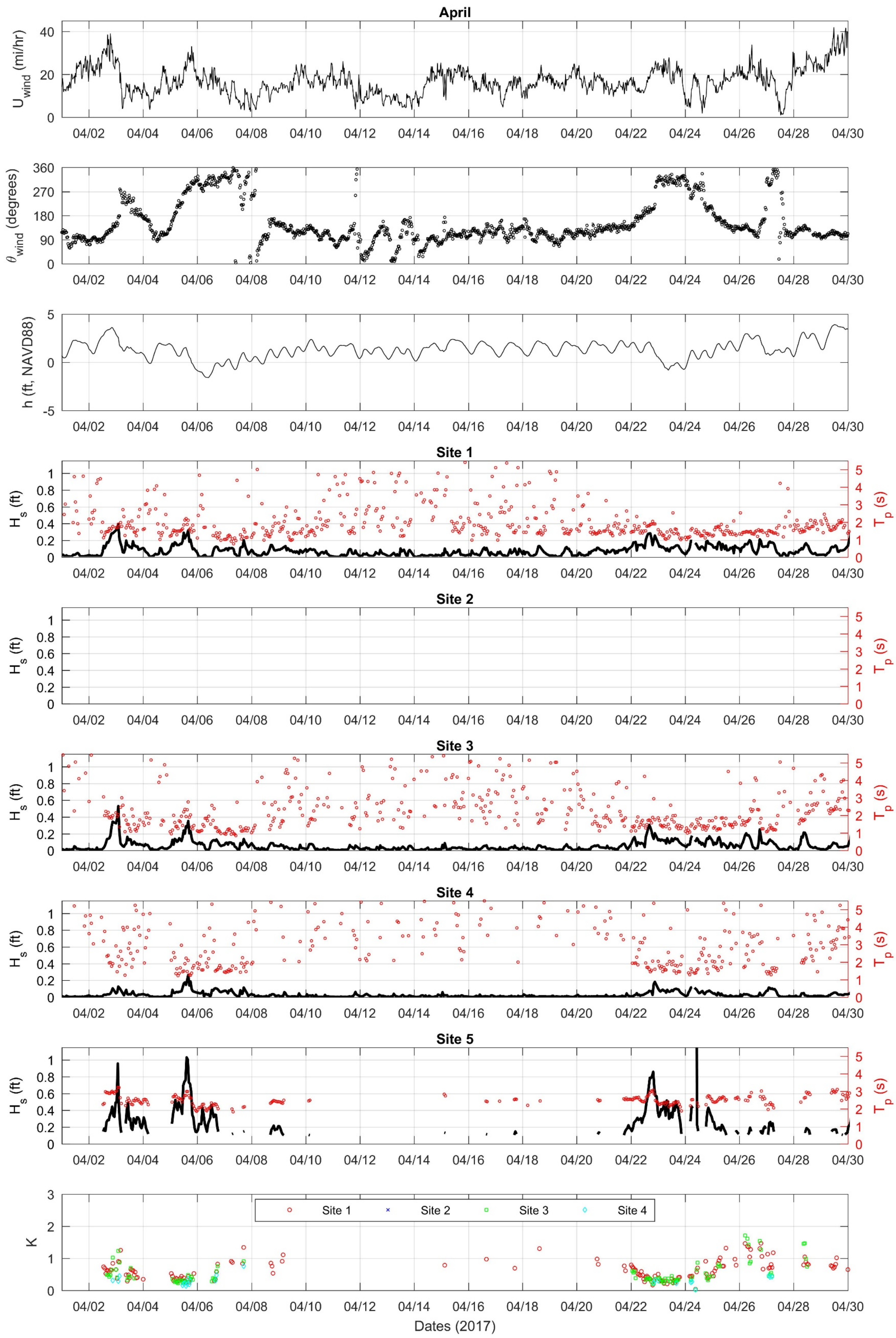


Figure A6. Significant Wave Height (Hs), Peak Wave Period (Tp), Water Surface Elevation (h), Wind Speed and Direction observed during April 2017. Bottom panel shows corresponding Wave Transmission Coefficient (K).

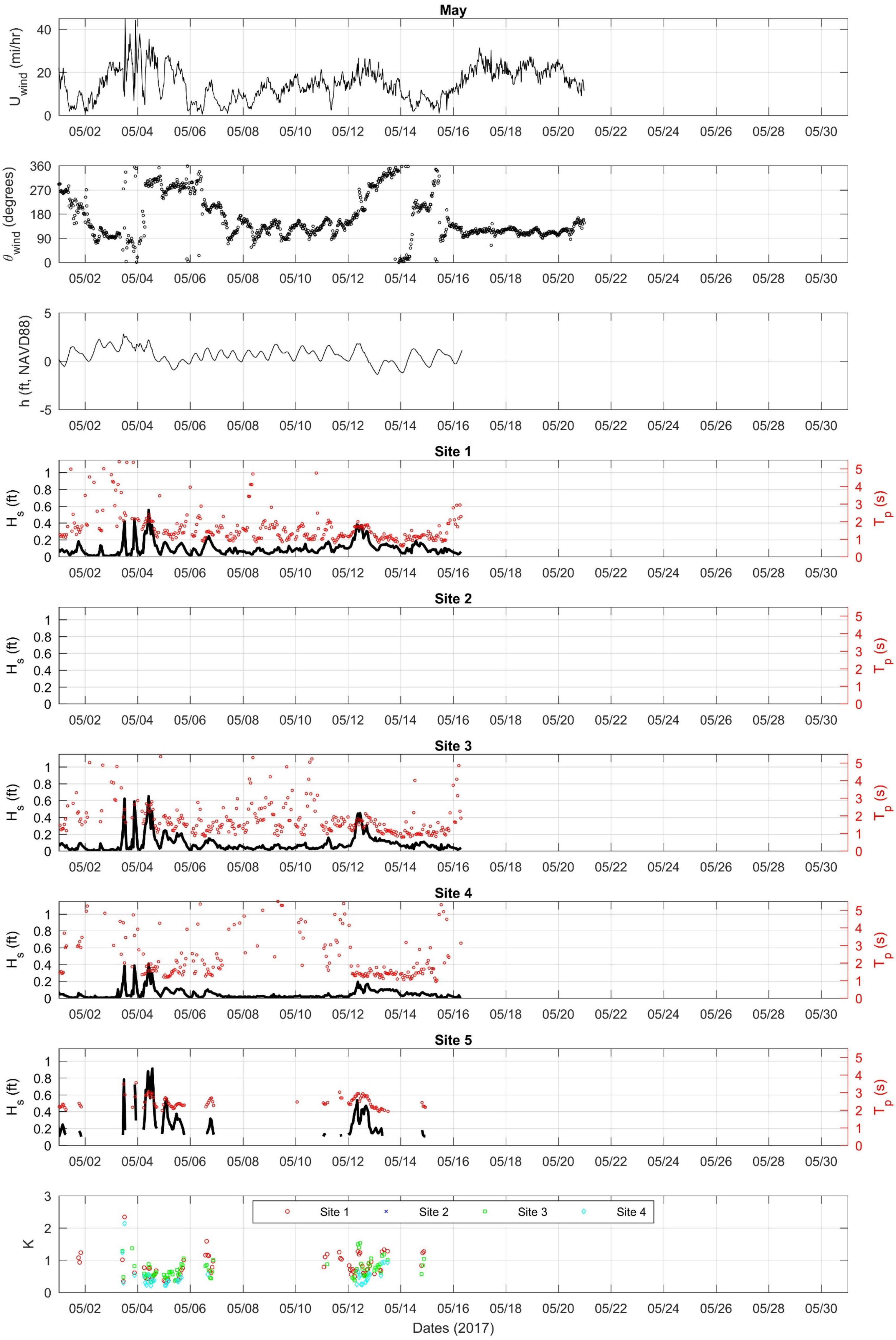


Figure A7. Significant Wave Height (Hs), Peak Wave Period (Tp), Water Surface Elevation (h), Wind Speed and Direction observed during May 2017. Bottom panel shows corresponding Wave Transmission Coefficient (K).