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Directional Wave Rider Buoy
(image courtesy of Fugro)

Cell 1 Regional Coastal Monitoring Programme
Wave & Tide Data Analysis Report 9: 2020-2021

North East Coastal Observatory

June 2021

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This study uses sea level monitoring data for Whitby and North Shields from the National Tide and Sea Level Facility, provided by the British Oceanographic Data Centre and funded by the Environment Agency.

Some of the wave data presented and analysed in this report has been obtained from the Cefas WaveNet site[1] and are subject to the Cefas data usage license as described on the next page.

[1] *http://www.cefas.defra.gov.uk/our-science/observing-and-modelling/monitoring-programmes/wavenet.aspx*

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Abbreviations and Acronyms

Acronym / Abbreviation	Definition
AONB	Area of Outstanding Natural Beauty
CD	Chart Datum
DGM	Digital Ground Model
EA	Environment Agency
HAT	Highest Astronomical Tide
LAT	Lowest Astronomical Tide
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
MLWN	Mean Low Water Neap
MLWS	Mean Low Water Spring
NOC	National Oceanography Centre
NTSLF	National Tide and Sea Level Facility
m	metres
OD	Ordnance Datum
PSMSL	Permanent Service for Mean Sea Level
WB	Wave Buoy
WMO	World Meteorological Organisation

Glossary of Terms

Term	Definition
Beach nourishment	Artificial process of replenishing a beach with material from another source.
Berm crest	Ridge of sand or gravel deposited by wave action on the shore just above the normal high water mark.
Breaker zone	Area in the sea where the waves break.
Coastal squeeze	The reduction in habitat area which can arise if the natural landward migration of a habitat under sea level rise is prevented by the fixing of the high water mark, e.g. a sea wall.
Downdrift	Direction of alongshore movement of beach materials.
Ebb-tide	The falling tide, part of the tidal cycle between high water and the next low water.
Fetch	Length of water over which a given wind has blown that determines the size of the waves produced.
Flood-tide	Rising tide, part of the tidal cycle between low water and the next high water.
Foreshore	Zone between the high water and low water marks, also known as the intertidal zone.
Geomorphology	The branch of physical geography/geology which deals with the form of the Earth, the general configuration of its surface, the distribution of the land, water, etc.
Groyne	Shore protection structure built perpendicular to the shore; designed to trap sediment.
Mean High Water (MHW)	The average of all high waters observed over a sufficiently long period.
Mean Low Water (MLW)	The average of all low waters observed over a sufficiently long period.
Mean Sea Level (MSL)	Average height of the sea surface over a 19-year period.
Offshore zone	Extends from the low water mark to a water depth of about 15 m and is permanently covered with water.
Storm surge	A rise in the sea surface on an open coast, resulting from a storm.
Swell	Waves that have travelled out of the area in which they were generated.
Tidal prism	The volume of water within the estuary between the level of high and low tide, typically taken for mean spring tides.
Tide	Periodic rising and falling of large bodies of water resulting from the gravitational attraction of the moon and sun acting on the rotating earth.
Topography	Configuration of a surface including its relief and the position of its natural and man-made features.
Transgression	The landward movement of the shoreline in response to a rise in relative sea level.
Updrift	Direction opposite to the predominant movement of longshore transport.
Wave direction	Direction from which a wave approaches.
Wave refraction	Process by which the direction of approach of a wave changes as it moves into shallow water.

Preamble

The Cell 1 Regional Coastal Monitoring Programme covers approximately 300km of the north east coastline, from the Scottish Border (just south of St. Abb's Head) to Flamborough Head in East Yorkshire. This coastline is often referred to as 'Coastal Sediment Cell 1' in England and Wales (Figure 0.1). Within this frontage the coastal landforms vary considerably, comprising low-lying tidal flats with fringing salt marshes, hard rock cliffs that are mantled with glacial sediment to varying thicknesses, softer rock cliffs and extensive landslide complexes.

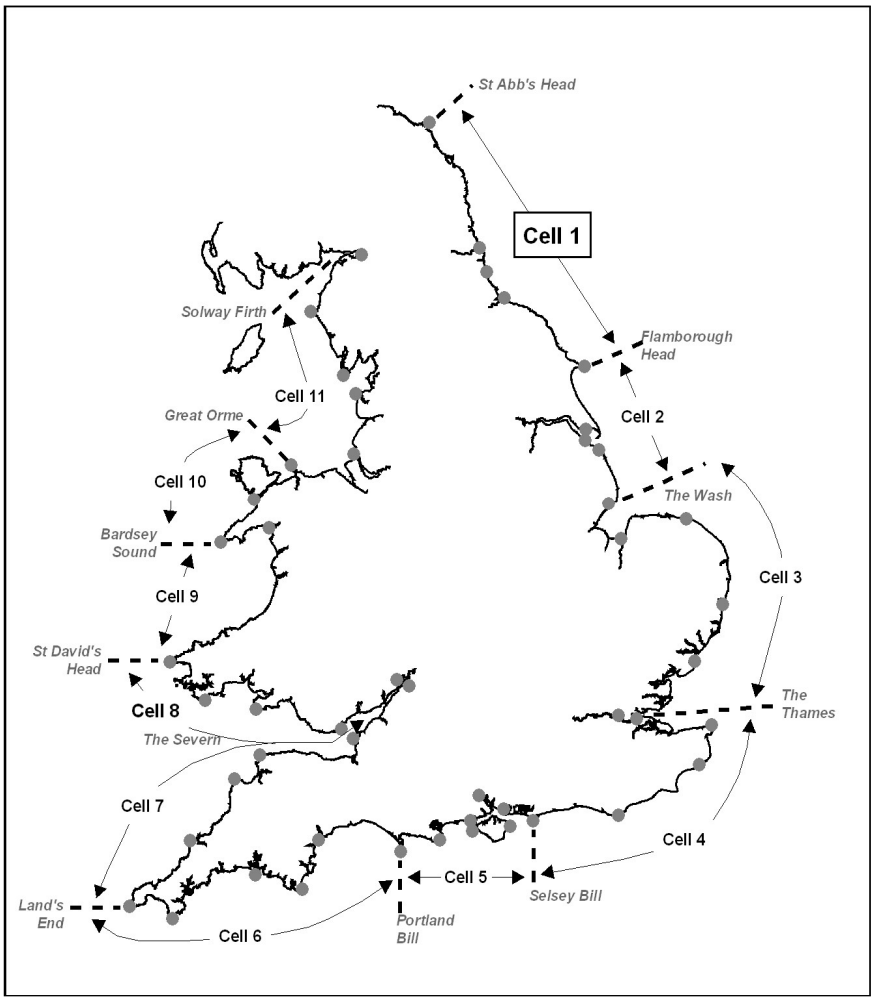


Figure 0.1 - Sediment Cells in England and Wales

The work commenced with a three-year monitoring programme in September 2008 that was managed by Scarborough Borough Council on behalf of the North East Coastal Group. This initial phase has been followed by two further five-year programmes of work, which started in 2011 and 2016 respectively. The work is funded by the Environment Agency, working in partnership with the organisations listed overleaf:

The main elements of the Cell 1 Regional Coastal Monitoring Programme involve:

- beach profile surveys
- topographic surveys
- cliff top recession surveys
- real-time wave and tide data collection
- bathymetric and sea bed characterisation surveys
- aerial photography
- LiDAR surveys
- walk-over cliff and coastal defence asset surveys

The beach profile surveys, topographic surveys and cliff top recession surveys are undertaken as a 'Full Measures' survey in autumn/early winter every year. Some of these surveys are then repeated the following spring as part of a 'Partial Measures' survey.

Each year, an Analytical Report is produced for each individual authority, providing a detailed analysis and interpretation of the 'Full Measures' surveys. This is followed by a brief Update Report for each individual authority, providing ongoing findings from the 'Partial Measures' surveys.

In addition, separate reports are produced for other elements of the programme as and when specific components are undertaken, such as wave data collection, bathymetric and sea bed sediment data collection, aerial photography and LiDAR surveys, and walk-over visual inspections of cliff and coastal defence assets.

The present report is **Wave & Tide Data Analysis Report 9.** This provides an update to the analysis presented in the baseline wave and tide data report and compares the wave data collected between April 2020 and March 2021, to the baseline analysis in Wave & Tide Data Analysis Report 1 published in 2013 and updates in Wave & Tide Data Analysis Reports 2 to 8.

1 Introduction

1.1 Study background and scope

Wave data collection is an integral part of the Cell 1 Regional Coastal Monitoring programme. Under the programme, wave data collection commenced when Waverider buoys were deployed by Cefas at Whitby and Newbiggin Ness in May 2010. These two buoys were decommissioned in June and November 2011 respectively.

Under a more recent phase of the programme, three new Waverider buoys were deployed in 2013 and have been operational since. These are located offshore from Scarborough, Whitby and Newbiggin Ness. The data from these new buoys has been disseminated in near real time on the Cell 1 Regional Coastal Monitoring programme and Channel Coast Observatory websites:

- www.northeastcoastalobservatory.org.uk
- www.channelcoast.org/
- www.coastalmonitoring.org/

The data can also be downloaded from the Cefas website:

- www.gov.uk/cefas.

Additionally under the programme, the existing tide gauge at Scarborough has been serviced and linked up to record concurrent water level data and a new tide gauge was deployed at Whitby.

The present report is **Wave & Tide Data Analysis Report 9** and provides an analysis of the wave and tide data collected during 2020-2021 as part of the programme. The report forms an update to and supersedes the baseline assessment in **Wave & Tide Data Analysis Report 1** (Halcrow, 2013), and the updates **Wave & Tide Data Analysis Reports 2** (Halcrow, 2014), **3** (CH2M, 2015), **4** (CH2M, 2016), **5** (Royal HaskoningDHV, 2017), **6** (Royal HaskoningDHV, 2018), **7** (Royal HaskoningDHV, 2019) and **8** (Royal HaskoningDHV, 2020).

This report also takes into consideration other freely available wave and tide data collected in the region, in particular the Cefas WaveNet Tyne Tees offshore wave buoy; tide gauge data from Whitby and Scarborough collected under the programme; tide gauge data from North Shields and Whitby collected by the National Tidal and Sea Level facility (NTSLF) run by the National Oceanographic Centre (NOC), formerly Proudman Oceanographic Laboratory (POL).

The purpose of this report is to update and extend the wave and tide data analysis undertaken in the previous reports and inform the assessment and interpretation of other data collected under the programme such as the beach, cliff and coastal defence monitoring.

1.2 Study area and available wave and tide data

The Cell 1 study area extends along the northeast coast of England, from the Scottish border through to Flamborough Head. The baseline report (Halcrow, 2013), considered the data at each location shown in **Figure 1.1**, which includes some historic datasets.

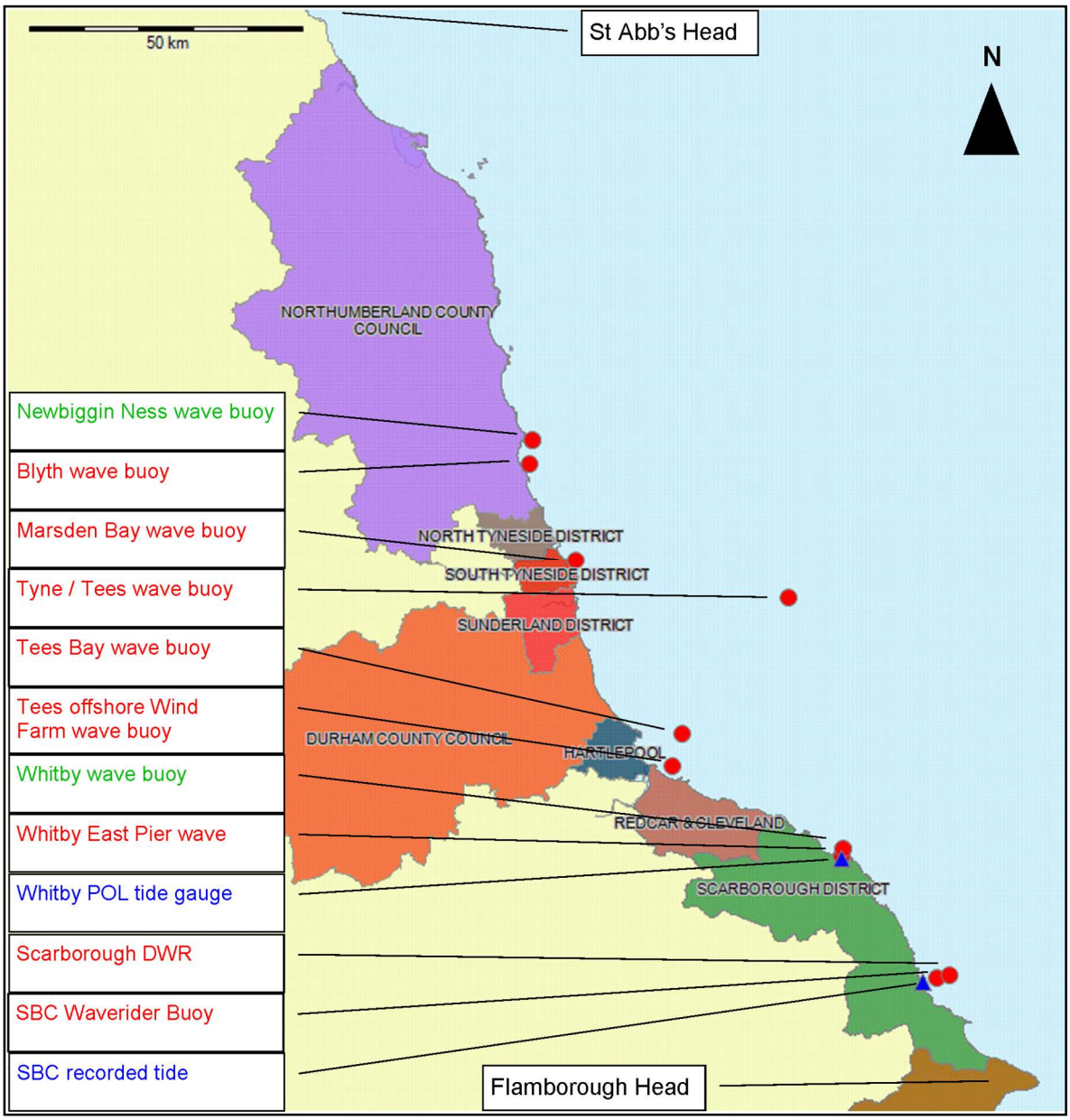


Figure 1.1: Study Area and historical data sets reviewed in the baseline report

In accordance with the recommendations in the baseline report, this update report concentrates on the following locations, progressing from North to South along the coastline:

- Newbiggin wave buoy (Cell 1 programme),
- North Shields NTSLF Class A Tide gauge (NOC, formerly POL),
- Tyne Tees wave buoy (Cefas / WaveNet),
- Whitby wave buoy (Cell 1 programme),
- Whitby NTSLF Class A Tide gauge (NOC, formerly POL),
- Whitby Harbour tide gauge (Cell 1 programme),
- Scarborough wave buoy (Cell 1 programme),
- Scarborough tide gauge (Cell 1 programme).

These locations are shown in **Figure 1.2** and more detailed location maps are shown in Appendix A.

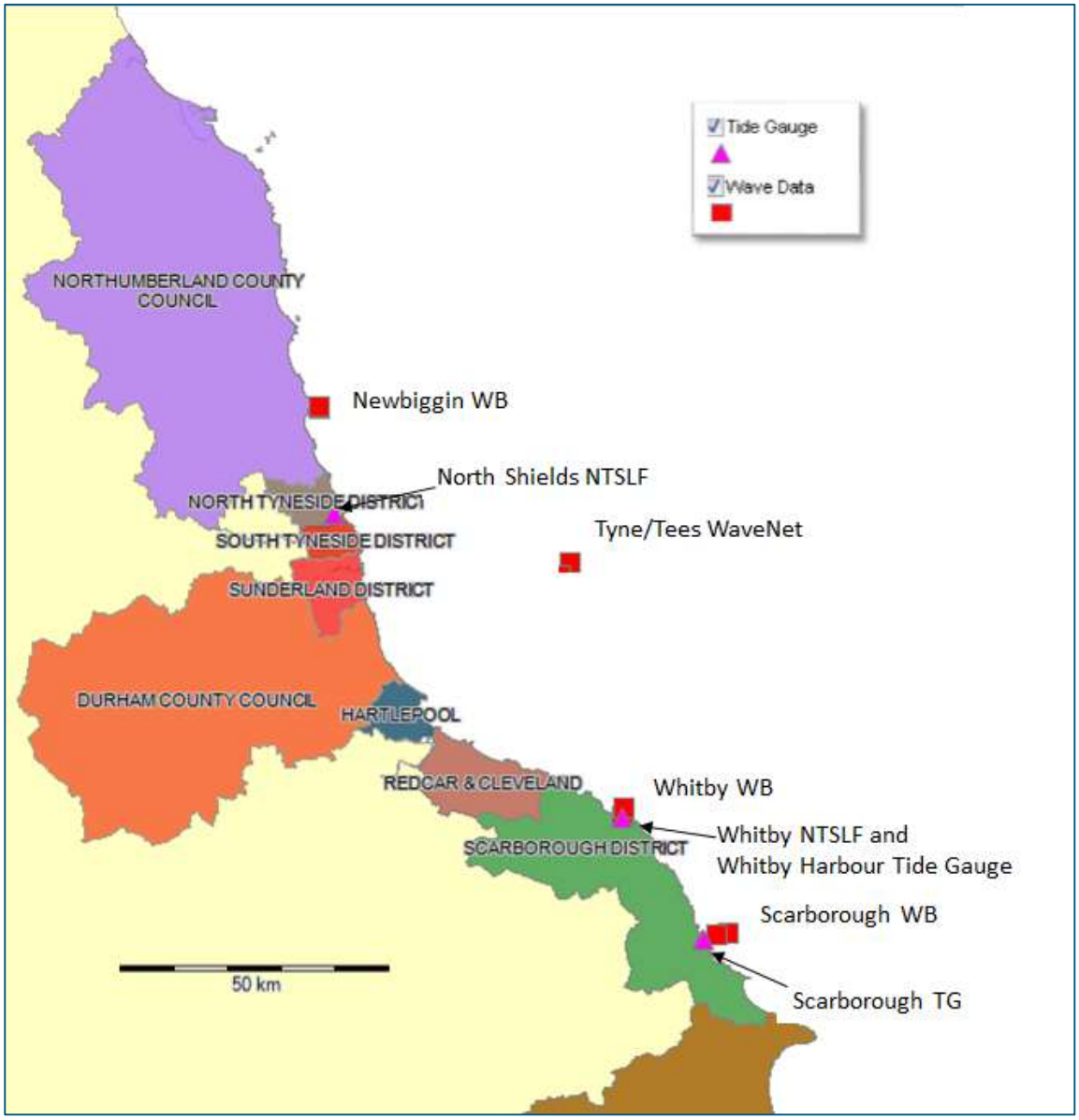


Figure 1.2: Updated data sets reviewed in this report

1.3 Methodology

The wave data received from the deployments at Newbiggin Ness, Whitby and Scarborough were imported into the Shoreline And Nearshore Data System (SANDS) database set up for the Cell 1 Regional Monitoring project for analysis and comparison with other datasets from the adjacent coastline. These datasets were reviewed in SANDS to check for any errors, inconsistencies or omissions.

Detailed graphs of the records of significant wave height, maximum wave height, mean and peak period, peak direction and water temperature for the Newbiggin Ness, Whitby and Scarborough wave buoy locations can be found in Appendices B, C and D respectively. These graphs were received from the Channel Coast Observatory (CCO) with the monthly data. Detailed plots of the tide gauge data and the 2020 report on analysis of the Scarborough and Whitby tide gauge data by the CCO are provided in Appendix E.

It was identified in the baseline report that it was important to consider the Cefas WaveNet Tyne Tees offshore wave buoy as this is the longest consistent record offshore of the project area (deployed in December 2006). Data was therefore downloaded from the Cefas website wavenet.cefas.co.uk/Map and loaded into SANDS for comparison.

The following wave analyses were carried out:

- Wave roses were produced from the wave height and direction data at each location;
- Scatter tables of peak period and wave height were generated at each location; and
- Storm analyses were undertaken at each location.

The data from April 2020 to March 2021 were compared to the previous data. Note that the analysis has included data available up to the end of March 2021 in order to cover the full winter 2020 to 2021 period.

The water level monitoring data from the Scarborough and Whitby tide gauges managed by Fugro-Emu for Scarborough BC were also added into SANDS for analysis. The tide gauge deployed at Whitby under the programme originally had operational problems and this is now the fourth time it has been included in the annual report. Data from the Class A national tide gauges maintained by NTSLF at Whitby and North Shields were also downloaded for inclusion in the analysis.

1.4 Summary of new data available

The new datasets from 2020-2021 considered in this report for comparison to the baseline data are listed in Table 1-1.

Table 1-1 List of updated datasets available for the present report

Name of Location	Type of Data	Approx. Water depth (m)	Start Time	End Time
Newbiggin Ness Wave Buoy (WB)	Wave Data	23m	01/04/2020 (deployed 21/06/2013)	31/03/2021
North Shields NTSLF Tide Record	Tidal Levels	N/A	01/04/2020 (deployed 24/01/1946)	28/02/2021
Tyne Tees WaveNet Site (WMO ID 62293)	Wave Data	65m	01/04/2020 (deployed 07/12/2006)	31/03/2021
Whitby Wave Buoy (WB)	Wave Data	17m	01/04/2020 (deployed 17/01/2013	31/03/2021
Whitby NTSLF Tide Record	Tidal Levels	N/A	01/04/2020 (deployed 01/01/1991)	28/02/2021
Whitby Harbour Tide Gauge (TG)	Tidal Levels	N/A	01/04/2020 (deployed 08/05/2013	31/03/2021
Scarborough Wave Buoy 2 (WB2)*	Wave Data	19m and 30m	01/04/2020 (deployed 17/01/2013)	31/03/2021
Scarborough Tide Gauge (TG)	Tidal Levels	N/A	01/04/2020 (deployed 28/04/2003)	31/03/2021

* Note that the location of the Scarborough WB was changed in June 2013. Data from the latter, further offshore location are designated as Scarborough WB2 in this report

2 Analysis of data

This section considers the data collected under the Cell 1 monitoring programme (i.e. the three wave buoys deployed by Fugro-EMU at Newbiggin Ness, Whitby and Scarborough respectively). It also reviews the longer term record for the Tyne Tees Cefas buoy and tide gauge data available from North Shields, Whitby and Scarborough.

2.1 Newbiggin Ness Waverider Buoy

The wave data in the baseline report for Newbiggin Ness was collected by the Cefas wave buoy deployed under the Cell 1 monitoring programme and published on the Cefas website. The baseline data set was just over 1 year in duration, running from 20/05/2010 to 07/06/2011.

Under the present phase of the programme the Newbiggin Ness wave buoy was deployed by Fugro-Emu on 21/06/2013 in the same location as used for the 2010-11 deployment.

Detailed monthly plots of the data collected during 2020-2021 are presented in Appendix B. The buoy was sent adrift on 10th July 2020 and was redeployed on the 24th July 2020.

The new data set for 2020-2021 has been compared to the baseline data.

2.1.1 Wave Height vs Peak Period

The Newbiggin wave height and zero crossing period data has been plotted on a scatter plot for 1st April to 31st March each year in Figure 2.1. Different symbols have been used to distinguish the baseline data of 2010/11 from different subsequent years of the current deployment. The largest measured wave heights to date were in the 2017/18 data, where several wave heights of over 5.5m were recorded (with associated periods of around 8 secs). Wave periods equalling or exceeding 10 secs have occurred on many occasions, spread over events in four years of records. In each of the last three years of records (2018/19, 2019/20 and 2020/21) these long period events coincided with relatively low significant wave heights (<2m). In the earlier 2014/15 data, they coincided with significant wave heights of up to around 3m. The highest significant wave height recorded during the 2020/21 data set was 4.9m with an associated wave period of 7.5 sec on the 6th February 2021; whilst the longest zero crossing period wave was 10.5 sec with an corresponding wave height of 1.5m on the 7th March 2021.

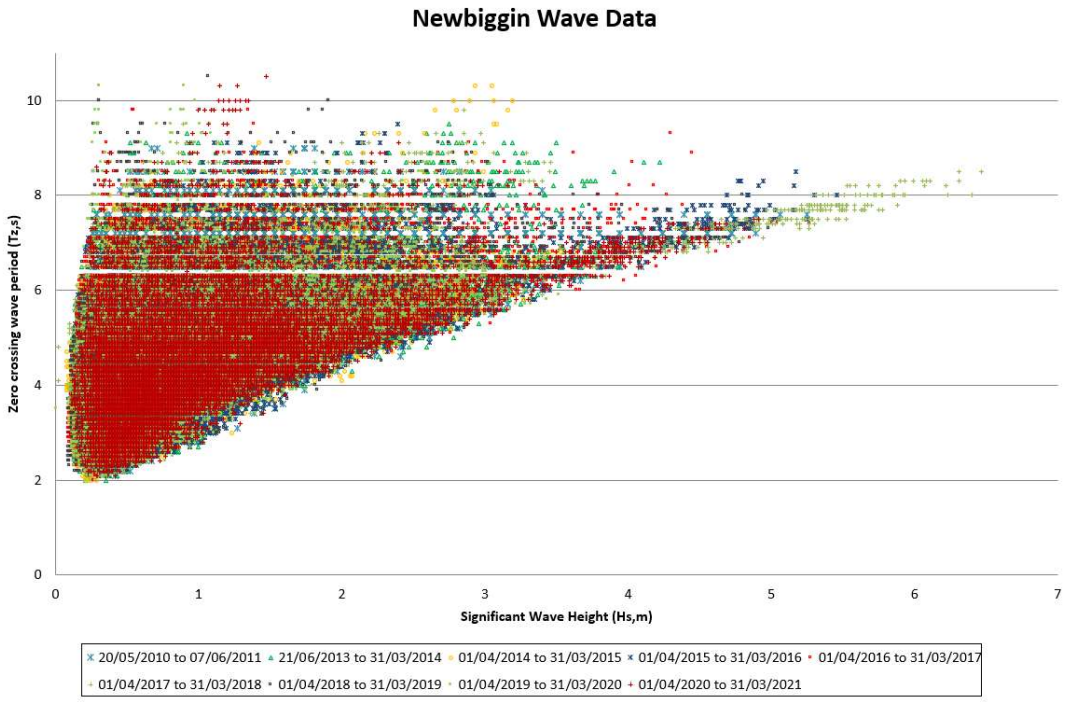


Figure 2.1 Scatter plot of Wave Height Vs Peak Period at Newbiggin wave buoy

2.1.2 Wave Rose

Wave roses showing wave height distribution by direction are shown in Figure 2.2.

The original deployment in 2010/11 showed that the waves predominantly approach the Newbiggin Ness wave buoy from the northeast (15 to 75 degrees, but especially from 30 to 60 degrees), with a smaller proportion from the east (75 to 105 degrees) and southeast (105 to 150 degrees). There is great similarity in observations at Newbiggin Ness in each year since the baseline, with the predominant waves occurring from the northeast sector in each year, although in 2013/14 southeasterly waves were of greater than typical prominence. The 2020/21 datasets shows good similarity to previous years of records.

Comparing the baseline wave roses in Figure 2.2 to the other locations analysed (see Figure 4.1) indicates that the Newbiggin Ness site is relatively sheltered against waves from due north.

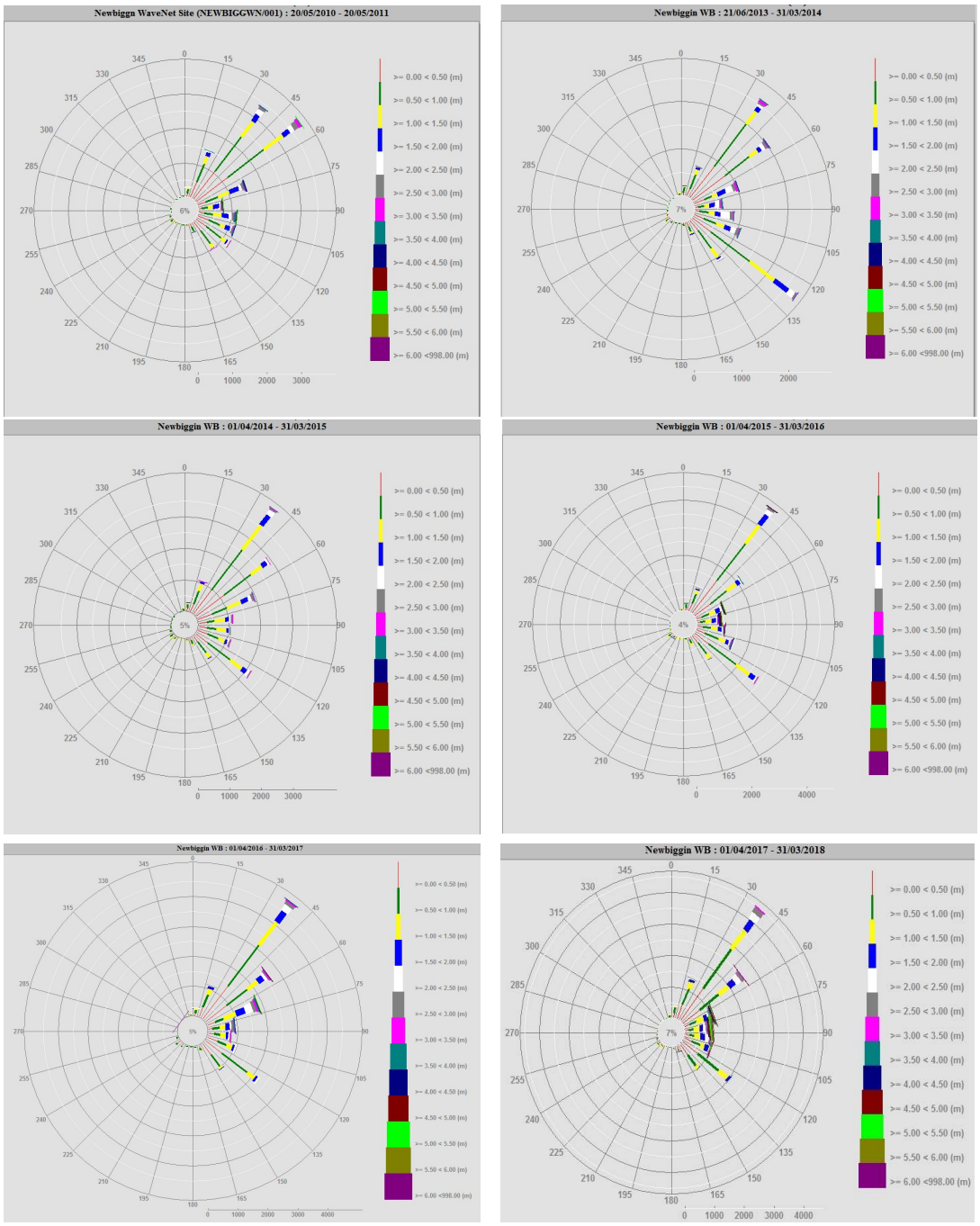


Figure 2.2 Wave roses for Newbiggin WB (original deployment in 2010/11 and subsequent data annually from 2013/14 to date)

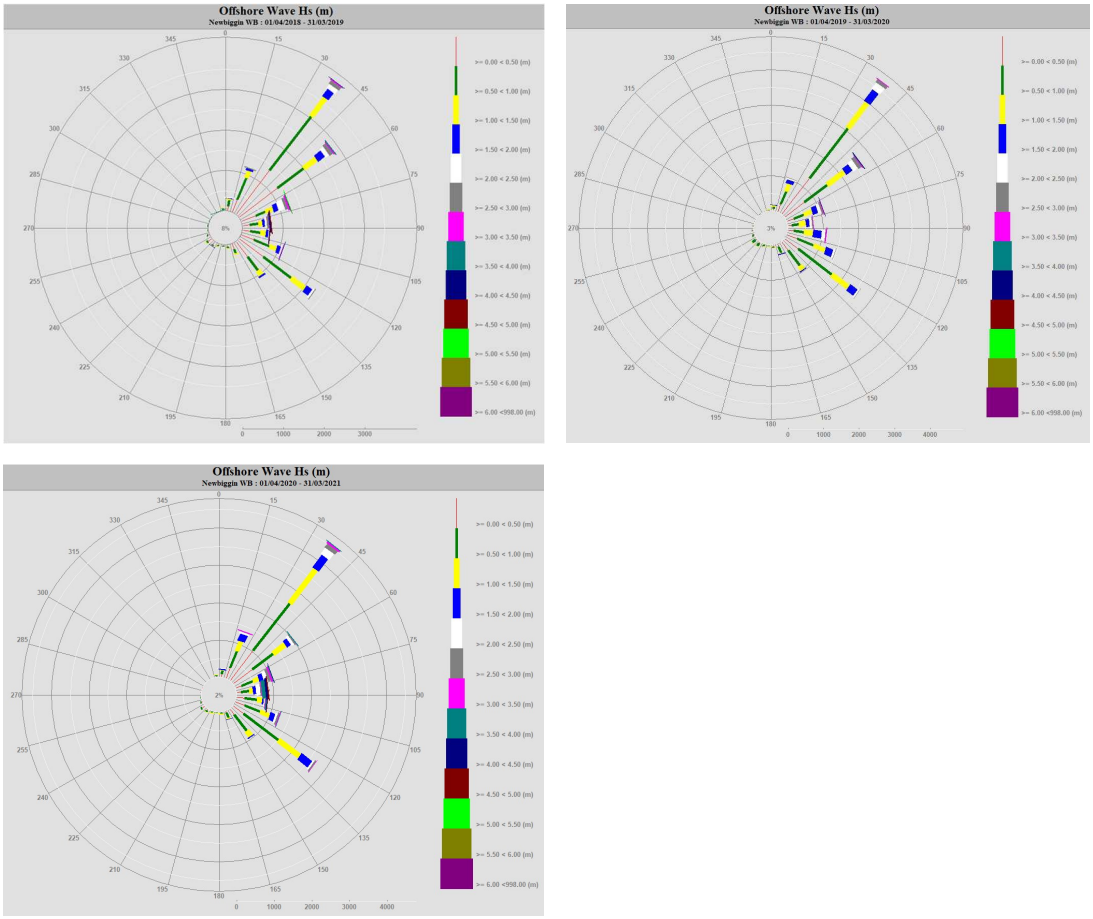


Figure 2.2 (continued) Wave roses for Newbiggin WB (original deployment in 2010/11 and subsequent data annually from 2013/14 to date)

2.1.3 Storm Analysis

The baseline report storm analysis of the Newbiggin Ness wave dataset, undertaken using a wave height threshold of 3m and a storm separation threshold of 120 hours, is shown in Table 2-1. The 3m threshold was chosen in order to identify the largest 5 to 10 storms each year. This analysis used the full baseline data range available, from 20/05/2010 to 07/06/2011. The storms recorded in the baseline dataset arrive from the northeast to east directions (47 to 105 degrees). The storm with the largest wave height at peak in the baseline report dataset, highlighted in bold, occurred on 8th to 10th November 2010.

Table 2-1 Storm analysis for Newbiggin Ness baseline dataset (20/05/2010 to 07/06/2011)

General Storm Information							At Peak					
Start Time	**End Time**	**Dur (Hrs)**	**Peak of Storm[1]**	**Mean Dir (°)**	**No of Events** (30 min dataset)	**Mean Dir Vector (°)**	**Hs (m)**	**Tp (s)**	**Tz (s)**	**Dir (°)**	**Energy @ Peak (KJ/m/s)[1]**	**Total energy (KJ/m/s)**
19/06/2010 07:00	20/06/2010 09:00	26.0	19/06/10 23:00	47	43	43	4.0	11.8	7.7	49	4.32 E+3	3.78 E+6
06/09/2010 18:30	07/09/2010 20:30	26.0	07/09/10 15:30	99	53	352	4.0	11.1	7.5	89	3.86 E+3	4.05 E+6
17/09/2010 10:00	17/09/2010 15:30	5.5	17/09/10 14:30	44	7	46	3.1	13.3	7.7	53	3.37 E+3	5.42 E+5
24/09/2010 03:00	25/09/2010 23:30	44.5	25/09/10 10:00	46	82	45	3.6	11.8	7.7	51	3.54 E+3	6.29 E+6
08/11/2010 12:30	**10/11/2010 00:30**	**36.0**	**08/11/10 22:00**	**84**	**72**	**6**	**5.4**	**28.6**	**8.5**	**56**	**4.66 E+4**	**9.23 E+6**
28/11/2010 10:30	02/12/2010 14:00	99.5	29/11/10 20:00	78	105	13	4.3	11.8	6.9	65	5.05 E+3	8.24 E+6
12/02/2011 01:30	12/02/2011 12:00	10.5	12/02/11 12:00	98	4	360	3.2	9.1	7.1	77	1.67 E+3	1.51 E+5
19/02/2011 06:00	19/02/2011 09:30	3.5	19/02/11 09:30	108	3	353	3.2	8.3	5.8	91	1.36 E+3	9.90 E+4

Notes: [1] The time of the storm peak is based on peak wave energy, which is calculated in SANDS using $E = \rho.g.H_s^2.L_o/8$, with the offshore wave length $L_o = g.Tp^2/2.\pi$

The results from storms analysis of the full sets of data subsequent to the baseline is shown in Table 2-2 below. To aid interpretation of the results, alternate (calendar) years have been shaded and the storm with the largest significant wave height each year has been highlighted in **bold text**. The annual storm with the highest wave energy at peak has also been highlighted in **bold red text** as this depends on wave period as well as wave height and so is not always the same as the largest wave height event.

The longest storm in 2013 ran from 10th to 14th October and had peak wave height of 4.2m. It is notable that the storm that occurred on 5th / 6th December 2013, causing widespread damage to beaches and coastal defences on the east coast, had a peak wave height of 3.2m on the afternoon of 6th December at Newbiggin and while it had highest wave energy at peak and an unusually long wave period, it did not have the largest peak wave height.

There was one storm from the southeast in the record, occurring on 1st January 2014. All other storms in 2014 were from the northeast.

There were six storms above the 3m threshold used at Newbiggin in 2015. The storm that started on 30th December had the highest significant wave height of 5.5m, with the peak on the 3rd January 2016. This storm also had the highest peak and total wave energy recorded that year at Newbiggin.

In 2016 there were only four storms above the 3m threshold, which is relatively low compared to other years. The highest significant wave height of 5.3m occurred on 22nd November 2016. The highest peak and total energy were recorded 6th November 2016.

In 2017 there were eight storms recorded above the 3m threshold, with four of them occurring in the first quarter of the year. The highest significant wave height of 4.3m was recorded on the 13th January 2017, this storm also had the highest peak energy recorded.

In 2018 seven storms were recorded above the 3m threshold, three of which were in the first quarter of the year. The highest significant wave height of 6.4m was recorded on the 1st March 2018. The highest peak and total energy were recorded on the 16th March 2018. The peak energy recorded during this event was, at the time, the second highest on record, only exceeded by the 8th November 2010 event, and the total energy recorded is the highest on record.

In the first quarter of 2019, four storms were recorded, with the highest significant wave height of 3.9m recorded on 27th January 2019. In the remainder of the calendar year, four further storms were recorded. The largest wave height recorded in 2019 was on 4th November (4.4m), which also corresponded with the greatest peak energy.

In the first quarter of 2020, no storms of sufficient duration and height (combined) were recorded to exceed the storm threshold, indicating the generally benign winter that was experienced. In the remainder of the calendar year, three storms were recorded above the threshold. The largest wave height recorded in 2020 was on 4th December (4.1m). The highest peak and total energy were recorded 19th November 2020.

In the first quarter of 2021, one storm of sufficient duration and height (combined) was recorded on 2nd February with a significant wave height of 4.9m.

Note that the analysis for the other Cell 1 wave buoys use higher 'storm thresholds' of 4m due to their more exposed locations.

Table 2-2 Storm analysis for Newbiggin WB (data 21/06/2013 to 31/03/2021)

General Storm Information							At Peak					
Start Time	End Time	Dur (hr)	Peak of Storm[1]	Mean Dir (°)	No. Events	Mean Dir Vector (°)	Hs (m)	Tp (s)	Tz (s)	Dir (°)	Energy @ Peak KJ/m/s	Total Energy (KJ/m)
06/09/2013 18:30:00	06/09/2013 22:30:00	4.0	06/09/2013 22:30:00	47	8	44.9	3.1	9.1	5.9	48	1.5 E+3	3.2 E+5
10/10/2013 00:30:00	**14/10/2013 08:00:00**	**103.5**	**10/10/2013 18:30:00**	**47**	**65**	**43.7**	**4.2**	**11.8**	**7.0**	**46**	**4.7 E+3**	**5.0 E+6**
30/11/2013 01:00:00	30/11/2013 05:00:00	4.0	30/11/2013 05:00:00	38	5	54.9	3.1	11.1	7.4	37	2.4 E+3	3.1 E+5
06/12/2013 01:30:00	06/12/2013 21:30:00	20.0	06/12/2013 16:30:00	47	27	44.4	3.2	16.7	8.5	53	**5.7 E+3**	2.5 E+6
01/01/2014 16:30:00	01/01/2014 17:30:00	1.0	01/01/2014 17:30:00	142	2	329.2	3.1	8.3	5.8	118	1.3 E+3	6.1 E+4
19/01/2014 05:30:00	**20/01/2014 10:30:00**	**29.0**	**19/01/2014 20:00:00**	**69**	**48**	**21.3**	**4.2**	**11.8**	**8.7**	**70**	**4.9 E+3**	**3.9 E+6**
29/01/2014 04:00:00	05/02/2014 21:30:00	185.5	05/02/2014 18:30:00	100	63	350.2	3.8	10.0	6.7	114	2.8 E+3	3.7 E+6
12/02/2014 16:00:00	14/02/2014 19:30:00	51.5	12/02/2014 18:00:00	126	7	329.3	3.4	9.1	5.9	118	1.9 E+3	2.6 E+5
26/03/2014 23:00:00	28/03/2014 01:00:00	26.0	27/03/2014 00:00:00	73	12	20.1	3.4	11.1	6.7	68	2.9 E+3	7.6 E+5
07/10/2014 17:00:00	07/10/2014 21:00:00	4.0	07/10/2014 18:00:00	67	6	23.6	3.2	13.3	9.8	66	3.5 E+3	5.4 E+5
13/10/2014 21:30:00	14/10/2014 03:00:00	5.5	14/10/2014 00:00:00	78	9	16.5	3.3	8.3	6.1	76	1.4 E+3	3.2 E+5
13/11/2014 19:00:00	17/11/2014 13:30:00	90.5	17/11/2014 08:00:00	70	28	20.8	3.6	11.1	6.8	65	3.2 E+3	1.8 E+6
31/01/2015 22:00:00	01/02/2015 11:30:00	13.5	01/02/2015 00:00:00	36	26	53.7	3.4	11.8	6.7	41	3.2 E+3	1.7 E+6
21/03/2015 14:30:00	21/03/2015 16:00:00	1.5	21/03/2015 16:00:00	45	3	47.5	3.2	11.1	7.1	44	2.4 E+3	1.8 E+5
03/05/2015 08:30	03/05/2015 16:00	7.5	03/05/15 14:30	111	13	342.9	3.2	9.1	6.6	107	1.7 E+3	4.9 E+5
07/10/2015 06:30	07/10/2015 10:00	3.5	07/10/15 06:30	66	3	25.4	3.1	10.5	8.0	63	2.0 E+3	1.6 E+5
21/11/2015 02:30	21/11/2015 11:00	8.5	21/11/15 06:00	39	18	51.3	4.6	11.1	7.1	38	5.1 E+3	1.8 E+6
30/12/2015 11:30	**07/01/2016 16:30**	**197.0**	**03/01/16 10:30**	**83**	**255**	**8.9**	**5.5**	**11.8**	**8.0**	**82**	**8.2 E+3**	**2.8 E+7**
16/01/2016 00:00	16/01/2016 04:00	4.0	16/01/16 00:00	51	3	44.5	3.1	12.5	7.4	45	2.9 E+3	2.2 E+5
14/10/2016 06:30	16/10/2016 05:30	47.0	15/10/16 22:30	66	30	25.55	3.3	11.8	8.0	66	3.0 E+3	2.0 E+6
05/11/2016 03:30	07/11/2016 06:00	50.5	06/11/16 18:30	62	56	28.43	4.1	13.3	7.5	72	**5.9 E+3**	5.4 E+6
21/11/2016 18:30	**22/11/2016 11:30**	**17.0**	**22/11/16 00:00**	**62**	**30**	**28.44**	**5.3**	**10.0**	**7.4**	**68**	**5.5 E+3**	**2.4 E+6**
02/01/2017 05:30	04/01/2017 21:30	64.0	04/01/17 15:00	43	26	47.69	3.7	11.8	7.5	44	3.7 E+3	2.1 E+6
13/01/2017 11:00	**13/01/2017 21:00**	**10.0**	**13/01/17 17:30**	**46**	**21**	**44.71**	**4.3**	**15.4**	**9.3**	**55**	**8.7 E+3**	**2.7 E+6**
07/02/2017 21:00	13/02/2017 05:30	128.5	12/02/17 16:30	74	95	17.56	4.2	10.0	6.9	84	3.5 E+3	6.4 E+6
23/02/2017 14:30	23/02/2017 17:00	2.5	23/02/17 14:30	43	6	44.69	3.2	13.3	5.8	56	3.5 E+3	4.1 E+5
08/05/2017 00:30	08/05/2017 02:30	2.0	08/05/17 01:30	40	5	49.40	3.4	10.0	6.7	42	2.2 E+3	2.9 E+5
29/06/2017 02:00	29/06/2017 10:00	8.0	29/06/17 09:00	64	9	27.27	3.2	9.1	6.5	75	1.6 E+3	3.2 E+5
28/11/2017 20:30	01/12/2017 01:00	52.5	30/11/17 19:30	41	21	49.97	3.4	10.5	6.6	39	2.5 E+3	1.2 E+6

General Storm Information							At Peak					
Start Time	End Time	Dur (hr)	Peak of Storm[1]	Mean Dir (°)	No. Events	Mean Dir Vector (°)	Hs (m)	Tp (s)	Tz (s)	Dir (°)	Energy @ Peak KJ/m/s	Total Energy (KJ/m)
08/12/2017 15:00	09/12/2017 09:00	18.0	08/12/17 17:00	52	17	39.26	3.5	15.4	8.5	55	5.6 E+3	1.9 E+6
06/01/2018 10:30	06/01/2018 18:00	7.5	06/01/18 13:30	43	6	49.03	3.4	11.8	6.7	45	3.2 E+3	3.7 E+5
27/02/2018 20:00	**06/03/2018 12:00**	**160.0**	**01/03/18 15:30**	**81**	**175**	**12.45**	**6.4**	**11.8**	**8.0**	**86**	**1.1 E+4**	**2.4 E+7**
15/03/2018 02:30	19/03/2018 07:00	100.5	16/03/18 18:00	80	195	11.33	6.3	12.5	8.5	62	**1.2 E+4**	3.1 E+7
02/04/2018 18:30	02/04/2018 19:30	1.0	02/04/2018 19:30	119	2	340.3	3.2	7.7	5.8	103	1.2 E+3	6.2 E+4
10/04/2018 20:30	11/04/2018 04:00	7.5	10/04/2018 22:00	69	14	21.4	3.5	10.5	7.3	66	2.7 E+3	9.2 E+5
27/10/2018 06:30	31/10/2018 01:00	90.5	30/10/2018 17:30	64	51	26.6	3.7	11.1	7.1	73	3.4 E+3	3.5 E+6
20/11/2018 03:00	21/11/2018 23:30	44.5	21/11/2018 09:30	81	85	9.6	4.8	11.1	7.4	69	5.7 E+3	9.0 E+6
02/01/2019 00:30	02/01/2019 02:00	1.5	02/01/2019 02:00	40	2	49.3	3.0	10.5	7.0	44	2.0 E+3	1.2 E+5
08/01/2019 14:00	09/01/2019 07:00	17.0	09/01/2019 00:00	47	13	45.9	3.4	11.1	7.1	46	2.8 E+3	8.3 E+5
27/01/2019 13:00	28/01/2019 05:30	16.5	27/01/2019 14:00	52	34	38.3	3.9	12.5	7.7	46	4.8 E+3	3.4 E+6
18/03/2019 13:30	18/03/2019 14:30	1.0	18/03/2019 14:30	54	2	42.0	3.0	12.0	8.0	48	2.8 E+3	1.5 E+5
04/05/2019 04:30	09/05/2019 06:30	122.0	04/05/2019 08:30	66	16	26.3	3.2	11.8	6.6	42	2.72E+3	7.63E+5
06/10/2019 12:30	06/10/2019 13:30	1.0	06/10/2019 13:00	101	3	351.3	3.2	8.3	6.0	97	1.42E+3	1.21E+5
04/11/2019 19:30	**08/11/2019 09:00**	**85.5**	**05/11/2019 01:00**	**58**	**47**	**32.4**	**4.4**	**11.8**	**7.3**	**55**	**5.22E+3**	**3.75E+6**
28/11/2019 10:00	29/11/2019 05:00	19.0	29/11/2019 05:00	47	9	44.4	3.0	11.1	7.4	51	2.23E+3	4.38E+5
25/09/2020 09:00	27/09/2020 06:00	45.0	27/09/2020 02:30	41	76	49.7	3.5	13.3	6.7	45	**4.18E+3**	5.61E+6
19/11/2020 10:00	19/11/2020 17:00	7.0	19/11/2020 14:30	44	3	47.6	3.2	13.3	8.2	48	3.48E+3	2.34E+5
04/12/2020 16:00	**05/12/2020 01:00**	**9.0**	**04/12/2020 20:00**	**93**	**19**	**357.3**	**4.1**	**10.5**	**6.8**	**93**	**3.64E+3**	**1.20E+6**
02/02/2021 20:30	13/02/2021 20:30	264.0	06/02/2021 19:30	82	284	8.0	4.9	11.1	7.5	80	5.86E+3	2.56E+7

2.2 North Shields Tide gauge

The tide gauge at North Shields is operated continuously by the National Tide and Sea Level Facility (NTSLF) on behalf of the Environment Agency as part of the main UK tide gauge network. Information on this tide gauge installation is available on the NTSLF website: http://www.ntslf.org/tgi/portinfo?port=North Shields including the site history reproduced below.

The Chart Datum at North Shields is 2.6m below Ordnance Datum (http://www.ntslf.org/tides/datum). Due to its location in the mouth of the estuary the recorded water levels can be influenced by high freshwater flows in the River Tyne.

Site history:

- 1946 – Earliest data available
- 1974 – A Munro gauge was installed over one of the stilling wells and an Ott digital gauge over the other
- 1984 – The Ott digital gauge was removed and a Wellhead unit was installed
- 1984 – The DATARING system was installed with potentiometers attached to the Munro gauge and the Wellhead unit
- 1993 – All equipment removed while a new tide gauge building was built
- 1993 – New building completed and all equipment reinstated
- 1998 – Wind speed and direction instruments installed
- 1998 – Both stilling wells blocked - the POL diving team cleared the blockage
- 2000 – POL data logger installed.

Table 2-3 Predicted tide levels at North Shields

Tidal State	Level (m Chart Datum)	Level (m Ordnance Datum)
HAT	5.73	3.13
LAT	0.00	-2.60
MHWS	5.12	2.52
MHWN	4.08	1.48
MLWN	1.90	-0.70
MLWS	0.73	-1.87
Highest predicted 2014	5.68	3.08
Lowest predicted 2014	0.08	-2.52
Highest predicted 2015	5.73	3.13
Lowest predicted 2015	0.06	-2.54
Highest predicted 2016	5.68	3.08
Lowest predicted 2016	0.10	-2.50
Highest predicted 2017	5.52	2.92
Lowest predicted 2017	0.25	-2.35
Highest predicted 2018	5.56	2.96
Lowest predicted 2018	0.1	-2.50
Highest predicted 2019	5.68	3.08
Lowest predicted 2019	0.03	-2.57
Highest predicted 2020	5.69	3.09
Lowest predicted 2020	0.01	-2.59
Highest predicted 2021	5.55	2.95
Lowest predicted 2021	0.12	-2.48

Tidal State	Level (m Chart Datum)	Level (m Ordnance Datum)
Highest predicted 2022	5.48	2.88
Lowest predicted 2022	0.19	-2.41

Note: Based on data from http://www.ntslf.org/tgi/portinfo?port=North Shields

Data are available on the internet in real time (http://www.ntslf.org/data/realtime?port=North Shields) and quality controlled data can be downloaded from the British Oceanographic Data Centre (BODC) website.

The BODC data for April 2020 to March 2021 were downloaded from the BODC website. These data were in Chart Datum. A detailed plot of the data classified as being of 'good quality' for 2020/21 is shown in Figure 2.3. There are no significant gaps in the data for 2020/21.

Although occasional data are available from 1946, there are many large gaps in the record up until 1964, but the overall record appears very consistent. The largest high water levels in the record were during the storm surge on the 5th December 2013 when a level of 3.98 mOD was attained at 16:15 hrs. This shows how exceptional the conditions were, with the previous maximum recorded water level of 3.56m occurring at 17:00 on 31st January 1953 (note that prior to 1990 only hourly data are available and so the actual maximum water level in the 1953 storm event may have been higher than the recorded 3.56 mOD).

In 2020/21, the maximum water level recorded at the North Shields tide gauge was 5.87mCD (3.27mOD) on 16th November 2020.

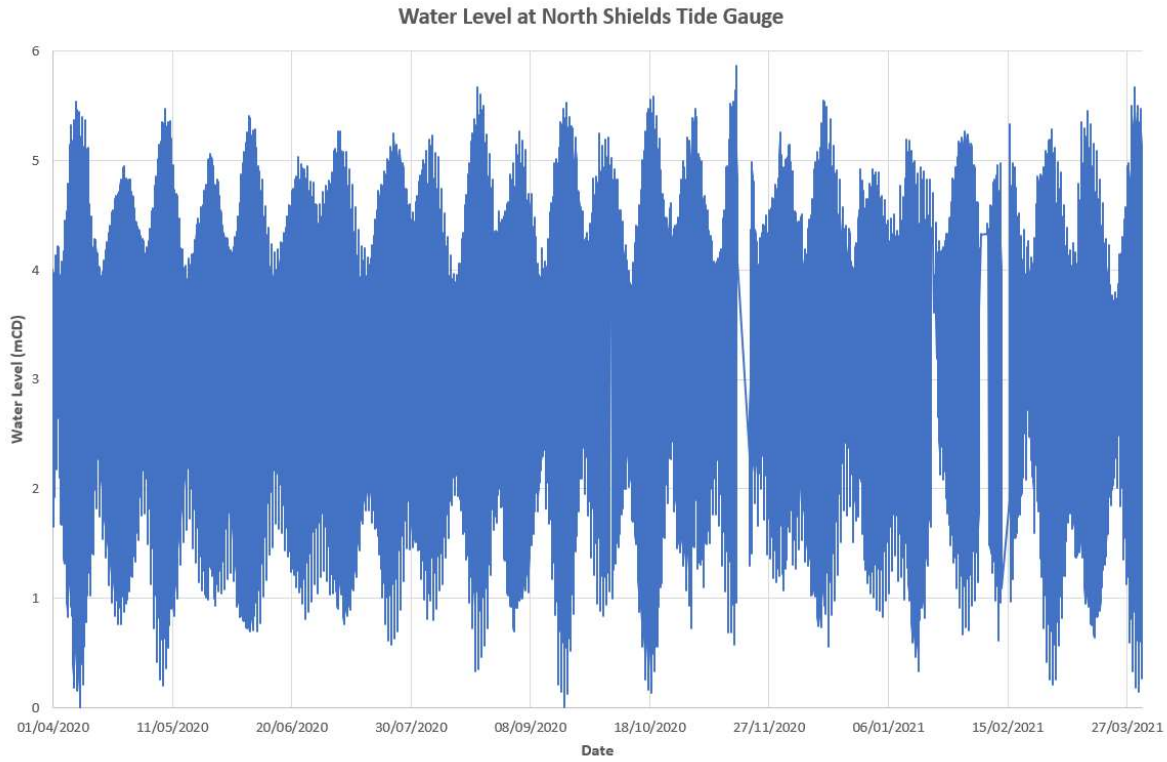


Figure 2.3 Water level data record for 2020-2021 at North Shields NTSLF Tide Gauge

Note: For earlier years please refer to previous reports.

2.3 Tyne Tees WaveNet Buoy

The full Tyne Tees wave buoy dataset was re-downloaded from the Cefas website in order to obtain as much post-recovery data as available. There were two significant gaps in the post-processed data (21/01/2008 to 08/04/2009 and 19/02/2014 to 12/05/2014) that were filled by telemetry data. There are no significant gaps in the 2020/21 wave data, although data from 1st January to 31st March 2021 are telemetered data.

This buoy was deployed by Cefas in 2006 and continues to operate as part of the National Wave Network (WaveNet) that is managed by Cefas for the Environment Agency alongside the UK strategic tide gauge network. The wave buoy is located 35km offshore in around 65m water depth and therefore potentially provides a suitable baseline of offshore data as the record extends from before the Cell 1 strategic programme commenced in 2008.

The 2013-14 report included a comparison of the recorded waves at Newbiggin and Whitby under the Cell 1 programme to the WaveNet buoy Tyne Tees buoy and also modelled data from the Met Office hindcast model. This found that there are generally similarities between the datasets but also some significant differences, which mainly relate to differences in fetch lengths and sheltering by the coast at the different locations.

It was noted in the 2013-14 report that the hindcast wave data for the nearest Met Office hindcast location (point 2084) to the Tyne Tees buoy, which at the time of the analysis was available from 1980 to 2012, showed a very similar temporal variation to the measured data at Tyne Tees, but the highest significant wave height on most storms was significantly under-estimated, with peak wave heights often greater than 0.5m below the measured value. This indicated that model calibration was poor for resolving peak wave heights during storms in this location. It was therefore recommended that caution should be applied when using these data and that consideration be given to adjusting or calibrating the Met Office hindcast offshore data if it is to be used to define boundary conditions for coastal modelling studies within Cell 1. No further modelled data has been obtained for this update report, but the plot in Figure 2.4, showing a comparison of predicted and measured storms in November and December 2009, has been included from the previous reports to demonstrate the issue.

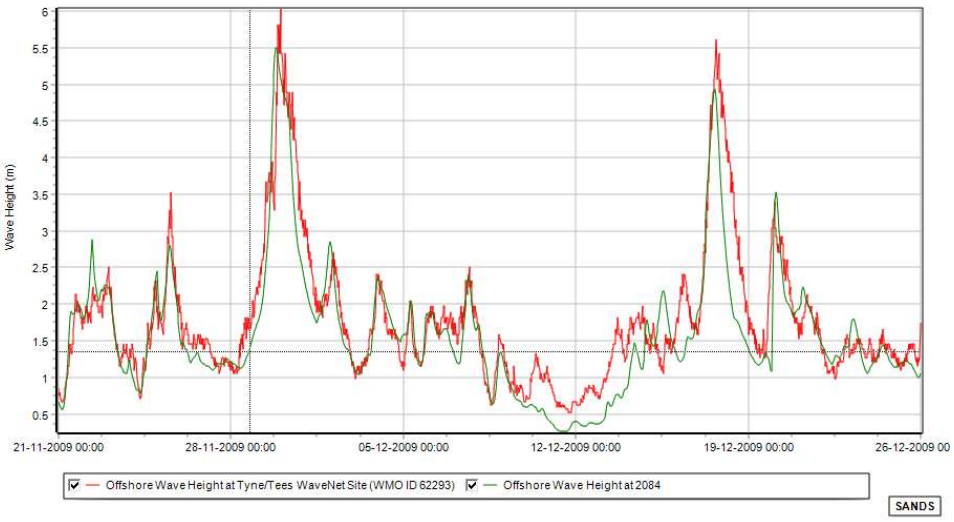


Figure 2.4 Comparison of recorded and modelled wave heights at Tyne Tees in winter 2009 showing under-prediction of modelled data

The data record that was reviewed at the Tyne Tees wave buoy for the baseline report ran from December 2006 to September 2012. This has been updated for this report with data to the end of March 2021. The scatter table and wave rose produced for the buoy now uses fourteen full years of wave data. Storm and extremes analyses have also been updated and are shown in the sub-sections below.

A comparison of wave heights at the Tyne Tees buoy to the data recorded at the Cell 1 programme buoys at Newbiggin, Whitby and Scarborough for 2020-21 is shown in Figure 2.5 below. This shows that generally the four wave buoys record similar patterns of storms. The highest storm wave heights are most often observed at Tyne Tees due to its deeper water deployment. The largest storms in the period April 2020 to March 2021 recorded at the Tyne Tees buoy were in September 2020 with a significant wave height of 6.6m and in February 2021 where the wave height reached 6m.

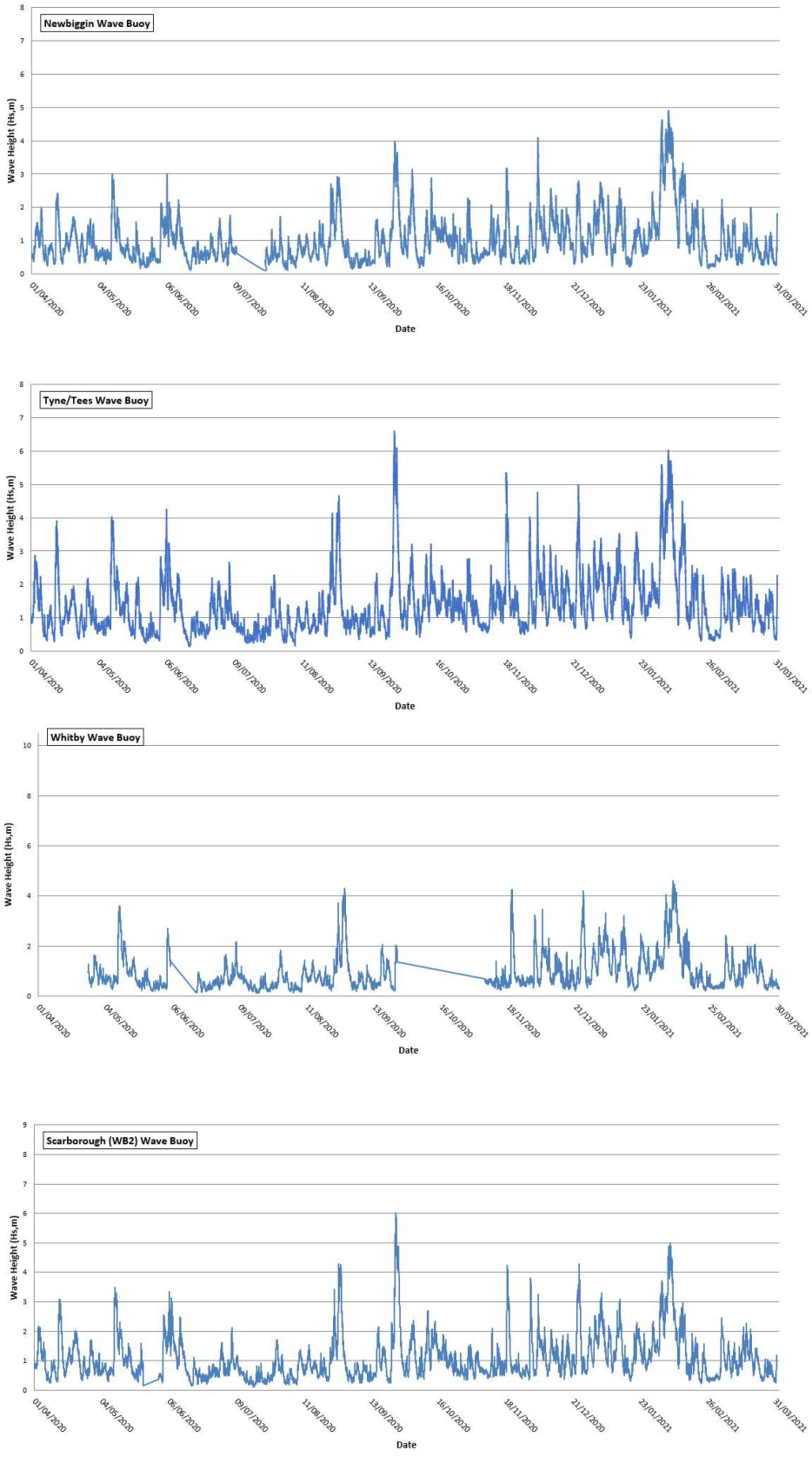


Figure 2.5 Comparison of recorded wave heights at Tyne Tees to the Cell 1 programme buoys from April 2020 to March 2021

2.3.1 Wave height vs Wave Period

The distribution of the wave height, peak and zero crossing period for the Tyne Tees wave data record is shown as a scatter plot in Figure 2.6. The plot shows some long period swell waves with heights of 0.5 to 1.5m and periods over 20s, and that the maximum storm wave heights of typically about 7m are associated with peak periods of 8 to 9s or zero crossing periods of 8 to 10s.

The largest significant wave height recorded in the 2020/21 dataset of 6.6m (with an associated zero crossing period of 8.2s) was on 25th September 2020. The longest zero crossing wave period recorded in the 2020/21 dataset of 10.9s (with an associated significant wave height of 2.2m) was recorded on the 7th March 2021.

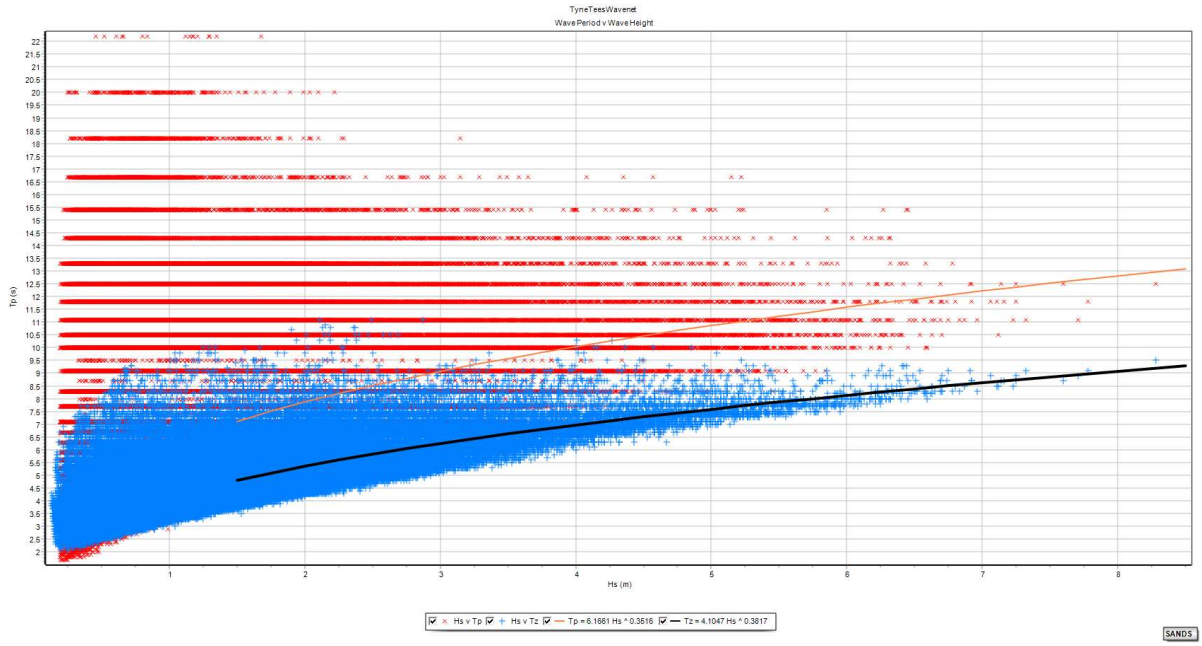


Figure 2.6 Scatter plot of Wave Height Vs Peak Period at Tyne Tees wave buoy site

Note that the horizontal banding shown in the Tp values appears to be due to the post-processing undertaken by Cefas on the post recovery data as the plot in some previous reports, which used the telemetry data, showed vertical rather than horizontal banding.

2.3.2 Wave Rose and Wave Direction Scatter Tables

The wave rose for Tyne Tees in Figure 2.7 has been updated to include the most recent year's record of wave data. The plot shows that the majority of the waves approach from the north to north-northeast sector (0-30 degrees). There is a small secondary peak in approach direction for waves from the south east sector (120-150 degrees). Other waves approach from easterly directions (30-120 degrees) located between the primary and secondary peaks. Due to the offshore location of this buoy there are also small peaks from the southwest and northwest that would represent calm periods along most of the inshore sections of the Cell 1 coast.

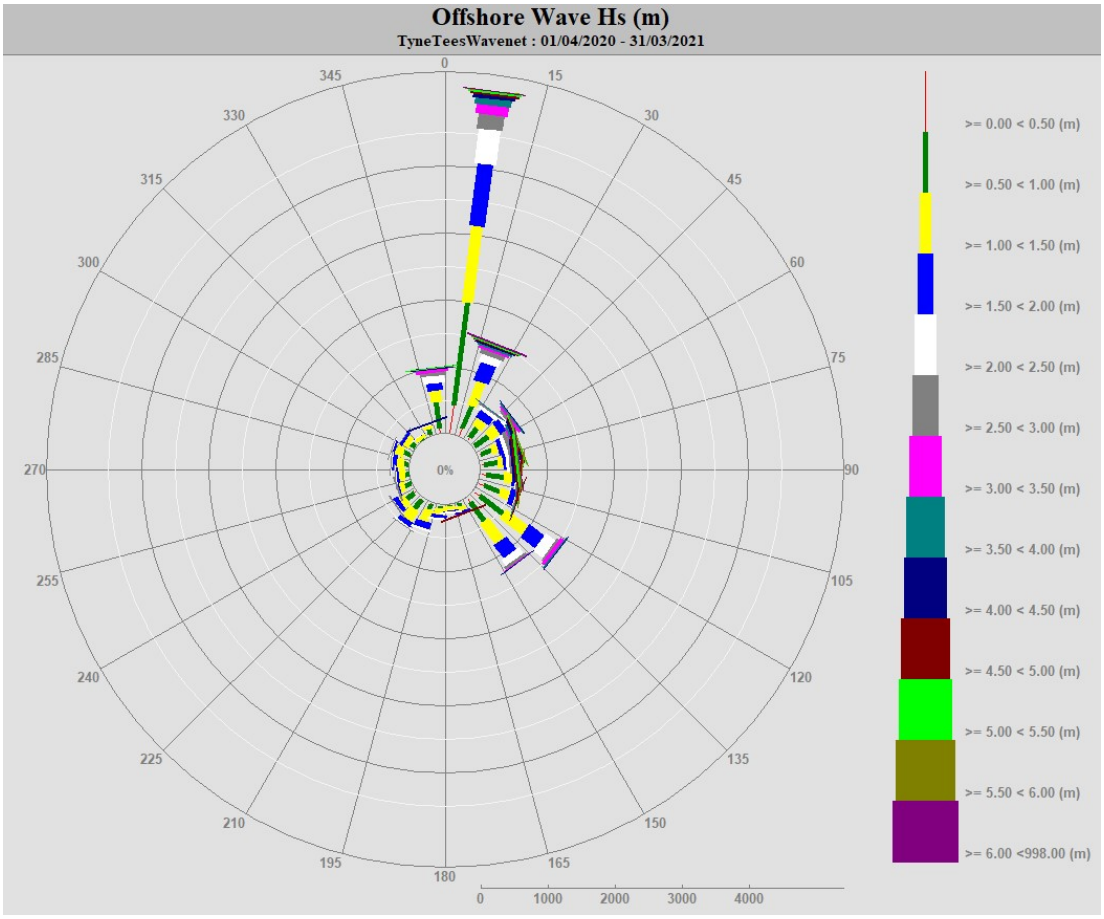


Figure 2.7 Wave Rose at Tyne Tees wave buoy site (WMO ID 62293)

2.3.3 Storm Analysis

A SANDS storm analysis of the Tyne Tees data set was undertaken using a wave height threshold of 4m and a storm separation threshold of 120 hours. This allows extraction of typically between three and ten of the biggest storms each year. The period of data examined ran from 07/12/2006 to 31/03/2021. As noted above, the analyses reported in previous reports have been updated by repeating the storms analysis with the quality controlled post-recovery data.

The storm analysis results are presented in Table 2-4 below. To aid interpretation of the results in Table 2-4, alternate (calendar) years have been shaded and the storm with the largest significant wave height each year has been highlighted in **bold text**. The annual storm with the highest wave energy at peak has also been highlighted in **bold red text** as this depends on wave period as well as wave height and so is not always the same as the largest wave height.

The storms mostly arrive from the north to northeast direction, 0 to 40 degrees, which has the longest fetch, but there are also a significant number of storms from other directions, particularly 80 to 140 degrees. The storm with largest Hs at peak (Hs = 8.3m) occurred on 27th January 2019, but was a relatively short duration storm (28hrs).

Comparing the annual storm records, it can be seen that 2010 had the most storms (13 no.). The year of 2010 was also unusual in that the largest storm had an incident direction of 73 degrees at peak, whereas in most other years direction at peak of the largest storm was from the north to northeast sector (0 to 45 degrees). The longest duration storm (226hrs) was in 2012 and this also had an unusual direction at peak of 96 degrees. From these results we might expect that the alongshore drift on the Cell 1 beaches in 2010 and 2012 to have been atypical with unusual changes from these storm conditions. This was indeed noted in several of the 2010 Full Measures reports. For example, the Hartlepool report noted unusual beach lowering along North Sands, and there was significant beach lowering at a number of locations at Sunderland.

The previously noted year with the fewest storms was 2011 (3 no.). This was reflected by accretion recorded in a number of the annual Full Measures reports. For example, recovery of the beaches at North Sands and Middleton beaches in Hartlepool, and recovery of beaches was noted at Sunderland.

The winter of 2012 to 2013 suffered with larger storms than usual, with the third largest peak wave height recorded on 23rd March 2013. The longest duration storm in the record was from 5th to 15th December 2012. The storm surge that damaged many defences and received significant media attention on 5th and 6th December 2013 does not appear to have had exceptional wave conditions at the Tyne Tees buoy, with a peak significant wave height of 4.7m and storm duration of 38 hours. However, the wave period was over 14 seconds, which is unusual and the longest storm wave period recorded.

There were only four storms in 2016, with one in January, one in April, and two in November. None of these storms appear particularly atypical from the overall record, although the storm in April was from the south-west. In 2017 there were eleven storms recorded above the threshold, the second highest number. The storm on 13th January 2017 had the fourth largest peak wave height recorded, and the second highest energy at peak.

In 2018, there were five storms recorded but in the first quarter of 2019 alone this was already exceeded by six storms. The storm with the greatest significant wave height in the entire Tyne Tees record to date occurred on 27th January 2019, reaching 8.3m in height. Four further storms were recorded in quarters two to four of 2019 (with the greatest significant wave height being 4.7m recorded on 9th December 2019) taking the total number for that year to ten.

There were no storms in the first quarter of 2020, but six through the rest of that year. The greatest significant wave height recorded was 6.6m on 25th September 2020, corresponding with the highest wave energy at peak.

In the first quarter of 2021, one storm exceeded the storm threshold on 2nd February 2021.

Table 2-4 Storm Analysis at Tyne Tees WaveNet Buoy (data to 31st March 2021)

General Storm Information							At Peak					
Start Time	End Time	Dur (hr)	Peak of Storm[1]	Mean Dir (°)	No. Events	Mean Dir Vector (°)	Hs (m)	Tp (s)	Tz (s)	Dir (°)	Energy @ Peak (KJ/m/s)	Total Energy (KJ/m)
19/03/2007 10:30	21/03/2007 05:30	43.0	20/03/2007 14:30	21	73	79.0	6.2	14.8	8.5	23	1.7 E+4	1.6 E+7
25/06/2007 20:00	26/06/2007 13:30	17.5	26/06/2007 10:00	33	28	81.5	4.4	10.3	7.2	23	4.0 E+3	2.7 E+6
26/09/2007 03:00	27/09/2007 05:00	26.0	26/09/2007 19:00	10	36	80.3	4.6	13.8	7.6	6	7.8 E+3	4.1 E+6
08/11/2007 20:00	**12/11/2007 15:00**	**91.0**	**09/11/2007 08:30**	**14**	**64**	**78.7**	**6.2**	**15.9**	**9.0**	**6**	**1.9 E+4**	**1.9 E+7**
19/11/2007 03:30	25/11/2007 21:30	162.0	23/11/2007 05:00	74	59	78.7	4.9	12.7	7.6	17	7.6 E+3	8.2 E+6
08/12/2007 03:00	10/12/2007 14:30	59.5	08/12/2007 03:30	65	11	85.0	4.1	12.8	7.6	17	5.4 E+3	1.2 E+6
03/01/2008 10:30	04/01/2008 01:30	15.0	03/01/2008 23:30	77	24	14.6	4.2	10.9	7.6	62	4.2 E+3	2.5 E+6
01/02/2008 15:00	02/02/2008 09:30	18.5	02/02/2008 00:00	37	34	80.8	6.0	16.4	9.0	17	1.9 E+4	9.6 E+6
10/03/2008 08:30	10/03/2008 12:30	4.0	10/03/2008 11:00	146	9	307.5	4.6	9.6	6.5	141	3.8 E+3	7.3 E+5
17/03/2008 15:00	**25/03/2008 03:00**	**180.0**	**22/03/2008 05:00**	**59**	**78**	**83.8**	**7.9**	**14.8**	**9.0**	**6**	**2.7 E+4**	**2.3 E+7**
05/04/2008 22:00	07/04/2008 05:00	31.0	06/04/2008 19:00	45	22	83.7	4.6	13.9	7.6	6	7.9 E+3	3.3 E+6
20/07/2008 16:00	21/07/2008 09:30	17.5	20/07/2008 23:30	15	8	76.0	4.2	11.8	7.6	11	4.9 E+3	9.1 E+5
03/10/2008 03:00	03/10/2008 20:30	17.5	03/10/2008 16:30	30	32	82.4	4.7	13.6	7.6	23	8.1 E+3	5.2 E+6
21/11/2008 04:00	25/11/2008 12:30	104.5	22/11/2008 11:30	15	112	75.8	6.0	15.6	8.5	11	1.7 E+4	2.2 E+7
10/12/2008 12:00	13/12/2008 18:00	78.0	13/12/2008 08:00	109	37	332.1	4.9	10.0	7.2	129	4.7 E+3	4.0 E+6
31/01/2009 16:30	03/02/2009 09:00	64.5	02/02/2009 22:00	84	57	7.2	5.8	11.4	8.5	84	8.7 E+3	8.1 E+6
23/03/2009 20:30	28/03/2009 20:30	120.0	28/03/2009 18:30	92	26	89.6	4.9	11.0	7.6	0	5.7 E+3	3.2 E+6
10/07/2009 01:30	10/07/2009 02:30	1.0	10/07/2009 01:30	13	2	79.0	4.2	11.9	7.2	11	5.0 E+3	2.3 E+5
29/11/2009 20:00	**30/11/2009 15:00**	**19.0**	**30/11/2009 00:30**	**17**	**39**	**73.3**	**6.0**	**11.2**	**8.0**	**11**	**9.0 E+3**	**6.3 E+6**
17/12/2009 10:30	18/12/2009 05:00	18.5	17/12/2009 19:30	64	36	26.2	5.4	12.7	8.0	68	9.4 E+3	5.7 E+6
30/12/2009 09:00	30/12/2009 23:00	14.0	30/12/2009 12:30	84	25	7.9	5.1	9.0	7.2	90	4.1 E+3	2.3 E+6
06/01/2010 05:30	06/01/2010 11:00	5.5	06/01/2010 06:30	30	10	63.7	4.2	12.7	7.2	11	5.7 E+3	1.1 E+6
29/01/2010 10:30	30/01/2010 00:30	14.0	29/01/2010 22:30	6	29	83.7	5.4	10.2	8.0	6	6.1 E+3	3.0 E+6
26/02/2010 22:30	27/02/2010 02:30	4.0	27/02/2010 01:00	18	7	72.4	4.6	10.1	7.6	17	4.2 E+3	7.0 E+5
19/06/2010 07:00	20/06/2010 08:30	25.5	19/06/2010 20:00	21	49	69.2	5.4	12.7	7.6	23	9.4 E+3	8.5 E+6
29/08/2010 14:00	30/08/2010 06:30	16.5	29/08/2010 22:30	145	27	91.8	4.9	10.6	7.6	0	5.3 E+3	2.9 E+6
06/09/2010 22:30	07/09/2010 16:00	17.5	07/09/2010 15:30	101	23	353.1	4.6	10.5	8.0	90	4.5 E+3	2.3 E+6
17/09/2010 07:00	17/09/2010 18:30	11.5	17/09/2010 08:30	10	17	80.7	4.7	13.1	8.0	11	7.5 E+3	2.9 E+6
24/09/2010 03:00	26/09/2010 00:00	45.0	24/09/2010 10:00	19	89	72.9	5.3	12.1	8.0	11	8.0 E+3	1.3 E+7
19/10/2010 23:30	24/10/2010 16:30	113.0	20/10/2010 10:00	13	17	78.2	4.2	13.4	7.2	17	6.4 E+3	1.9 E+6
08/11/2010 14:00	**09/11/2010 20:30**	**30.5**	**09/11/2010 10:00**	**87**	**60**	**3.4**	**5.6**	**10.5**	**8.0**	**73**	**6.9 E+3**	**7.8 E+6**
17/11/2010 11:00	17/11/2010 18:30	7.5	17/11/2010 12:00	135	10	322.2	4.7	9.2	6.9	129	3.7 E+3	8.1 E+5
29/11/2010 19:30	02/12/2010 08:30	61.0	29/11/2010 21:00	80	46	11.7	5.1	11.2	7.6	56	6.3 E+3	5.5 E+6

General Storm Information							At Peak					
Start Time	End Time	Dur (hr)	Peak of Storm[1]	Mean Dir (°)	No. Events	Mean Dir Vector (°)	Hs (m)	Tp (s)	Tz (s)	Dir (°)	Energy @ Peak (KJ/m/s)	Total Energy (KJ/m)
16/12/2010 15:00	17/12/2010 06:30	15.5	17/12/20 10 03:30	10	27	80.5	4.6	12.5	7.6	17	6.4 E+3	3.2 E+6
23/07/2011 14:00	**24/07/2011 11:00**	**21.0**	**24/07/20 11 03:00**	**23**	**39**	**67.1**	**4.7**	**12.8**	**7.6**	**17**	**7.2 E+3**	**5.8 E+6**
24/10/2011 18:30	25/10/2011 09:30	15.0	25/10/20 11 09:30	103	26	348.5	4.1	11.3	6.9	79	4.2 E+3	2.6 E+6
09/12/2011 08:30	09/12/2011 12:00	3.5	09/12/20 11 10:30	6	6	83.8	4.5	14.3	8.3	6	**8.0 E+3**	1.2 E+6
05/01/2012 15:30	06/01/2012 05:00	13.5	06/01/20 12 03:00	11	23	79.5	4.6	12.5	7.6	17	6.4 E+3	2.9 E+6
03/04/2012 13:30	04/04/2012 10:30	21.0	03/04/20 12 16:00	64	43	26.5	5.3	10.5	7.3	49	6.0 E+3	5.5 E+6
24/09/2012 08:30	25/09/2012 10:30	26.0	25/09/20 12 01:30	74	50	16.7	4.7	12.3	8.0	62	6.7 E+3	7.4 E+6
26/10/2012 16:30	27/10/2012 14:30	22.0	26/10/20 12 23:00	10	37	80.5	4.9	15.3	7.6	11	**1.1 E+4**	5.7 E+6
05/12/2012 16:00	15/12/2012 01:30	225.5	14/12/20 12 19:30	53	47	38.4	5.4	10.5	7.6	96	6.4 E+3	5.6 E+6
20/12/2012 06:00	**21/12/2012 14:30**	**32.5**	**20/12/20 12 23:00**	**103**	**62**	**347.6**	**5.6**	**11.3**	**8.0**	**96**	**8.0 E+3**	**8.6 E+6**
18/01/2013 18:30	22/01/2013 06:00	83.5	21/01/20 13 10:00	81	56	8.9	6.7	11.2	8.5	84	1.1 E+4	1.1 E+7
06/02/2013 08:00	07/02/2013 06:00	22.0	06/02/20 13 12:30	42	45	82.2	5.4	11.9	7.6	11	8.2 E+3	6.7 E+6
07/03/2013 21:00	10/03/2013 21:30	72.5	08/03/20 13 04:00	65	40	25.5	4.9	10.7	7.6	73	5.4 E+3	4.4 E+6
18/03/2013 09:00	25/03/2013 01:30	160.5	23/03/20 13 14:30	85	157	5.0	6.0	12.1	8.0	90	1.1 E+4	2.8 E+7
23/05/2013 18:00	**24/05/2013 12:00**	**18.0**	**23/05/20 13 22:30**	**13**	**35**	**77.3**	**6.7**	**12.5**	**8.5**	**17**	**1.4 E+4**	**7.1 E+6**
10/09/2013 13:00	10/09/2013 19:30	6.5	10/09/20 13 14:00	11	14	79.4	4.4	11.0	7.2	11	4.6 E+3	1.5 E+6
09/10/2013 21:30	11/10/2013 09:00	35.5	10/10/20 13 21:30	65	65	79.5	5.6	12.5	7.8	25	9.5 E+3	1.3 E+7
29/11/2013 22:30	30/11/2013 06:30	8.0	30/11/20 13 00:30	42	17	84.5	5.6	12.7	8.0	11	1.0 E+4	3.3 E+6
05/12/2013 14:00	07/12/2013 04:30	38.5	06/12/20 13 20:00	24	60	80.8	4.7	17.0	9.0	6	1.3 E+4	1.2 E+7
27/12/2013 09:30	27/12/2013 12:30	3.0	27/12/20 13 10:00	218	3	248.9	4.1	7.3	6.5	203	1.8 E+3	1.3 E+5
05/02/2014 04:00	05/02/2014 18:00	14.0	05/02/20 14 05:30	139	9	318.6	4.4	9.3	6.9	129	3.3 E+3	7.2 E+5
12/02/2014 20:00	**14/02/2014 19:30**	**47.5**	**12/02/20 14 21:00**	**172**	**12**	**279.1**	**4.6**	**8.9**	**6.5**	**141**	**3.2 E+3**	**8.6 E+5**
21/10/2014 22:00	22/10/2014 01:30	3.5	21/10/20 14 23:00	6	5	84.0	4.4	11.5	7.6	6	**5.0 E+3**	6.0 E+5
31/01/2015 09:30	01/02/2015 19:30	34.0	31/01/20 15 23:30	66	66	87.9	6.2	13.1	8.0	6	1.3 E+4	1.3 E+7
03/09/2015 05:30	04/09/2015 06:00	24.5	03/09/20 15 18:30	13	15	78.1	4.4	10.5	6.8	11	4.3 E+3	1.6 E+6
21/11/2015 01:30	**21/11/2015 14:30**	**13.0**	**21/11/20 15 05:30**	**72**	**27**	**85.9**	**7.1**	**11.8**	**8.5**	**356**	**1.4 E+4**	**5.7 E+6**
30/12/2015 09:30	07/01/2016 12:00	194.5	03/01/20 16 13:00	81	190	10.3	5.3	11.8	8.5	75	7.6 E+3	2.5 E+7
14/01/2016 11:00	16/01/2016 03:00	40.0	15/01/20 16 23:30	58	19	80.8	4.7	12.5	7.8	27	6.9 E+3	2.1 E+6
25/04/2016 19:30	26/04/2016 03:00	7.5	25/04/20 16 23:00	239	13	89.2	5.1	11.8	7.9	359	7.1 E+3	1.7 E+6
05/11/2016 04:00	07/11/2016 02:30	46.5	06/11/20 16 20:00	76	82	65.2	5.4	12.5	8.0	63	**8.9E+3**	1.3 E+7
21/11/2016 18:30	**21/11/2016 23:30**	**5.0**	**21/11/20 16 20:30**	**63**	**11**	**27.7**	**5.5**	**9.5**	**7.3**	**58**	**5.3 E+3**	**1.2 E+6**
02/01/2017 05:00	04/01/2017 22:00	65.0	04/01/20 17 14:00	13	35	77.9	5.0	14.3	8.3	10	1.0 E+4	6.0 E+6
13/01/2017 08:00	**14/01/2017 08:00**	**24.0**	**13/01/20 17 16:30**	**85**	**48**	**78.1**	**6.5**	**15.4**	**8.8**	**11**	**2.0 E+4**	**1.3 E+7**
12/02/2017 02:30	12/02/2017 21:00	18.5	12/02/20 17 07:00	74	29	17.3	4.4	10.5	7.1	66	4.3 E+3	2.9 E+6

General Storm Information							At Peak					
Start Time	End Time	Dur (hr)	Peak of Storm[1]	Mean Dir (°)	No. Events	Mean Dir Vector (°)	Hs (m)	Tp (s)	Tz (s)	Dir (°)	Energy @ Peak (KJ/m/s)	Total Energy (KJ/m)
23/02/2017 15:00	23/02/2017 18:30	3.5	23/02/2017 15:00	14	5	77.1	4.3	12.5	6.7	13	5.6 E+3	5.8 E+5
25/04/2017 19:00	26/04/2017 05:30	10.5	26/04/2017 05:30	145	7	88.62	4.0	11.8	6.9	8	4.5 E+3	7.3 E+5
08/05/2017 02:00	08/05/2017 03:00	1	08/05/2017 02:30	20	3	70.63	4.3	11.1	7.1	25	4.6 E+3	3.7 E+5
29/10/2017 05:30	29/10/2017 13:30	8	29/10/2017 13:00	7	15	82.68	4.5	12.5	7.8	14	6.3 E+3	1.9 E+6
12/11/2017 12:00	12/11/2017 22:00	10	12/11/2017 16:00	204	18	91.8	4.6	9.1	7.1	353	3.5 E+3	1.6 E+6
29/11/2017 00:00	01/12/2017 03:30	51.5	29/11/2017 03:30	42	46	85.44	4.5	11.8	7.3	6	5.4 E+3	5.1 E+6
08/12/2017 07:00	09/12/2017 20:00	37	08/12/2017 17:00	28	67	80.12	5.6	14.3	8.3	18	1.3 E+4	1.5 E+7
27/12/2017 21:30	28/12/2017 02:30	5	28/12/2017 00:00	14	5	76.4	4.1	12.5	7.3	18	5.3 E+3	6.7 E+5
06/01/2018 12:00	06/01/2018 15:00	3	06/01/2018 12:00	9	2	80.64	4.0	12.5	7.4	8	5.0 E+3	2.7 E+5
01/02/2018 13:30	02/02/2018 05:00	15.5	01/02/2018 23:30	112	23	87.88	4.7	10.5	7.5	3	4.8 E+3	2.5 E+6
26/10/2018 21:00	30/10/2018 19:00	94.0	27/10/18 15:00	65	49	78.58	5.5	11.1	7.70	10	7.4 E+3	6.5 E+6
20/11/2018 06:00	21/11/2018 16:00	34.0	21/11/18 07:30	80	62	10.20	5.1	11.1	7.30	69	6.3 E+3	8.2 E+6
15/12/2018 15:00	**16/12/2018 02:30**	**11.5**	**15/12/18 20:30**	**131**	**23**	**320.36**	**6.1**	**11.1**	**7.80**	**129**	**8.9 E+3**	**4.0 E+6**
01/01/2019 19:30	02/01/2019 14:30	19.0	02/01/19 04:30	10	29	80.38	4.1	16.7	8.30	10	9.2 E+3	4.8 E+6
08/01/2019 05:00	09/01/2019 07:00	26.0	08/01/19 06:30	27	51	81.61	4.8	13.3	7.80	10	8.1 E+3	7.8 E+6
17/01/2019 04:00	17/01/2019 15:30	11.5	17/01/19 13:30	85	22	87.03	5.3	10.5	7.80	1	6.2 E+3	2.7 E+6
27/01/2019 03:30	**28/01/2019 07:30**	**28.0**	**27/01/19 14:00**	**101**	**47**	**78.41**	**8.3**	**12.5**	**9.50**	**359**	**2.1 E+4**	**9.6 E+6**
07/03/2019 18:30	08/03/2019 08:30	14.0	07/03/19 21:00	158	25	87.71	5.2	10.5	7.70	350	5.8 E+3	3.1 E+6
18/03/2019 02:00	18/03/2019 09:30	7.5	18/03/19 03:30	15	11	76.05	4.7	12.5	8.40	30	6.9 E+3	1.8 E+6
04/05/2019 03:30	04/05/2019 16:30	13.0	04/05/19 11:00	9	26	80.71	4.6	13.3	7.40	10	7.4 E+3	3.5 E+6
04/11/2019 21:00	05/11/2019 11:30	14.5	04/11/19 23:30	44	27	46.58	4.5	11.8	7.80	48	5.7 E +3	3.5 E+6
28/11/2019 13:30	29/11/2019 08:00	18.5	29/11/19 04:30	30	19	77.45	4.2	11.8	7.30	28	4.9 E+3	2.1 E+6
09/12/2019 06:30	10/12/2019 01:00	18.5	09/12/19 18:00	111	35	86.85	4.7	13.3	8.70	8	7.80 E+3	5.3 E+6
06/06/2020 07:30	06/06/2020 09:00	1.5	06/06/20 08:00	358	4	101.85	4.18	10.0	6.90	350	3.45E+3	3.8 E+5
26/08/2020 08:30	29/08/2020 20:00	83.5	29/08/20 16:00	11	29	79.37	4.66	10.0	7.00	10	4.28E+3	2.5 E+6
25/09/2020 06:30	**27/09/2020 08:30**	**50.0**	**25/09/20 17:30**	**15**	**101**	**74.93**	**6.57**	**11.1**	**8.20**	**23**	**1.05E+4**	**1.8 E+7**
19/11/2020 08:00	19/11/2020 21:30	13.5	19/11/20 12:00	57	27	80.62	5.25	13.3	8.70	4	9.61E+3	5.7 E+6
30/11/2020 23:00	04/12/2020 21:00	94.0	04/12/20 18:30	122	9	354.50	4.75	10.0	7.30	93	4.45E+3	9.7 E+5
24/12/2020 16:30	25/12/2020 02:00	9.5	24/12/20 18:00	10	18	79.85	4.97	10.0	7.30	6	4.87 E+3	2.0 E+6
02/02/2021 22:30	13/02/2021 17:30	259.0	07/02/21 21:00	82	212	8.95	5.69	11.8	7.80	91	8.89 E+3	2.97 E+7

Notes: [1] The time of the storm peak is based on peak wave energy, which is calculated in SANDS using $E = \rho.g.H_s^2.L_o/8$, with the offshore wave length $L_o = g.Tp^2/2.\pi$

2.4 Whitby Waverider Buoy

In the baseline report, one full year's data for Whitby (October 2010 to October 2011) was analysed in SANDS to prepare a baseline wave rose and scatter table. The new data collected is from a very similar location and now covers the period from 17th January 2013 to 31st March 2021. The data were imported into SANDS for comparison and analysis alongside the other available monitoring data; see Figure 2.5.

Supporting monthly plots of the new data are provided in Appendix C. The Whitby wave buoy was out of service between 17/02/2020 and 25/04/2020. This unusually long outage period was due to UK Government's lockdown restrictions associated with the Coronavirus (COVID-19) pandemic which delayed the ability to rectify the issue. The buoy came also adrift of its station and did not record during the periods between 5th to 17th June 2020 and 24th September to 6th November 2020.

2.4.1 Wave Height vs Peak Period

The Whitby wave height and zero crossing period data has been plotted on a scatter plot for 1st April to 31st March each year in Figure 2.8. Different symbols have been used to distinguish the baseline data of 2010/11 from different subsequent years of the current deployment. The largest measured significant wave height to date of 6.7 was recorded in the 2015/16 data, with an associated zero crossing wave period of 8.3 secs. The longest zero crossing period wave (11.4 secs) occurred in the 2015/16 data, but with a very low corresponding significant wave height (0.1m). The highest significant wave height recorded during this new data set was 4.6m with an associated wave period of 7.5 sec on the 7th February 2021; whilst the longest zero crossing period wave was 10.8 sec with an corresponding significant wave height of 2.4m on the 20th November 2020.

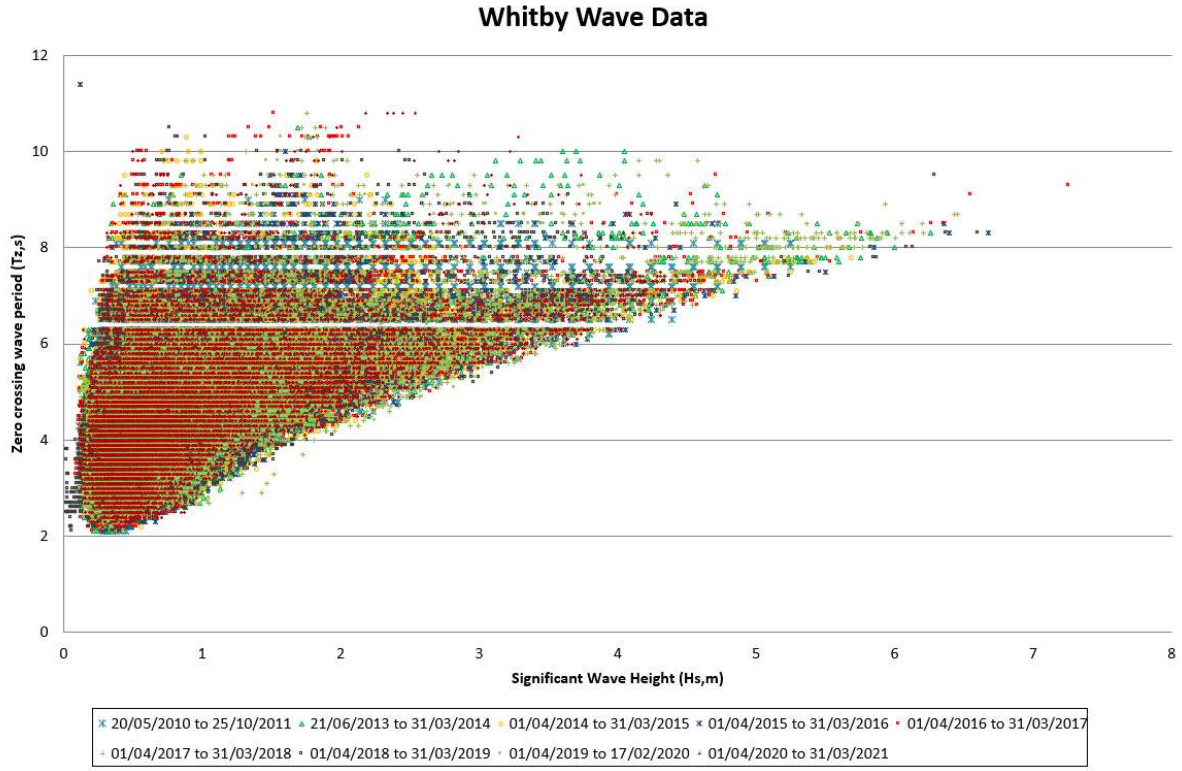
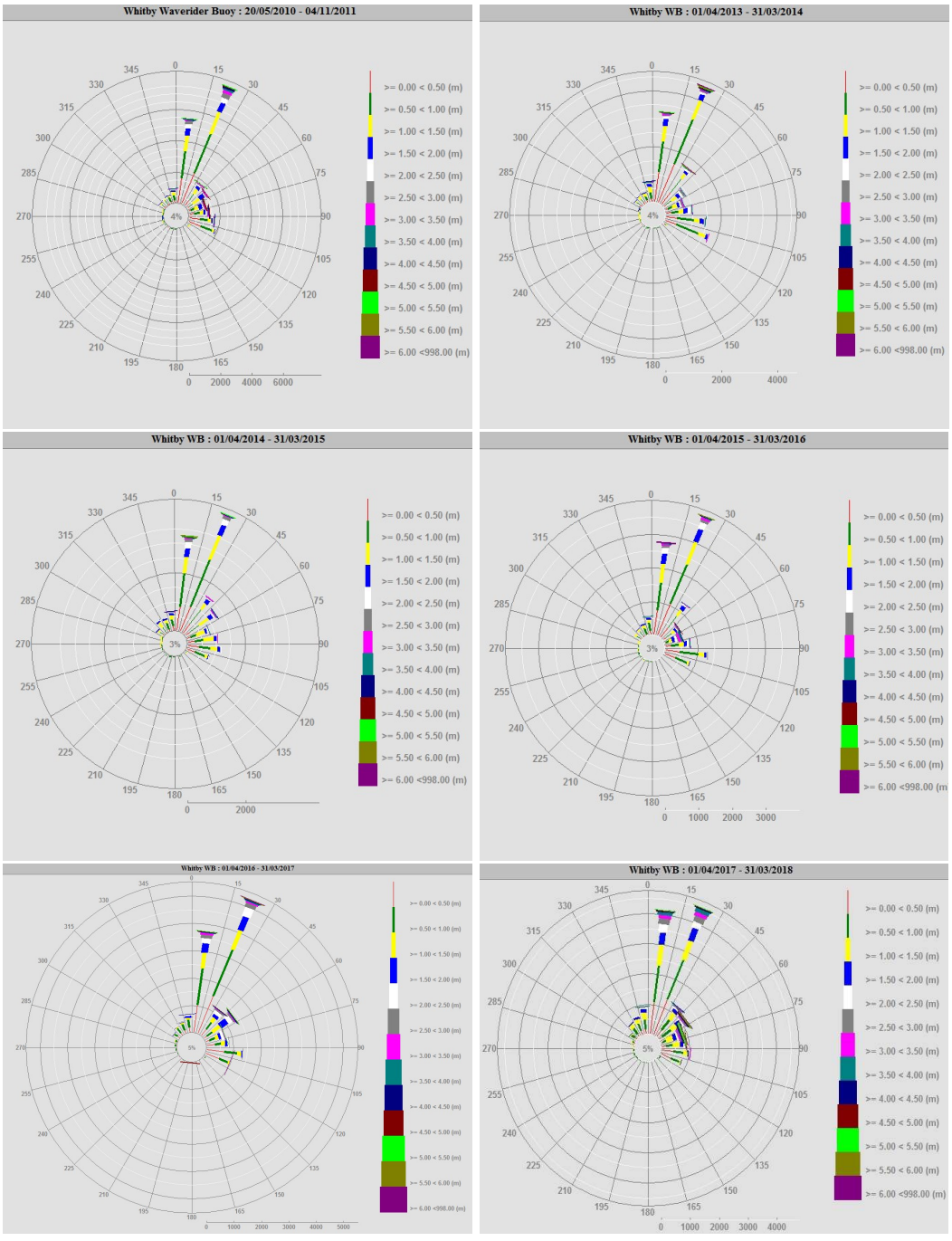


Figure 2.8 Scatter plot of Wave Height Vs Zero crossing period at Whitby wave buoy

2.4.2 Wave Rose

The directional data of the wave record has also been used to plot wave roses for the baseline dataset and all subsequent data sets, all of which show a quite similar distribution, see Figure 2.9 below. The wave roses show that the waves predominantly approach the coastline at Whitby from the north by northeast direction (0 to 30 degrees). In the most recent year's record, a larger than usual proportion of waves approached the buoy from the south-east sector (105-120 degrees).



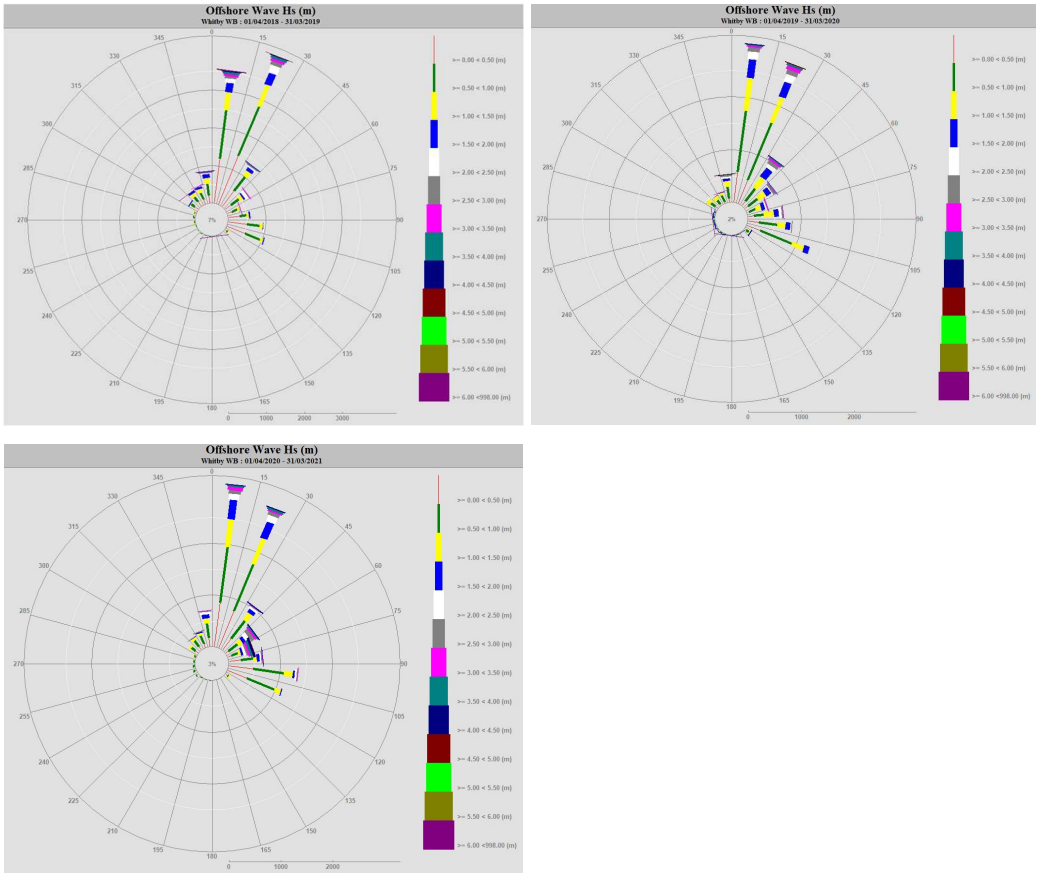


Figure 2.9 Wave Roses at Whitby wave buoy site
(original deployment in 2010/11 and subsequent data annually from 2013/14 to date)

2.4.3 Storm Analysis

A storm analysis of the baseline Whitby data set was originally undertaken for the baseline report using a wave height threshold of 4m and a storm separation threshold of 120 hours. The period of data examined ran from 20/05/2010 to 25/10/2011. The analysis was revised for the 2014/15 report using a slightly lower threshold of 3.9m to detect more storms and the updated results with the latest data now to 31/03/2021 are presented in Table 2-5 below. The storms mostly arrive from the north to east-northeast (5 to 66 degrees). The storm in the baseline record with the previous largest wave height (5.1m H_{mo}) at peak occurred on 25th September 2010. The storms analysis of the new data is shown in Table 2-6. To aid interpretation of the results in the storm tables alternate (calendar) years have been shaded and the storm with the largest significant wave height each year has been highlighted in **bold text**. The annual storm with the highest wave energy at peak has also been highlighted in **bold red text** as this depends on wave period as well as wave height and so is not always the same.

Table 2-5 Storm Analysis results for Whitby baseline dataset (20/05/2010 to 25/10/2011)

General Storm Information					At Peak						
Start Time	End Time	Duration (Hours)	Peak of Storm[1]	Mean Dir (°)	No of Events (30 min dataset)	Mean Dir Vector (°)	Hs (m)	Tp (s)	Dir (°)	Energy @ Peak (KJ/m/s)	Total Energy (KJ/m)
19/06/2010 08:30	20/06/2010 09:30	25.0	20/06/2010 00:00	26	47	64.7	4.9	13.5	28	**8.6 E+3**	7.6 E+6
29/08/2010 15:00	30/08/2010 06:30	15.5	29/08/2010 17:30	6	16	84.4	4.4	9.5	6	3.5 E+3	1.4 E+6
17/09/2010 09:00	17/09/2010 12:30	3.5	17/09/2010 11:00	24	3	67.5	4.4	13.5	22	6.9 E+3	5.8 E+5
24/09/2010 05:30	**26/09/2010 04:00**	**46.5**	**25/09/2010 17:00**	**24**	**84**	**66.6**	**5.1**	12.2	**28**	**7.5 E+3**	**1.2 E+7**
20/10/2010 08:00	20/10/2010 11:30	3.5	20/10/2010 11:30	26	3	69.0	3.9	11.0	22	4.9 E+3	3.2 E+5
08/11/2010 17:30	09/11/2010 19:00	25.5	09/11/2010 05:30	66	28	25.4	4.7	11.8	68	5.3 E+3	3.1 E+6
29/11/2010 19:30	02/12/2010 01:30	54.0	29/11/2010 22:00	61	24	29.9	4.7	12.8	56	6.1 E+3	2.8 E+6
16/12/2010 19:00	16/12/2010 20:30	1.5	16/12/2010 20:30	14	2	78.5	3.9	9.1	17	3.6 E+3	1.7 E+5
23/07/2011 15:30	24/07/2011 11:00	19.5	24/07/2011 03:00	28	36	62.1	4.2	10.8	22	5.8 E+3	4.9 E+6

Notes: [1] The time of the storm peak is based on peak wave energy, which is calculated in SANDS using $E = \rho.g.H_s^2.L_o/8$, with the offshore wave length $L_o = g.Tp^2/2.\pi$

Comparing the storm data at Whitby in Table 2-5 and Table 2-6 with those in Table 2-1 and Table 2-2 for Newbiggin, it can be seen that several of the storms were recorded at both locations, but the durations, peak wave heights and directions for the storms were quite different. Due to the differing conditions the storm analysis also identified different storms at both locations.

Table 2-6 Storm analysis for Whitby WB (data 17/01/2013 to 31/03/2021)

General Storm Information							At Peak					
Start Time	End Time	Duration (hr)	Peak of Storm	Mean Dir (°)	No of Events	Mean Dir Vector	Hs (m)	Tp (s)	Tz (s)	Dir (°)	Energy @ Peak (KJ/m/s)	Total Energy (KJ/m)
21/01/2013 02:30	22/01/2013 03:00	24.5	21/01/2013 14:30	64	38	26.7	5.0	11.1	8.2	61	6.0 E+3	5.0 E+6
06/02/2013 11:00	07/02/2013 04:00	17.0	06/02/2013 18:30	17	35	73.5	4.8	11.8	7.1	16	6.4 E+3	4.3 E+6
08/03/2013 03:30	11/03/2013 05:30	74.0	11/03/2013 04:00	58	12	35.5	4.3	10.0	7.1	45	3.7 E+3	1.1 E+6
18/03/2013 18:30	24/03/2013 17:30	143.0	23/03/2013 13:00	70	95	20.3	5.2	11.1	8.2	72	6.6 E+3	1.2 E+7
23/05/2013 21:00	**24/05/2013 12:30**	**15.5**	**24/05/2013 00:00**	**20**	**27**	**70.3**	**5.8**	12.5	**8.3**	**24**	**1.0 E+4**	**5.0 E+6**
10/09/2013 14:00	10/09/2013 22:30	8.5	10/09/2013 16:00	19	17	71.5	4.4	11.1	6.9	24	4.6 E+3	1.8 E+6
10/10/2013 01:30	11/10/2013 06:30	29.0	11/10/2013 00:00	30	57	69.2	5.7	13.3	8.3	31	**1.1 E+4**	1.1 E+7
30/11/2013 00:00	30/11/2013 06:30	6.5	30/11/2013 03:30	16	13	74.8	4.8	12.5	7.4	20	7.1 E+3	2.1 E+6
05/12/2013 20:00	06/12/2013 22:00	26.0	06/12/2013 19:30	20	45	70.6	4.7	16.7	9.1	32	1.2 E+4	8.2 E+6
14/10/2014 04:30	**14/10/2014 05:30**	**1.0**	**14/10/2014 05:30**	**52**	**2**	**40.3**	**4.1**	**8.3**	**6.5**	**53**	**2.3 E+3**	**1.2 E+5**
31/01/2015 10:30	01/02/2015 18:00	31.5	01/02/2015 02:30	14	60	79.1	**5.7**	11.8	7.8	11	8.9 E+3	9.0 E+6
03/09/2015 18:30	04/09/2015 07:00	12.5	03/09/2015 18:30	26	3	64.9	3.9	10.5	6.5	27	3.3 E+3	2.6 E+5
21/11/2015 07:00	**21/11/2015 15:30**	**8.5**	**21/11/2015 07:30**	**16**	**14**	**75.3**	**6.7***	**12.5***	**8.3***	**14**	**1.4 E+4**	**2.7 E+6**
03/01/2016 08:00	06/01/2016 13:00	77.0	03/01/2016 10:00	63	20	29.3	4.7	11.1	8.5	58	5.3 E+3	2.2 E+6
14/01/2016 13:00	16/01/2016 06:00	41.0	14/01/2016 13:30	10	12	80.3	4.7	10.5	7.1	0	4.8 E+3	1.3 E+6
05/11/2016 06:00	07/11/2016 02:00	44.0	05/11/2016 06:00	50	62	58.8	4.8	28.6	8.0	191	**3.8 E+4**	9.7 E+6
21/11/2016 18:30	**21/11/2016 22:30**	**4.0**	**21/11/2016 21:00**	**50**	**9**	**40.8**	**5.1**	**9.1**	**7.4**	**52**	**4.2 E+3**	**8.3 E+5**
02/01/2017 06:30	04/01/2017 21:30	63.0	04/01/2017 12:30	21	32	70.5	4.9	12.5	8.3	23	7.5 E+3	5.0 E+6
13/01/2017 09:30	14/01/2017 03:00	17.5	13/01/2017 19:00	**27**	**24**	**70.5**	**6.6**	**14.3**	**9.1**	**24**	**1.7 E+4**	**5.5 E+6**
12/02/2017 02:30	12/02/2017 19:30	17.0	12/02/2017 05:00	55	26	35.8	4.6	10.5	7.3	48	4.7 E+3	2.7 E+6
23/02/2017 18:00	23/02/2017 19:00	1.0	23/02/2017 18:00	23	2	73.3	4.4	9.1	6.8	14	3.1 E+3	1.2 E+5
29/10/2017 07:30	29/10/2017 14:30	7.0	29/10/2017 14:30	16	11	74.4	4.0	11.8	7.3	18	4.4 E+3	1.2 E+6
12/11/2017 14:00	13/11/2017 00:00	10.0	12/11/2017 18:00	14	17	76.2	4.5	10.0	7.1	7	4.0 E+3	1.5 E+6
28/11/2017 23:00	01/12/2017 04:30	53.5	30/11/2017 23:00	28	29	74.5	4.5	10.5	6.8	10	4.5 E+3	2.9 E+6
08/12/2017 12:00	09/12/2017 15:00	27.0	08/12/2017 21:30	20	52	70.8	5.1	15.4	8.7	18	1.2 E+4	1.2 E+7
01/02/2018 15:30	02/02/2018 05:00	13.5	02/02/2018 02:30	15	14	76.1	4.8	11.1	7.4	18	5.6 E+3	1.4 E+6
28/02/2018 01:30	**02/03/2018 21:00**	**67.5**	**01/03/2018 12:00**	**65**	**114**	**26.9**	**6.1**	**11.8**	**8.3**	**56**	**1.0 E+4**	**1.8 E+7**

General Storm Information							At Peak					
Start Time	End Time	Duration (hr)	Peak of Storm	Mean Dir (°)	No of Events	Mean Dir Vector	Hs (m)	Tp (s)	Tz (s)	Dir (°)	Energy @ Peak (KJ/m/s)	Total Energy (KJ/m)
15/03/2018 16:30	18/03/2018 21:00	76.5	18/03/2018 05:30	61	131	28.9	6.1	11.8	8.3	68	1.0 E+4	2.2 E+7
05/04/2018 00:00	05/04/2018 04:00	4.0	05/04/18 02:30	161	7	83.0	4.6	10.0	7.3	20	4.2 E+3	7.0 E+5
26/10/2018 23:00	27/10/2018 12:00	13.0	27/10/18 03:00	15	12	75.8	4.5	10.0	6.8	17	3.96 E+3	1.22 E+6
08/01/2019 09:30	09/01/2019 06:00	20.5	08/01/19 09:30	16	21	74.9	4.2	13.3	8.7	11	6.21 E+3	2.62 E+6
17/01/2019 10:00	17/01/2019 14:30	4.5	17/01/19 13:00	12	8	79.1	4.1	11.1	6.9	20	4.10 E+3	7.69 E+5
27/01/2019 14:30	**28/01/2019 07:00**	**16.5**	**27/01/19 16:00**	**18**	**26**	**73.2**	**6.6**	**13.3**	**8.3**	**13**	**1.52 E+4**	**5.44 E+6**
08/03/2019 00:30	08/03/2019 01:00	0.5	08/03/19 00:30	170	2	89.8	4.2	10.5	7.1	3	3.76 E+3	2.15 E+5
04/05/2019 07:00	04/05/2019 16:30	9.5	04/05/19 12:00	19	13	71.9	4.1	12.5	6.9	16	5.15 E+3	1.41 E+6
05/11/2019 08:30	08/11/2019 01:30	65.0	05/11/19 08:30	39	5	54.2	4.0	11.1	6.9	32	3.91 E+3	4.06 E+5
28/11/2019 17:00	29/11/2019 06:00	13.0	29/11/19 06:00	25	2	68.2	3.9	11.1	7.3	28	3.85 E+3	1.82 E+5
09/12/2019 08:00	09/12/2019 14:00	6.0	09/12/19 11:00	202	9	91.2	4.1	10.5	6.7	0	3.69 E+3	8.73 E+5
28/08/2020 16:00	**29/08/2020 17:00**	**25.0**	**29/08/20 16:30**	**21**	**7**	**70.1**	**4.3**	**10.5**	**6.8**	**18**	**3.93 E+3**	**5.72 E+5**
19/11/2020 11:00	19/11/2020 18:30	7.5	19/11/20 18:30	16	10	75.3	4.2	13.3	8.7	32	**6.27 E+3**	1.55 E+6
24/12/2020 19:00	24/12/2020 22:30	3.5	24/12/20 19:00	23	5	69.5	4.2	10.5	7.1	20	3.82 E+3	4.69 E+5
03/02/2021 07:30	08/02/2021 17:00	129.5	07/02/21 23:00	66	59	25.3	4.3	11.8	7.3	72	5.05 E+3	6.82 E+6

Note *= As noted in the CCO annual report in Appendix E, the waves were breaking at the buoy location during several hours of this storm.

In 2020, only three storms were recorded, but as noted previously there were some considerable periods of operational downtime; particularly during the tail-end of the 2019/20 winter and the start of the 2020/21 winter. One storm was recorded in the first quarter of 2021.

2.5 Whitby NTSLF Tide Gauge

There is a tide gauge at Whitby that is operated continuously by the National Tide and Sea Level Facility (NTSLF) on behalf of the Environment Agency as part of the main UK tide gauge network. Information on this tide gauge installation is available on the NTSLF website: http://www.ntslf.org/tgi/portinfo?port=Whitby, including the site history reproduced below. The Chart Datum at Whitby is 3m below Ordnance Datum (http://www.ntslf.org/tides/datum). Due to its location in the mouth of the estuary the recorded water levels can be significantly influenced by high freshwater flows in the River Esk.

Whitby Tide Gauge Site history

- 1980 – Installed Aanderaa recorder attached to a pneumatic bubbler
- 1989 – DATARING system installed with full-tide pressure points; the Aanderaa recorder was removed
- 1995 – New steel work with two full-tide and mid-tide measuring systems installed
- 2002 – POL data logger installed.

Note that the issues with missing extreme low water level measurements are noted on the PSMSL website, see further information in Section 3.4.

Data is available on the internet in real time (http://www.ntslf.org/data/realtime?port=Whitby) and quality controlled data can be downloaded from the British Oceanographic Data Centre (BODC) website.

Previous reports have looked at the tide gauge data going back to 1980. Figure 2.10 shows the tide level at Whitby for 1980 to 2016. The latest reports have looked at each year of data as it became available.

Table 2-7 Predicted tide levels at Whitby

Tidal State	Level (m Chart Datum)	Level (m Ordnance Datum)
HAT	6.21	3.21
MHWS	5.59	2.59
MHWN	4.50	1.50
MLWN	2.25	-0.75
MLWS	0.99	-2.01
LAT	0.22	-2.78
Highest predicted 2013	6.03	3.03
Lowest predicted 2013	0.41	-2.59
Highest predicted 2014	6.17	3.17
Lowest predicted 2014	0.32	-2.68
Highest predicted 2015	6.21	3.21
Lowest predicted 2015	0.28	-2.72
Highest predicted 2016	6.14	3.14
Lowest predicted 2016	0.32	-2.68
Highest predicted 2017	5.97	2.97
Lowest predicted 2017	0.48	-2.52
Highest predicted 2018	6.05	3.05
Lowest predicted 2018	0.35	-2.65
Highest predicted 2019	6.16	3.16
Lowest predicted 2019	0.27	-2.73
Highest predicted 2020	6.16	3.16

Tidal State	Level (m Chart Datum)	Level (m Ordnance Datum)
Lowest predicted 2020	0.24	-2.76
Highest predicted 2021	6.01	3.01
Lowest predicted 2021	0.35	-2.65
Highest predicted 2022	5.97	2.97
Lowest predicted 2022	0.45	-2.55

Note: Based on data from http://www.ntslf.org/tgi/portinfo?port=Whitby

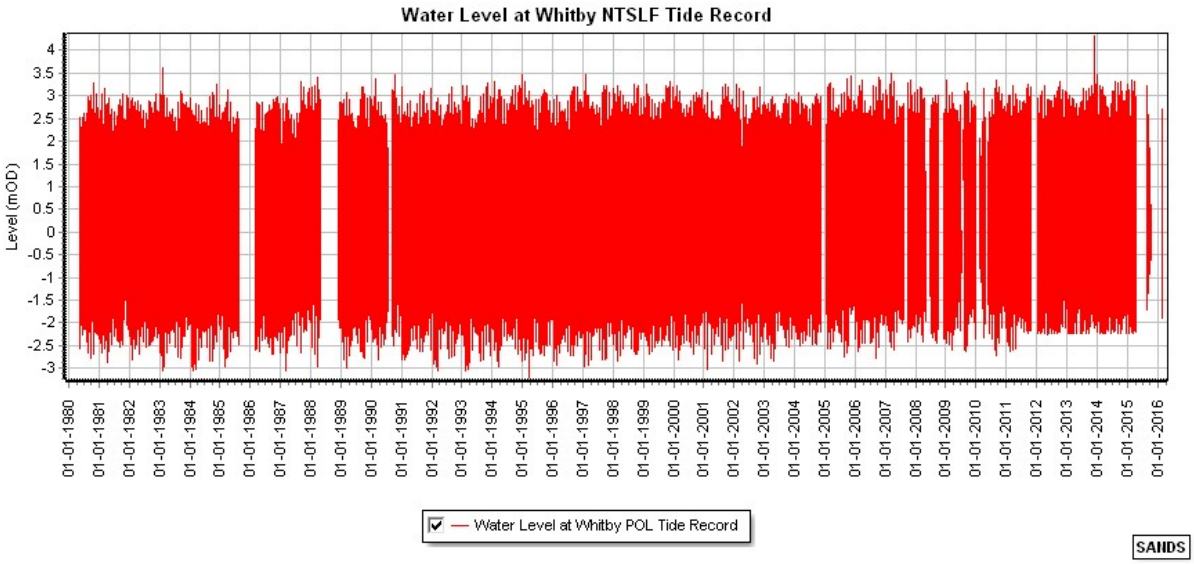


Figure 2.10 Water Level data availability at Whitby NTSLF tide gauge site for 1980-2016

In the 2020/21 dataset, the data for April and May 2020 has been flagged as 'poor' quality by NTSLF and has therefore not been plotted in Figure 2.11. There are no significant gaps in the data between June 2020 and March 2021.

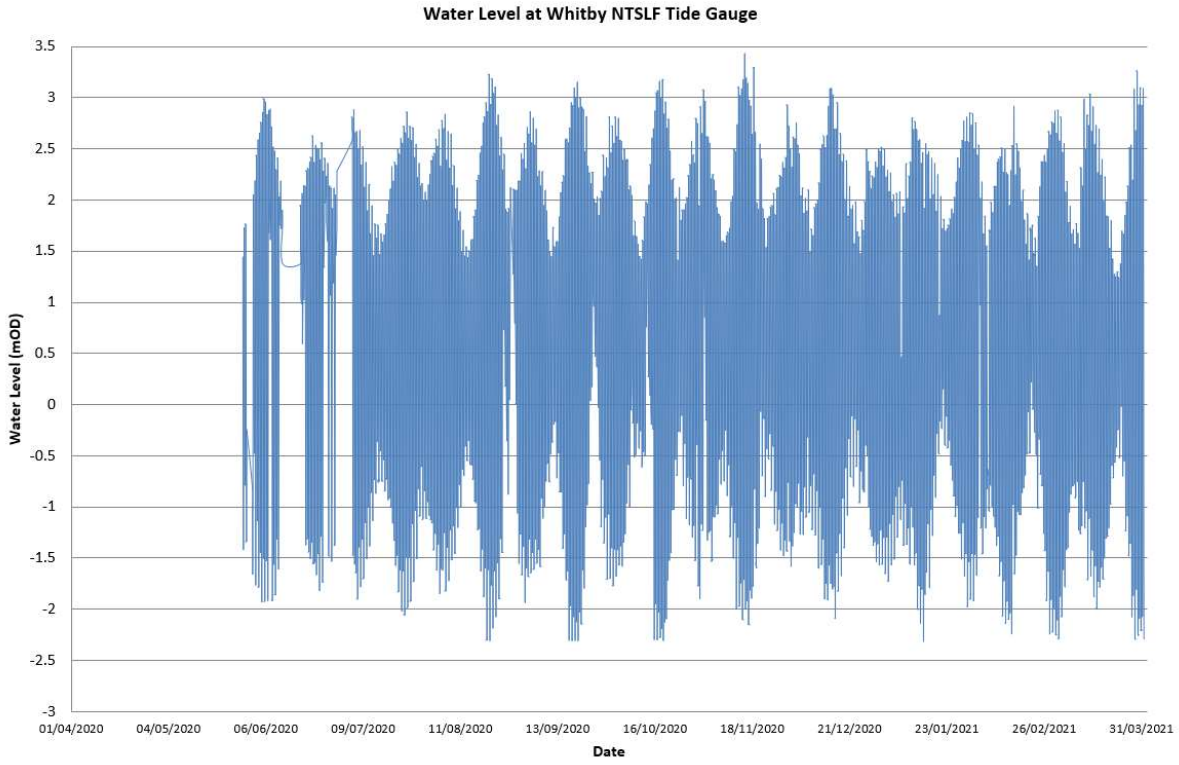


Figure 2.11 Water level data record at Whitby NTSLF tide gauge site for 2020-2021

In 2020/21, the maximum water level recorded at the Whitby NTSLF tide gauge was 3.43mOD on 16th November 2020.

2.6 Whitby Harbour Tide Gauge

A tide gauge was deployed in Whitby by Fugro Emu for the Cell 1 regional monitoring programme during May 2013. Unfortunately, there were problems with the deployment and the instrumentation such that reliable data was not received until early 2014. Data from this tide gauge was therefore first included in the Cell 1 report on wave and tide data for 2014/15.

The data set for 2020 was obtained from the Channel Coast Observatory (CCO) following their quality review and assessment of the data. The CCO report is included in Appendix E and the standard tidal heights they derived are presented in Table 2-8 below.

Tidal levels		
Observation period	January 2014 – July 2015	
Tide Level	Elevation (OD)	Elevation (CD)
HAT	3.14	6.14
MHWS	2.52	5.52
MHWN	1.41	4.41
MLWN	-0.79	2.21
MLWS	-1.91	1.09
LAT	-2.91	0.09

Table 2-8 Standard tidal levels at Whitby Harbour Tide Gauge (CCO,2020)

The data from the two Whitby tide gauges has been compared by plotting the data together. An example for a short period in 2014 is shown in Figure 2.12. As noted in the 2014/15 report, comparing the derived standard tidal level data in Table 2-7 and Table 2-8, it is apparent that the levels recorded from the Cell 1 gauge are around 0.2m lower than those from the nearby NTSLF gauge. Analysis of the two data sets from February to December 2014 revealed a mean difference of -0.18m and standard deviation of 0.02m. This takes account of concurrent measurements only and ignores gaps. The NTSLF gauge did not record (or had flagged quality issues for) levels for low water on the larger spring tides, which is discussed further in Sections 3.4 and 4.2. Some of the lowest tides are also not picked up by the Cell 1 gauge.

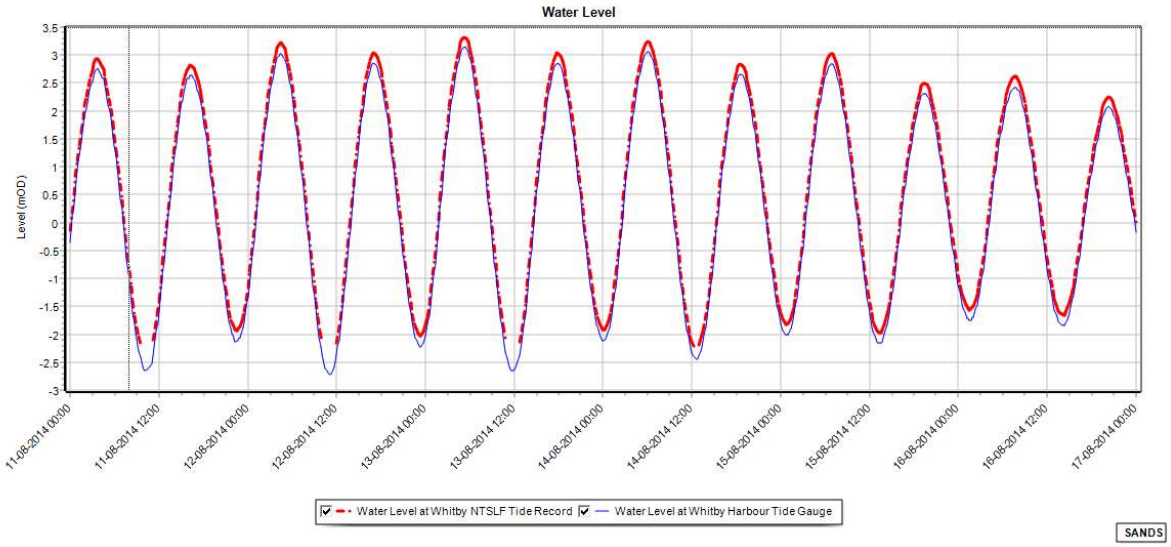


Figure 2.12 Example comparison of water level data from Whitby tide gauges

The reason for the 0.18m difference between the recorded levels remains uncertain but appears most likely to relate to differences between the datum surveys for the two sites. Noting the issues with long term level change in the NTSLF data it appears possible that there has been a datum shift of the NTSLF gauge and it is recommended that both gauges are resurveyed to resolve the issue. At the time of writing this report there are no current plans to address the issues at the NTSLF gauge in the short term, however in the long term ideally the Environment Agency would like to replace the gauge.

Figure 2.13 shows the water level time series data for 2020/21. There are minor gaps in the data between 6th to 11th May and 16th to 17th June 2020. The highest water level recorded with the Whitby Harbour Tide Gauge in 2020-21 was 3.25mOD on 16th November 2020.

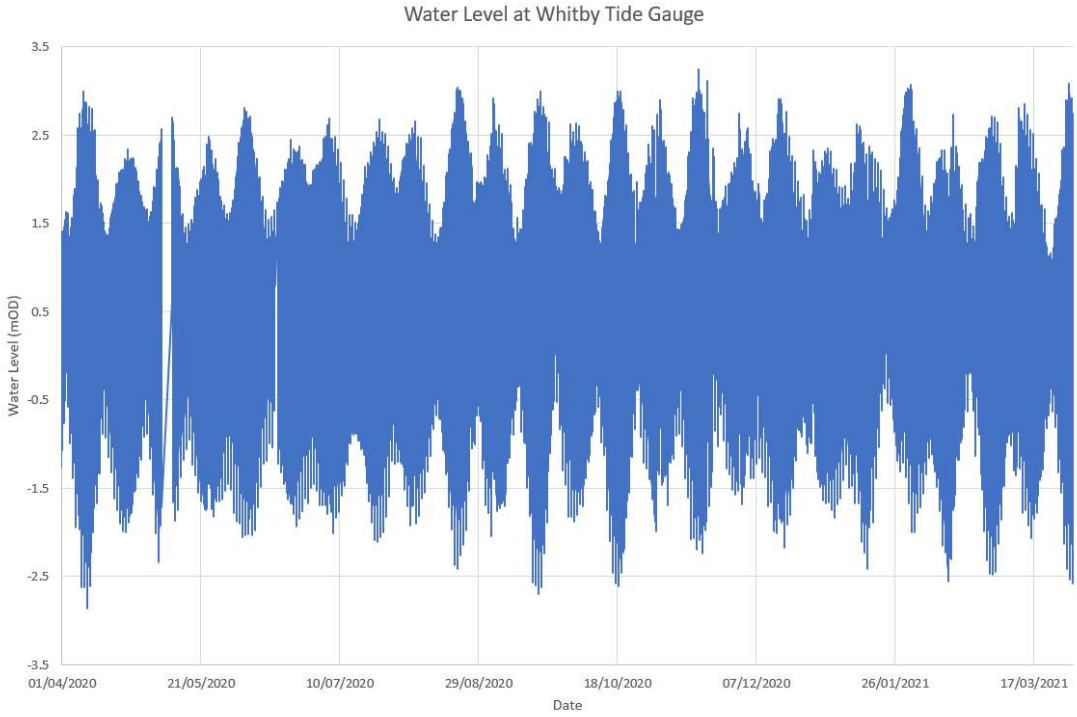


Figure 2.13 Water level data record at Whitby CCO tide gauge site for 2020-2021

Annual maxima water levels extracted from the Whitby tide gauge are shown in Table 2-9 below. The highest recorded water level was 3.48mOD on 13th January 2017 and had an associated surge of 1.24m.

Table 2-9 Annual maxima data from Whitby Tide gauge (source CCO, 2020)[2]

Year	Annual extreme maxima		Annual surge maxima		Z_0 (OD)	Annual recovery rate
	Elevation (OD) *(Surge)*	Date/Time	Value (m)	Date/Time		
2014	3.15 *(0.31)*	13-Aug-2014 05:20	1.06	21-Oct-2014 20:20	-	95%
2015	3.18 *(0.31)*	21-Feb-2015 17:40	1.18	13-Nov-2015 12:10	-	98%
2016	3.15 *(0.13)*	19-Sep-2016 05:10	1.34	26-Dec-2016 21:10	-	99%
2017	3.48 *(0.78)*	13-Jan-2017 16:20	1.24	13-Jan-2017 10:50	-	99%
2018	3.10 *(0.31)*	03-Jan-2018 16:40	0.75	13-Oct-2018 10:00	0.314	99%
2019	3.23 *(0.15)*	01/10/2019 05:20	1.18	08/01/2019 00:40	0.350	97%
2020	3.35 *(0.81)*	10-Feb-2020 04:30	1.16	14-Jan-2020 13:20	0.396	98%

[2] *CCO 2020, Whitby tide gauge annual report, see Appendix E*

2.7 Scarborough Waverider Buoy

Baseline data

At Scarborough, data from the Waverider buoys deployed by Cefas and Emu (labelled as SBC and DWR wave buoys, respectively) were considered in the baseline report. These were located about 2.8 and 4.8 km offshore respectively. The data record reviewed at the original SBC buoy recorded by Cefas extends from April 2003 to July 2004 and the record for the DWR wave buoy recorded by Emu extends from April 2004 to March 2006.

Scatter tables and wave roses were produced for both datasets using full available records. Storm and extremes analyses were carried out for the full record of the DWR wave data (only); the resulting figures and tables are shown in the sub-sections below.

Subsequent data

Under the latest phase of the programme, a Waverider buoy was deployed by Fugro-Emu offshore from Scarborough on 17th January 2013 at 54˚17.460'N, 000˚21.000'W. This is at a similar offshore distance to the original SBC location.

On 10th June 2013 the buoy was serviced and, following requests from fishermen, the buoy was moved to a further offshore location at 54˚17.605'N, 000˚19.082'W, which is a similar offshore distance to the previous DWR location.

Details of these deployments are given in previous reports. Monthly plots of the data for April 2020 to March 2021 are included in Appendix D.

There are several gaps in the historic data when the buoy was off station due to damage or being adrift from its moorings. These include:

- 21st November to 17th December 2013
- 25th May to 8th June 2016
- 6th November to 15th November 2016
- 16th March to 20th April 2017
- 23rd June to 17th July 2018
- 27th December 2018 to 31st January 2019
- 2nd to 11th April 2019
- 2nd to 13th November 2019.

During the latest (2020/21) data record, no data were recorded between 24/05/2020 and 01/06/2020 due to similar problems.

2.7.1 Wave height vs Wave Period

The wave height and zero crossing period data at Scarborough (from both the original DWR and SBC wave buoys and the subsequent deployments) has been plotted as a scatter plot (Figure 2.14). Different symbols have been used to distinguish between different subsequent years of the current deployment. The largest measured significant wave height to date of 6.7m was in the 2016/17 data, with associated period of 8.7 secs). Whilst this is something of an isolated event, several other large wave height and relatively long period events were recorded in that year's dataset. The Scarborough wave buoy was not recording between 24/05/2020 and 01/06/2020. The highest significant wave height recorded during this new data set was 6.0m with an associated wave period of 8.0 sec on the 25th September 2020; whilst the longest zero crossing period wave (longest on record) was 9.3 sec with an corresponding wave height of 1.4m on the 8th March 2021.

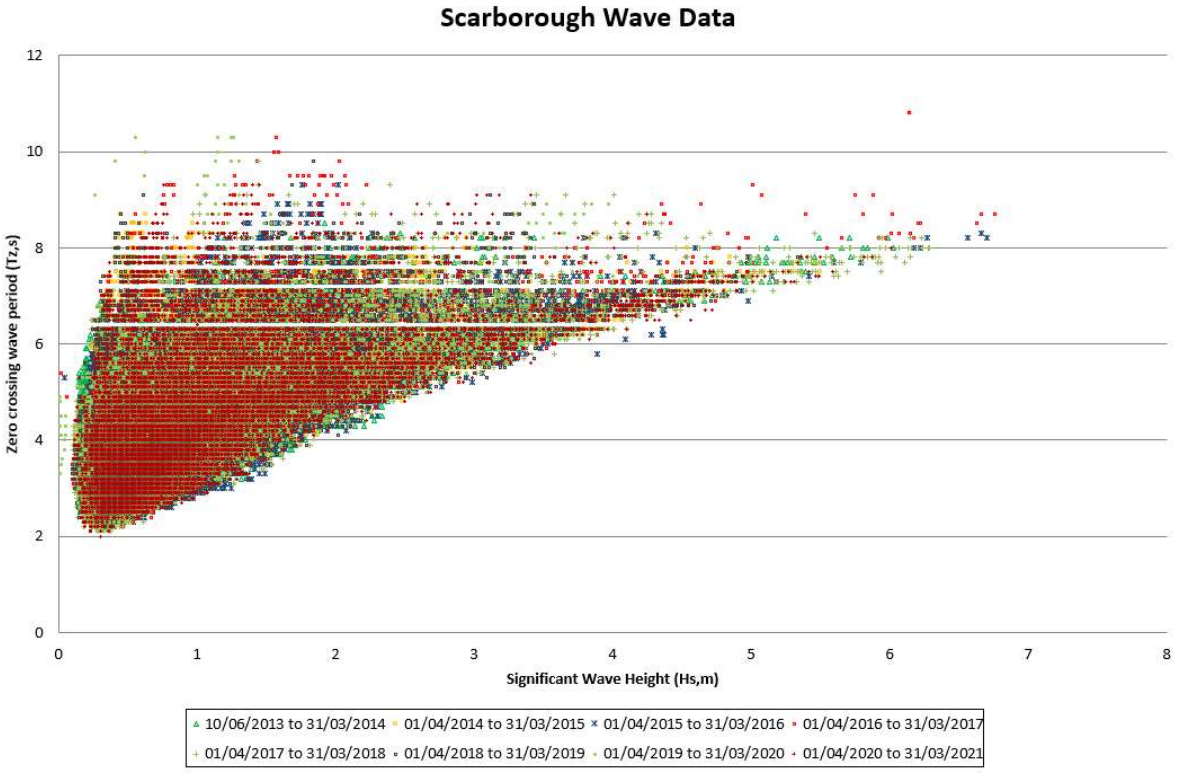


Figure 2.14 Scatter plot of Wave Height Vs Peak Period offshore Scarborough

2.7.2 Wave Rose

The wave rose analysis of the baseline Scarborough DWR and SBC Waverider datasets (Figure 2.15 and Figure 2.16 respectively) show that the majority of the waves come from the north to northeast (0-30 degrees). The SBC dataset also shows a secondary wave direction from 105 to 120 degrees. This is interesting as the DWR buoy is further offshore and so might have been expected to have a wider spread of directions. It may be that the wider direction spread is made more apparent at the closer inshore location as it is slightly more sheltered from waves from the north, but alternatively the difference is more likely to reflect the different conditions occurring during the two time periods analysed.

A wave rose for the data subsequently collected from the current location known as Scarborough WB2 is given in Figure 2.17. All three wave roses show fairly similar distributions, with most storms from 0 to 30 degrees and a secondary direction of 105 to 135 degrees. The 2017/18 wave rose however also showed an increased contribution from 345 to 0 degrees, which also occurs on the 2018/19 data. The record from the most recent year shows a broadly similar pattern to the preceding year.

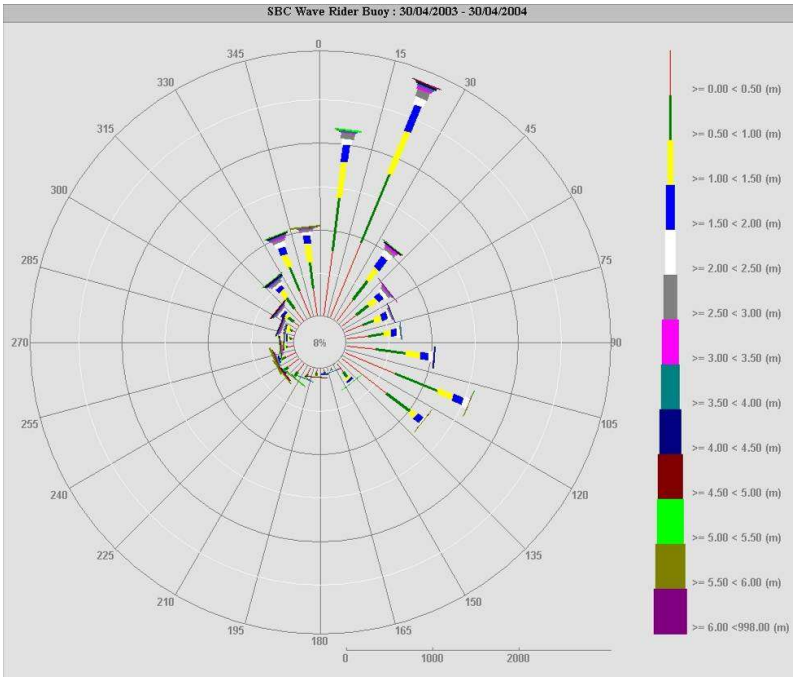


Figure 2.15 Wave Rose at Scarborough SBC site (2003 – 2004)

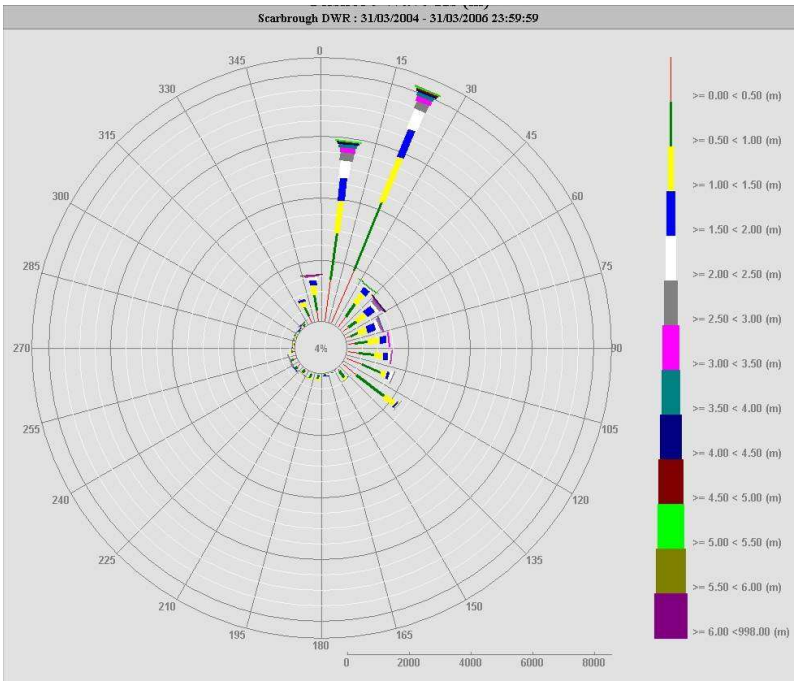


Figure 2.16 Wave Rose at Scarborough DWR site (2004 - 2006)

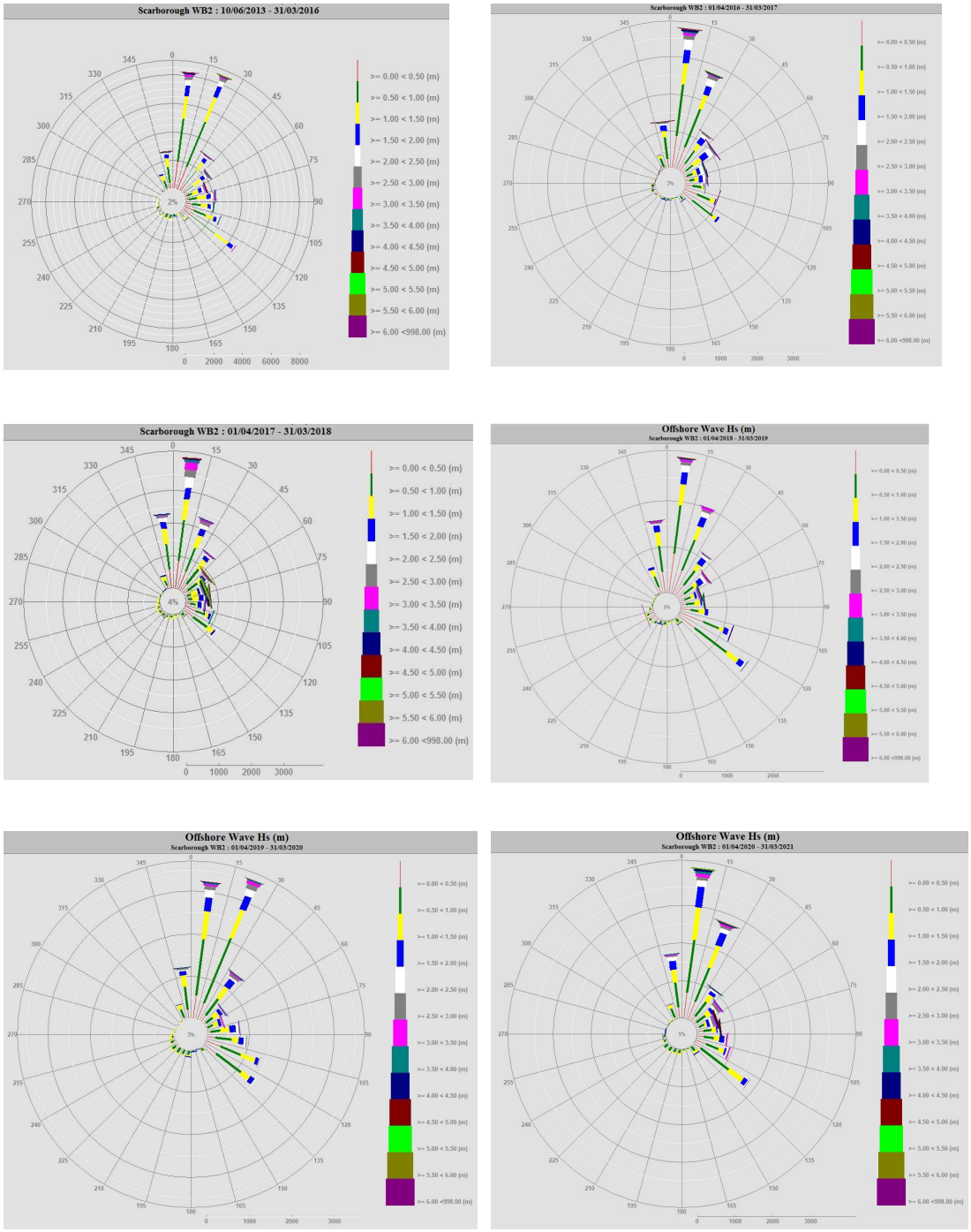


Figure 2.17 Wave Rose at Scarborough WB2 site (data annually from 2013/14 to date)

2.7.3 Storm Analysis

A baseline storm analysis was carried out on the Scarborough DWR wave data (between 30/04/2003 and 31/03/2006), using a storm separation threshold of 120 hours and a wave height threshold of 4m. The results are shown in Table 2-10 below.

As with the other wave buoy analyses, alternate (calendar) years have been shaded, the largest storm Hs each year is highlighted in **bold text** and the largest wave energy at storm peak highlighted in **bold red text**. Note that only 2004 and 2005 are complete years so the conclusions that can be drawn from this baseline analysis are limited. The largest recorded wave height at the storm peak was 6.3m on 28th January 2004. The largest wave energy at peak occurred on 25th November 2005.

Storms analysis from the Waverider buoy subsequently deployed offshore from Scarborough as part of the current programme in January 2013 is provided in Table 2-11 below. This uses the full data set, ignoring the change of location in June 2013.

It should be noted that the buoy was off station during the early December 2013 storm and the January 2019 storm and to clarify this notes have been added in the appropriate tables below.

Table 2-10 Storm analysis for Scarborough DWR wave buoy baseline dataset (2003 – 2006)

General Storm Information							At Peak			
Start Time	**End Time**	**Dur (Hs)**	**Peak of Storm[1]**	**Mean Dir (°)**	**No of Events (30 min dataset)**	**Mean Dir Vector (°)**	**Hs (m)**	**Tp (s)**	**Dir (°)**	**Energy @ Peak (KJ/m/s)**
14/12/2003 20:05	15/12/2003 20:35	25	15/12/2003 01:05	197	44	100.2	5.2	8.7	13	2808.3
21/12/2003 06:05	**22/12/2003 08:05**	**26**	**21/12/2003 10:05**	**205**	**52**	**198.0**	**6.1**	8.7	**18**	**3961.0**
28/01/2004 14:05	**29/01/2004 08:05**	**18**	**28/01/2004 14:05**	**281**	**19**	**121.2**	**6.3**	**6.5**	**56**	**2321.3**
08/02/2004 11:35	08/02/2004 23:35	12	08/02/2004 14:35	227	22	190.1	5.8	7.6	242	2123.2
22/02/2004 13:05	27/02/2004 06:35	114	22/02/2004 14:05	177	64	99.0	4.1	9.8	25	2233.6
12/11/2004 21:05	13/11/2004 01:35	4.5	12/11/2004 23:35	7	8	82.9	4.4	9.7	4	**2467.5**
23/01/2005 19:05	24/01/2005 09:35	15	24/01/2005 00:05	23	30	67.4	5.4	10.0	20	4047.8
19/02/2005 08:35	24/02/2005 14:05	126	24/02/2005 02:35	36	33	54.7	4.6	9.0	46	2363.1
08/04/2005 05:05	**09/04/2005 01:05**	**20**	**08/04/2005 11:05**	**15**	**40**	**74.9**	**5.6**	**11.0**	**16**	**5286.2**
24/11/2005 18:35	26/11/2005 10:05	40	25/11/2005 03:05	22	40	76.2	4.5	20.2	22	**11368.1**
16/12/2005 10:36	17/12/2005 18:35	32	16/12/2005 11:36	18	56	72.5	4.7	13.9	11	5799.2
08/02/2006 21:35	**10/02/2006 00:35**	**27**	**09/02/2006 16:35**	**21**	**54**	**68.9**	**5.2**	**10.2**	**16**	**3920.2**
28/02/2006 11:35	01/03/2006 00:05	13	28/02/2006 22:05	11	11	79.4	4.0	9.9	8	2183.3

Notes: [1] The time of the storm peak is based on peak wave energy, which is calculated in SANDS using $E = \rho.g.H_s^2.L_o/8$, with the offshore wave length $L_o = g.Tp^2/2.\pi$

Table 2-11 Storm analysis for Scarborough WB (data 17/01/2013 to 31/03/2021)

General Storm Information							At Peak					
Start Time	End Time	Dur (hr)	Peak of Storm	Mean Dir	No of Events	Mean Dir Vector	Hs (m)	Tp (s)	Tz (s)	Dir	Energy @ Peak (KJ/m/s)	Total Energy (KJ/m)
21/01/2013 02:00	21/01/2013 20:00	18	21/01/2013 13:00	68	35	22	5.1	11.1	7.8	65	6.4 E+3	4.5 E+6
06/02/2013 13:30	07/02/2013 02:00	12.5	06/02/2013 17:00	14	15	77	4.3	11.1	7.4	17	4.5 E+3	1.7 E+6
22/03/2013 20:00	24/03/2013 23:00	51	23/03/2013 15:30	74	99	16	5.1	11.8	7.7	65	7.1 E+3	1.4 E+7
23/05/2013 21:30	24/05/2013 10:30	13	24/05/2013 00:30	19	27	71	5.7	11.8	8.5	18	**9.0 E+3**	4.9 E+6
10/09/2013 13:00	10/09/2013 22:30	9.5	10/09/2013 19:30	13	19	77	5.0	10.0	7.3	13	4.9 E+3	2.3 E+6
10/10/2013 02:00	**11/10/2013 06:30**	**28.5**	**10/10/2013 23:00**	**28**	**56**	**72**	**5.8**	12.5	**8.0**	**21**	**1.1 E+4**	**1.1 E+7**
Data missing for 5th / 6th December 2013 storm as buoy was off station from 21st November 2013 until 17th December 2013												
14/10/2014 03:00	**14/10/2014 06:00**	**3**	**14/10/2014 04:30**	**61**	**4**	**33**	**4.4**	**9.1**	**6.7**	**61**	**3.2 E+3**	**3.2 E+5**
31/01/2015 14:30	01/02/2015 18:30	28.0	31/01/2015 23:30	20	57	77	4.8	13.3	7.5	25	**8.0 E+3**	8.2 E+6
21/11/2015 04:30	**21/11/2015 16:30**	**12.0**	**21/11/2015 09:30**	**11**	**22**	**80**	**6.2***	**11.8**	**8.0**	**11**	**1.1 E+4**	**4.2 E+6**
03/01/2016 06:00	**06/01/2016 13:00**	**79.0**	**06/01/2016 03:00**	**68**	**26**	**26**	**5.0**	**10.5**	**7.8**	**65**	**5.4 E+3**	**2.9 E+6**
14/01/2016 14:00	16/01/2016 06:00	40.0	16/01/2016 05:00	100	15	81	4.2	11.8	7.5	13	4.9 E+3	1.5 E+6
13/01/2017 10:30	**14/01/2017 04:00**	**17.5**	**13/01/2017 17:00**	**101**	**32**	**82**	**6.7**	**13.3**	**8.7**	**4**	**1.6 E+4**	**9.4 E+6**
12/02/2017 02:00	12/02/2017 20:30	18.5	12/02/2017 05:30	63	31	28	4.9	10.0	7.4	55	4.7 E+3	3.1 E+6
23/02/2017 18:00	23/02/2017 21:00	3.0	23/02/2017 19:30	136	5	86	4.5	10.0	7.3	4	4.0 E+3	4.3 E+5
12/11/2017 15:00	12/11/2017 22:30	7.5	12/11/2017 19:00	192	6	90	4.1	10.0	6.8	359	3.3 E+3	4.6 E+5
08/12/2017 14:00	09/12/2017 12:00	22.0	08/12/2017 20:00	14	29	76	4.6	14.3	8.0	13	8.6 E+3	4.4 E+6
01/02/2018 17:00	02/02/2018 04:00	11.0	02/02/2018 02:00	81	8	87	4.3	11.1	7.0	6	4.6 E+3	9.4 E+5
28/02/2018 08:30	**02/03/2018 23:00**	**62.5**	**01/03/2018 19:30**	**76**	**113**	**14**	**6.3**	**11.1**	**8.0**	**84**	**9.6 E+3**	**1.9 E+7**
16/03/2018 05:00	18/03/2018 22:00	65.0	17/03/2018 21:00	69	126	22	5.8	11.8	7.8	68	9.3 E+3	2.0 E+7
05/04/2018 03:00	05/04/2018 03:30	0.5	05/04/18 03:30	2	2	88	4.1	10.0	6.8	3	3.2 E+3	1.9 E+5
27/10/2018 03:30	30/10/2018 19:00	87.5	27/10/18 15:00	31	19	79	4.8	11.1	7.3	10	5.5 E+3	2.3 E+6
20/11/2018 12:30	21/11/2018 08:00	19.5	20/11/18 16:00	74	33	18	5.3	10.0	7.8	68	5.6 E+3	3.8 E+6
15/12/2018 19:30	15/12/2018 22:30	3.0	15/12/18 21:30	127	4	336	4.4	10.0	6.9	110	3.9 E+3	3.3 E+6
Data missing for January 2019 storms as buoy was off station from 27th December 2018 to 31st January 2019												
04/05/2019 09:30	04/05/2019 12:30	3.0	04/05/19 11:00	12	5	79	4.4	11.1	7.4	14	**4.62 E+3**	5.56 E+5
07/11/2019 22:30	07/11/2019 23:30	1.0	07/11/19 23:30	34	2	58	4.1	8.3	6.6	34	2.33 E+3	1.30 E+5
09/12/2019 08:00	**09/12/2019 11:30**	**3.5**	**09/12/19 11:00**	**119**	**8**	**91**	**4.5**	**10.5**	**7.4**	**3**	**4.48 E+3**	**7.85 E+5**
28/08/2020 17:00	29/08/2020 19:30	26.5	29/08/20 18:00	17	15	74	4.1	10.5	6.8	14	3.60 E+3	1.26 E+6

25/09/2020 08:00	**27/09/2020 06:00**	**46.0**	**25/09/20 20:00**	**14**	**87**	**76**	**6.0**	**11.1**	**8.0**	**16**	**8.78 E+3**	**1.41 E+7**
19/11/2020 13:00	19/11/2020 18:00	5.0	19/11/20 13:00	21	5	70	4.3	14.3	8.7	23	7.28 E+3	8.26 E+5
24/12/2020 19:30	24/12/2020 23:00	3.5	24/12/20 21:30	7	6	83	4.3	10.0	6.9	6	3.61 E+3	6.05 E+5
06/02/2021 12:30	08/02/2021 17:00	52.5	07/02/21 16:30	72	89	18	5.0	11.1	7.5	82	6.03 E+3	1.16 E+7

The storm on the 13th January 2017 had the highest peak wave height and the highest peak wave energy in the record (noting that the record omits the December 2013 storm and the January 2019 storm). This storm was unusual in that the wave direction was south by south-east, whilst the more usual wave directions recorded are north by north-east and east by north-east.

In 2019 only three storms were recorded, with Hs only slightly exceeding the storm threshold. In 2020 four storms were recorded, one with a significant wave height of 6m (25th September 2020). To date in 2021 one storm was recorded in February 2021.

2.8 Scarborough Tide Gauge

The Scarborough tide gauge was deployed by Emu on behalf of SBC in April 2003 as part of a local monitoring initiative prior to the start of the regional programme. The data runs from 28/04/2003 to 31/10/2018, with a number of gaps in the record. The tide gauge was damaged in early November 2018 and no data was recorded until installation of new equipment in June 2019.

A detailed plot showing the data available for 2020/21 is shown in Figure 2.18. There is a small gap in the data between 14th and 16th December 2020. The highest water level recorded with the Scarborough Tide Gauge during 2020/21 was 3.41mOD on 16th November 2020.

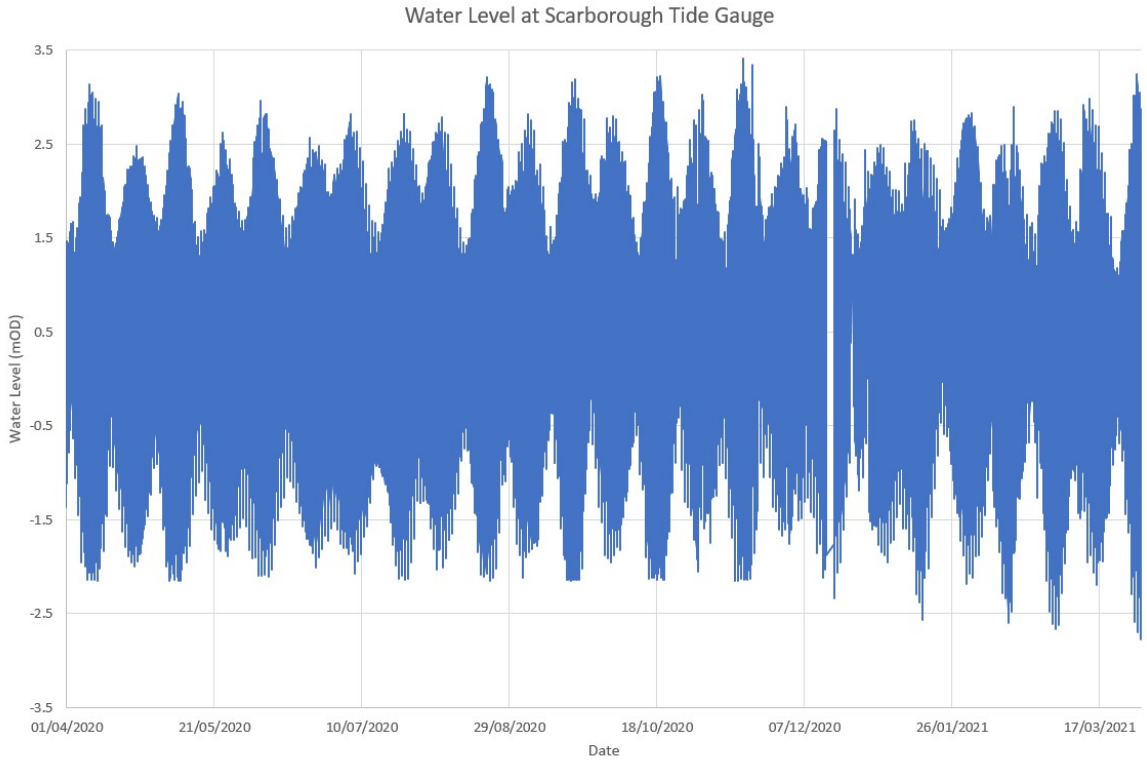


Figure 2.18 Water Levels at Scarborough TG Recorded Tide Site for 2020-21

The Scarborough tide gauge data has been analysed and quality controlled by Fugro-EMU and Channel Coast Observatory. The CCO report is included in Appendix E and standard tidal heights are presented in Table 2-12.

It should be noted that when the site was checked and re-surveyed by Fugro-EMU in June 2013, a discrepancy was found compared to the original datum established in 2003, with the tide gauge zero then 0.195m higher than previously assumed. It is not known when the offset applies from, but Fugro-EMU noted in 2013 that *"this offset brings the data back in line with predictions created through the harmonic analysis of the data from 2003 and also predictions created from the Admiralty harmonic constants for Scarborough."*

Table 2-12 Standard tidal levels at Scarborough

Tidal levels		
Observation period	January 2013 – October 2014	
Tide Level	Elevation (OD)	Elevation (CD)
HAT	3.34	6.59
MHWS	2.52	5.77
MHWN	1.38	4.63
MLWN	-0.86	2.39
MLWS	-2.00	1.25
LAT	-3.02	0.23

Notes: Source – CCO report for 2020 data, see Appendix E
See also note above re-potential issues with datum for 2006 to 2011 data.

Annual maxima water levels extracted from the Scarborough tide gauge are shown in Table 2-13 below. The highest recorded water level was 4.39mOD on 5th December 2013 at 17:20, and had an associated surge of 1.66m. This is significantly higher than any of the previous 10 years or any of the subsequent years, the maximum of which was 3.66m in January 2005.

Table 2-13 Annual maxima data from Scarborough Tide gauge (source CCO, 2020)[3]

Year	Annual extreme maxima		Annual surge maxima		Z_0 (OD)	Annual recovery rate
	Elevation (OD) *(Surge)*	Date/Time	Value (m)	Date/Time		
2003	3.05 *(-0.03)*	28-Sep-2003 05:10	1.13	21-Dec-2003 09:40	-	76%
2004	3.09 *(0.34)*	22-Feb-2004 17:10	0.96	18-Nov-2004 04:00	0.292	99%
2005	3.66 *(0.86)*	12-Jan-2005 17:20	1.18	20-Jan-2005 08:20	0.287	99%
2006*	3.30 *(0.17)*	30-Mar-2006 16:30	1.29	31-Oct-2006 15:40	-	77%
2007*	3.40 *(0.71)*	25-Nov-2007 04:00	1.60	08-Nov-2007 21:30	0.221	97%
2008*	3.05 *(0.16)*	09-Mar-2008 17:20	0.90	22-Feb-2008 02:10	-	65%
2009*	3.19 *(0.44)*	12-Jan-2009 16:50	1.15	18-Jan-2009 16:30	-	84%
2010*	3.21 *(0.05)*	11-Sep-2010 05:30	0.81	12-Nov-2010 04:20	-	82%
2011*	3.03 *(-0.14)*	21-Mar-2011 17:10	1.33	04-Feb-2011 11:00	-	80%
2012	2.94 *(0.06)*	17-Oct-2012 04:40	0.92	05-Jan-2012 16:40	-	70%
2013	4.39 *(1.66)*	05-Dec-2013 17:20	1.75	05-Dec-2013 15:50	0.186	98%
2014	3.40 *(0.51)*	04-Jan-2014 18:00	1.16	21-Oct-2014 20:20	-	88%
2015	3.29 *(0.29)*	21-Feb-2015 17:40	1.23	10-Jan-2015 17:30	-	98%
2016	3.13 *(0.17)*	17-Sep-2016 04:00	1.54	26-Dec-2016 21:20	-	100%
2017	3.43 *(0.79)*	13-Jan-2017 16:20	1.22	13-Jan-2017 10:50	-	100%
2018	3.27 *(0.26)*	12-Sep-2018 05:40	0.80	28-Jan-2018 05:20	-	82%
2019	3.40 *(0.50)*	29-Sep-2019 16:30	1.00	09-Dec-2019 06:30	-	47%
2020	3.44 *(0.96)*	10-Feb-2020 04:50	1.24	14-Jan-2020 13:50	0.412	98%

* Possible datum shift by up to -0.195m

[3] *CCO 2020, Scarborough tide gauge annual report, see Appendix E*

3 Problems encountered and uncertainty in analysis

3.1 Wave data

The Tyne Tees wave data is available in both telemetry and post recovery format from the Cefas WaveNet site. At the time of writing, post-recovery data were available up to the end of December 2020. For the months of January, February and March 2021 telemetry data was used in this report. The data set analysed is therefore a combination of telemetry and post recovery data, to give greatest coverage.

As noted elsewhere in this report, the Scarborough Waverider buoy was moved to a new (further offshore) location in June 2013 after its initial deployment in January of that year. Whilst the offshore distances of these two deployment sites are similar to those used in earlier deployments in 2003-04 (the SBC buoy) and 2004-06 (the DWR buoy), respectively, the water depths and precise locations are slightly different. This means that the data from the 2013 deployment and subsequent re-deployment are not necessarily directly comparable to data from the original SBC and DWR sites, respectively.

Generally, there have been a number of notable data gaps in the wave records from the Scarborough buoy in particular, due to buoy damage or the buoy coming adrift of its moorings. Whilst occasional gaps have been recorded for similar reasons at the Newbiggin and Whitby buoys, they appear generally more stable locations, although in the 2020/21 period the Whitby buoy was off line for an uncharacteristically long period and large number of times. Recovery of the buoy when off-line was sometimes hampered in 2020 by the UK Government's lock-down restrictions associated with the Coronavirus (COVID-19) pandemic.

In the 2020/21 wave datasets, there were notable gaps in data coverage, caused by buoys being out of service, damaged or adrift on the following dates:

- 17/02/2020 to 25/04/2020 - Whitby
- 24/05/2020 to 01/06/2020 - Scarborough
- 05/06/2020 to 17/06/2020 - Whitby
- 10/07/2020 to 24/07/2020 – Newbiggin
- 24/09/2020 to 06/11/2020 – Whitby

3.2 Water level data

The North Shields tide gauge data from BODC has only occasional minor gaps, with no significant gaps in the 2020/21 data record.

The Whitby NTSLF tide gauge has some notable gaps in the long term historic record, including data flagged as 'poor' quality by NTSLF in April and May 2020 (and thus omitted from this report). There also appears to be a datum issue compared to the Cell 1 Whitby gauge. It is known that in the long term the Environment Agency would like to replace the Whitby NTSLF tide gauge.

As noted in the baseline report there is uncertainty over datum changes for the Scarborough tide gauge between the original deployment in 2003 and the site checks in 2013, with a discrepancy of 0.195m. The data record has no significant gaps in 2020/21.

4 Key findings and recommendations

This report has analysed new wave and water level data available relevant to coastal Cell 1 for 2020/21 as an update to the previous baseline and subsequently reports. Future reports in this series should compare the data recorded in subsequent years with the results presented here. The key points are summarised below:

- Offshore wave directions incident on the Cell 1 coast are predominantly between 0 and 30 degrees (north to northeast), with a secondary wave approach direction from the northeast to southeast also observed although some parts of the coast are more sheltered from fetches to the southeast.
- The largest significant wave heights (H_s) in the records to March 2021 are:
    - Newbiggin 27th February 2018 (6.4m);
    - Tyne Tees 27th January 2019 (8.3m);
    - Whitby 21st November 2015 (6.7m)^;

  ^ The 10.3m recording from 27th January 2019 was flagged as potentially being spurious data in the record and has been removed from the record for the analysis in this report. However, during this event a valid recording of 6.6m was recorded which, jointly with an event on 13th January 2017, is the second highest on record.

    - Scarborough 13th January 2017 (6.7m)*/**.

  * The 9.0m recording from 13th January 2017 was flagged as potentially being spurious data in the record and has been removed from the record for the analysis in this report. However, during this event a valid recording of 6.7m was recorded which is the highest on record.

  ** Note that the Scarborough wave buoy was not recording through January 2019 when a major storm on 27th of that month may have resulted in a different largest H_s at this site.
- In 2020/21 the largest significant wave heights recorded at the wave buoys were:
    - Newbiggin 6th February 2020 (4.9m)
    - Tyne Tees 25th September 2020 (6.6m)
    - Whitby 7th February 2020 (4.6m)
    - Scarborough 25th September 2020 (6.0m)
- In 2020/21 the highest water levels recorded at the tide gauges were:
    - North Shields 16th November 2020 (3.27mOD)
    - Whitby NTSLF 16th November 2020 (3.43mOD)
    - Whitby 16th November 2020 (3.25mOD)
    - Scarborough 16th November 2020 (3.41mOD)
- The Newbiggin Ness wave buoy site is partially sheltered from waves from the north. The data from 2020/21 is consistent with previous records.
- The longest consistent wave record in the region is for the Wavenet Tyne Tees buoy, which has been operating since late 2006. Analysis of the 2006 to 2021 data from Tyne Tees indicates that the stormiest year was 2010 (thirteen storms recorded) whilst the years with the fewest number of storms were 2011 and 2014 (three in each year).
- The Met Office offshore wave hindcast modelled data for 1980 to 2012 was shown to under-predict wave heights during storm events by up to 0.5m and so should be treated with caution if used for boundary conditions in modelling studies.

- Analysis of the Cell 1 tide gauge located in Whitby Harbour has previously found that there is a datum issue with either or both Whitby tide gauges. The data from the national gauge is considered unreliable by NOC from April 2015 onwards. It is recommended that this is investigated further and new datum level surveys are undertaken for both gauges.

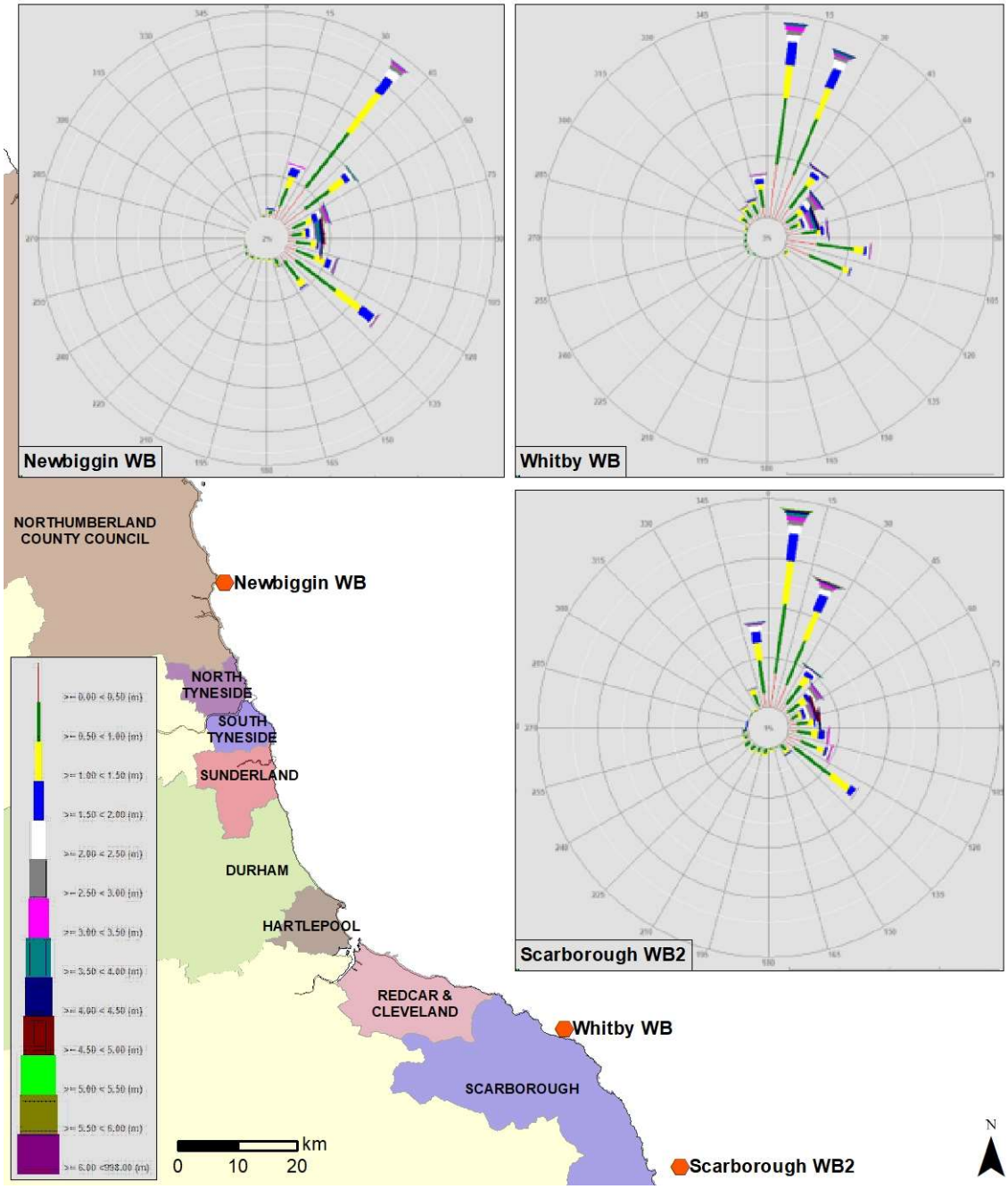


Figure 4.1 Wave Roses (2020/21) from Newbiggin Ness, Whitby and Scarborough

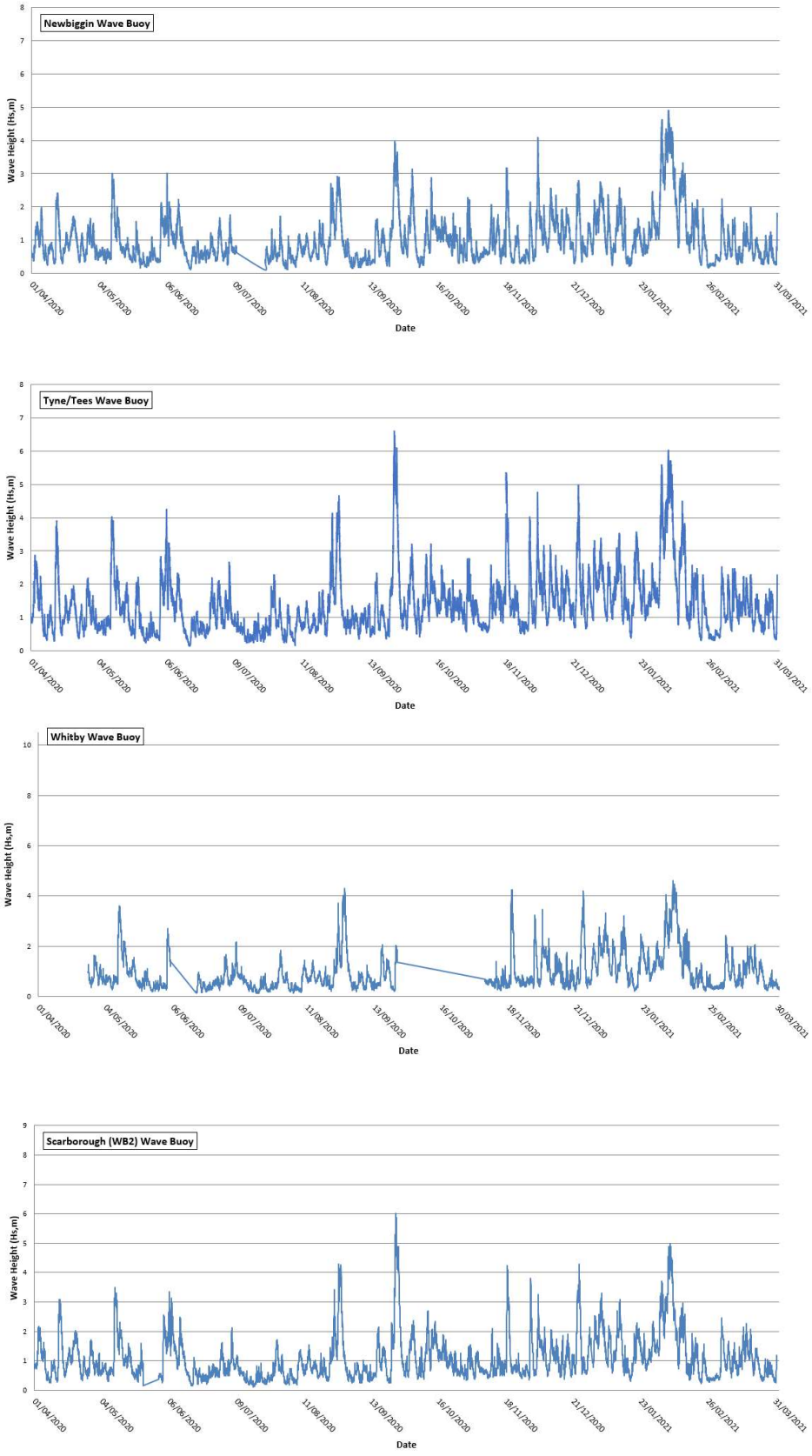


Figure 4.2 Wave height data for 2020-21 in Cell 1

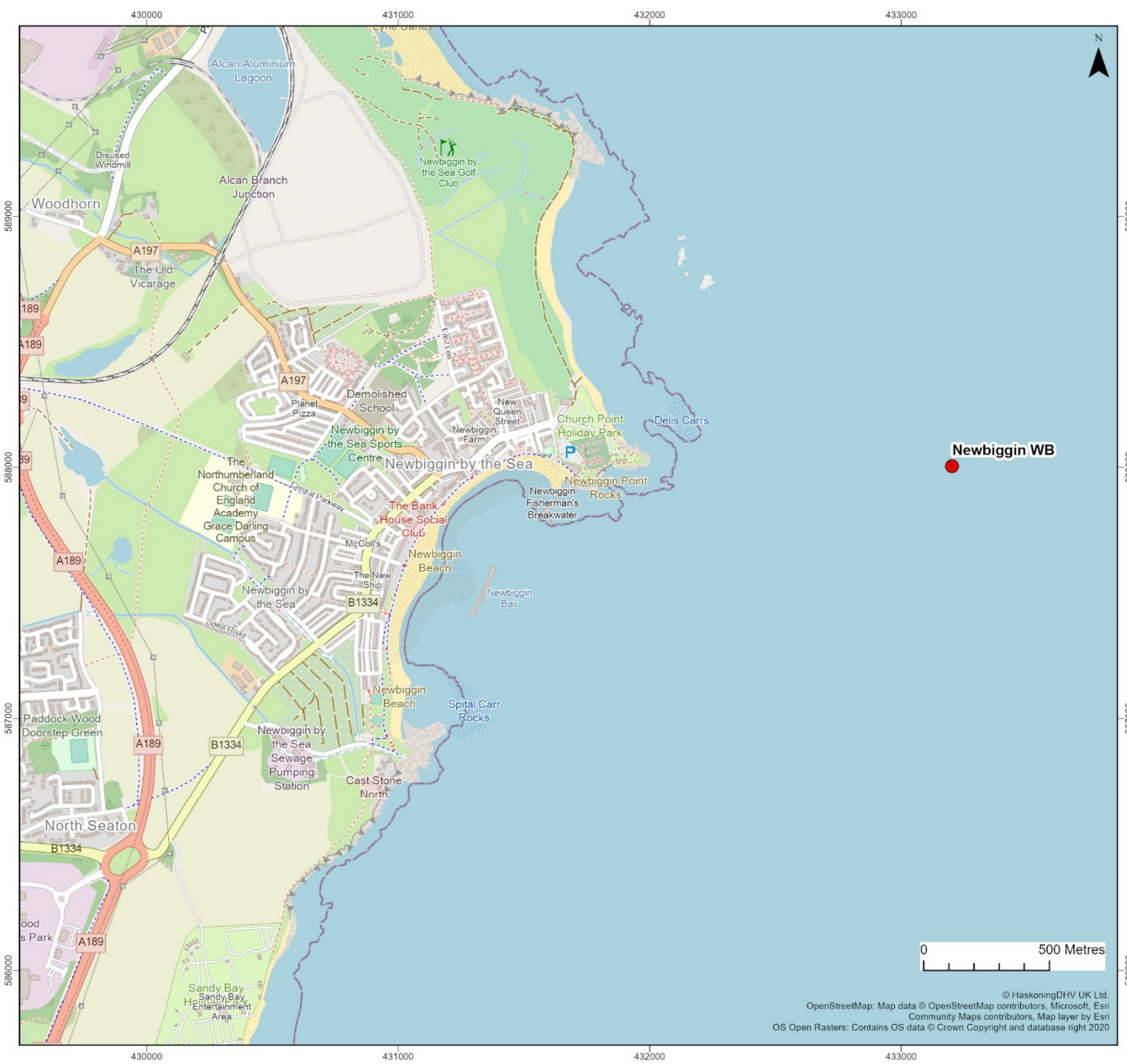
This report has documented the annual review and analysis of wave and tide data across Cell 1, presenting analysis of the data sets collected at the three wave buoys that were deployed under the strategic monitoring programme at Newbiggin Ness, Whitby and Scarborough, alongside data from the Cefas buoy located at Tyne Tees that is operated as part of the national programme.

Tide gauge data collected under the programme from Whitby and Scarborough has also been analysed and compared to the data from the tide gauges at Whitby and North Shields that are operated as part of the national tide and sea level forecasting programme.

Wave conditions during the 2020/21 period showed similar wave approach directions to those recorded in most previous years. At all four wave buoys there were fewer than the average number of storms in the calendar year 2020.

Appendices

Appendix A: Detailed Location of Wave Buoys and Tide Gauges



Legend

Wave & Tide Locations

- Wave Buoy (Current)

Client: North East Coastal Group	Project: Cell 1 Regional Coastal Monitoring Programme

Title:

Appendix A - Figure 1

WAVE & TIDES

Location of Newbiggin wave buoy

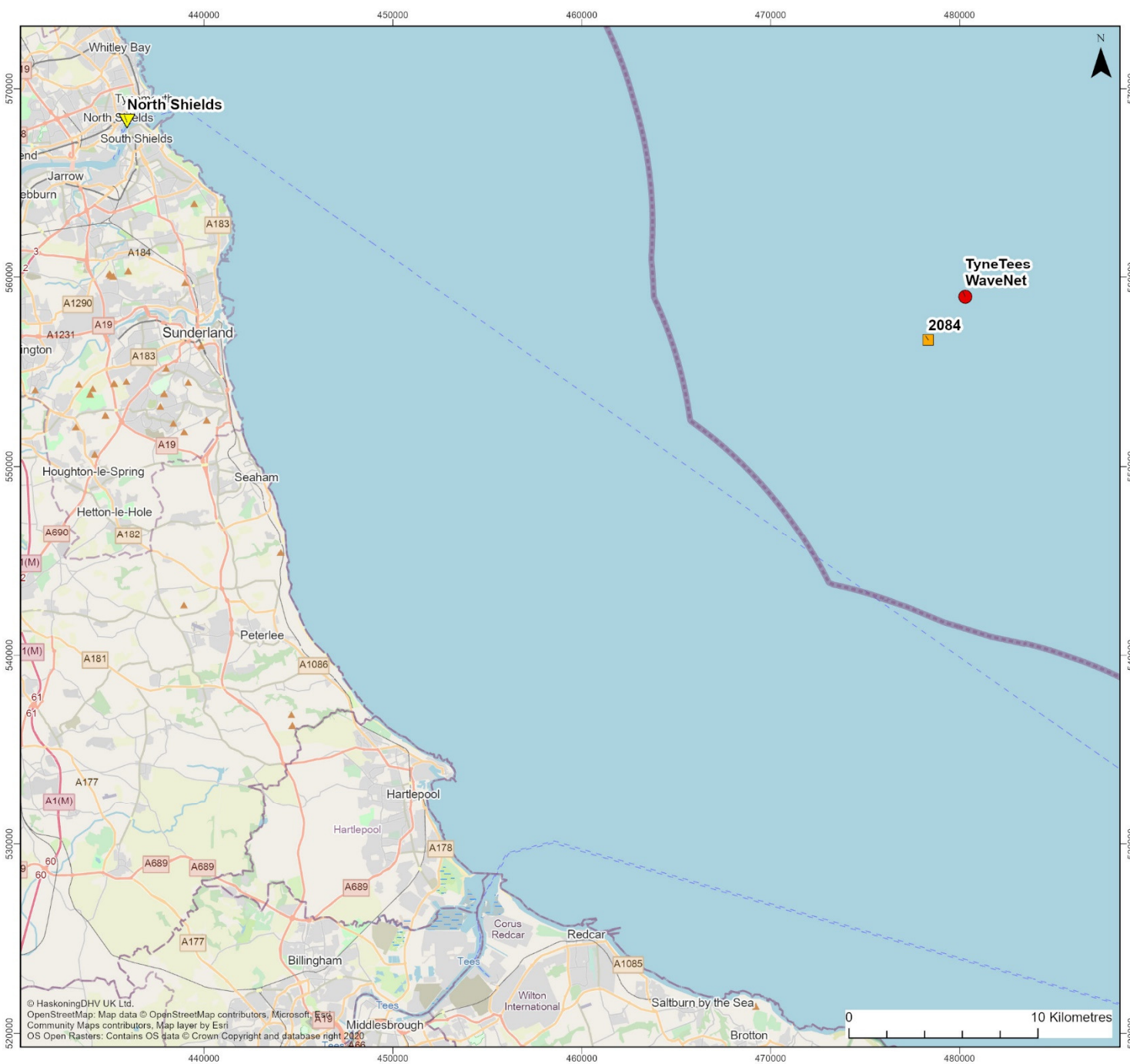
Report: Wave & Tide Report

Revision:	Date:	Drawn:	Checked:	Size:	Scale:
0	June 2021	TC	NJC	A3	1:15,000

Co-ordinate system: British National Grid

Royal HaskoningDHV
Enhancing Society Together

North East Coastal Observatory



Legend

Wave & Tide Locations

- Wave Buoy (Current)
- Tide Gauge
- MetOffice Hindcast Point

Client:	Project:
North East Coastal Group	Cell 1 Regional Coastal Monitoring Programme

Title:

Appendix A - Figure 2

WAVE & TIDES

Location of Tyne Tees wave buoy, MetOffice hindcast point 2084 and North Shields tide gauge

Report:

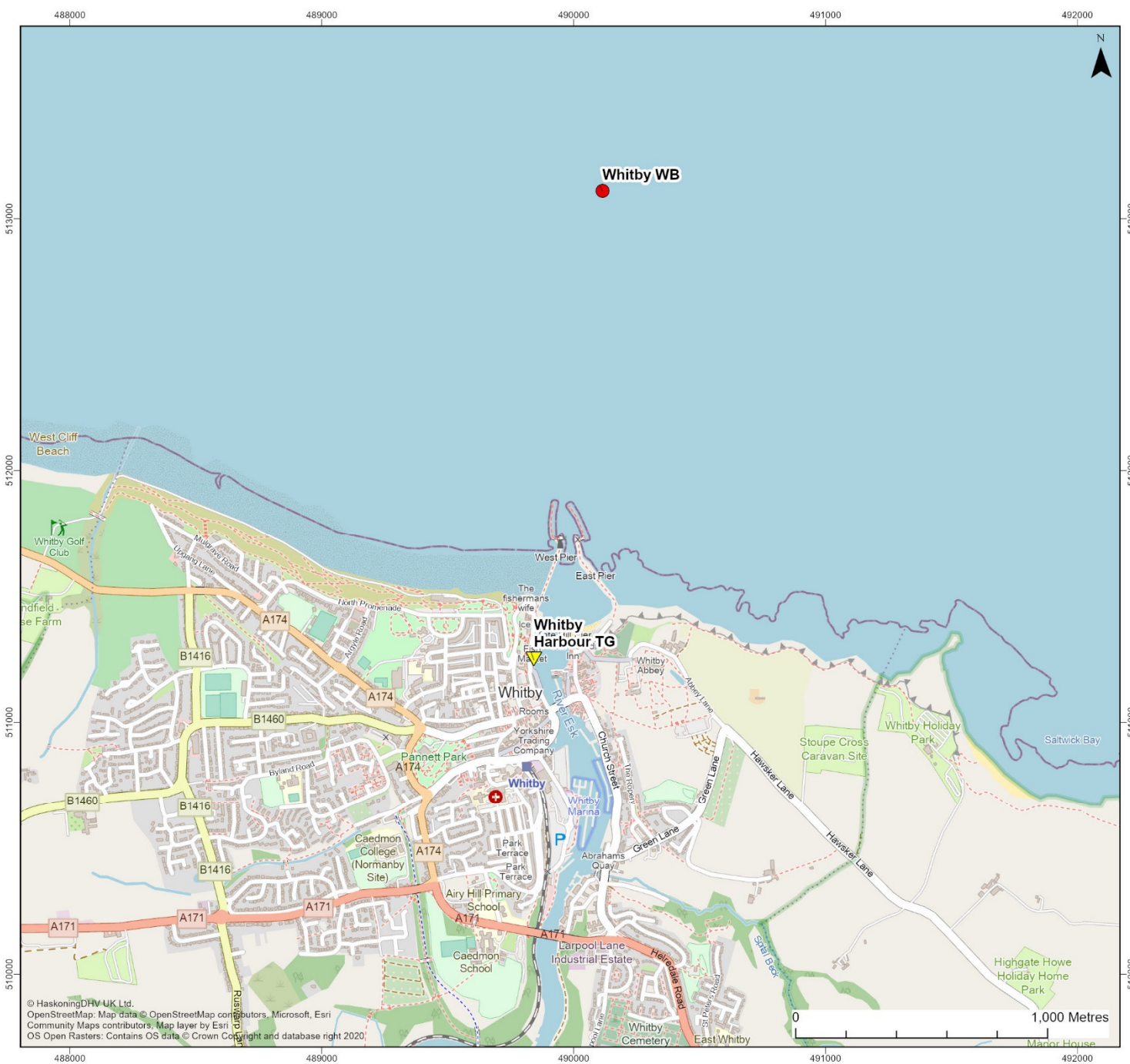
Wave & Tide Report

Revision:	Date:	Drawn:	Checked:	Size:	Scale:
0	June 2021	TC	NJC	A3	1:200,000

Co-ordinate system: British National Grid

Royal HaskoningDHV
Enhancing Society Together

North East Coastal Observatory



Legend

Wave & Tide Locations

- Wave Buoy (Current)
- Tide Gauge

Client:	Project:
North East Coastal Group	Cell 1 Regional Coastal Monitoring Programme

Title:

Appendix A - Figure 3

WAVE & TIDES

Location of Whitby wave buoy and tide gauge

Report:

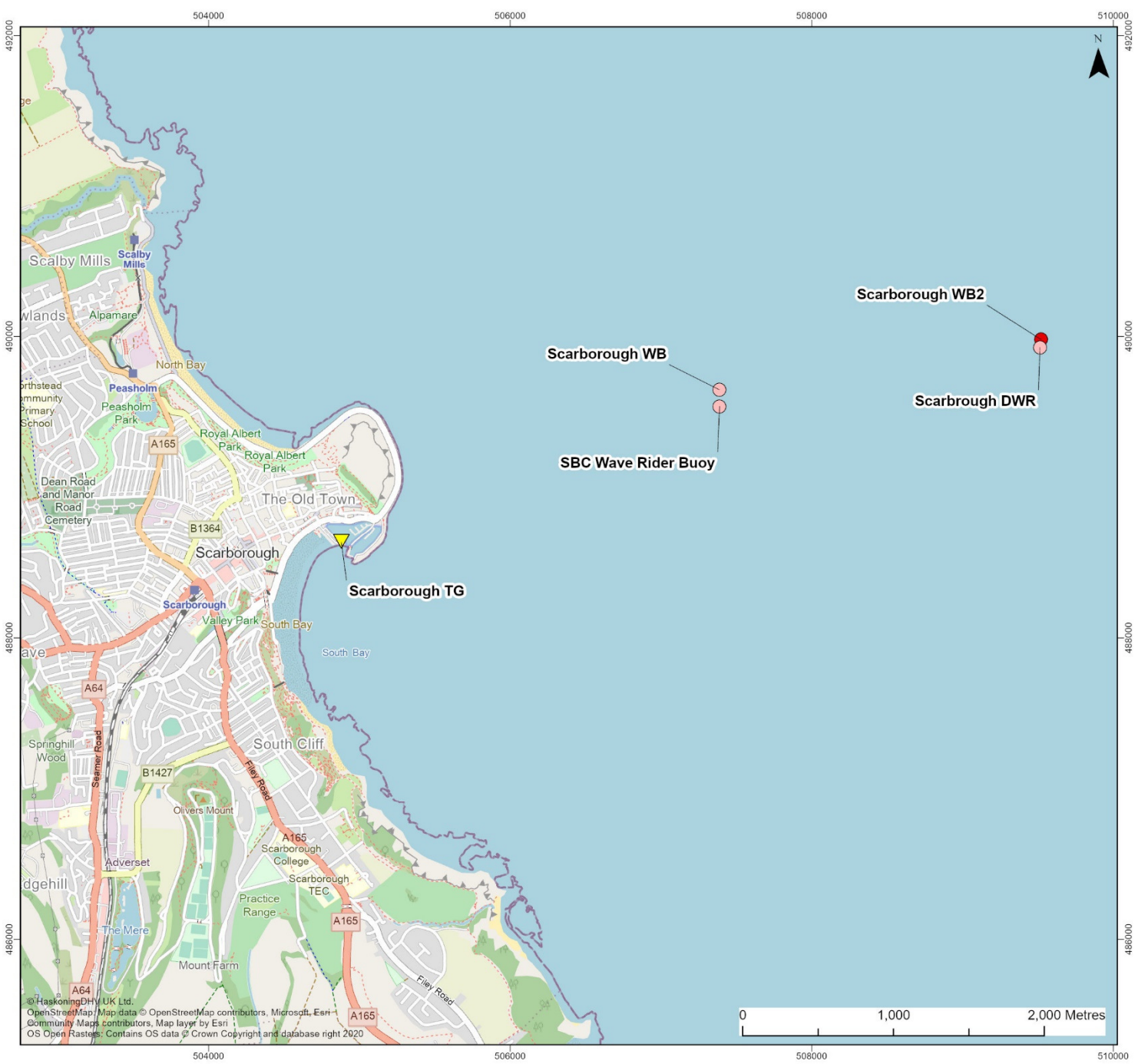
Wave & Tide Report

Revision:	Date:	Drawn:	Checked:	Size:	Scale:
0	June 2021	TC	NJC	A3	1:15,000

Co-ordinate system: British National Grid

Royal HaskoningDHV
Enhancing Society Together

North East Coastal Observatory



Legend

Wave & Tide Locations

- Wave Buoy (Current)
- Wave Buoy (Historic)
- Tide Gauge

Client:	Project:
North East Coastal Group	Cell 1 Regional Coastal Monitoring Programme

Title:

Appendix A - Figure 4

WAVE & TIDES

Location of Scarborough wave buoys and tide gauge

Report:

Wave & Tide Report

Revision:	Date:	Drawn:	Checked:	Size:	Scale:
0	June 2021	TC	NJC	A3	1:25,000

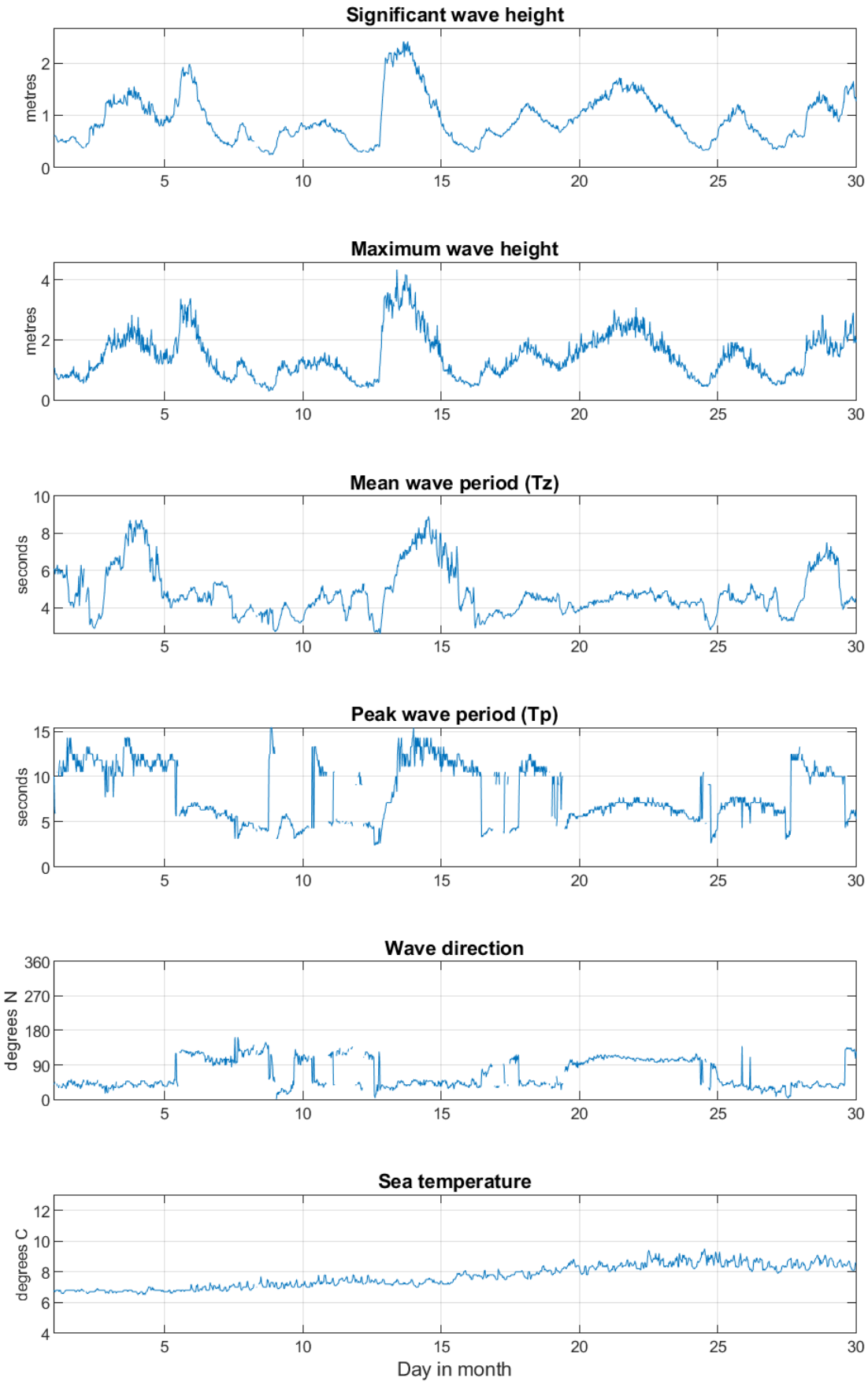
Co-ordinate system: British National Grid

Royal HaskoningDHV
Enhancing Society Together

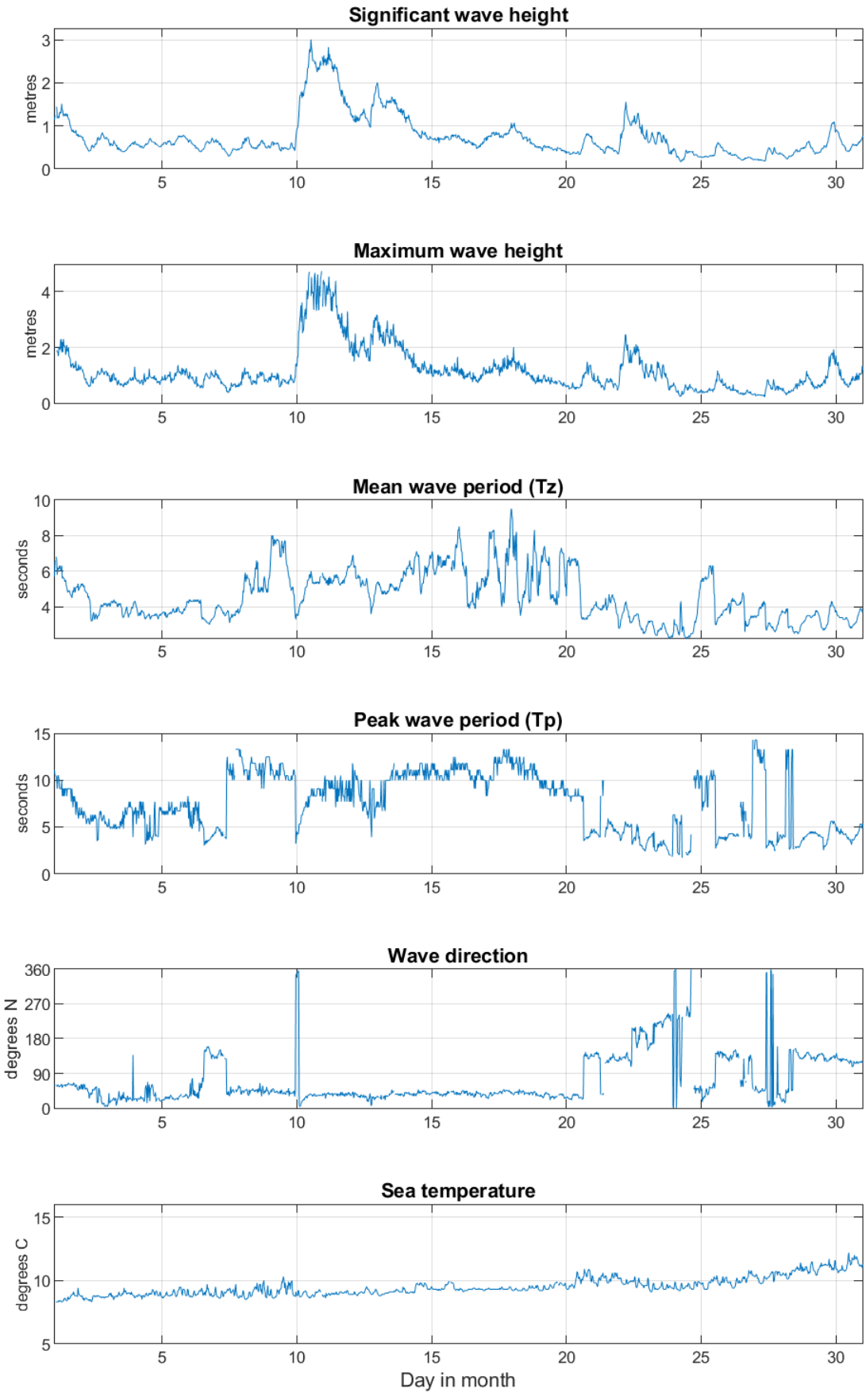
North East Coastal Observatory

Appendix B: Supporting Graphs - Newbiggin Wave Buoy

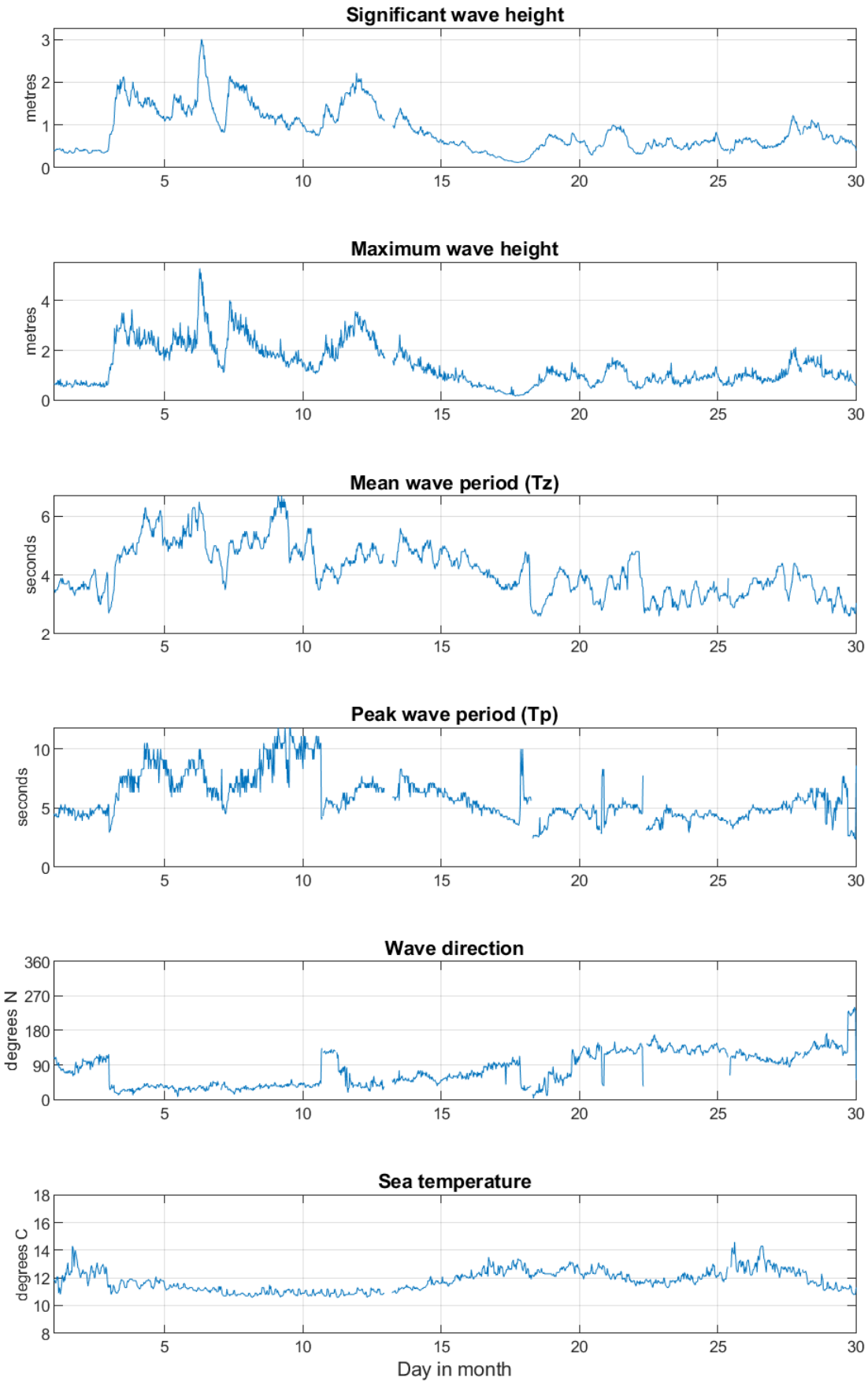
Newbiggin - April 2020



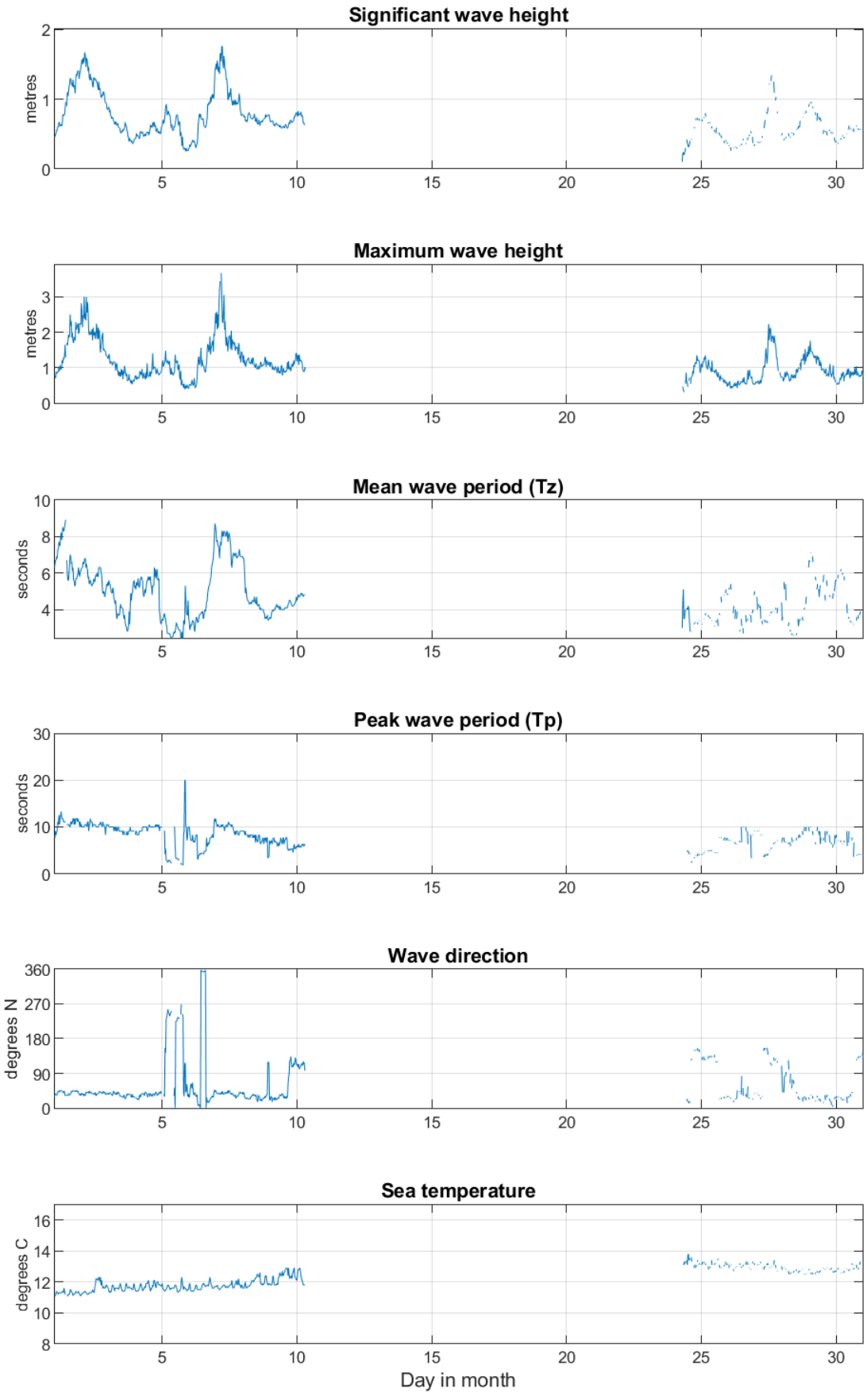
Newbiggin - May 2020



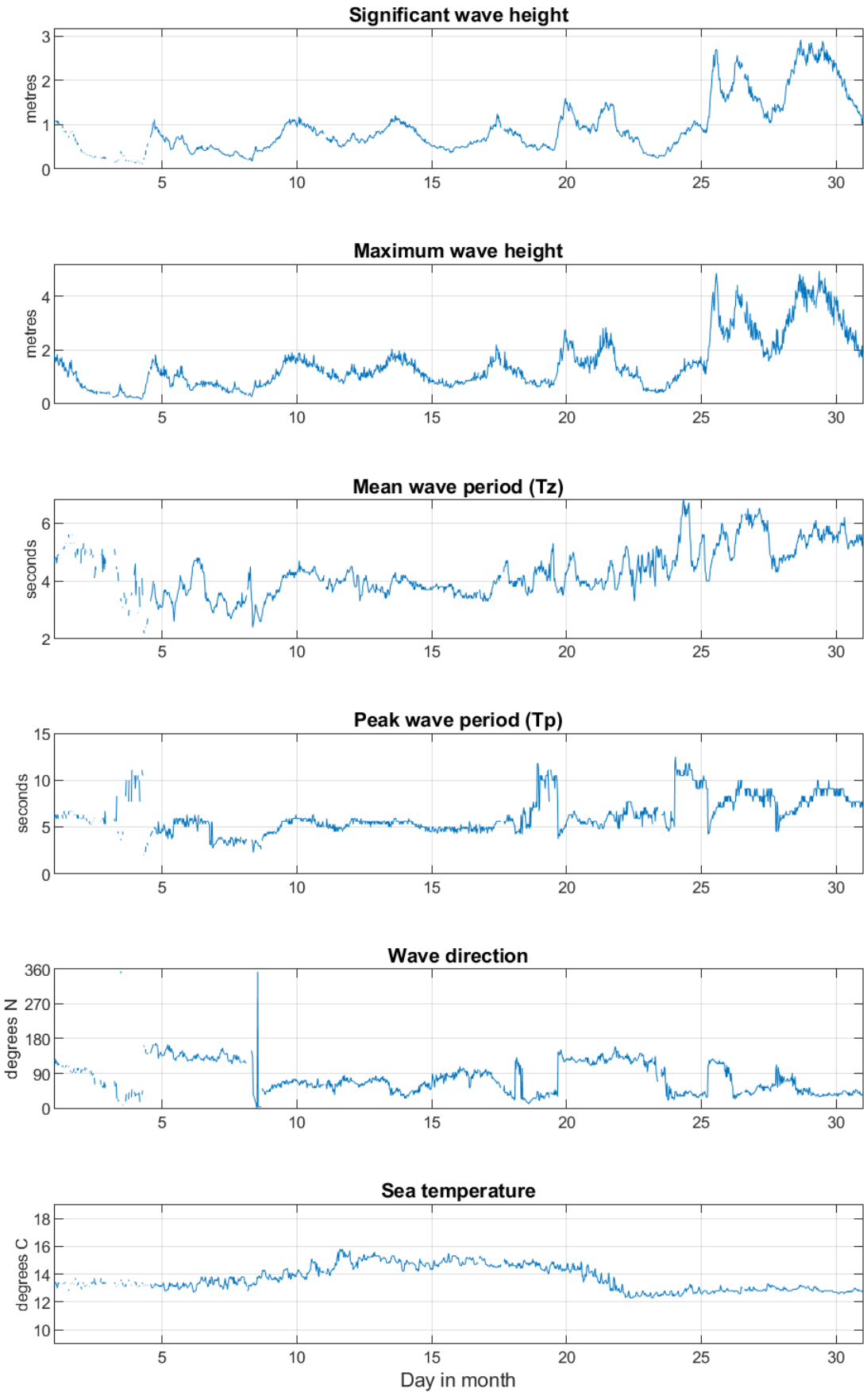
Newbiggin - June 2020



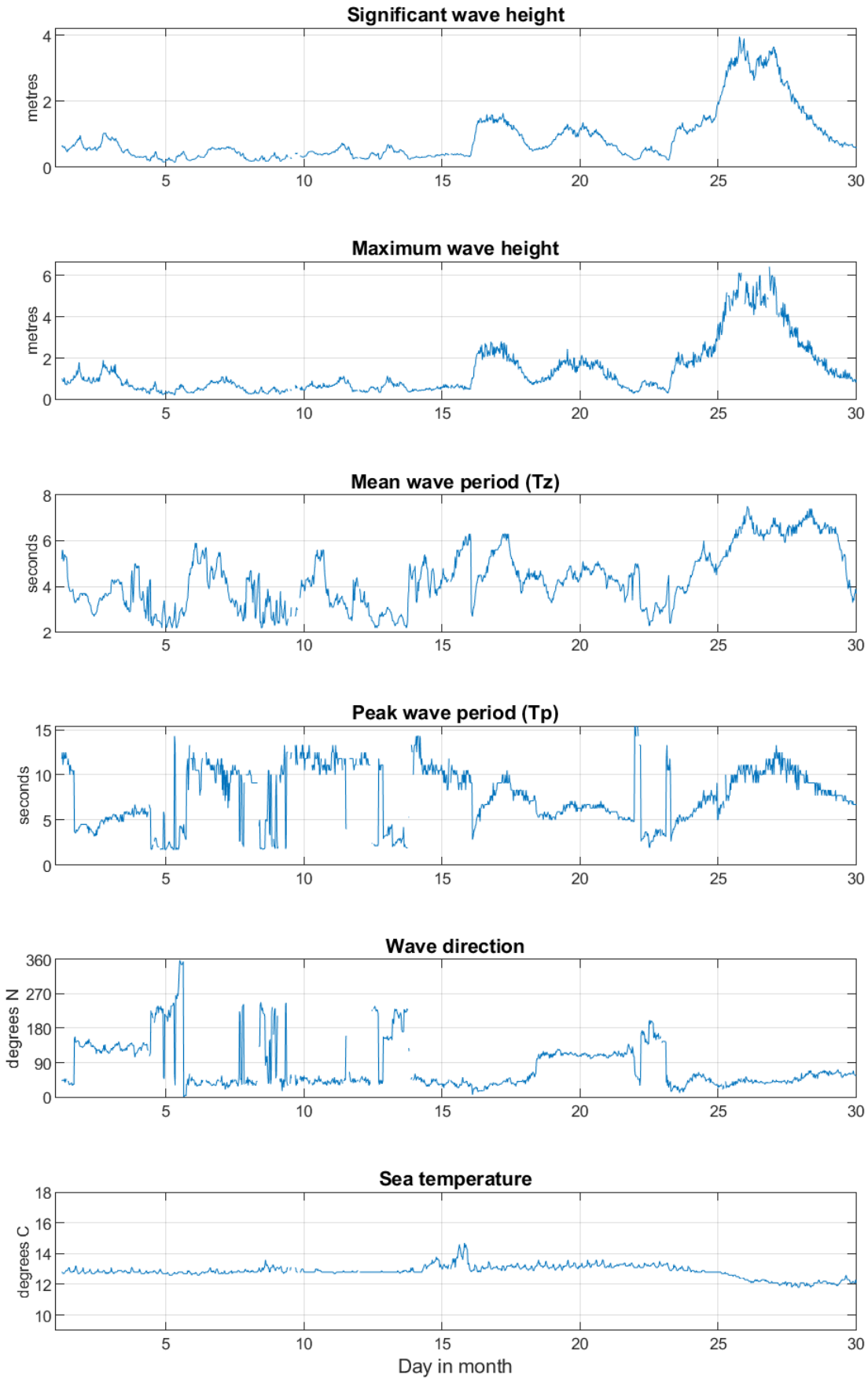
Newbiggin - July 2020



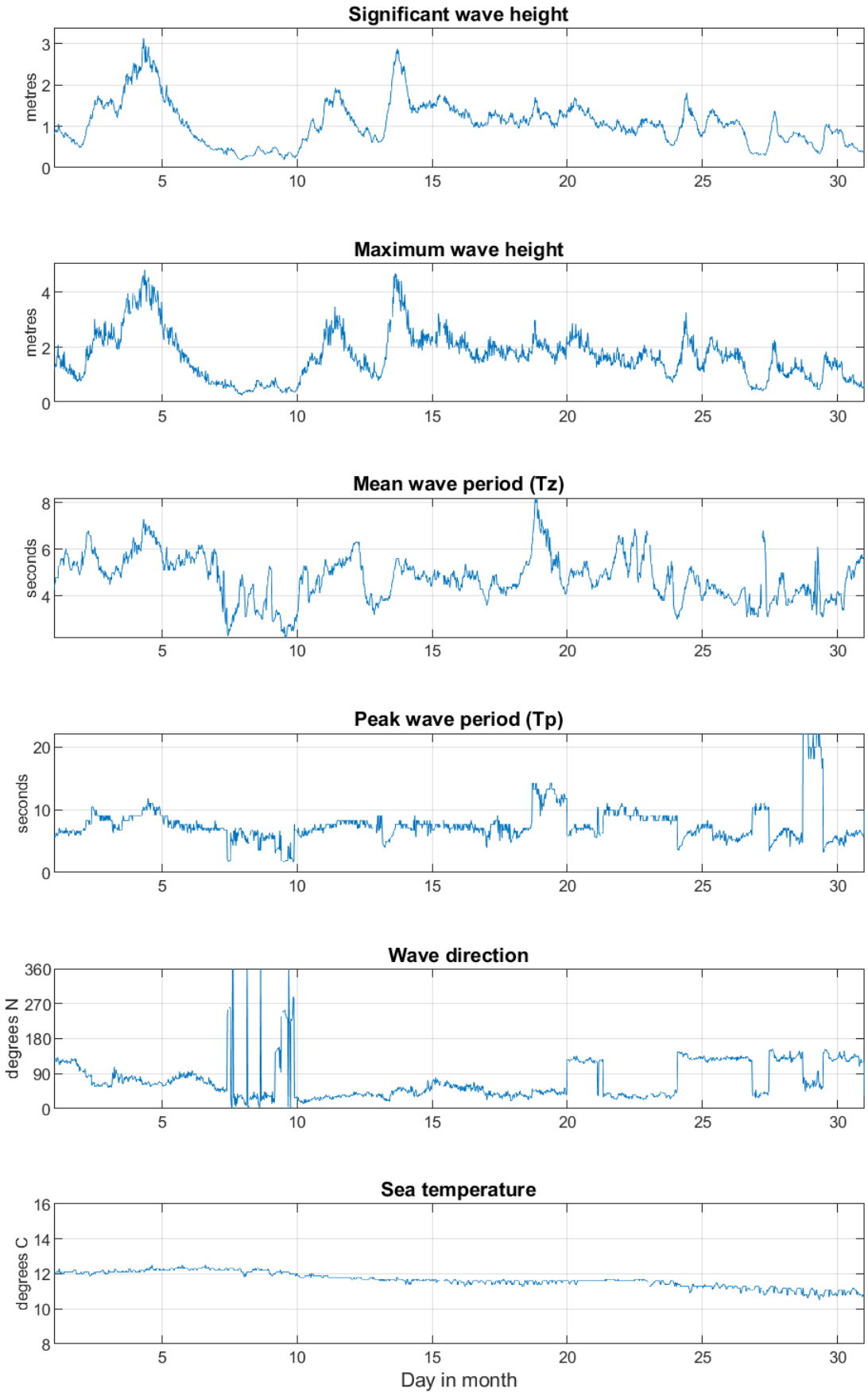
Newbiggin - August 2020



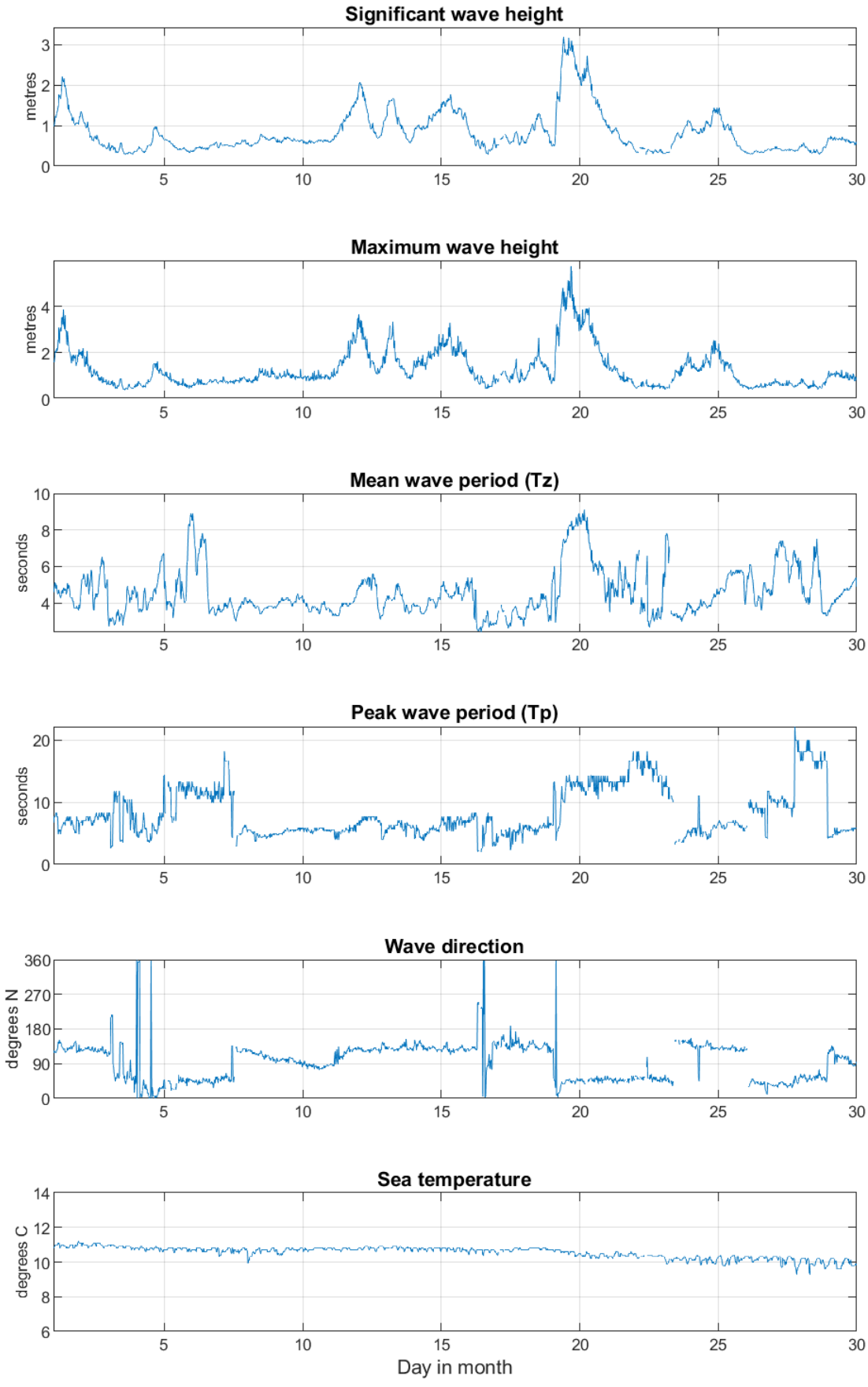
Newbiggin - September 2020



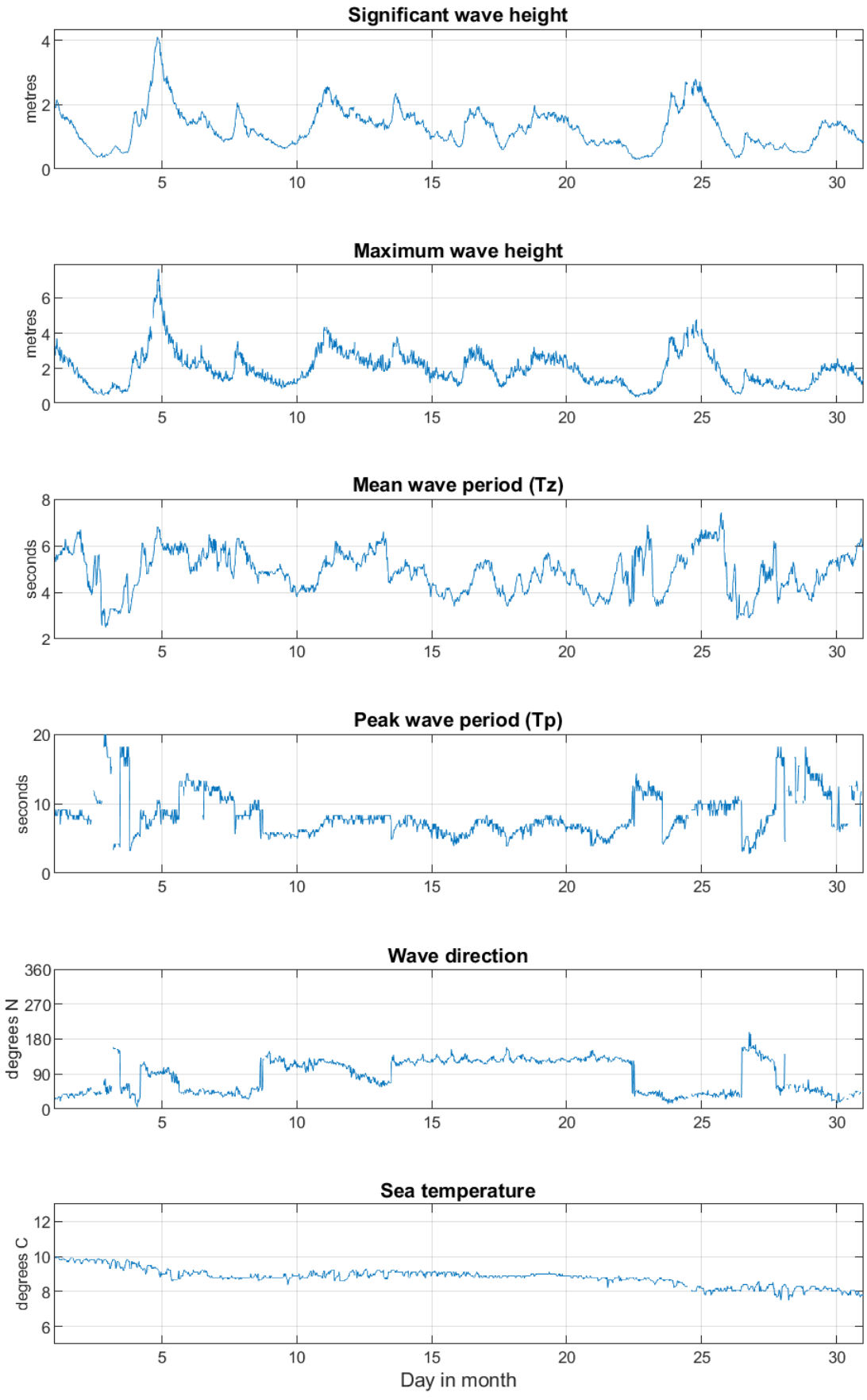
Newbiggin - October 2020



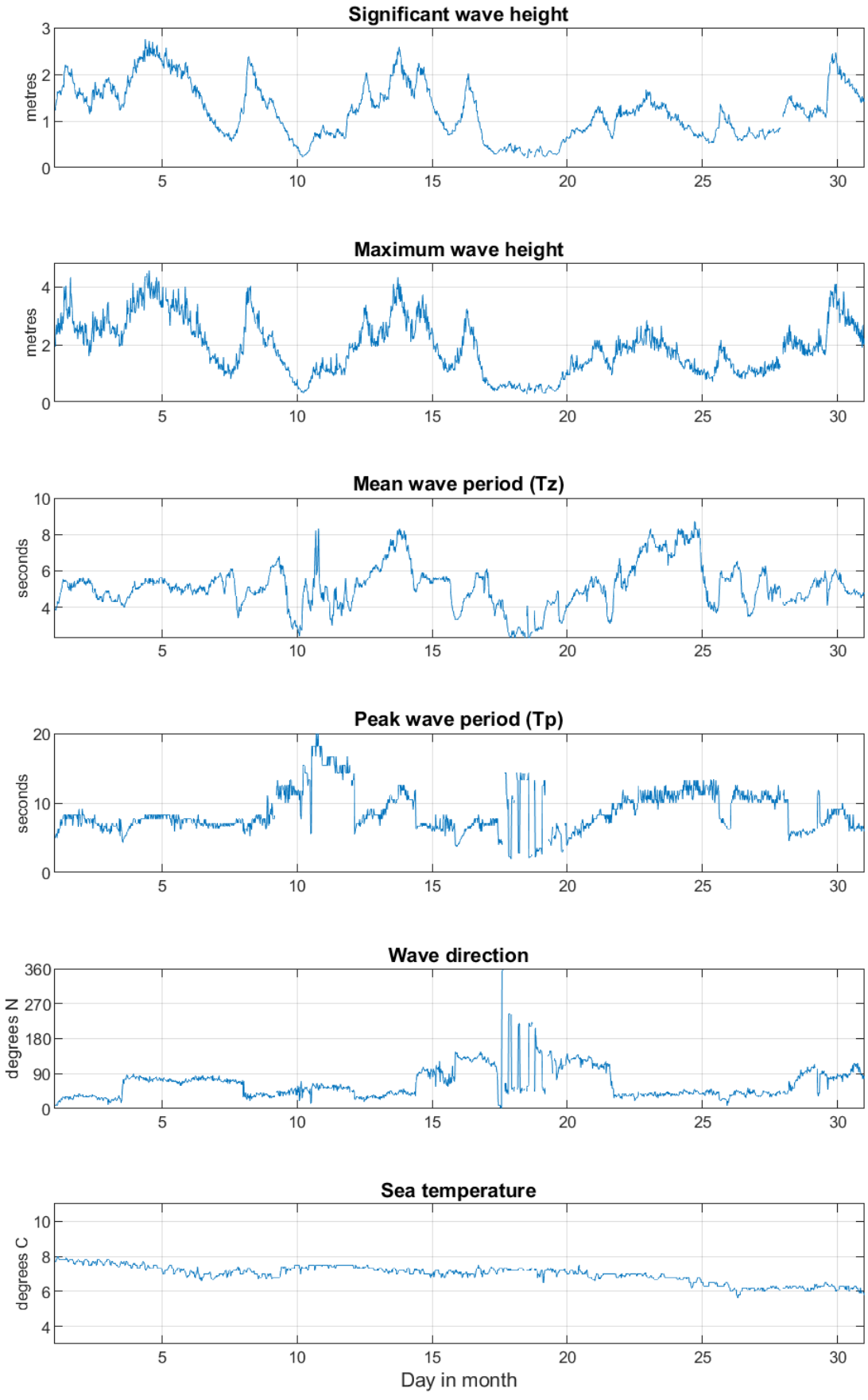
Newbiggin - November 2020



Newbiggin - December 2020



Newbiggin - January 2021



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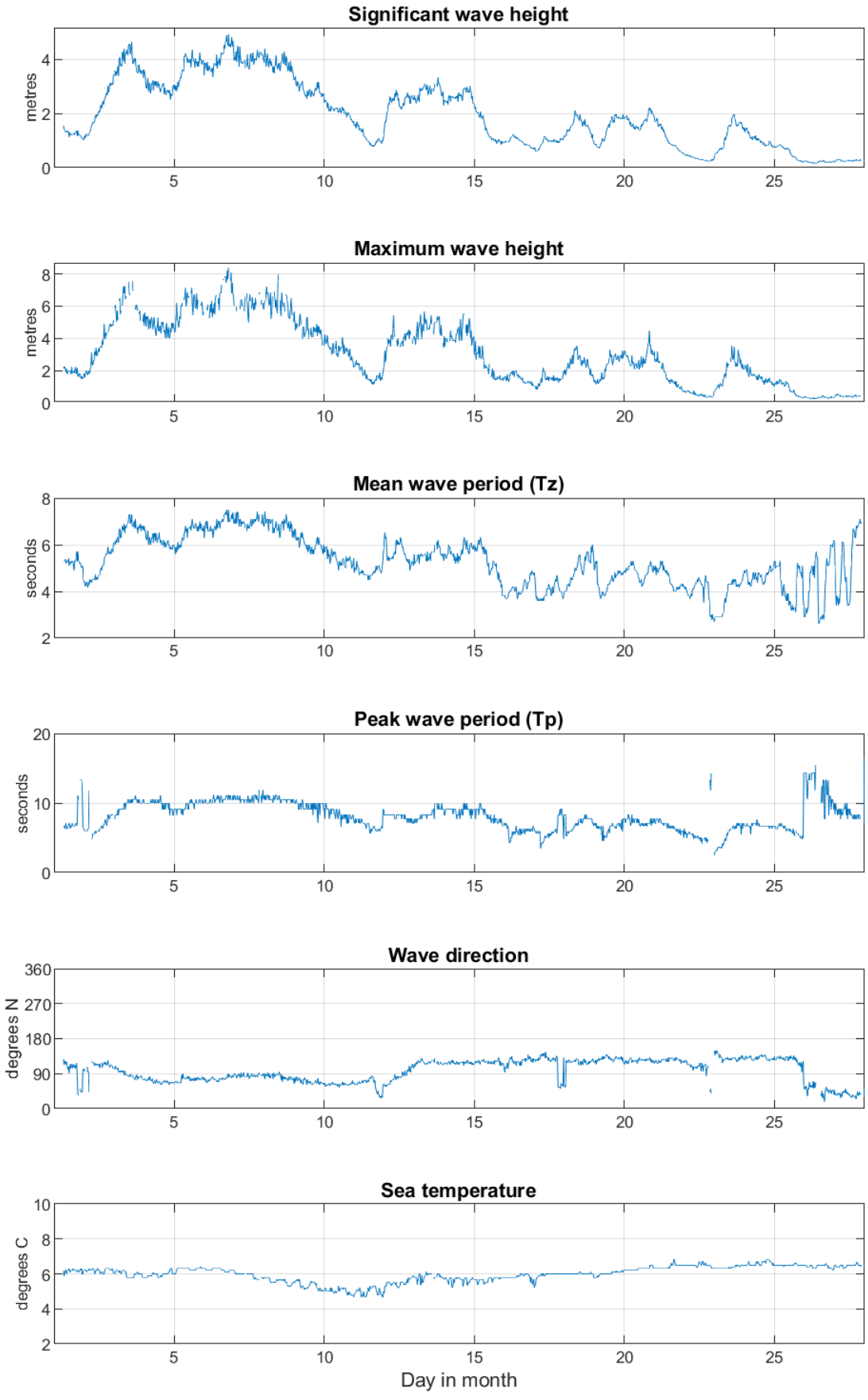
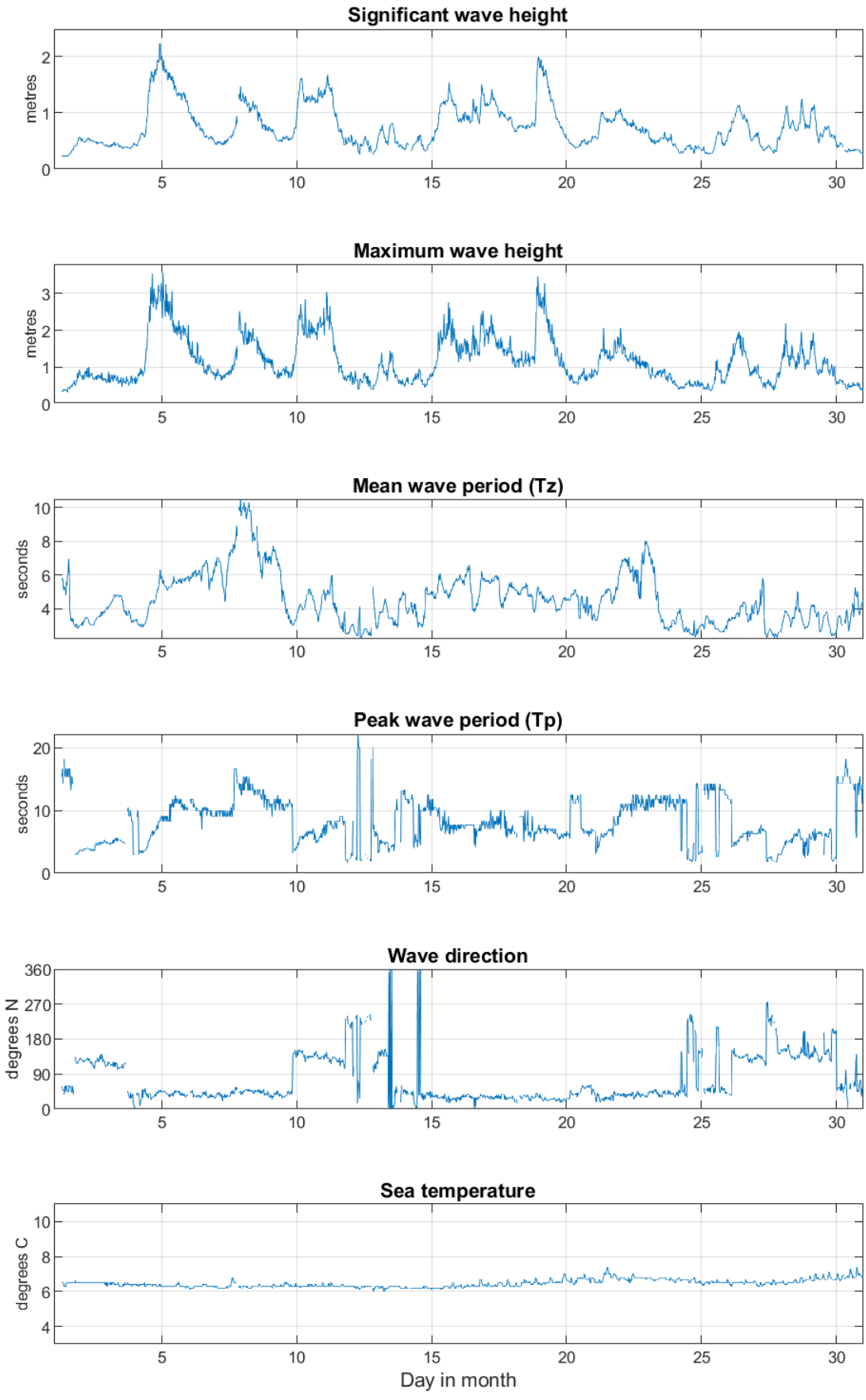
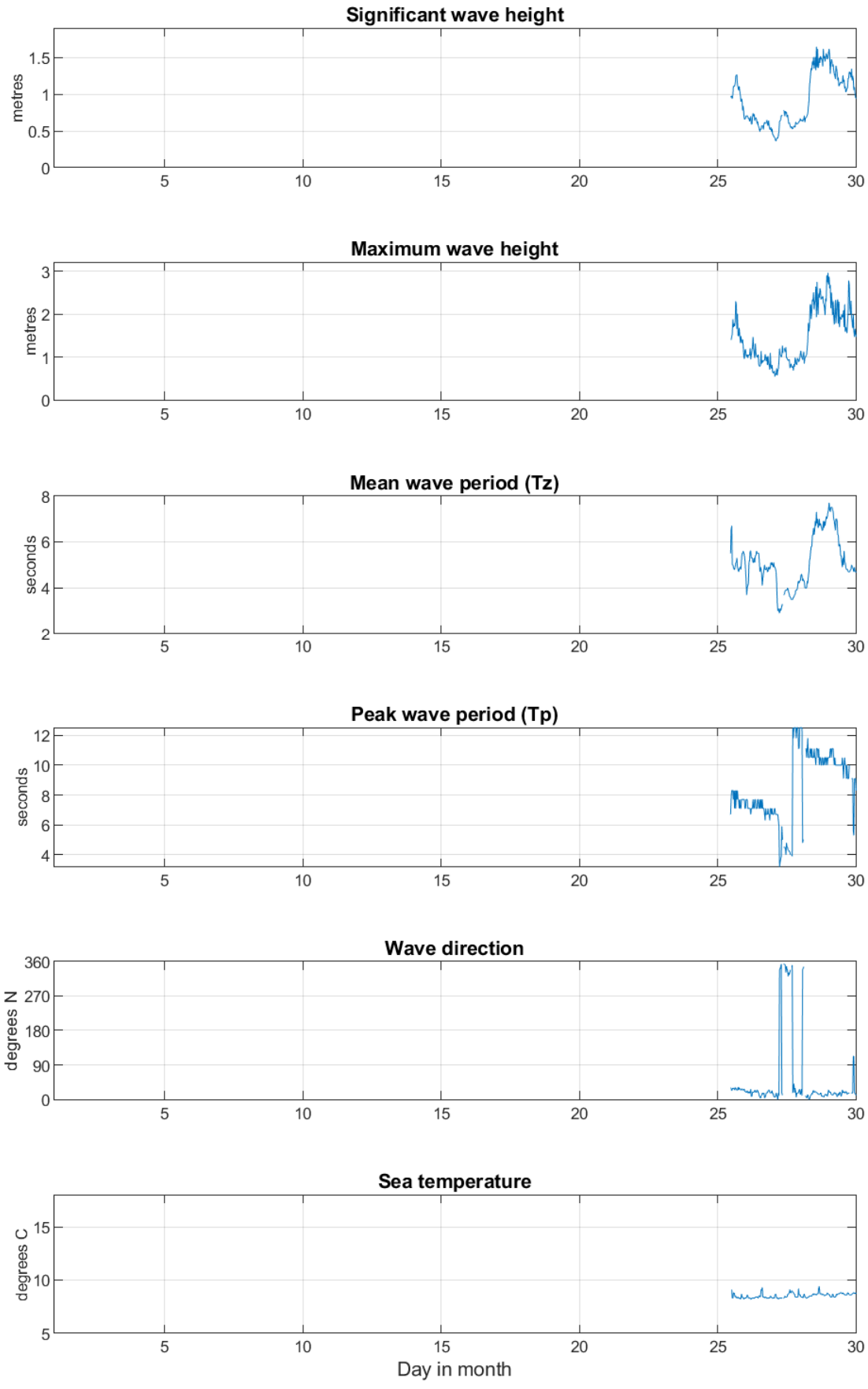


Newbiggin - March 2021

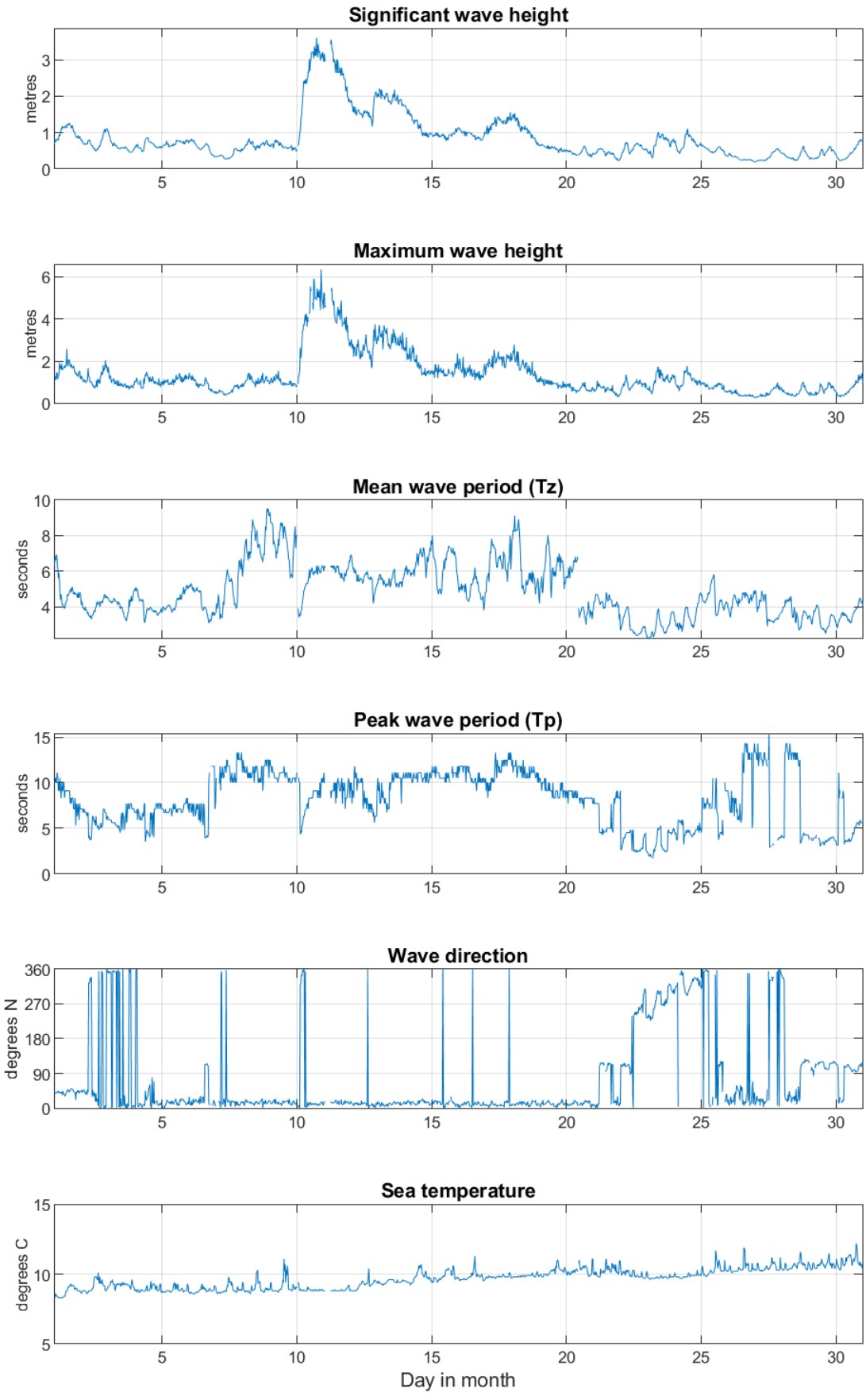


Appendix C: Supporting Graphs - Whitby Wave Buoy

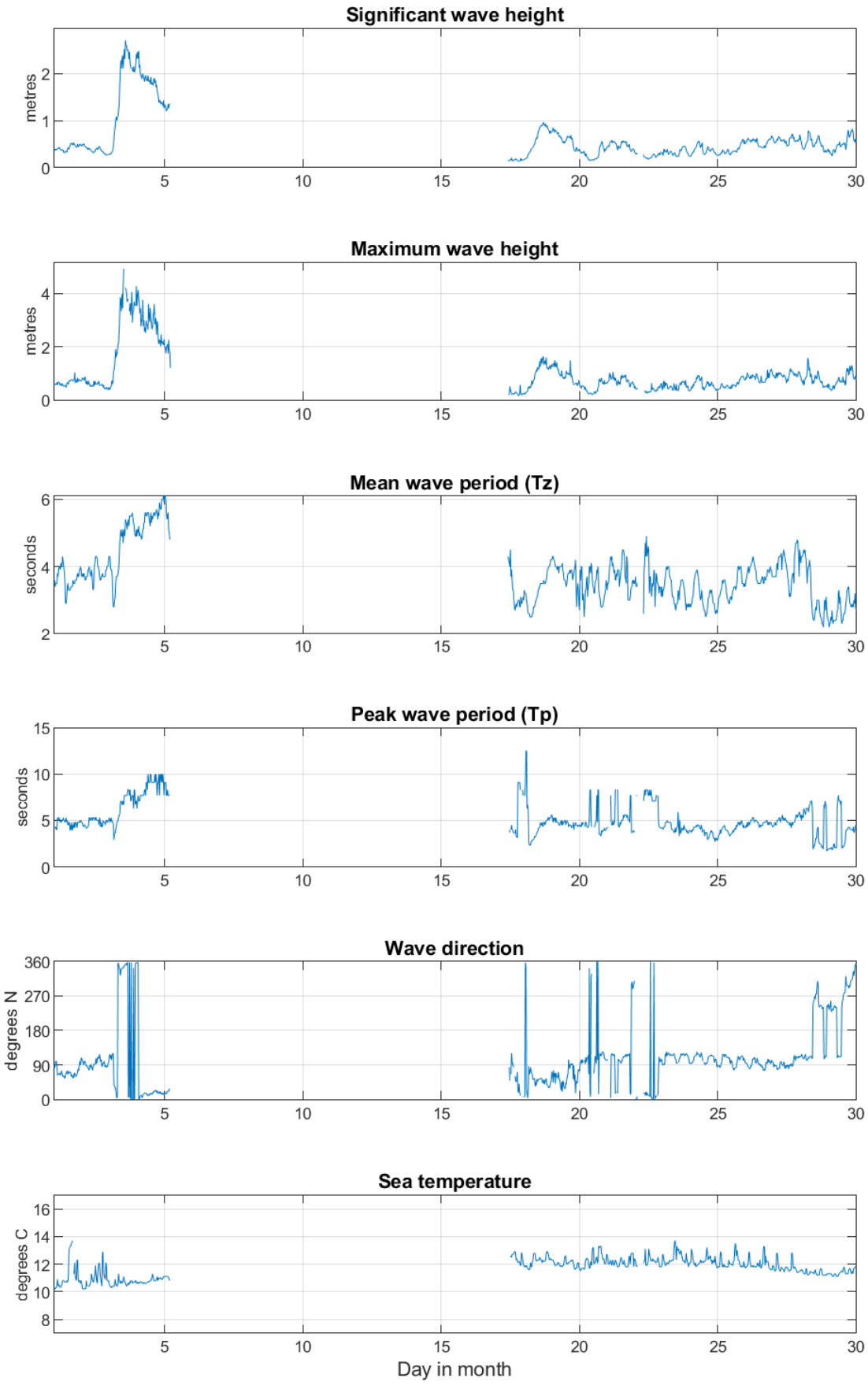
Whitby - April 2020



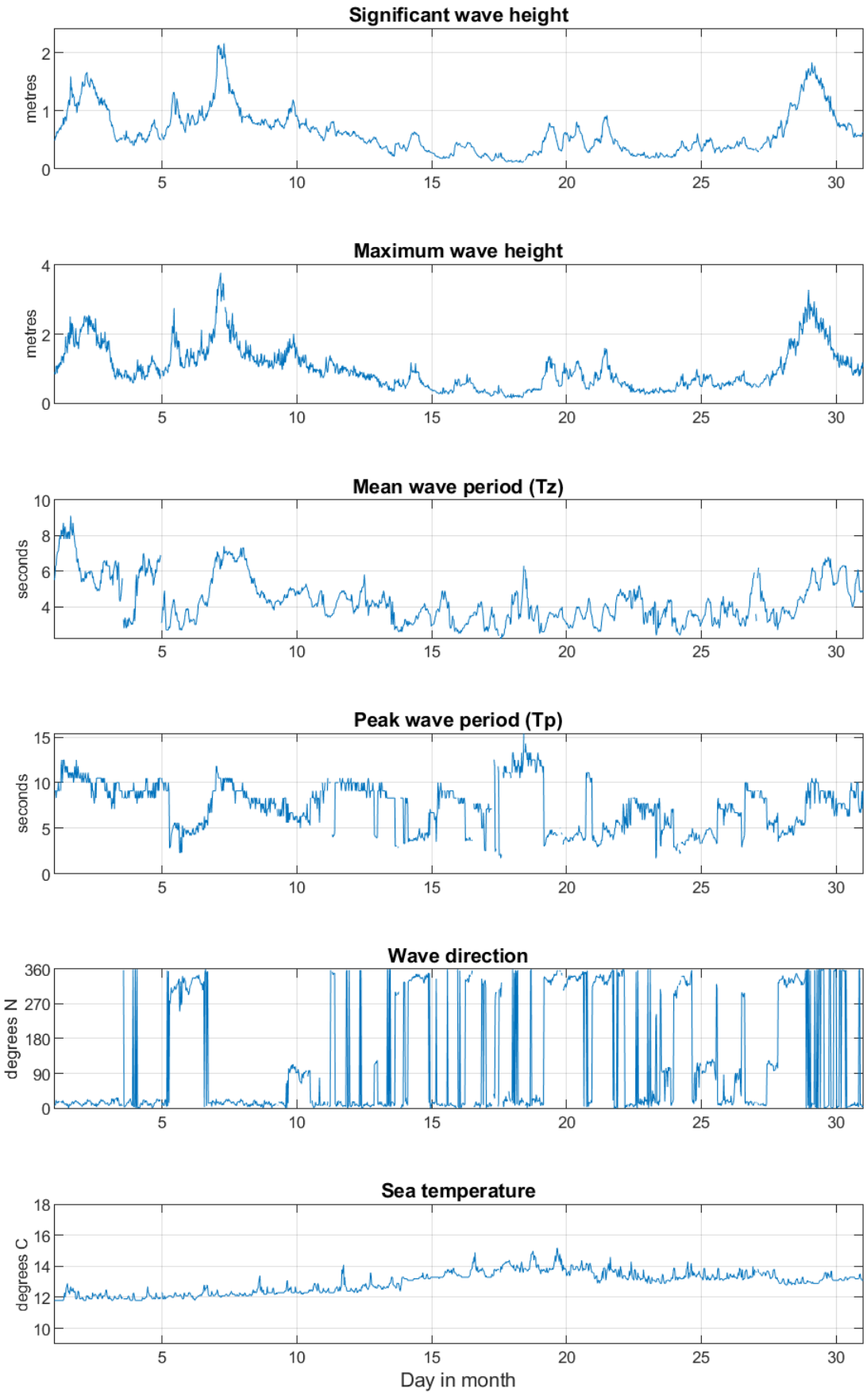
Whitby - May 2020



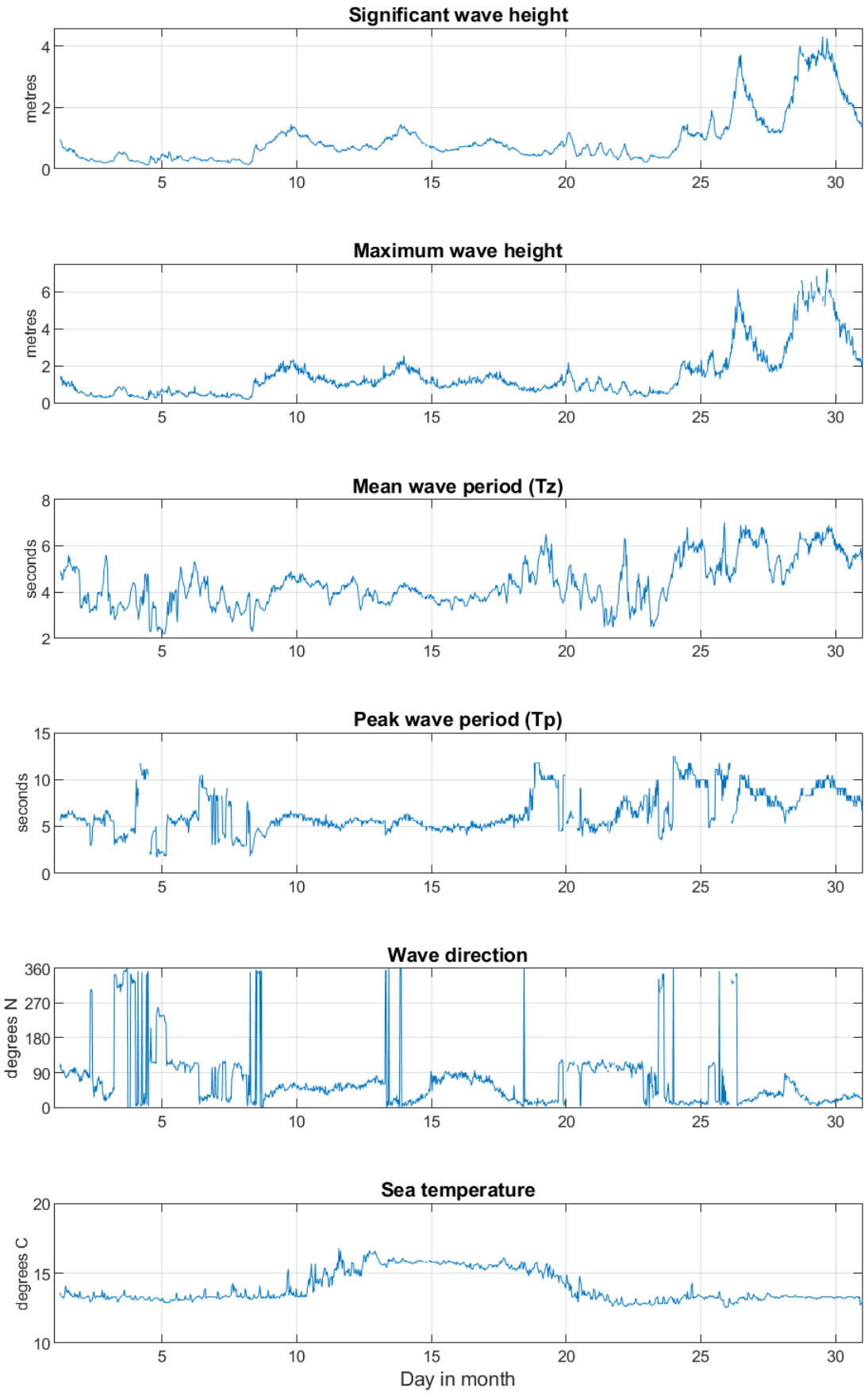
Whitby - June 2020



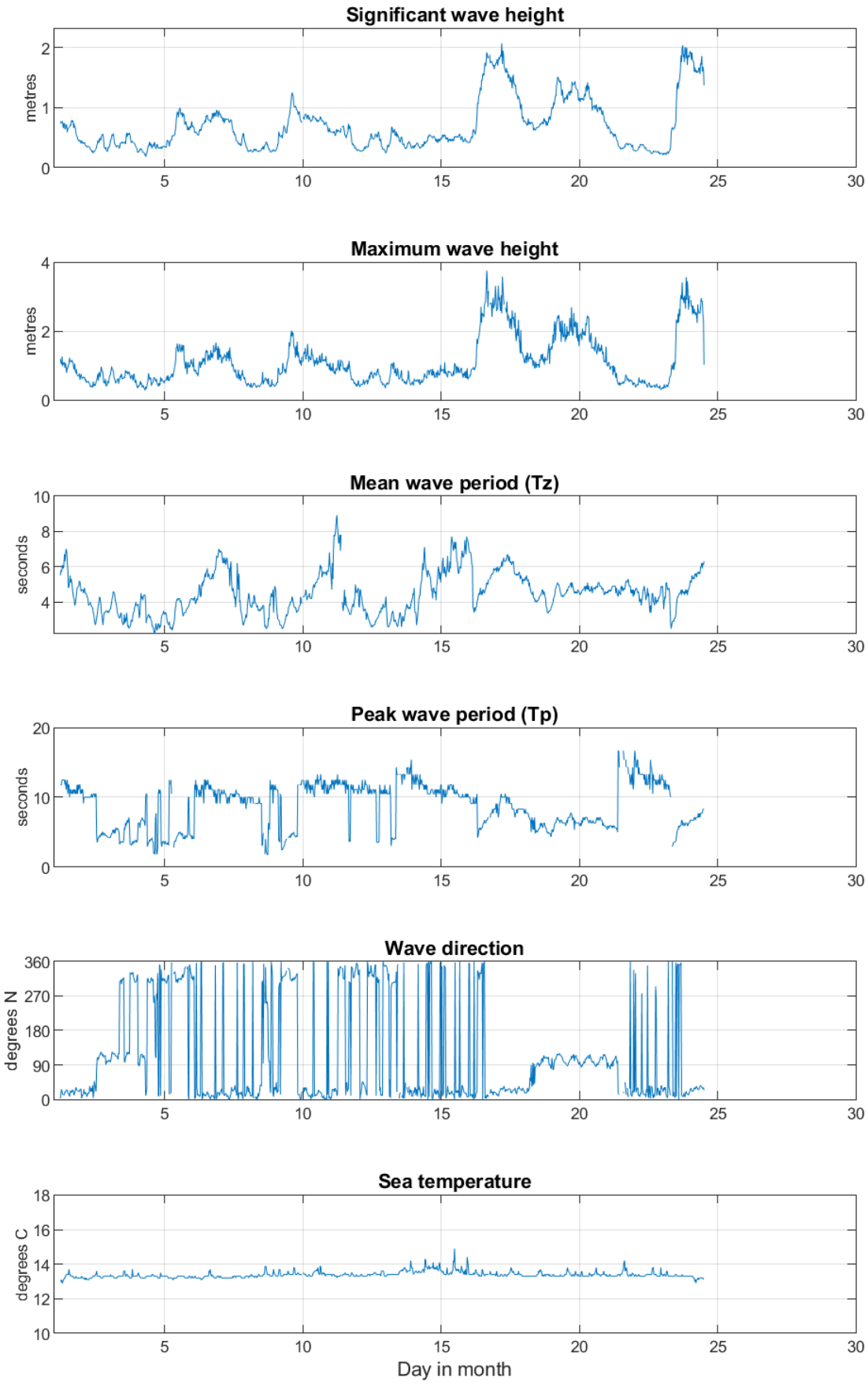
Whitby - July 2020



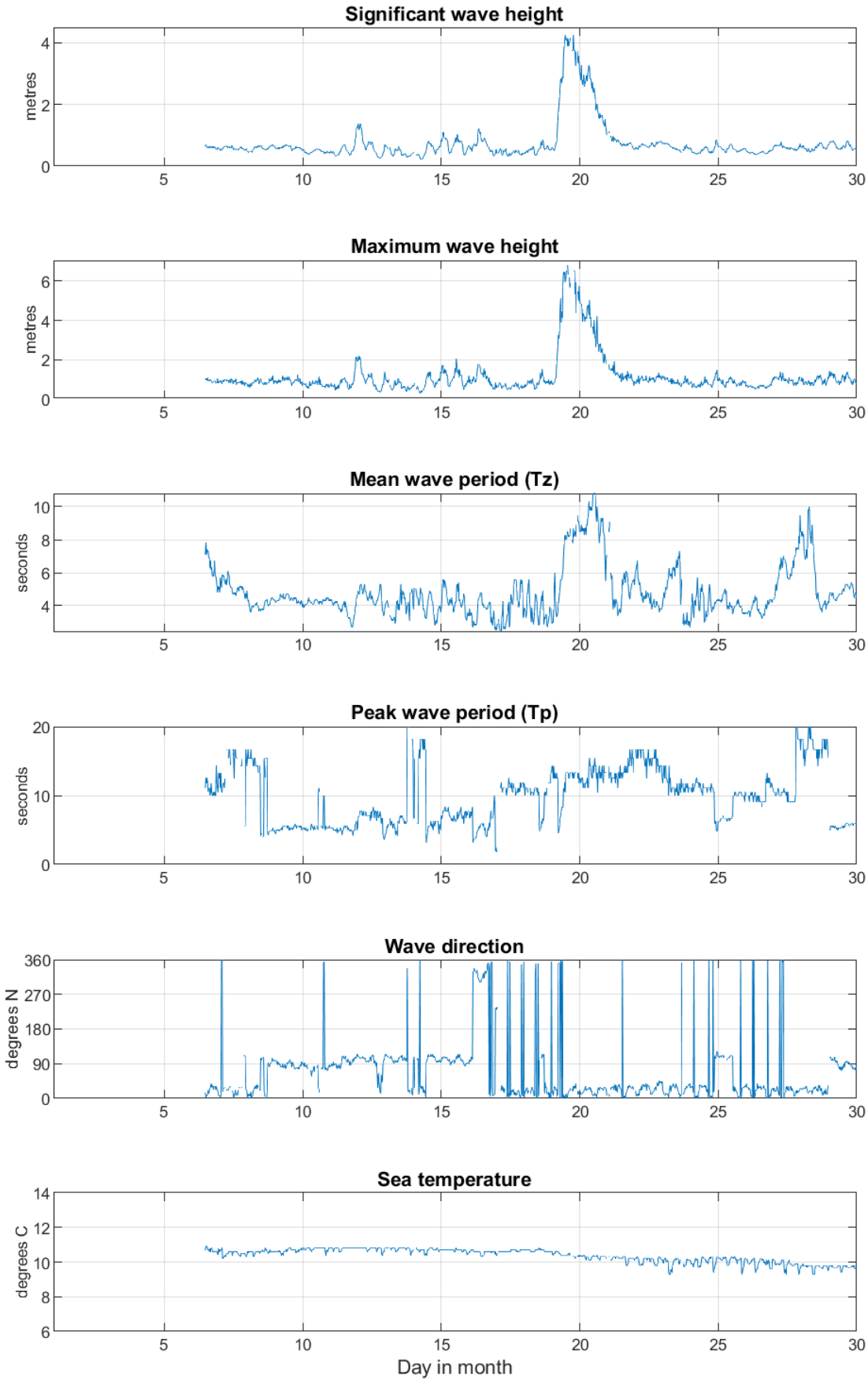
Whitby - August 2020



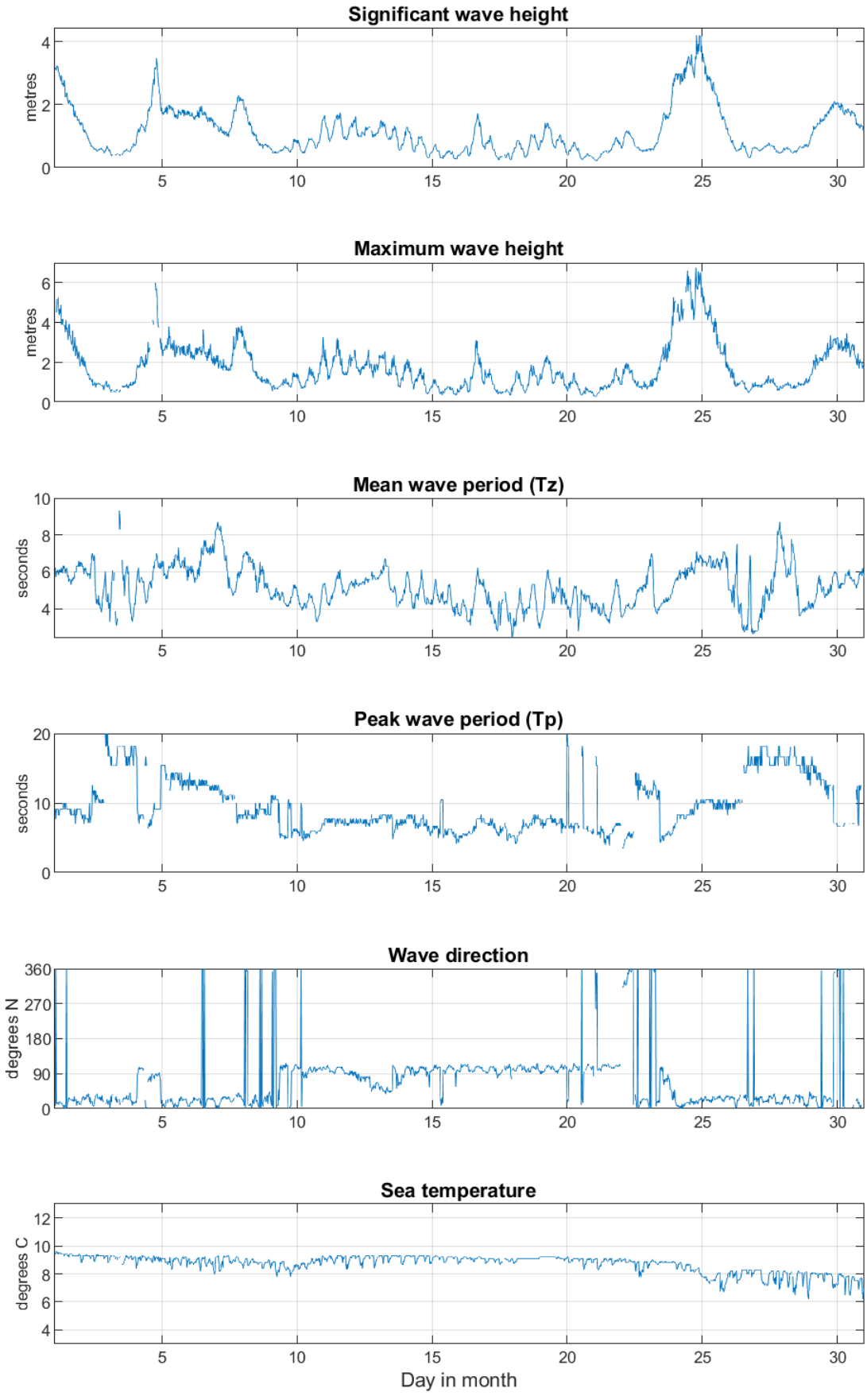
Whitby - September 2020



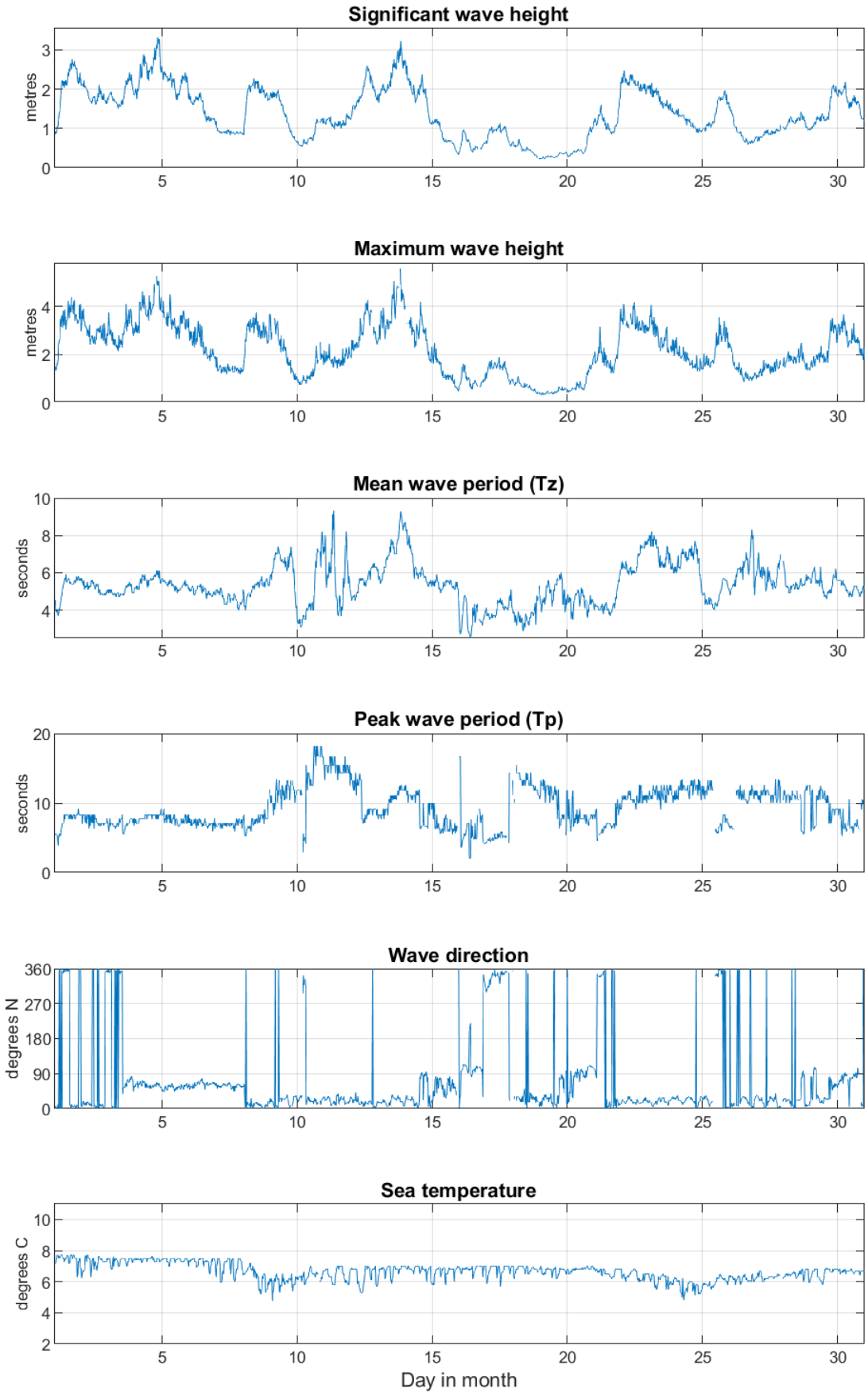
Whitby - November 2020



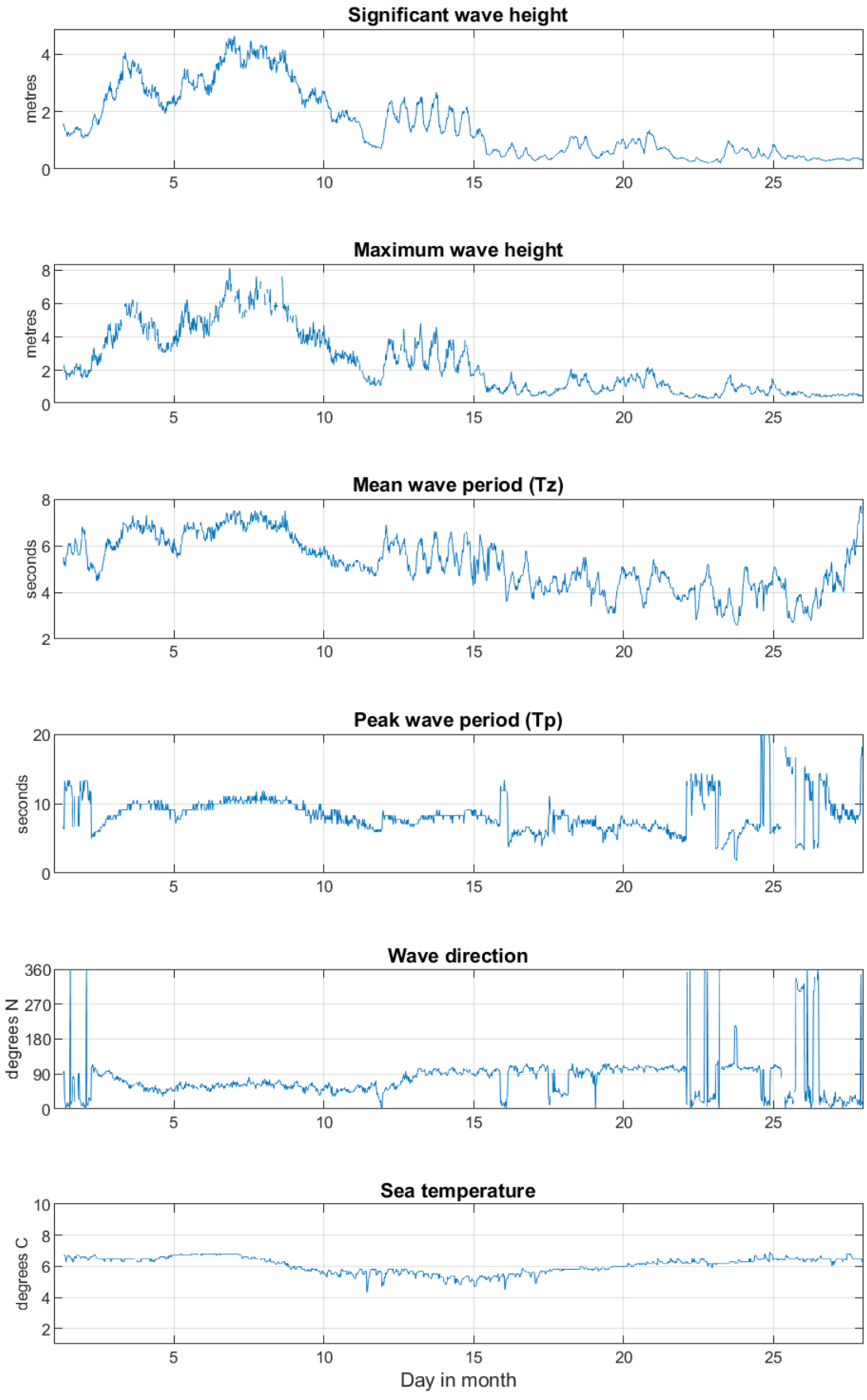
Whitby - December 2020



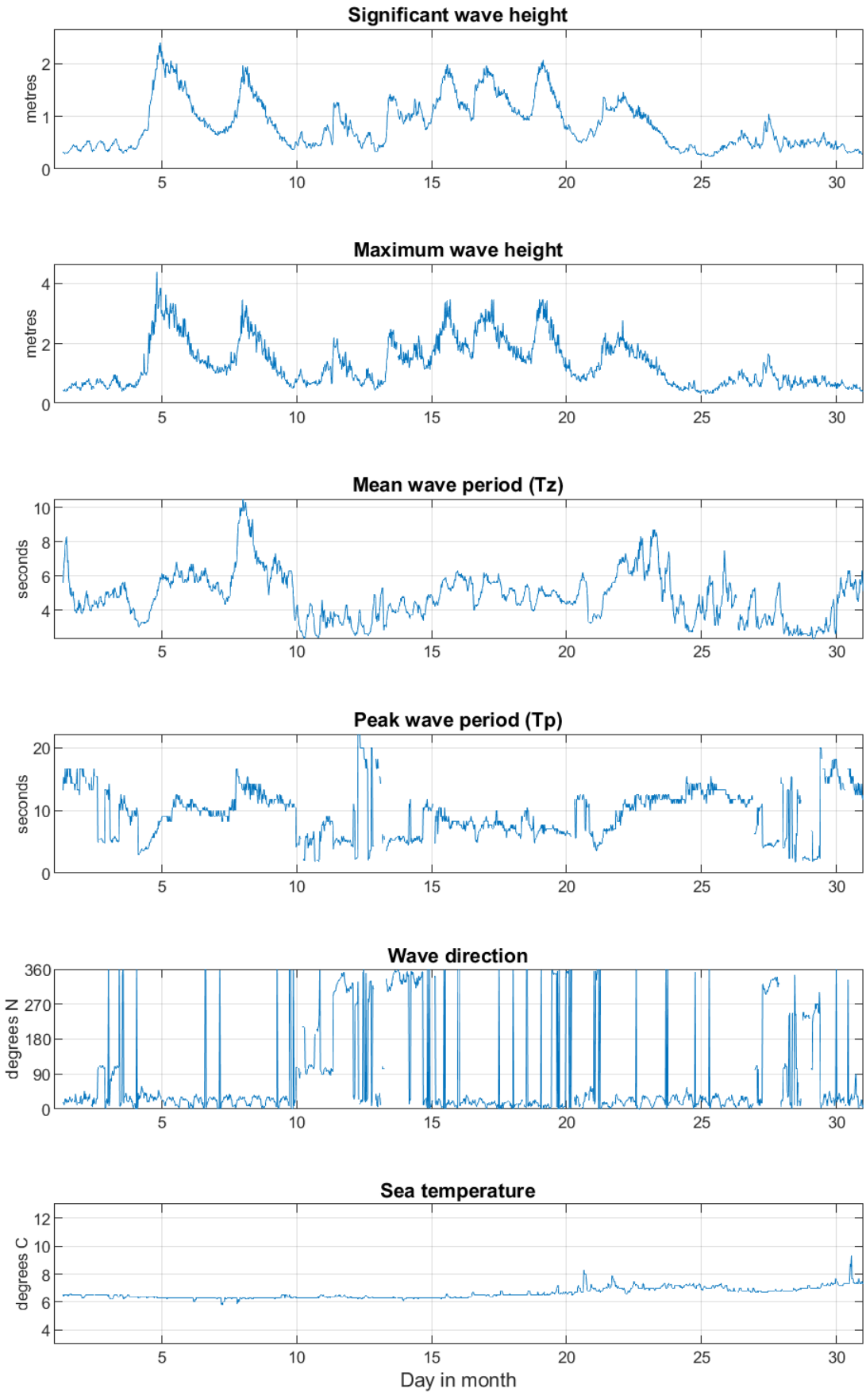
Whitby - January 2021



Whitby - February 2021

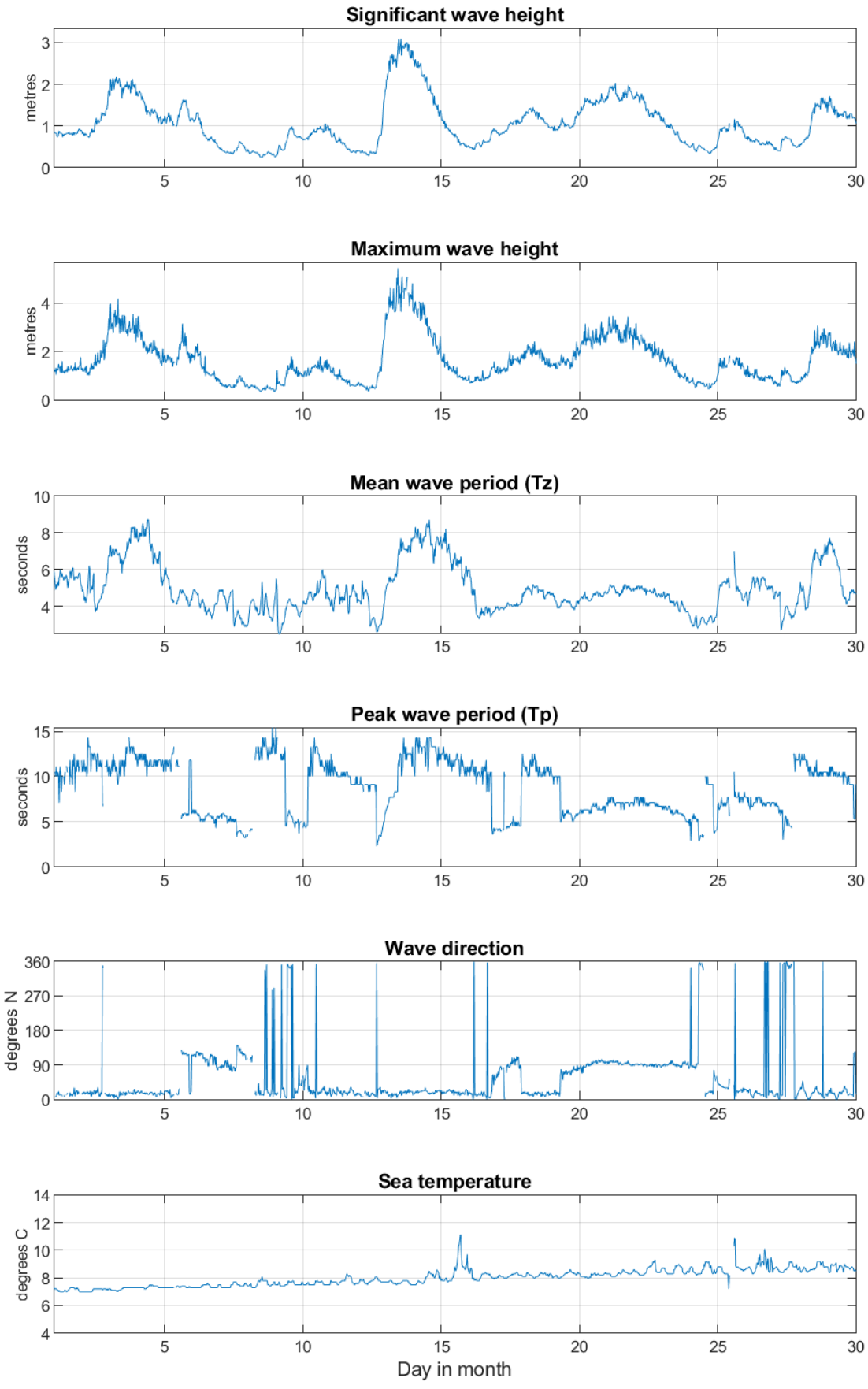


Whitby - March 2021

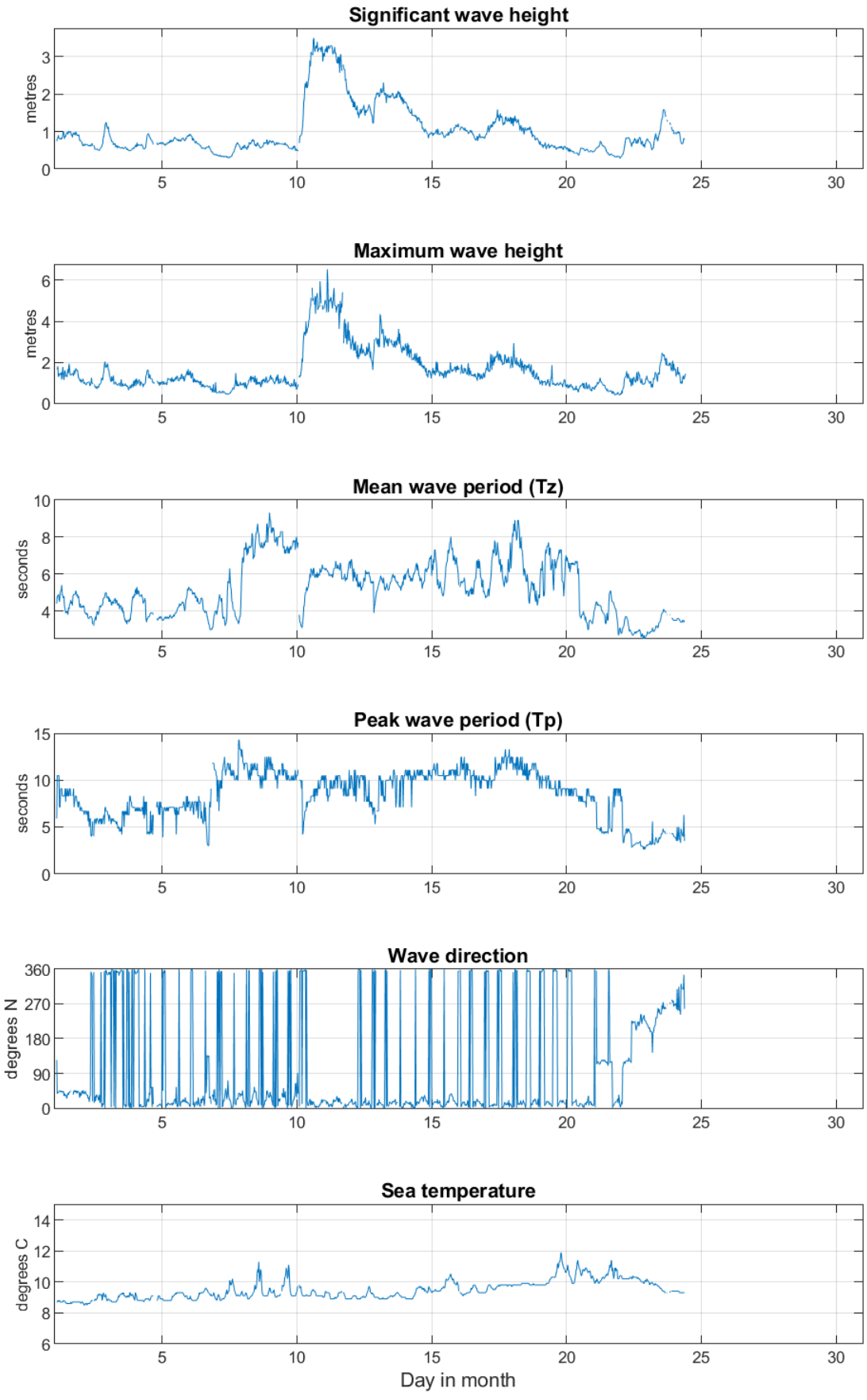


Appendix D: Supporting Graphs - Scarborough Wave Buoy

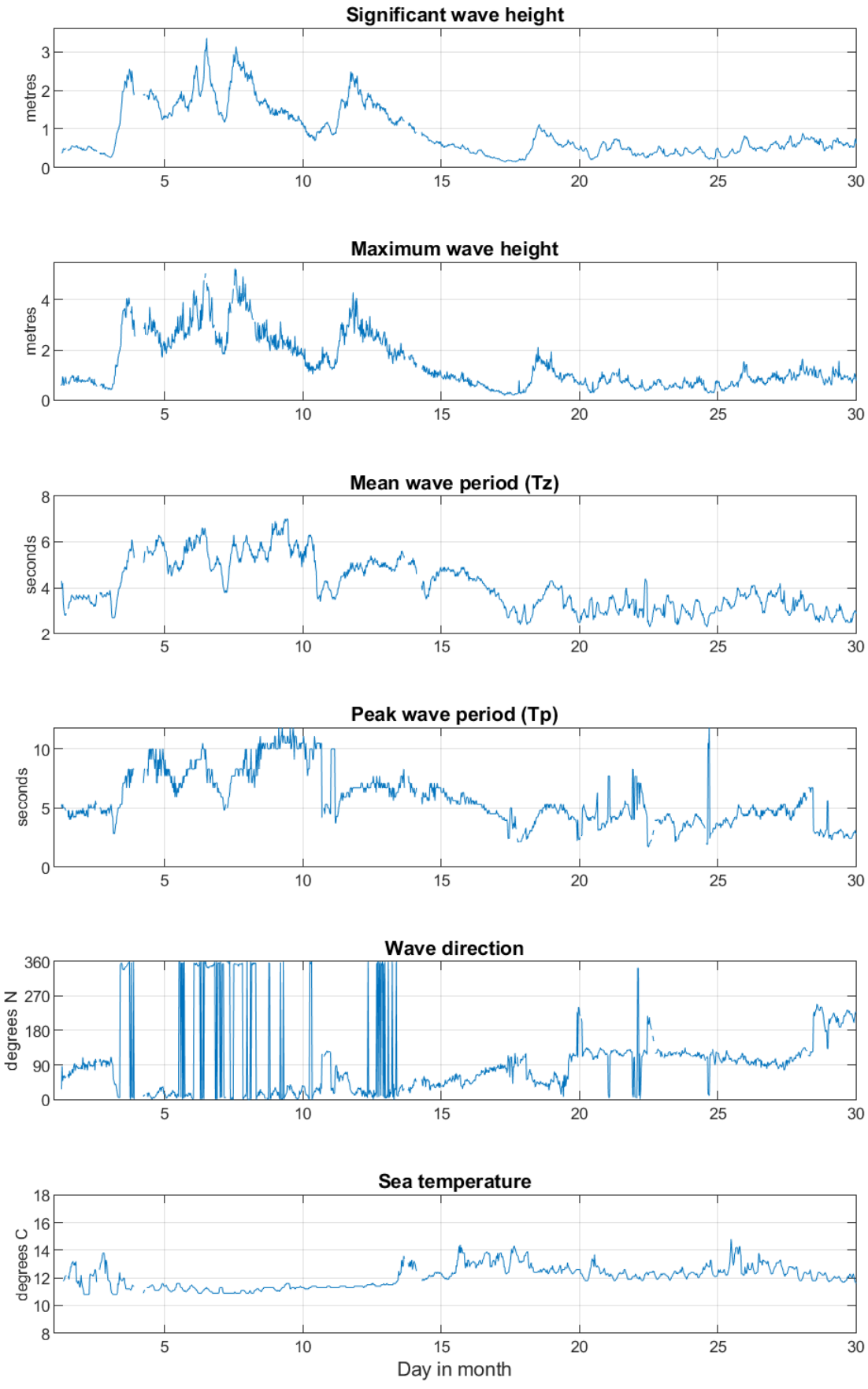
Scarborough - April 2020



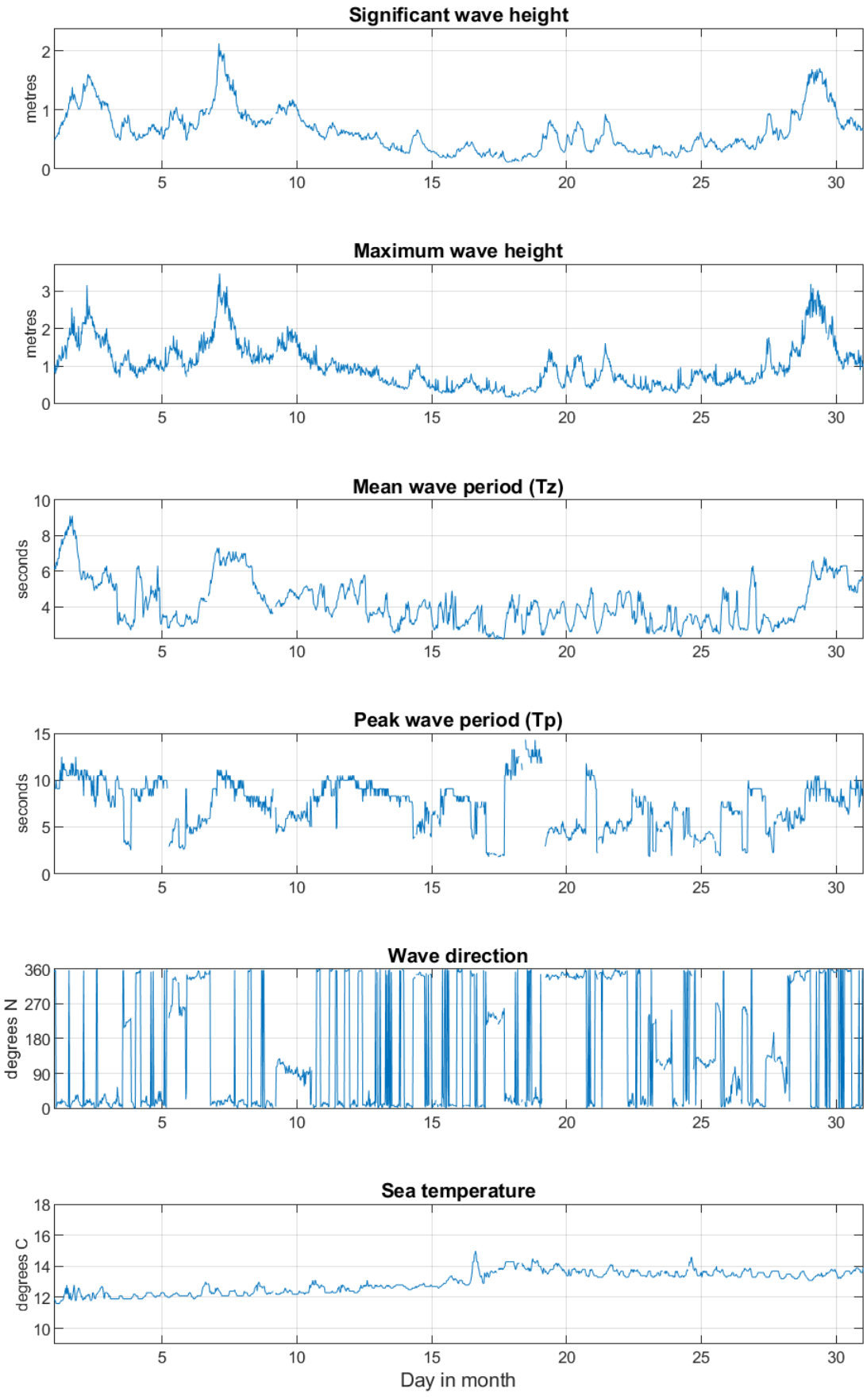
Scarborough - May 2020



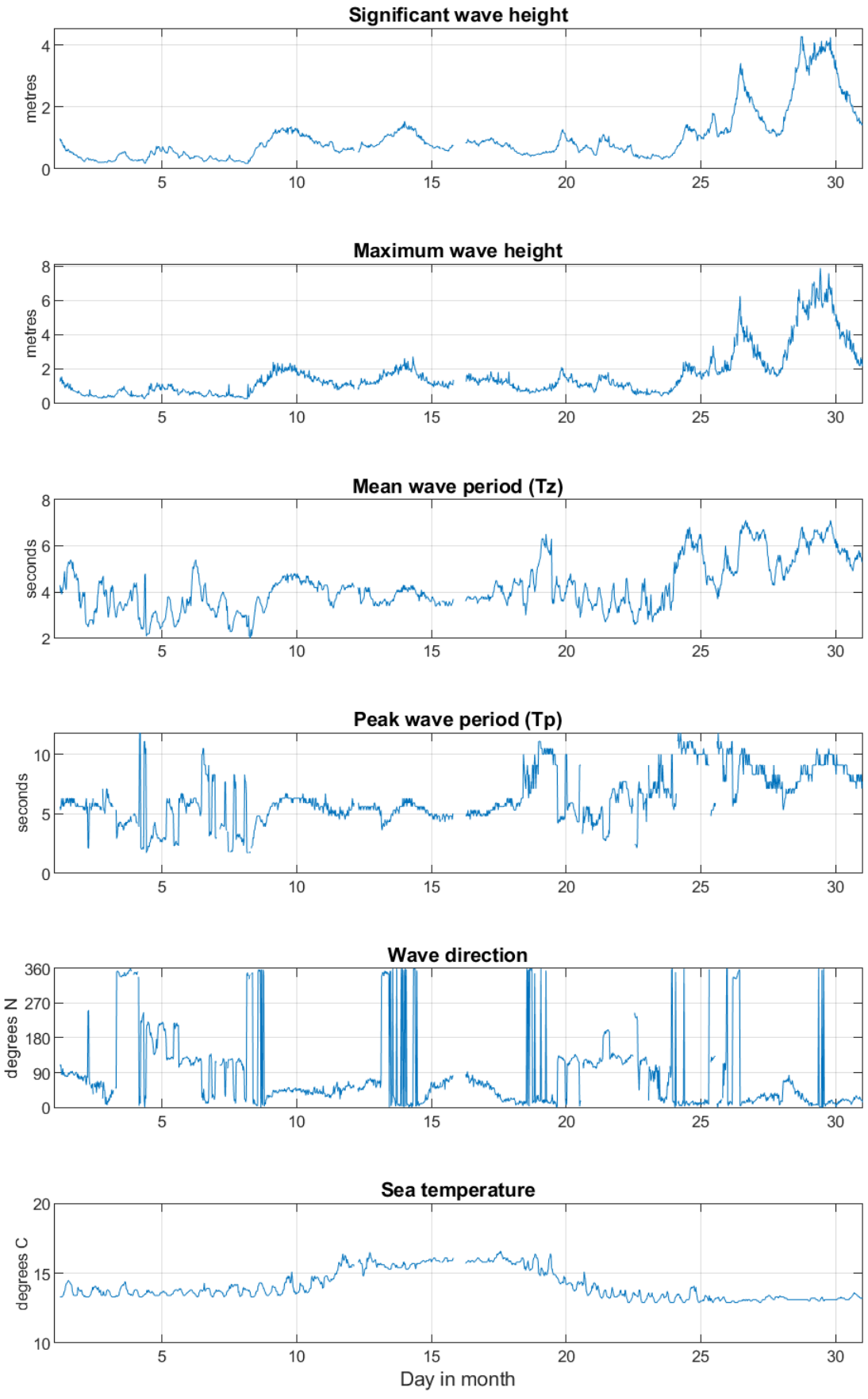
Scarborough - June 2020



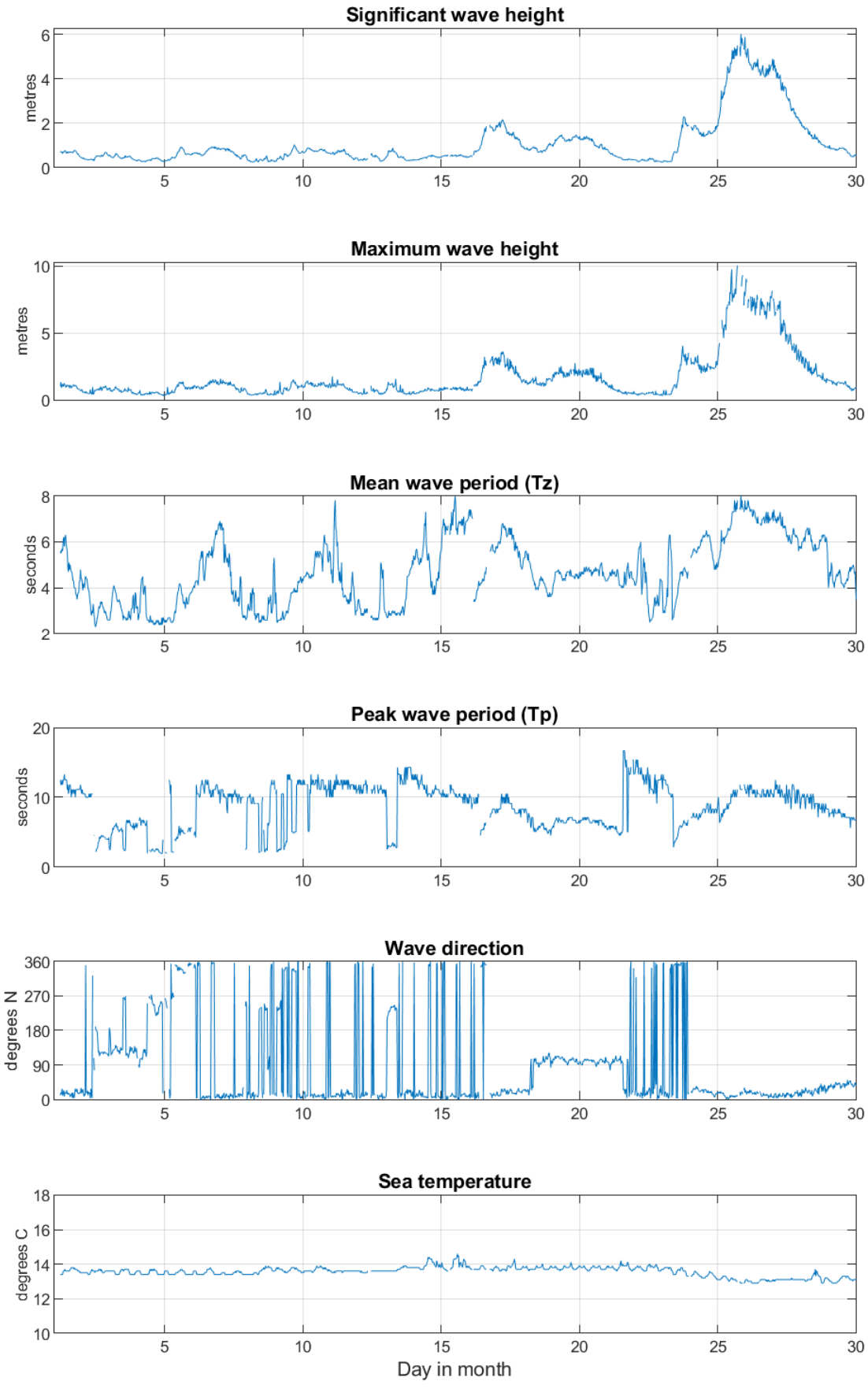
Scarborough - July 2020



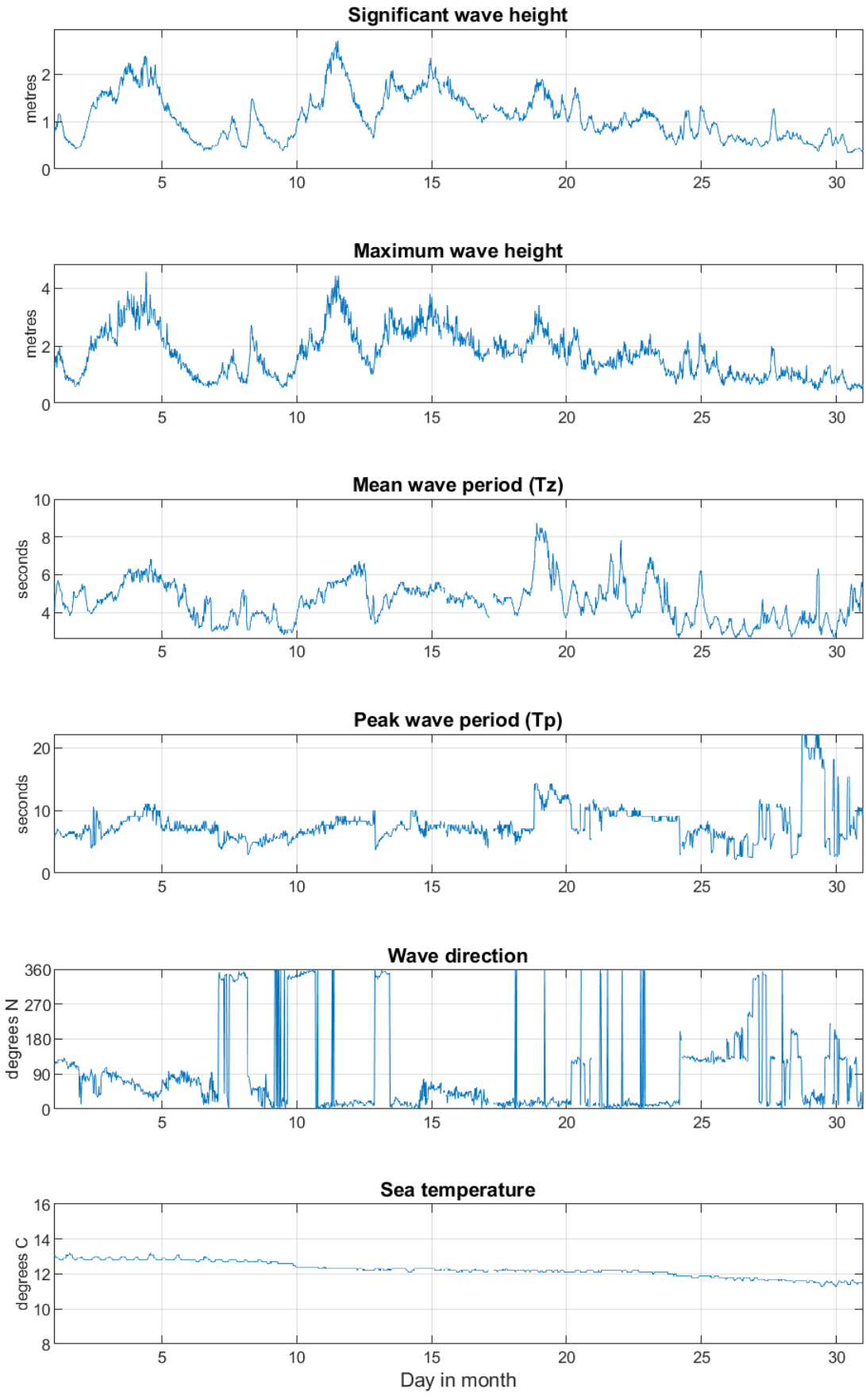
Scarborough - August 2020



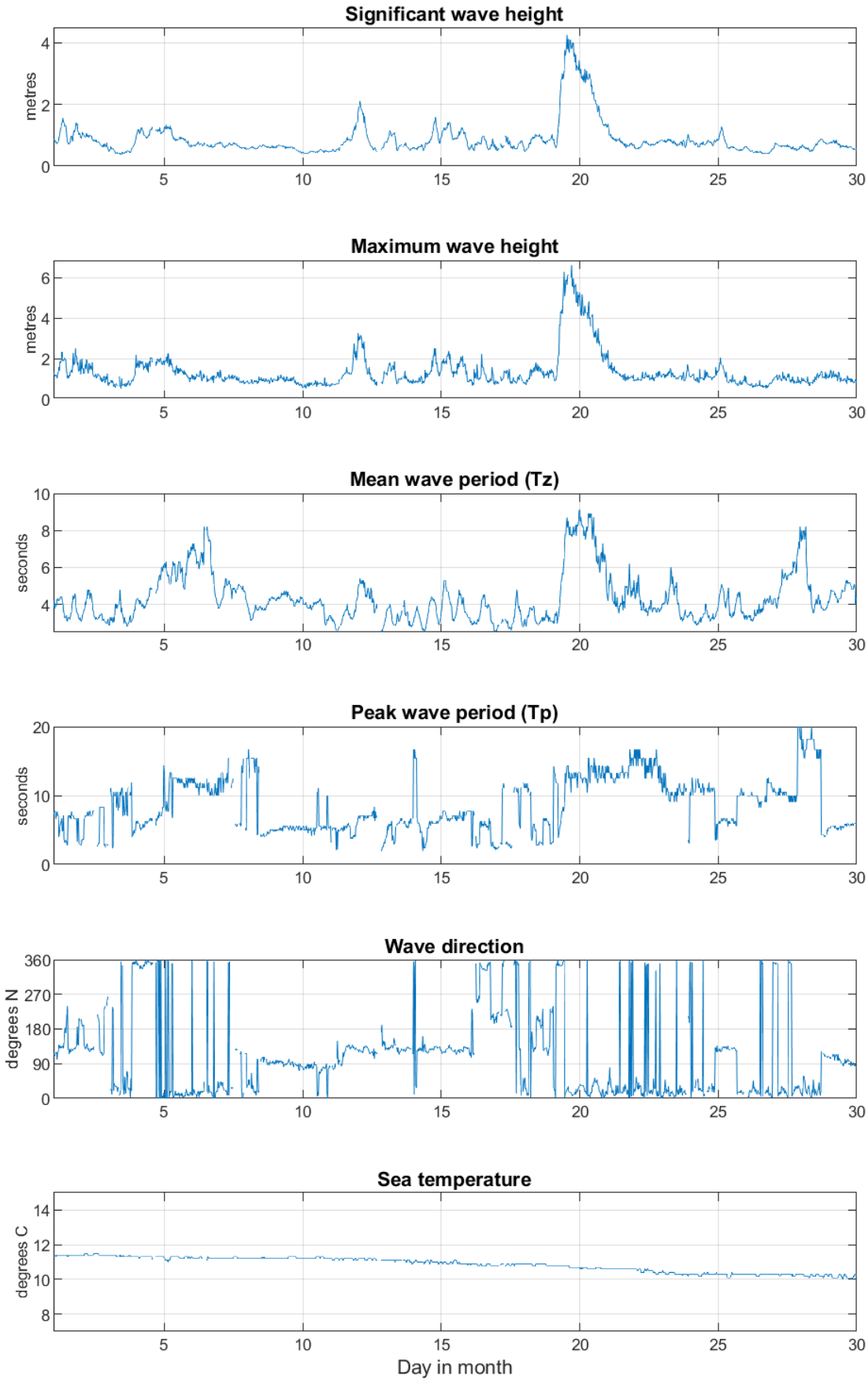
Scarborough - September 2020



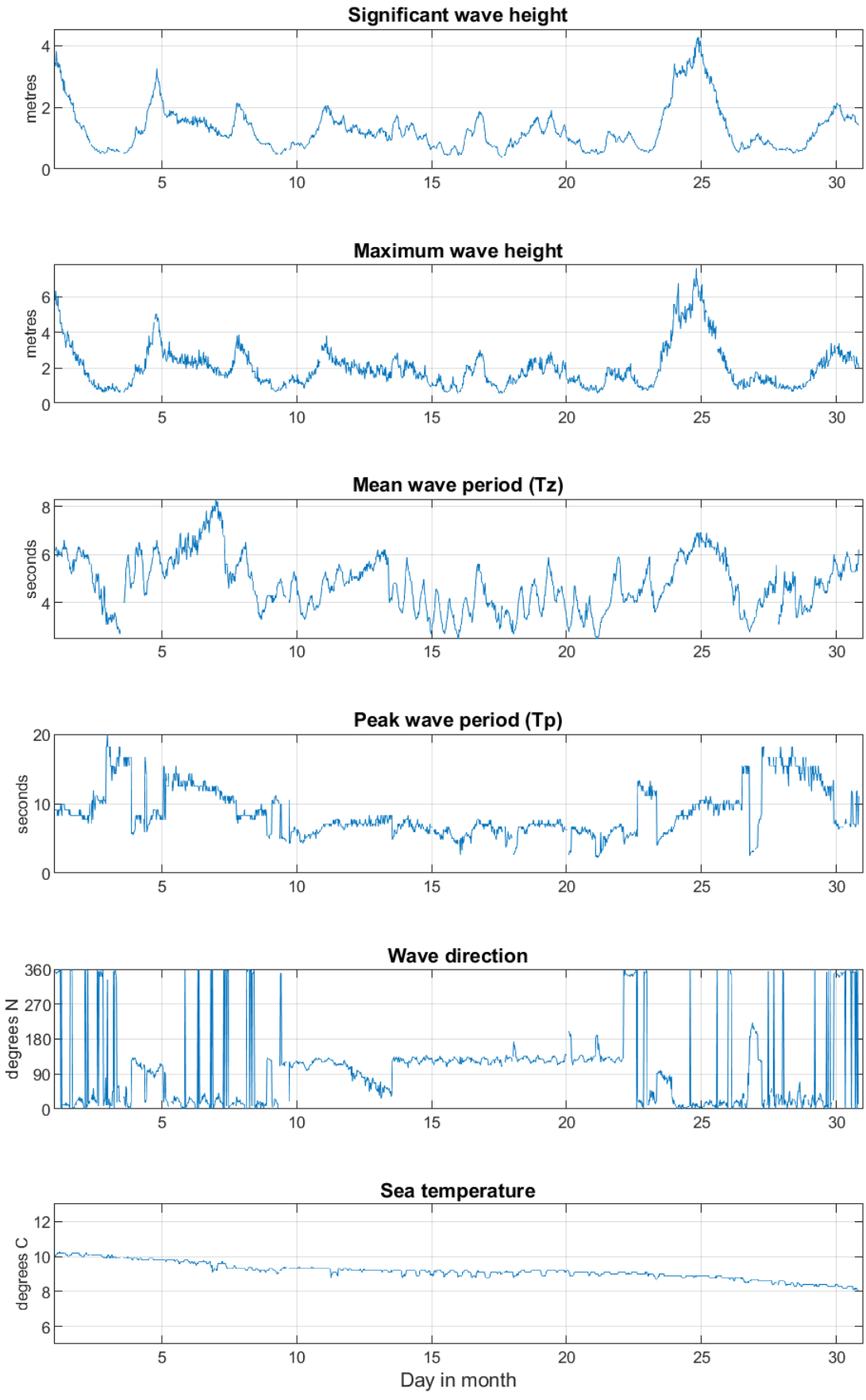
Scarborough - October 2020



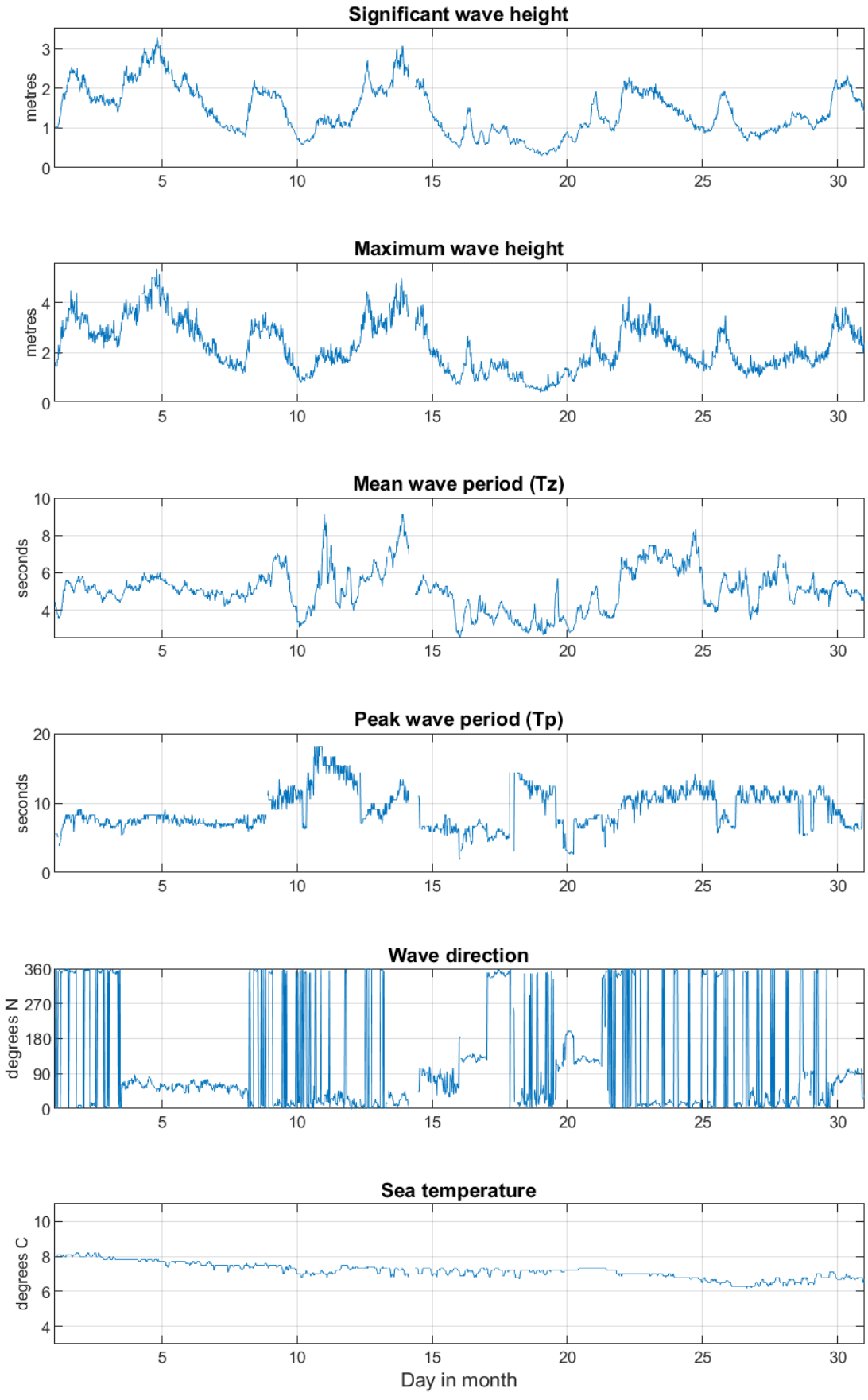
Scarborough - November 2020



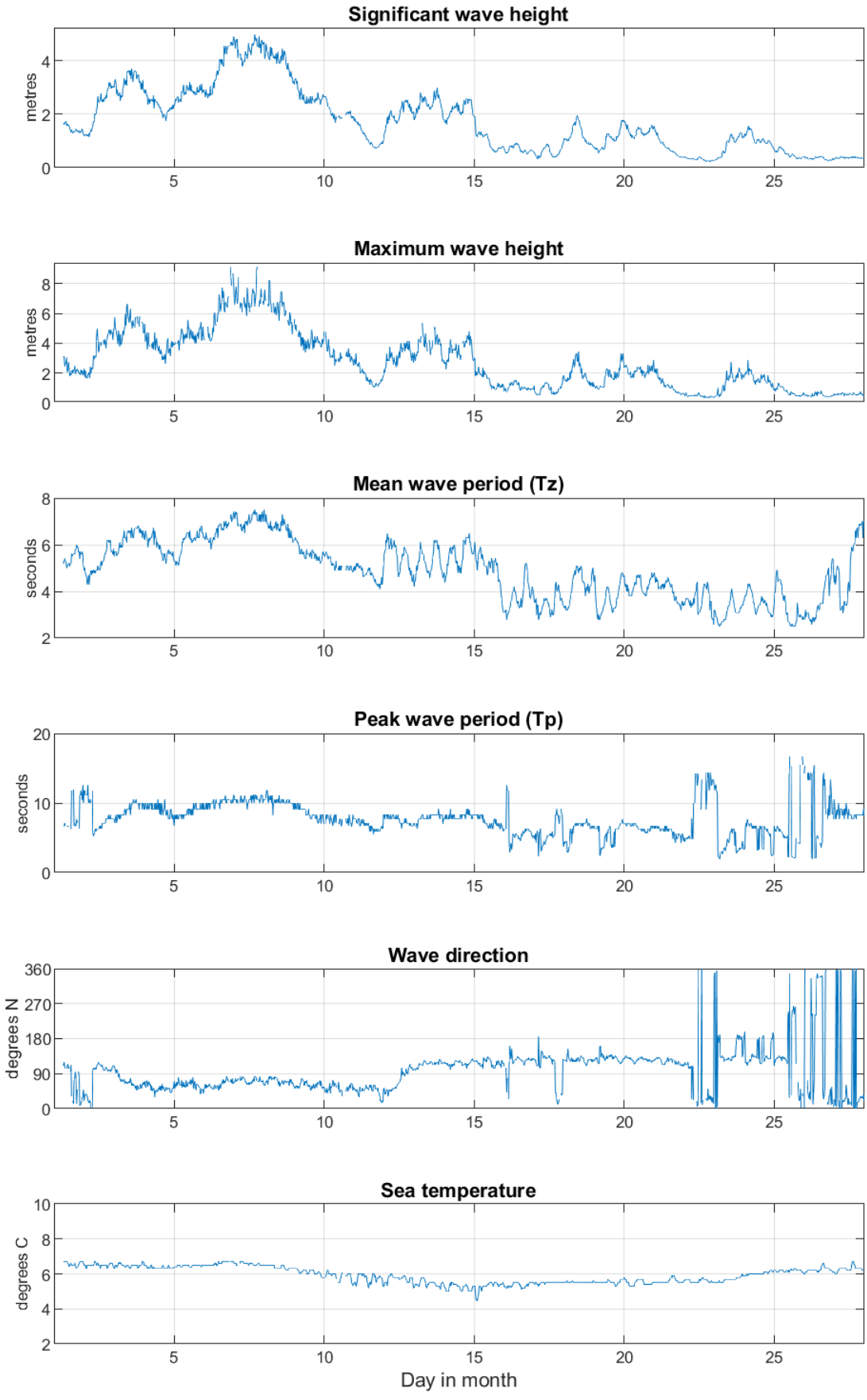
Scarborough - December 2020



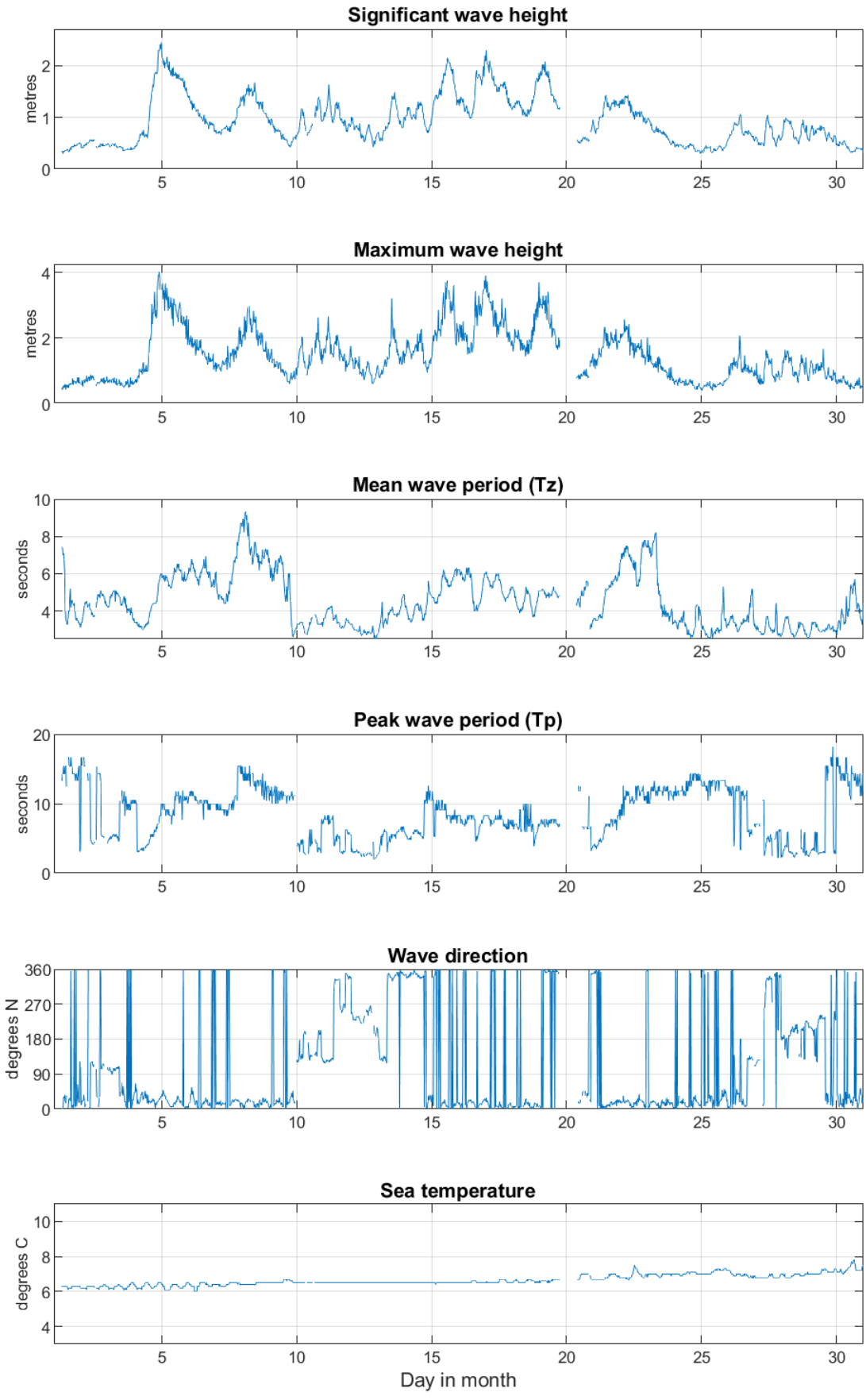
Scarborough - January 2021



Scarborough - February 2021



Scarborough - March 2021



Appendix E: Annual reports for Scarborough & Whitby tide gauges and Newbiggin, Whitby & Scarborough wave buoys

Scarborough Tide Gauge

Location

OS: 504898E 488622N
WGS84: *Latitude:* 54° 16.950' N *Longitude:* 00° 23.417' W

Instrument

Valeport 740 (Druck Pressure Transducer)

Benchmarks

Benchmark	*Description*
TGBM = 4.18m above Ordnance Datum Newlyn	Port BM on western slipway of inner harbour 504750.75E 488754.385N
TGZ = -2.52m above Ordnance Datum Newlyn	
TGZ = 0.73m above Chart Datum	
TGZ = 6.70m below TGBM	

Datum

All data are to Ordnance Datum Newlyn. The height of Chart Datum relative to Ordnance Datum at Scarborough is -3.25m (Admiralty Tide Tables, Supplementary Table III).

Survey information

The site was surveyed on 13 June 2013, where the tide gauge offset was found to be 0.195m higher than on the previous survey in 2003. The datum appeared to have changed during the period 2006-2011.

Site characteristics

The pressure transducer is mounted in a stilling well in Scarborough harbour.

Data quality

Recovery rate (%)	Sample interval
98	10 minutes

Service history

The gauge was first deployed on 28 April 2003 and maintained until December 2005. Measurements continued, and full maintenance was resumed in 2011. The instrument is serviced at 9-month intervals.

Measurements

The pressure transducer samples at 4 Hz. Tidal elevations are derived, every 10 minutes, as the 40 second average of the 4 Hz readings. The time stamp is the start of the measuring burst. Although the time stamp is accurate, the instrument has to be started manually after servicing and it is not always possible to start exactly on a 10 minute integer. Measurements are interpolated to the hour and 10 minute intervals, if the original time series is not on the hour. Missing data exceeding 2 hours are not interpolated. All data measured prior to the gauge being fully surveyed were adjusted to the correct elevations, but it has proven difficult to establish where the datum changed occurred between 2006 and 2011. The highest values during these years are included in the Amax tables, since the date/times are valid, but the elevations should be used with caution.

Residuals and Elevations (OD and CD) for the whole year are shown in Figures 1 to 3 respectively.

Statistics

All times GMT

Month	Extreme maxima		Extreme minima	
	Elevation (OD)	Date/Time	Elevation (OD)	Date/Time
January	3.31	14-Jan-2020 18:20:00	-2.10	10-Jan-2020 22:20:00
February	3.44	10-Feb-2020 04:50:00	-2.58	12-Feb-2020 00:40:00
March	3.33	11-Mar-2020 05:00:00	-2.29	13-Mar-2020 01:00:00
April	3.14	08-Apr-2020 16:10:00	-2.32	09-Apr-2020 11:00:00
May	3.04	08-May-2020 16:40:00	-2.15	09-May-2020 11:40:00
June	2.96	05-Jun-2020 15:40:00	-2.11	08-Jun-2020 12:10:00
July	2.82	06-Jul-2020 04:40:00	-2.21	24-Jul-2020 13:00:00
August	3.21	21-Aug-2020 05:20:00	-2.17	22-Aug-2020 12:40:00
September	3.19	20-Sep-2020 05:50:00	-2.16	17-Sep-2020 11:10:00
October	3.23	19-Oct-2020 05:20:00	-2.19	20-Oct-2020 00:10:00
November	3.41	16-Nov-2020 04:10:00	-2.23	15-Nov-2020 09:50:00
December	2.88	17-Dec-2020 17:40:00	-2.34	16-Dec-2020 23:30:00

Month	Surge maxima		Surge minima	
	Value (m)	Date/Time	Value (m)	Date/Time
January	1.24	14-Jan-2020 13:50:00	-0.47	11-Jan-2020 02:50:00
February	1.07	10-Feb-2020 01:40:00	-0.52	09-Feb-2020 02:10:00
March	0.87	10-Mar-2020 22:50:00	-0.33	23-Mar-2020 02:30:00
April	0.96	02-Apr-2020 17:50:00	-0.14	06-Apr-2020 00:30:00
May	0.48	10-May-2020 06:20:00	-0.24	25-May-2020 01:50:00
June	0.44	05-Jun-2020 05:30:00	-0.18	28-Jun-2020 19:30:00
July	0.43	06-Jul-2020 07:10:00	-0.21	07-Jul-2020 01:00:00
August	0.52	05-Aug-2020 14:30:00	-0.18	04-Aug-2020 23:20:00
September	0.69	25-Sep-2020 09:50:00	-0.29	17-Sep-2020 02:10:00
October	0.70	25-Oct-2020 01:50:00	-0.74	31-Oct-2020 17:20:00
November	1.01	02-Nov-2020 12:40:00	-0.54	20-Nov-2020 15:40:00
December	0.74	01-Dec-2020 00:20:00	-0.29	08-Dec-2020 17:10:00

Month	Mean Level	
	No. of days	Elevation (OD)
January	30	0.515
February	29	0.458
March	29	0.339
April	30	0.357
May	30	0.322
June	30	0.340
July	30	0.359
August	31	0.426
September	30	0.442
October	30	0.474
November	30	0.492
December	29	0.425

Highest values in 2020			
Extreme		**Surge**	
Elevation (OD) *(Surge component)*	Date/Time	Value (m)	Date/Time
3.44 *(0.96)*	10-Feb-2020 04:50:00	1.24	14-Jan-2020 13:50:00
3.41 *(0.38)*	16-Nov-2020 04:10:00	1.16	14-Jan-2020 15:10:00
3.34 *(0.90)*	19-Nov-2020 06:30:00	1.07	10-Feb-2020 01:40:00
3.33 *(0.67)*	11-Mar-2020 05:00:00	1.02	08-Jan-2020 06:50:00
3.32 *(0.49)*	10-Mar-2020 16:30:00	1.01	02-Nov-2020 12:40:00
3.31 *(0.75)*	14-Jan-2020 18:20:00	1.01	10-Feb-2020 01:10:00
3.31 *(0.36)*	12-Mar-2020 18:10:00	1.01	17-Feb-2020 16:00:00
3.26 *(0.56)*	10-Feb-2020 16:50:00	0.98	02-Nov-2020 13:20:00
3.24 *(0.28)*	11-Mar-2020 17:30:00	0.96	02-Apr-2020 17:50:00
3.24 *(0.54)*	13-Feb-2020 19:10:00	0.94	31-Jan-2020 04:40:00

Year	**Annual extreme maxima**		**Annual surge maxima**		**Z_0 (OD)**	**Annual recovery rate**
	Elevation (OD) *(Surge)*	Date/Time	Value (m)	Date/Time		
2003	3.05 *(-0.03)*	28-Sep-2003 05:10	1.13	21-Dec-2003 09:40	-	76%
2004	3.09 *(0.34)*	22-Feb-2004 17:10	0.96	18-Nov-2004 04:00	0.292	99%
2005	3.66 *(0.86)*	12-Jan-2005 17:20	1.18	20-Jan-2005 08:20	0.287	99%
2006*	3.30 *(0.17)*	30-Mar-2006 16:30	1.29	31-Oct-2006 15:40	-	77%
2007*	3.40 *(0.71)*	25-Nov-2007 04:00	1.60	08-Nov-2007 21:30	0.221	97%
2008*	3.05 *(0.16)*	09-Mar-2008 17:20	0.90	22-Feb-2008 02:10	-	65%
2009*	3.19 *(0.44)*	12-Jan-2009 16:50	1.15	18-Jan-2009 16:30	-	84%
2010*	3.21 *(0.05)*	11-Sep-2010 05:30	0.81	12-Nov-2010 04:20	-	82%
2011*	3.03 *(-0.14)*	21-Mar-2011 17:10	1.33	04-Feb-2011 11:00	-	80%
2012	2.94 *(0.06)*	17-Oct-2012 04:40	0.92	05-Jan-2012 16:40	-	70%
2013	4.39 *(1.66)*	05-Dec-2013 17:20	1.75	05-Dec-2013 15:50	0.186	98%
2014	3.40 *(0.51)*	04-Jan-2014 18:00	1.16	21-Oct-2014 20:20	-	88%
2015	3.29 *(0.29)*	21-Feb-2015 17:40	1.23	10-Jan-2015 17:30	-	98%
2016	3.13 *(0.17)*	17-Sep-2016 04:00	1.54	26-Dec-2016 21:20	-	100%
2017	3.43 *(0.79)*	13-Jan-2017 16:20	1.22	13-Jan-2017 10:50	-	100%
2018	3.27 *(0.26)*	12-Sep-2018 05:40	0.80	28-Jan-2018 05:20	-	82%
2019	3.40 *(0.50)*	29-Sep-2019 16:30	1.00	09-Dec-2019 06:30	-	47%
2020	3.44 *(0.96)*	10-Feb-2020 04:50	1.24	14-Jan-2020 13:50	0.412	98%

***** Possible datum shift by up to -0.195m

Tidal levels		
Observation period	January 2013 – October 2014	
Tide Level	Elevation (OD)	Elevation (CD)
HAT	3.34	6.59
MHWS	2.52	5.77
MHWN	1.38	4.63
MLWN	-0.86	2.39
MLWS	-2.00	1.25
LAT	-3.02	0.23

General

The time series of 10 minute tidal elevations for one year is quality-checked in accordance with ESEAS guidelines, flagged and archived. The archived time series is continuous and monotonic, with missing data given as 9999. The missing data shown are days where the entire 24 hours of data are missing.

Monthly extreme maxima/minima are the maximum and minimum water levels from all measured data for that month. Monthly surge maxima/minima (residuals) are calculated in a similar manner from the time series of residuals. Residuals are derived as the measured tidal elevation minus the predicted tidal elevation.

The monthly Mean Level is calculated as the average of all readings for the given month. The annual Z_0 is the value of Mean Sea Level derived by the harmonic analysis of the year's data. These values should not be used for any purpose without consideration of the recovery rate.

Acknowledgements

Tidal predictions and tide levels were produced by Fugro GB Marine Limited.

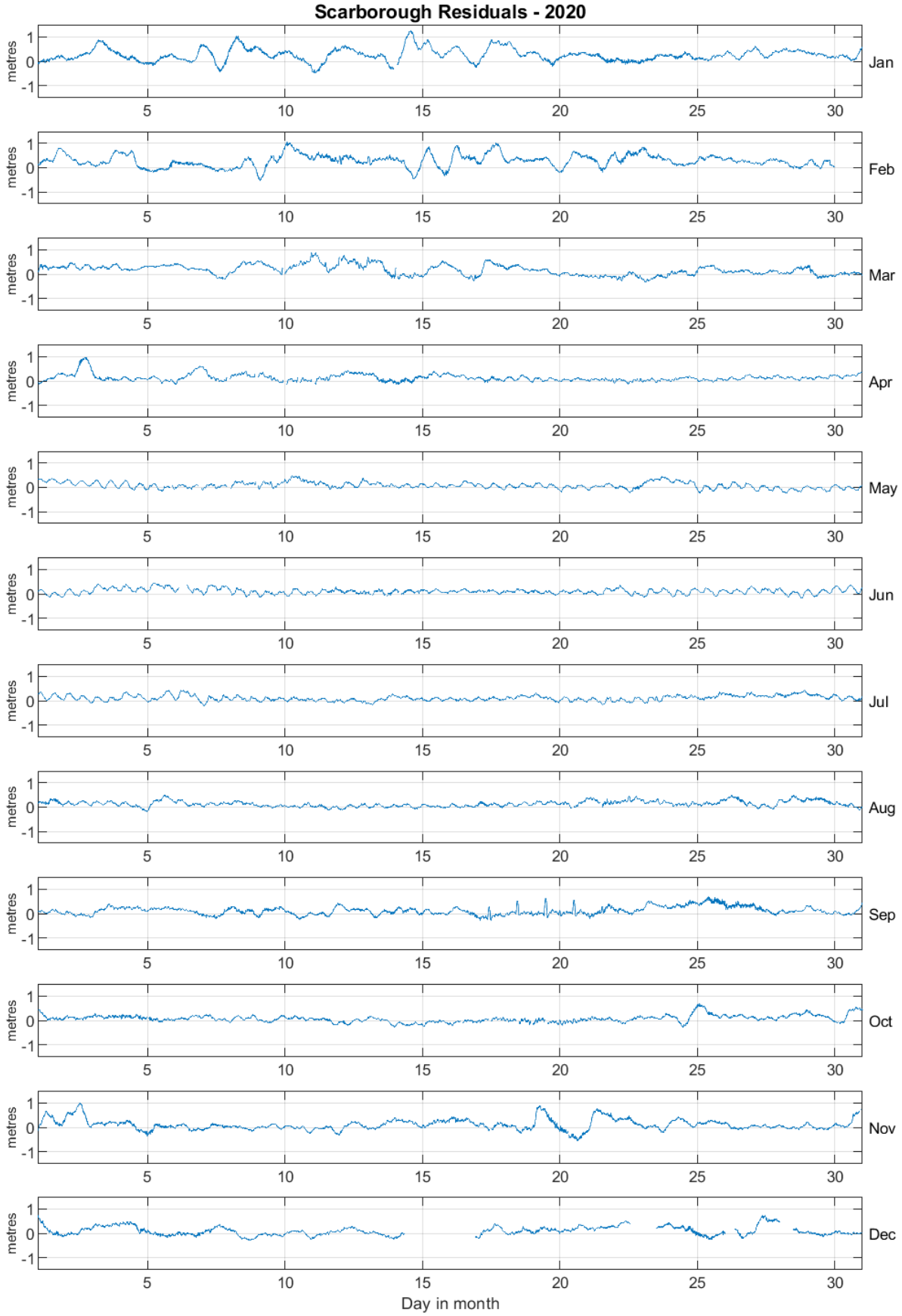


Figure 1: Scarborough residuals for 2020

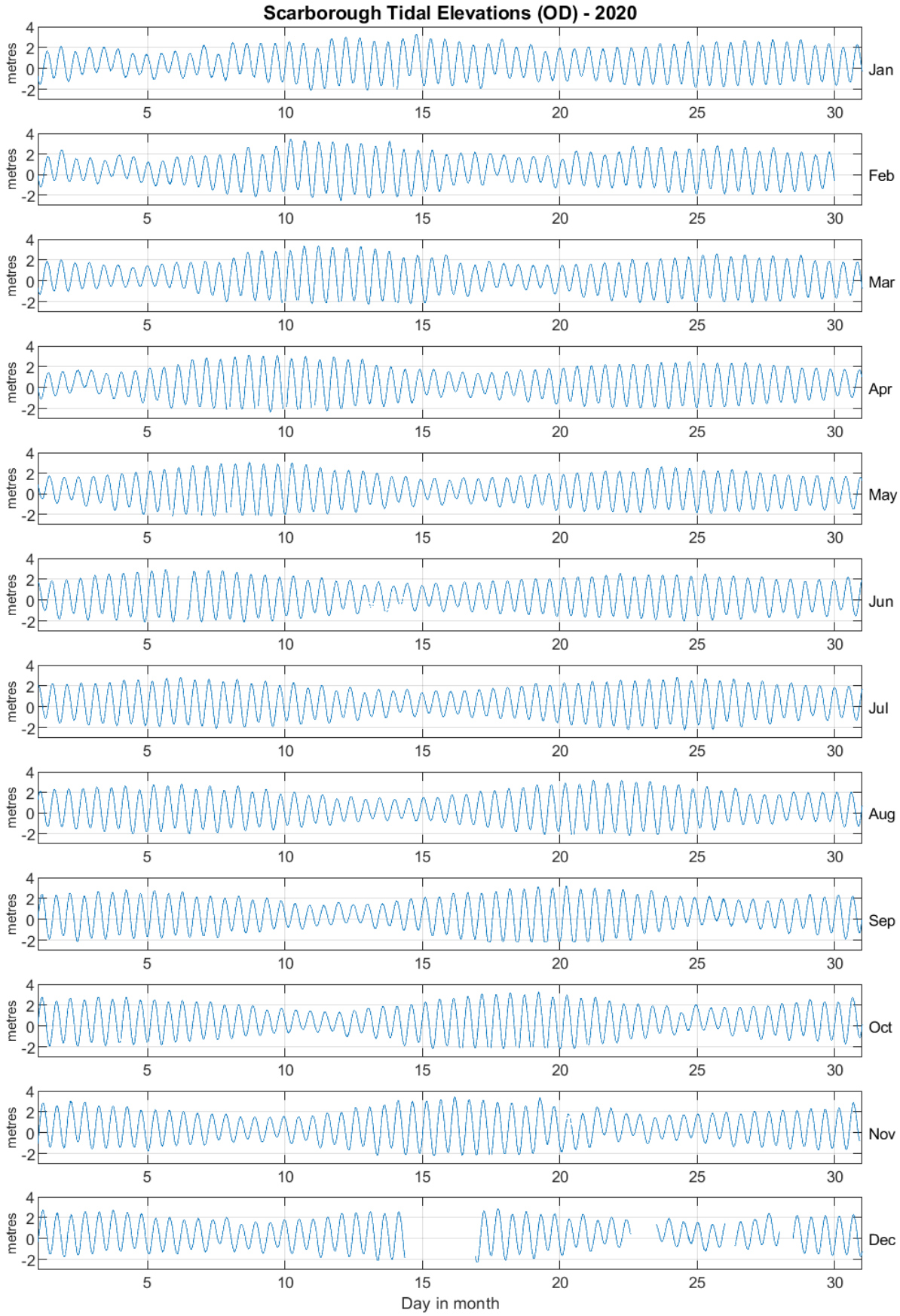


Figure 2: Scarborough tidal elevations for 2020 relative to Ordnance Datum

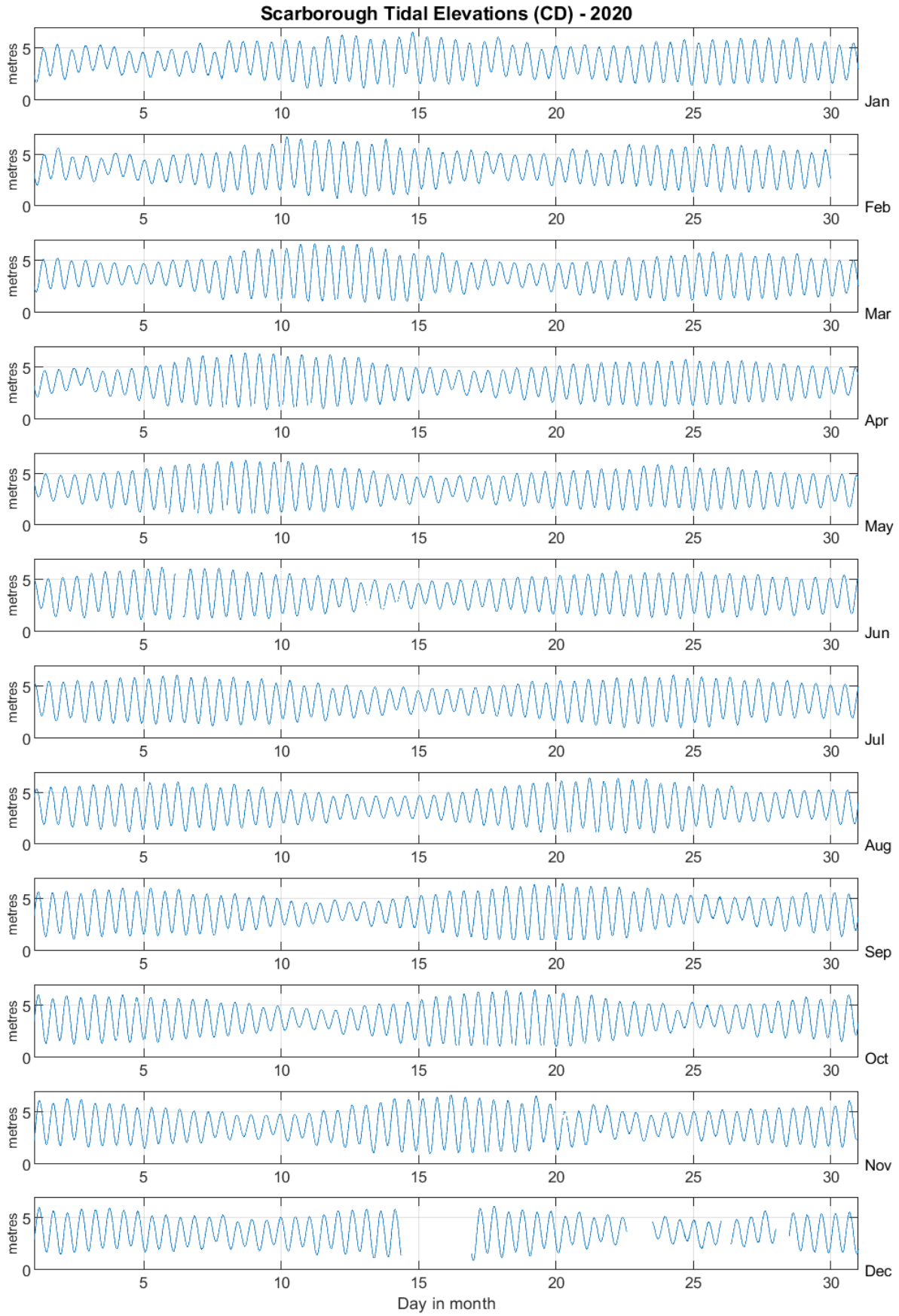


Figure 3: Scarborough tidal elevations for 2020 relative to Chart Datum

Whitby Harbour Tide Gauge

Location

OS: 489842E 511247N
WGS84: *Latitude:* 54° 29.318' N *Longitude:* 00° 36.878' W

Instrument

Valeport Tidemaster (Drück Pressure Transducer). The tide gauge transducer is fixed to a weighted stainless steel strop located in a stilling well.

Benchmarks

Benchmark	*Description*
TGBM = 4.453 m above Ordnance Datum Newlyn	SW Bolt on mooring bollard adjacent to tide gauge, 50 mm above ground on fish quay outside Watch Keeper's Office (54° 29' 19.210"N, 000° 36' 52.620"W)
TGZ = 3.403 m below Ordnance Datum Newlyn	
TGZ = 0.403 m below Chart Datum	
TGZ = 7.856 m below TGBM	

Datum

All data are to Ordnance Datum Newlyn. The height of Chart Datum relative to Ordnance Datum at Whitby is -3.00 m (Admiralty Tide Tables, Supplementary Table III).

Survey information

The site was surveyed on 05 September 2013.

Site characteristics

The tide gauge is located beneath the Fish Quay on the western side of the River Esk, 600 m from the Whitby Harbour entrance.

Data Quality

Recovery rate (%)	Sample interval
98	10 minutes

Service history

The gauge was first deployed on 8 May 2013 and is serviced at 9-monthly intervals.

Sometime between 13 September 2018 and 12 July 2019, the tide gauge was hit, resulting in a reference change of +3cm. No correction has so far been applied to the 2018 data.

Measurements

The pressure transducer samples at 8 Hz. Tidal elevations are derived every 1 minute, as the average of the 8 Hz readings over a 30 second burst. The time stamp is the start of the measuring burst. Data readings on the hour and at 10 minute intervals are transmitted.

Residuals and Elevations (OD and CD) for the whole year are shown in Figures 1 to 3 respectively.

Statistics

All times GMT

Month	Extreme maxima		Extreme minima	
	Elevation (OD)	Date/Time	Elevation (OD)	Date/Time
January	3.22	14-Jan-2020 18:20:00	-2.53	14-Jan-2020 00:00:00
February	3.35	10-Feb-2020 04:30:00	-2.45	13-Feb-2020 01:00:00
March	3.21	11-Mar-2020 04:40:00	-2.63	09-Mar-2020 22:10:00
April	3.00	08-Apr-2020 16:00:00	-2.86	09-Apr-2020 23:20:00
May	2.70	10-May-2020 18:00:00	-2.33	05-May-2020 20:40:00
June	2.81	05-Jun-2020 15:30:00	-2.05	04-Jun-2020 21:10:00
July	2.69	06-Jul-2020 04:20:00	-2.11	23-Jul-2020 11:50:00
August	3.04	21-Aug-2020 05:10:00	-2.41	21-Aug-2020 11:40:00
September	2.99	20-Sep-2020 05:30:00	-2.70	19-Sep-2020 11:10:00
October	3.00	19-Oct-2020 05:20:00	-2.61	18-Oct-2020 11:00:00
November	3.25	16-Nov-2020 04:00:00	-2.24	17-Nov-2020 11:10:00
December	2.91	15-Dec-2020 03:50:00	-2.17	16-Dec-2020 23:30:00

Month	Surge maxima		Surge minima	
	Value (m)	Date/Time	Value (m)	Date/Time
January	1.16	14-Jan-2020 13:20:00	-0.52	11-Jan-2020 02:40:00
February	0.92	17-Feb-2020 15:40:00	-0.56	14-Feb-2020 16:30:00
March	0.73	11-Mar-2020 01:40:00	-0.49	23-Mar-2020 02:30:00
April	0.89	02-Apr-2020 17:00:00	-0.20	14-Apr-2020 03:30:00
May	0.40	23-May-2020 11:10:00	-0.25	28-May-2020 06:10:00
June	0.49	06-Jun-2020 10:20:00	-0.18	01-Jun-2020 10:30:00
July	0.39	06-Jul-2020 10:30:00	-0.20	12-Jul-2020 23:10:00
August	0.44	29-Aug-2020 07:00:00	-0.25	31-Aug-2020 11:10:00
September	0.73	03-Sep-2020 13:50:00	-0.30	17-Sep-2020 02:30:00
October	0.61	25-Oct-2020 01:30:00	-0.78	31-Oct-2020 17:50:00
November	0.98	02-Nov-2020 11:50:00	-0.56	20-Nov-2020 15:40:00
December	0.69	27-Dec-2020 08:50:00	-0.37	25-Dec-2020 11:10:00

Month	Mean Level	
	No. of days	Elevation (OD)
January	30	0.510
February	29	0.459
March	29	0.309
April	30	0.300
May	27	0.286
June	30	0.346
July	30	0.365
August	31	0.402
September	30	0.442
October	30	0.411
November	30	0.468
December	30	0.440

Highest values in 2020			
Extreme		**Surge**	
Elevation (OD) *(Surge component)*	Date/Time	Value (m)	Date/Time
3.35 *(0.81)*	10-Feb-2020 04:30:00	1.16	14-Jan-2020 13:20:00
3.25 *(0.27)*	16-Nov-2020 04:00:00	1.08	14-Jan-2020 14:20:00
3.22 *(0.60)*	14-Jan-2020 18:20:00	0.98	02-Nov-2020 11:50:00
3.21 *(0.54)*	11-Mar-2020 04:40:00	0.96	08-Jan-2020 06:30:00
3.16 *(0.31)*	10-Mar-2020 16:30:00	0.92	17-Feb-2020 15:40:00
3.15 *(0.19)*	12-Mar-2020 18:00:00	0.92	10-Feb-2020 00:50:00
3.15 *(0.43)*	10-Feb-2020 16:40:00	0.91	02-Nov-2020 13:00:00
3.11 *(0.68)*	19-Nov-2020 06:20:00	0.89	02-Apr-2020 17:00:00
3.08 *(0.10)*	11-Mar-2020 17:10:00	0.88	10-Feb-2020 01:10:00
3.06 *(0.41)*	12-Mar-2020 05:40:00	0.86	16-Feb-2020 05:30:00

Year	Annual extreme maxima		Annual surge maxima		Z_0 (OD)	Annual recovery rate
	Elevation (OD) *(Surge)*	Date/Time	Value (m)	Date/Time		
2014	3.15 *(0.31)*	13-Aug-2014 05:20	1.06	21-Oct-2014 20:20	-	95%
2015	3.18 *(0.31)*	21-Feb-2015 17:40	1.18	13-Nov-2015 12:10	-	98%
2016	3.15 *(0.13)*	19-Sep-2016 05:10	1.34	26-Dec-2016 21:10	-	99%
2017	3.48 *(0.78)*	13-Jan-2017 16:20	1.24	13-Jan-2017 10:50	-	99%
2018	3.10 *(0.31)*	03-Jan-2018 16:40	0.75	13-Oct-2018 10:00	0.314	99%
2019	3.23 *(0.15)*	01/10/2019 05:20	1.18	08/01/2019 00:40	0.350	97%
2020	3.35 *(0.81)*	10-Feb-2020 04:30	1.16	14-Jan-2020 13:20	0.396	98%

Tidal levels		
Observation period	January 2014 – July 2015	
Tide Level	Elevation (OD)	Elevation (CD)
HAT	3.14	6.14
MHWS	2.52	5.52
MHWN	1.41	4.41
MLWN	-0.79	2.21
MLWS	-1.91	1.09
LAT	-2.91	0.09

General

The time series of 10 minute tidal elevations for one year is quality-checked in accordance with ESEAS guidelines, flagged and archived. The archived time series is continuous and monotonic, with missing data given as 9999. The missing data shown are days where the entire 24 hours of data are missing.

Monthly extreme maxima/minima are the maximum and minimum water levels from all measured data for that month. Monthly surge maxima/minima (residuals) are calculated in a similar manner from the time series of residuals. Residuals are derived as the measured tidal elevation minus the predicted tidal elevation.

The monthly Mean Level is calculated as the average of all readings for the given month. The annual Z_0 is the value of Mean Sea Level derived by the harmonic analysis of the year's data. These values should not be used for any purpose without consideration of the recovery rate.

Acknowledgements

Tidal predictions and tide levels were produced by Fugro GB Marine Limited.

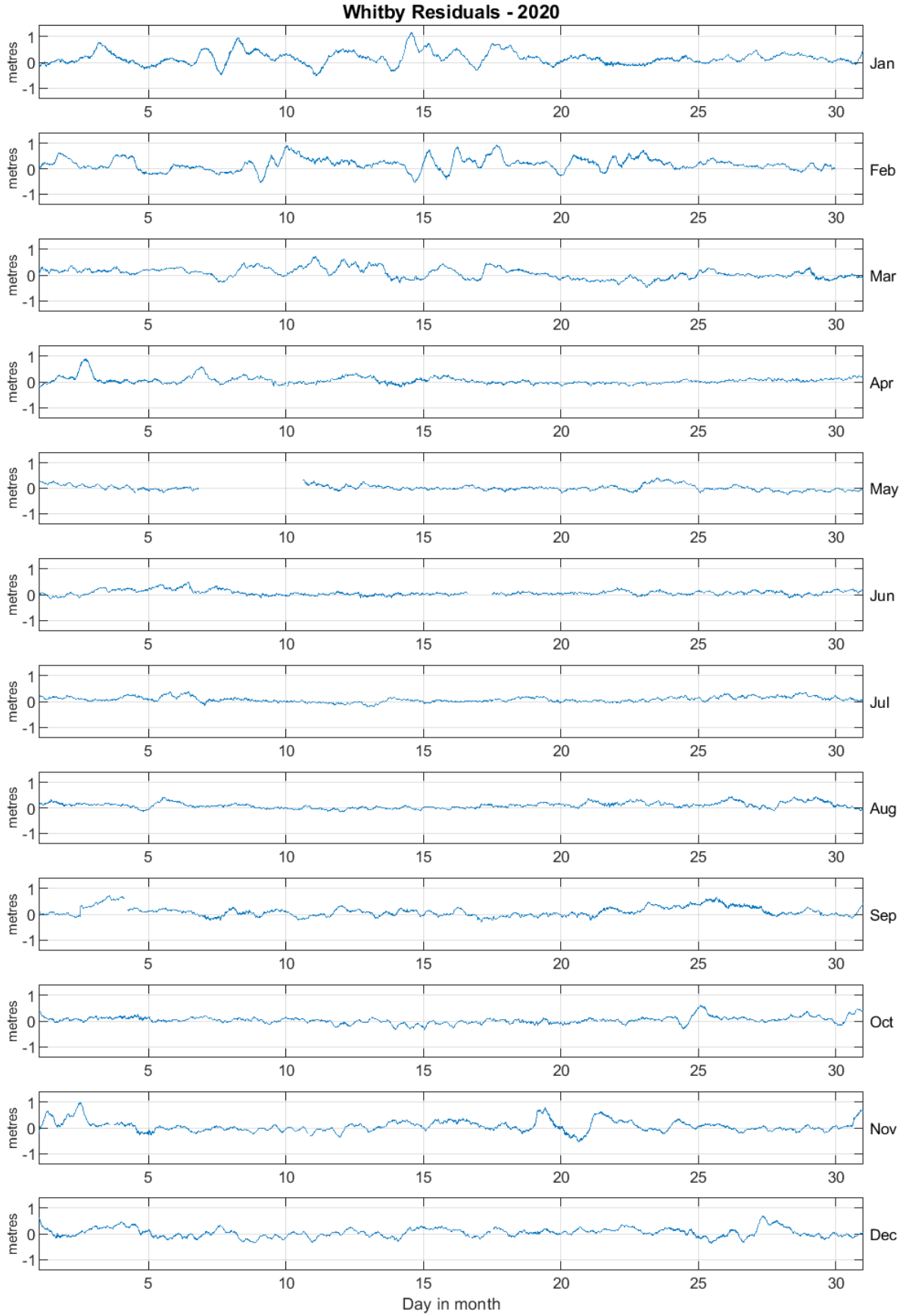


Figure 1: Whitby Harbour residuals for 2020

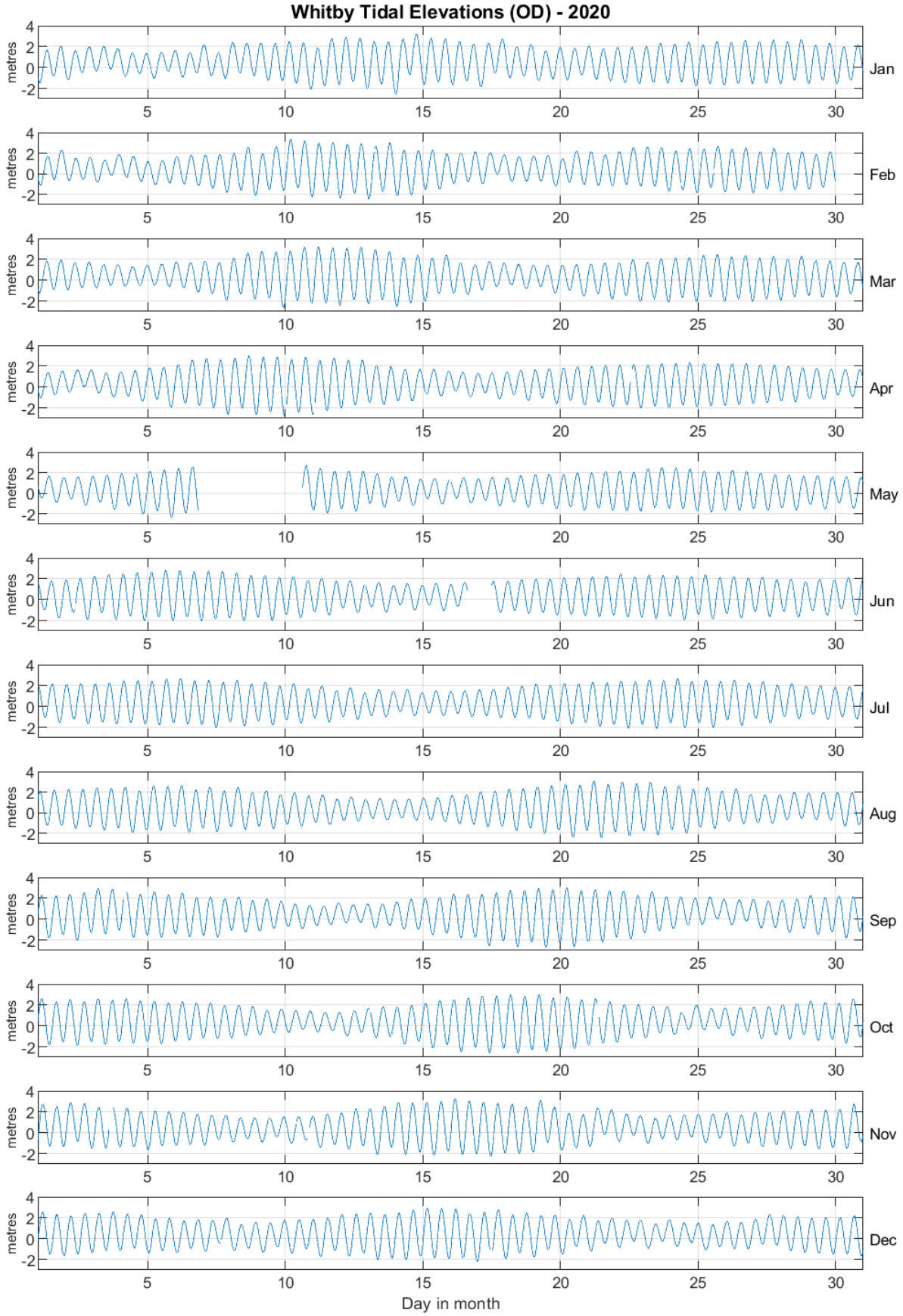


Figure 2: Whitby Harbour tidal elevations for 2020 relative to Ordnance Datum

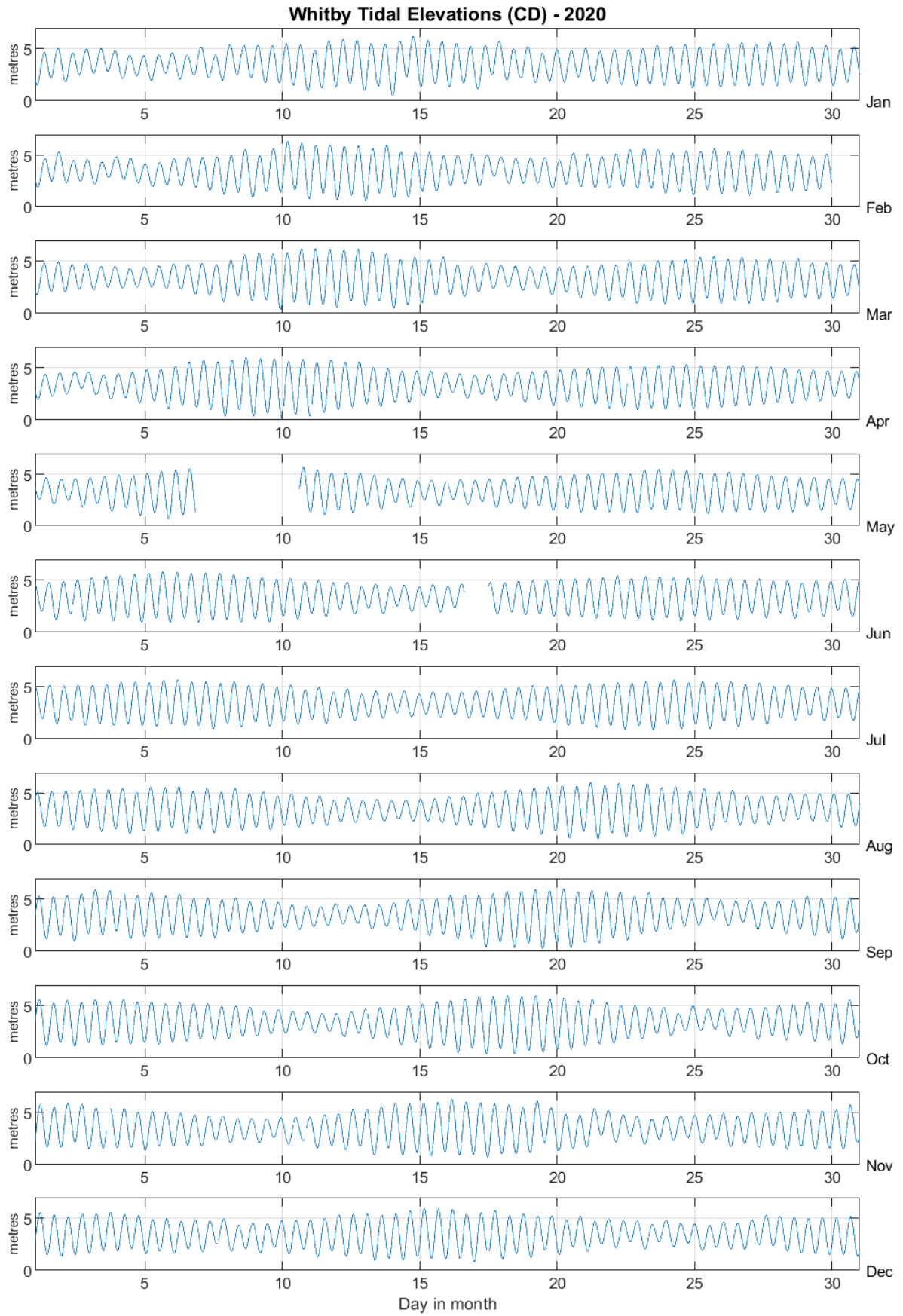


Figure 3: Whitby Harbour tidal elevations for 2020 relative to Chart Datum

Newbiggin Directional Waverider Buoy

Location	
OS	433325 E 587994 N
WGS84	*Latitude:* 55° 11.11' N *Longitude:* 01° 28.69' W
Instrument type	
Datawell Directional Waverider Mk III	
Water depth	~18m CD

Buoy in situ off Newbiggin-by-the-Sea. Photo courtesy of Fugro GB Marine Limited

Location of buoy (Google mapping, image ©2016 Getmapping plc)

Data Quality

Recovery rate (%)	Sample interval
96	30 minutes

Monthly Averages - 2020

All times are GMT

Month	H_s (m)	T_p (s)	T_z (s)	Dir. (°)	SST (°C)	Bimodal seas (%)	No. of days
January	0.77	9.0	4.5	93	7.7	3	31
February	0.91	9.0	4.3	95	6.7	10	29
March	1.02	8.6	4.8	82	6.4	8	31
April	0.93	8.1	4.8	68	7.7	6	30
May	0.74	7.5	4.5	73	9.6	3	31
June	0.86	6.0	4.2	77	11.8	2	30
July	0.72	7.5	4.6	66	12.3	0	17
August	0.91	6.5	4.3	80	13.7	1	31
September	0.88	7.6	4.3	82	12.8	1	30
October	1.08	7.6	4.8	75	11.6	5	31
November	0.82	8.1	4.5	95	10.5	1	30
December	1.25	8.3	4.9	84	8.8	10	31

Monthly Averages - All Years (June 2013 – December 2020)

Month	H_s (m)	T_p (s)	T_z (s)	Dir. (°)	SST (°C)	Bimodal seas (%)
January	1.17	9.3	5.0	82	7.3	6
February	1.12	8.6	4.7	87	6.5	5
March	1.08	8.5	4.9	78	6.2	5
April	0.95	7.6	4.6	72	7.3	5
May	0.85	7.0	4.4	71	9.2	3
June	0.76	6.6	4.4	70	11.4	1
July	0.60	6.0	4.1	82	13.0	1
August	0.65	6.3	4.1	87	13.4	1
September	0.76	6.9	4.3	79	13.0	1
October	1.11	7.9	4.7	81	11.8	5
November	1.19	8.3	5.0	79	10.2	4
December	0.97	8.9	4.8	84	8.6	5

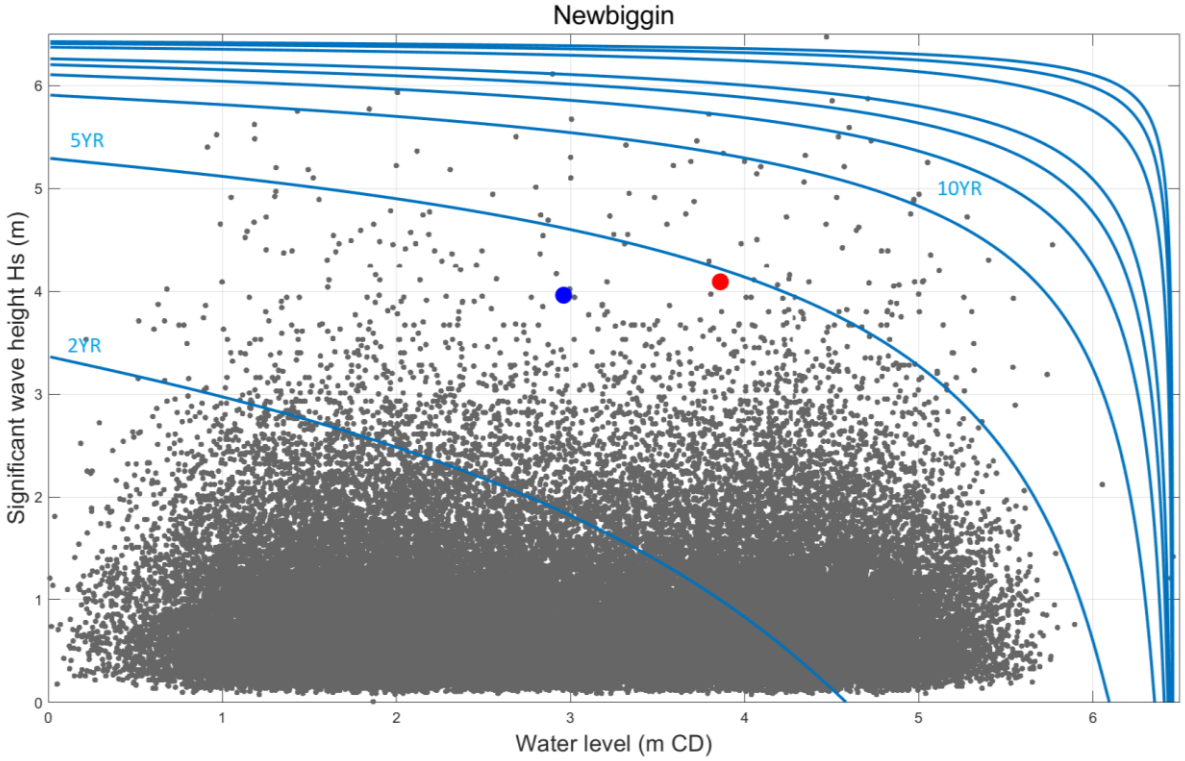
Storm Analysis

Date/Time	H_s (m)	T_p (s)	T_z (s)	Dir. (°)	Water level elevation* (OD)	Tidal stage (hours re. HW)	Tidal range (m)	Tidal surge* (m)	Max. surge* (m)
04-Dec-2020 20:00:00	4.09	10.5	6.8	93	1.26	HW +2	3.59	0.12	0.20
25-Sep-2020 18:30:00	3.96	10.5	6.6	44	0.36	HW –4	1.90	0.24	0.32

** Tidal information is obtained from the National Network gauge at North Shields. The surge shown is the residual at the time of the highest Hs. The maximum tidal surge is the largest surge during the storm event.*

Joint return periods

Joint return periods for water level and significant wave height are based on 0.5 hourly records and calculated using a copula function. For more details on the copula function, see Dhoop & Thompson 2021. The grey point cloud represents the measured joint wave heights and water levels at Newbiggin and North Shields respectively, plotted against one another.



Date/Time	Symbol	H_s (m)	Water level elevation		Joint Return Period
			OD	CD	
04-Dec-2020 20:00:00		4.09	1.26	3.86	1 in 2 years
25-Sep-2020 18:30:00		3.96	0.36	2.96	1 in 2 years

Annual Statistics

Year	Annual H_s exceedance** (m)						Annual Maximum H_s	
	0.05%	0.5%	1%	2%	5%	10%	Date	A_{max} (m)
2013	3.92	3.26	3.04	2.71	2.27	1.88	10-Oct-2013 18:30:00	4.15
2014	3.76	3.27	3.01	2.73	2.24	1.86	19-Jan-2014 19:30:00	4.22
2015	3.90	2.90	2.67	2.37	1.97	1.61	21-Nov-2015 04:00:00	4.74
2016	5.04	4.47	3.99	3.10	2.22	1.82	03-Jan-2016 10:00:00	5.46
2017	4.00	3.40	3.07	2.80	2.35	1.87	13-Jan-2017 16:00:00	4.45
2018	6.09	5.34	4.87	4.18	2.62	2.07	16-Mar-2018 16:00:00	6.47
2019	4.01	3.15	2.90	2.69	2.28	1.84	05-Nov-2019 01:00:00	4.36
2020	3.90	3.12	2.82	2.52	2.01	1.66	04-Dec-2020 20:00:00	4.09

*** i.e. 5 % of the H_s values measured in 2013 exceeded 2.27 m*

Significant wave height return periods

Return periods for significant wave height can be calculated since the buoy has been deployed for more than 5 years. The return periods are based on 0.5 hourly records and are calculated for periods up to 10 times the record length using a peaks-over-threshold method and Generalised Pareto Distribution (GPD).

Observation period	June 2013 to December 2020	
Return period (years)	**Significant wave height (m)**	**Comments**
0.25	3.32	No depth limitation
1	4.38	
2	4.90	
5	5.56	
10	6.03	
20	6.48	Depth-limited at MLWS
50	7.05	

Distribution plots

The distribution of wave parameters are shown in the accompanying graphs/tables of:

- Annual time series of H_s (red line is 3.32 m storm alert threshold)
- Incidence of storm waves for 2020. Storm events are defined using the Peaks-over-Threshold method. The highest H_s of each storm event is shown
- Wave height exceedance each year since deployment
- Percentage of occurrence of H_s, T_p, T_z and Direction for 2020
- Wave rose (percentage of occurrence of Direction vs. H_s) for all measured data
- Joint distribution of all parameters for all measured data, given as percentage of occurrence

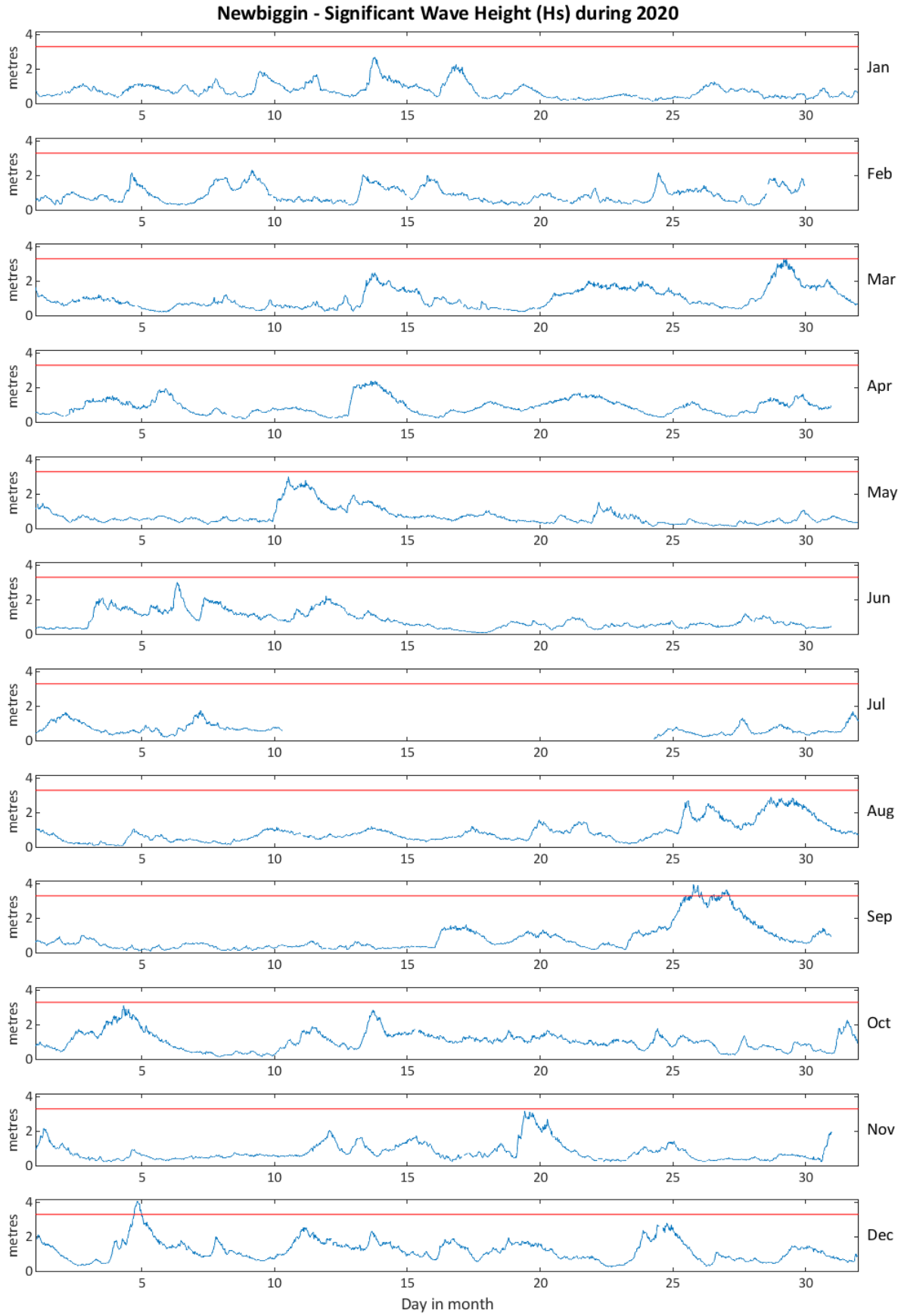
General

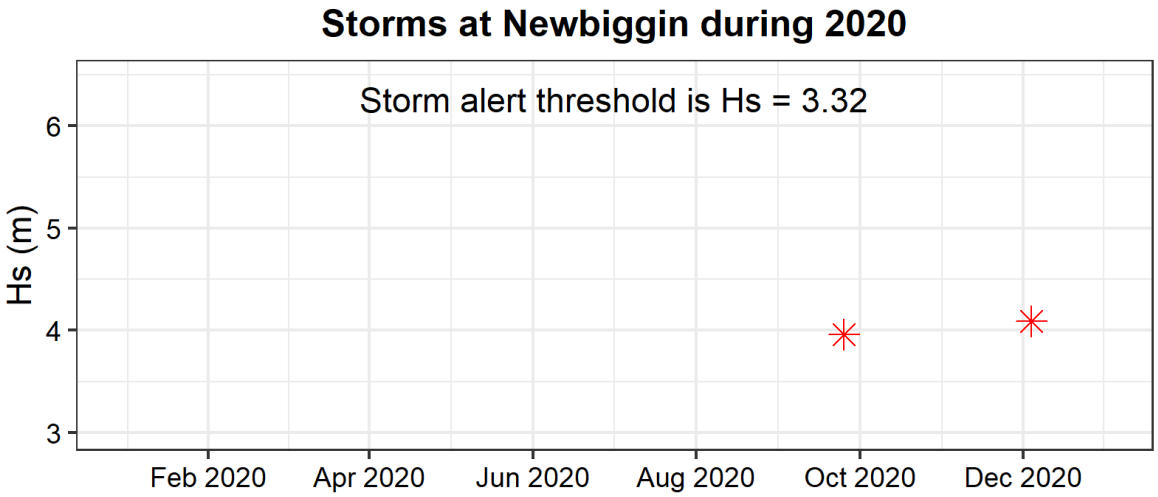
The buoy, owned by Scarborough Borough Council, was deployed on 21 June 2013, at which time the magnetic declination at the site was 2.2° west, changing by 0.18° east per year. A DWR had previously been deployed at this location from 20 May 2010 to 04 February 2011.

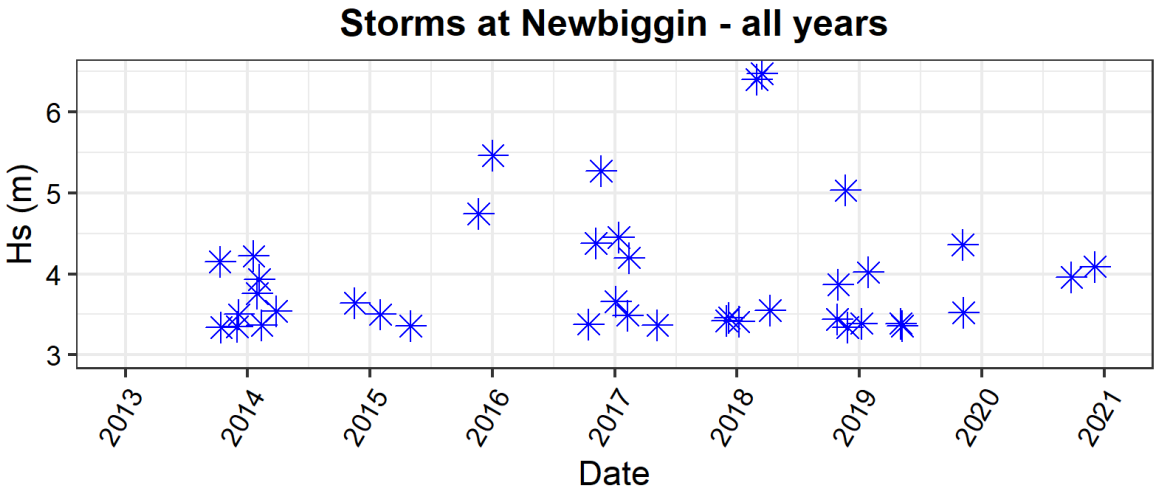
Acknowledgements

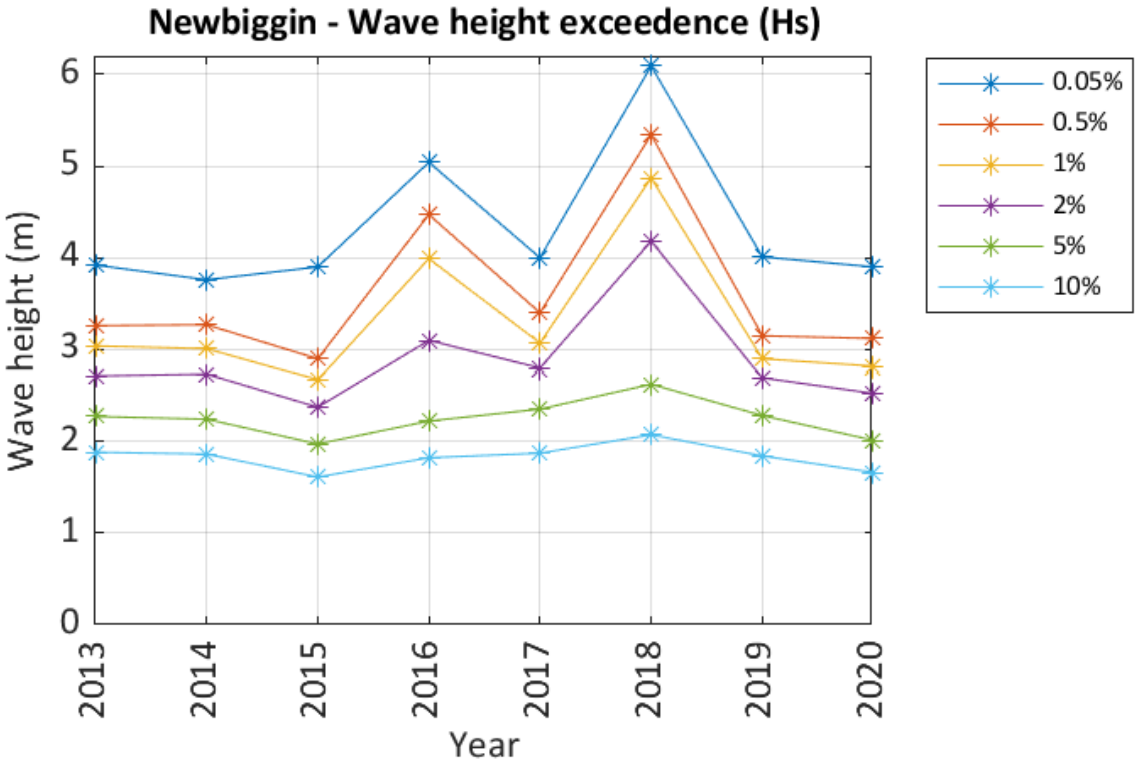
The shore station is kindly hosted by Newbiggin Sailing Club / Newbiggin Maritime Centre.

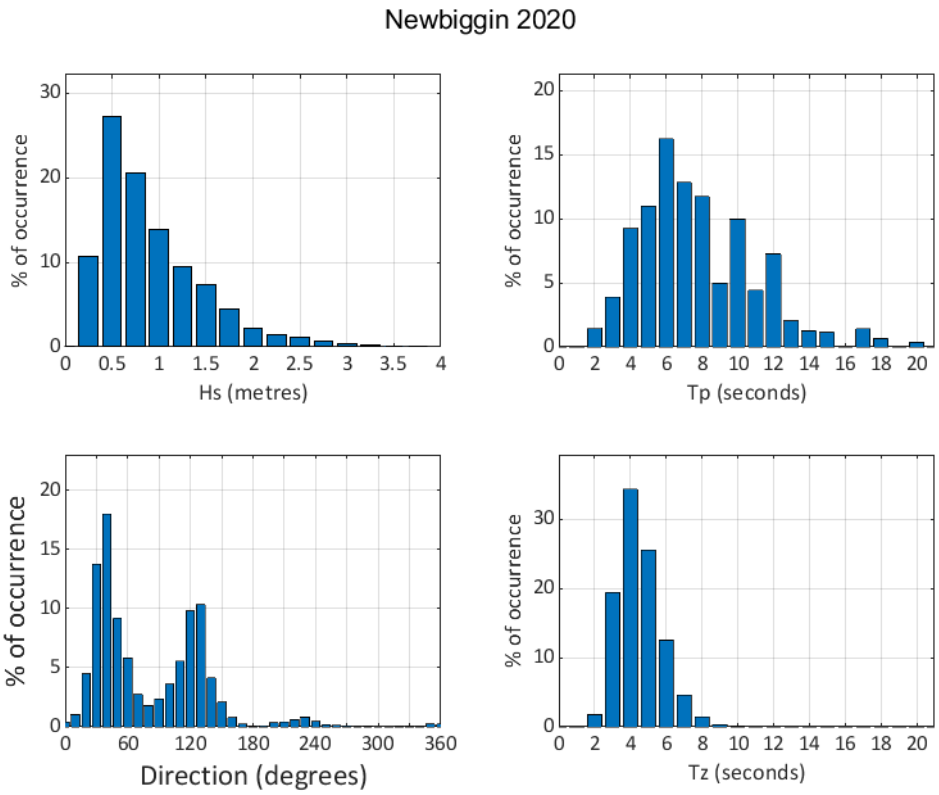
Tidal data at North Shields were provided by the British Oceanographic Data Centre from the UK national tide gauge network, owned and operated by the Environment Agency.

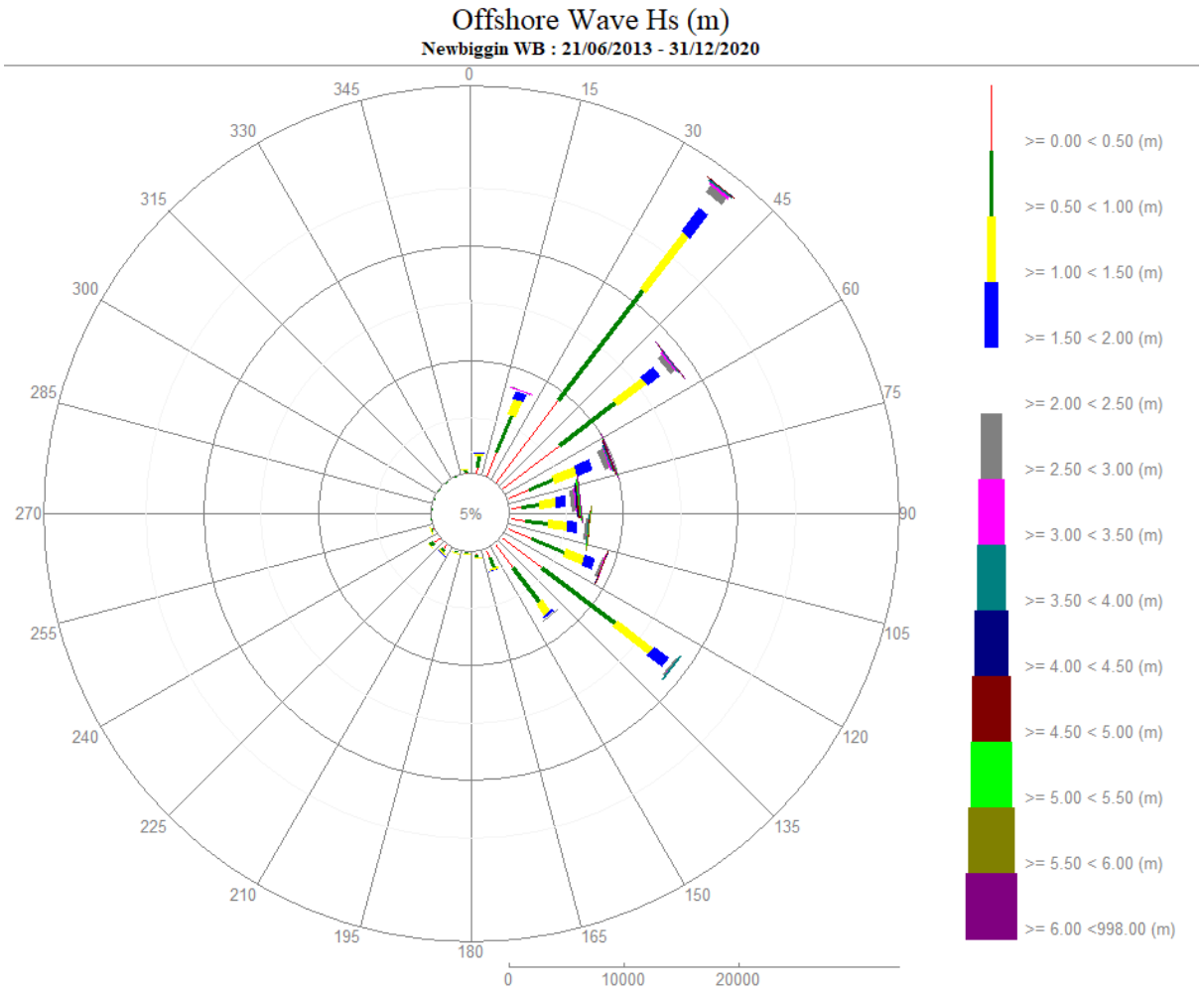

Newbiggin - Significant Wave Height (Hs) during 2020
metres
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Day in month

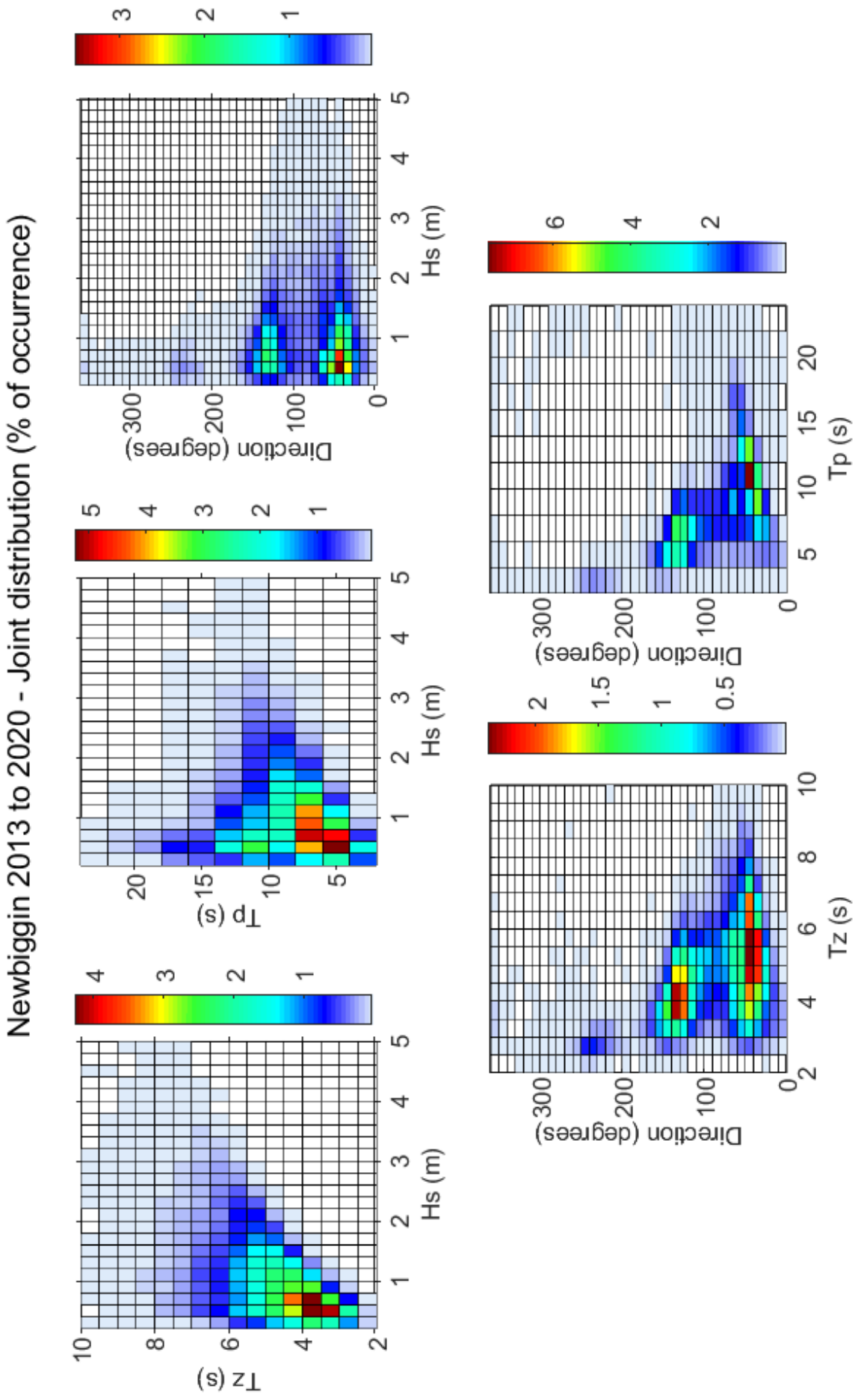

Storms at Newbiggin during 2020
Storm alert threshold is Hs = 3.32
Hs (m)
6
5
4
3
Feb 2020
Apr 2020
Jun 2020
Aug 2020
Oct 2020
Dec 2020


Storms at Newbiggin - all years
Hs (m)
6
5
4
3
2013
2014
2015
2016
2017
2018
2019
2020
2021
Date


Newbiggin - Wave height exceedence (Hs)
Wave height (m)
6
5
4
3
2
1
0
2013
2014
2015
2016
2017
2018
2019
2020
Year
0.05%
0.5%
1%
2%
5%
10%


Newbiggin 2020
% of occurrence
Hs (metres)
Tp (seconds)
Direction (degrees)
Tz (seconds)


Offshore Wave Hs (m)
Newbiggin WB : 21/06/2013 - 31/12/2020
5%
>= 0.00 < 0.50 (m)
>= 0.50 < 1.00 (m)
>= 1.00 < 1.50 (m)
>= 1.50 < 2.00 (m)
>= 2.00 < 2.50 (m)
>= 2.50 < 3.00 (m)
>= 3.00 < 3.50 (m)
>= 3.50 < 4.00 (m)
>= 4.00 < 4.50 (m)
>= 4.50 < 5.00 (m)
>= 5.00 < 5.50 (m)
>= 5.50 < 6.00 (m)
>= 6.00 <998.00 (m)


Newbiggin 2013 to 2020 - Joint distribution (% of occurrence)
Direction (degrees)
Hs (m)
Tp (s)
Tz (s)

Whitby Directional Waverider Buoy

Location	
OS	490311 E 513027 N
WGS84	*Latitude:* 54° 30.27' N *Longitude:* 00° 36.41' W
Instrument type	
Datawell Directional Waverider Mk III	
Water depth	~17m CD

Buoy in situ off Whitby beach. Photo courtesy of Fugro GB Marine Limited

Location of buoy (Google mapping, image ©2016 The GeoInformation Group)

Data Quality

Recovery rate (%)	Sample interval
66	30 minutes

Monthly Averages - 2020

All times are GMT

Month	H_s (m)	T_p (s)	T_z (s)	Dir. (°)	SST (°C)	Bimodal seas (%)	No. of days
January	0.81	10.1	4.9	89	7.5	9	31
February	1.05	8.8	4.6	116	6.8	-	17
March	-	-	-	-	-	-	0
April	0.88	8.2	5.1	52	8.6	-	6
May	0.86	8.1	4.8	72	9.7	3	31
June	0.60	5.2	3.7	109	11.8	-	18
July	0.64	7.3	4.3	116	13.0	1	31
August	0.95	6.5	4.4	69	13.9	2	31
September	0.70	8.7	4.5	110	13.4	-	23
October	-	-	-	-	-	-	0
November	0.76	9.7	4.8	73	10.3	-	24
December	1.14	9.5	5.1	70	8.7	12	31

Monthly Averages - All Years (January 2013 – December 2020)

Month	H_s (m)	T_p (s)	T_z (s)	Dir. (°)	SST (°C)	Bimodal seas (%)
January	1.21	9.8	5.2	83	7.1	10
February	1.14	9.2	5.0	79	6.2	6
March	1.26	9.2	5.2	72	6.2	7
April	1.01	8.0	4.8	72	7.3	7
May	0.95	7.7	4.8	64	9.3	2
June	0.78	6.8	4.5	71	11.6	1
July	0.59	6.2	4.1	101	13.8	0
August	0.68	6.7	4.3	92	14.0	1
September	0.81	7.4	4.5	95	13.5	2
October	1.10	8.7	5.0	80	12.2	5
November	1.27	9.2	5.2	77	10.2	7
December	0.98	10.2	5.0	69	8.4	8

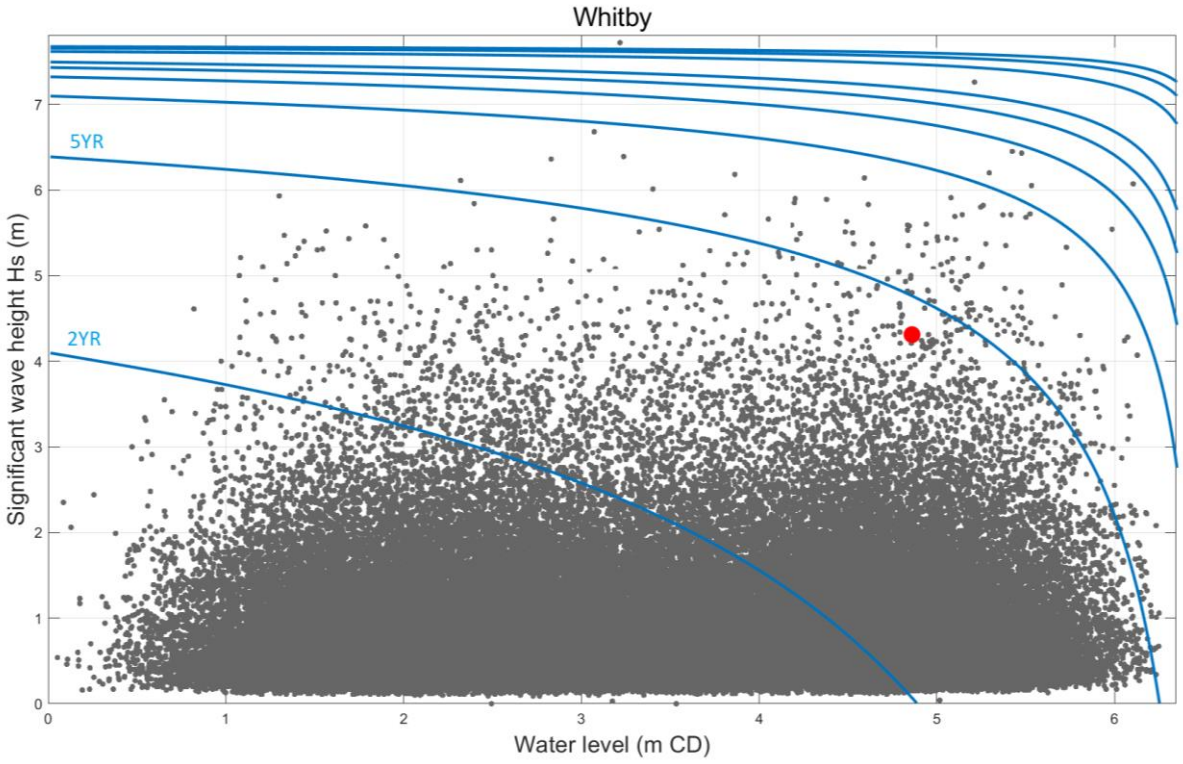
Storm Analysis

Date/Time	H_s (m)	T_p (s)	T_z (s)	Dir. (°)	Water level elevation* (OD)	Tidal stage (hours re. HW)	Tidal range (m)	Tidal surge * (m)	Max. surge* (m)
29-Aug-2020 12:30:00	4.31	10.0	6.6	17	1.86	HW	2.65	0.30	0.40

** Tidal information is obtained from the pressure transducer at Whitby Harbour. The surge shown is the residual at the time of the highest Hs. The maximum tidal surge is the largest surge during the storm event.*

Joint return periods

Joint return periods for water level and significant wave height are based on 0.5 hourly records and calculated using a copula function. For more details on the copula function, see Dhoop & Thompson 2021. The grey point cloud represents the measured joint wave heights and water levels at Whitby DWR and Whitby harbour tide gauge respectively, plotted against one another.



Date/Time	Symbol	H_s (m)	Water level elevation		Joint Return Period
			OD	CD	
29-Aug-2020 12:30:00	●	4.31	1.86	4.86	1 in 2 years

Annual Statistics

Year	Annual H_s exceedance** (m)						Annual Maximum H_s	
	0.05%	0.5%	1%	2%	5%	10%	Date	A_{max} (m)
2013	5.75	4.74	4.39	3.89	2.96	2.18	10-Oct-2013 16:00:00	6.00
2014	3.74	3.16	2.81	2.53	2.11	1.74	14-Oct-2014 05:00:00	4.10
2015	5.63	4.06	3.45	2.97	2.21	1.75	21-Nov-2015 03:30:00	7.72
2016	4.71	4.02	3.54	3.05	2.45	2.06	06-Nov-2016 20:00:00	5.05
2017	5.33	4.31	3.96	3.57	2.76	2.09	13-Jan-2017 14:00:00	7.26
2018	5.93	5.08	4.43	3.69	2.48	1.91	01-Mar-2018 15:00:00	6.45
2019	5.83	3.97	3.76	3.44	2.80	2.18	27-Jan-2019 16:00:00	6.60
2020	4.19	3.67	3.35	2.92	1.97	1.57	29-Aug-2020 12:30:00	4.31

*** i.e. 5 % of the H_s values measured in 2013 exceeded 2.96 m*

Significant wave height return periods

Return periods for significant wave height can be calculated since the buoy has been deployed for more than 5 years. The return periods are based on 0.5 hourly records and are calculated for periods up to 10 times the record length using a peaks-over-threshold method and Generalised Pareto Distribution (GPD).

Observation period	January 2013 to December 2020	
Return period (years)	**Significant wave height (m)**	**Comments**
0.25	4.41	No depth limitation
1	5.56	
2	6.13	
5	6.86	Depth-limited at MLWS
10	7.41	
20	7.94	Depth-limited at HAT
50	8.64	

Distribution plots

The distribution of wave parameters are shown in the accompanying graphs/tables of:

- Annual time series of H_s (red line is 4.41 m storm alert threshold)
- Incidence of storm waves for 2020. Storm events are defined using the Peaks-over-Threshold method. The highest H_s of each storm event is shown
- Wave height exceedance each year since deployment
- Percentage of occurrence of H_s, T_p, T_z and Direction for 2020
- Wave rose (percentage of occurrence of direction vs. H_s) for all measured data
- Joint distribution of all parameters for all measured data, given as percentage of occurrence

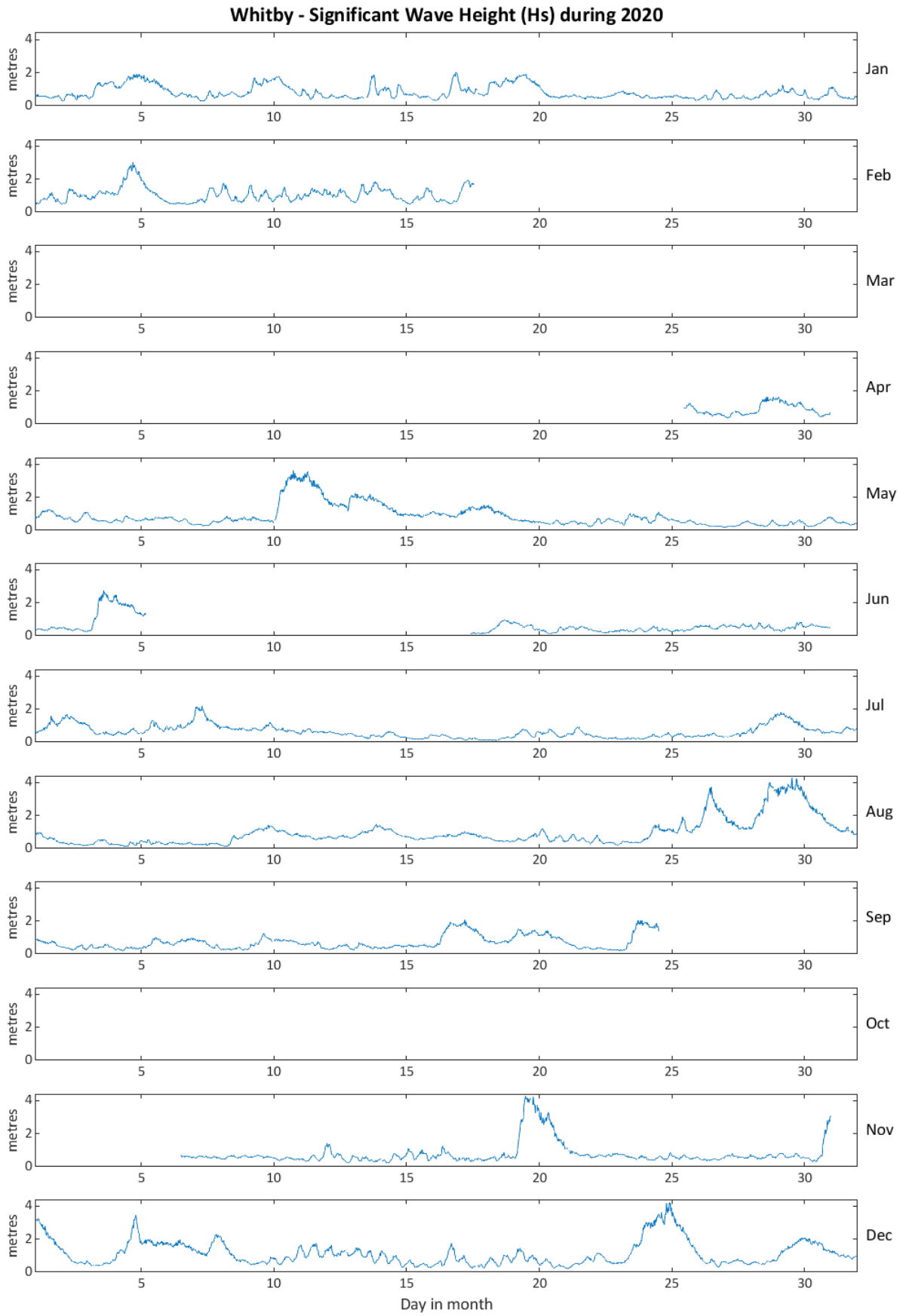
General

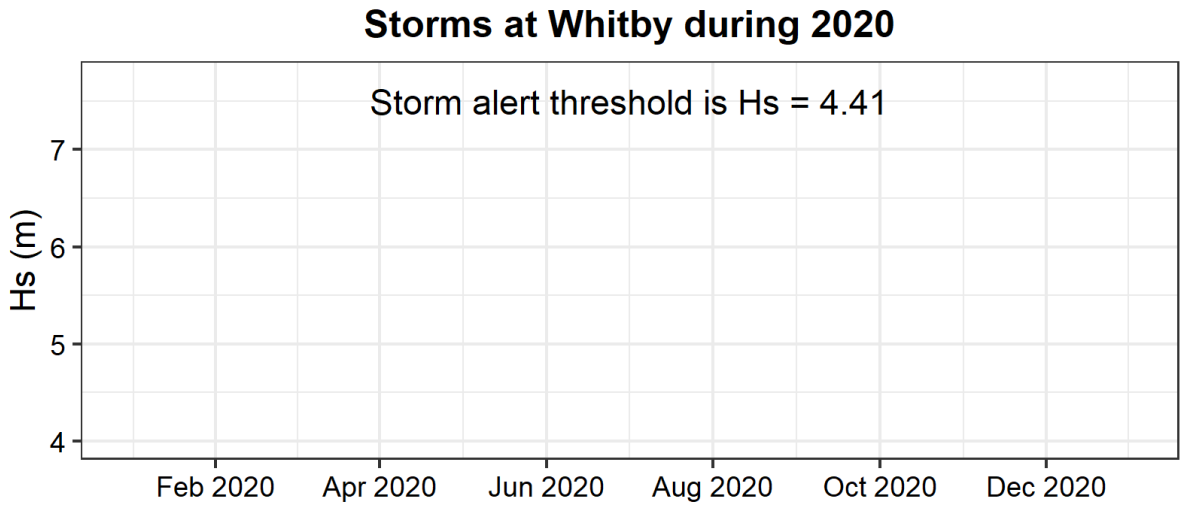
The buoy, owned by Scarborough Borough Council, was deployed on 18 January 2013, at which time the magnetic declination at the site was 1.8° west, changing by 0.18° east per year. A DWR had previously been deployed at this location from 20 May 2010 to 04 February 2011.

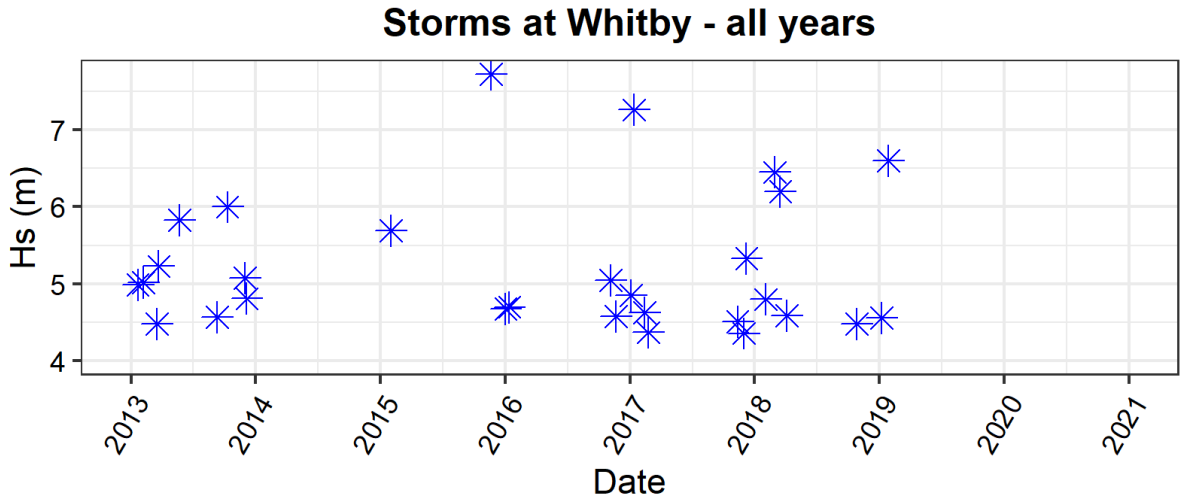
Acknowledgements

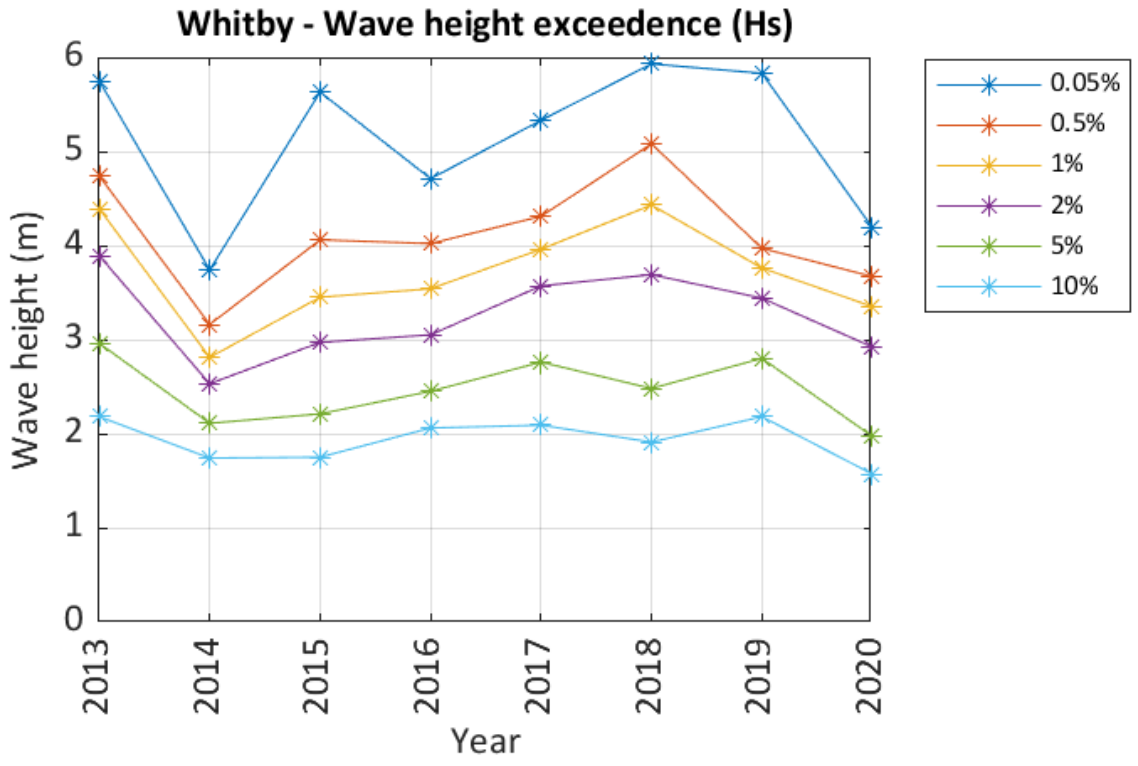
The shore station is kindly hosted by North Yorkshire County Council.

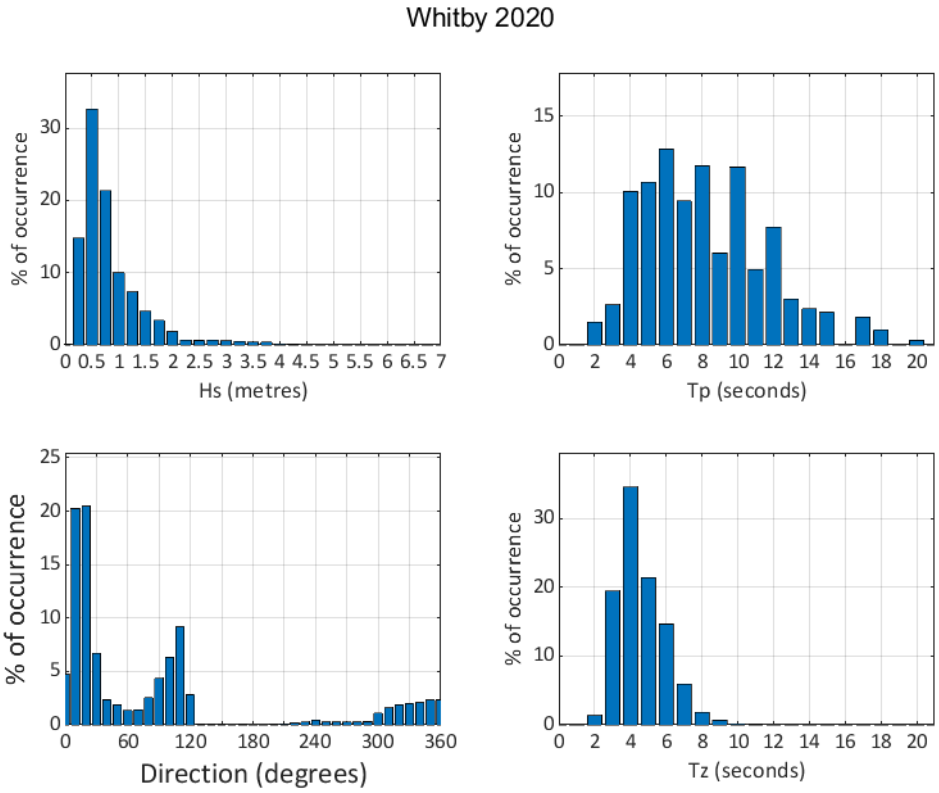
Tidal predictions were supplied by Fugro GB Marine Limited.

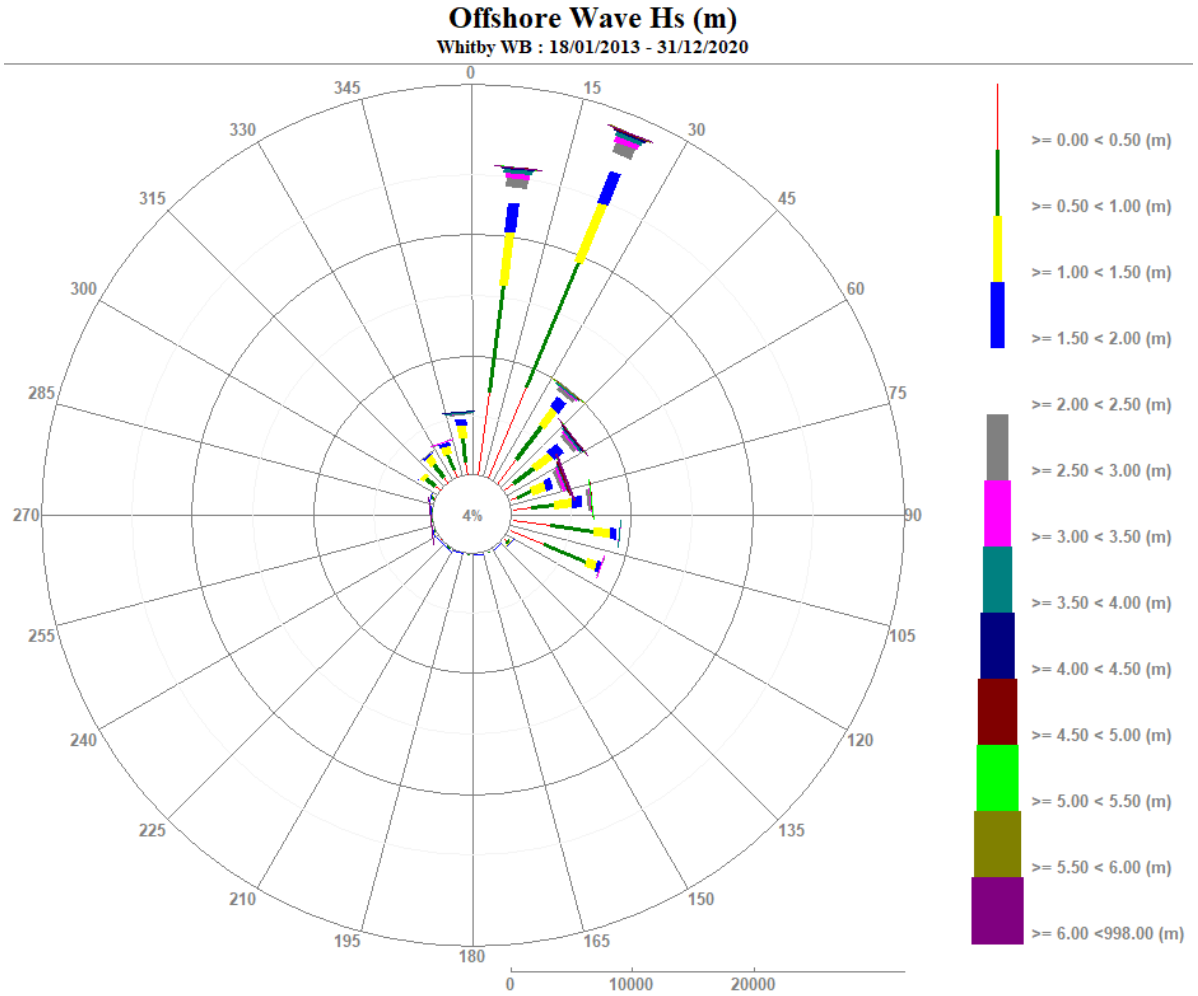

Whitby - Significant Wave Height (Hs) during 2020
metres
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0
2
4
5
10
15
20
25
30
Day in month

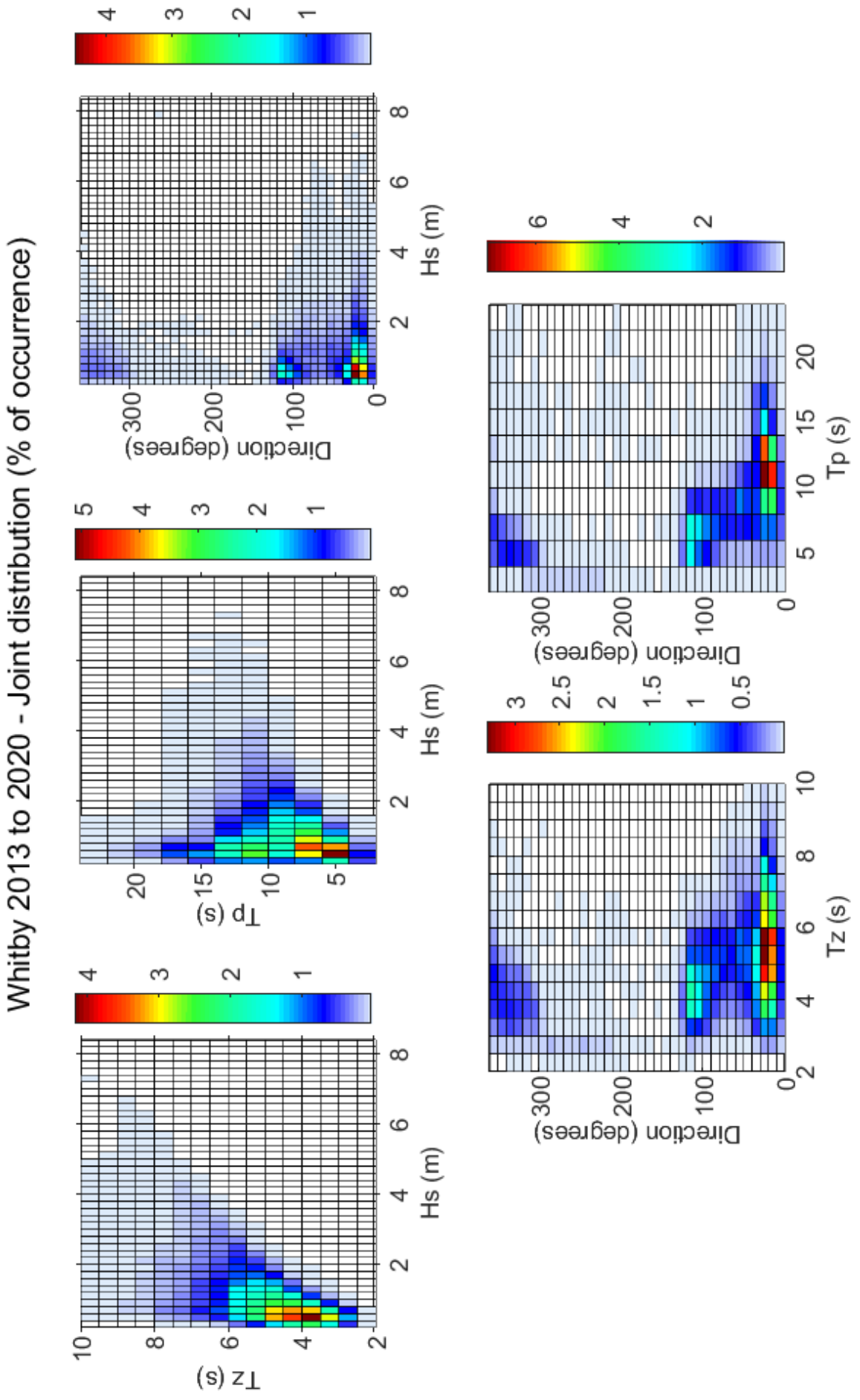

Storms at Whitby during 2020
Storm alert threshold is Hs = 4.41
Hs (m)
7
6
5
4
Feb 2020
Apr 2020
Jun 2020
Aug 2020
Oct 2020
Dec 2020


Storms at Whitby - all years
Hs (m)
7
6
5
4
2013
2014
2015
2016
2017
2018
2019
2020
2021
Date


Whitby - Wave height exceedence (Hs)
Wave height (m)
6
5
4
3
2
1
0
2013
2014
2015
2016
2017
2018
2019
2020
Year
0.05%
0.5%
1%
2%
5%
10%


Whitby 2020
% of occurrence
Hs (metres)
Tp (seconds)
Direction (degrees)
Tz (seconds)


Offshore Wave Hs (m)
Whitby WB : 18/01/2013 - 31/12/2020
4%
>= 0.00 < 0.50 (m)
>= 0.50 < 1.00 (m)
>= 1.00 < 1.50 (m)
>= 1.50 < 2.00 (m)
>= 2.00 < 2.50 (m)
>= 2.50 < 3.00 (m)
>= 3.00 < 3.50 (m)
>= 3.50 < 4.00 (m)
>= 4.00 < 4.50 (m)
>= 4.50 < 5.00 (m)
>= 5.00 < 5.50 (m)
>= 5.50 < 6.00 (m)
>= 6.00 <998.00 (m)


Whitby 2013 to 2020 - Joint distribution (% of occurrence)
Hs (m)
Tz (s)
Tp (s)
Direction (degrees)

Scarborough Directional Waverider Buoy

Location			
OS	509598 E 489943 N		
WGS84	*Latitude:* 54° 17.60' N *Longitude:* 00° 19.06' W		
Instrument type			
Datawell Directional Waverider Mk III			
Water depth	~19m CD	Buoy in situ off Scarborough beach. Photo courtesy of Fugro GB Marine Limited	Location of buoy (Google mapping, image ©2016 Infoterra Ltd & Bluesky)

Data Quality

Recovery rate (%)	Sample interval
97	30 minutes

Monthly Averages - 2020

All times are GMT

Month	H_s (m)	T_p (s)	T_z (s)	Dir. (°)	SST (°C)	Bimodal seas (%)	No. of days
January	0.86	9.1	4.4	97	7.8	7	31
February	1.06	8.6	4.3	121	7.0	15	29
March	1.14	8.7	4.6	78	6.8	10	31
April	1.05	8.7	4.9	54	8.0	8	30
May	1.02	8.4	5.2	97	9.5	2	23
June	0.92	5.8	4.1	103	12.1	2	30
July	0.65	7.3	4.2	144	13.0	0	31
August	1.00	6.4	4.3	84	14.1	2	31
September	1.07	8.6	4.6	84	13.5	2	30
October	1.09	7.7	4.6	90	12.2	5	31
November	0.88	8.4	4.3	113	10.8	3	30
December	1.28	8.7	4.8	104	9.1	11	30

Monthly Averages - All Years (January 2013 – December 2020)

Month	H_s (m)	T_p (s)	T_z (s)	Dir. (°)	SST (°C)	Bimodal seas (%)
January	1.24	8.9	4.7	102	7.2	9
February	1.22	8.5	4.6	96	6.3	7
March	1.31	8.6	4.9	87	6.2	6
April	1.08	7.8	4.7	79	7.1	7
May	0.92	7.5	4.5	80	9.1	2
June	0.81	6.7	4.3	87	11.7	1
July	0.63	6.1	4.0	109	13.7	0
August	0.69	6.6	10.2	108	14.0	1
September	0.89	7.2	4.3	100	13.5	2
October	1.18	8.0	4.7	95	12.5	5
November	1.28	8.3	4.8	97	10.7	5
December	1.11	9.2	4.6	90	8.8	10

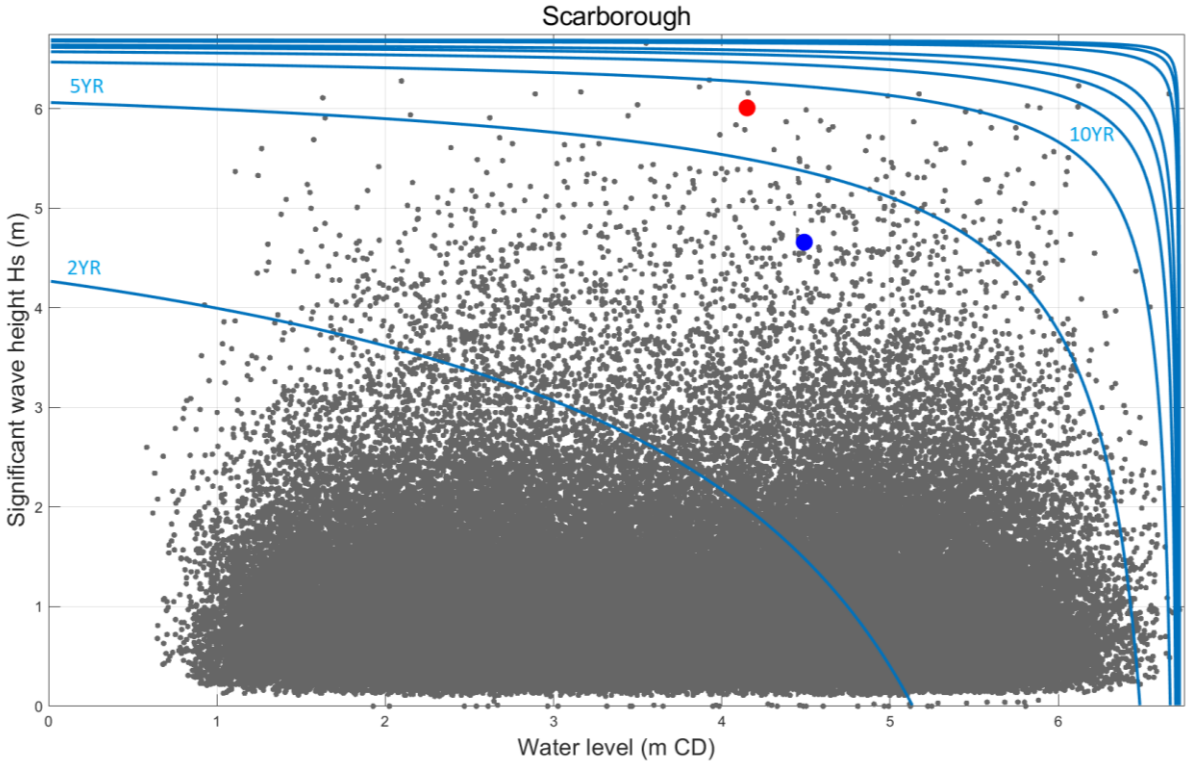
Storm Analysis

Date/Time	H_s (m)	T_p (s)	T_z (s)	Dir. (°)	Water level elevation* (OD)	Tidal stage (hours re. HW)	Tidal range (m)	Tidal surge* (m)	Max. surge* (m)
25-Sep-2020 20:00:00	6.01	11.1	8.0	16	0.90	HW -3	2.19	0.50	0.63
29-Mar-2020 05:00:00	4.66	10.5	7.1	28	1.24	HW -2	3.52	0.09	0.38

** Tidal information is obtained from the tide gauge at Scarborough. The surge shown is the residual at the time of the highest Hs. The maximum tidal surge is the largest surge during the storm event.*

Joint return periods

Joint return periods for water level and significant wave height are based on 0.5 hourly records and calculated using a copula function. For more details on the copula function, see Dhoop & Thompson 2021. The grey point cloud represents the measured joint wave heights and water levels at the Scarborough DWR and Scarborough tide gauge respectively, plotted against one another.



Date/Time	Symbol	H_s (m)	Water level elevation		Joint Return Period
			OD	CD	
25-Sep-2020 20:00:00		6.01	0.90	4.15	1 in 5 years
29-Mar-2020 05:00:00		4.66	1.24	4.49	1 in 2 years

Annual Statistics

Year	Annual H_s exceedance** (m)						Annual Maximum H_s	
	0.05%	0.5%	1%	2%	5%	10%	Date	A_{max} (m)
2013	5.49	4.91	4.44	3.74	2.88	2.12	10-Oct-2013 18:00:00	5.81
2014	3.91	3.16	2.95	2.63	2.22	1.84	14-Oct-2014 04:00:00	4.45
2015	5.79	4.28	3.57	3.10	2.30	1.82	21-Nov-2015 06:00:00	6.70
2016	4.46	4.00	3.65	3.07	2.45	2.09	06-Jan-2016 02:00:00	4.98
2017	5.97	4.29	3.91	3.45	2.79	2.16	13-Jan-2017 16:30:00	6.66
2018	6.13	5.16	4.58	3.92	2.73	2.10	01-Mar-2018 19:00:00	6.29
2019	4.19	3.58	3.28	3.02	2.4	1.89	09-Dec-2019 10:00:00	4.57
2020	5.40	4.25	3.74	3.12	2.22	1.76	25-Sep-2020 20:00:00	6.01

** *i.e.* 5 % of the H_s values measured in 2013 exceeded 2.88 m

Significant wave height return periods

Return periods for significant wave height can be calculated since the buoy has been deployed for more than 5 years. The return periods are based on 0.5 hourly records and are calculated for periods up to 10 times the record length using a peaks-over-threshold method and Generalised Pareto Distribution (GPD).

Observation period	January 2013 to December 2020	
Return period (years)	**Significant wave height (m)**	**Comments**
0.25	4.38	No depth limitation
1	5.49	
2	5.91	
5	6.36	
10	6.63	
20	6.86	
50	7.10	

Distribution plots

The distribution of wave parameters are shown in the accompanying graphs/tables of:

- Annual time series of H_s (red line is 4.38 m storm alert threshold)
- Incidence of storm waves for 2020. Storm events are defined using the Peaks-over-Threshold method. The highest H_s of each storm event is shown
- Wave height exceedance each year since deployment
- Percentage of occurrence of H_s, T_p, T_z and Direction for 2020
- Wave rose (percentage of occurrence of direction vs. H_s) for all measured data
- Joint distribution of all parameters for all measured data, given as percentage of occurrence

General

The buoy, owned by Scarborough Borough Council, was deployed on 18 January 2013, at which time the magnetic declination at the site was 1.66° west, changing by 0.18° east per year.

Acknowledgements

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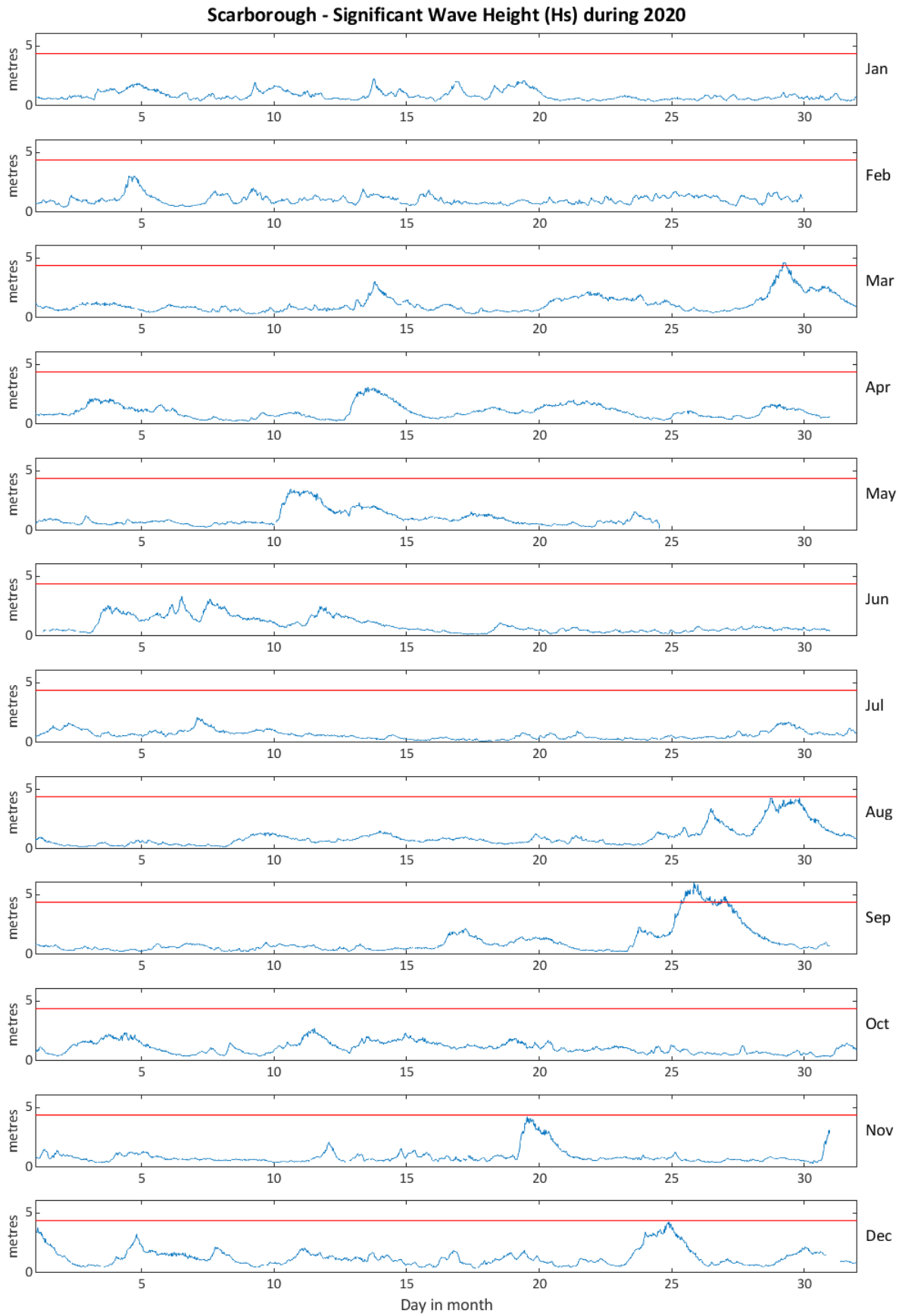
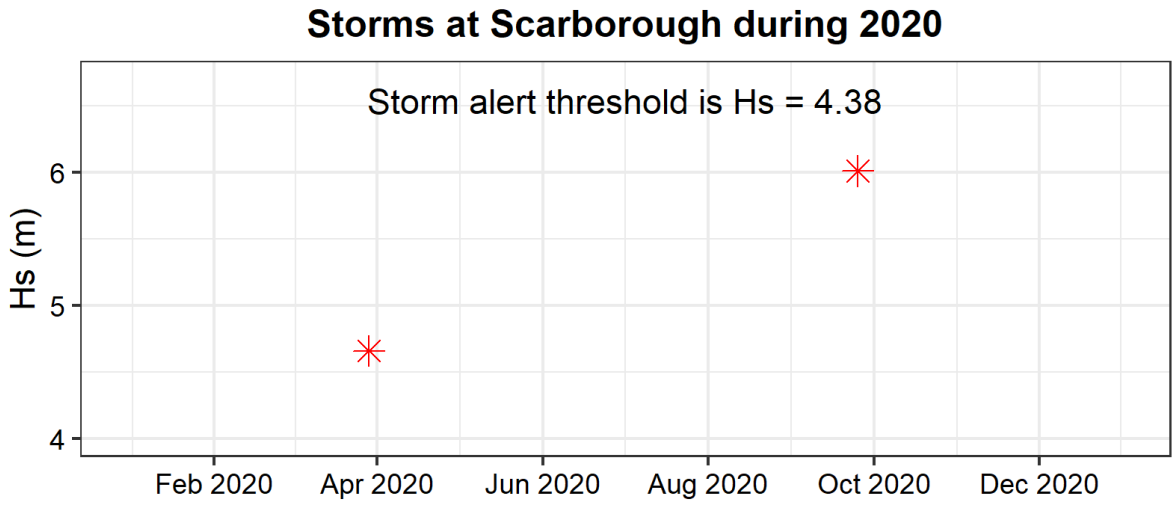
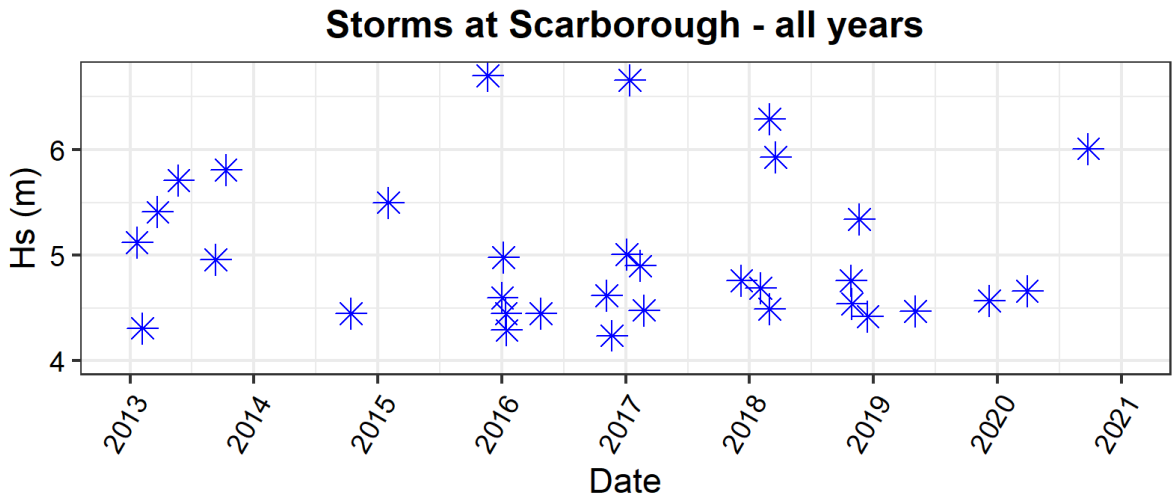
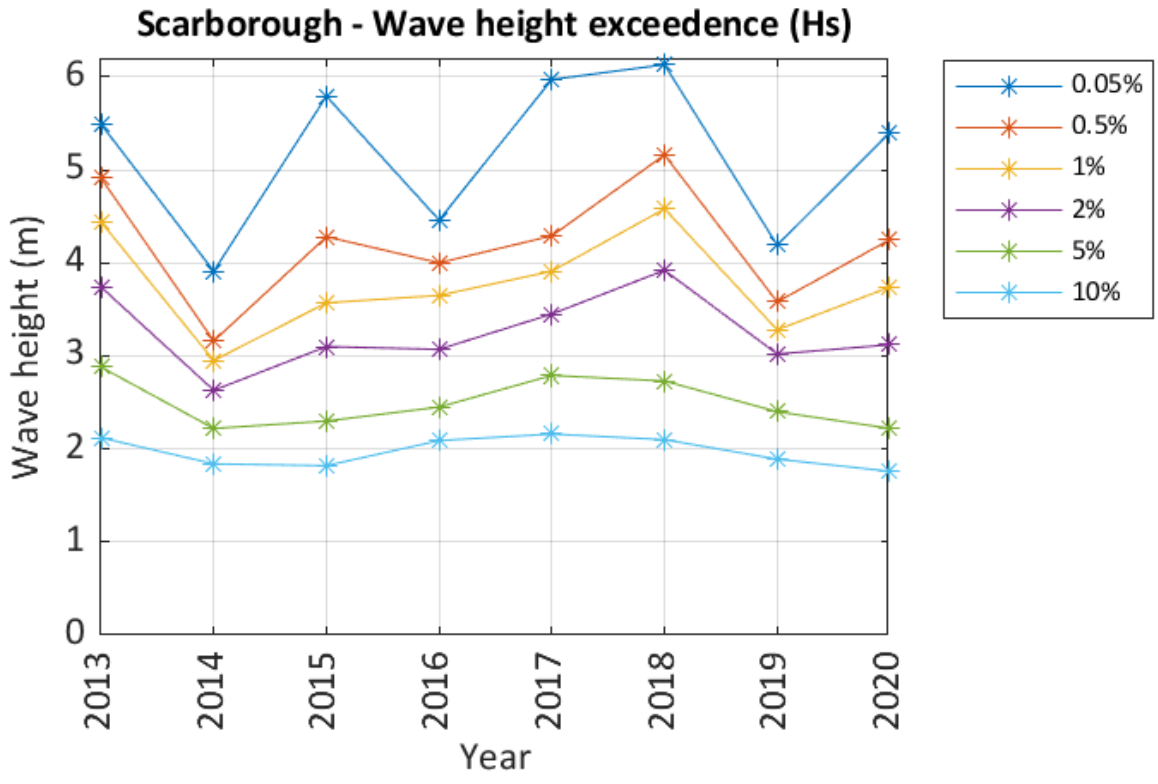
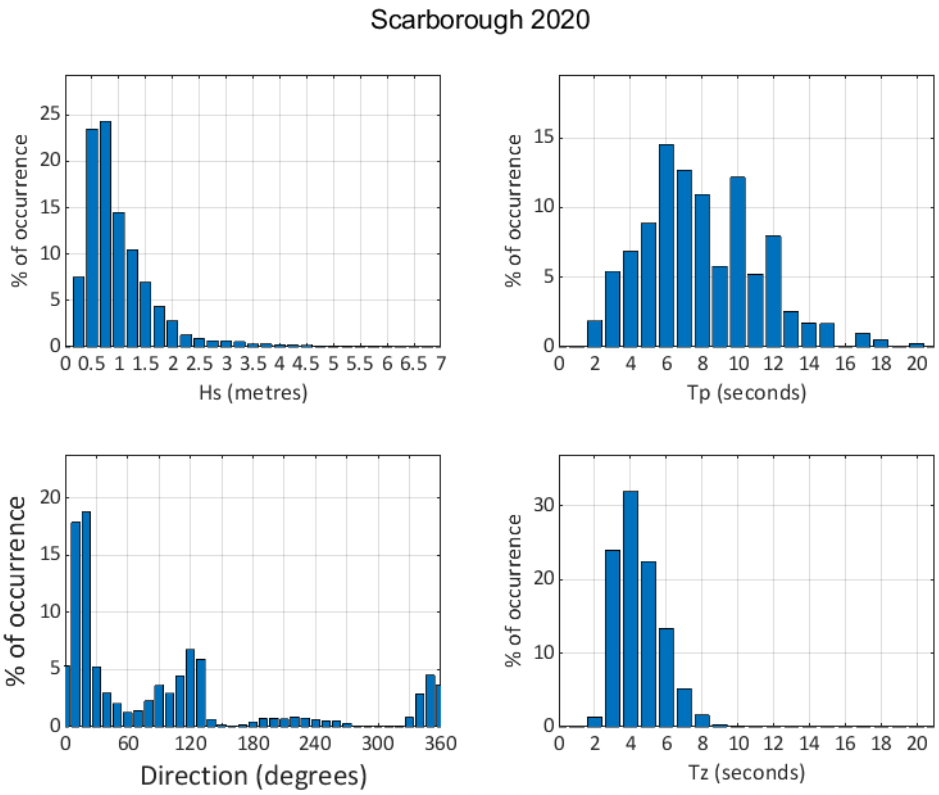
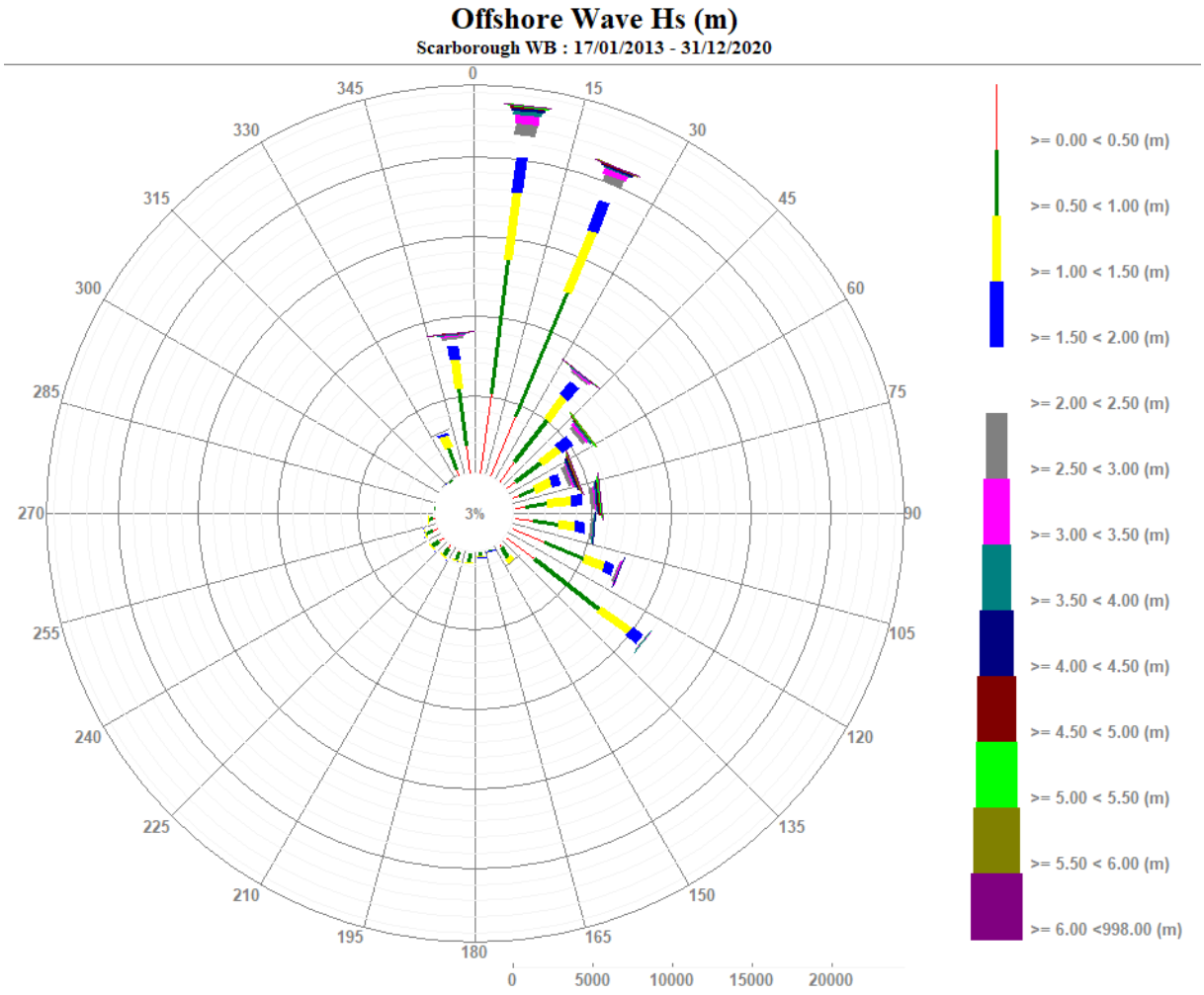

Scarborough - Significant Wave Height (Hs) during 2020
metres
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0
5
10
15
20
25
30
Day in month

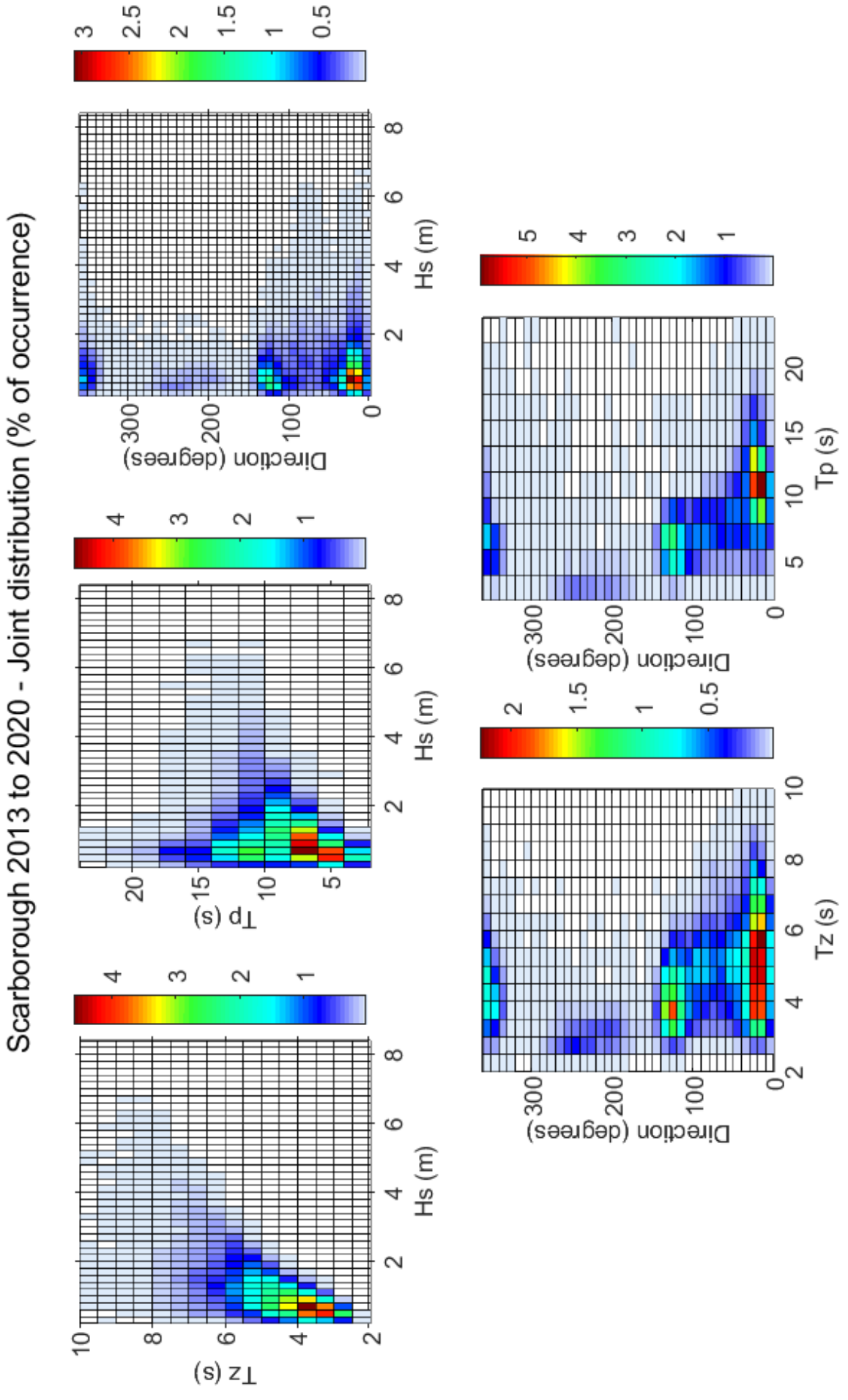

Storms at Scarborough during 2020
Storm alert threshold is Hs = 4.38
Hs (m)
6
5
4
Feb 2020
Apr 2020
Jun 2020
Aug 2020
Oct 2020
Dec 2020


Storms at Scarborough - all years
Hs (m)
6
5
4
2013
2014
2015
2016
2017
2018
2019
2020
2021
Date


Scarborough - Wave height exceedence (Hs)
Wave height (m)
6
5
4
3
2
1
0
2013
2014
2015
2016
2017
2018
2019
2020
Year
0.05%
0.5%
1%
2%
5%
10%


Scarborough 2020
% of occurrence
Hs (metres)
Tp (seconds)
Direction (degrees)
Tz (seconds)


Offshore Wave Hs (m)
Scarborough WB : 17/01/2013 - 31/12/2020
3%
>= 0.00 < 0.50 (m)
>= 0.50 < 1.00 (m)
>= 1.00 < 1.50 (m)
>= 1.50 < 2.00 (m)
>= 2.00 < 2.50 (m)
>= 2.50 < 3.00 (m)
>= 3.00 < 3.50 (m)
>= 3.50 < 4.00 (m)
>= 4.00 < 4.50 (m)
>= 4.50 < 5.00 (m)
>= 5.00 < 5.50 (m)
>= 5.50 < 6.00 (m)
>= 6.00 <998.00 (m)


Scarborough 2013 to 2020 - Joint distribution (% of occurrence)
Direction (degrees)
Hs (m)
Tp (s)
Tz (s)