OCS Study
BOEM 2018-029

Field Observations During Wind Turbine Foundation Installation at the Block Island Wind Farm, Rhode Island

Appendix F: Turbine Scour Monitoring Report

US Department of the Interior
Bureau of Ocean Energy Management
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May 2018

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U.S. Department of the Interior
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Scour Monitoring at the Block Island Wind Farm, Rhode Island

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March 2018

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ABOUT THE COVER

Cover photo: BIWF scour monitors. Photo by HDR RODEO Team.

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List of Abbreviations and Acronyms

AWAC	Acoustic Wave and Current Profiler
CTD	Salinity, Temperature and Depth
MLW	Mean Low Water
UTC	Coordinated Universal Time
WGS84	World Geodetic System, 1984
WTG	Wind Turbine Generator

1 Introduction

As part of the assessment of the Block Island Wind Farm Installation, Fugro was contracted by HDR Environmental, Operations and Construction Inc. (HDR) to study scour around a turbine. The survey involved the installation of two scour monitors on opposite legs of Platform 3 (WTG3) (**Figure 1** and **Tables 1** to **5**). The scour monitors measure changes in seabed elevation around the base of the jacket legs.

An acoustic wave and current (AWAC) profiler was also deployed in a seabed frame approximately 500 m southeast of the turbine (**Figure 1** and **Tables 1 to 5**). The wave, water level and current data collected by the AWAC have been used to inform an assessment of the factors affecting seabed level changes as measured by the scour monitors.

AWAC and scour monitor configurations are presented in **Tables 6** and **7**, respectively. Both units were originally intended to be installed for a period of at least nine months, with maintenance scheduled at approximately three-month intervals. The contract was then extended for a further three months.

1.1 Deployment Position and Dates

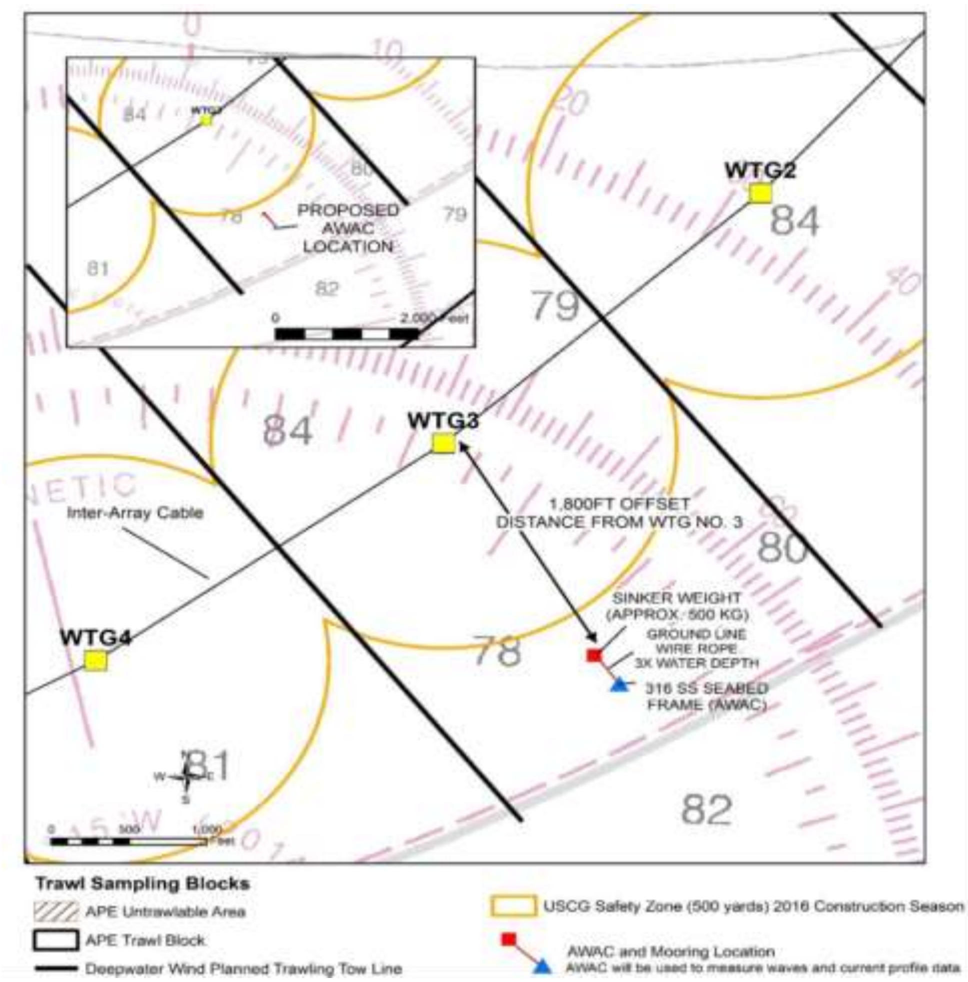

Figure 1. Location of Deployed Equipment

Table 1. Equipment Positions – Deployment

Location Name	Latitude (WGS84)	Longitude (WGS84)	UTM Coordinates (NAD83 Zone 19 N)	Deployment Date
Seabed Frame	41° 06' 34.5" N	071° 31' 00.5" W	288674.5 m E, 4553973.8 m N	15 June 2016
Anchor Weight	41° 06 '36.2" N	071° 31' 01.1" W	288662.0 m E, 4554026.6 m N	15 June 2016
Scour Monitors (WTG3)	41° 06' 54.0" N	071° 31' 15.6" W	288339.6 m E, 4554585.4 m N	28 July 2016

Table 2. Equipment Positions – Service 1

Location Name	Latitude (WGS84)	Longitude (WGS84)	UTM Coordinates (NAD83 Zone 19 N)	Deployment Date
Seabed Frame	41° 06' 34.1" N	071° 30' 59.2" W	288703.2 m E, 4553962.3 m N	10 November 2016
Anchor Weight	41° 06' 35.9" N	071° 31' 00.7" W	288670.4 m E, 4554016.9 m N	10 November 2016
Scour Monitors (WTG3)	41° 06' 54.0" N	071° 31' 15.6" W	288339.6 m E, 4554585.4 m N	08 November 2016

Table 3. Equipment Positions – Service 2

Location Name	Latitude (WGS84)	Longitude (WGS84)	UTM Coordinates (NAD83 Zone 19 N)	Deployment Date
Seabed Frame	41° 06' 35.9" N	071° 31' 00.7" W	288671.0 m E, 4554018.1 m N	06 March 2017
Anchor Weight	41° 06' 34.1" N	071° 31' 00.7" W	288669.4 m E, 4553962.6 m N	06 March 2017
Scour Monitors (WTG3)	41° 06' 54.0" N	071° 31' 15.6" W	288339.6 m E, 4554585.4 m N	21 March 2017

Table 4. Equipment Positions – Service 3

Location Name	Latitude (WGS84)	Longitude (WGS84)	UTM Coordinates (NAD83 Zone 19 N)	Deployment Date
Seabed Frame	41° 06' 34.1" N	071° 30' 59.3" W	288703.2 m E, 4553962.3 m N	15 June 2017
Anchor Weight	41° 06' 36.2" N	071° 31' 00.8" W	288668.1 m E, 4554028.6 m N	15 June 2017
Scour Monitors (WTG3)	41° 06' 54.0" N	071° 31' 15.6" W	288339.6 m E, 4554585.4 m N	14 June 2017

Table 5. Equipment Positions – Recovery

Location Name	Latitude (WGS84)	Longitude (WGS84)	UTM Coordinates (NAD83 Zone 19 N)	Recovery Date
Seabed Frame	41° 06' 34.6" N	071° 30' 59.6" W	288695.5 m E, 4553976.3 m N	21 October 2017
Anchor Weight	41° 06' 36.6" N	071° 31' 01.0" W	288664.7 m E, 4554038.9 m N	21 October 2017
Scour Monitors (WTG3)	41° 06' 54.0" N	071° 31' 15.6" W	288339.6 m E, 4554585.4 m N	17 October 2017

1.2 Project Aims and Results

The key aims of the project can be summarized as follows:

- To generate a 12-month data set of seabed elevation and oceanographic data;
- To test the concept of monitoring scour with fixed acoustic instrumentation;
- To inform on the possible use of the systems in future developments.

The general outcomes of the study were as follows:

- The scour monitoring equipment was installed on WTG3 for a period in excess of 14 months and provided a near continuous data set for the duration of the deployment;
- A seabed mounted wave, current, temperature and water level monitoring station returned a data set of over 16 months covering the entire period of observations by the scour monitors;
- The scour monitors returned the following data:
  - Continuous acoustic return data along four beams per instrument;
  - Seabed elevations at distance up to 10 m from foundation;
  - Changes in the seabed elevation were seen to occur at a variety of periodicities:
    - Less than one day, consistent with the periodicity of the local tidal forcing;
    - Over the course of a week to a month, appearing to coincide with perturbations to the tidal current flow resulting from increased wave energy;
    - A seasonal signal consistent with increased wave activity in the winter months, and calmer conditions in the summer months.
  - The orientation of the acoustic beams allowed observation of the variation in seabed level with distance from the foundation, and response of the seabed to physical ocean oceanographic forcing.
- Issues encountered with the scour data:
  - Orientation of the scour monitor on the southeast leg meant the data were collected closer to the foundation than planned;
  - Corruption of one scour monitor beam on the southeast leg occurred during the final three months, probably due interference from the structure.
- Lessons learnt:
  - Early interaction with construction team is vital to allow bracketing to be mounted and orientated correctly;
  - At sites with a strong seasonal thermocline it is essential for long term variation in the seabed levels to be calculated using a speed of sound derived from a model of (or average of) the conditions between the scour monitor and the seabed. In this case the presence of a strong summer thermocline caused errors in the initial range calculations. Vertical CTD profiles taken in the summer months showed that the thermocline depth was approximately midway between the scour monitor and the seabed. Thus, the average speed of sound between the scour monitor and the seabed AWAC was calculated and used to correct the acoustic ranges.
- Future opportunities:
  - The scour monitors provide a long-term time series of seabed elevations at specific points close to the foundation (in this case up to 10 m) that can be used to enhance the understanding of the variation in seabed levels;
  - The scour monitors allow measurement of the seabed response in conditions where bathymetric surveys are not feasible;
  - For future sites the scour monitors could be used at a limited selection of foundations in order to support the assumptions about seabed mobility made during design, or if scour occurs under specific circumstances then appropriate preventative intervention can be designed and actioned to maximize the life of the structures.

2 AWAC Configuration Information

Table 6. AWAC Summary Information

Block Island AWAC		
Serial numbers	AWAC:	WAV 6058 / WPR 1457 WAV 6133 / WPR 1444
	LRT:	216060-002
	SMB:	EMU 1188
	Lantern:	EMU 1361
	Buoy tracker:	744906 958629
AWAC configuration	Instrument frequency:	600 kHz
	Current profile interval:	600 s
	Cells:	38
	Cell size:	1 m
	Waves samples:	1024 at 1 Hz
	Wave sample interval:	3600 s
	Currents averaging period:	60 s
	Blanking distance:	1 m
	Coordinate system:	Beam
	Power level:	High
	Assumed duration:	90 days
	Estimated depth:	38 m
	Battery:	Estimated utilization 78 %
	Memory required:	58.1 MB of > 300 MB
Mooring	The seabed frame was attached to a 75 m 12.7 mm greased galvanized steel ground line using two 4 tonne rated stainless steel shackles and a 2 tonne rated stainless steel shackle. The ground line was attached to a 500 kg scrap chain anchor using 3.25 tonne Crosby safety shackles. The anchor was connected to a 50 m 12.7 mm greased galvanized steel riser wire using a 3.25 tonne Crosby safety shackle. The riser was attached to a 2 m 16 mm galvanized steel chain with a 3.25 tonne Crosby safety shackle to the surface marker buoy.	
Surface marker buoy	Mobilis 1200 yellow buoy 1.2 m diameter and 1.5 m in height. Top mounted solar charging navigational light was configured with the following flash pattern: 5 (y) in 20 (s)	

Seabed frame and AWAC

Surface marker buoy

3 Scour Configuration Information

Table 7. Scour Monitor Summary

Block Island Scour Monitors	
Location	WTG3
Serial numbers	North East: AQD 12905; North East: AQD 13444 South East: AQD 12892; South East: AQD 13429
Scour monitor configuration	Instrument frequency: 1 MHz Cells: 96 Cell size: 0.35 M Blanking distance: 0.36 M Coordinate system: Beam Power level: Low Assumed duration: 90 days Depth of site (to MLW): 26.23 m Depth of instrument (to (MLW): 8.73 m
Installation details	Each instrument was secured into its housing by means of stainless steel jubilee clips. The housing comprises of a stainless-steel tube for protecting the instrument and an external locating plate designed to fit onto a mounting bracket. The mounting brackets are permanently installed on the turbine. During the installation the locating plate was attached to the mounting bracket and secured by divers. An anode was also attached to each housing prior to installation.

Scour monitor in bracketing

4 Data Collection

4.1 Data Return

Due to weather and other delays, an increased total quantity of data was collected by both the scour monitors and AWAC, as shown in **Table 8**. Data have been examined and only those records that pass all quality control tests are included in the data summary below.

Table 8. Data Return Summary

Deployment	Data Collected – AWAC	Data Collected – Scour Monitors
1	4 months and 24 days	3 months and 3 days
2	3 months and 26 days	4 months and 10 days
3	3 months and 9 days	3 months and 3 days
4	4 months and 6 days	4 months and 3 days
Overall	**16 months and 3 days**	**14 months and 19 days**

4.2 Oceanographic Data Summary

4.2.1 Water Levels

The Block Island tidal environment is dominated by the open ocean tidal signal, and is therefore characterized by a semidiurnal microtidal (less than 2 m range) signal. The mean spring range is 1.07 m and the mean high water to mean low water interval difference is 6.13 hours, thus the tide curve is near symmetrical. The autumn and winter months show multiple periods of non-tidal (residual) sea level variations. **Figure 2** presents an extract of the sea level observations and the calculated non-tidal values from a 60-point harmonic analysis of the 16 months of data. The residual values vary by up to ±0.5 m and are thus approximately the same range as the astronomically forced tide. The form of these appear to indicate two potential forcing processes:

- Short to medium term suppression or enhancement of the sea level resulting from atmospheric forcing, either variations in atmospheric pressure or wind enhancement;
- 24- to 48-hour oscillations in the residuals that are indicative of a coastally-trapped (or Kelvin) wave, however additional data and analysis would be needed to correctly define these.

4.2.2 Currents

The current data recorded at the study location were orientated along a northeast – southwest axis. The maximum expected depth average tidal current is predicted to be less than 0.4 m/s, based on the results of a 60-point harmonics analysis. The non-tidal component of the flow exceeds the tidal component. **Figure 3** presents the depth average observed current and the non-tidal component, which is of the same magnitude as the observations on multiple occasions. This indicates that atmospheric forcing of the current is dominant in the study area.

In order to understand the general flow pattern in the study area the data are presented as a progressive vector plot in **Figure 4**. The data are shown as total water movement past the measurement point, with a label added at 28-day intervals. The summer months show a progressive movement of the water mass to the southwest, which changes to a general motion to the east during the winter months.

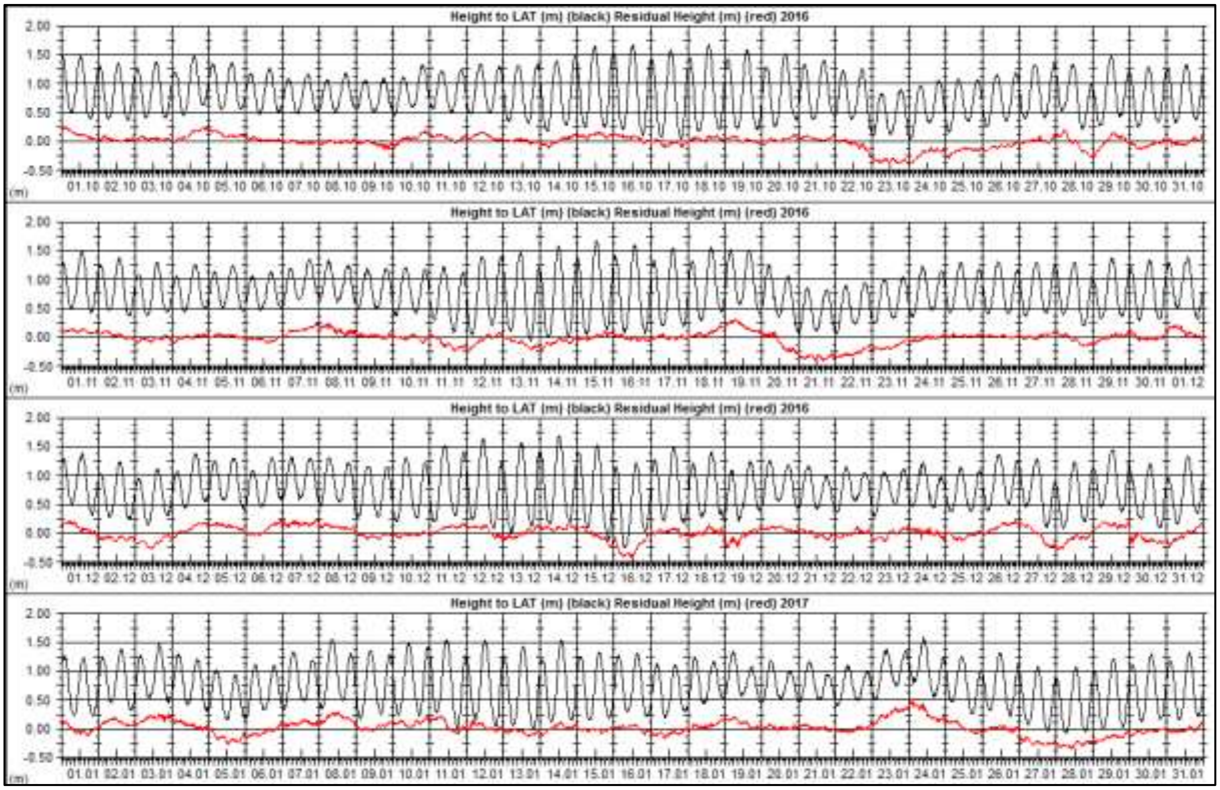

Figure 2. Winter Water Level Data - Height to Lowest Astronomic Tide and Residuals

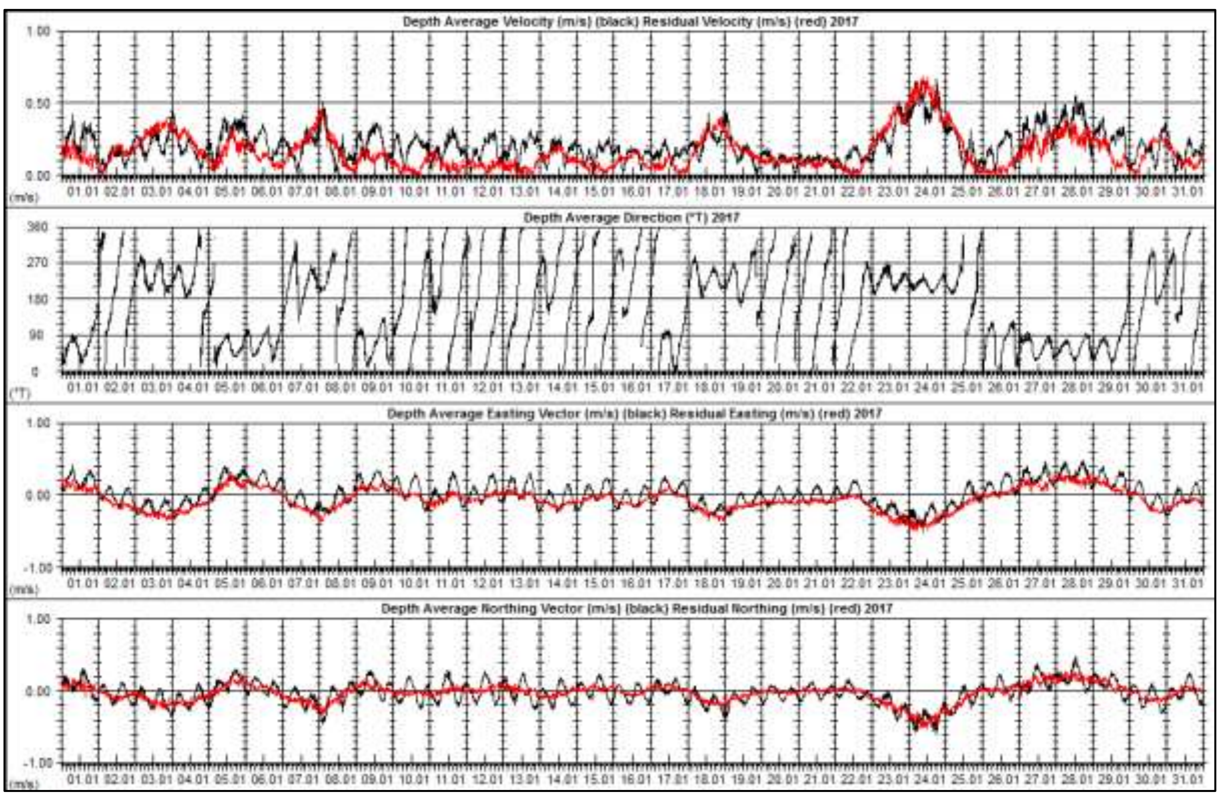

Figure 3. January 2017 Current Data – Observed and Non-tidal Components

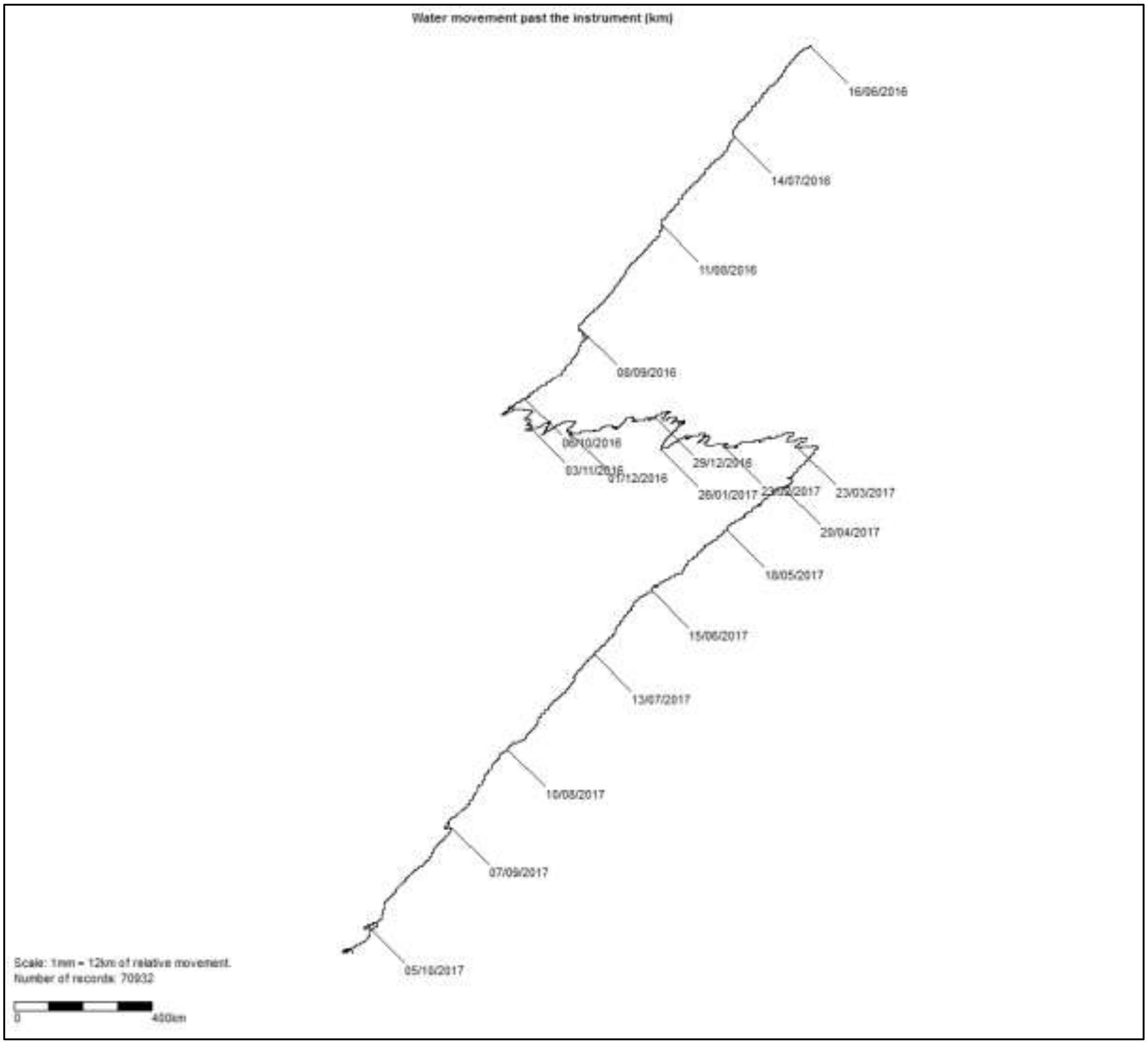

Figure 4. All current data – progressive vector plot

4.2.3 Waves

The Block Island Offshore Wind Farm is sheltered by Block Island and the mainland to the north and west, thus the wave climate is dominated by waves coming from the south and east. **Figure 5** presents a hodogram (rose plot) of the significant wave height against the direction for all observations. **Figure 6** presents an example time series of the wave heights, periods and coming directions for March 2017. The wave climate during the measurement campaign was seasonal with wave heights not exceeding 3 m for the months of June, July and August, increasing through autumn to spring; the largest wave recorded was observed in March.

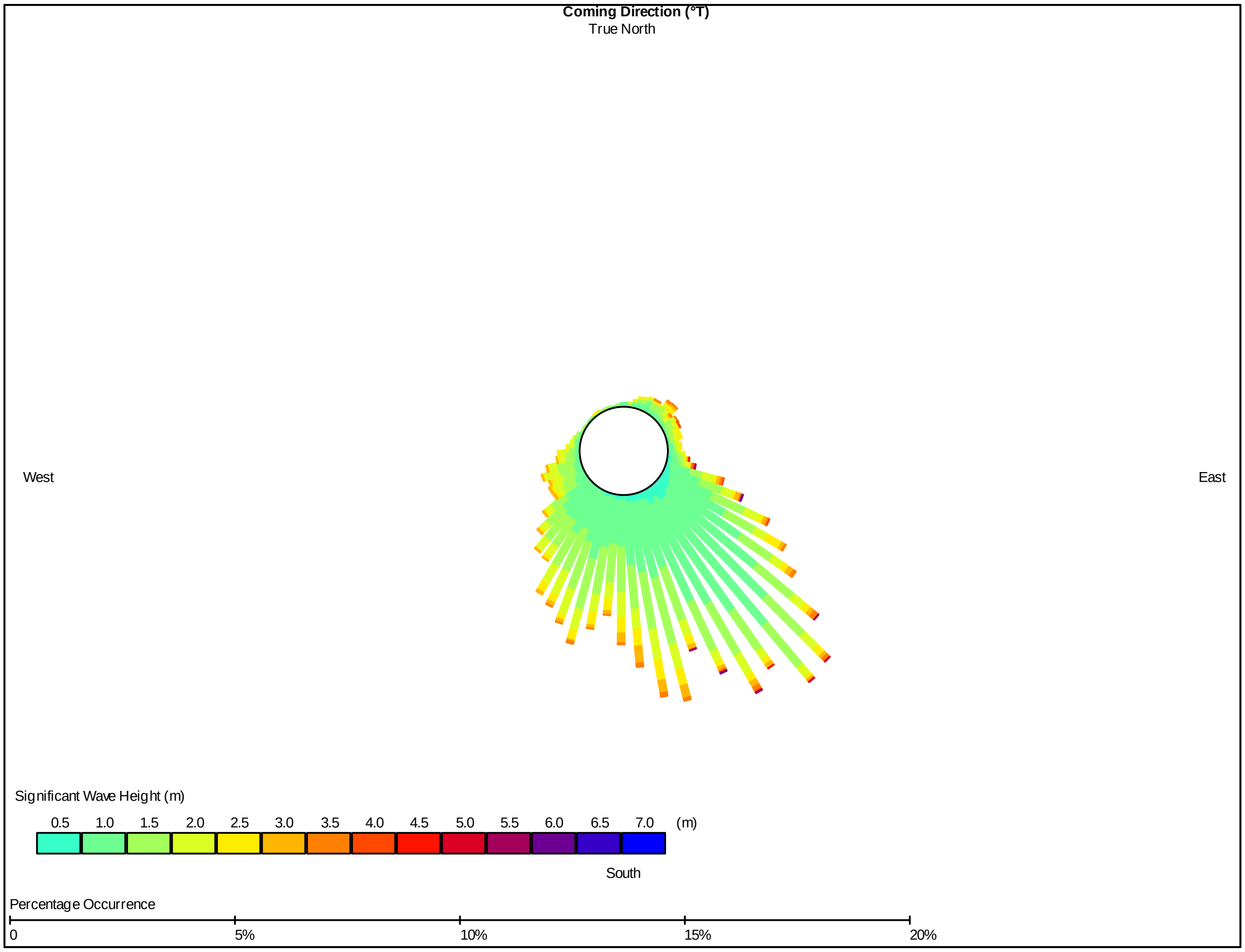

Figure 5. All Wave Data – Significant Wave Height Versus Coming Direction Hodogram (rose plot)

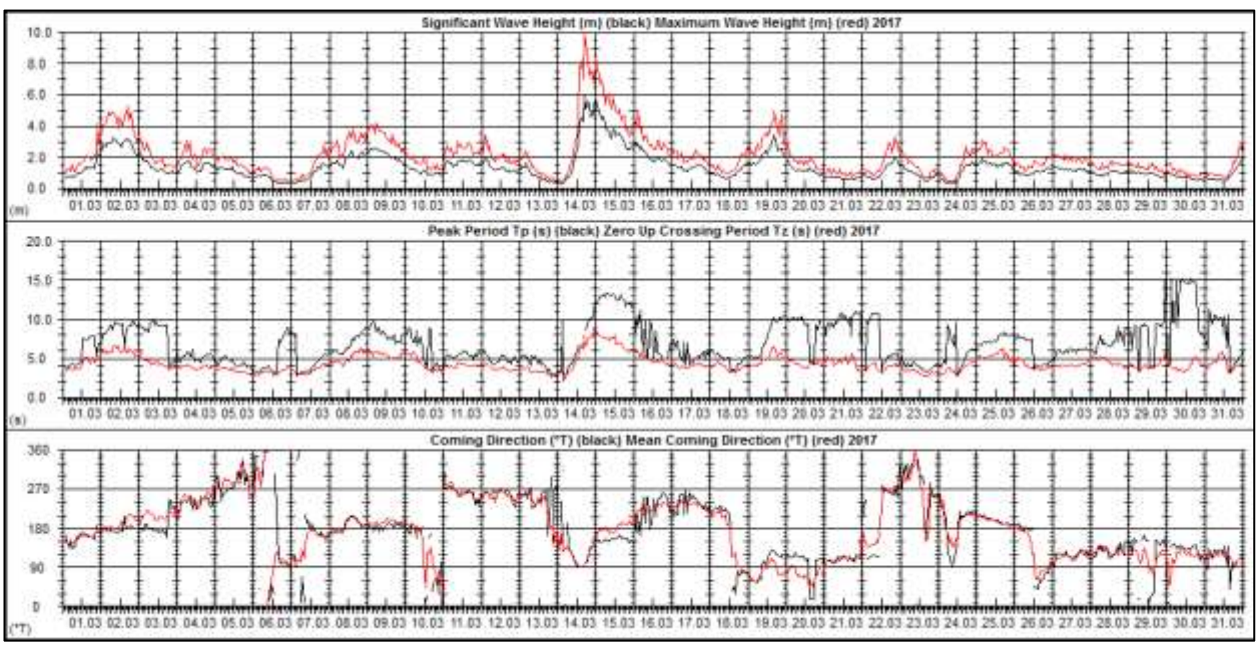

Figure 6. March 2017 Wave Data

Table 9 presents a summary of the significant wave heights for each month and the number of storm events observed (a storm event was defined as any period were significant wave height exceeded 3 m for this report). The seasonality of the reported events is clear with the highest number recorded in January and through the winter months; however, there is a second smaller peak in September, coincident with the period of anticipated hurricane activity. The duration of storm events observed in September appear to be of longer duration than those in the winter months. However, the duration of the data is insufficient to confirm the statistical significance of this observation.

Table 9. Monthly Significant Wave Height Statistics

Month	Maximum (m)	Mean (m)	Minimum (m)	Average number of events with significant wave height > 3m, and approximate total duration
January	4.74	1.507	0.38	4 events 40 hours
February	5.24	1.228	0.32	2 events 24 hours
March	6.04	1.407	0.32	3 events 60 hours
April	3.63	1.307	0.32	2 events 23 hours
May	3.06	1.189	0.36	1 event 1 hour
June	2.3	0.999	0.36	0 events (in 2 months)
July	2.14	0.886	0.38	0 events (in 2 months)
August	2.89	0.913	0.37	0 events (in 2 months)
September	3.5	1.396	0.4	2 events 40 hours (in 2 months)
October	3.28	1.254	0.31	1 event 3 hours (in 2 months)
November	2.94	1.209	0.39	0 events
December	3.44	1.385	0.32	2 events 24 hours

4.3 Seabed Data Summary

4.3.1 Long Term Trends

Figure 7 to **Figure 10** and **Figure 11** to **Figure 14** present a temporal summary of seabed level data from beam 1 to 4 for SE and NE scour monitors, respectively. Beam 1 is orientated at an angle of 5° and therefore represents measurements taken closest to the turbine. In contrast beam 4 is orientated at an angle of 20° and represents measurements taken furthest from the turbine. Scour data from the SE leg contained higher levels of interference, which resulted in a loss of the seabed return signal for the 5° beam during the fourth deployment. Thus, summary statistics from the SE leg are unreliable during July, September and October 2017. The NE leg showed relatively little interference and data were thus available for all month on all beams.

Figure 15 to **Figure 17** present a temporal summary of oceanographic data from the AWAC.

Measurements from both SE and NE units show a slow reduction in the monthly mean seabed level by around 0.2 m over 14 months. The range of seabed levels (monthly maximum and minimum) exhibit a variation of up to 0.6 m over the month. There appears some correlation between the greatest levels of scour and the highest significant wave heights as measured by the AWAC. It is possible that increased wave action during the winter and early spring lead to reductions in seabed level. Some recovery of the seabed level is seen, particularly on the SE leg. This may be due to increased deposition of sediments following winter conditions close to the foundation. The NE unit shows a small recovery of the mean seabed level (<0.1 m) during the summer months, July to September, but does not recover to the levels observed at the start of the study.

Figure 7. SE Beam 1 Scour Depth

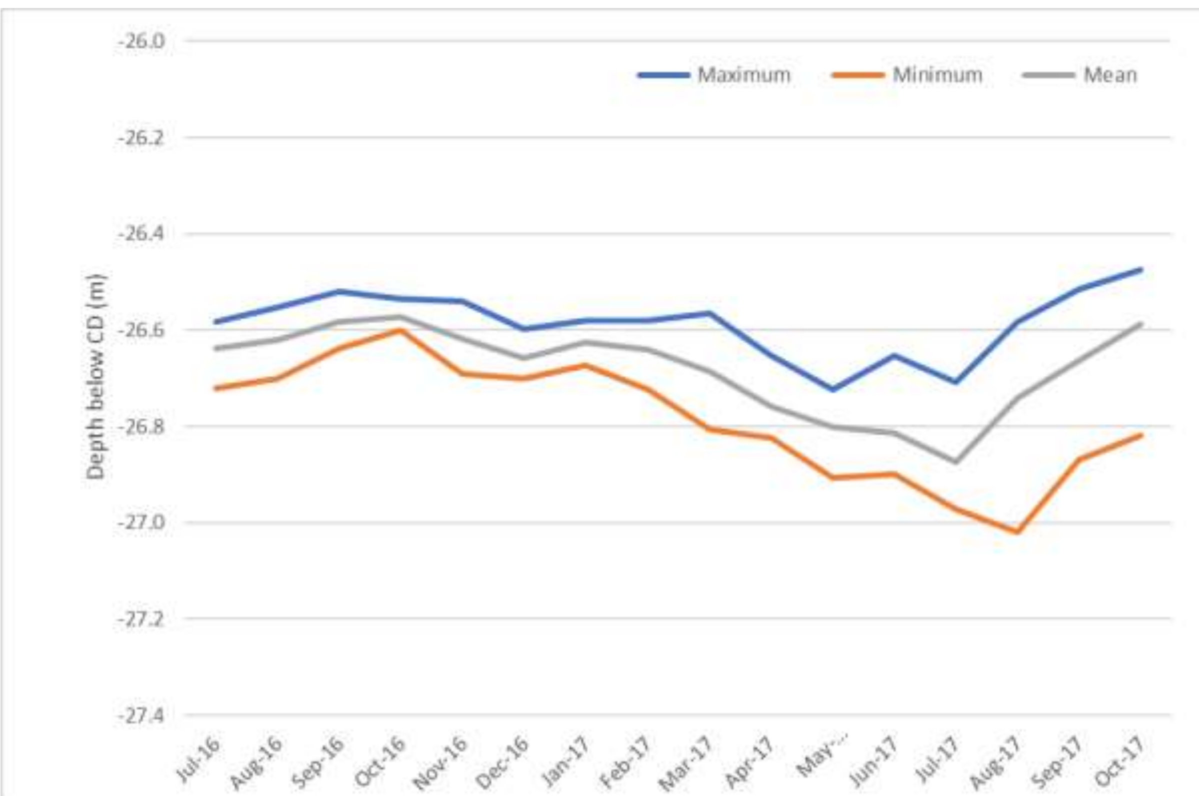

Figure 8. Figure 4.1: SE Beam 2 Scour Depth

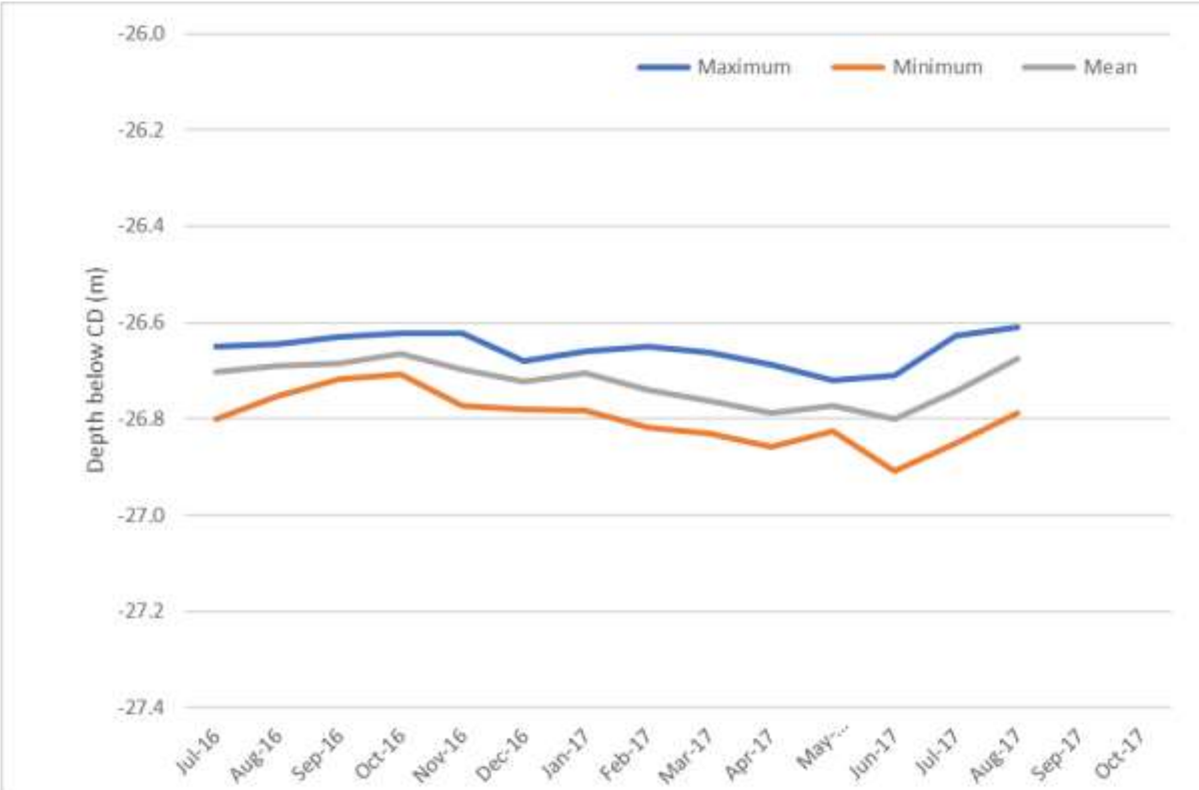

Figure 9. SE Beam 3 Scour Depth

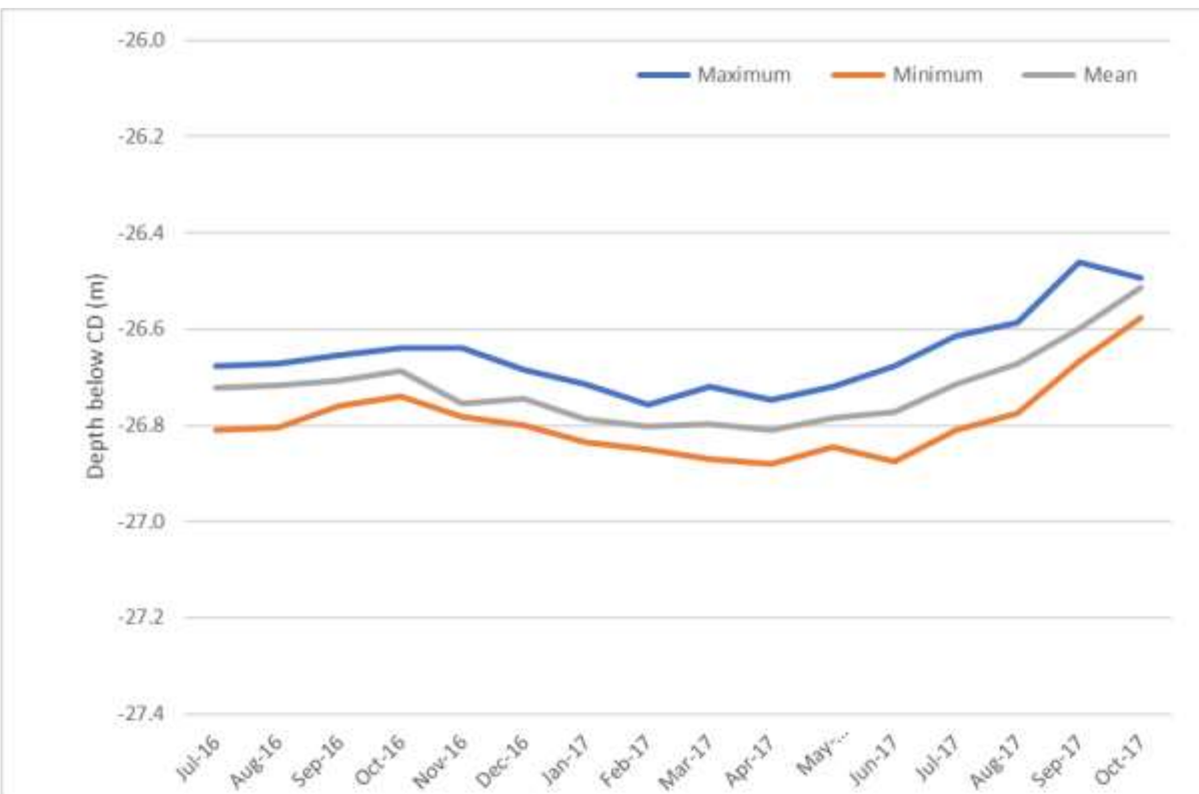

Figure 10. SE Beam 4 Scour Depth

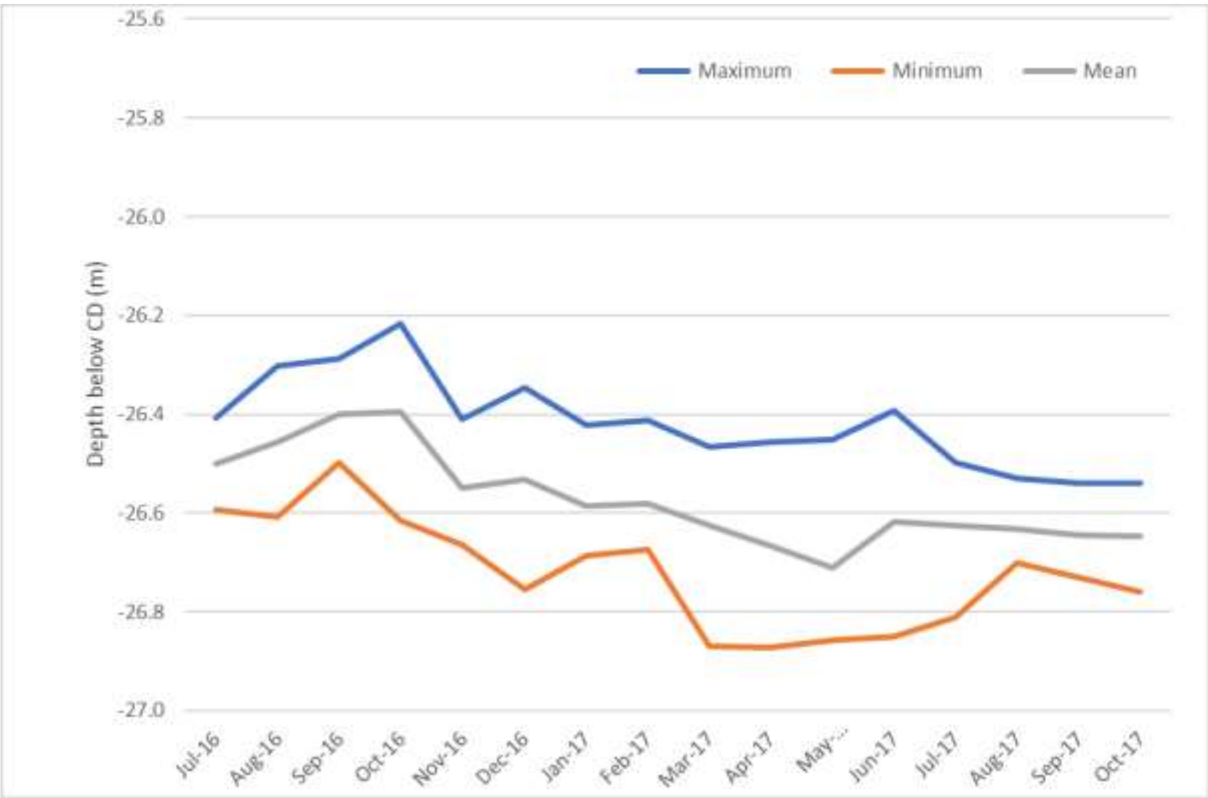

Figure 11. NE Beam 1 Scour Depth

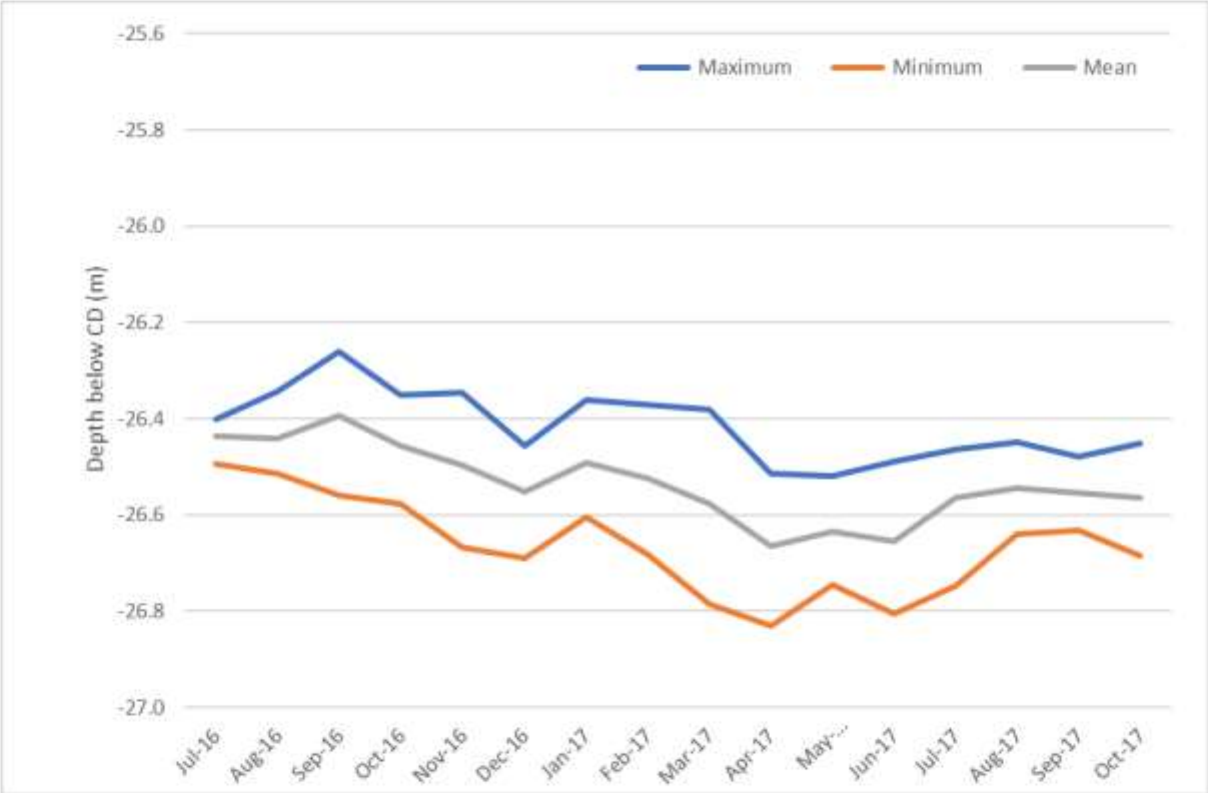

Figure 12. NE Beam 2 Scour Depth

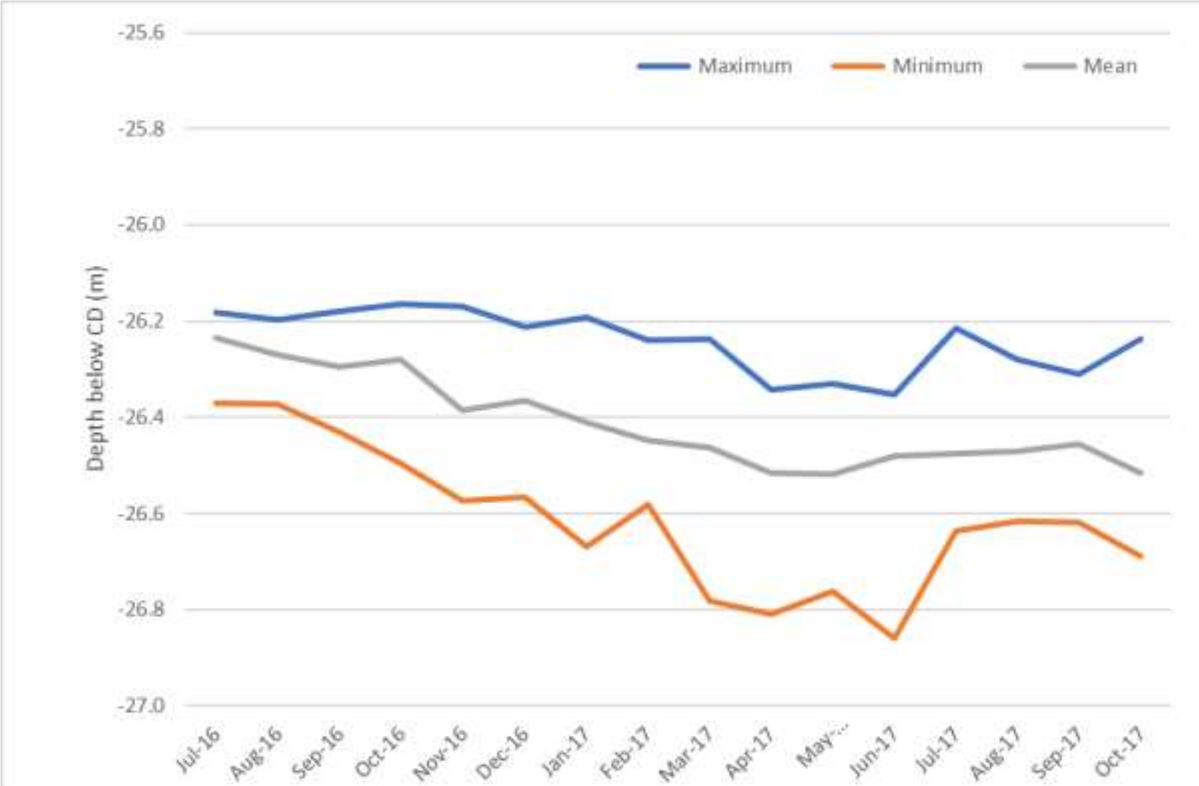

Figure 13. NE Beam 3 Scour Depth

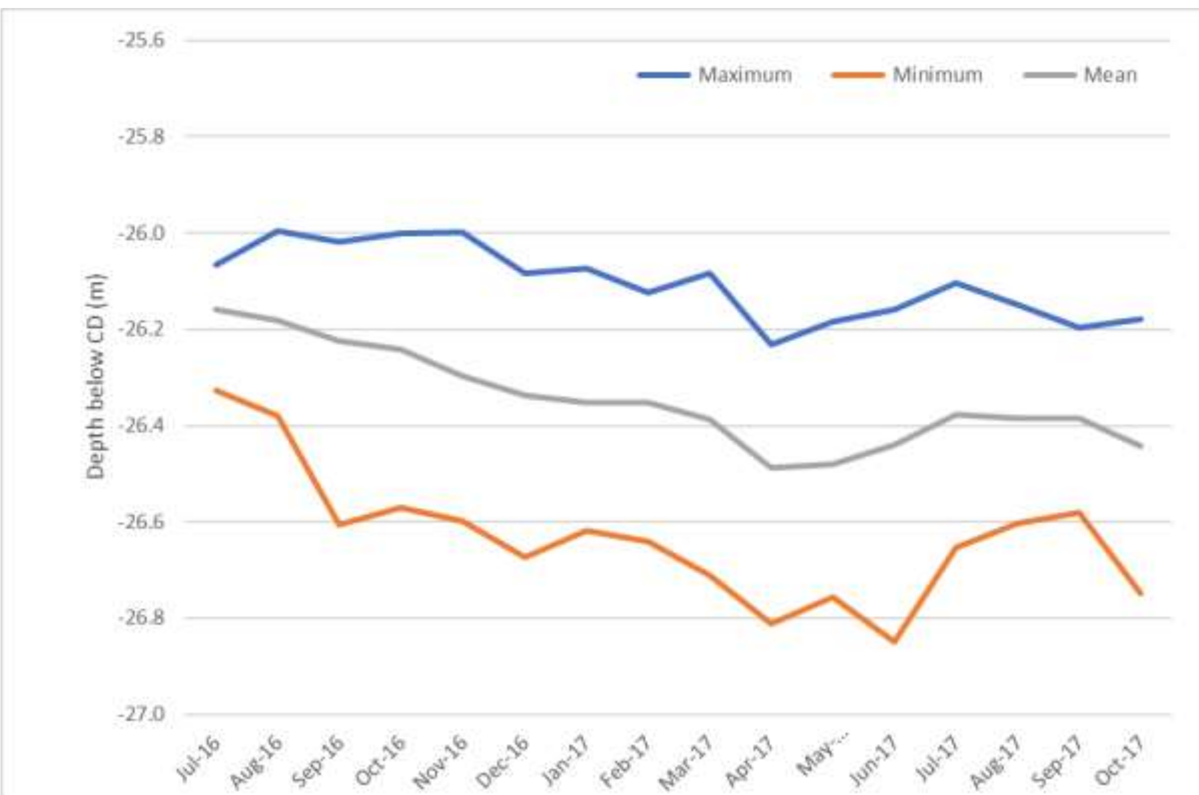

Figure 14. NE Beam 4 Scour Depth

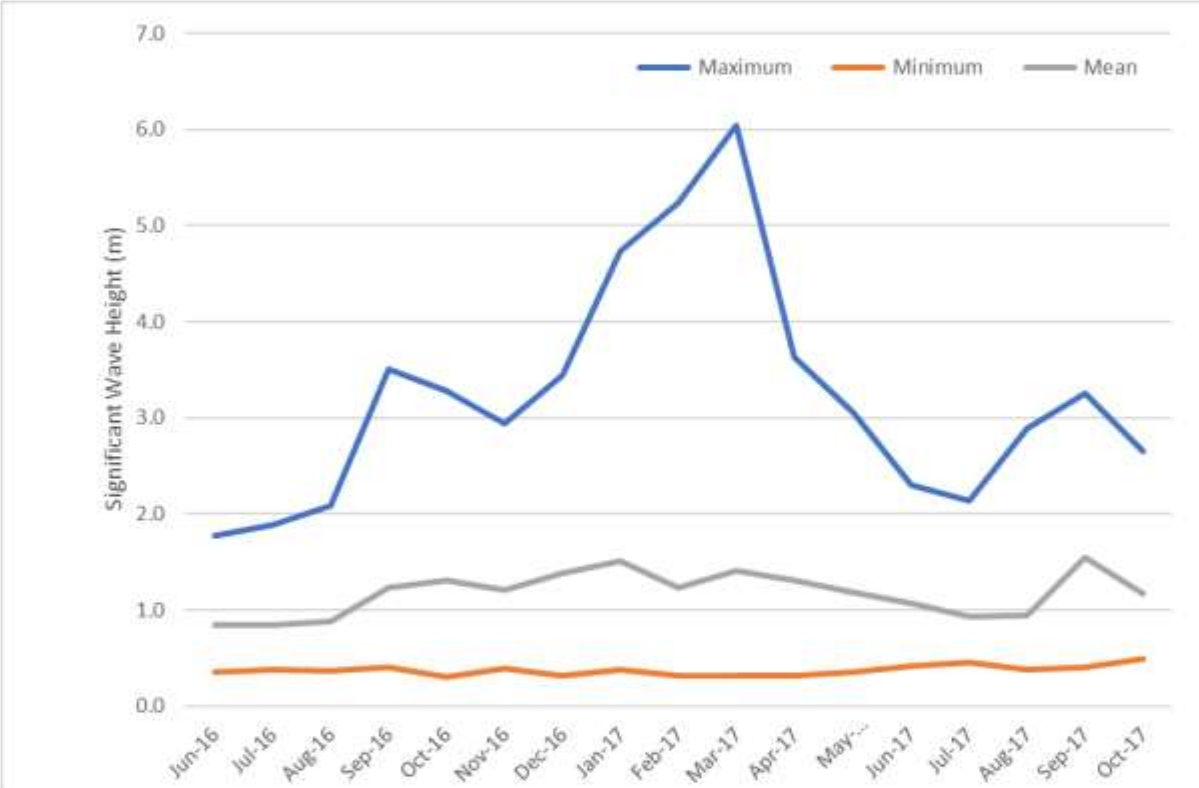

Figure 15. Significant Wave Height

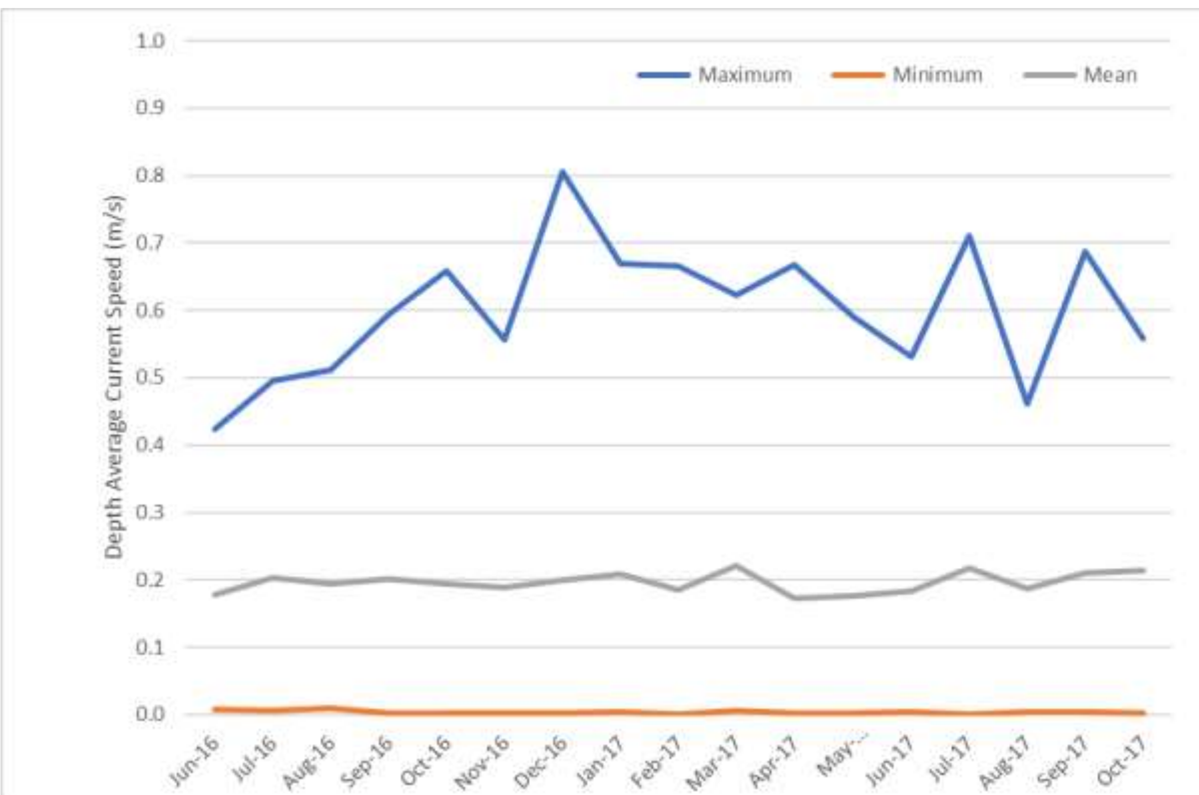

Figure 16. Depth Average Velocity

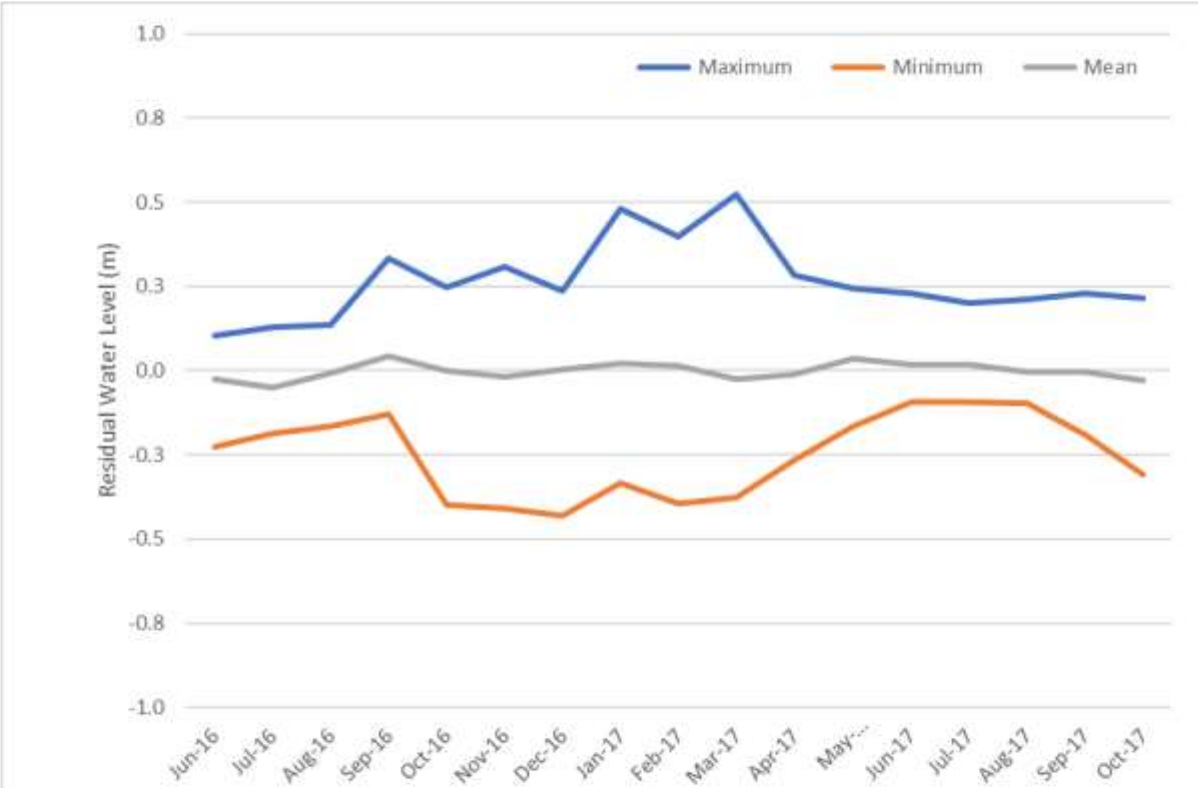

Figure 17. Residual Water Level

4.3.2 Short Term Trends

Short term trends show the seabed level responding to changing oceanographic conditions. Bed levels appear to fluctuate by up to 0.2 m with tidal conditions. The current flow in the Block Island development responds to increased wave action which significantly alters the flow pattern around the structure leading to a change in the seabed topography at or close to the structure. **Figure 18** and **Figure 19** present a comparative time series of scour heights from the northeast sensor compared to the sea level, wave and current data. The scour data presented are based on a 3-hour rolling mean, with beam 1 closest to the foundation (approximately 5 m) and beam 4 furthest from the foundation (approximately 10 m). The seabed level is generally lowest closest to the structure and increases progressively with distance from the foundation.

Variability of approximately 0.2 m over 12 to 24 hours, is seen in August data (**Figure 18**) and tends to occur in line with the tidal forcing, being most obvious during the period when the net current flow is from the northeast towards the southwest. The presence of an area of sand ripples that are migrating into the area around the foundation during the summer months have been observed in bathymetric surveys conducted at the site (Fugro's Seafloor Disturbance and Recovery Monitoring Program Survey 3, May 2017, Block Island Wind Farm, 2017). Ripples that are approximately 0.1 to 0.2 m tall (peak to trough) are inferred to be dynamic and in the area surrounding monitoring site.

During periods of increased wave activity, the seabed level shows reduced variation, for example between 23 and 25 January 2017 (**Figure 19**). Further work is needed to understand the mechanism for this; however, it is possible that the local seabed morphology changes and the sand ripples that migrate across the site during calm conditions are levelled by the increased seabed disturbance.

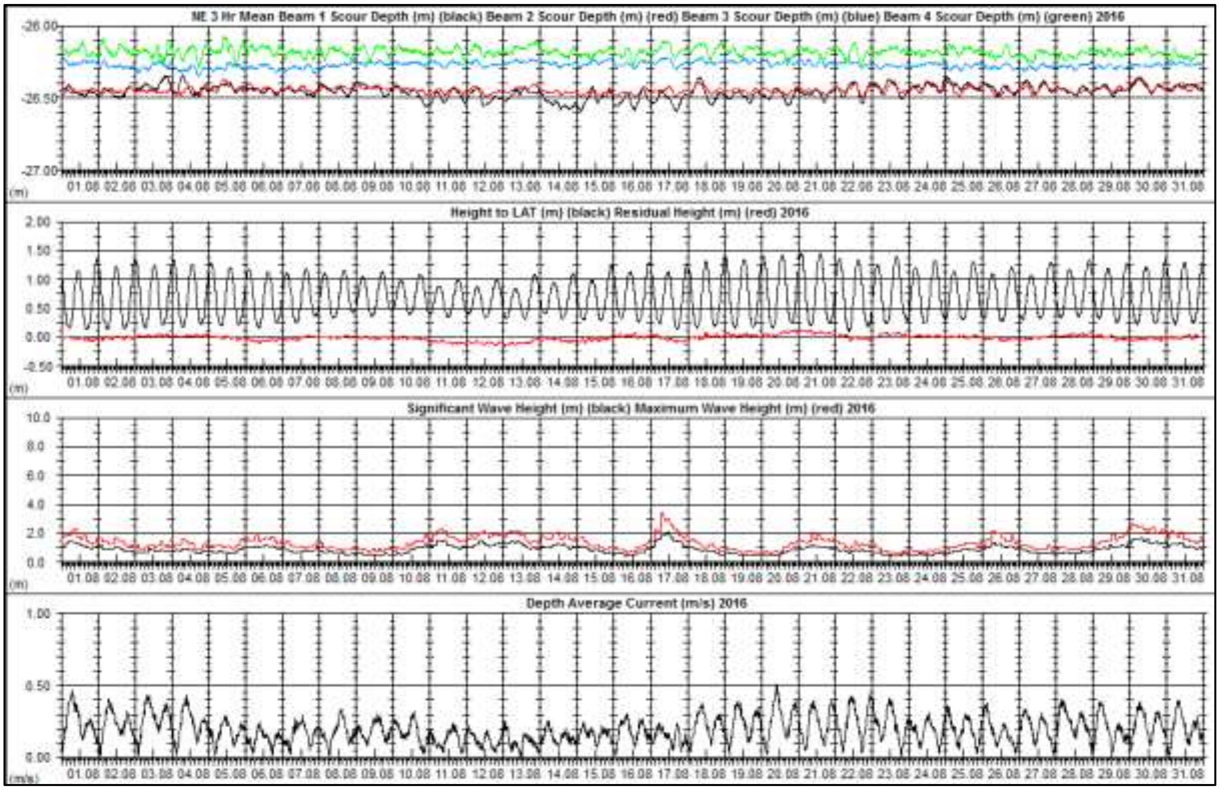

Figure 18. Comparative time series for August 2016

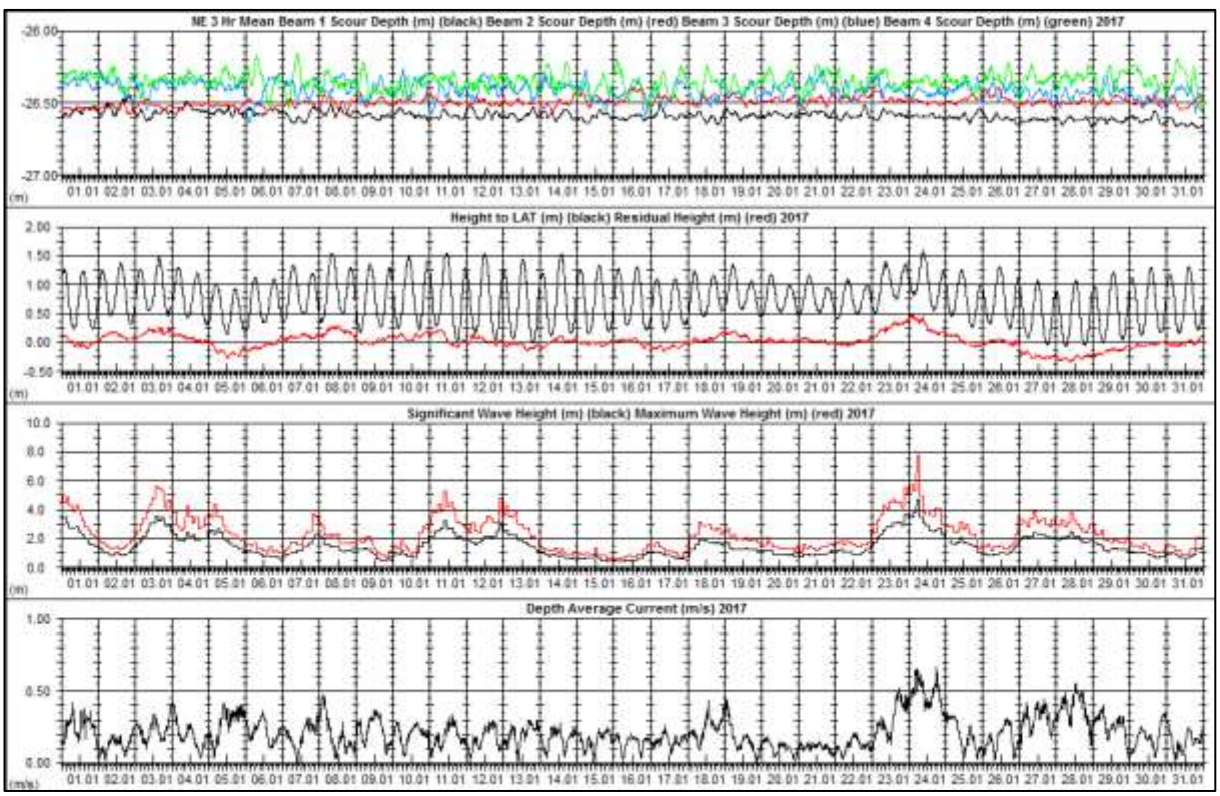

Figure 19. Comparative time series for January 2017

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