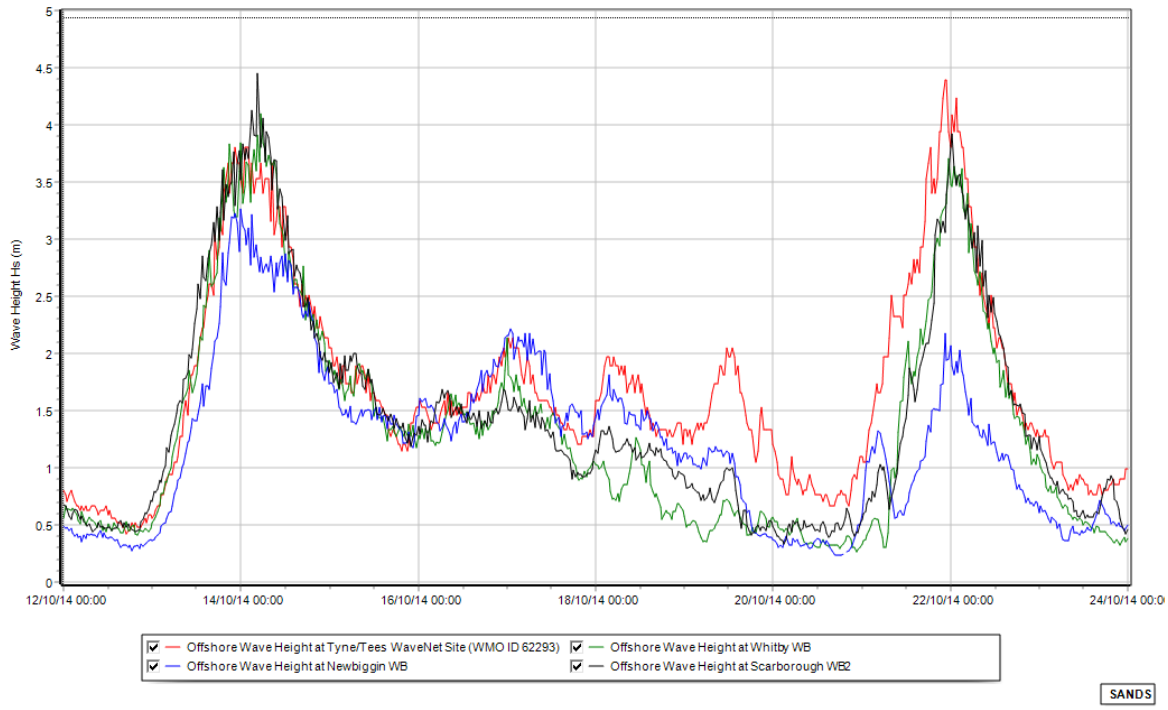

Measured wave heights in Cell 1 during October 2014 storms

Cell 1 Regional Coastal Monitoring Programme
Wave Data Analysis Report 3: 2014 - 2015

Final Report
July 2015

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Scarborough Borough Council
Cell 1 Wave and Tide data Report 2014 – 15

Contents Amendment Record

This report has been issued and amended as follows:

Issue	Revision	Description	Date	Authors
1	0	Draft Final	07.01.15	A Parsons original draft Alan Frampton reviewer
2	0	Final – updated following client comments	23.10.15	A Parsons

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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 (http://www.cefas.defra.gov.uk/our-science/observing-and-modelling/monitoring-programmes/wavenet.aspx) and are subject to the Cefas data usage license as described on the next page.

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 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.

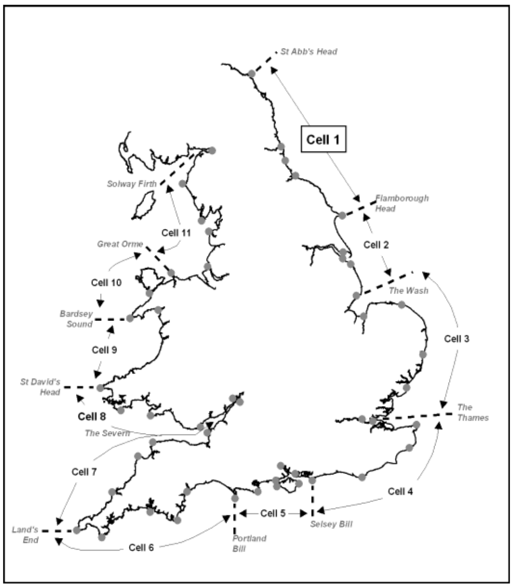


Figure 0.1 Sediment Cells in England and Wales

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 a five-year programme of work, which started in October 2011. The work is funded by the Environment Agency, working in partnership with the following organisations:

The original three year programme of work was undertaken as a partnership between Royal Haskoning, Halcrow and Academy Geomatics. For the current five year programme of work the data collection associated with beach profiles, topographic surveys and cliff top surveys is being undertaken by Academy Geomatics. The analysis and reporting for the programme is being undertaken by Halcrow.

Wave and tide data collection under the present phase of the programme started in January 2013. The data collection is being undertaken by Fugro Emu, and the new wave and tide data that is being collected is available in near real-time on both the Channel Coast Observatory website http://www.coastalmonitoring.org and the www.northeastcoastalobservatory.org.uk website developed for this programme.

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

- beach profile surveys
- topographic surveys
- cliff top recession surveys
- real-time wave data collection
- bathymetric and sea bed characterisation surveys
- aerial photography
- walk-over 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 walk-over visual inspections.

The present report is **Wave Data Analysis Report 3.** This provides an update to the analysis presented in the baseline wave data report and compares the wave data collected between March 2014 and March 2015, to the baseline established in Wave Data Analysis Report 1 published in 2013.

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 present programme data collection commenced in June 2010 when two Waverider buoys were deployed at Whitby and Newbiggin in May 2010 by Cefas. These two buoys were decommissioned in June and November 2011 respectively.

Under the current phase of the programme, three new Waverider buoys have been deployed. 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 website at www.northeastcoastalobservatory.org.uk and the Channel Coast Observatory website http://www.channelcoast.org/ and http://www.coastalmonitoring.org/ The data can also be downloaded from the Cefas website http://www.cefas.defra.gov.uk/our-science/observing-and-modelling/monitoring-programmes/wavenet.aspx.

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.

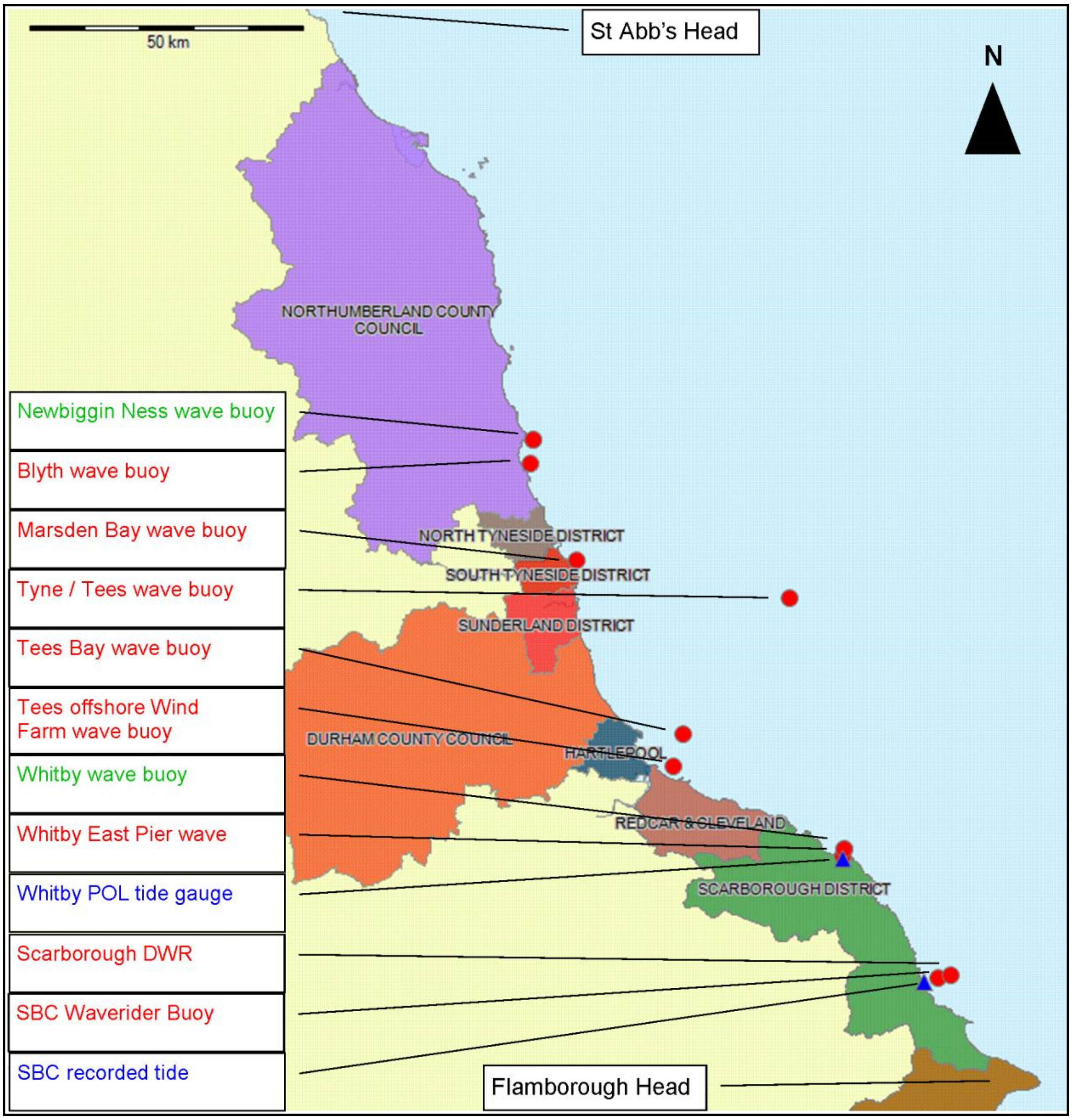
The present report is **Wave Data Analysis Report 3** and provides an analysis of the wave data collected during 2014-2015 as part of the programme. The report forms an update to the baseline assessment in **Wave Data Analysis Report 1 (Halcrow, 2013)** and **Wave Data Analysis Report 2 (Halcrow, 2014)**. It also takes into consideration other freely available 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; and tide gauge data from North Shields and Whitby collected by NTSLF. The purpose of the report is to extend the analysis undertaken in the baseline report 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 below. 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),
- South 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 below and more detailed location maps are shown in Appendix A.



Note: green text denotes the wave buoys that were installed by Cefas within the Cell 1 programme.

Figure 1.1 Study Area and historical data sets reviewed in the baseline report, Halcrow 2013

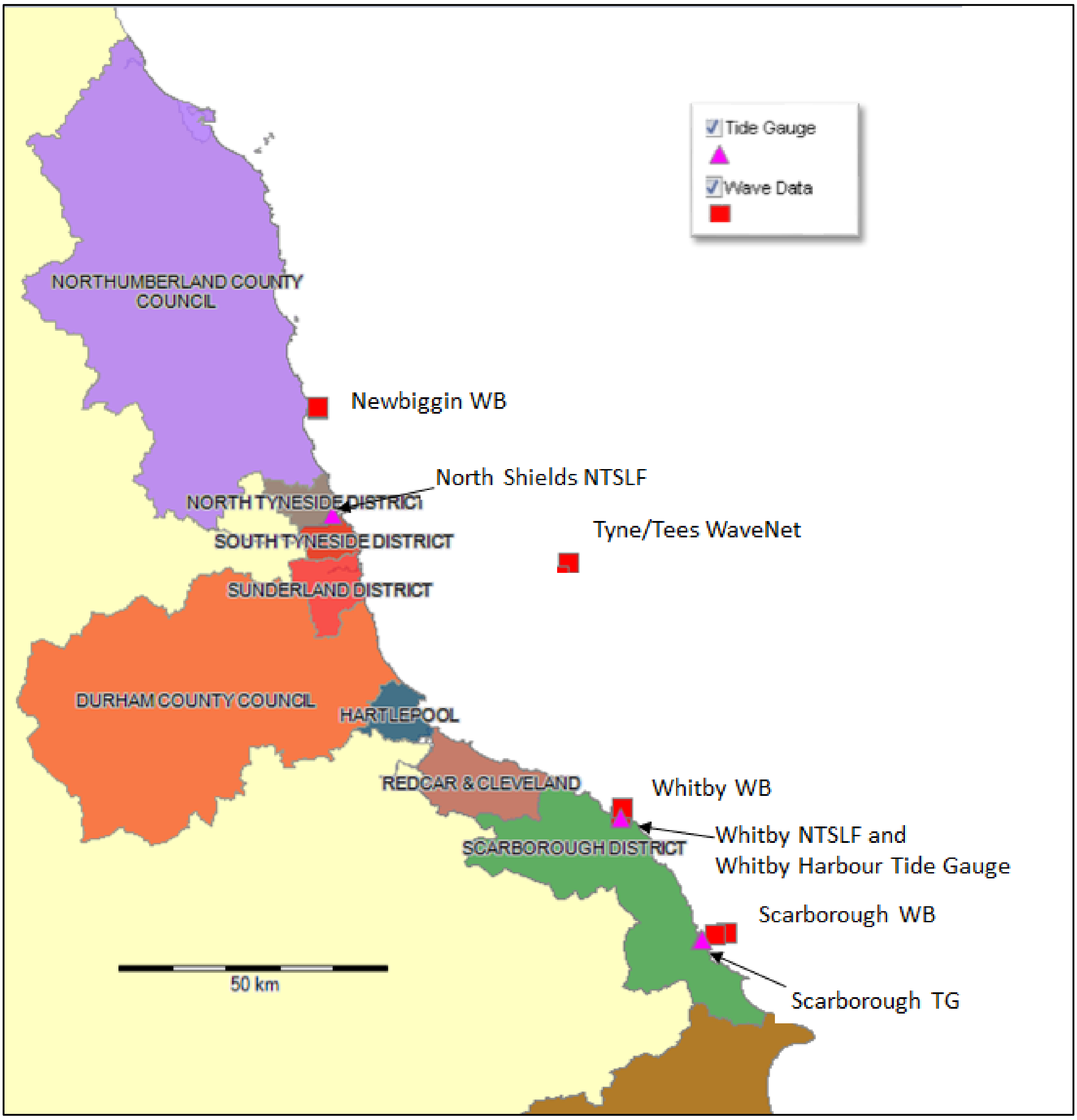


Figure 1.2 Updated data sets reviewed in this report

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. The data sets 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. A report by Fugro-Emu describing the deployment of the instrumentation has been attached in Appendix F. Reports on analysis of the wave data for 2014 at Newbiggin and Whitby are provided in Appendix G. Detailed plots of the tide gauge data and the 2014 report on analysis of the Scarborough tide gauge data by the CCO is 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 it has the longest consistent record offshore of the project area (deployed in December 2006). Data was therefore downloaded from the Cefas website http://cefasmapping.defra.gov.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 February 2014 to March 2015 were compared to the previous data. Note that the analysis has included data available up to the end of March 2015 in order to cover the full winter 2014 to 2015 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 the first 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 and added to SANDS for inclusion in the analysis as was also done for the previous report (Halcrow, 2014).

1.4. Summary of new data available

The new data sets considered in this report for comparison to the baseline data are listed in Table 1-1 below.

Table 1-1 List of updated datasets available for the 2014 to 2015 report

Name of Location	Type of Data	Approx. Water depth (m)	Start Time	End Time
Newbiggin Ness WB	Wave Data	23m	01/02/2014 (deployed 21/06/2013)	31/03/2015 (ongoing)
North Shields NTSLF Tide Record	Tidal Levels	N/A	01/02/2014 (deployed 24/01/1946)	31/03/2015 (ongoing)
Tyne Tees WaveNet Site (WMO ID 62293)	Wave Data	65m	01/02/2014 (deployed 07/12/2006)	31/03/2015 (ongoing)
Whitby WB	Wave Data	17m	01/02/2014 (deployed 17/01/2013	31/03/2015 (ongoing)
Whitby NTSLF Tide Record	Tidal Levels	N/A	01/01/2014 (deployed 01/01/1991)	31/03/2015 (ongoing)
Scarborough WB2*	Wave Data	19m and 30m	01/02/2014 (deployed 17/01/2013)	31/03/2015 (ongoing)
Scarborough TG	Tidal Levels	N/A	01/01/2014 (deployed 28/04/2003)	31/12/2014 (ongoing)

* 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 and runs 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 the previous 2010-11 deployment. Detailed monthly plots of the data collected during 2014 are presented in Appendix B.

The new data set for 2014 has been compared to the baseline data using scatter plots and tables produced in SANDS using the time series data analysis facilities.

2.1.1. Wave Height vs Peak Period

The wave height and zero crossing period for the baseline and new wave data records for Newbiggin have been plotted together on a scatter plot (see Figure 2.1 below). As the data sets are quite short no definitive conclusions can be drawn yet. The wave height / period relationships in Figure 2.1 appear similar. The largest wave heights were observed in the 2010/11 data but there are some longer period waves observed in both 2013/14 and 2014/15 data sets.

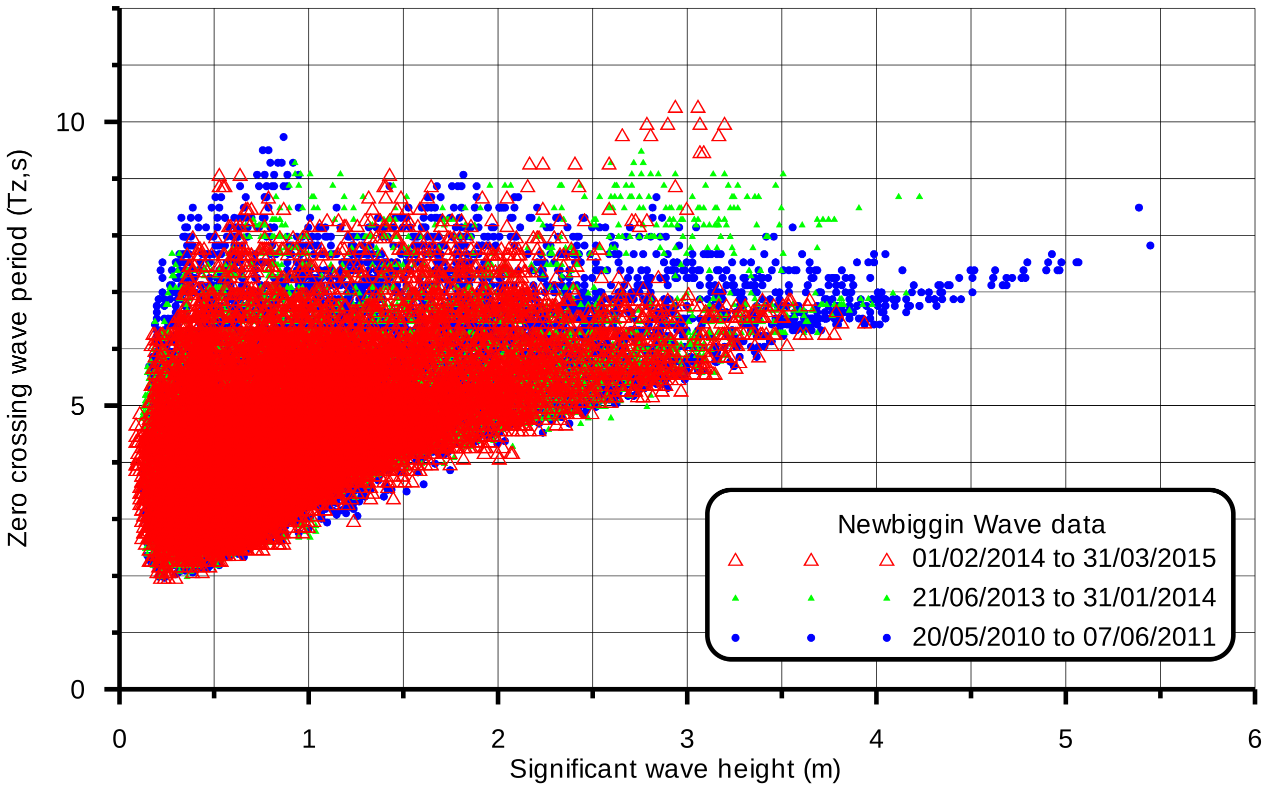


Figure 2.1 Scatter plot of Wave Height Vs Peak Period at Newbiggin wave buoy

2.1.2. Wave Rose

Wave roses showing wave height distribution by direction are shown in Figure 2.2 and Figure 2.3 below. The baseline plot in Figure 2.2 is a full years' data from the original deployment and shows that the waves predominantly approach the Newbiggin Ness wave buoy from the Northeast (30 to 60 degrees).

Comparing the baseline wave rose in Figure 2.2 to the other locations analysed (see Figure 5.1) indicated that the Newbiggin Ness site is relatively sheltered from waves from the north.

The 2013/14 wave data reported in 2014 was noted to show a different directional distribution to the baseline plot, with a more significant proportion of waves from the southeast; see left hand image of Figure 2.3. The 2014/15 data in the right hand image of Figure 2.3 shows a consistent distribution to 2013/14. Until more data is collected we cannot comment further on the typicality of the three wave roses, differences between them or annual variability in storms.

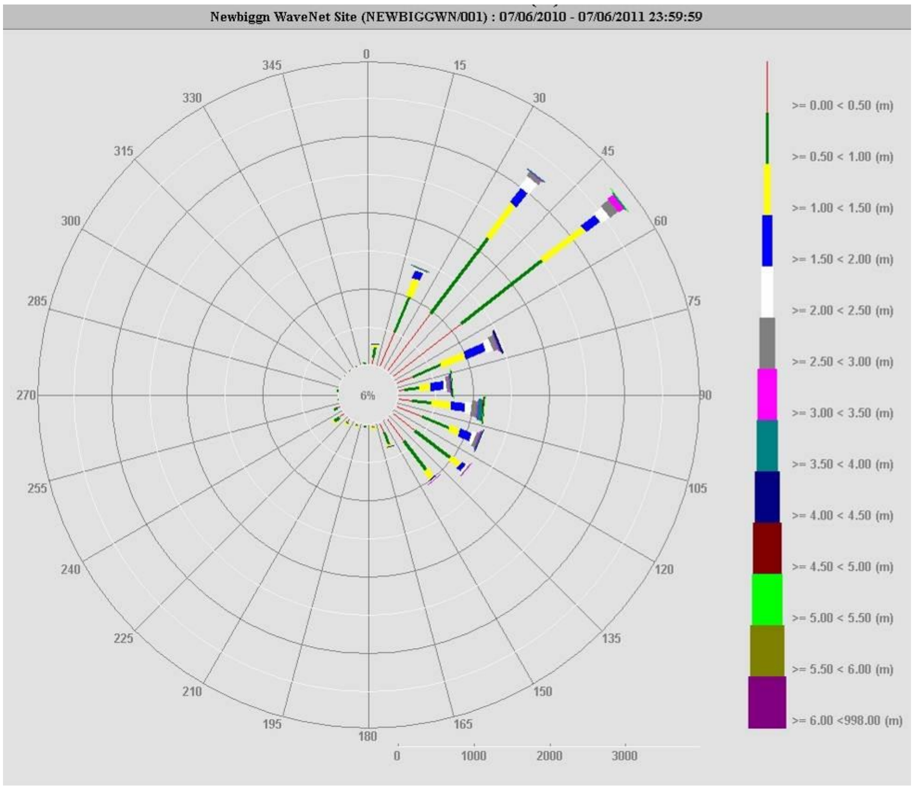


Figure 2.2 Baseline wave rose for Newbiggin wave buoy site (7/06/2010 to 7/06/2011)

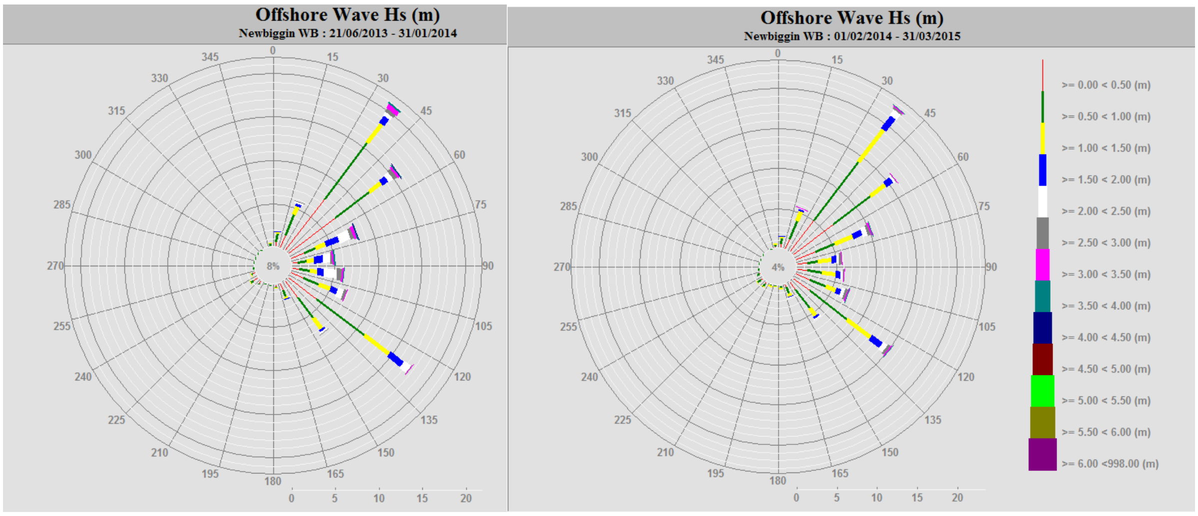


Figure 2.3 Wave roses for Newbiggin WB site new data 2013/14 and 2014/15

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 data range available, from 20/05/2010 to 07/06/2011. The storms recorded in the 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 data set, highlighted in bold, occurred on 8th to 10th November 2010.

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

General Storm Information							At Peak					
Start Time	**End Time**	**Dur (Hrs)**	**Peak of Storm**	**Mean Dir (°)**	**No of Events** (30 min dataset)	**Mean Dir Vector (°)**	**Hs (m)**	**Tp (s)**	**Tz (s)**	**Dir (°)**	**Energy[1] @ Peak (KJ/m/s)**	**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

The results from storms analysis of the full set of new data is shown in Table 2-2 below. To aid interpretation of the results, alternate years have been shaded **and the storm with the largest peak wave height each year has been highlighted in bold**. 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 longest storm in 2013 ran from 10th to 14th October and had peak wave height of 4.2m. There was one storm from the Southeast direction in the record, occurring on 1st January 2014. 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 were 7 storms above the 3m threshold used at Newbiggin in 2014, which is similar to other years, but notably more than observed at the other Cell 1 wave buoys, where higher thresholds of 4m are normally used due to their more exposed locations. The highest significant wave height recorded in 2014 was 4.2m and occurred during the storm on 19th January 2014. This storm also had the highest peak wave energy.

[1] The storm wave energy 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 2-2 Storm analysis for Newbiggin WB (data 21/06/2013 to 31/03/2015)

General Storm Information							At Peak					
Start Time	**End Time**	**Dur (hr)**	**Peak of Storm**	**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

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

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

As described in the 2013-14 report, data is 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 2014 to March 2015 was downloaded and imported into SANDS for analysis alongside the other monitoring data. An updated plot showing data availability for the NTSLF tidal gauge record at North Shields is shown in Figure 2.4 below (Data Source: BODC, https://www.bodc.ac.uk/data/online_delivery/). The data are at hourly intervals prior to 1993 and then at 15 minute intervals. The data were adjusted from Chart Datum to Ordnance Datum during import to SANDS.

Although there is occasional data available from 1946, there are many large gaps in the record up until 1964, as illustrated in Figure 2.4, but the overall record appears very consistent. The spike in the high water levels shown near the end of the plot is the storm surge level of 3.98 mOD at 16:15 on the 5th December 2013. 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). Table 2-4 lists the 15 maximum observed water levels at North Shields.

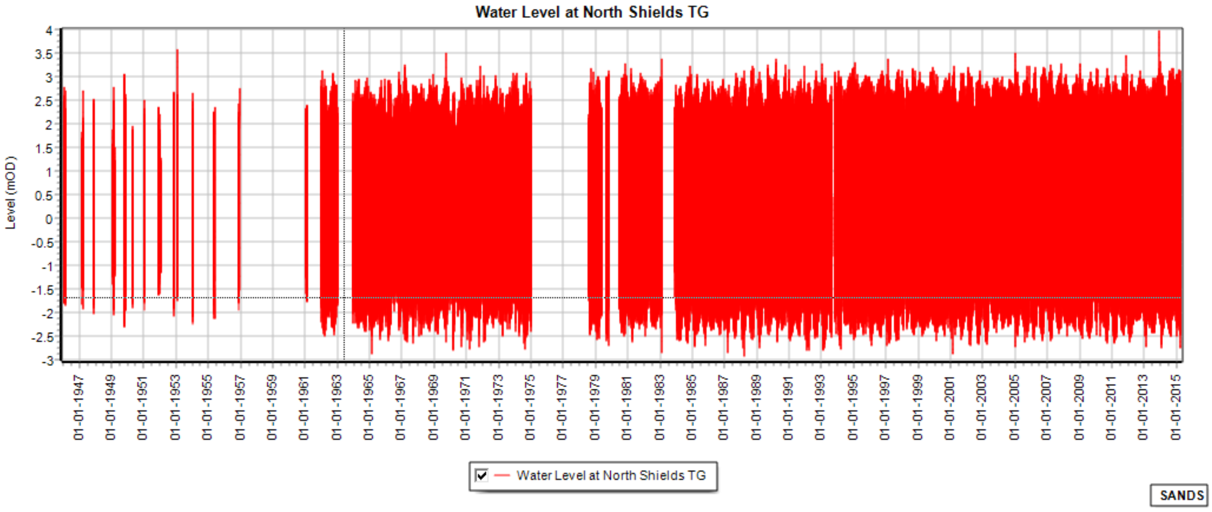


Figure 2.4 Plot of water level data availability at North Shields NTSLF Tide Gauge

Table 2-4 Maximum observed water levels at North Shields

Date	Level (mOD)
05/12/2013 16:15	3.98
31/01/1953 17:00	3.56
12/01/2005 16:45	3.51
29/09/1969 05:00	3.50
27/11/2011 16:30	3.45
09/02/1997 16:30	3.38
27/02/1990 17:00	3.37
01/02/1983 18:00	3.37
04/01/2014 17:15	3.32
01/02/1995 16:00	3.31
11/01/1993 05:00	3.28
25/10/1980 04:00	3.27
12/01/2009 16:15	3.27
25/11/2007 03:00	3.26
07/10/1990 05:00	3.26

Based on analysis of data sourced from https://www.bodc.ac.uk/data/online_delivery/

Extreme water level predictions from the Environment Agency's (EA) 2011 national Coastal Flood Boundary (CFB) Conditions study for a location offshore from North Shields and SANDS analysis of the tide gauge data to the end of November 2013 are shown in Table 2-5 below. This indicates that the December 5th 2013 storm surge, which caused extensive damage to defences and beaches on the east coast, had an annual exceedance probability (chance each year) of between 1 in 200 and 1 in 500 based on the analysis of previous data.

Table 2-5 Predicted extreme tide levels at North Shields

Annual Exceedance probability	Extreme Level (m OD) from EA CFB Study (2011)[1]	Confidence intervals (m) from EA CFB Study (2011)[1]	Extreme levels from SANDS analysis of North Shields NTSLF(mOD)[2]
1 in 1	3.20	0.1	3.16
1 in 2	3.27	0.1	3.25
1 in 5	3.38	0.1	3.37
1 in 10	3.46	0.1	3.46
1 in 20	3.55	0.1	3.55
1 in 25	3.58	0.1	

Annual Exceedance probability	Extreme Level (m OD) from EA CFB Study (2011)[1]	Confidence intervals (m) from EA CFB Study (2011)[1]	Extreme levels from SANDS analysis of North Shields NTSLF(mOD)[2]
1 in 50	3.67	0.1	3.67
1 in 75	3.72	0.1	
1 in 100	3.76	0.2	3.76
1 in 150	3.82	0.2	
1 in 200	3.87	0.2	3.85
1 in 250	3.90	0.2	
1 in 300	3.92	0.2	3.91
1 in 500	4.00	0.3	3.97
1 in 1,000	4.11	0.3	

Notes:
(1) data from EA (2011), Chainage 3630
http://evidence.environment-agency.gov.uk/FCERM/en/Default/FCRM/Project.aspx?ProjectID=F162D56F-87C4-4F14-B77B-A8A3EFDB363F&PageId=a0fe6dfc-506a-452c-9bff-a7ec06b4e6b0
(2) Data to end of November 2013, excluding the December 2013 surge; results taken from 2013-14 report.

According to data from the NTSLF, the highest predicted tide at North Shields (not allowing for atmospheric effects i.e. surge) for the period 2008 to 2026 is 3.13 mOD (5.73 mCD) on 30 September 2015, see Table 2-3. This is because there is a long period 18.6 year fluctuation in the influence of the Moon on our tides, and the peak of the current cycle occurs in September 2015; see EA Advisory note in Appendix H. However, as demonstrated by the data in Table 2.4 and 2.5, it is the combined influence of weather and tides that result in extreme water levels at the Cell 1 coast.

2.3. Tyne Tees WaveNet Buoy

This buoy was deployed by Cefas in 2006 and continues to operate as part of the National Network managed by Cefas for the Environment Agency alongside the UK strategic tide gauge network. The wave buoy is located some 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 data sets 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 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 wave height on most storms was significantly under-estimated, with peak wave heights often 0.5m or more less than measured. This indicates that the model calibration was not good for resolving peak wave heights during storms in this location. It is therefore recommended that caution should be used and consideration given to adjusting or calibrating the Met Office hindcast offshore data if it is to be used as boundary conditions for coastal modelling studies in Cell 1. No further modelled data has been obtained for this update report, but the plot in Figure 2.5 showing a comparison of predicted and measured storms in November and December 2009 has been included from the previous report to demonstrate the issue.

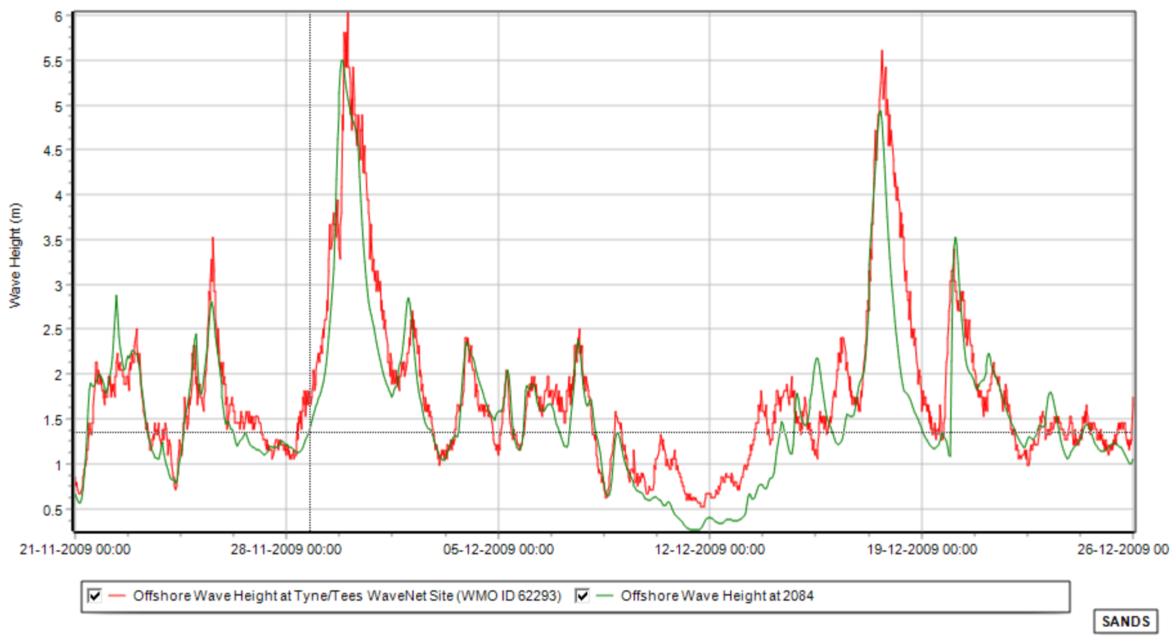


Figure 2.5 Comparison of recorded and modelled wave heights at Tyne Tees in winter 2009 showing under-prediction of modelled data

The data record which 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 March 2015. The scatter table and wave rose was produced for the buoy now using 8 full years of wave data. Storm and extremes analyses were also carried out 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 can be seen in Figure 2.6 below. This shows that generally the four wave buoys record similar storms and although highest storm wave heights are often observed at Tyne /Tees this is not always the case, and sometimes they are larger at Scarborough as the distribution observed varies with each storm. The largest storm in the period April 2014 to March 2015 was in early February 2015.

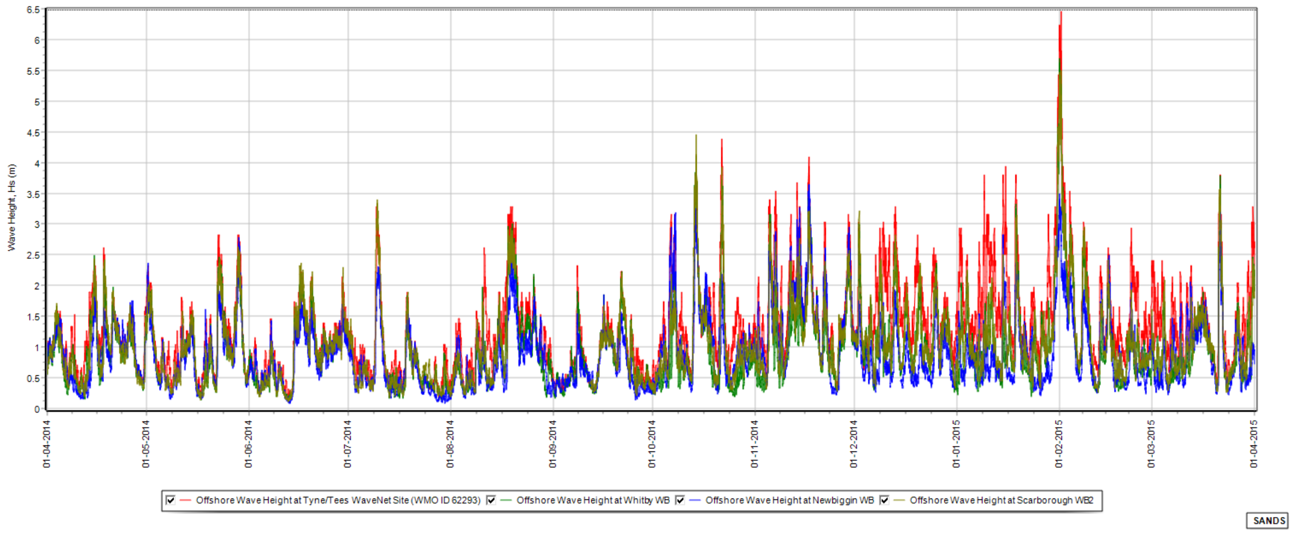


Figure 2.6 Comparison of recorded wave heights at Tyne Tees to the Cell 1 programme buoys from April 2014 to March 2015

2.3.1. Wave height vs Wave Period

The distribution of the wave height, peak and zero crossing period for the wave data record is shown as a scatter plot in Figure 2.7 below. 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 about 8m are associated with peak periods of 12 to 14s or zero crossing periods of 8 to 10s.

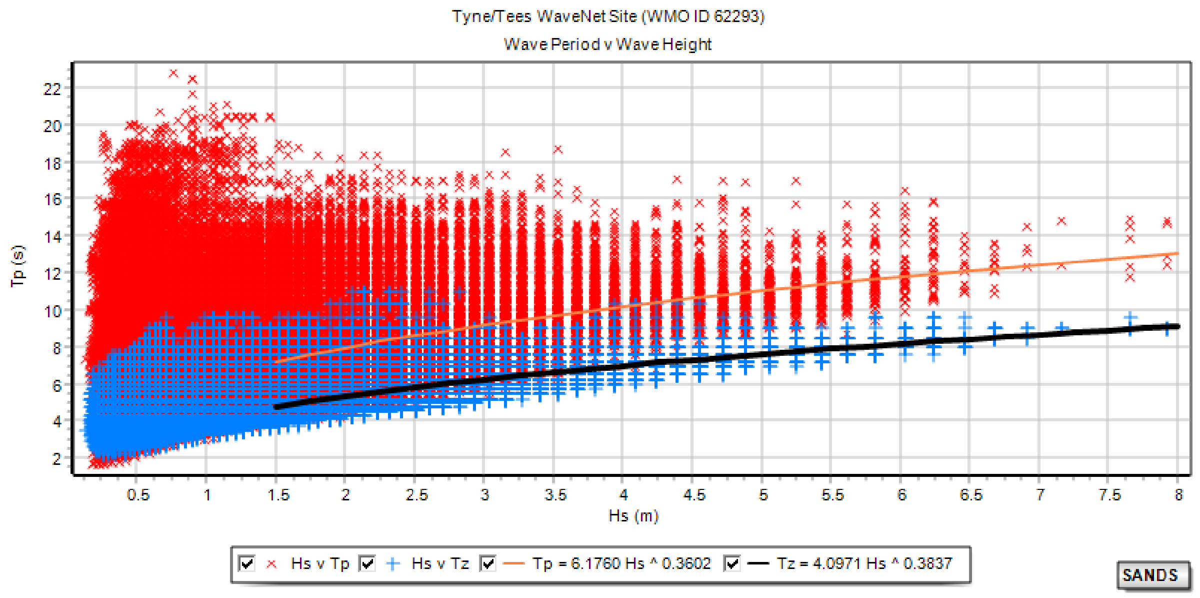


Figure 2.7 Scatter plot of Wave Height Vs Peak Period at Tyne Tees wave buoy site

2.3.2. Wave Rose and Wave Direction Scatter Tables

The wave rose for Tyne Tees in Figure 2.8 has been updated to include 8 full years of wave data. The plot shows that the majority of the waves come from the north to north-northeast (0-30 degrees). There is a small secondary peak from the south east (120-150 degrees). Due to the offshore location of this buoy there are also small peaks from the southwest and northwest, although of course these would represent calm periods at most of the Cell 1 coast.

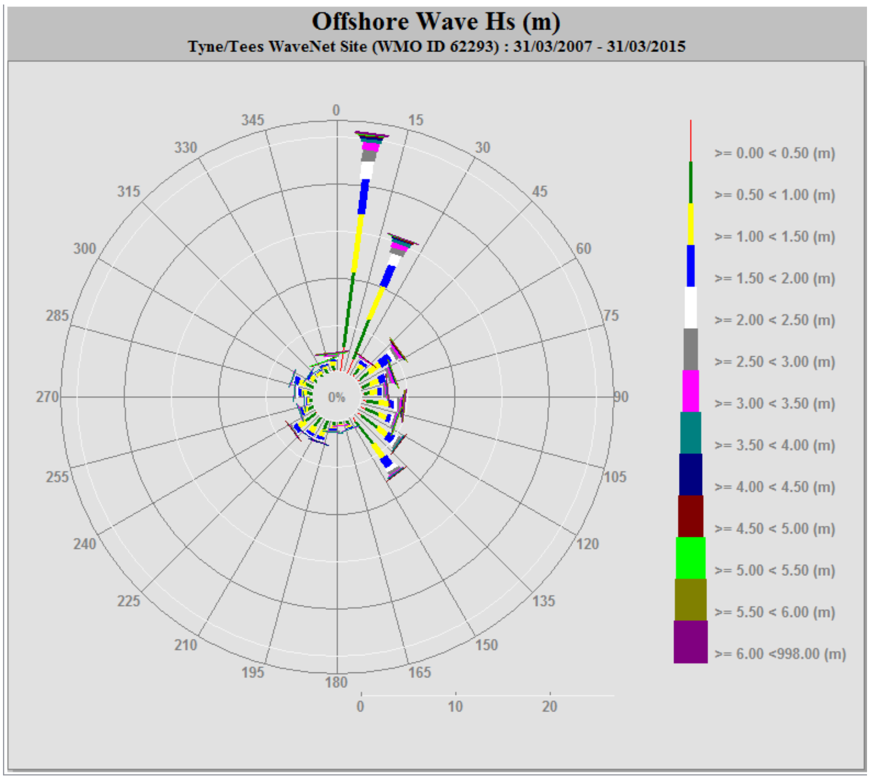


Figure 2.8 Wave Rose at Tyne Tees wave buoy site (WMO ID 62293)

The associated wave height and wave period vs wave direction data are provided below in Table 2-6 and Table 2-7 respectively.

Table 2-6 Wave Height and Direction Scatter Table for Tyne Tees WaveNet Site

Offshore Wave Direction

Offshore Wave Height	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-360	Total
0-0.5	5994	984	582	1474	1664	247	266	560	188	204	172	438	12773
0.5-1	16506	2698	2109	3624	6761	763	1704	3253	1316	1995	896	1297	42922
1-1.5	13456	2552	2215	2577	4056	499	1399	2112	932	1662	976	944	33380
1.5-2	8129	2171	1633	1506	2503	261	837	1126	524	1121	431	746	20988
2-2.5	4073	900	707	824	1251	91	320	262	174	563	138	388	9691
2.5-3	2552	538	612	623	714	43	134	163	125	288	71	314	6177
3-3.5	1677	295	346	309	289	8	25	39	37	68	14	134	3241
3.5-4	947	149	225	179	160	3	15	7	6	16	2	59	1768
4-4.5	456	55	132	127	60		5	2				34	871
4.5-5	295	29	80	74	19			1				28	526
5-5.5	155	7	62	71								21	316
5.5-6	60	1	25	21								10	117
6-6.5	51		5	16								4	76
6.5-7	9		2									1	12
7-7.5	2												2
7.5-8	9												9
Total	54371	10379	8735	11425	17477	1915	4705	7525	3302	5917	2700	4418	

Location: Tyne/Tees WaveNet Site (WMO ID62293);
Date range :01/04/2007 to 31/03/2015 (8 years of data)
Offshore Wave Direction Peak (x) vs Offshore Wave Height Hm0 (y), showing numbers of 30 min observations.

Table 2-7 Wave Period and Direction Scatter Table for Tyne Tees WaveNet Site

Offshore Wave Direction

Offshore Wave Tp	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-360	Total
0-2	1		3	1	2	3	2	2		1		1	16
2-4	321	100	107	363	1393	676	1417	2969	1341	1705	660	279	11331
4-6	2576	1590	2053	4552	8911	977	2843	3863	1642	3548	1784	1795	36134
6-8	8766	4348	3850	4664	5318	113	207	267	169	401	143	1222	29468
8-10	15569	3158	2117	1436	1363	6	2	8	4	8		379	24050
10-12	14470	913	502	226	46	8	6	14	3	5	6	280	16479
12-14	7000	78	8	6	8	3	10	8	3	2		129	7255
14-16	2309	19	2	8	9	4	6	16		10	1	46	2430
16-18	552	7		1	10	1	6	6	1	12		17	613
18-20	207	5			4	4	7	5		1	2	19	254
20-22	21	1			5			5				3	35
22-24	2											1	3
Total	51794	10219	8642	11257	17069	1795	4506	7163	3163	5693	2596	4171	

Location: Tyne/Tees WaveNet Site (WMO ID62293);
Date range :01/04/2007 to 31/03/2015 (8 years of data
Offshore Wave Direction Peak (x) vs Offshore Peak Wave Period Tp (y), showing numbers of 30 minute observations.

2.3.3. Extremes Analysis

The extreme wave height analysis undertaken for the Tyne Tees buoy location in the baseline report has been updated. As previously, a wave height threshold of 4.6m was used, which provided 48 peaks in 8.6 years. The maximum significant wave height recorded over the period was 7.9m on 23/03/2008. The Gumbel distribution used for extrapolation gives a good correlation coefficient of 0.988 and the visual fit appeared satisfactory. Below 1 in 5, the results are within 0.2m of the values reported in the previous report, but the difference increases above this, with the 1 in 30 height being 0.4m higher. Given the length of the record (8.6 years), the data should only be considered reliable up to a 1 in 30 year return period. The results of the extremes analysis are shown in Table 2-8 below.

Table 2-8 Extremes Analysis for Tyne Tees buoy

Return Period (1 in X years)	Gumbel Fit Extreme Wave Height (Hs, m)
0.2	4.7
0.3	5.3
0.5	5.8
1	6.3
2	6.8
3	7.1
5	7.5
10	7.9
20	8.4
30	8.7

2.3.4. 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 3 and 10 storms of the biggest storms each year. The period of data examined ran from 07/12/2006 to 31/03/2015. Note that the 2012 to 2015 analysis uses the telemetry data download, rather than the checked post-recovery data used for earlier years. Future updates to this report may update this analysis if more accurate data becomes available.

The storm analysis results are presented in Table 2-9 below. To aid interpretation of the results in Table 3.4, alternate years have been shaded **and the storm with the largest significant wave height each year has been highlighted in bold**. 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, e.g. in 2009 and 2010.

Plots of storm direction and storm duration are shown in Figure 2.9 and Figure 2.10 below. 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 largest peak wave height (Hs = 7.9m) was associated with the longest duration storm (180 hours) in March 2008.

Comparing the annual storm records, it can be seen that 2010 had the most storms (13). 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. From these results we might expect that the alongshore drift on the Cell 1 beaches in 2010 may have been atypical with unusual changes from the 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. In 2014 two of the three storms had wave directions from south east.

The previously noted year with the fewest storms was 2011. 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 analysis for 2014 for this report shows that there were only 3 storms in 2014, with two in February and one in October. The February 2014 storms were unusually from the south east to south sector whilst the October storm was from the north, which is more typical of the data set.

The winter of 2012 to 2013 appears to have suffered with larger storms than usual, with the second 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.

The latest data in Table 2-9 shows that there was only 3 storms during 2014, with no events reaching the storm threshold between the middle of February 2014 and late October. It would therefore be expected that the Cell 1 beaches will have had a period of recovery from the 2013 storm damage. In many cases the 2014 Full Measures reports indicate partial or full beach recovery after the December 2013 storms, but there are examples where this was not the case. At some locations, e.g. Sandsend, the 2015 Partial Measures reports which review beach profile data collected in spring 2015 show beach levels as low as they were during the December 2013 post storm profile.

Table 2-9 Storm Analysis at Tyne Tees WaveNet Buoy (data to 31st March 2015)

General Storm Information							At Peak					
Start Time	**End Time**	**Dur (hr)**	**Peak of Storm**	**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	20/03/2007 14:30	23	64	78.2	6.2	14.8	8.5	23	1.7E+04	1.4E+07
25/06/2007 20:30	26/06/2007 13:30	17	26/06/2007 10:00	54	18	77.3	4.4	10.3	7.2	23	4.0E+03	1.7E+06
26/09/2007 03:00	27/09/2007 05:00	26	26/09/2007 19:00	11	33	79.7	4.6	13.8	7.6	6	**7.8E+03**	3.6E+06
08/11/2007 20:00	**12/11/2007 15:00**	**91**	**09/11/2007 08:30**	**16**	**58**	**77.7**	**6.2**	15.9	**9.0**	**6**	**1.9E+04**	**1.6E+07**
19/11/2007 03:30	25/11/2007 21:30	162	23/11/2007 05:00	88	52	76.8	4.9	12.7	7.6	17	7.6E+03	6.8E+06
08/12/2007 03:00	10/12/2007 14:30	59.5	08/12/2007 03:30	106	8	82.9	4.1	12.8	7.6	17	5.4E+03	7.5E+05
03/01/2008 10:30	04/01/2008 01:30	15	03/01/2008 23:30	77	24	14.6	4.2	10.9	7.6	62	4.2E+03	2.5E+06
01/02/2008 15:00	02/02/2008 09:30	18.5	02/02/2008	41	30	80.1	6.0	16.4	9.0	17	1.9E+04	8.7E+06
10/03/2008 08:30	10/03/2008 12:30	4	10/03/2008 11:00	146	9	307.5	4.6	9.6	6.5	141	3.8E+03	7.3E+05
17/03/2008 15:00	**25/03/2008 03:00**	**180**	**22/03/2008 05:00**	**81**	**58**	**82.1**	**7.9**	14.8	**9.0**	**6**	**2.7E+04**	**1.7E+07**
05/04/2008 22:00	07/04/2008 05:00	31	06/04/2008 19:00	49	20	83.1	4.6	13.9	7.6	6	7.9E+03	3.0E+06
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	4.9E+03	9.1E+05
03/10/2008 03:00	03/10/2008 20:30	17.5	03/10/2008 16:30	55	17	76.7	4.7	13.6	7.6	23	**8.1E+03**	2.8E+06
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	1.7E+04	2.2E+07
10/12/2008 12:00	13/12/2008 18:00	78	13/12/2008 08:00	109	37	332.1	4.9	10.0	7.2	129	4.7E+03	4.0E+06
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	8.7E+03	8.1E+06
23/03/2009 22:30	28/03/2009 20:30	118	28/03/2009 16:30	217	14	89.4	5.3	10.0	7.6	6	5.4E+03	1.3E+06
10/07/2009 01:30	10/07/2009 02:30	1	10/07/2009 01:30	13	2	78.7	4.2	11.9	7.2	11	5.0E+03	2.3E+05
29/11/2009 20:30	**30/11/2009 15:00**	**18.5**	**30/11/2009 00:30**	**18**	**36**	**72.7**	**6.0**	11.2	**8.0**	**11**	**9.0E+03**	**5.9E+06**
17/12/2009 10:30	18/12/2009 05:00	18.5	17/12/2009 19:30	64	36	26.3	5.4	12.7	8.0	68	**9.4E+03**	5.7E+06
30/12/2009 09:00	30/12/2009 23:00	14	30/12/2009 12:30	84	24	7.7	5.1	9.0	7.2	90	4.1E+03	2.3E+06
06/01/2010 05:30	06/01/2010 11:00	5.5	06/01/2010 06:30	30	10	63.6	4.2	12.7	7.2	11	5.7E+03	1.1E+06
29/01/2010 10:30	30/01/2010 00:30	14	29/01/2010 22:30	9	21	81.9	5.4	10.2	8.0	6	6.0E+03	2.1E+06
26/02/2010 22:30	27/02/2010 02:30	4	27/02/2010 01:00	18	7	72.4	4.6	10.1	7.6	17	4.2E+03	7.0E+05
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	**9.4E+03**	8.5E+06
29/08/2010 14:00	30/08/2010 06:30	16.5	30/08/2010 01:00	243	17	92.8	4.7	10.3	7.6	6	4.7E+03	1.6E+06

General Storm Information							At Peak					
Start Time	**End Time**	**Dur (hr)**	**Peak of Storm**	**Mean Dir (°)**	**No Events**	**Mean Dir Vector (°)**	**Hs (m)**	**Tp (s)**	**Tz (s)**	**Dir (°)**	**Energy @ Peak (KJ/m/s)**	**Total Energy (KJ/m)**
06/09/2010 22:30	07/09/2010 16:00	17.5	07/09/2010 15:30	101	22	353.2	4.6	10.5	8.0	90	4.5E+03	2.3E+06
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	7.5E+03	2.9E+06
24/09/2010 03:00	26/09/2010	45	24/09/2010 10:00	21	80	71.6	5.3	12.1	8.0	11	8.0E+03	1.2E+07
20/10/2010 02:00	24/10/2010 16:30	110.5	20/10/2010 10:00	13	16	78.2	4.2	13.4	7.2	17	6.4E+03	1.8E+06
08/11/2010 14:00	**09/11/2010 20:30**	**30.5**	**09/11/2010 10:00**	**88**	**58**	**3.0**	**5.6**	10.5	**8.0**	**73**	**6.9E+03**	**7.8E+06**
17/11/2010 11:00	17/11/2010 18:30	7.5	17/11/2010 12:00	136	9	322.4	4.7	9.2	6.9	129	3.7E+03	8.1E+05
29/11/2010 19:30	02/12/2010 08:30	61	29/11/2010 21:00	80	45	11.8	5.1	11.2	7.6	56	6.3E+03	5.4E+06
16/12/2010 15:00	17/12/2010 06:30	15.5	17/12/2010 03:30	12	22	79.1	4.6	12.5	7.6	17	6.4E+03	2.8E+06
23/07/2011 14:00	**24/07/2011 11:00**	**21**	**24/07/2011 03:00**	**23**	**39**	**67.1**	**4.7**	12.8	**7.6**	**17**	**7.2E+03**	**5.8E+06**
24/10/2011 18:30	25/10/2011 09:30	15	25/10/2011 09:30	103	26	348.5	4.1	11.3	6.9	79	4.2E+03	2.6E+06
09/12/2011 08:30	09/12/2011 10:00	1.5	09/12/2011 08:30	7	3	84.0	4.1	14.2	8.0	6	6.7E+03	4.8E+05
05/01/2012 16:00	06/01/2012 05:00	13	06/01/2012 03:00	12	19	79.0	4.6	12.5	7.6	17	6.4E+03	2.6E+06
03/04/2012 13:30	04/04/2012 10:30	21	03/04/2012 17:30	66	38	25.1	5.6	9.7	7.6	56	5.9E+03	5.5E+06
24/09/2012 08:30	25/09/2012 10:30	26	25/09/2012 01:30	74	50	16.7	4.7	12.3	8.0	62	6.6E+03	7.4E+06
26/10/2012 16:30	27/10/2012 14:30	22	26/10/2012 23:00	12	34	79.4	4.9	15.3	7.6	11	1.1E+04	4.9E+06
05/12/2012 16:00	15/12/2012 01:30	225.5	14/12/2012 19:30	78	31	18.4	5.4	10.5	7.6	96	6.4E+03	4.5E+06
20/12/2012 06:00	**21/12/2012 14:30**	**32.5**	**20/12/2012 23:00**	**101**	**56**	**348.4**	**5.6**	11.3	**8.0**	**96**	**8.0E+03**	**8.8E+06**
18/01/2013 18:30	22/01/2013 06:00	83.5	21/01/2013 10:00	81	54	9.2	6.7	11.2	8.5	84	1.1E+04	1.1E+07
06/02/2013 08:00	07/02/2013 06:00	22	06/02/2013 12:30	47	38	81.6	5.4	11.9	7.6	11	8.2E+03	6.1E+06
07/03/2013 21:00	10/03/2013 21:30	72.5	08/03/2013 04:00	67	37	24.6	4.9	10.7	7.6	73	5.4E+03	4.3E+06
18/03/2013 09:00	25/03/2013 00:30	159.5	23/03/2013 14:30	85	153	5.1	6.0	12.1	8.0	90	1.0E+04	2.8E+07
23/05/2013 18:00	**24/05/2013 12:00**	**18**	**23/05/2013 22:30**	**13**	**32**	**77.5**	**6.7**	12.5	**8.5**	**17**	**1.4E+04**	**7.1E+06**
10/09/2013 13:00	10/09/2013 19:30	6.5	10/09/2013 14:00	11	14	79.3	4.4	11.0	7.2	11	4.6E+03	1.5E+06
09/10/2013 22:30	11/10/2013 09:00	34.5	10/10/2013 17:00	68	62	79.8	5.4	12.7	7.6	22	9.4E+03	1.2E+07
29/11/2013 22:30	30/11/2013 06:30	8	30/11/2013 00:30	42	17	84.5	5.6	12.7	8.0	11	1.0E+04	3.3E+06
05/12/2013 14:00	07/12/2013 04:30	38.5	06/12/2013 20:00	24	59	80.8	4.7	17.0	9.0	6	1.3E+04	1.2E+07
27/12/2013 09:30	27/12/2013 12:30	3	27/12/2013 10:00	218	3	249.3	4.1	7.3	6.5	202	1.8E+03	1.3E+05
05/02/2014 04:00	05/02/2014 18:00	14	05/02/2014 05:30	139	9	318.4	4.4	9.3	6.9	129	3.3E+03	7.2E+05
12/02/2014 20:00	**14/02/2014 19:00**	**47**	**12/02/2014 21:00**	**183**	**8**	**275.6**	**4.6**	8.9	**6.5**	**141**	**3.2E+03**	**7.8E+05**
21/10/2014 22:00	22/10/2014 01:30	3.5	21/10/2014 23:00	6	5	84.4	4.4	11.5	7.6	6	**5.0E+03**	6.0E+05
31/01/2015 08:30	01/02/2015 19:30	35.0	31/01/15 23:30	78	71	88.7	6.2	13.1	8.0	6	1.3 E+4	1.4 E+7

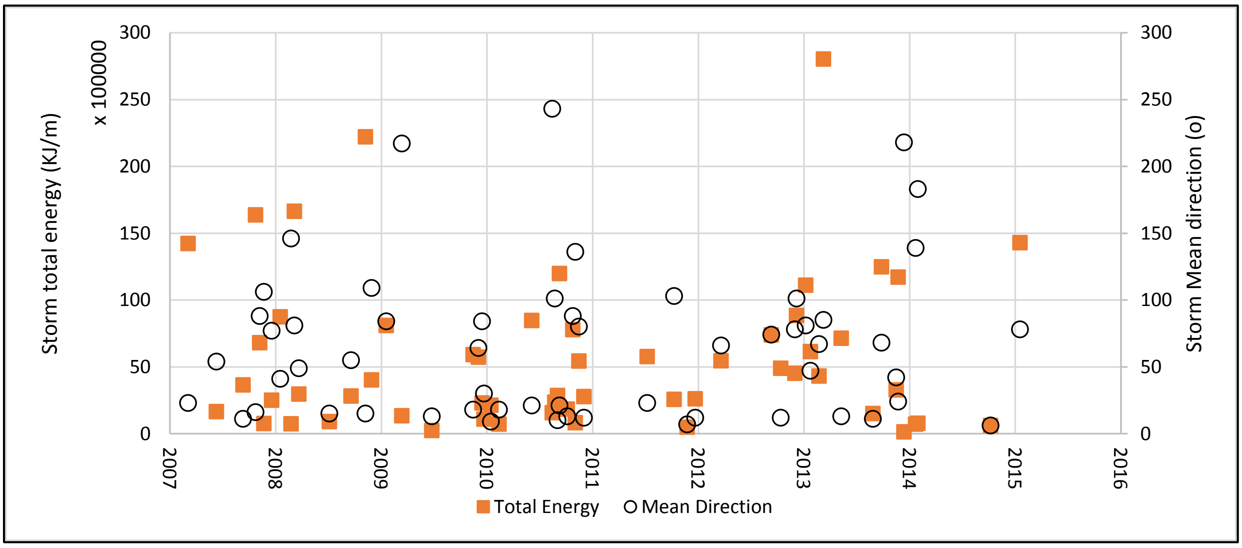


Figure 2.9 Total storm energy and wave direction at the peak of each storm for Tyne Tees Wave Buoy

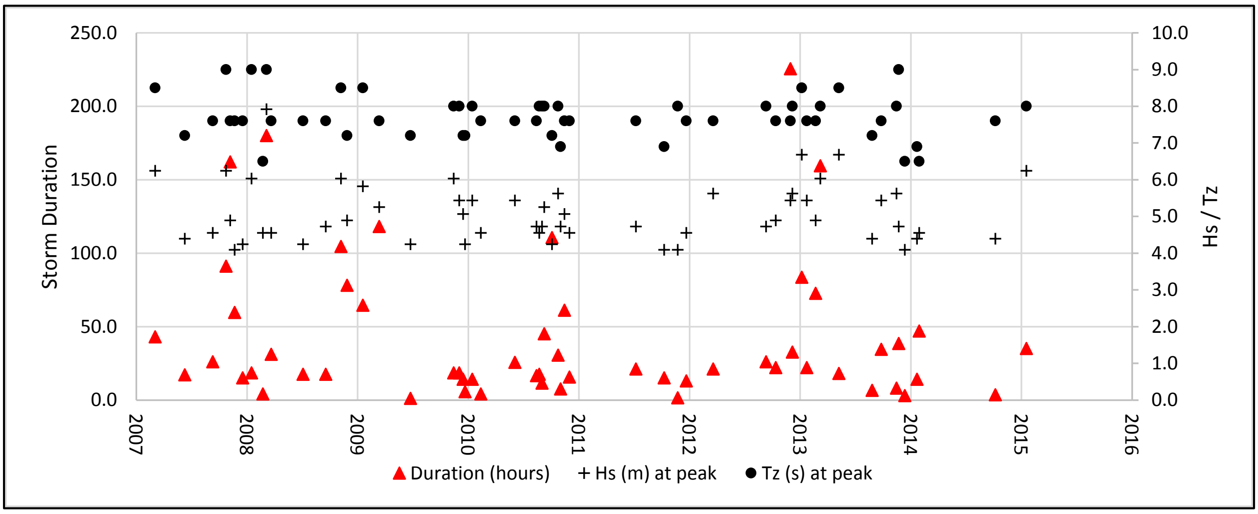


Figure 2.10 Storm duration, with Hs and Tz at peak for Tyne Tees Wave Buoy

A comparison between the wave energy at Tyne Tees Wave buoy, and wave energy from storms in the Met Office model hindcast is shown in Figure 2.11. Visual inspection of Figure 2.11 shows the model data indicates a decline in storm energy since a peak in 2004/05 up to the end of the dataset in 2012, however there were similar patterns from 1995 to 2002 and from 1981 to 1985, so this is not unusual. The data from the Tyne Tees buoy also shows a decline from 2009, but then shows an increase over the winter 2013/14.

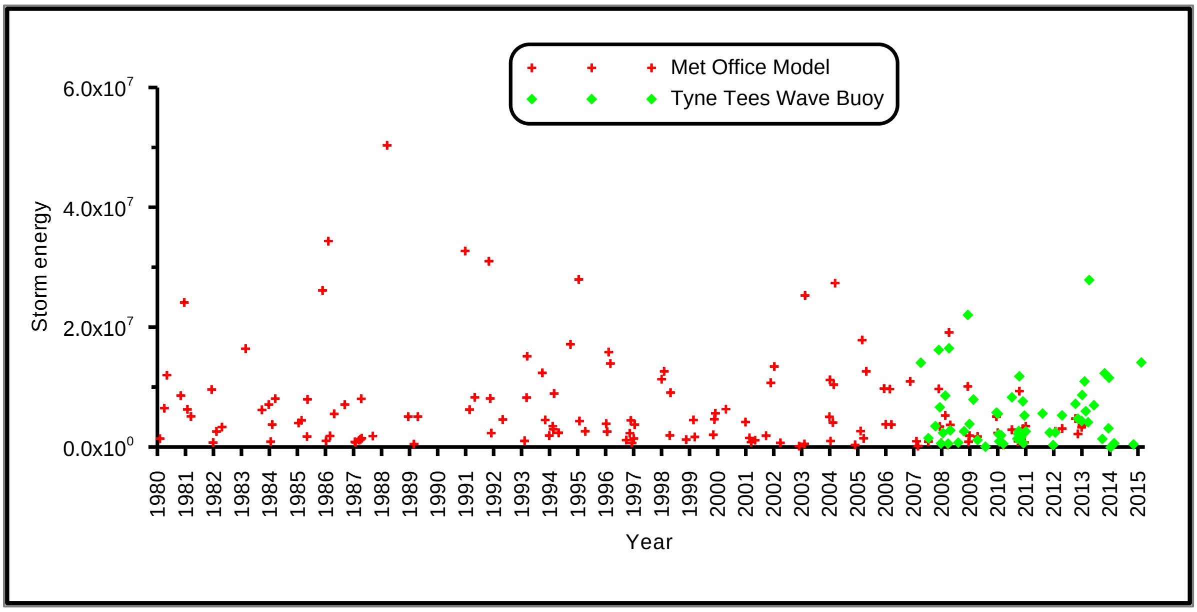


Figure 2.11 Storm energy comparison for Met Office model and Tyne Tees Wave Buoy

An analysis of the joint occurrence of waves and water levels has been undertaken using the measured NTSLF water level data from North Shields and the measured wave data from the Tyne Tees buoy. The results, which supersede those in the earlier reports, are presented as a scatter table of the number of occurrences of joint events in Table 2-10.

Table 2-10 Scatter table for Tyne Tees WaveNet data vs North Shields water levels

	Water level (mOD) at North Shields														
	-2.5 - -3.0	-2.0 - -2.5	-1.5 - -2.0	-1.0 - -1.5	-0.5 - -1.0	0.0 - -0.5	0.5 - 0.0	1.0 - 0.5	1.5 - 1.0	2.0 - 1.5	2.5 - 2.0	3.0 - 2.5	3.5 - 3.0	4.0 - 3.5	4.5 - 4.0
Wave Height (Hs,m) at Tyne/Tees															
7.00 - 8.00	0	0	0	0	1	1	0	0	1	2	6	0	0	0	0
6.00 - 7.00	0	0	3	11	8	10	11	18	20	10	9	8	0	0	0
5.00 - 6.00	0	0	7	27	60	66	53	59	56	71	46	26	3	0	0
4.00 - 5.00	2	13	43	154	197	190	182	175	185	197	131	31	4	1	0
3.00 - 4.00	6	52	176	554	736	649	576	596	668	691	457	100	4	3	0
2.00 - 3.00	11	133	706	1714	2253	2152	1840	1856	2258	2275	1337	366	13	0	0
1.00 - 2.00	14	477	2748	6230	7703	7063	6081	6118	7512	7705	4849	1151	38	0	0
0.00 - 1.00	9	665	3329	6473	8061	7107	6130	6231	7731	8030	4978	1334	37	0	0

Based on 8.1 years of data accounting for gaps with records at 0.5 hour intervals,
Data period is 7th December 2006 to 30 June 2015

2.4. Whitby Waverider Buoy

In the baseline report, one full year's data for Whitby, from October 2010 to October 2011, was analysed in SANDS to prepare a wave rose and scatter table for the baseline. The new data collected is from a very similar location and now covers the period from 17th January 2013 to 31st March 2015. The data were imported into SANDS for comparison and analysis alongside the other available monitoring data; see Figure 2.6.

There are gaps in the new data in 2014 from 5th May to 12th May and from 26th June to 12th July whilst the buoy was off station following possible damage by a fishing vessels. Supporting data tables and monthly plots of the new data are provided in Appendix C.

2.4.1. Wave Height vs Peak Period

The distribution of the wave height and peak period for the wave data record has been plotted as a scatter plot with the data for 17th January 2013 to 30th January 2014 and 1st February 2014 to 31st March 2015 overlaid on the baseline data (20/05/2010 to 25/10/2011); see Figure 2.12 below. The distribution of wave height and period appears similar, although there are several larger storm waves in the new data set and also some longer period swell.

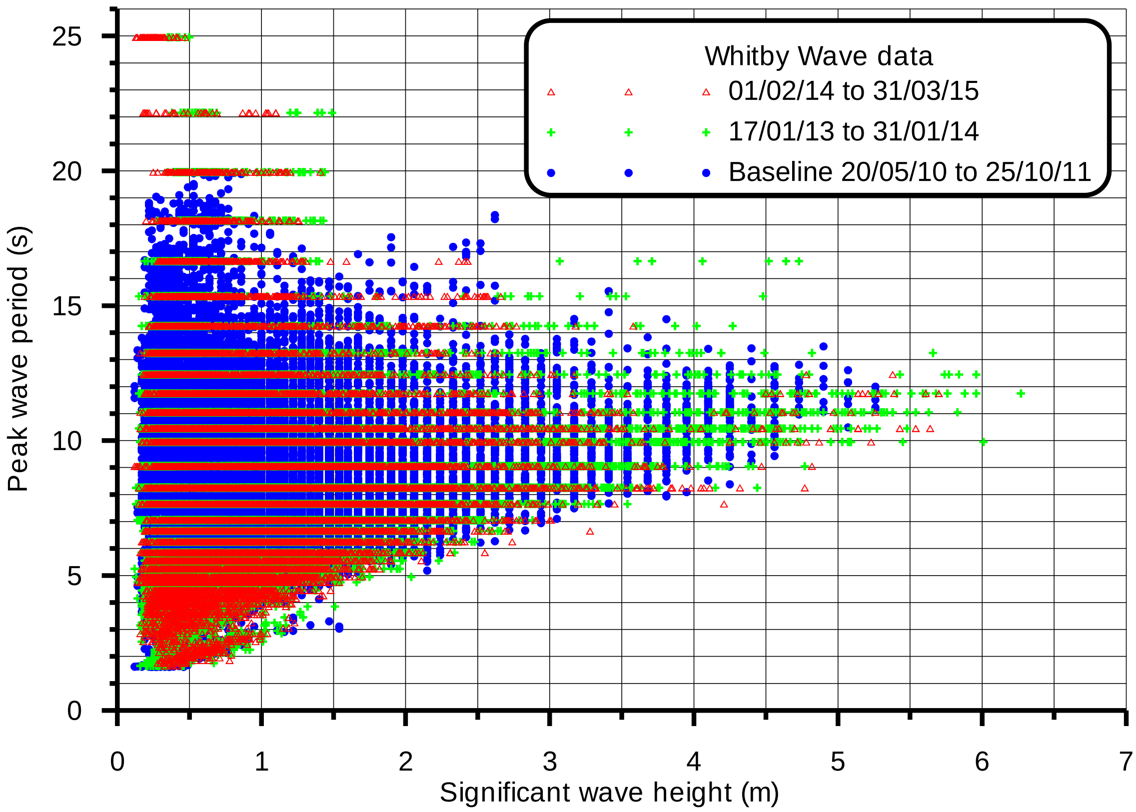


Figure 2.12 Scatter plot of Wave Height Vs Peak Period at Whitby wave buoy site

2.4.2. Wave Rose

The directional data of the wave record has also been used to plot a wave rose for the baseline and new data sets, with both showing a quite similar distribution, see Figure 2.13 and Figure 2.14 below. The wave roses are fairly similar and show that the waves predominantly approach the coastline at Whitby from the northeast by north direction (0 to 30 degrees).

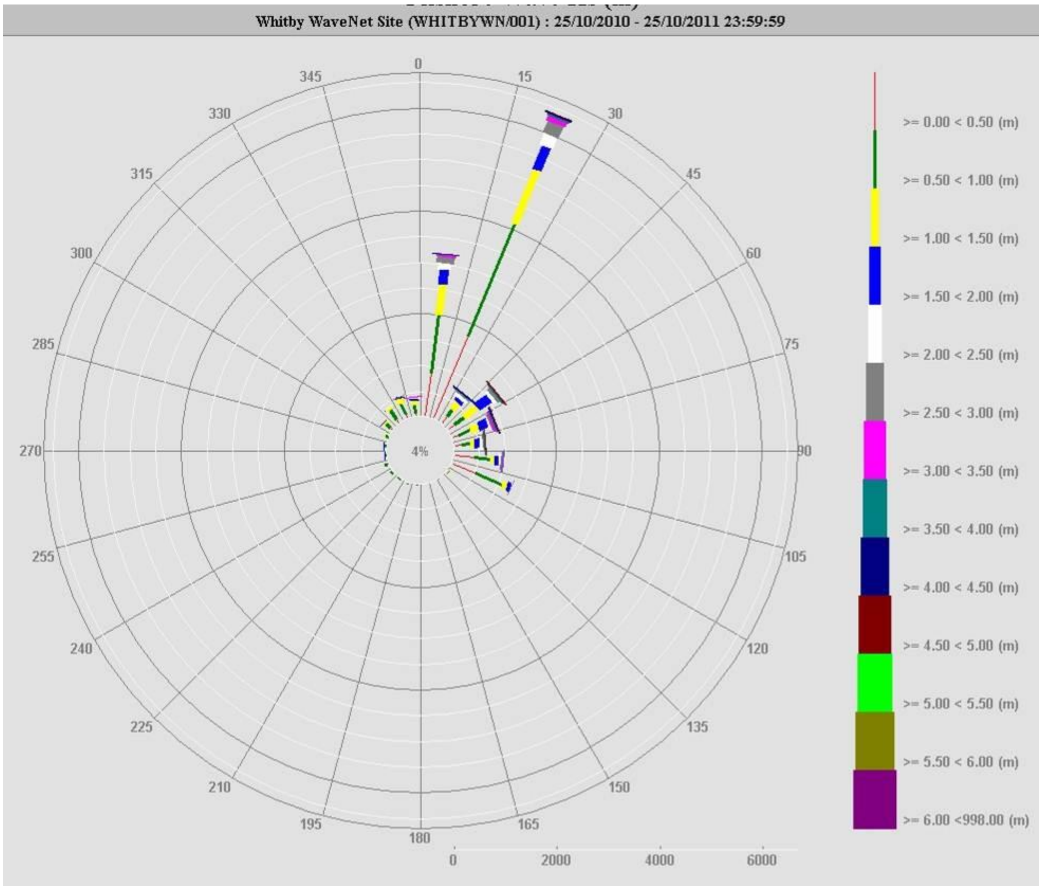


Figure 2.13 Baseline wave rose at Whitby wave buoy site – data for 2010 to 2011

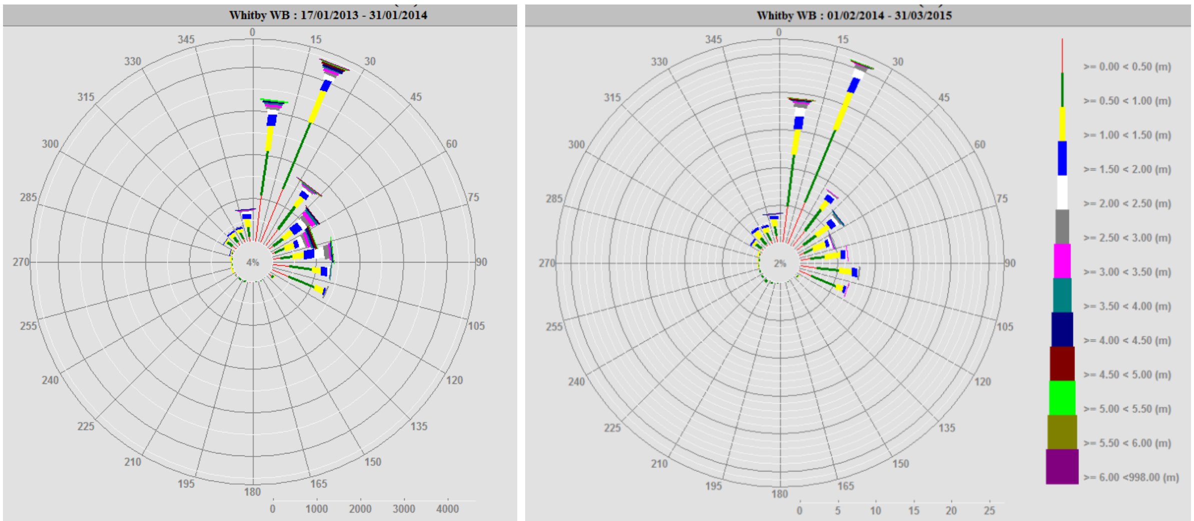


Figure 2.14 Wave Roses at Whitby wave buoy site – new data 2013/14 and 2014/15

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 has been revised for this report using a slightly lower threshold of 3.9m to detect more storms and the updated results are presented in Table 2-11 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 2-12. To aid interpretation of the results in the storm Tables alternate years have been shaded **and the storm with the largest peak wave height each year has been highlighted in bold**. 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 2-11 Storm Analysis results for Whitby – Baseline data 20/05/2010 to 25/10/2011

General Storm Information					At Peak						
Start Time	End Time	Duration (Hours)	Peak of Storm	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	20/06/10 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	29/08/10 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	17/09/10 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**	**25/09/10 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	20/10/10 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	09/11/10 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	29/11/10 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	16/12/10 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	24/07/11 03:00	28	36	62.1	4.2	10.8	22	5.8 E+3	4.9 E+6

Comparing the storm data at Whitby in Table 2-11 and Table 2-12 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 2-12 Storm analysis for Whitby WB (data 17/01/2013 to 31/03/2015)

General Storm Information							At Peak					
StartTime	EndTime	Duration (hr)	Peak of Storm	Mean Dir	No of Events	Mean Direction 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	21/01/13 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	06/02/13 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	11/03/13 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	23/03/13 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**	**24/05/13 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	10/09/13 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	11/10/13 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	30/11/13 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	06/12/13 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**	**14/10/14 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	01/02/15 02:30	14	60	79.1	**5.7**	11.8	7.8	11	8.9 E+3	9.0 E+6

The storms analysis for the new data at Whitby show that by far the largest peak wave energy was associated with the storm that occurred from 5th to 6th December 2013, although this did not have the largest wave height. The largest peak wave height in the record is 5.8m during the storm from 23rd to 24th May 2013. Storms in October 2013 and January 2015 had the next highest peak wave height of 5.7m. The data for 2014 shows that the conditions during 2014 were significantly less stormy at Whitby than either 2011 or 2013, with only one short duration storm identified, occurring on 14th October 2014.

As we only have three years of wave data it is not yet possible to say if the conditions observed are more or less stormy than usual. Further insight into this can be gained by reference to the longer data set from the Tyne Tees wave buoy, or the longer term Met Office model data analysed in the 2013-14 report.

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.

Table 2-13 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

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

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.

An example plot of water level data from the POL tidal gauge record at Whitby is shown in Figure 2.15 below (Source: BODC, https://www.bodc.ac.uk/data/online_delivery/). The data available for analysis at the time of writing the baseline report was from 01/01/1991 to

30/04/2011, with data available at 15min intervals. The data availability was checked again when writing the 2013-14 report and additional data from 1980 to 1990, at hourly intervals and the 15min data from April 2011 to January 2014 was downloaded and added to the project SANDS database. The data from February 2014 to March 2015 has been added to the analysis for this report. All data were adjusted from Chart Datum to Ordnance datum when imported to SANDS.

There are occasional gaps in the Whitby data as illustrated in the example plot below in Figure 2.15, but the overall record appears very consistent. The spike in the high water levels shown near the end of the plot is the storm surge level of 4.32 mOD at 17:15 on the 5th December 2013. This shows how exceptional the conditions of that event were, with the previous maximum observed water level of 3.6 mOD occurring at 18:00 on 1st February 1983 (note that prior to 1990 only hourly data are available and so the maximum water level may have been higher than the recorded 3.6 mOD). The 15 highest water levels observed at Whitby are presented in descending order in Table 2-14.

Table 2-14 Maximum observed water levels at Whitby

Date	Level (mOD)
05/12/2013 17:15	4.32
01/02/1983 18:00	3.61
18/03/2007 15:15	3.48
07/10/1990 05:00	3.47
04/01/2014 18:00	3.46
09/02/1997 17:15	3.46
01/01/1995 15:30	3.46
15/11/2005 03:00	3.43
20/03/1988 17:00	3.42
07/10/2006 03:15	3.42
27/02/1990 17:00	3.39
20/09/2005 04:45	3.36
12/01/2009 16:45	3.35
11/09/2010 05:30	3.35
09/11/2007 03:15	3.35

Based on data from https://www.bodc.ac.uk/data/online_delivery/

Extreme water level predictions from the Environment Agency (EA)'s 2011 national Coastal Flood Boundary (CFB) Conditions study for a location offshore from Whitby are shown in Table 2-15 below. This indicates that the December 5th 2013 storm surge, which caused extensive flooding around Whitby town centre had an annual exceedence probability (chance each year) of between 1 in 100 and 1 in 500.

Table 2-15 Predicted extreme tide levels at Whitby

Annual Exceedence probability	Extreme Level (m OD) from EA CFB Study (2011)[1]	Confidence intervals (m) from EA CFB Study (2011)[1]	Extreme levels from SANDS analysis of Whitby NTSLF (mOD)[2]
1 in 1	3.37	0.1	3.3
1 in 2	3.46	0.1	3.4
1 in 5	3.58	0.1	3.6
1 in 10	3.68	0.1	3.7
1 in 20	3.78	0.1	3.8
1 in 25	3.81	0.2	
1 in 50	3.92	0.2	3.9
1 in 75	3.98	0.2	
1 in 100	4.02	0.3	4.0
1 in 150	4.09	0.3	
1 in 200	4.14	0.3	4.1

Annual Exceedence probability	Extreme Level (m OD) from EA CFB Study (2011)[1]	Confidence intervals (m) from EA CFB Study (2011)[1]	Extreme levels from SANDS analysis of Whitby NTSLF (mOD)[2]
1 in 250	4.17	0.3	
1 in 300	4.20	0.4	
1 in 500	4.29	0.4	
1 in 1,000	4.41	0.5	

Note: data from EA (2011), Chainage 3718
(2) Data to end of January 2014, results taken from 2013-14 report.

In the previous annual report, the water level data from the Whitby NTSLF tide gauge were also analysed in SANDS to derive extreme levels to compare to the EA 2011 CFB data. The Peak over Threshold approach was used, with a threshold of 2.2m and data bins of 0.1m. This analysis excluded the 5th December 2013 storm as its inclusion would affect the statistical results. The results, which had a correlation coefficient of 0.979 for the Gumbel fit are given in the right hand column of Table 2-15 and are very similar to the results of the EA CFB study. Note that the confidence levels for the EA data should also be assumed to apply to the local data analysis undertaken with SANDS. The set of return periods derived in SANDS is different to the EA CFB study so results are not available to compare for all return periods.

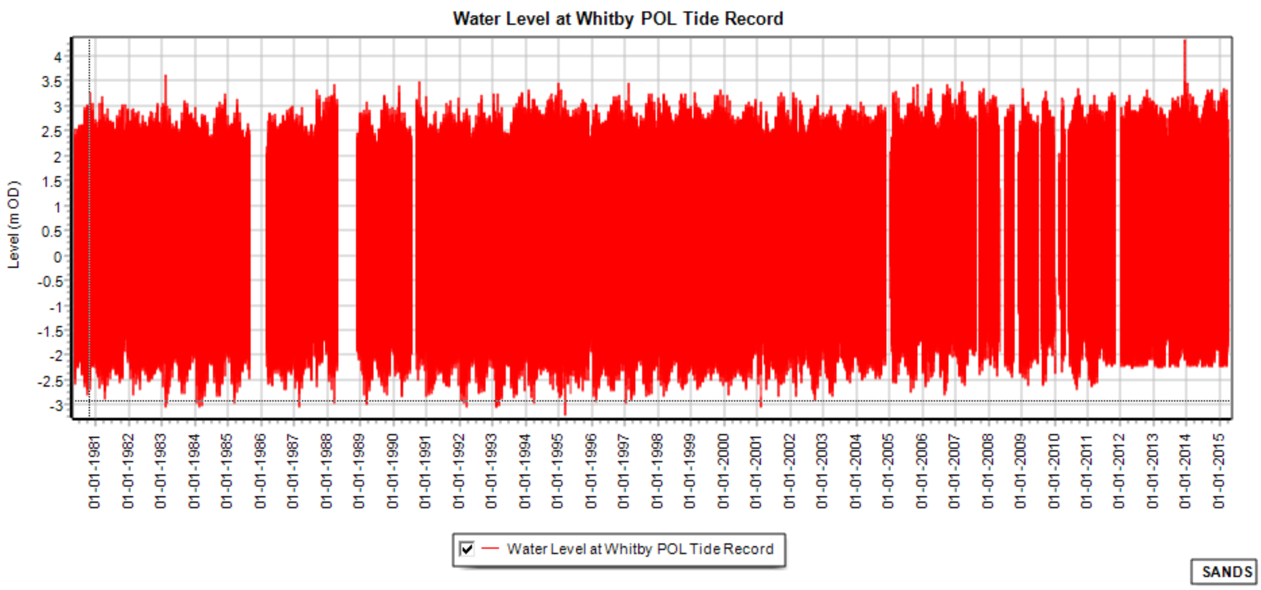


Figure 2.15 Water Level data availability at Whitby NTSLF tide gauge site

The Whitby tide gauge data has also been used to consider the joint occurrence of high waves and high water levels as these are the most damaging events for coastal defences and most likely to precipitate coastal erosion events. The baseline report gave a table with less than 1 full year of data from 20/05/2010 to 30/04/2011. For this report, the previous wave data at the Whitby Waverider buoy location has been combined with the new data collected up to March 2015 to produce an updated analysis, which is presented in Table 2-16 below. This appears to indicate a slight tendency for larger waves to occur at higher water levels. This may in part be due to depth limited wave breaking at the wave buoy which was located in about 16m water depth. However, it is difficult to draw conclusions as the combined record analysed has only 3.3 years of data. It is recommended that the analysis is updated in future when a longer concurrent data set is available.

Table 2-16 Scatter table of water level and offshore wave height at Whitby

		Water level (mOD) from NTSLF gauge at Whitby														
		-2.5 - -3	-2 - -2.5	-1.5 - -2	-1 - -1.5	-0.5 - -1	0 - -0.5	0.5 - 0	1 - 0.5	1.5 - 1	2 - 1.5	2.5 - 2	3 - 2.5	3.5 - 3	4 - 3.5	4.5 - 4
Wave height (Hs, m) from Whitby Waverider Buoy	7.00 - 8.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.00 - 7.00	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
	5.00 - 6.00	0	0	0	1	7	2	3	7	12	11	11	8	0	0	0
	4.00 - 5.00	0	0	0	19	34	49	43	50	60	63	50	32	5	0	0
	3.00 - 4.00	0	5	15	87	140	124	141	129	150	213	130	42	2	3	4
	2.00 - 3.00	0	12	135	329	432	447	372	402	485	573	391	144	8	0	0
	1.00 - 2.00	10	159	856	1511	1968	1909	1606	1758	2128	2303	1740	675	63	0	0
	0.00 - 1.00	9	366	1937	3711	4640	4312	3763	3713	4337	4951	3500	1403	130	0	0

Water Level (x) vs Offshore Wave Height Hm0 (y) (numbers of 30 minute observations)
For date range: 20/05/2010 to 25/10/2011 and 17/01/13 to 31/03/2015 (3.3 years of data)

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 has therefore not been included in the two previous Cell 1 reports on wave and tide data. However, following review of the draft version of this report data from January 2014 to July 2015 was provided for consideration.

The latest dataset 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 2-17 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 2-17 Standard tidal levels at Whitby Harbour Tide Gauge (CCO, 2015)

The highest water level recorded with the Whitby Harbour Tide Gauge in 2014 was 3.15mOD on 13th August 2014. However, data is only available from 16th January and so omits the highest water level of 2014 that was detected at the NTSLF gauge on 4th January 2014 (3.46mOD).

The data from the two Whitby tide gauges has been compared by plotting the data together, see example in Figure 2.16 and also by comparing the derived standard tidal level data in Table 2-13 and Table 2-17, which both show that the levels recorded from the Cell 1 gauge are around 0.2m lower than those from the NTSLF gauge which is situated nearby. Analysis of the differences between 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. As illustrated in Figure 2.16 the NTSLF gauge did not record levels for low water on the larger spring tides; this 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.

The reason for the 0.18m difference between the levels recorded at the two gauges is 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 CCO are corresponding with NOC regarding the observed differences between the two tide gauges.

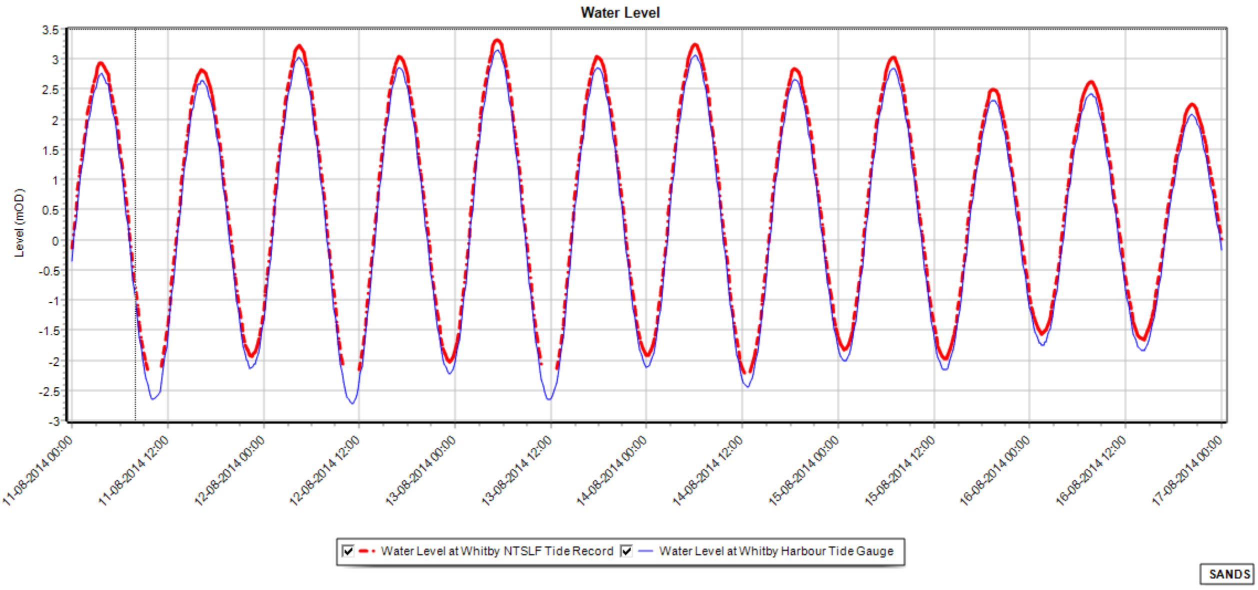


Figure 2.16 Example comparison of water level data from Whitby tide gauges

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) 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 Emu DWR wave buoy runs from April 2004 to March 2006 and the record for the Cefas SBC buoy runs from April 2003 to July 2004. Scatter tables and wave roses were produced for both datasets using full years of data and these were for two and one year respectively. Storm and extremes analyses were carried out for the full record of the DWR wave data; the resulting figures and tables are shown in the sub-sections below.

New 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 similar 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 similar to the previous DWR location. Details of the deployment are given in Appendix F and monthly plots of the data are included in Appendix D. There are gaps in the data set when buoy came adrift on 21st November 2013 until it was redeployed on 17th December 2013 and from 20th August 2014 to 12th September 2014.

2.7.1. Wave height vs Wave Period

The distribution of the wave height and peak period for the baseline wave data record at Scarborough DWR and Scarborough SBC wave buoys has been plotted as a scatter plot (see Figure 2.17 and Figure 2.18 below, respectively). The new data for the further offshore site has been overlaid on Figure 2.17 to compare to the baseline, and has also been plotted in Figure 2.19 to show fits for both peak and zero crossing period.

The new data plotted in red and green in Figure 2.17 covers the period from June 2013 to March 2015 and it is notable that the wave periods for the larger wave heights show a higher peak period than the baseline data. The 2013-14 and 2014-15 data sets show quite similar distributions. Comparing the blue 'baseline' 2003 to 2006 data to the new data from the current programme, there appears to be an issue with some of the wave period data in the baseline data set. The lower peak in periods for wave heights greater than 4.5m suggests that although the baseline data set was indicated to be peak period, Tp, some of the records may actually be Tmo (Tz). The wave height to period relationship for the baseline data set should therefore be treated with caution.

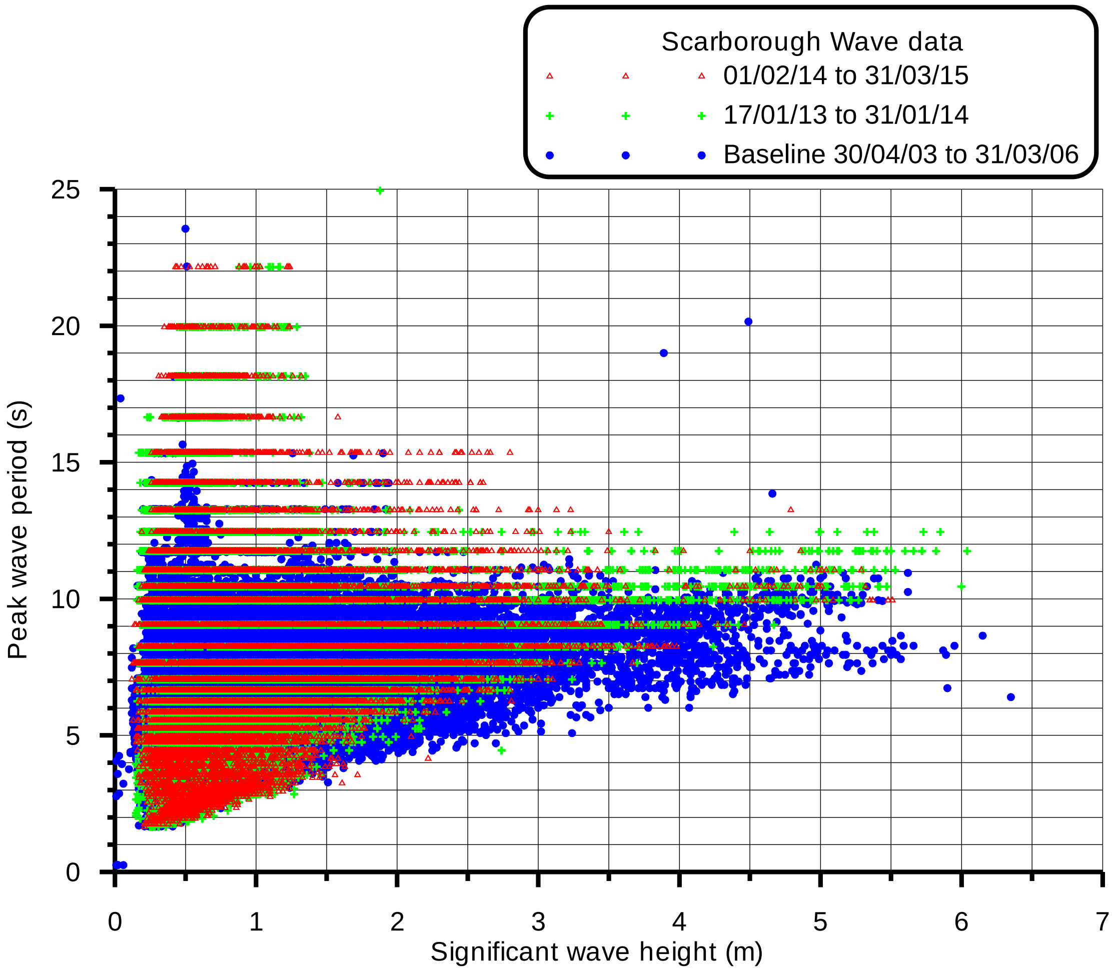


Figure 2.17 Scatter plot of Wave Height Vs Peak Period offshore Scarborough

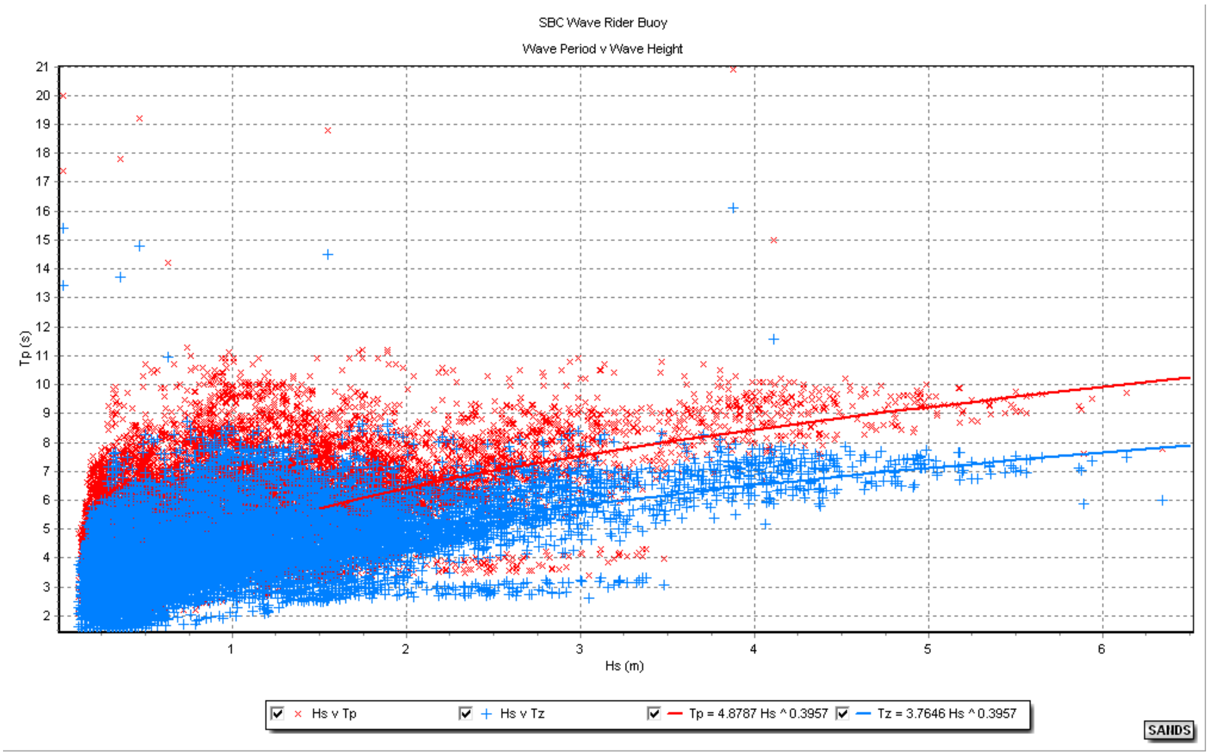


Figure 2.18 Scatter plot Wave Height Vs Period at Scarborough SBC site (April 2003 to April 2004)

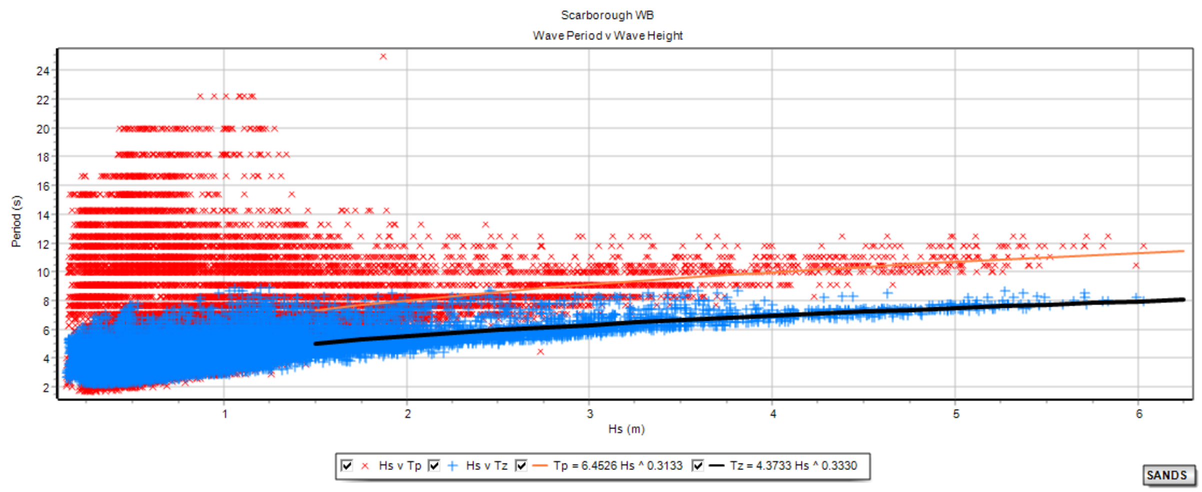


Figure 2.19 Scatter plot Wave Height Vs Period at Scarborough WB2 site (June 2013 to March 2015)

2.7.2. Wave Rose

The wave rose analysis of the baseline Scarborough DWR and SBC Waverider datasets (Figure 2.20 and Figure 2.21 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 between the two time periods analysed.

Wave roses for the new data collected from the current, further offshore, location known as Scarborough WB2, which is very close to the location of the previous DWR data set, is given in Figure 2.22. 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.

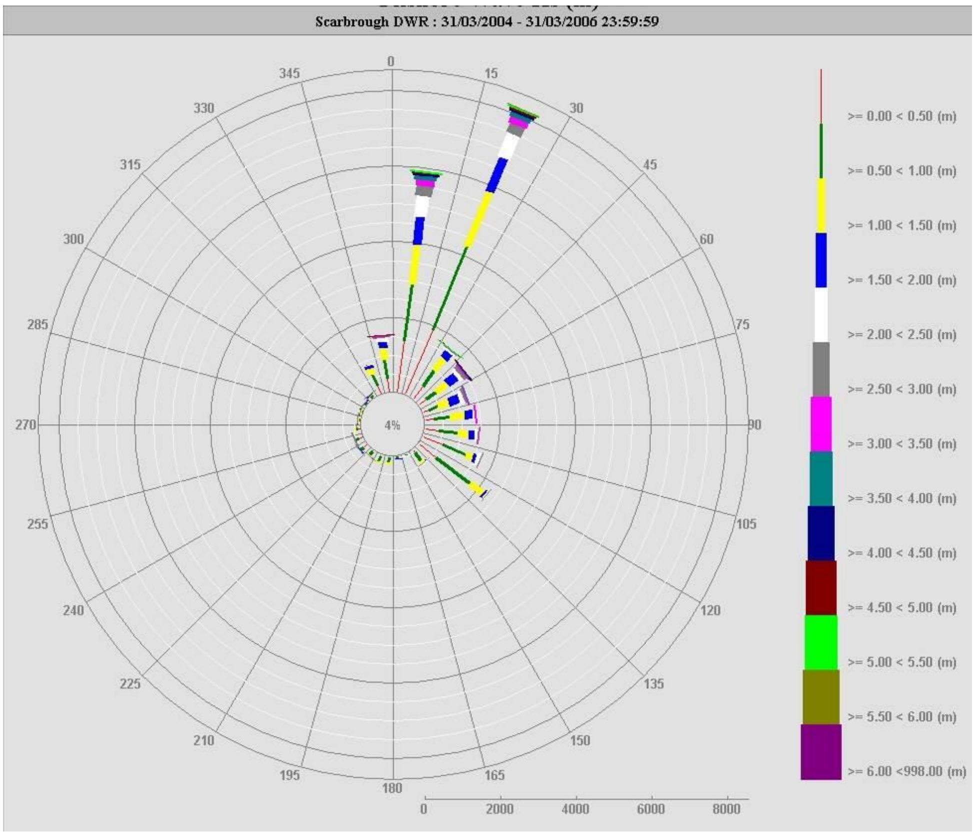


Figure 2.20 Wave Rose at Scarborough DWR site

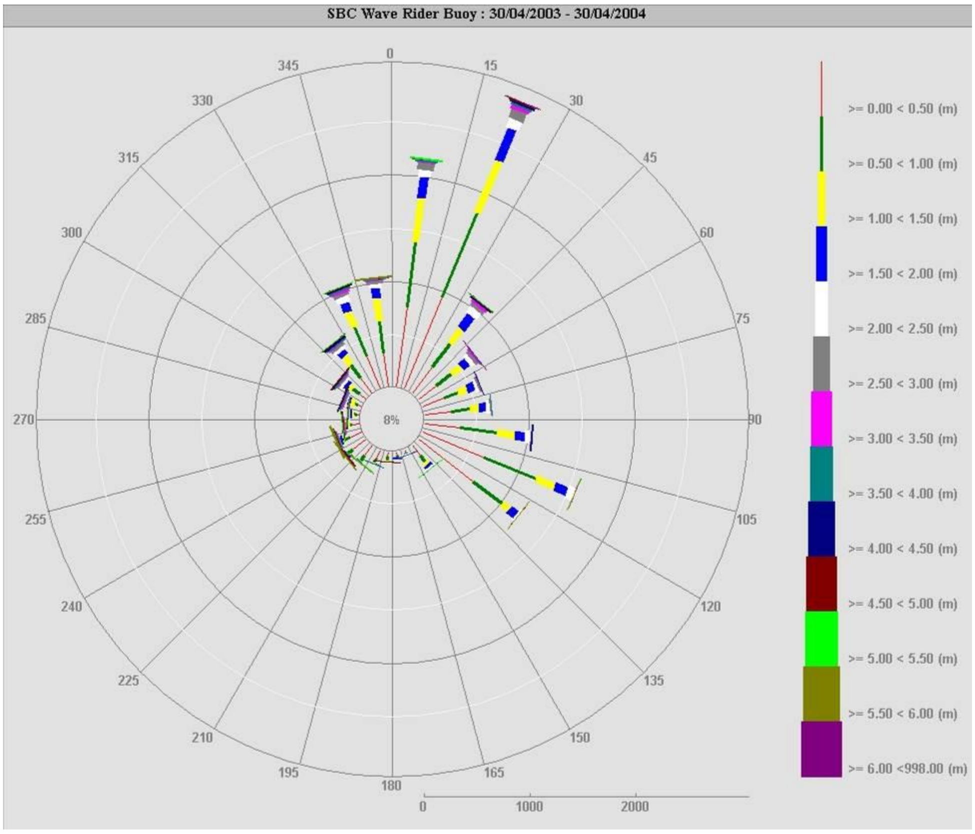


Figure 2.21 Wave Rose at Scarborough SBC site

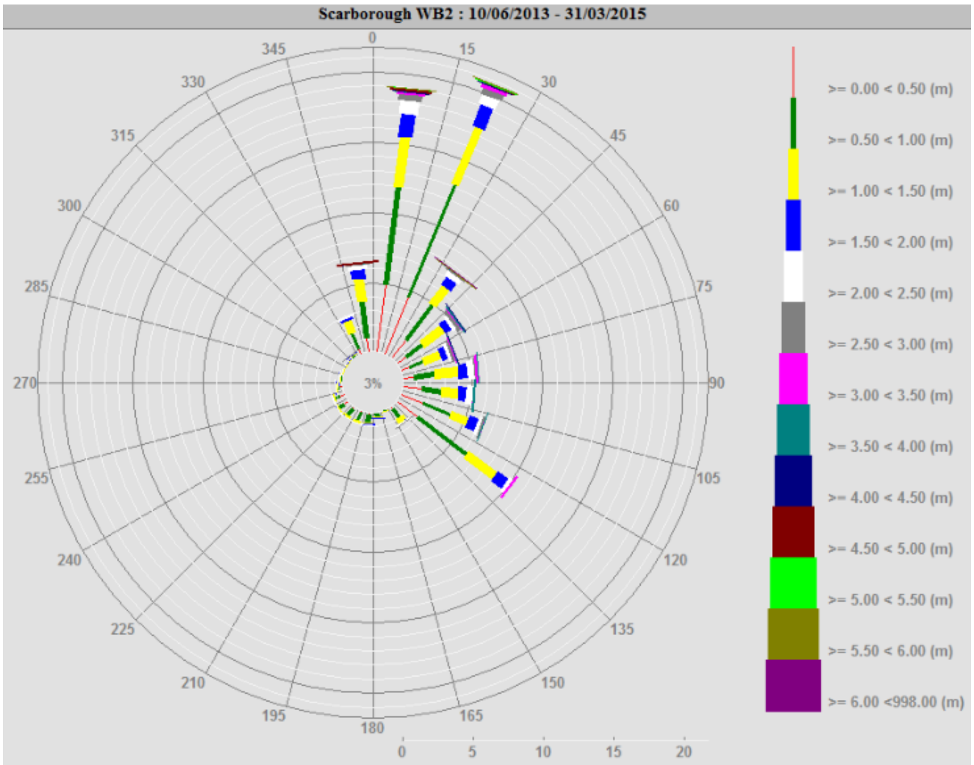


Figure 2.22 Wave Rose at Scarborough WB2 site (June 2013 to March 2015)

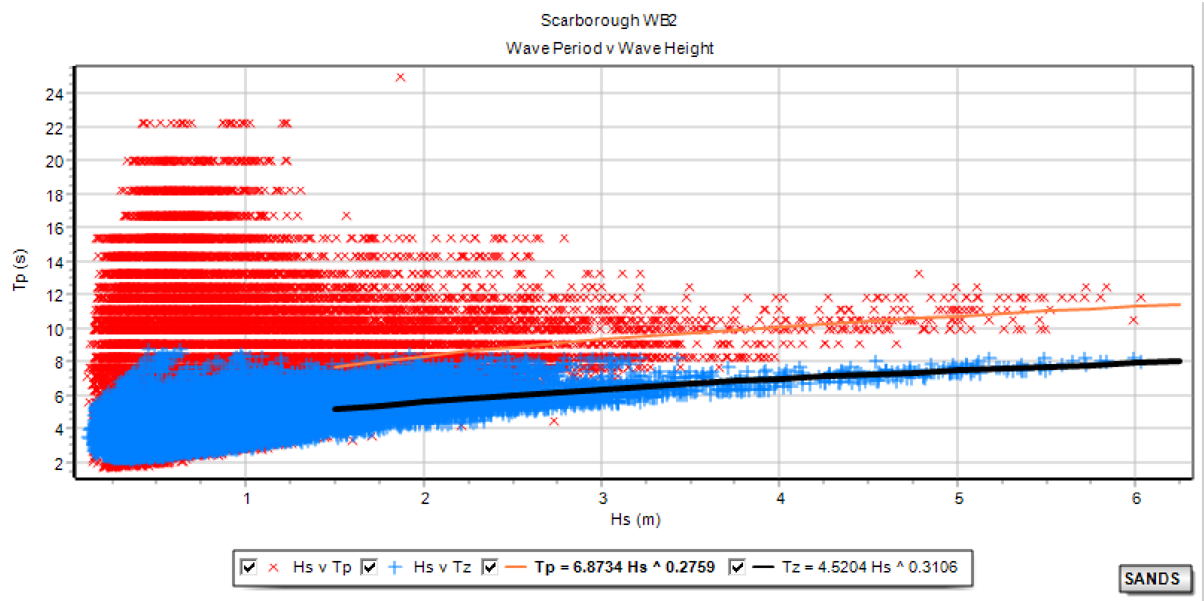


Figure 2.23 Scatter plot of Wave Height Vs Period for all data at Scarborough WB2 site

2.7.3. Extremes Analysis

In the baseline report the longest set of data at the Scarborough DWR buoy location was analysed to estimate extreme wave height values. A peak wave height threshold of 4m was used, providing 18 peaks in 2.92 years. The Gumbel distribution gave a reasonable correlation coefficient of 0.986 and satisfactory visual fit. Given the length of the record, the data should only be read up to a 1 in 10 year return period. The new data sets collected from the two locations off Scarborough SBC are not long enough to complete such an analysis. The results of the extremes analysis from the baseline report are shown in Table 2-18 below.

Table 2-18 Extremes Analysis for Scarborough DWR

Return Period (1 in x years)	Gumbel Fit Extreme Wave Height (Hs, m)
0.2	4.5
0.3	4.9
0.5	5.4
1	5.8
2	6.3
3	6.5
5	6.8
10	7.3

The maximum recorded wave height (Hs) in the data recorded at the Scarborough WB2 location was 6.0m, on 10th October 2013. The maximum height recorded between January 2014 and March 2015 is 5.5m, on 1st February 2015. Comparing these to the baseline extremes analysis indicates that they were approximately equal to the expected worst annual storm.

2.7.4. Storm Analysis

A 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 2-19 below.

As with the Tyne Tees analysis, alternate years have been shaded, the largest storm each year **is highlighted in bold** and the largest wave energy at storm peak **highlighted in bold red**. Note that only 2004 and 2005 are complete years so the conclusions that can be drawn from this 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.

Table 2-19 Storm analysis for Scarborough DWR wave buoy – baseline info

General Storm Information							At Peak			
Start Time	**End Time**	**Dur (Hs)**	**Peak of Storm**	**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

Storms analysis from the new Waverider buoy deployed offshore from Scarborough as part of the current programme in January 2013 is provided in Table 2-20 below. This uses the full data set, ignoring the change of location in June 2013. The storm with the highest energy at peak was the October 2013 storm. It should be noted that the buoy was off station during the early December 2013 storm and to clarify a note has been added in the table below. Similarly to the situation at Whitby, there was only one storm identified during 2014; at Scarborough the peak wave height was 4.4m and duration only 3 hours. The only storm recorded during winter 2014/15 had a peak wave height of 4.8m and 28 hour duration.

Table 2-20 Storm analysis for Scarborough WB (data 17/01/2013 to 31/03/2015)

General Storm Information							At Peak					
Start Time	End Time	Dur (hr)	Peak of Storm	Mean Dir	No of Events	Mean Direction 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	6.4E+03	4.5E+06
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	4.5E+03	1.7E+06
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	7.1E+03	1.4E+07
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	9.0E+03	4.9E+06
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	4.9E+03	2.3E+06
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**	**1.1E+04**	**1.1E+07**
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	3.2E+03	3.2E+05
31/01/2015 14:30	01/02/2015 18:30	28.0	31/01/15 23:30	20	57	76.74	4.8	13.3	7.5	25	8.0 E+3	8.2 E+6

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 available from the Scarborough tide gauge record is shown in Figure 2.24 below. The data runs from 28/04/2003 to 31/12/2014, with a number of gaps in the record.

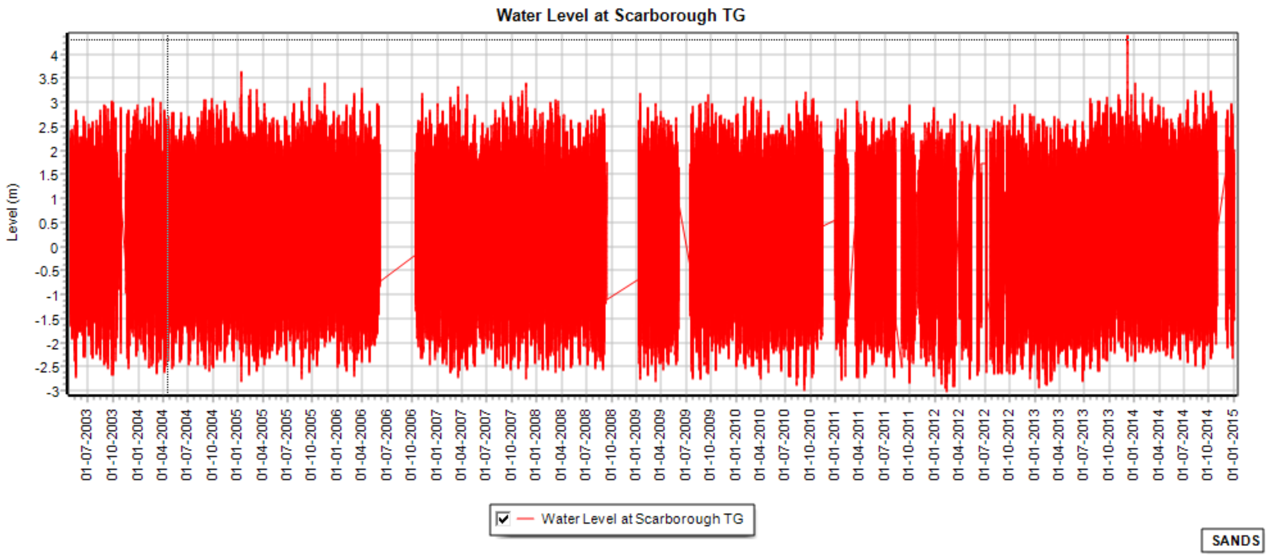


Figure 2.24 Water Levels at Scarborough TG Recorded Tide Site

The Scarborough tide gauge data has been analysed and quality controlled by Fugro-EMU and Channel Coast Observatory, and standard tidal heights are presented in Table 2-21 below. However, it should be noted that when the site was checked and re-surveyed by Fugro-EMU in June 2013, a discrepancy was found with the original datum established in 2003, with the tide gauge zero now 0.195m higher than previously assumed. It is not known when the offset applies from, but Fugro-EMU (2013)[2] note 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 2-21 Predicted tide levels at Scarborough

Tidal State	Level (m Ordnance Datum)
HAT	3.10
MHWS	2.46
MHWN	1.31
MSL	0.175
MLWN	-0.96
MLWS	-2.11
LAT	-3.04

Notes: Based on analysis of 2007 data collected at Scarborough by Fugro EMU;
See note above re-potential issue with datum.

Annual maxima water levels extracted from the Scarborough tide gauge are shown in Table 2-22 below. The highest recorded water level in 2013 was 4.39 mOD 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, the maximum of which was 3.66m in January 2005. Comparing the measured water level of the 5th December 2013 surge to the predicted extremes from the EA's 2011 Coastal Flood Boundary (CFB) conditions data in Table 2-23 shows that the event had an annual exceedance probability of between 1 in 150 and 1 in 500.

[2] Fugro EMU, August 2013, Northeast regional coastal monitoring framework; hydrodynamic services; December 2012 to June 2013 Reports.

The 10 years of water level data from the Scarborough tide gauge prior to the December 2013 storm surge were analysed in SANDS to derive extreme levels to compare to the EA 2011 CFB data in the previous report. The Peak over Threshold approach was used, with a threshold of 2.2m and data bins of 0.1m. The analysis excluded the 5th December 2013 storm as its inclusion would affect the statistical results. The results, which had a good correlation coefficient of 0.996 for the Gumbel fit, are given in the second from right column in Table 2-23 and are very similar to the results of the EA CFB study. The analysis has been updated for this report to include all data recorded at the gauge, and results are presented in the right hand column of Table 2-23, showing that inclusion of the 2013 surge event increases the extreme water level estimates by around 0.2m. Note that the confidence levels for the EA CFB data should also be assumed to apply to the local data analysis with SANDS. The set of return periods derived in SANDS is different to the EA CFB study so results are not available to compare for all return periods.

Table 2-22 Annual maxima data from Scarborough Tide gauge analysis (source CCO, 2015)[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%

* Possible datum shift by up to -0.195m

Table 2-23 Predicted extreme tide levels at Scarborough

Annual Exceedence probability	Extreme Level (m OD) from EA CFB Study (2011)[1]	Confidence intervals (m) from EA CFB Study (2011)[1]	Extreme levels from SANDS analysis of Scarborough TG (mOD)[2]	Extreme levels from SANDS analysis of Scarborough TG to Dec 2014 (mOD)[3]
1 in 1	3.39	0.1	3.3	3.5
1 in 2	3.48	0.1	3.4	3.6
1 in 5	3.60	0.1	3.6	3.8
1 in 10	3.70	0.1	3.7	3.9
1 in 20	3.80	0.1	3.8	4.1
1 in 25	3.84	0.2		
1 in 50	3.95	0.2	4.0	4.3
1 in 75	4.00	0.2		
1 in 100	4.04	0.3	4.1	4.5
1 in 150	4.12	0.3		
1 in 200	4.17	0.3	4.2	4.6
1 in 250	4.20	0.3		

[3] CCO February 2015, Scarborough tide gauge annual report, see Appendix E

1 in 300	4.23	0.4	4.3	4.7
1 in 500	4.33	0.4		
1 in 1,000	4.45	0.5		

Notes: (1)data from EA (2011), Chainage 3750
http://evidence.environment-agency.gov.uk/FCERM/en/Default/FCRM/Project.aspx?ProjectID=F162D56F-87C4-4F14-B77B-A8A3EFDB363F&PageId=a0fe6dfc-506a-452c-9bff-a7ec06b4e6b0
(2) Data to end of November 2013, results taken from 2013-14 report, Excludes the Dec 2013 storm.
(3) Data to end of December 2014, analysis for this report

The water level data has also been used to analyse joint occurrence of waves and water levels data, by tabulating the frequencies of coincident wave and water level measurements, see Table 2-24 below.

In the baseline report the water level and wave height analysis required post-processed interpolation to derive water level at the same times as the wave height data. The data has now been reprocessed and quality controlled by CCO (see report in Appendix E), which made the analysis straightforward in SANDS. The analysis uses the data only from the further offshore location as this is the location where there is most data available, and this is the current location of the Scarborough wave buoy. Note that the data excludes the 5th December 2013 storm surge because as noted earlier there is a gap in the data set whilst wave buoy was off station between 21st November 2013 and 17th December 2013. There are also a considerable number of other gaps in the matched wave / water level data set, as the total merged record length is just 2.4 years. This analysis supersedes the previous reports.

Table 2-24 Scatter table of water level and wave height at Scarborough

	Water level (mOD) at Scarborough TG														
	-2.5 - -3.0	-2.0 - -2.5	-1.5 - -2.0	-1.0 - -1.5	-0.5 - -1.0	0.0 - -0.5	0.5 - 0.0	1.0 - 0.5	1.5 - 1.0	2.0 - 1.5	2.5 - 2.0	3.0 - 2.5	3.5 - 3.0	4.0 - 3.5	4.5 - 4.0
Wave Height (Hs,m)															
7.00 - 8.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.00 - 7.00	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0
5.00 - 6.00	0	0	0	5	12	8	6	6	5	4	10	7	0	0	0
4.00 - 5.00	0	2	4	20	35	19	23	21	20	27	20	17	1	0	0
3.00 - 4.00	0	2	18	47	58	50	47	51	73	88	54	9	1	0	0
2.00 - 3.00	0	24	129	230	325	271	253	277	342	335	198	50	2	0	0
1.00 - 2.00	28	288	885	1176	1288	1173	1111	1224	1487	1432	1059	331	7	0	0
0.00 - 1.00	24	650	1806	2919	3326	2952	2628	2894	3496	3405	1993	701	43	0	0

Water Level (x) vs Offshore Wave Height Hm0 (y) (numbers of 30 minute observations)
Data range :31/04/2004 to 19/07/2004 and 10/06/2013 to 31/12/2014 (2.4 years data when accounting for gaps)

3. Discussion of variability in waves and water levels and longer term trends

3.1. Data availability

The wave and water level monitoring data collected under the Cell 1 programme are starting to build a record that will improve the understanding of the variability and trends in storm waves and water levels. However the duration of the data collection so far is less than 10-years for most sites. The length of the data records within Cell 1 are identified in Table 3-1 below.

Table 3-1 Duration of data sets in Cell 1 and comments on reliability

Name of Location	Type of Data	Data period	Comments
Newbiggin Ness WB	Wave Data	20/05/2010 to 07/06/2011 and 21/06/2013 - ongoing	About 3 years data available, not yet sufficient to identify typical annual variability or for trends analysis
North Shields NTSLF Tide Record	Tidal Levels	Intermittent data since 24/01/1946 Monthly and annual mean data from 1895 to present	Monthly and annual mean sea level data has previously been analysed to identify long term sea level trends, see Section 3.2
Tyne Tees WaveNet Site (WMO ID 62293)	Wave Data	07/12/2006 - ongoing	About 9 years of data available, see Section 3.3
Met Office WWIII model	Wave data	1980 – ongoing	Up to 35 years available; data for 1980 to 2012 was reported on in the 2013-14 report. See also Section 3.3
Whitby WB	Wave Data	01/02/2014 (deployed 17/01/2013	About 3 years data available, not yet sufficient to identify typical annual variability or for trends analysis
Whitby NTSLF Tide Record	Tidal Levels	Digital data from 1991 – ongoing and monthly and annual mean data from 1981 - ongoing	Monthly and annual mean sea level data has previously been analysed but found unreliable for to identifying long term sea level trends, see Section 3.4. Issues with tide gauge datum and unexplained high rate of sea level rise.
Whitby Harbour Tide Gauge	Tidal Levels	16/01/2014 - ongoing	About 18 months of data. Close proximity to Whitby NTSLF gauge, very similar signal but about 0.18m datum level difference.
Scarborough Wave buoys	Wave Data	2003 – 2006 and 2013 - ongoing	A total of about 5 years of data available, not yet sufficient to identify typical annual variability or for trends analysis. Changes in the location result in data not being fully consistent. Comparison of data from current programme to the older baseline data indicates that there may be an issue with some of the wave periods in the 2003 – 2006 data.
Scarborough TG	Tidal Levels	01/01/2014 (deployed 28/04/2003)	Uncertainty over possible datum changes during period when gauge was not maintained between 2006 and 2011

3.2. North Shields tide record

The tide gauge data from North Shields is one of the longer UK data sets and has been analysed by a number of researchers investigating long term trends in mean sea level. In addition to the digital data identified through NTSLF in Table 1-1, Table 3-1 identifies annual mean data are available from 1901 through the PSMSL.

Trend analysis for mean sea level at North Shields is reported in Woodworth et al (2009)[4]. Their analysis used data from 1901 to 2006 and found a long term trend of 1.92 ± 0.12 mm/yr. They also provide estimates of long term land level changes at tide gauges, with an estimate of 0.0 mm/yr for North Shields. The Woodworth analysis was careful to only include years that had data for all months in order to remove seasonal impacts. The latest published monthly and annual data for North Shields has been downloaded from the PSMSL website http://www.psmsl.org/data/obtaining/stations/95.php and is plotted in Figure 3.1 below. In Figure 3.1, the linear fitted trend for all of the annual data shows a rate of rise of 1.903 mm/yr whilst the trend for all of the monthly data shows a trend of 1.911 mm/yr.

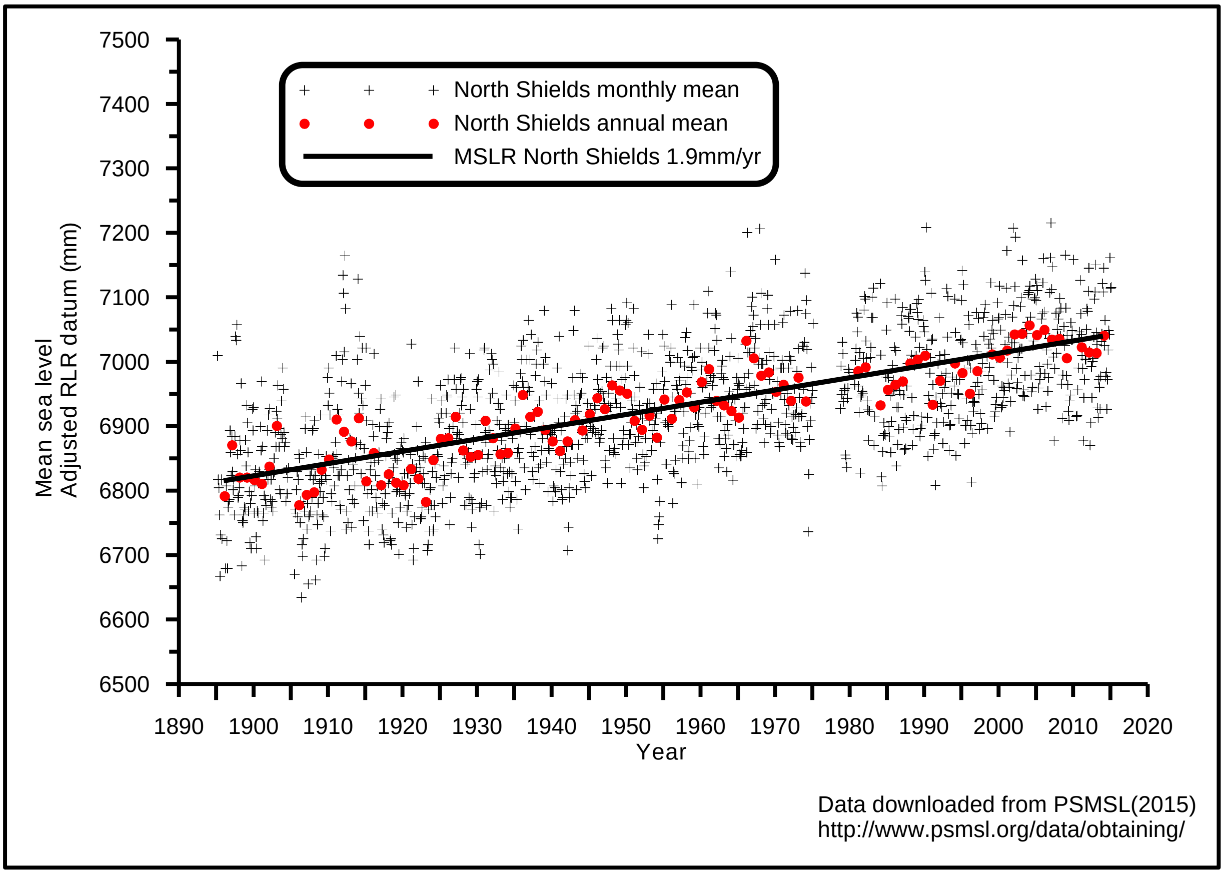


Figure 3.1 Annual and monthly mean sea level data for North Shields, 1895 to 2015

3.3. Tyne / Tees Wavenet site

Measured wave data from the Cefas offshore WaveNet site covers about 8 years. Whilst this is shorter than the 30 year period typically used to define average climates it is the longest consistent offshore wave record for the Cell 1 coast. To assess the annual variability of storms, Figure 3.3 below compares the annual maximum peak storm wave heights from the Tyne Tees buoy over the measured record length to the data from the Met Office WWIII model from 1980

[4] P.L. Woodworth, F.N. Teferle, R.M. Bingley, I. Shennan and S.D.P. Williams, Trends in UK mean sea level revisited, Geophys. J. Int. (2009) 176, 19–30.

to 2012 that was obtained for the 2013-14 report. There is a lot of scatter in both data sets. The variability in the shorter period of measured data does not appear unrealistic in the context of variability of the much longer set of modelled data. The fitted line to the 33 years of modelled data shows a very slight upward trend in annual maximum wave heights. However, as demonstrated by the fitted trend line for the shorter data set, the annual variability is so much larger than any annual trend that the fitted trend line for the Tyne Tees data set is totally unrealistic.

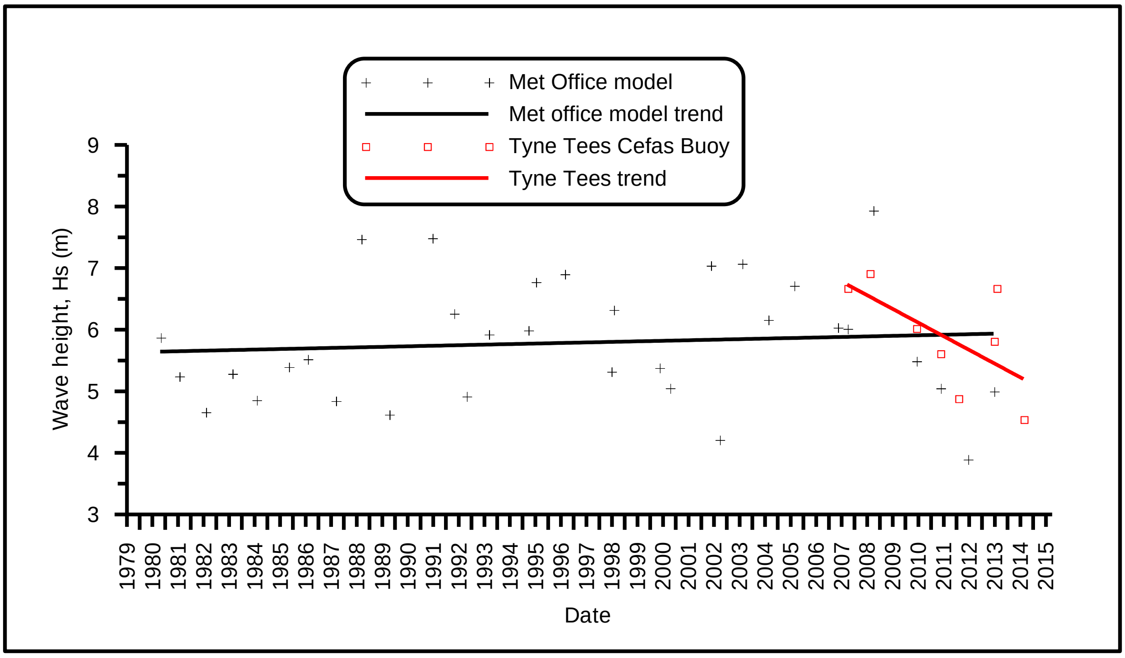


Figure 3.2 Annual maximum wave height from Met office model and Tyne Tees Buoy

3.4. Whitby tide record

Tide gauge data at Whitby NTSLF is available since 1980. However, it was noted by Woodworth et al (2009)[4] to be unreliable for mean sea level trend analysis because the PSMSL documentation made clear that the data were of poor quality. The rate of vertical land level change reported by Woodworth at Whitby is −0.48mm/yr, although this is estimated by interpolation from geological data, not GPS land level monitoring.

The annual and monthly mean data for the Whitby site was downloaded from PSMSL and is plotted in Figure 3.3. This shows an annual trend of +7.1mm/year, which is not consistent with other longer term tide gauges in the UK, e.g. the rate at Immingham on the Humber given by Woodworth is 0.54 ± 0.39 mm/yr and the long term rate of change at North Shields is 1.9mm/yr; see Figure 3.1.

The PSMSL documentation for the Whitby tide gauge records http://www.psmsl.org/data/obtaining/stations/1505.php mentions multiple problems at the site, several mentions of the gauge recording “flat low-waters”. This is taken to mean that the gauge does not always measure the full tidal range due to sedimentation or blockage. Removing low water values from the data would result in spuriously high mean sea levels, hence the erroneous rate of rise of the derived mean sea level. The low water problems with the data set are highlighted on the graph in Figure 4.1. The PSMSL site also says to treat data from 1997 onwards as “suspect”.

The annual mean data for Whitby were also analysed to determine rate of change over shorter periods; data from 1980 to 1997 indicate a trend of 2.1mm/yr. If 180mm is removed from data from 2012 to 2014, based on the finding that the NTSLF gauge data is 0.18m higher than the Cell 1 Whitby gauge in 2014, the overall rate of rise would be about 3.0mm/yr. This suggests that the datum problem may be with the NTSLF gauge rather than the Whitby Cell 1 gauge.

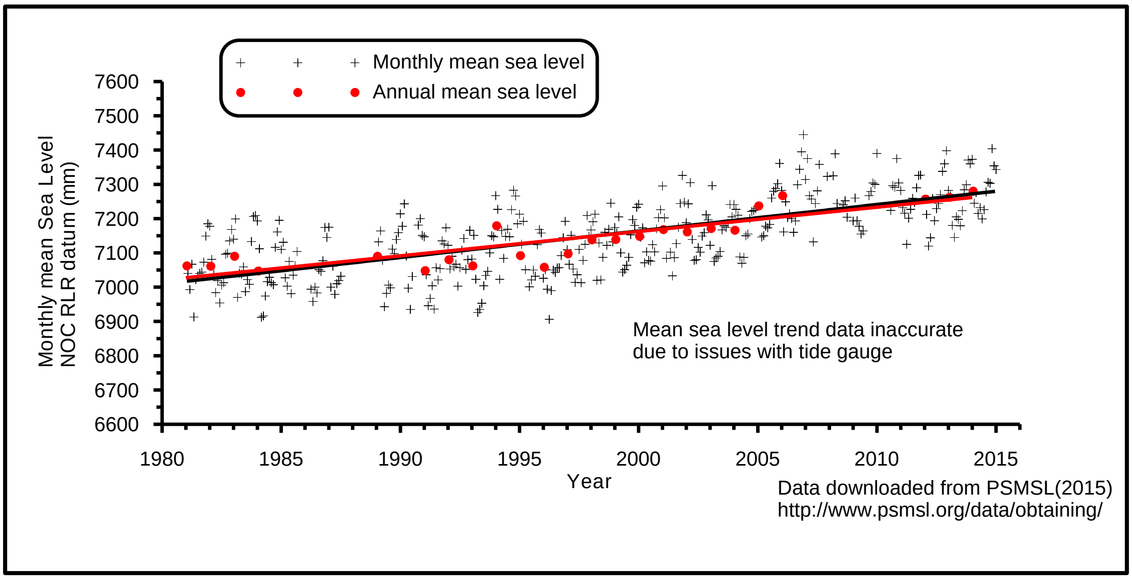


Figure 3.3 Annual and monthly mean sea level data for Whitby, 1980 to 2015

4. Problems encountered and uncertainty in analysis

4.1 Wave data

As noted in the report, the Scarborough Waverider buoy was moved to a new location after the initial deployment. Although the locations used are the same as two previous wave buoys the different water depths and coastal sheltering means that the new data from the two sites are not directly comparable

The Whitby Waverider buoy was off station from 5th to 12th February and 25th June to 12th July 2014. The Scarborough Waverider was off station due to incidents between 1st and 3rd of June and 21 August to 12th September 2014.

The Tyne Tees wave data is available in both telemetry and post recovery format from the Cefas WaveNet site. However, the latest data for 2013 is only available as telemetry, i.e. non quality controlled data. Also, some of the data for earlier years, e.g. 2008, is missing from the post recovery data set. The data set analysed is therefore a combination of telemetry and post recovery data, to give greatest coverage.

4.2 Water level data

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 has been quality checked by CCO since the baseline report, but this uncertainty still remains. The data for November 2014 is missing from the record.

The consideration of variability and trends in the longer term data sets highlighted problems with the Whitby NTSLF tide gauge and a datum issue compared to the Cell 1 Whitby gauge. In addition to gaps in the data there is missing data on the extreme low waters and this is notable when viewing multiple years of the data; see Figure 4.1.

It is recommended that the datum level surveys are checked for both of the Whitby tide gauges to establish which is correct and if possible the data should be corrected.

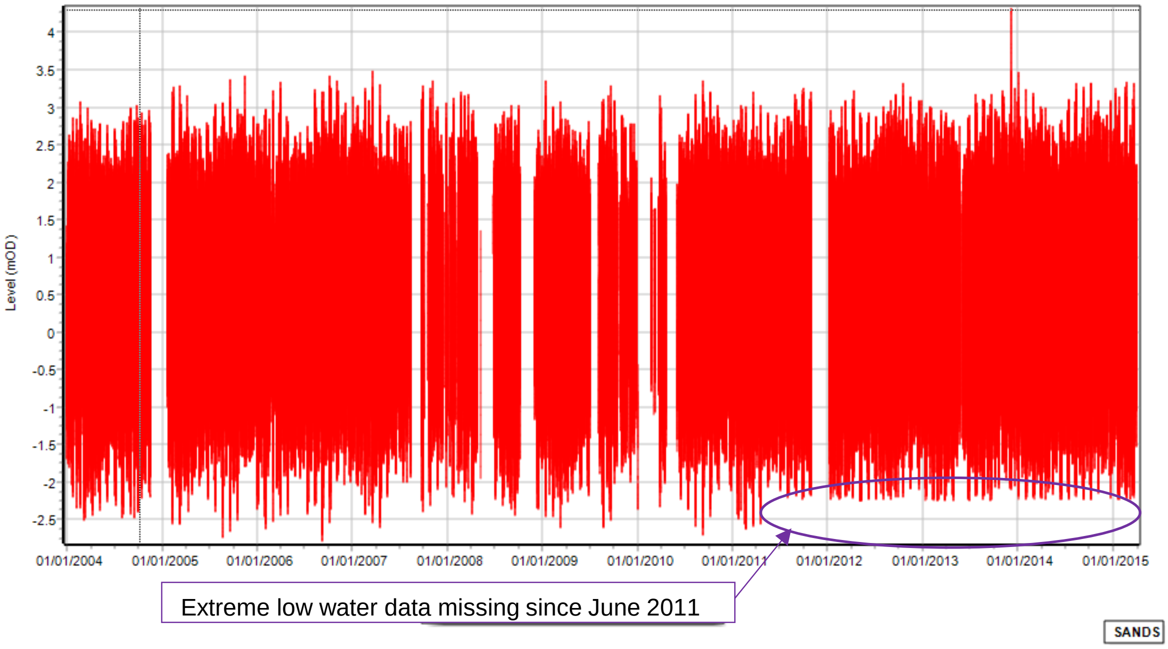


Figure 4.1 Illustration of problems with Whitby NTSLF tide gauge

5. Summary of key findings and recommendations

This report has analysed new wave and water level data available relevant to Sediment Cell 1 as an update to the previous baseline 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 east to southeast also observed although some parts of the coast are more sheltered from fetches to the southeast.
- The waves at the Newbiggin Ness site are partially sheltered from waves from the north. The data from 2014-15 is consistent with the data in 2013-14, but the wave rose is notably different to the baseline data from 2010-11 collected by Cefas, which did not show the secondary wave direction from the southeast.
- The longest consistent wave record in the region is for the Wavenet Tyne Tees buoy, which has been operating since late 2006.
- 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 2006 to 2014 data from Tyne Tees indicates that the stormiest year was 2010 whilst the years with the least number of storms were 2011 and 2014. Due to the limited period of data available from Newbiggin, Whitby and Scarborough it is not yet possible to make reliable comparisons to Tyne Tees.
- The wave data from 2014-15 at the four Cell 1 wave buoys consistently show the conditions to have been less stormy that in previous years. However, when considered against the longer record from the Met Office hindcast model the conditions do not seem unusual as there were similar periods in the 1980s and 1990s.
- The storm surge that occurred in early December 2013 resulted in higher water levels than previously observed in Cell 11, exceeding the 1953 storm at North Shields. As demonstrated in last years' report, inclusion of data from the December 2013 storm in extreme water level analysis results in extreme levels increasing by 100 to 200mm. As noted in the 2013-14 report it is recommended that the extreme water level statistics for the whole of Cell 1 are revised to take the December 2013 event into account for future predictions. It is understood that the Environment Agency are planning to undertake a study to update their national dataset, with a planned start in 2016.
- The data sets have been reviewed to assess medium to long term changes and it has been demonstrated that the even the longest wave data set from Tyne Tees is of insufficient length to capture the annual storm variability demonstrated in the longer period of data available from the Met Office hindcast wave model.
- Analysis of the Cell 1 tide gauge located in Whitby Harbour has found that there is a datum issue with either or both Whitby tide gauges. It is recommended that this is investigated further and new datum level surveys are undertaken for both gauges.

The wave roses for Newbiggin Ness, Tyne Tees, Whitby, Scarborough DWR and Scarborough SBC are collated in Figure 5.1 to supplement the points made above.

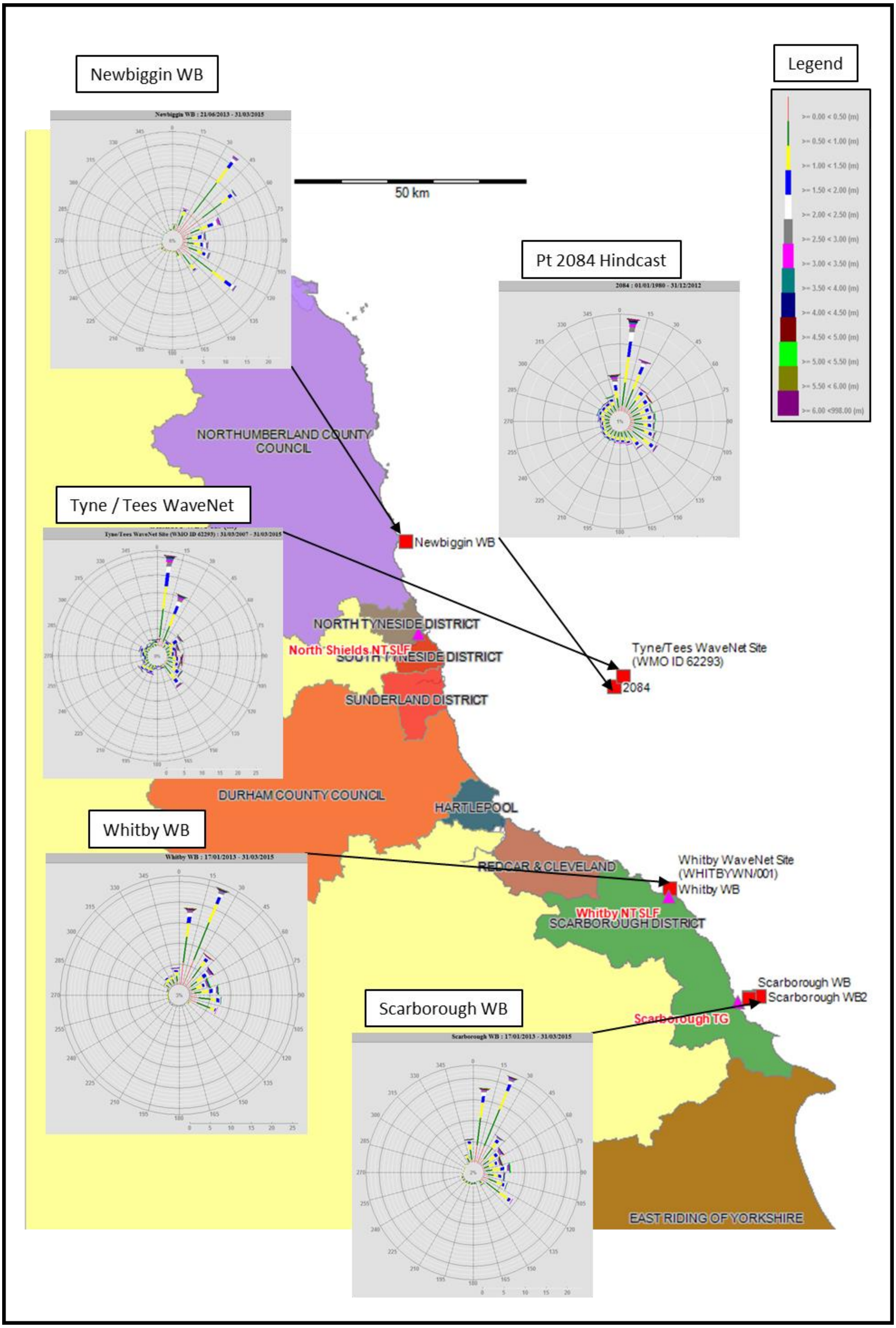


Figure 5.1 Wave Rose Locations from Newbiggin Ness to Scarborough

6. Conclusions

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 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 monitoring programme.

Wave conditions during the period from February 2014 to March 2015 were notably less stormy than the previous years.

As noted in the 2013-14 report it is recommended that the extreme water level statistics for the whole of Cell 1 are revised to take the December 2013 event into account for future predictions. It is understood that the Environment Agency are planning to undertake a study to update their national extreme water level dataset, known as the coastal flood boundary (CFB) conditions, with a planned start in 2016.

Appendices

Appendix A

Detailed Location of Wave Buoys

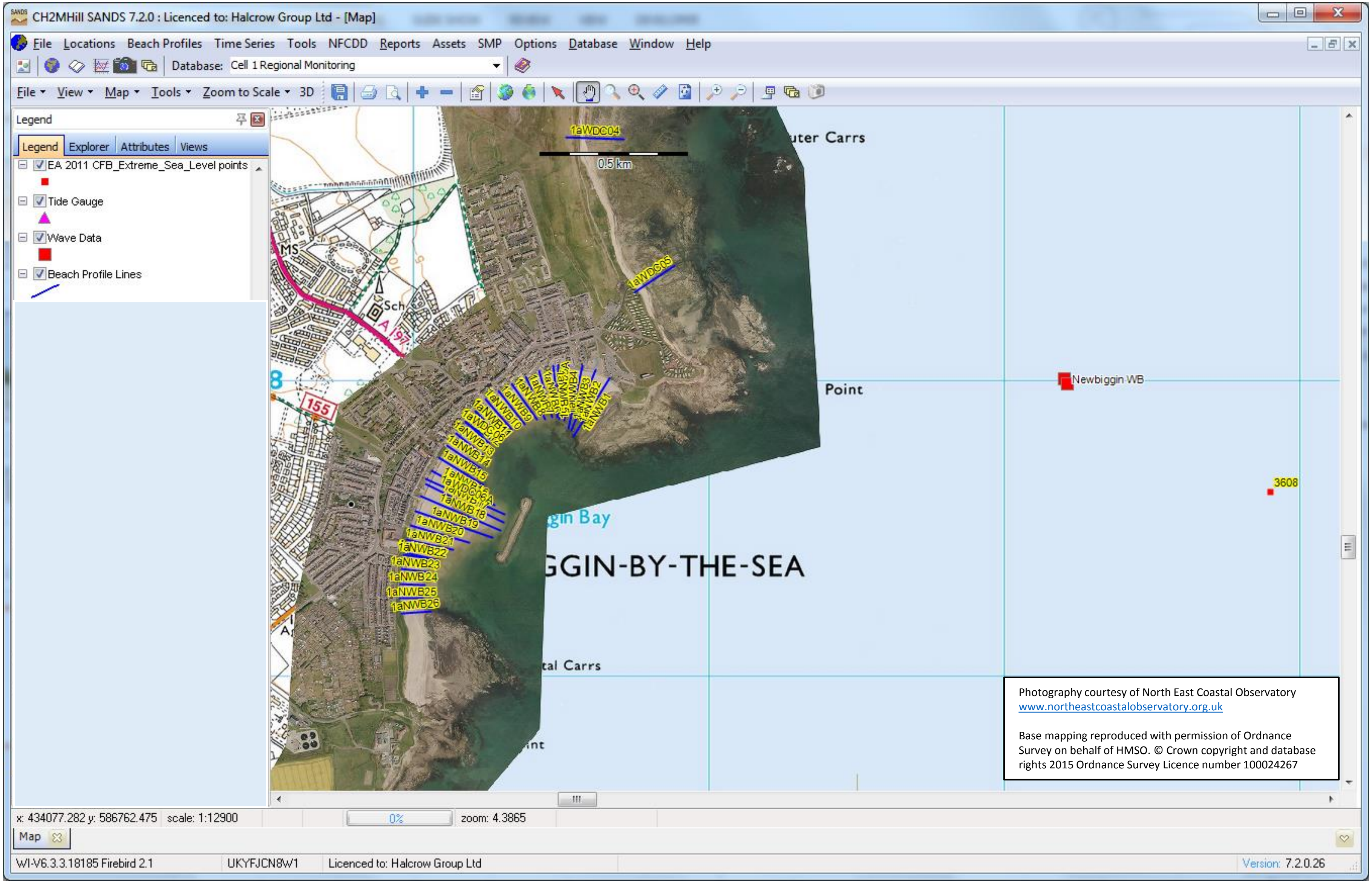


Figure A1 Location of Newbiggin Ness wave buoy

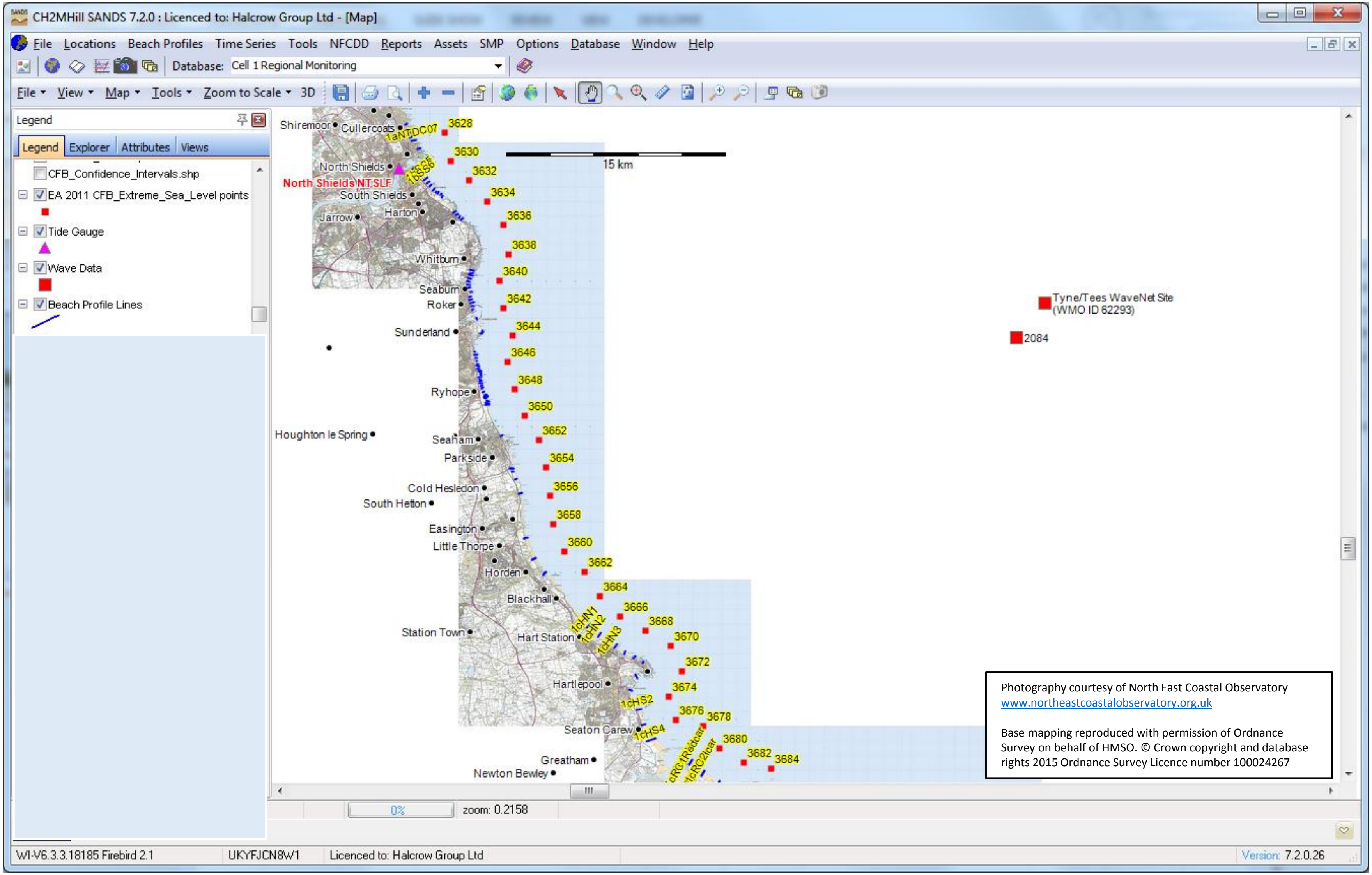


Figure A2 Location of Tyne Tees wave buoy, Met Office hindcast point 2084 and North Shields tide gauge

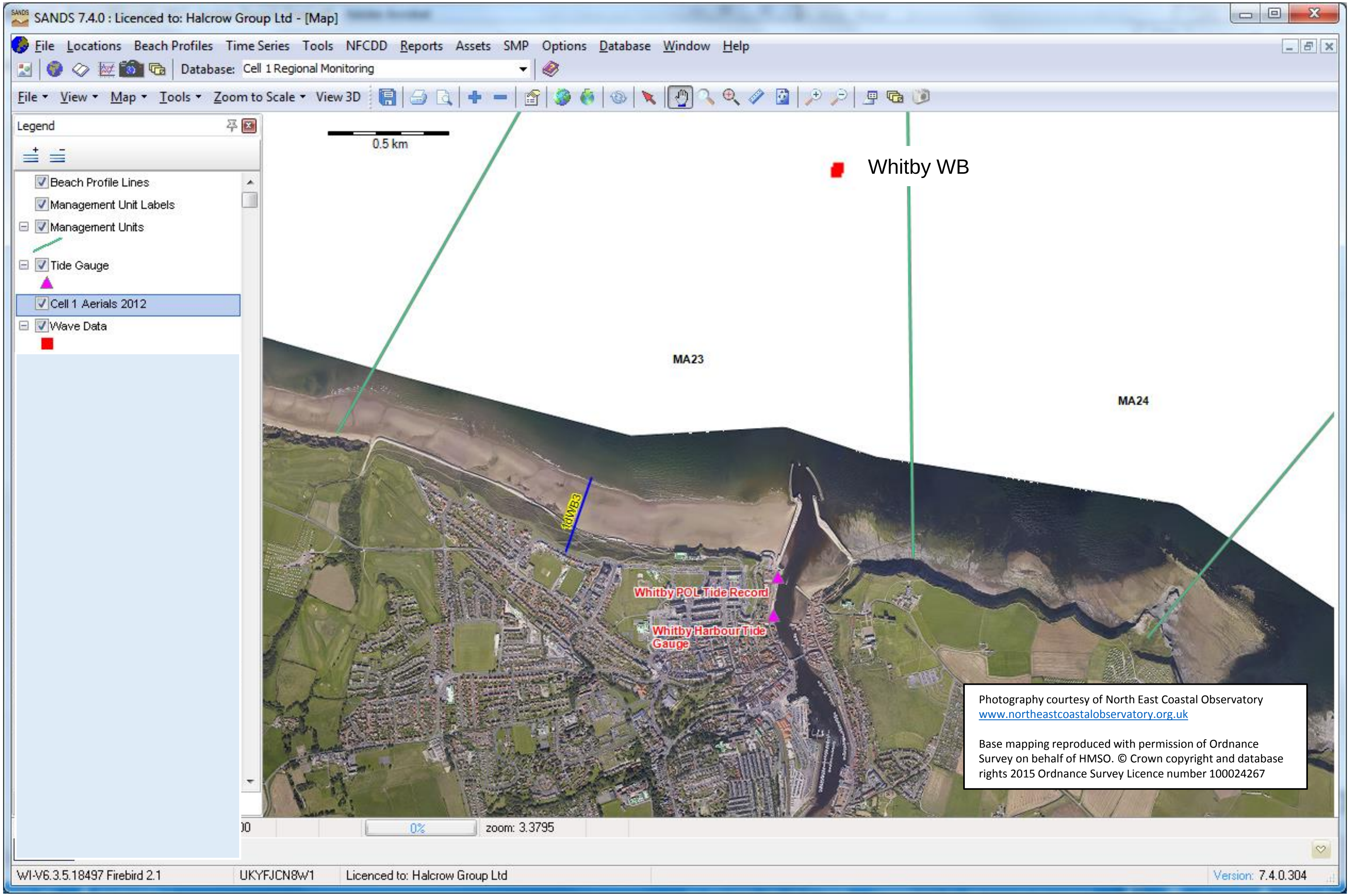


Figure A3 Location of Whitby wave buoy and tide gauges

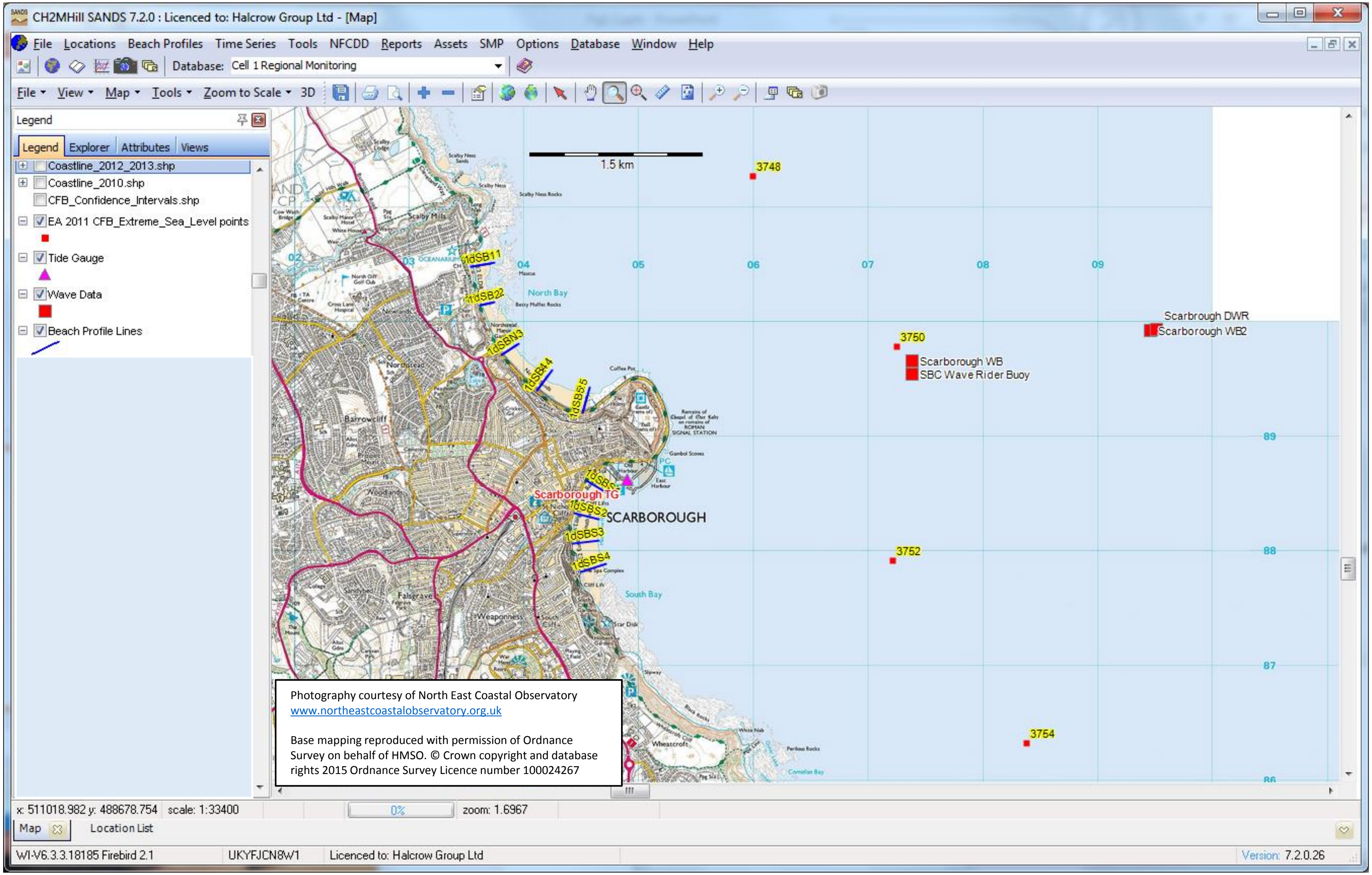
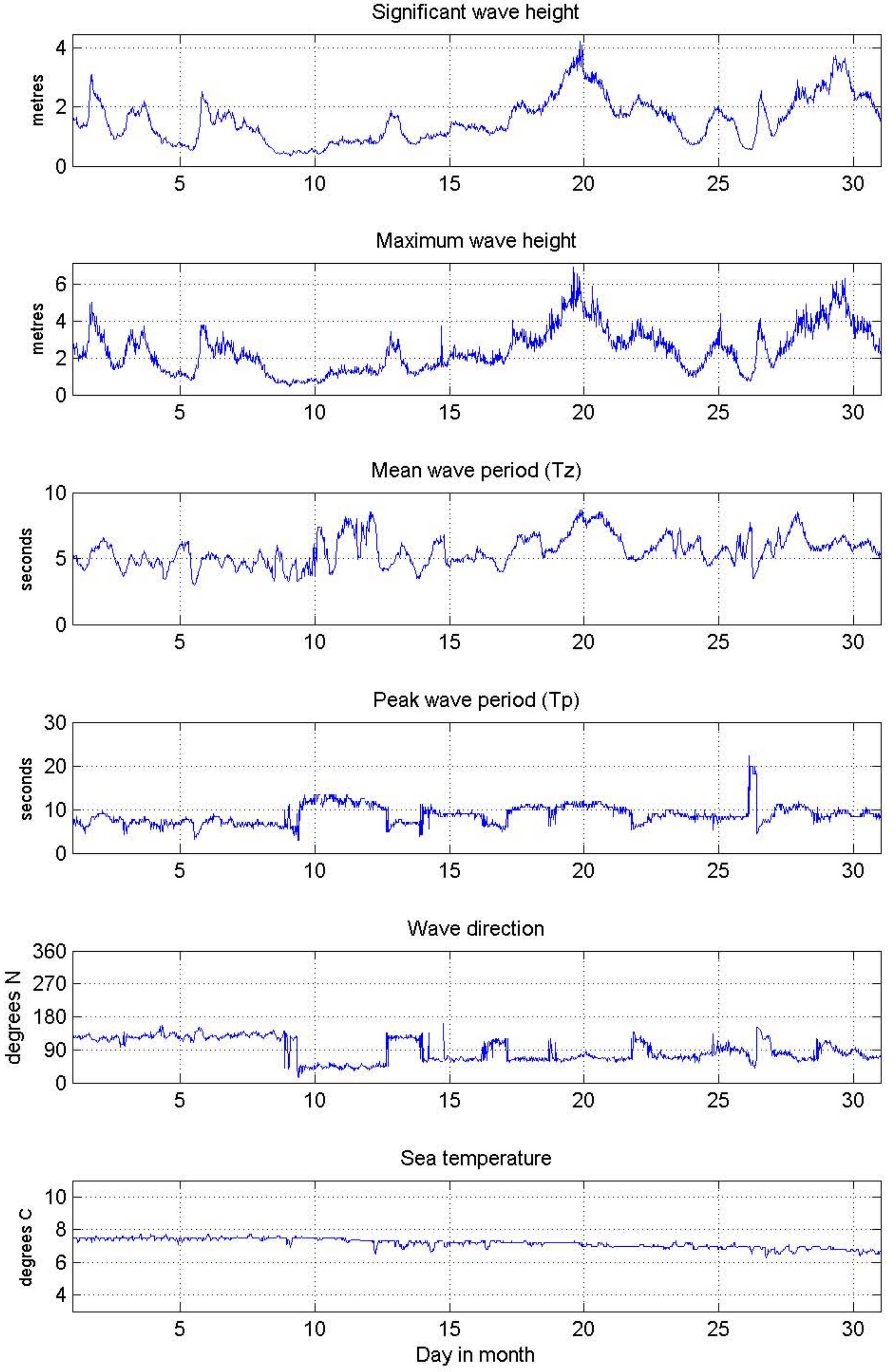


Figure A4 Locations of Scarborough wave buoys and tide gauge

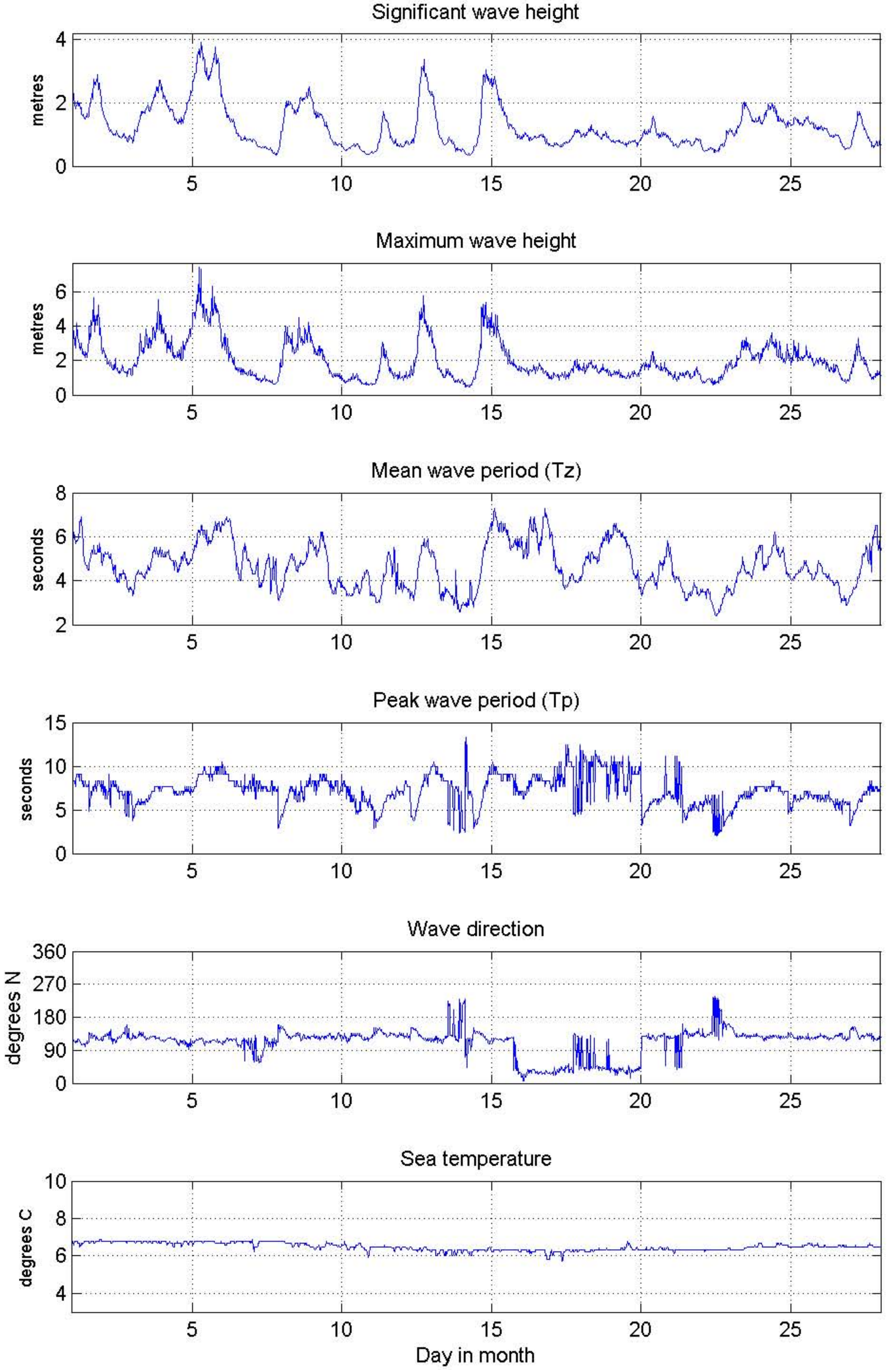
Appendix B

Supporting Graphs: Newbiggin Wave Buoy

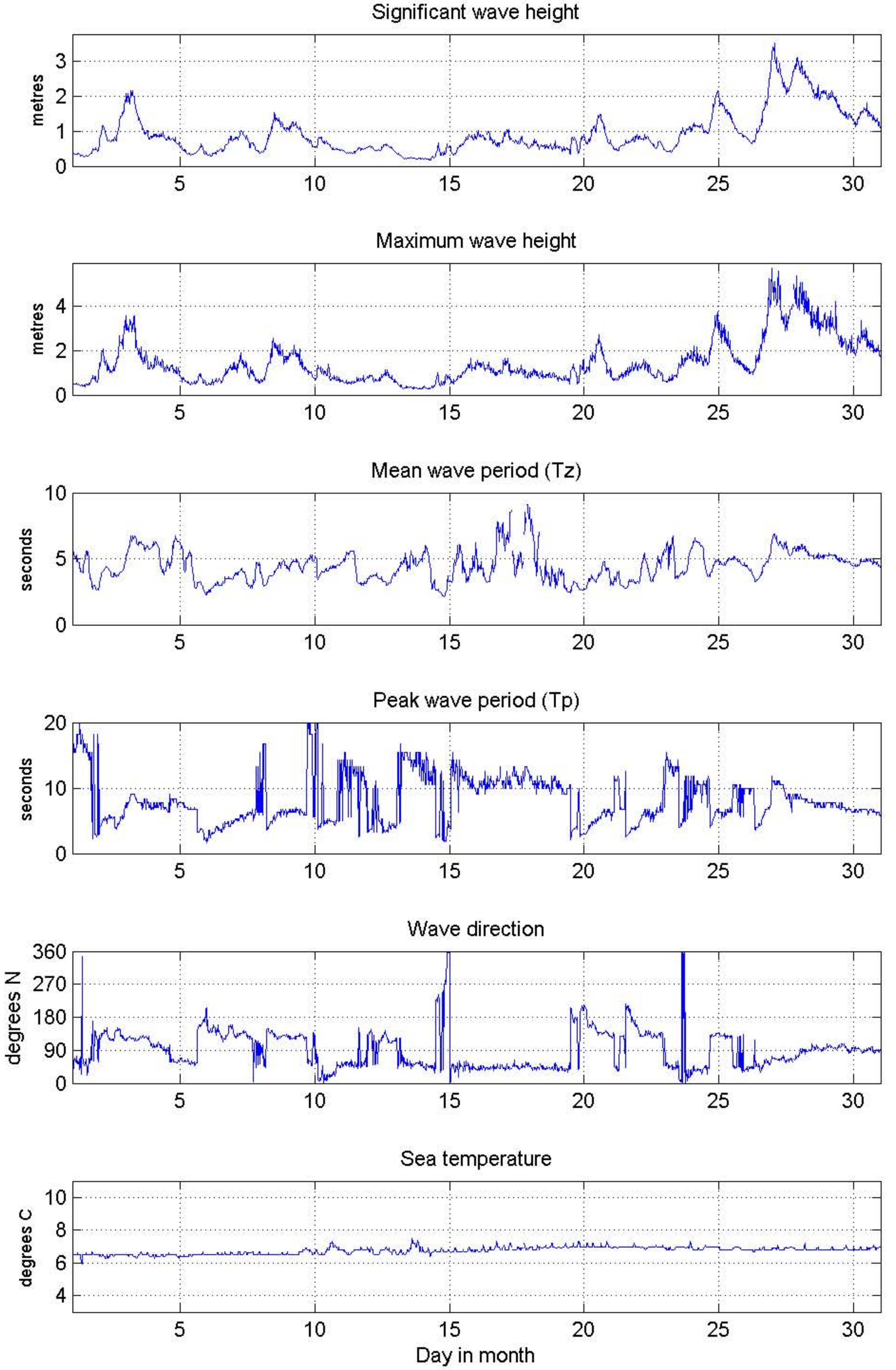
Newbiggin - January 2014



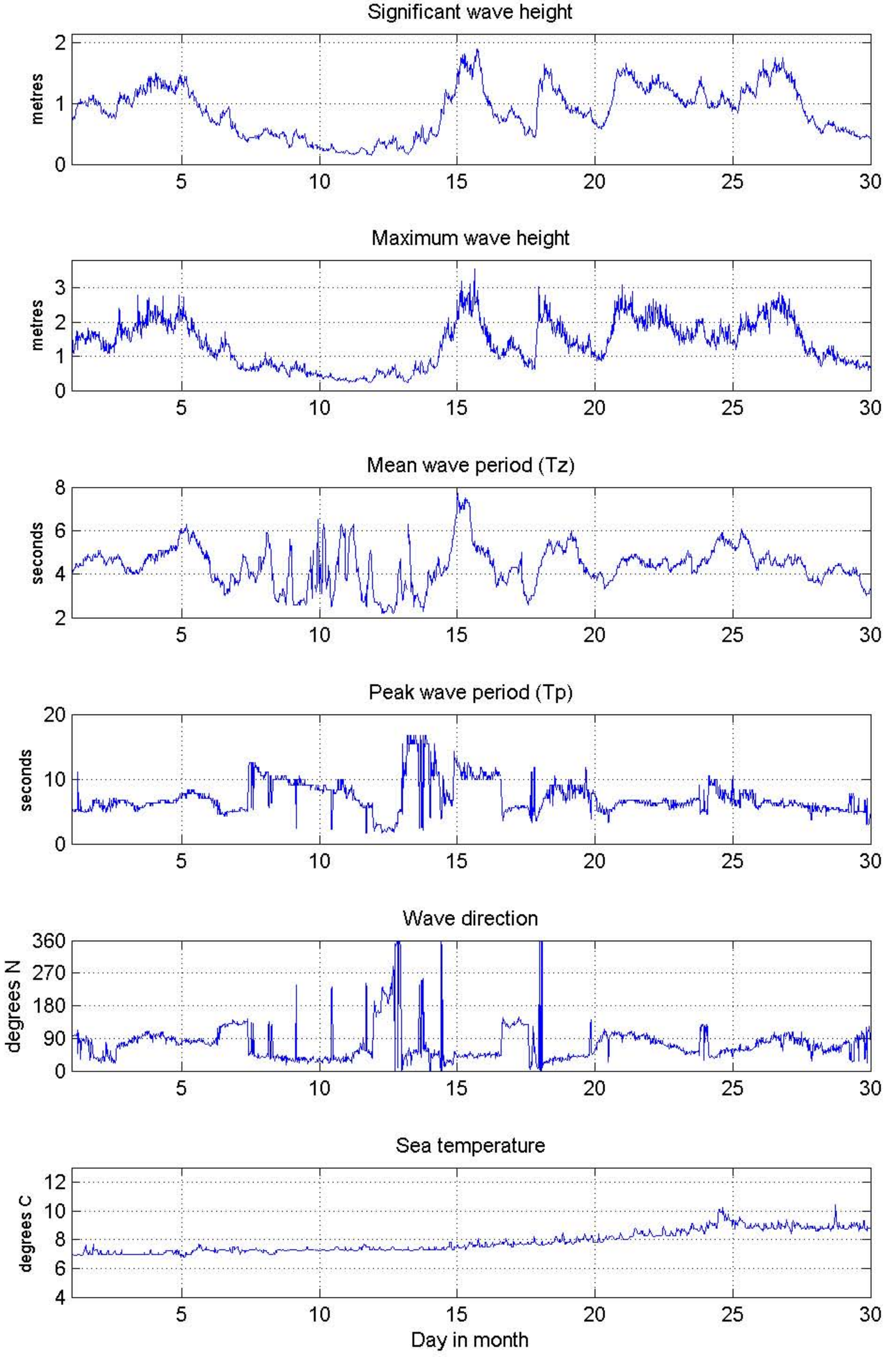
Newbiggin - February 2014



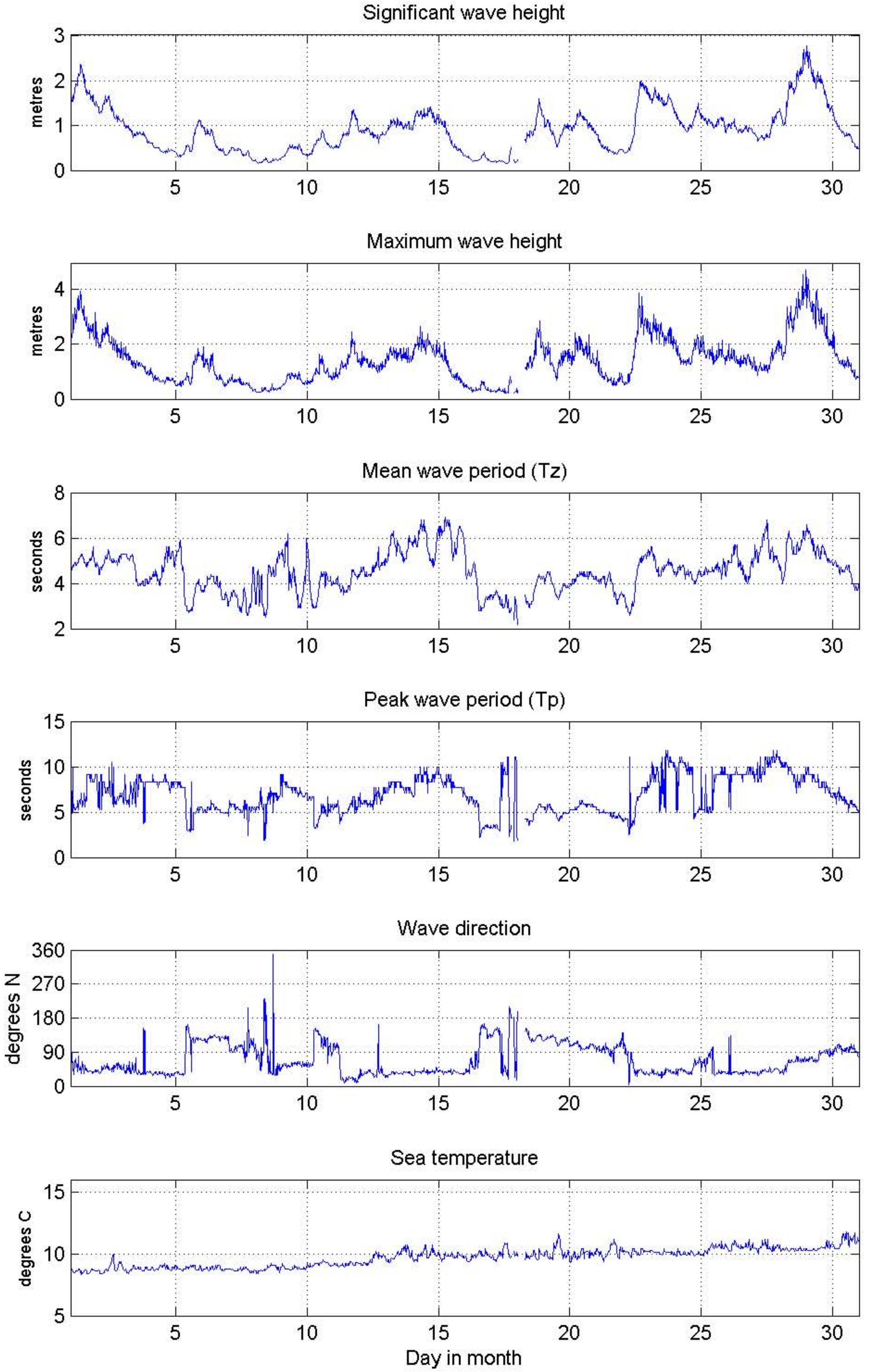
Newbiggin - March 2014



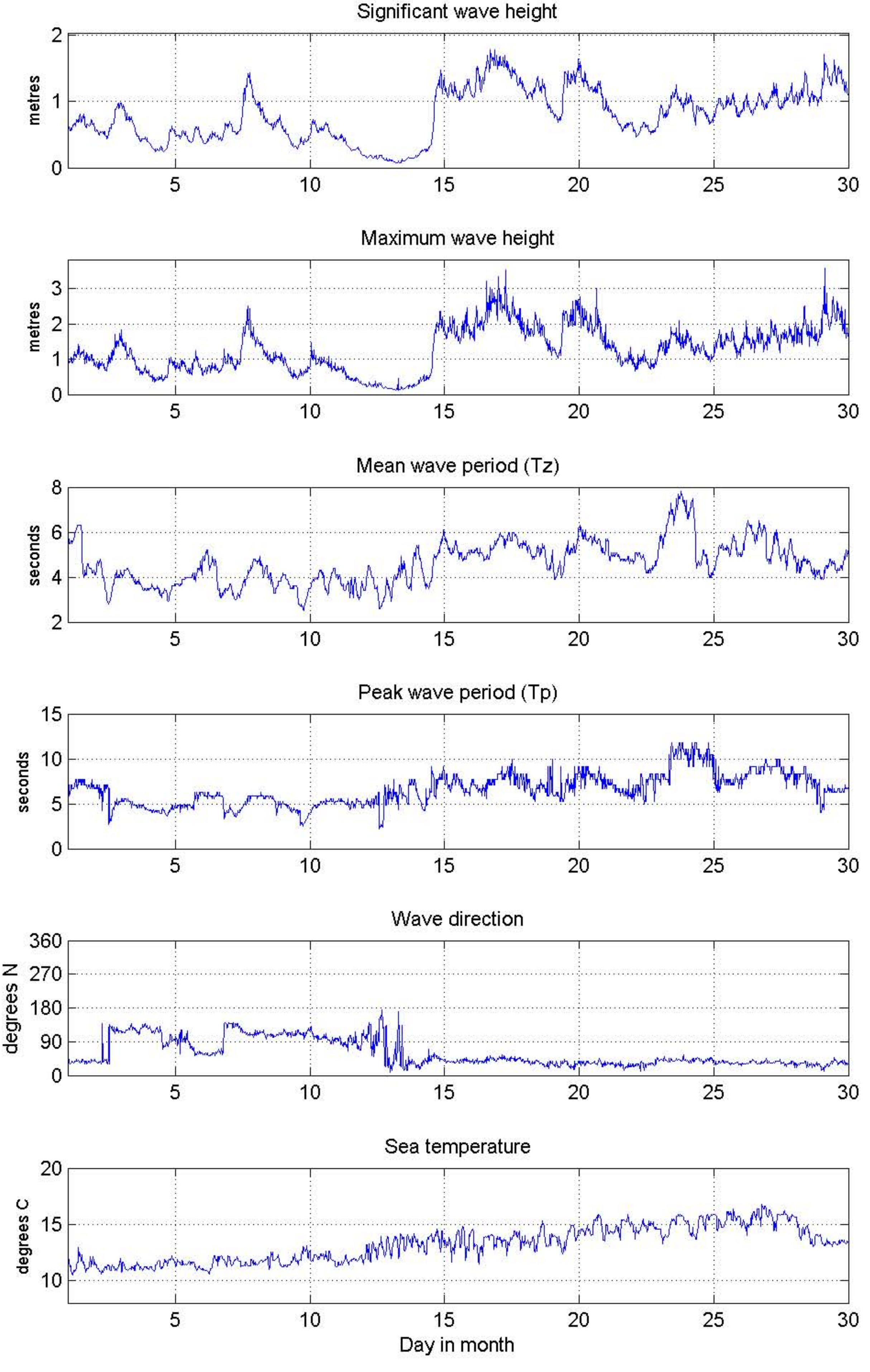
Newbiggin - April 2014

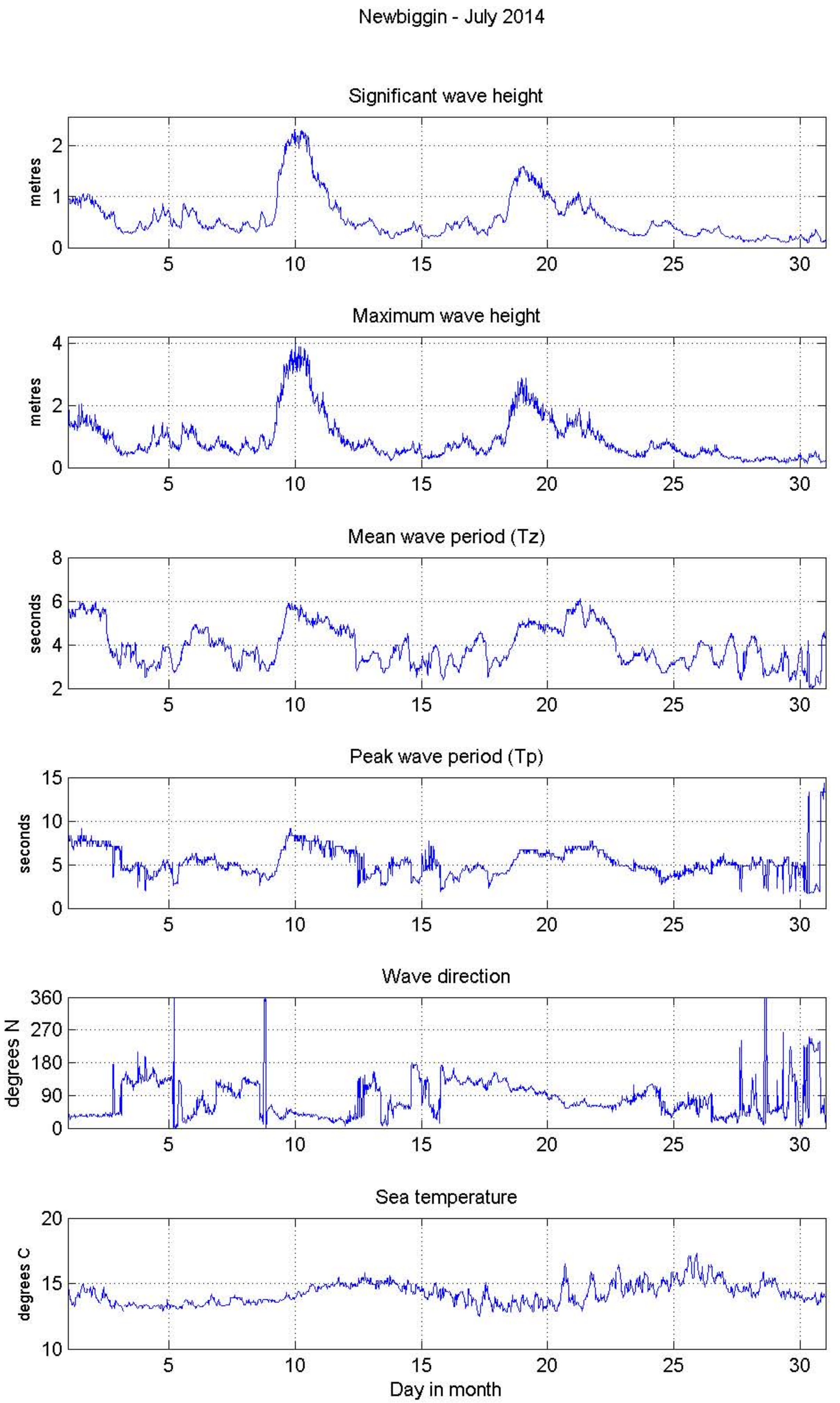


Newbiggin - May 2014



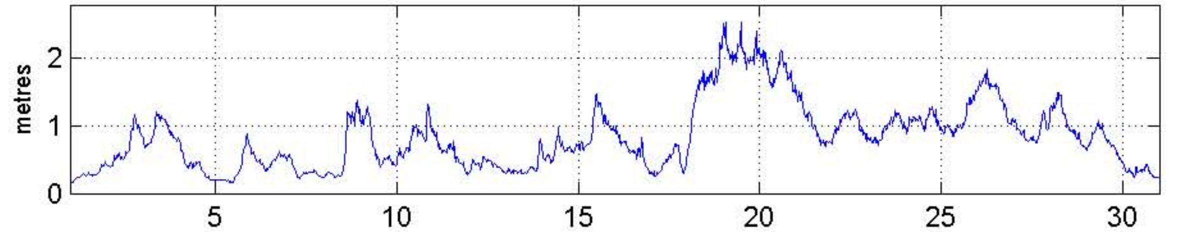
Newbiggin - June 2014



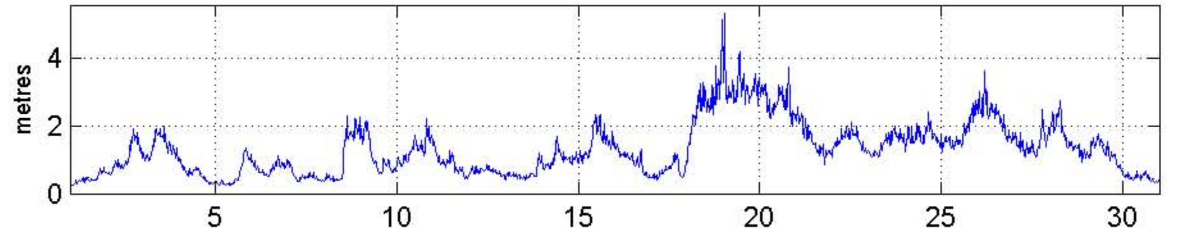

Newbiggin - July 2014
Significant wave height
metres
Maximum wave height
metres
Mean wave period (Tz)
seconds
Peak wave period (Tp)
seconds
Wave direction
degrees N
Sea temperature
degrees C
Day in month

Newbiggin - August 2014

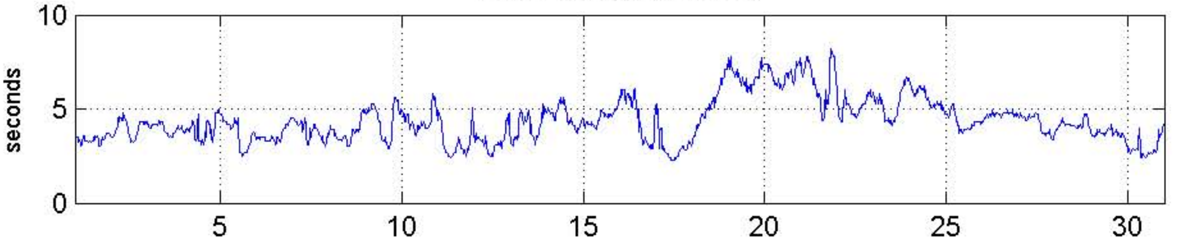
Significant wave height



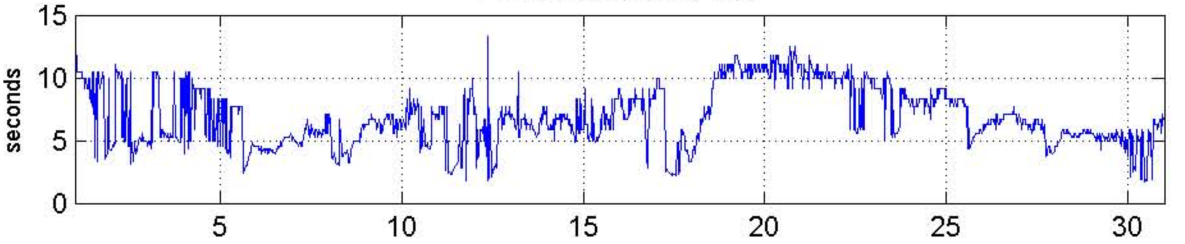
Maximum wave height



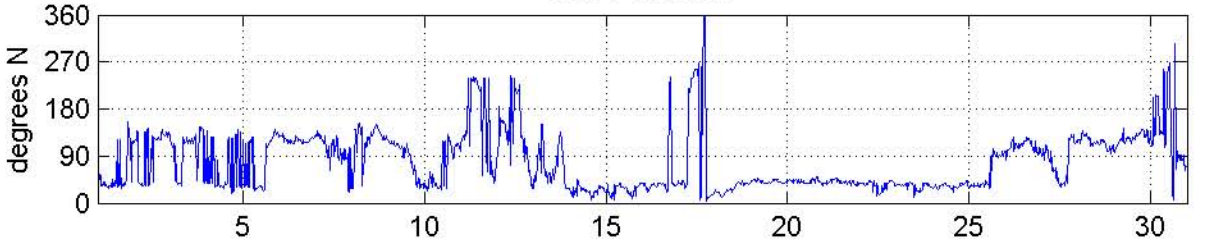
Mean wave period (Tz)



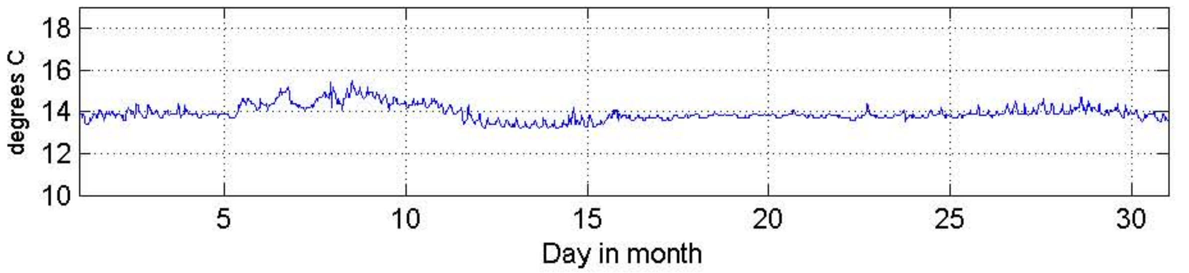
Peak wave period (Tp)



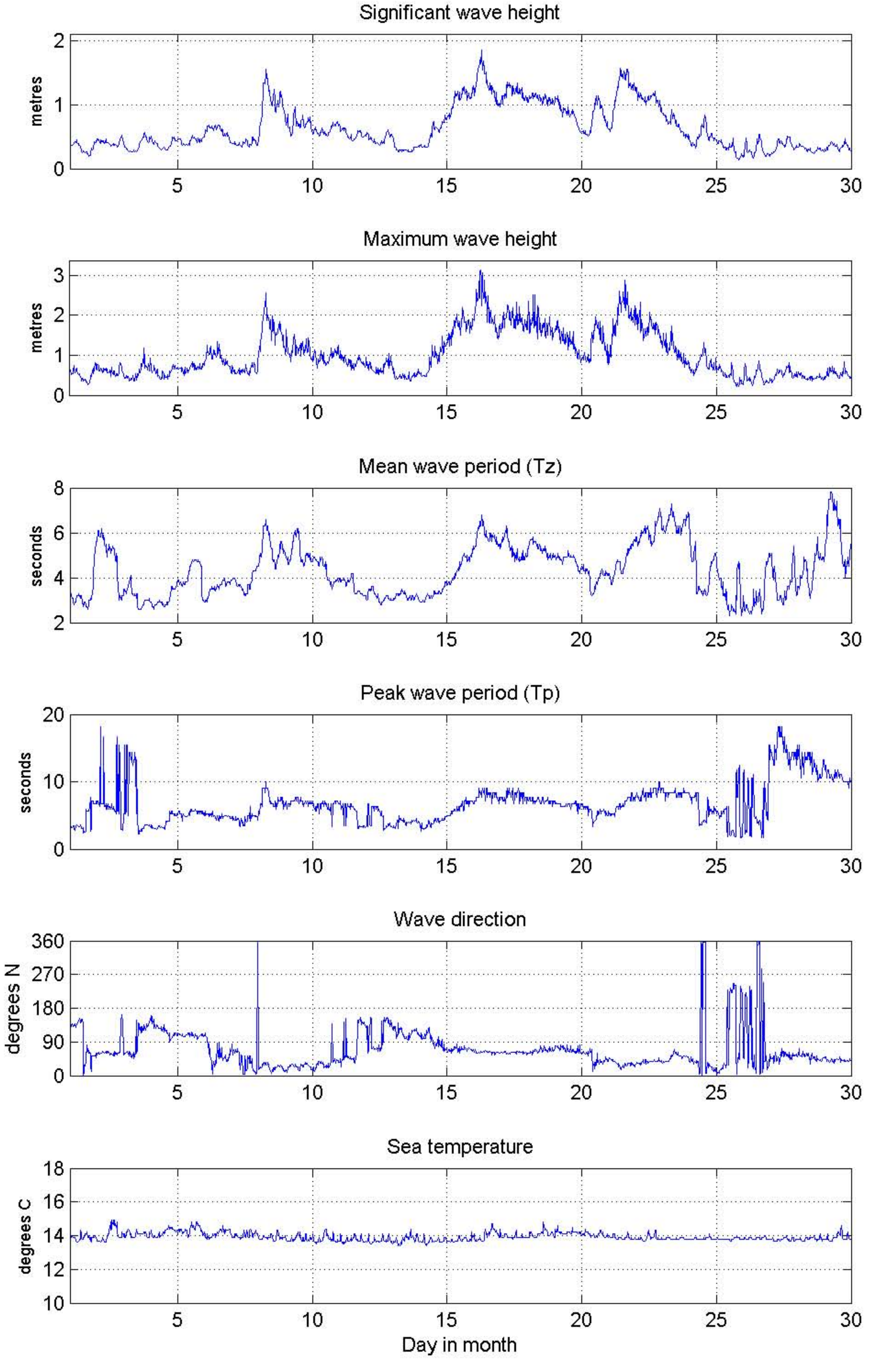
Wave direction



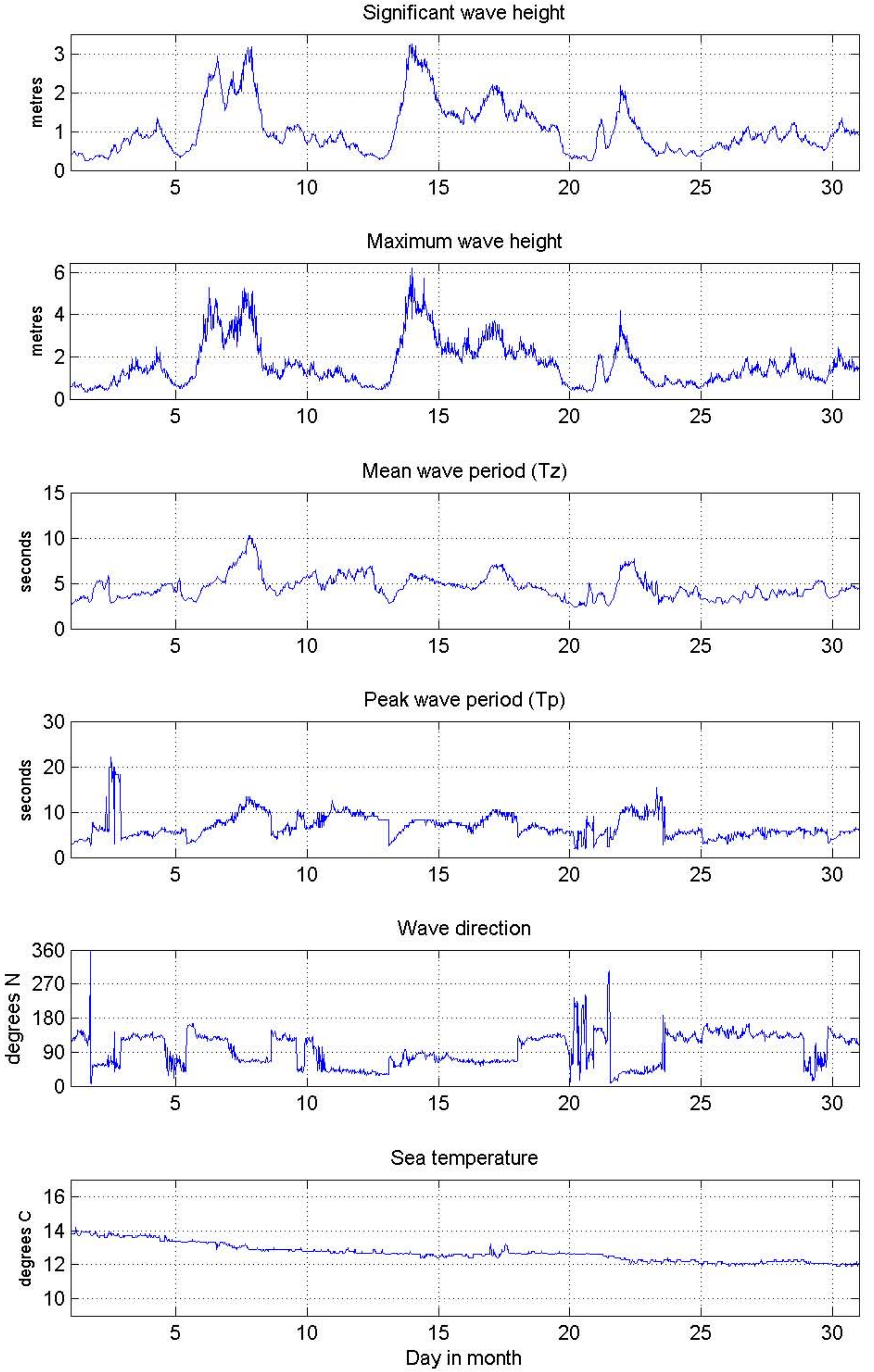
Sea temperature



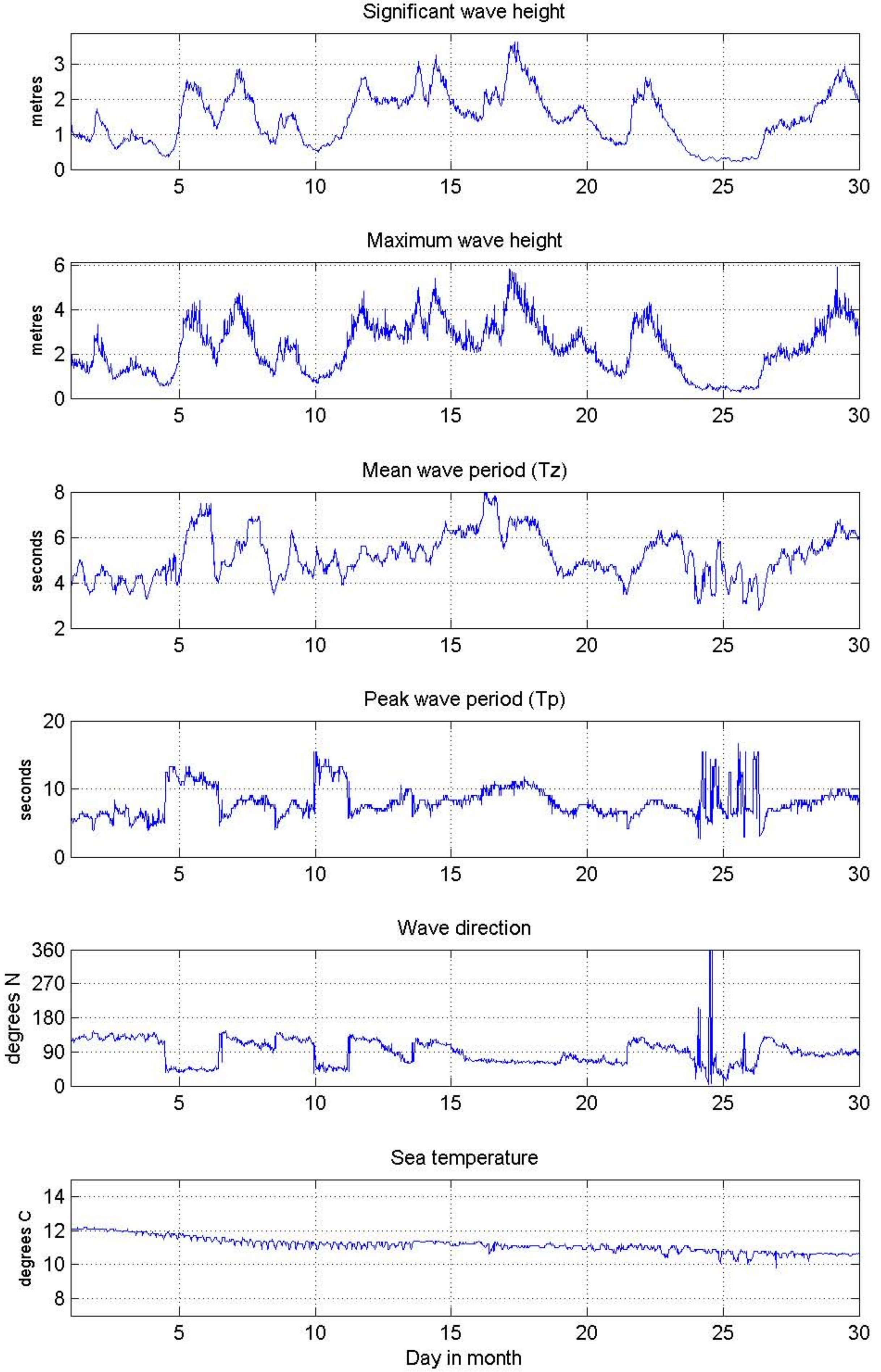
Newbiggin - September 2014



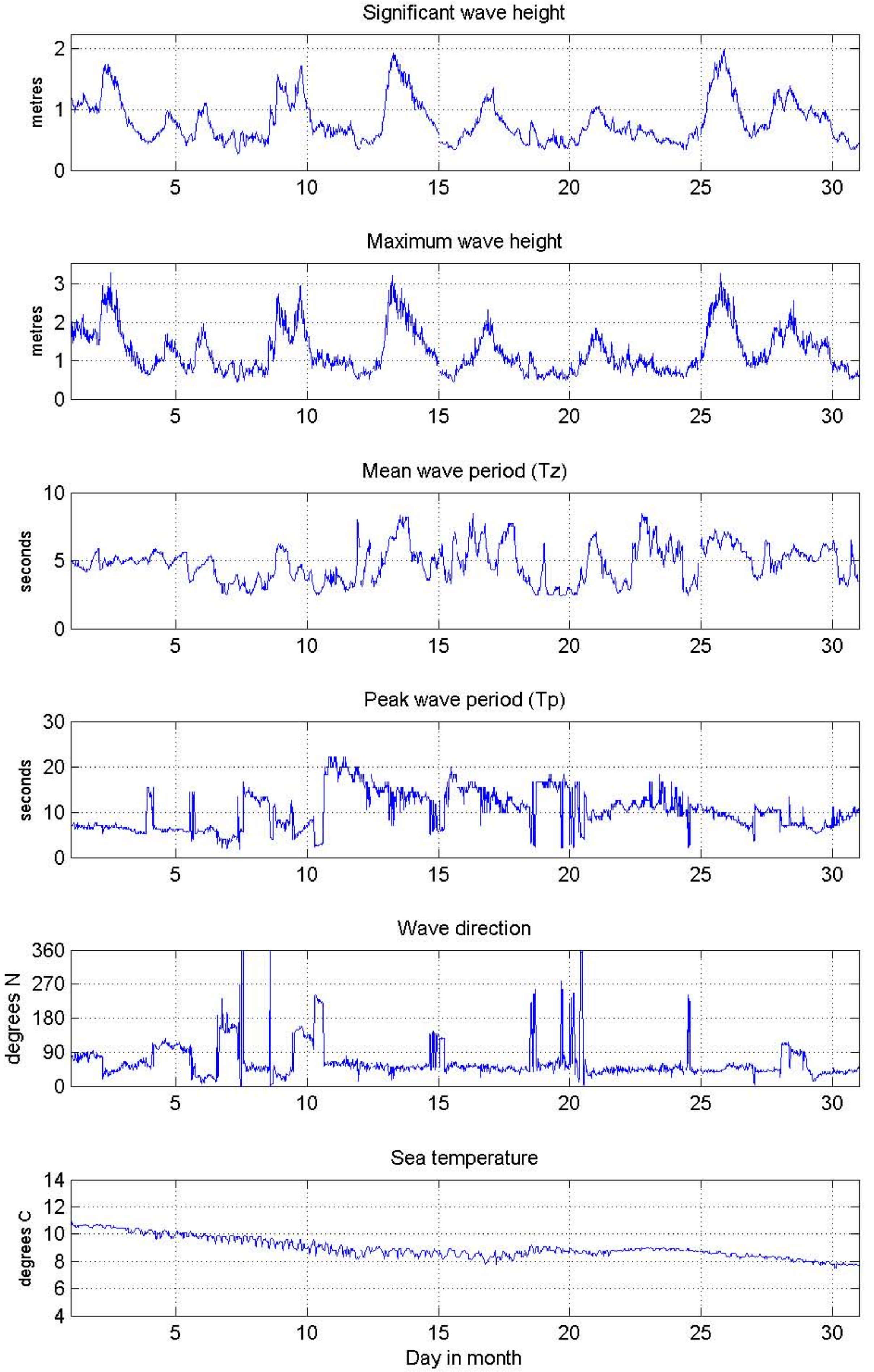
Newbiggin - October 2014



Newbiggin - November 2014



Newbiggin - December 2014



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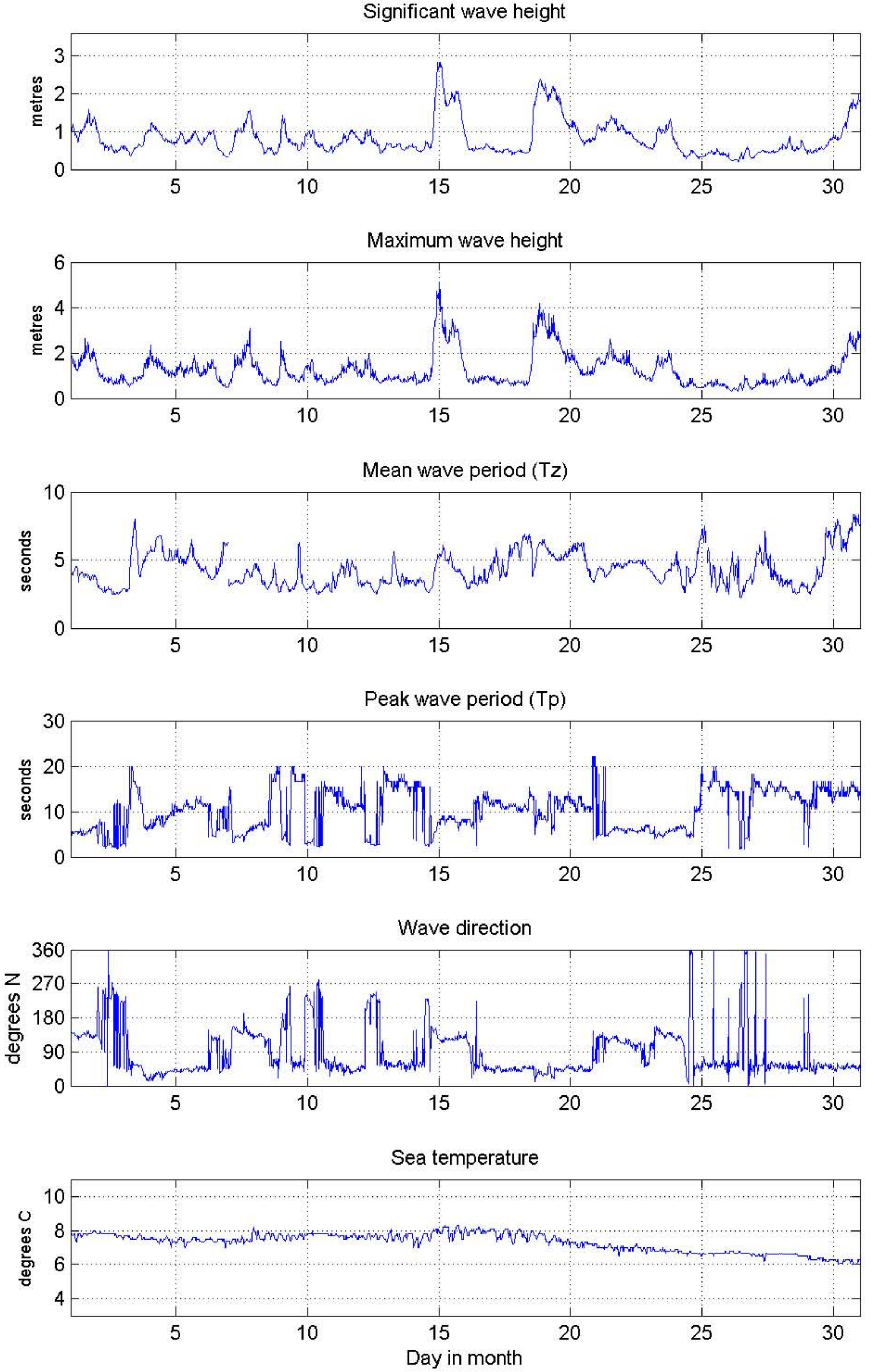

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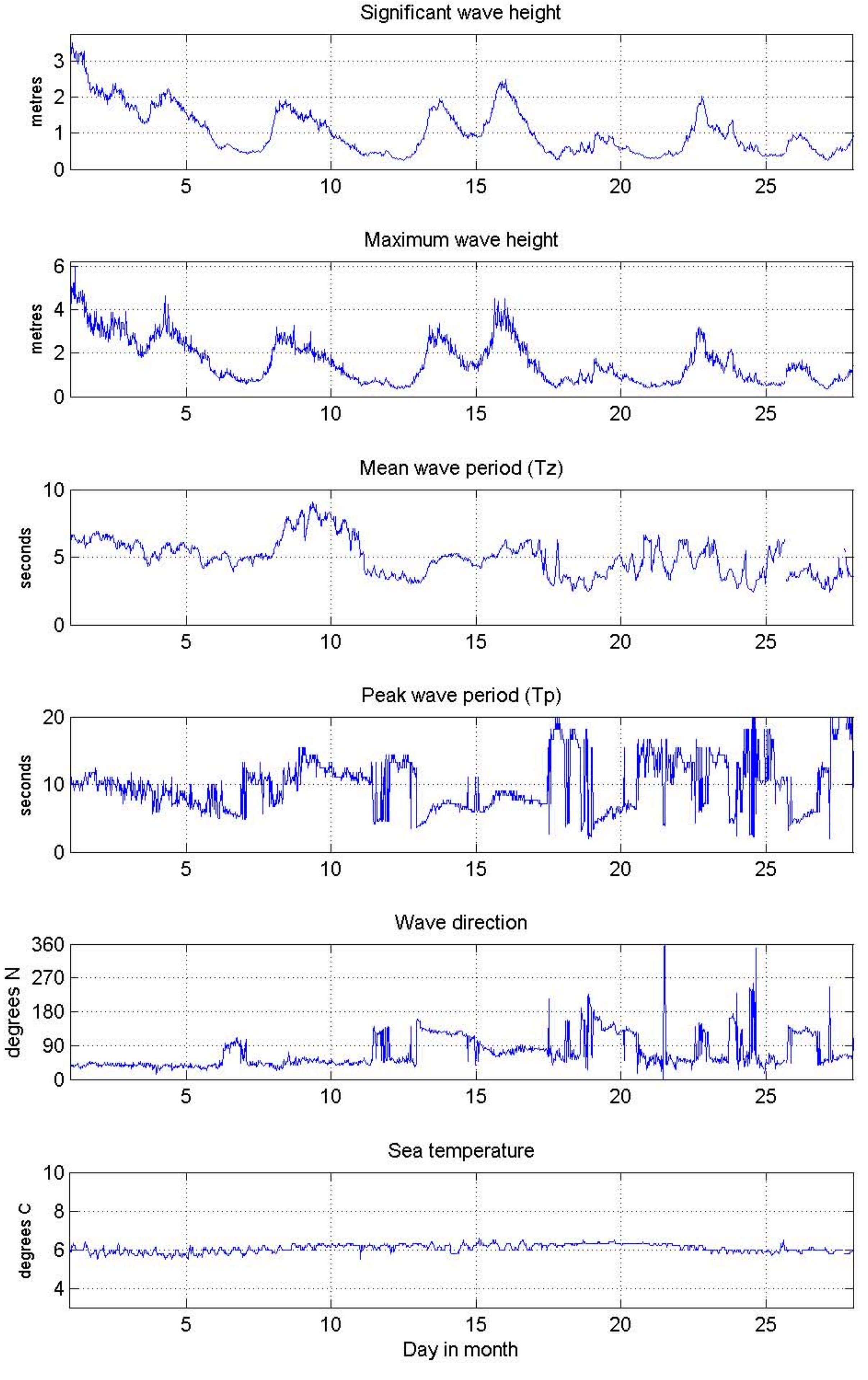
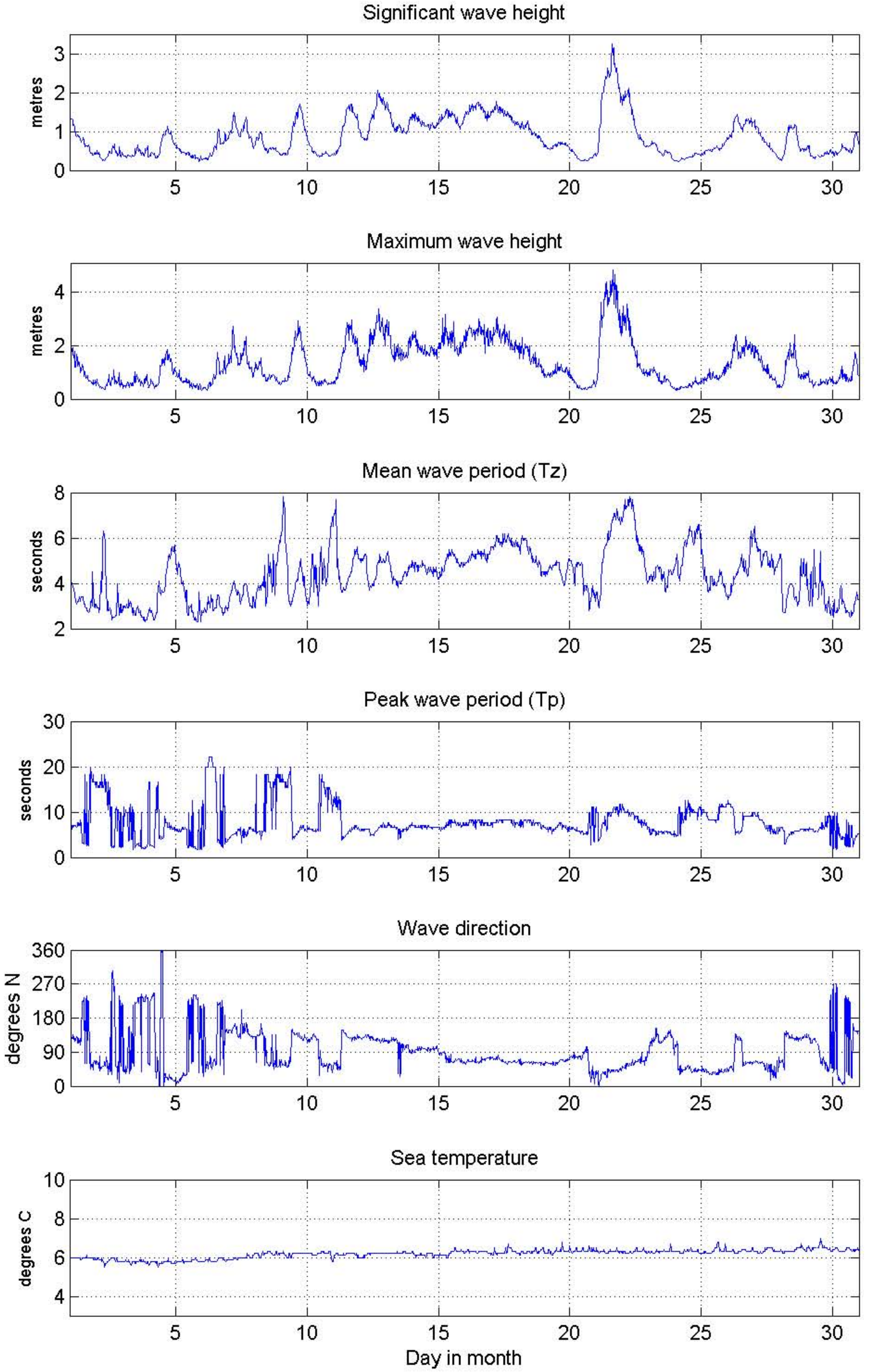


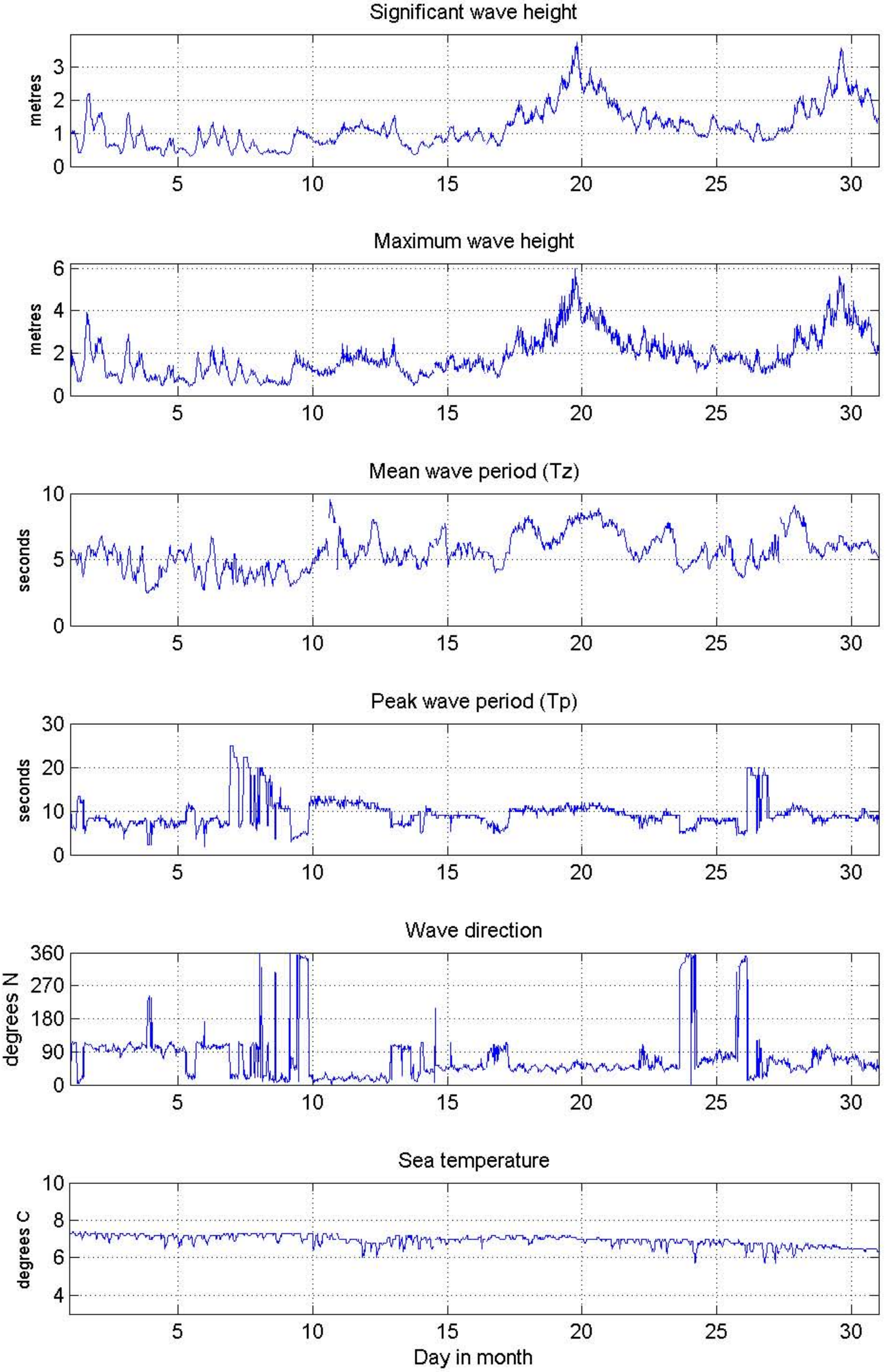
Newbiggin - March 2015



Appendix C

Supporting Graphs: Whitby Wave Buoy

Whitby - January 2014



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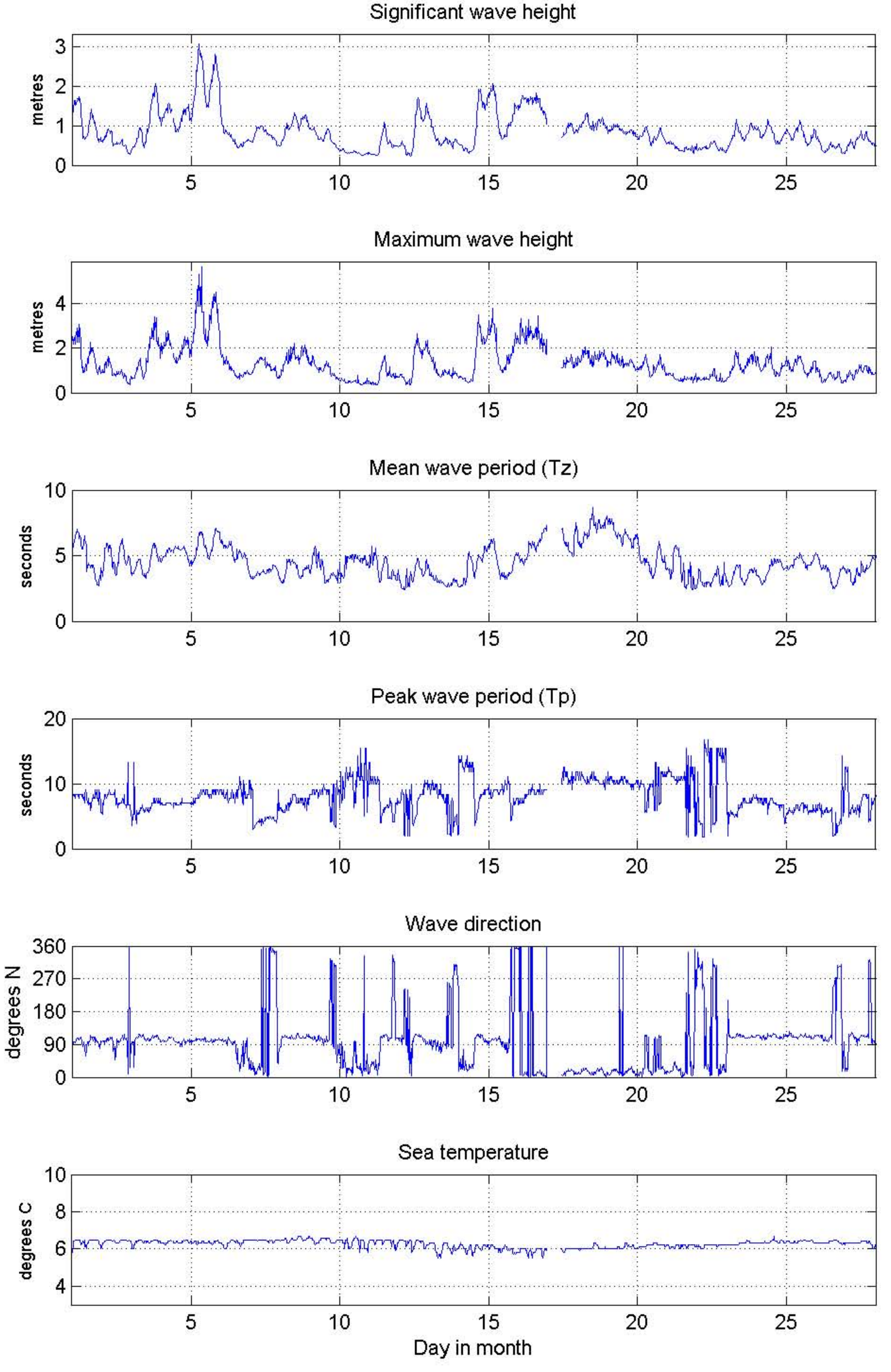
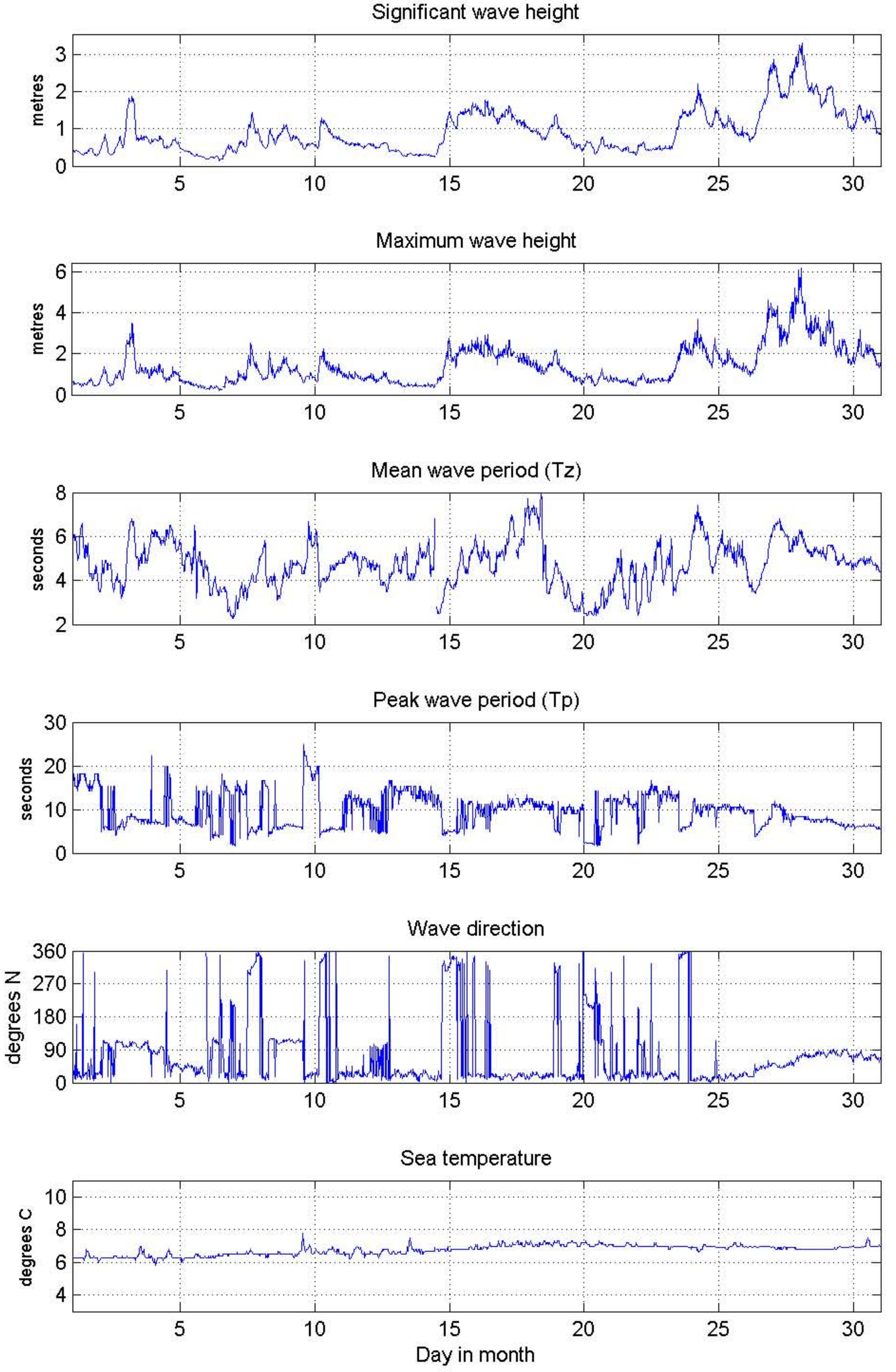
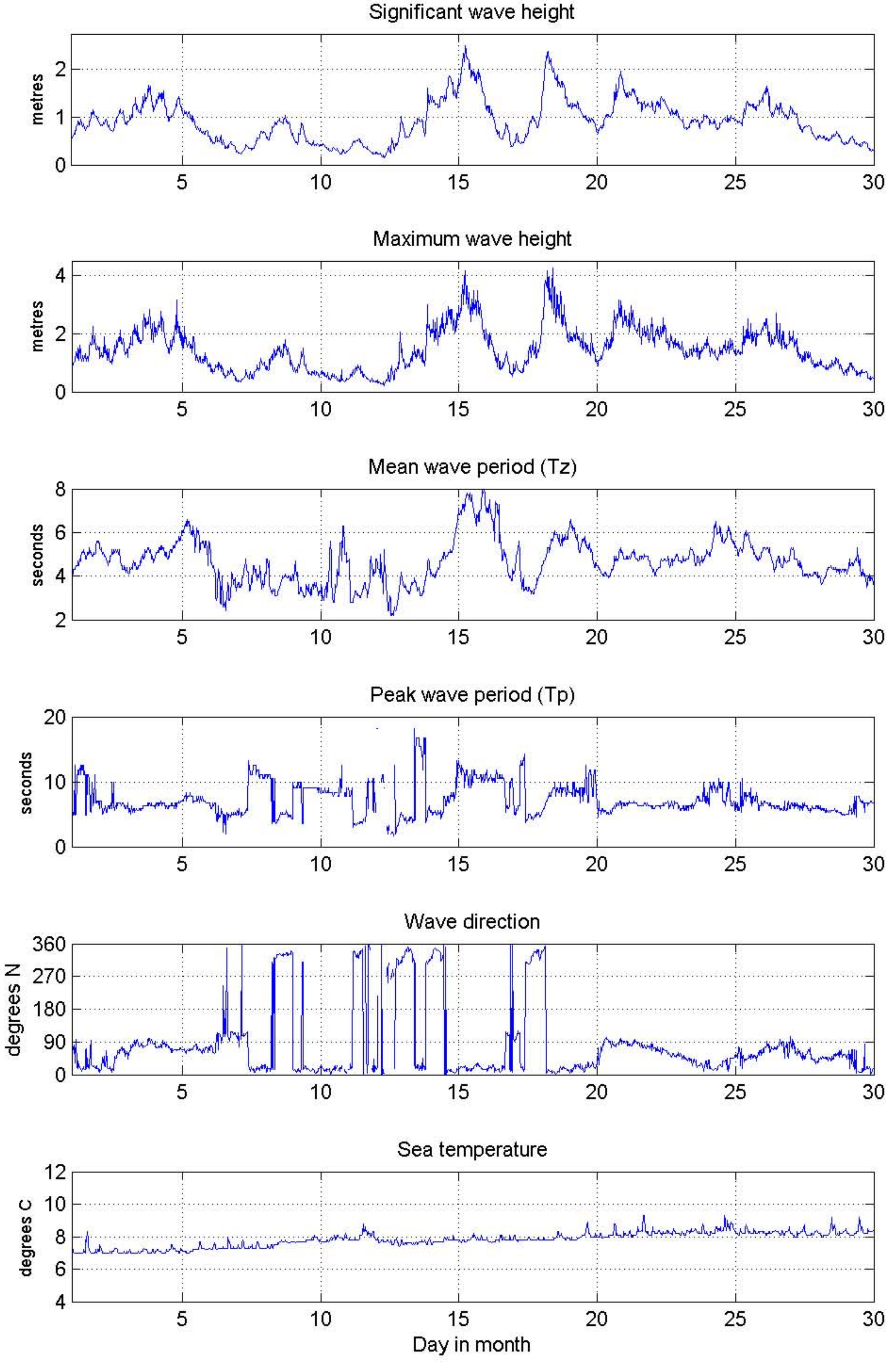


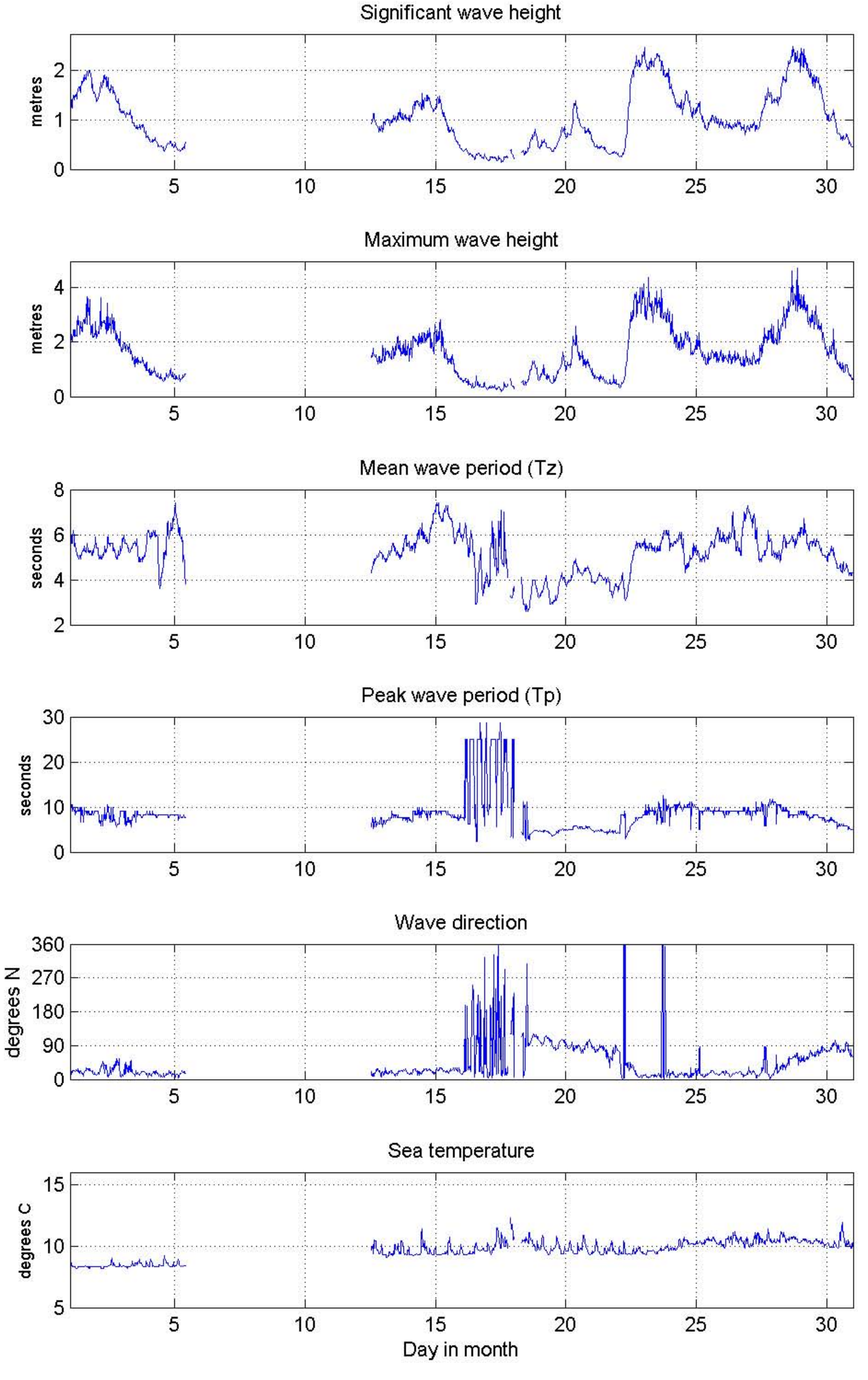
Whitby - March 2014



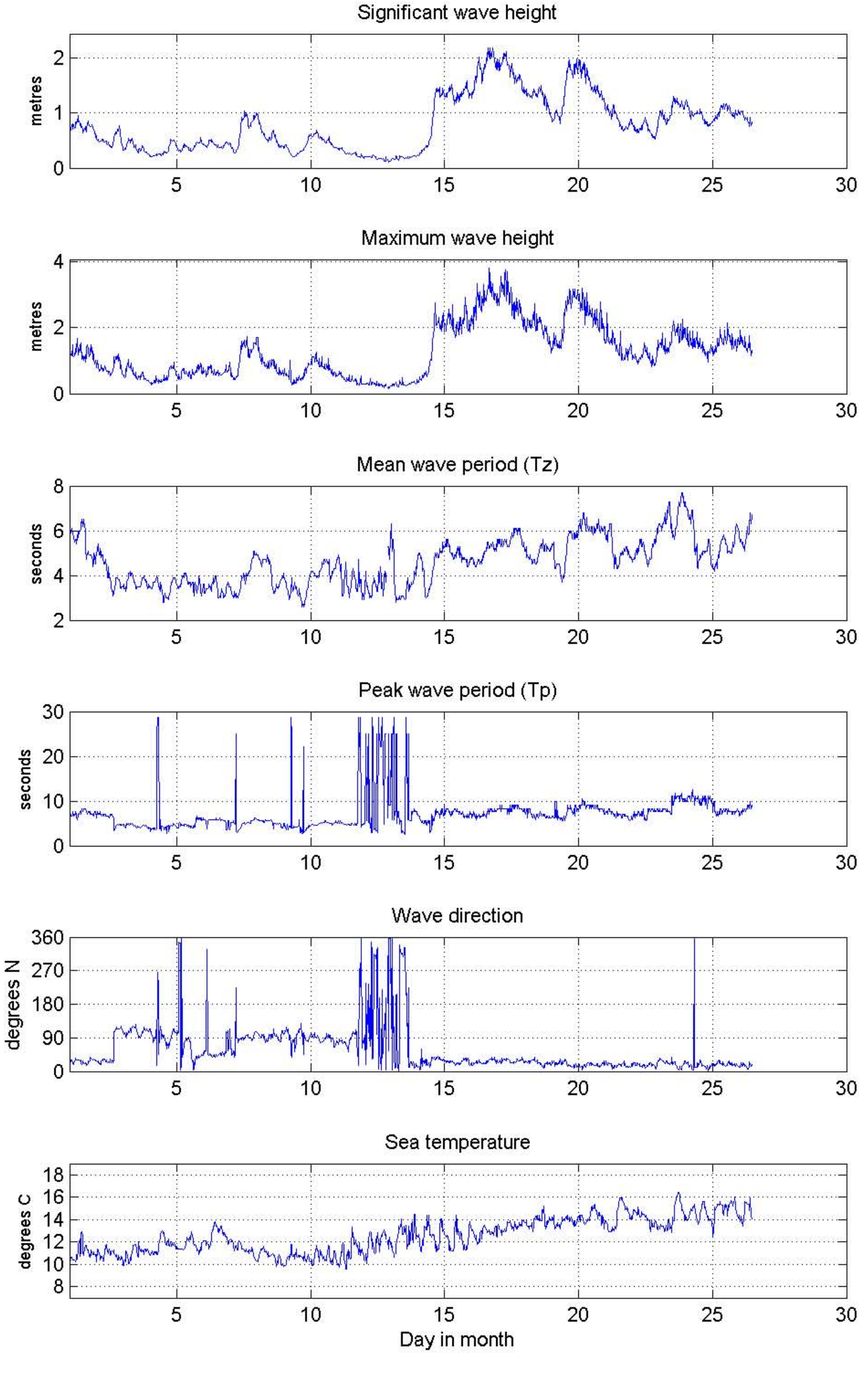
Whitby - April 2014



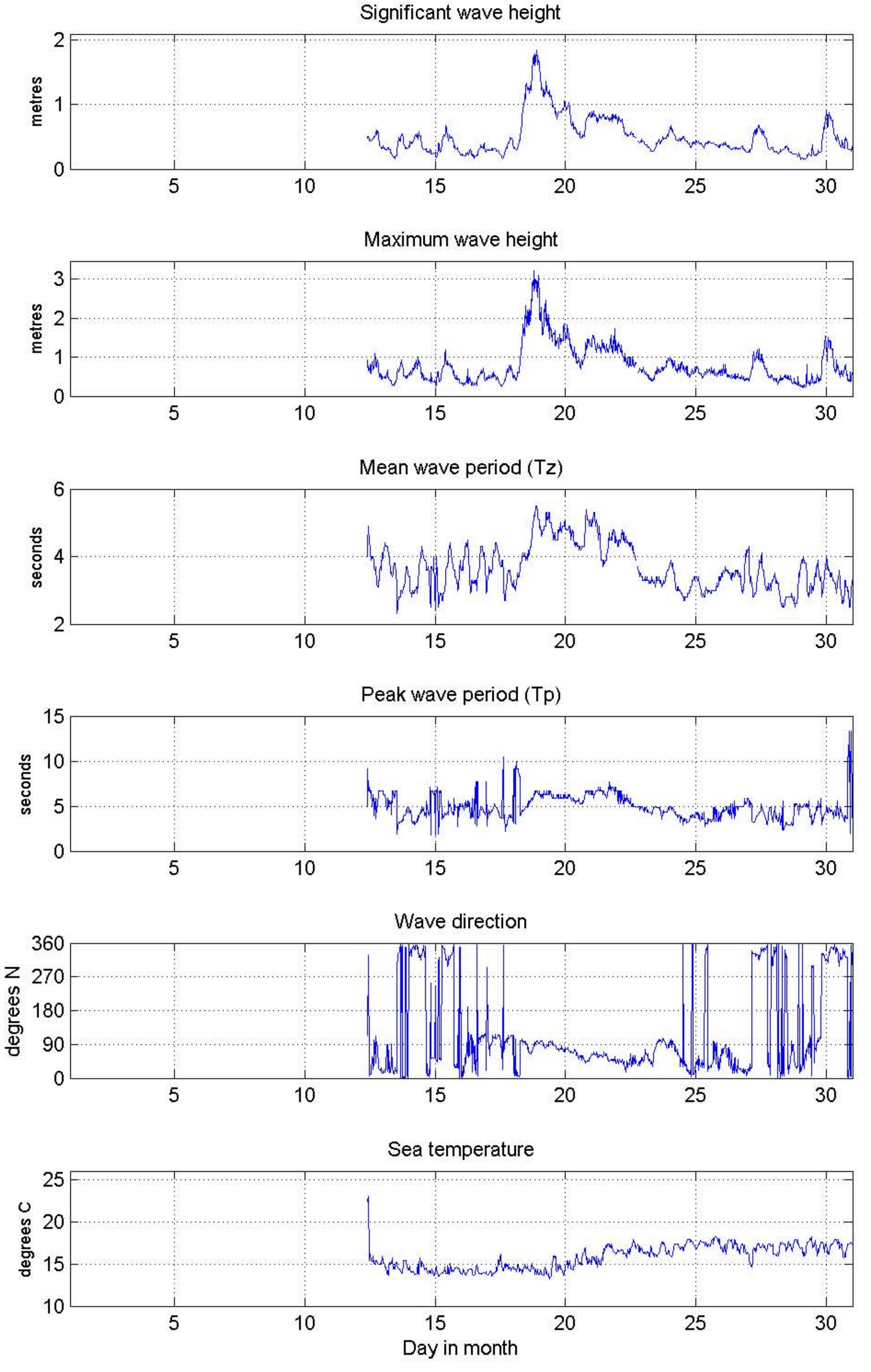
Whitby - May 2014



Whitby - June 2014



Whitby - July 2014



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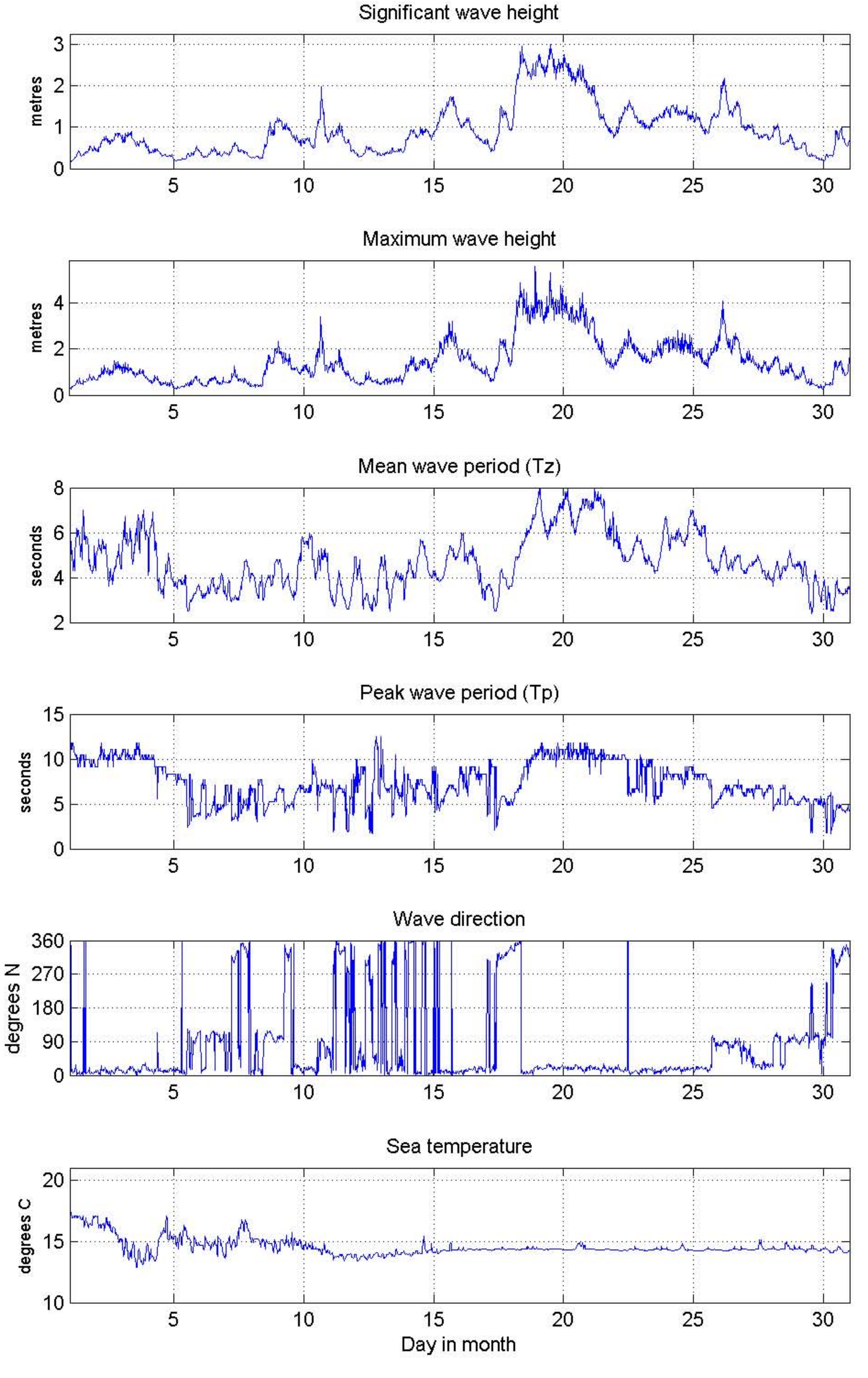

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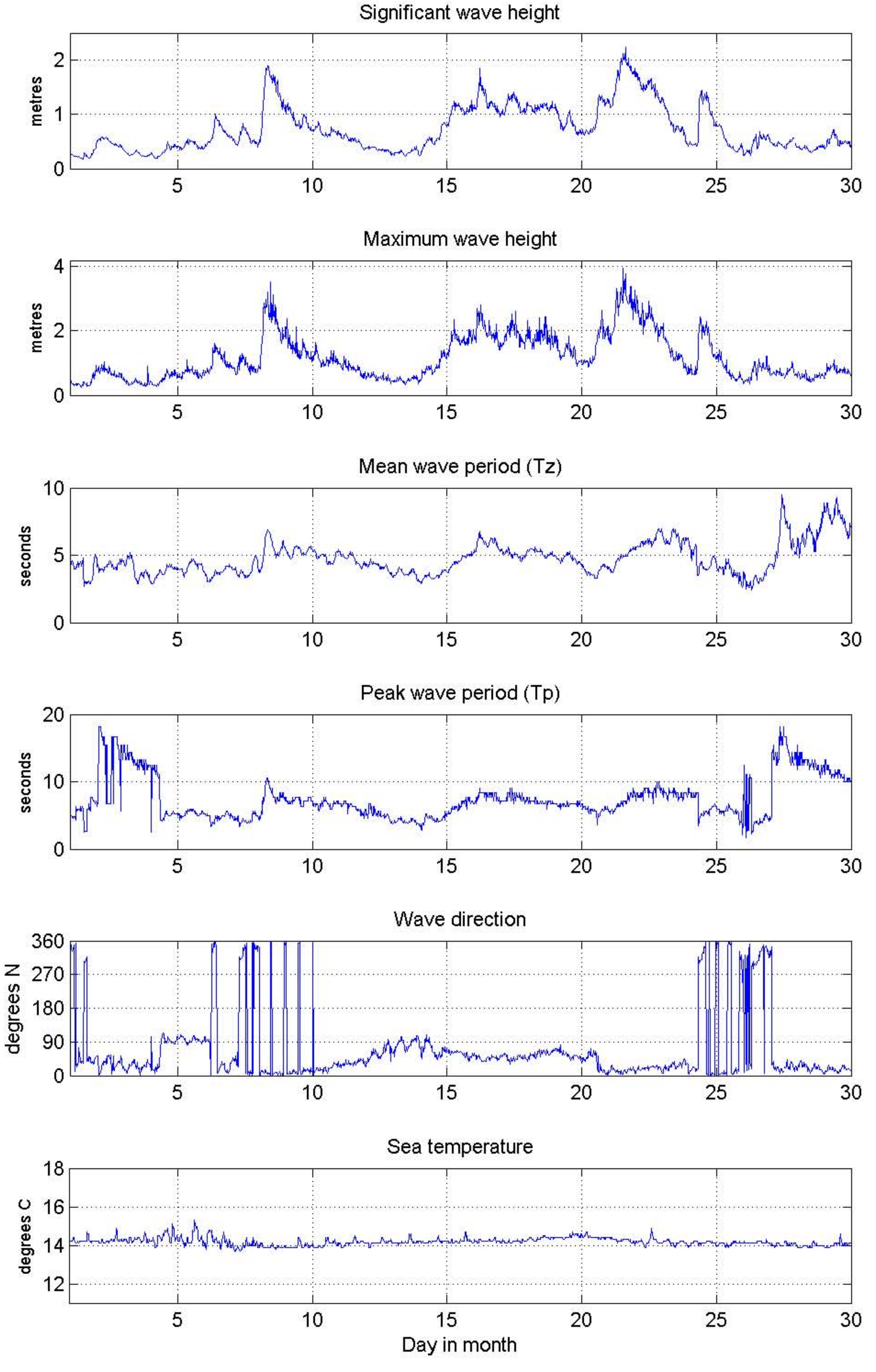
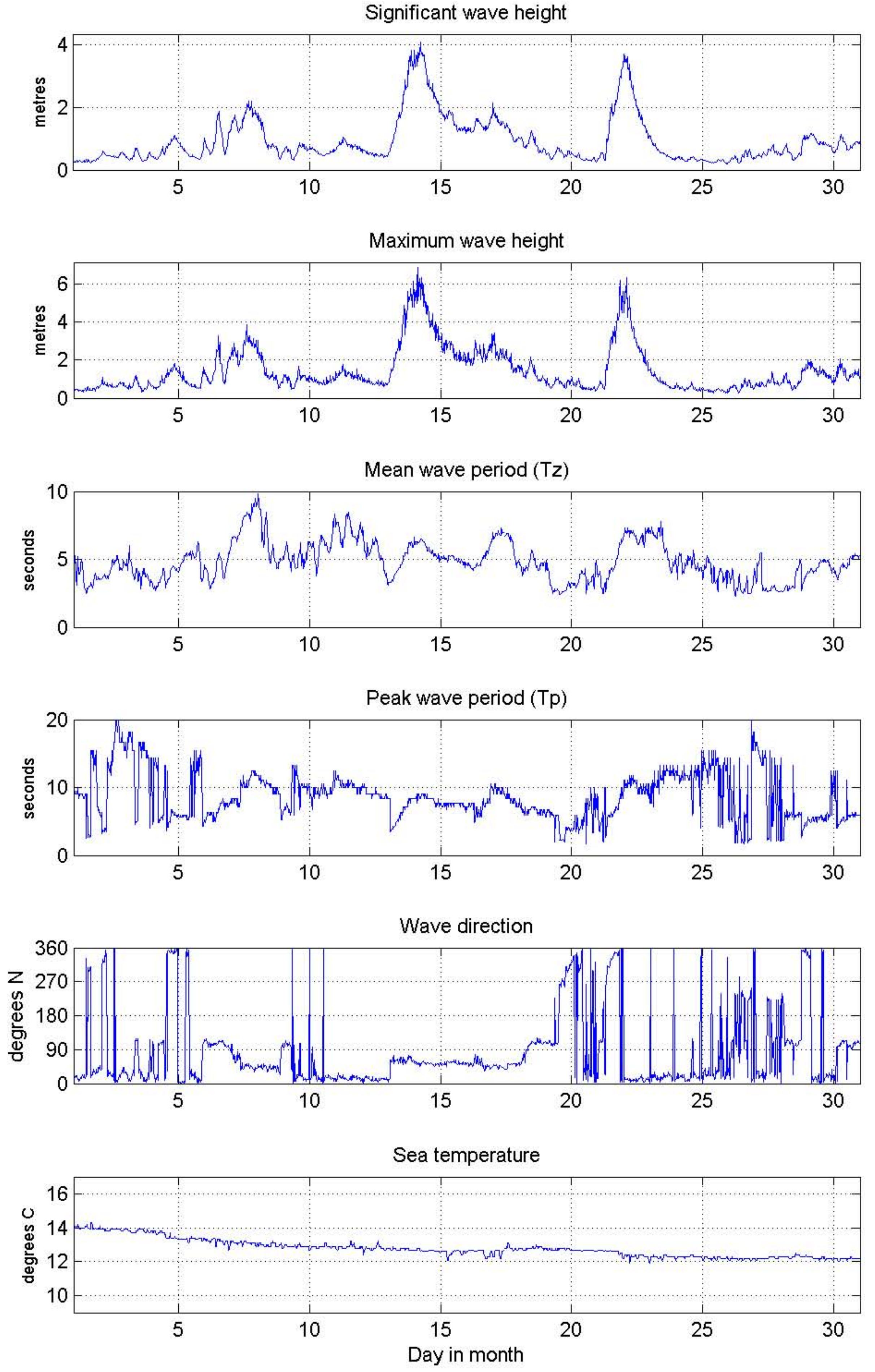


Whitby - October 2014



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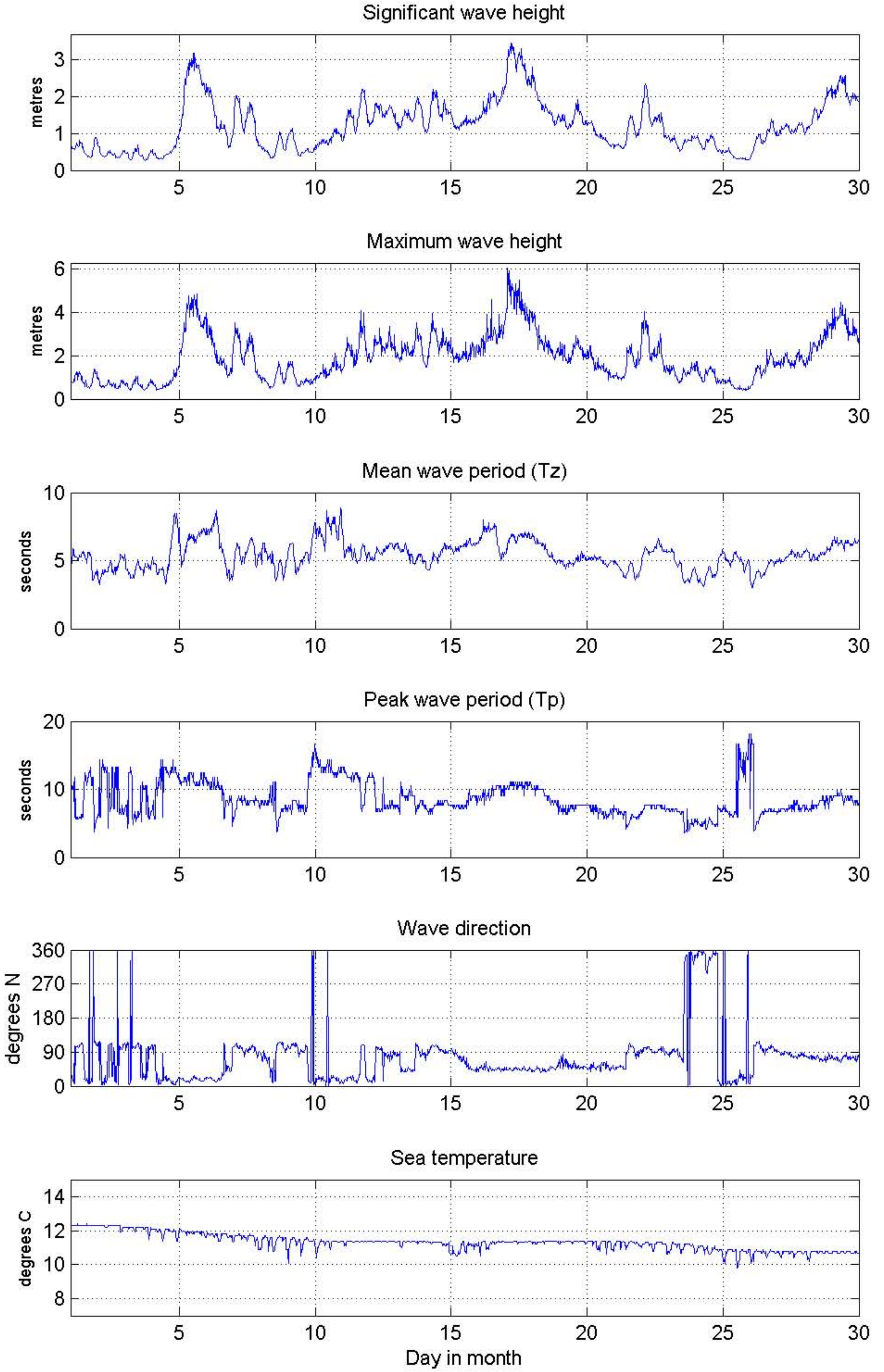

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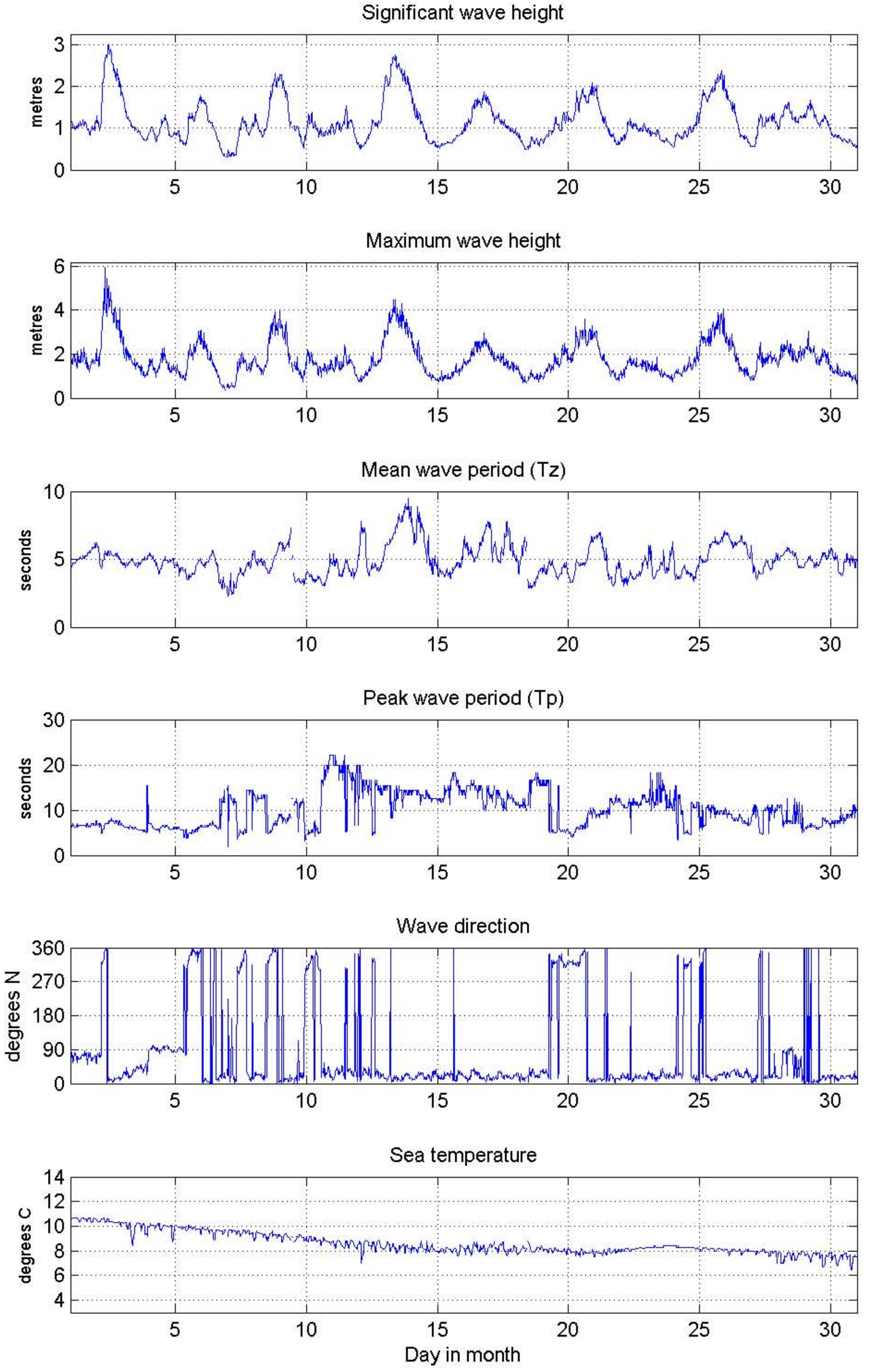

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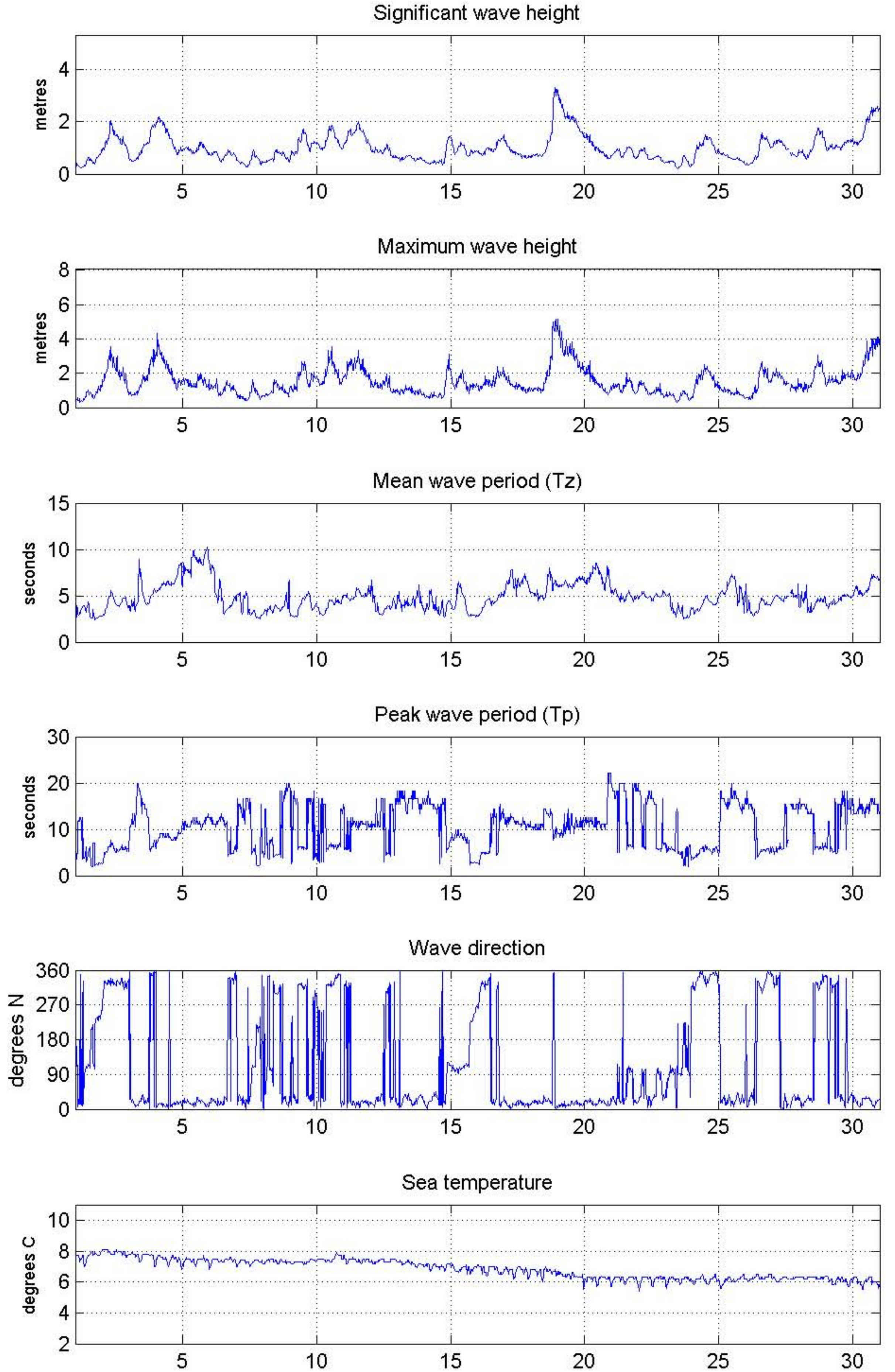

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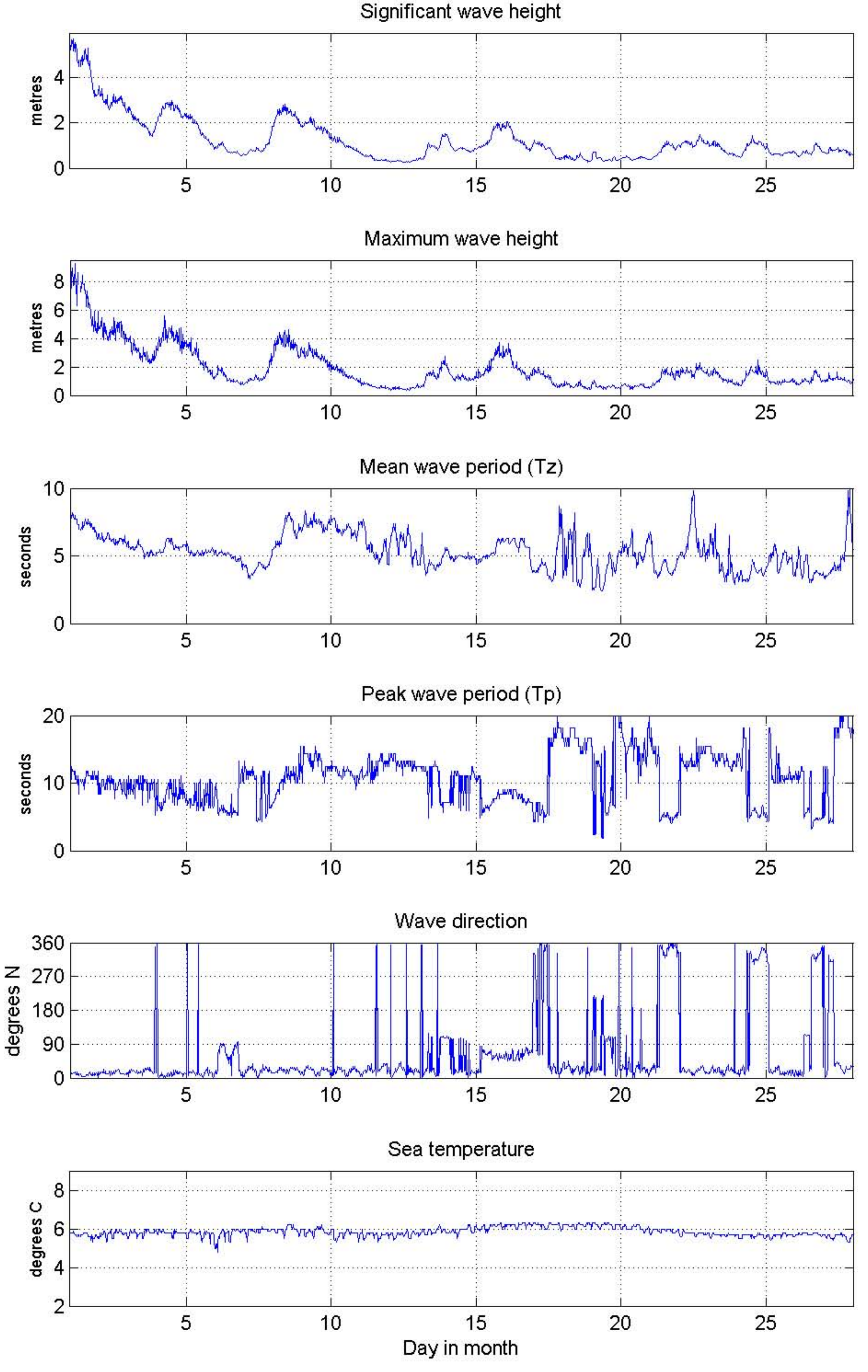
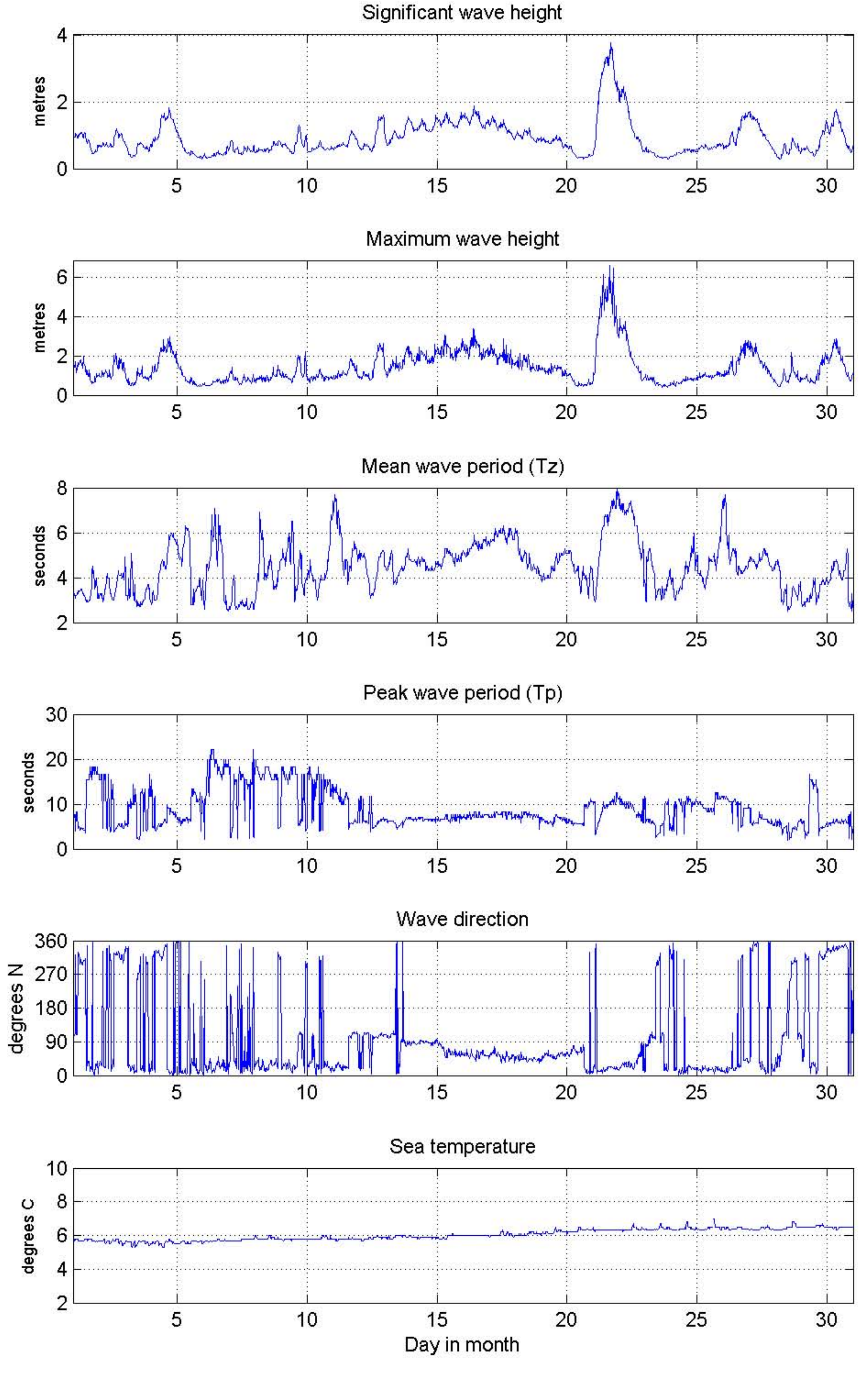


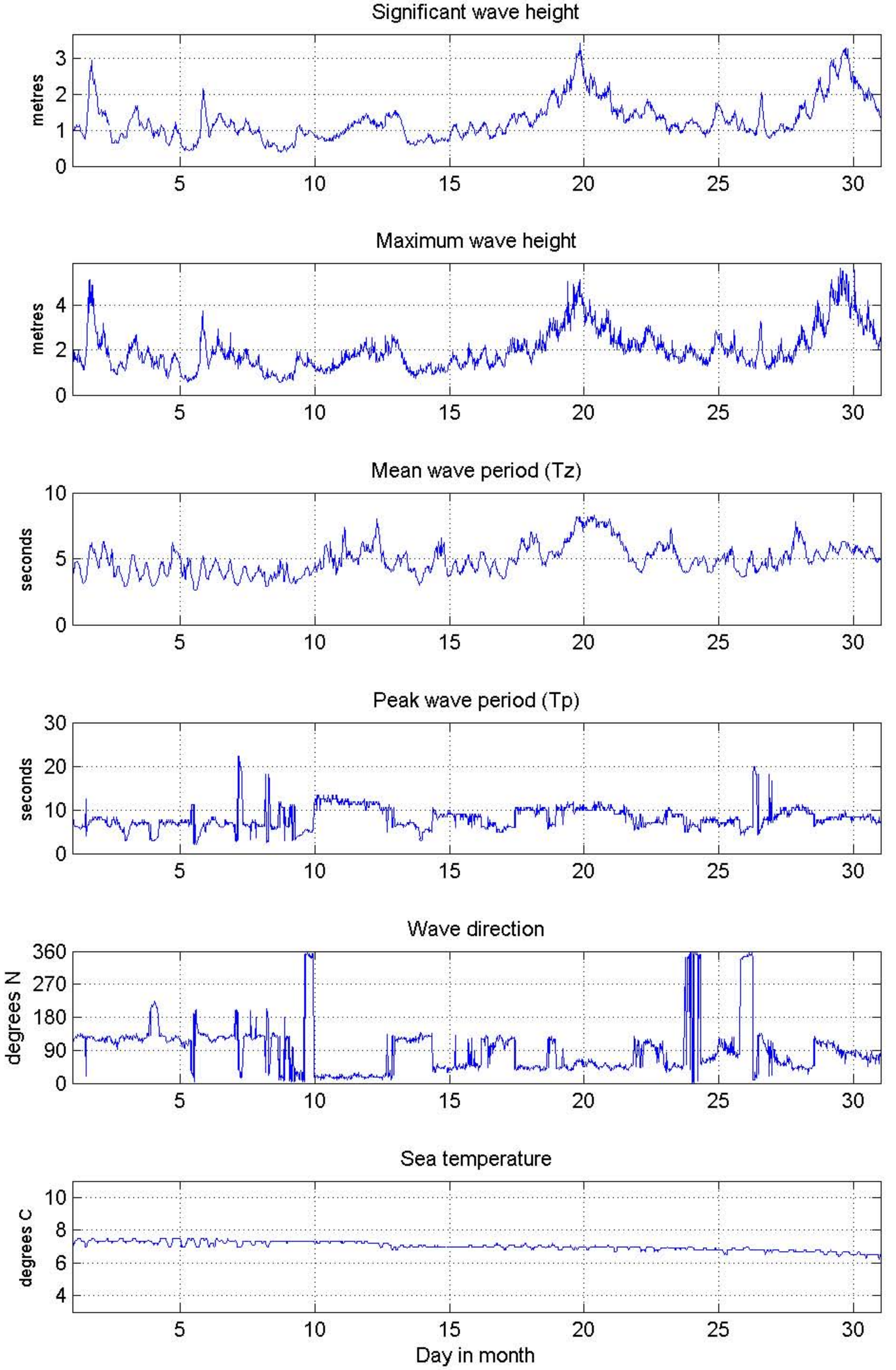
Whitby - March 2015



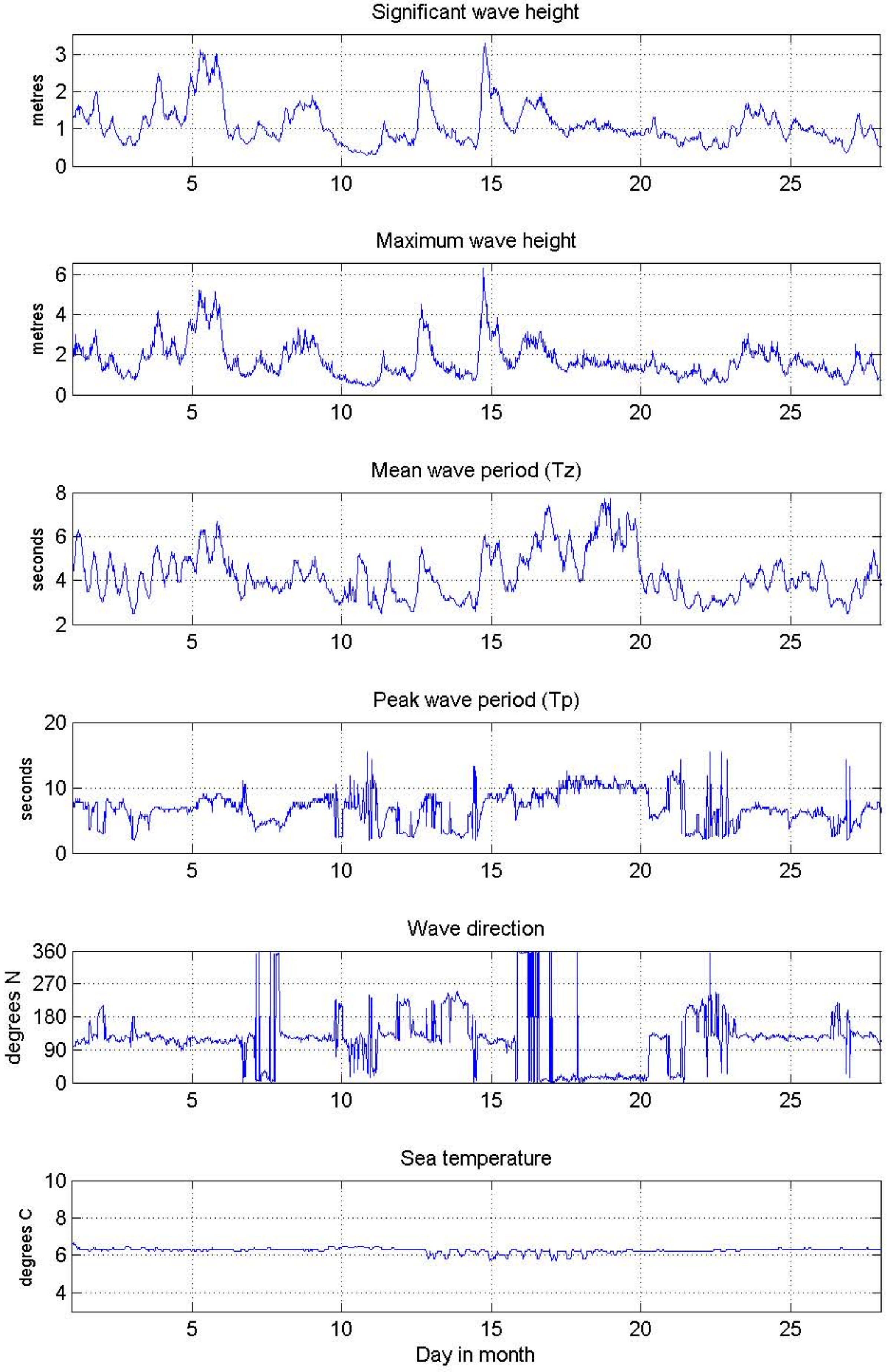
Appendix D

Supporting Graphs: Scarborough Wave Buoy

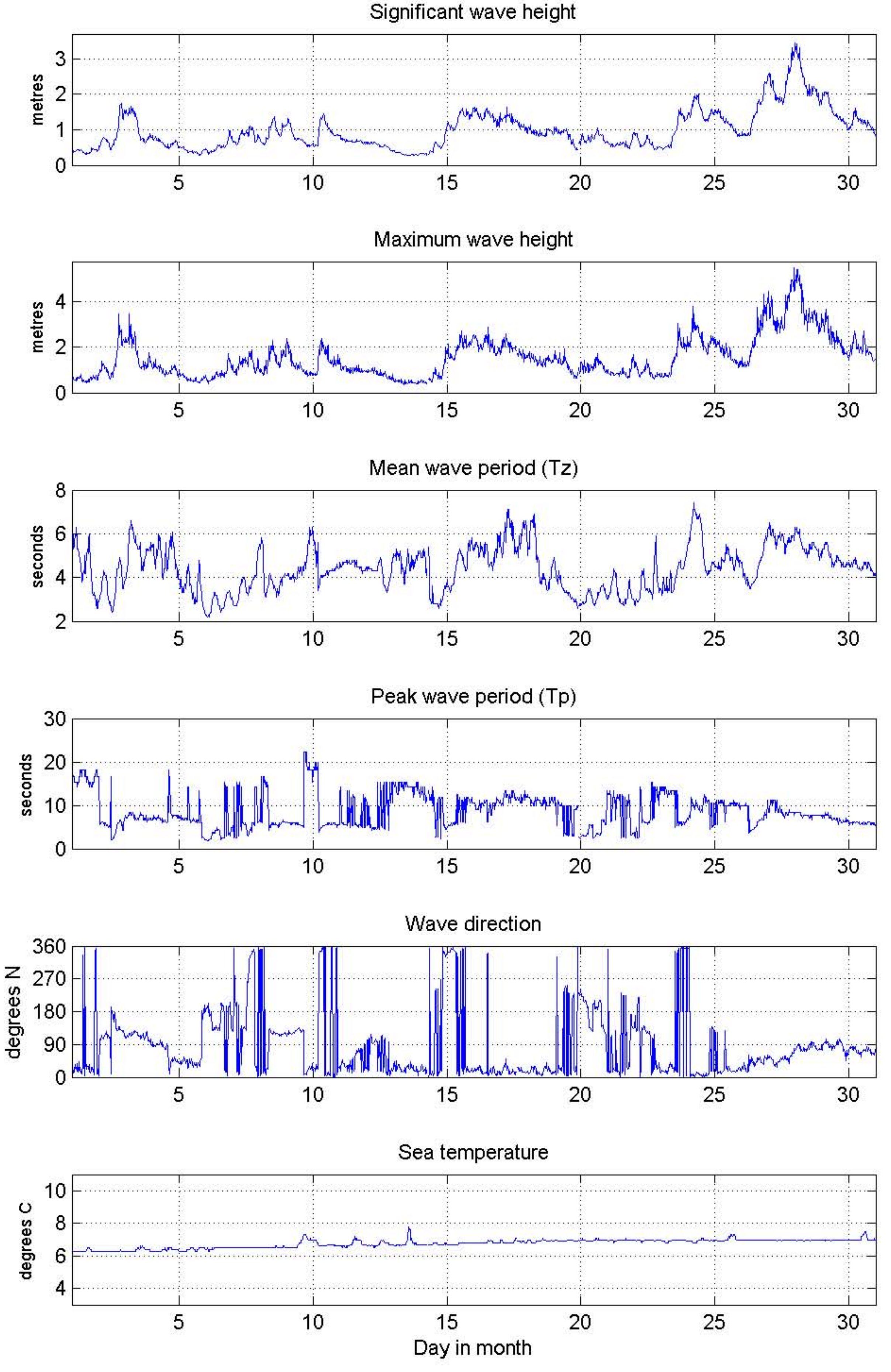
Scarborough - January 2014



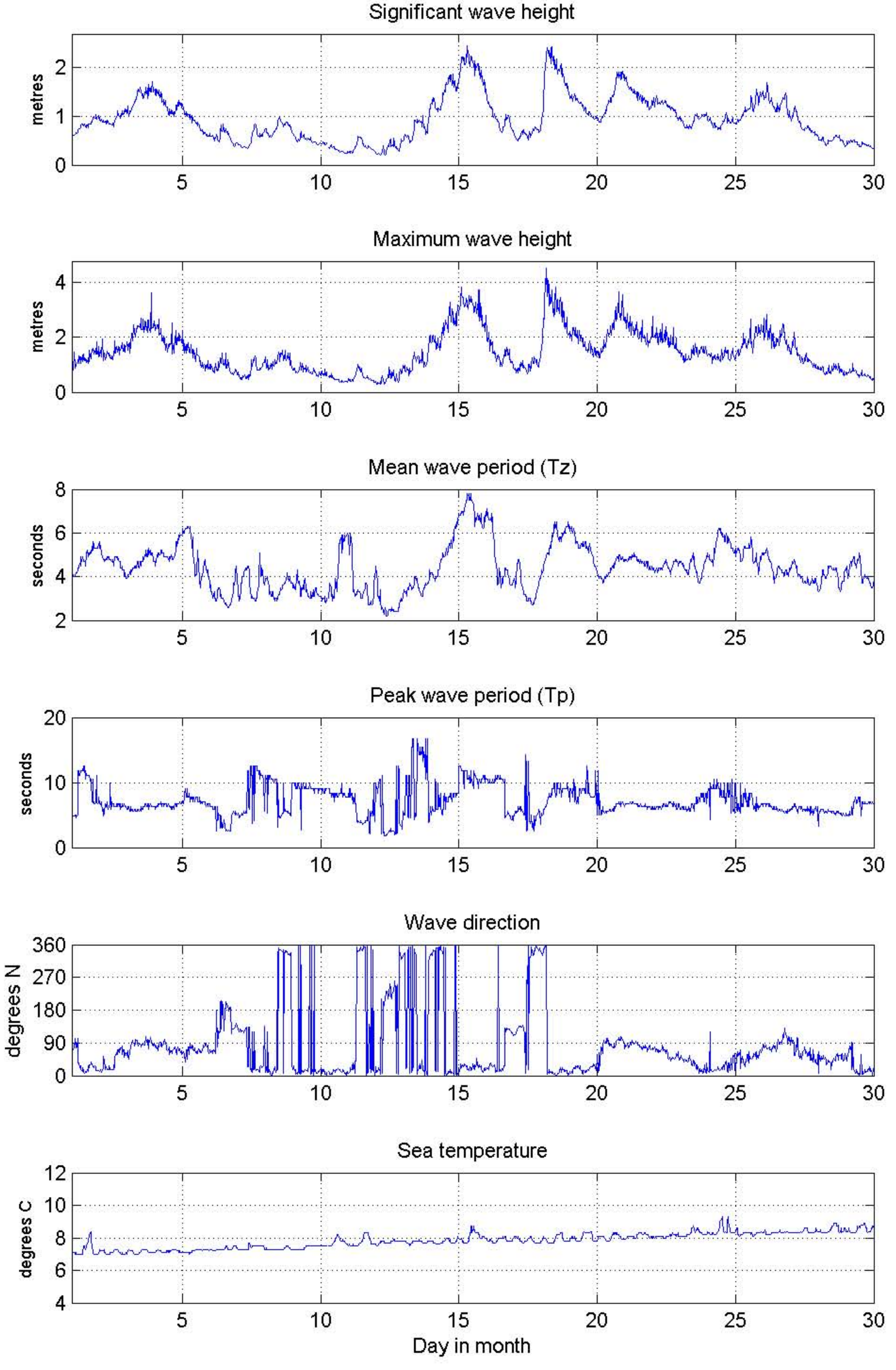
Scarborough - February 2014



Scarborough - March 2014

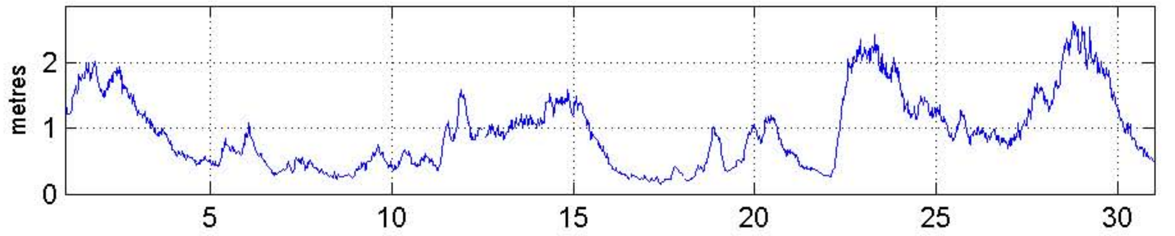


Scarborough - April 2014

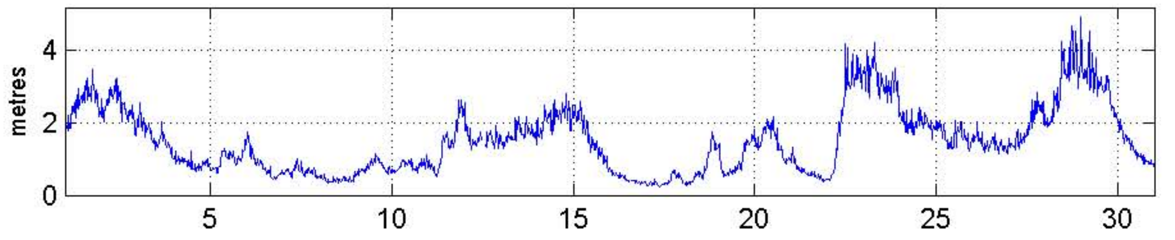


Scarborough - May 2014

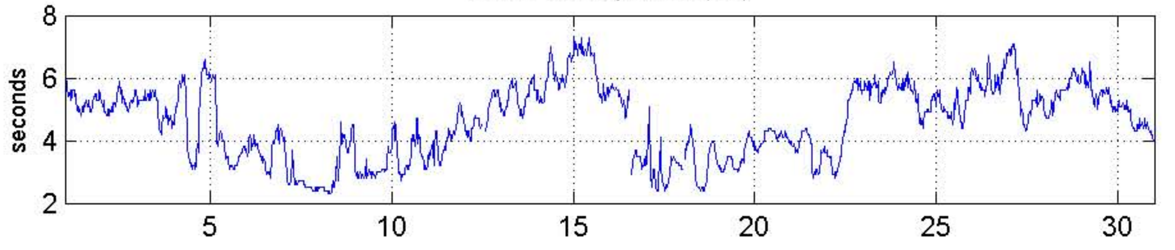
Significant wave height



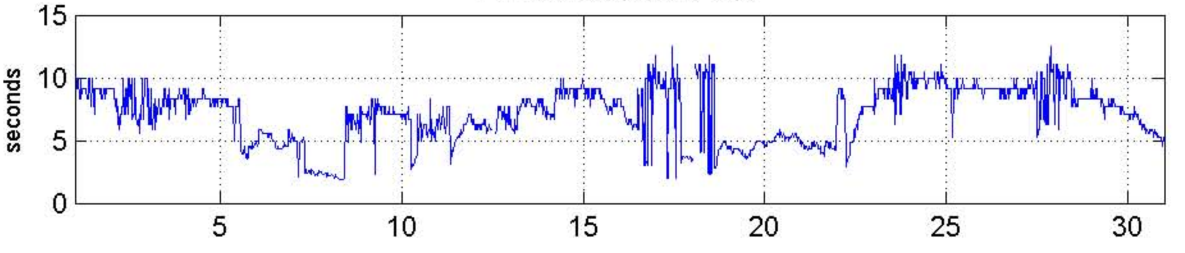
Maximum wave height



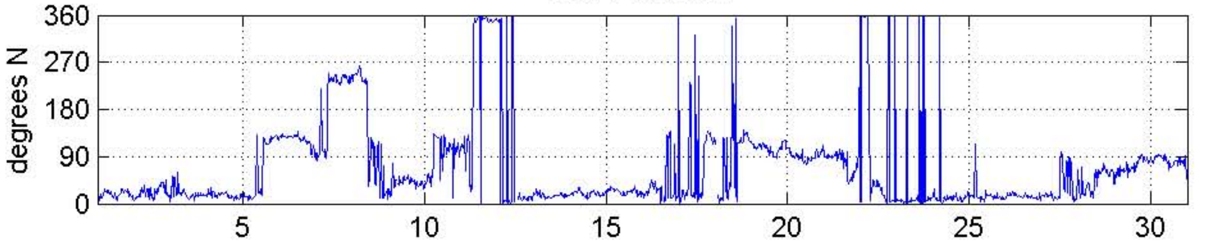
Mean wave period (Tz)



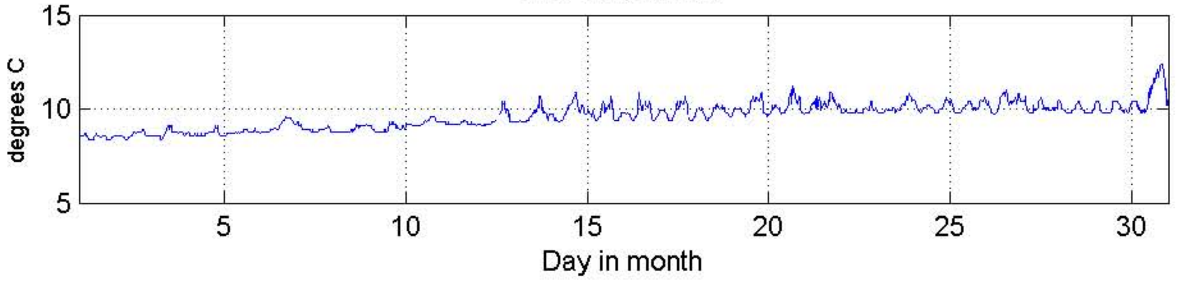
Peak wave period (Tp)



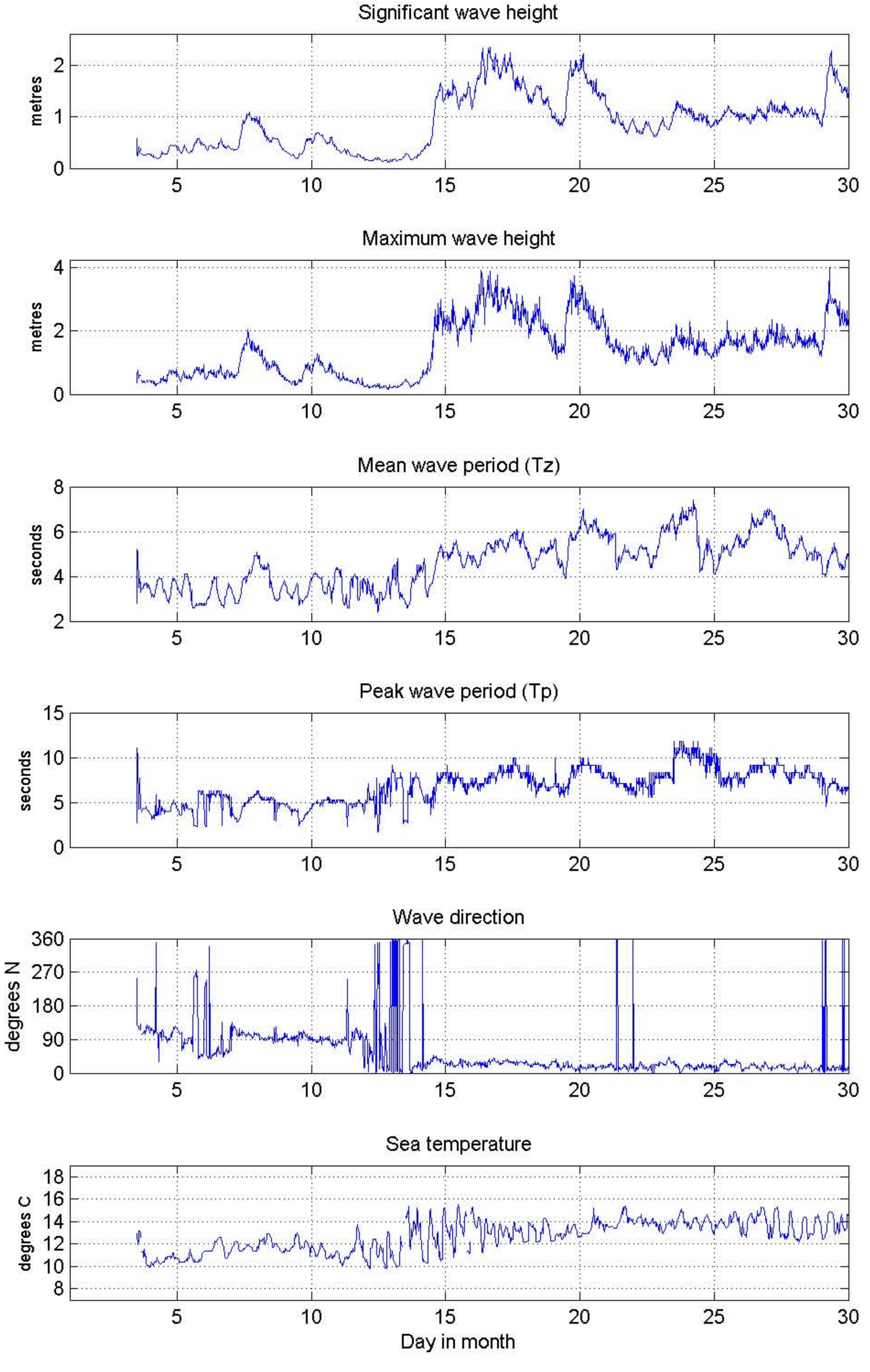
Wave direction



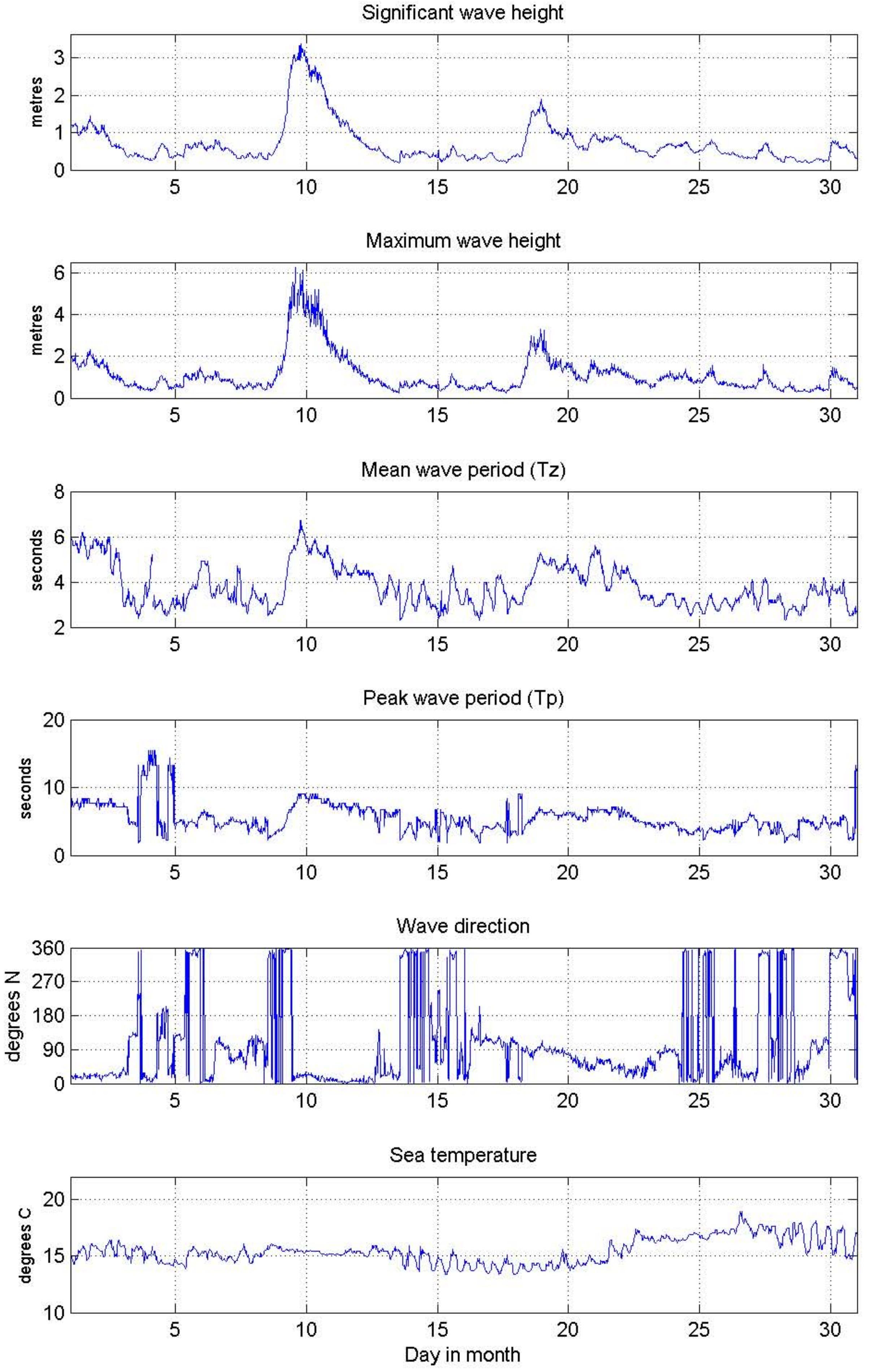
Sea temperature



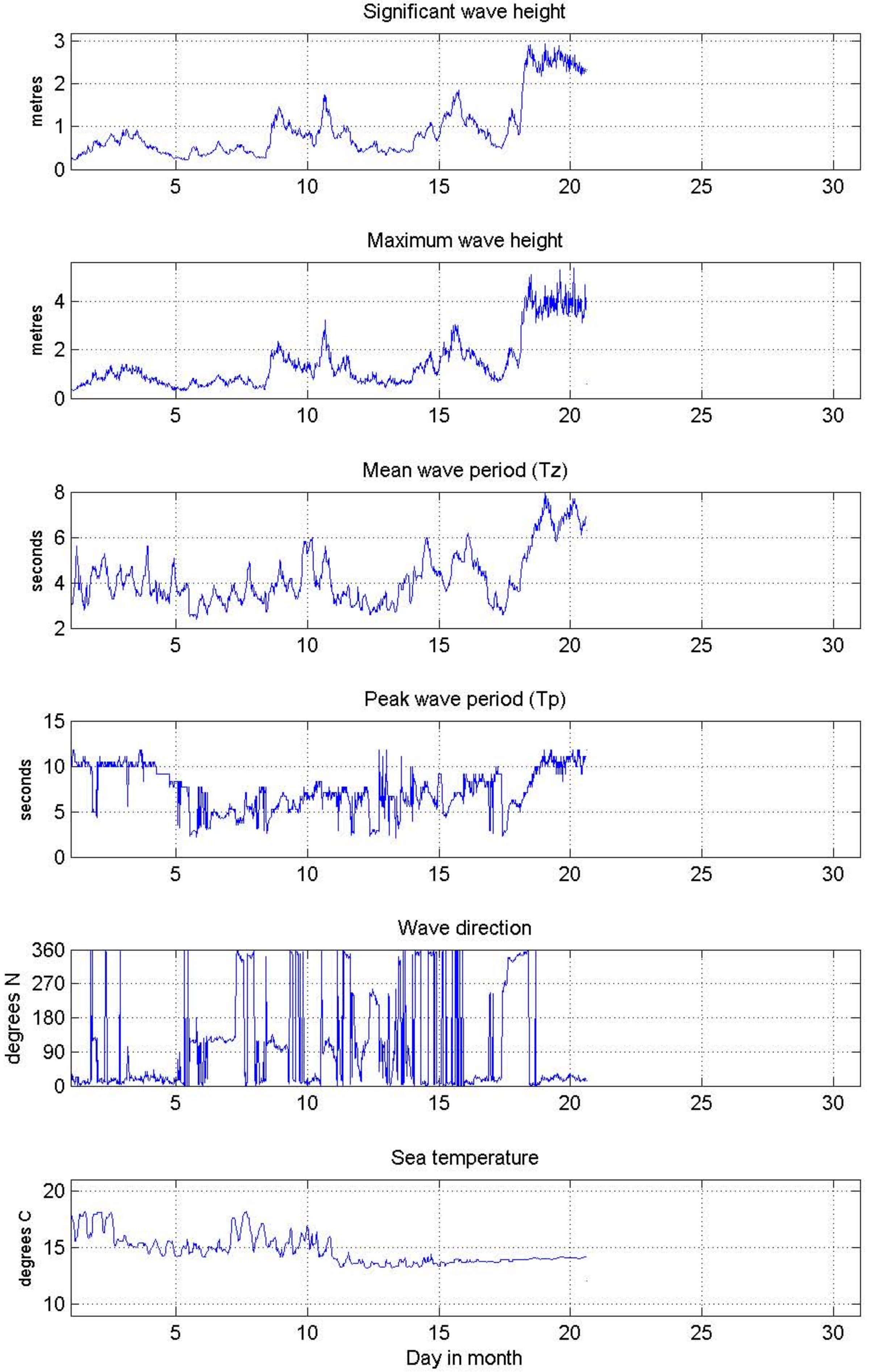
Scarborough - June 2014



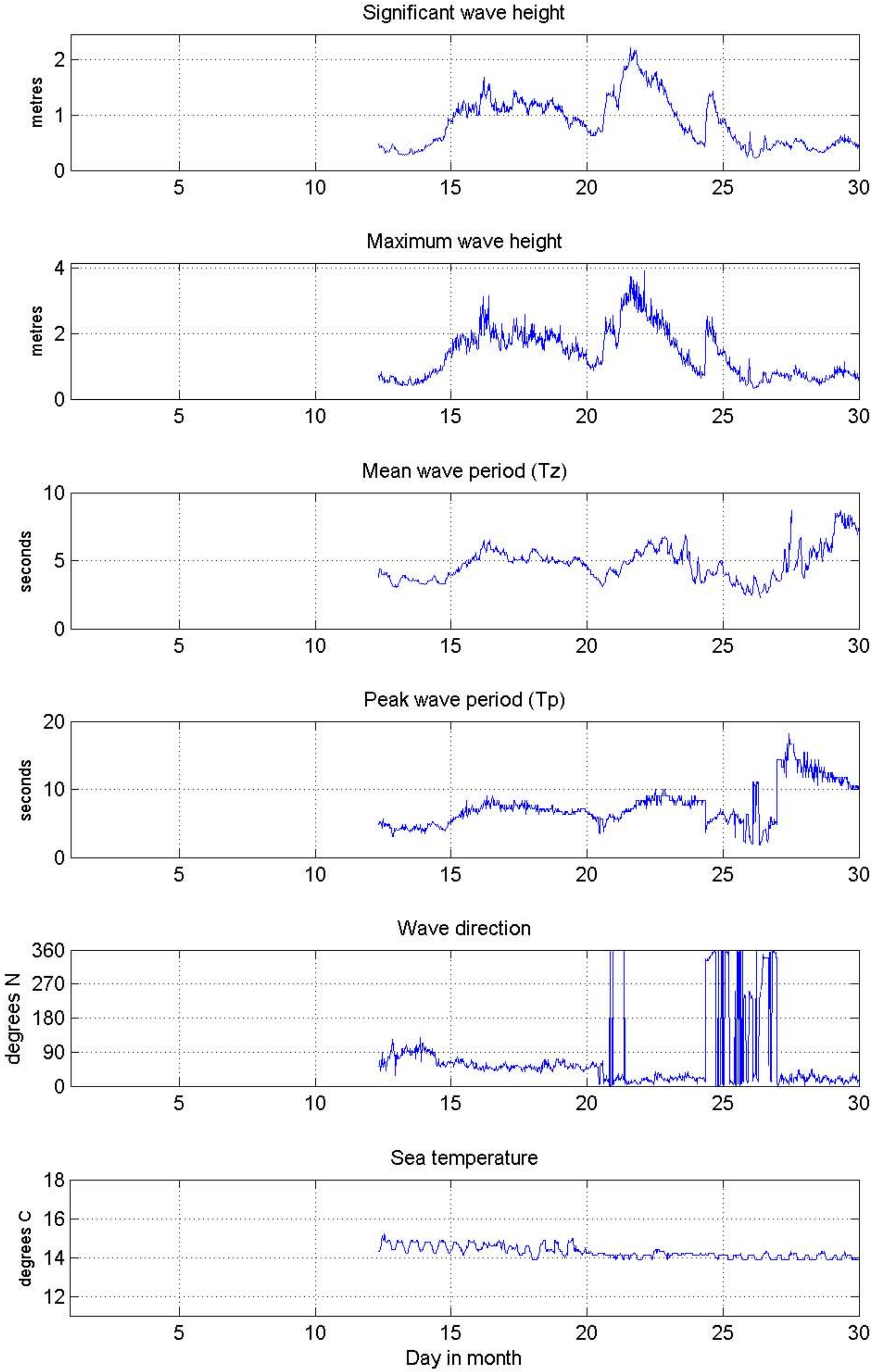
Scarborough - July 2014



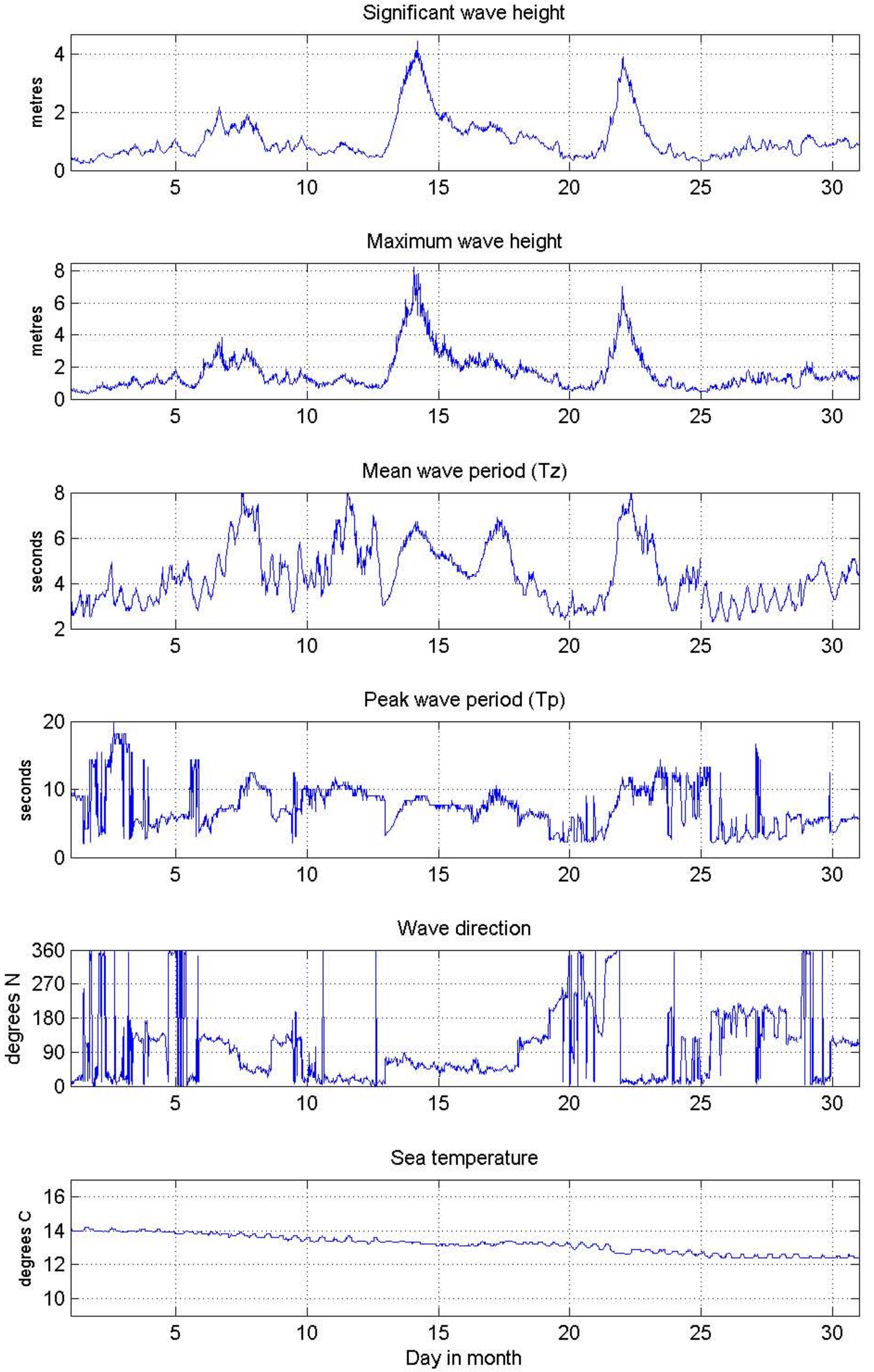
Scarborough - August 2014



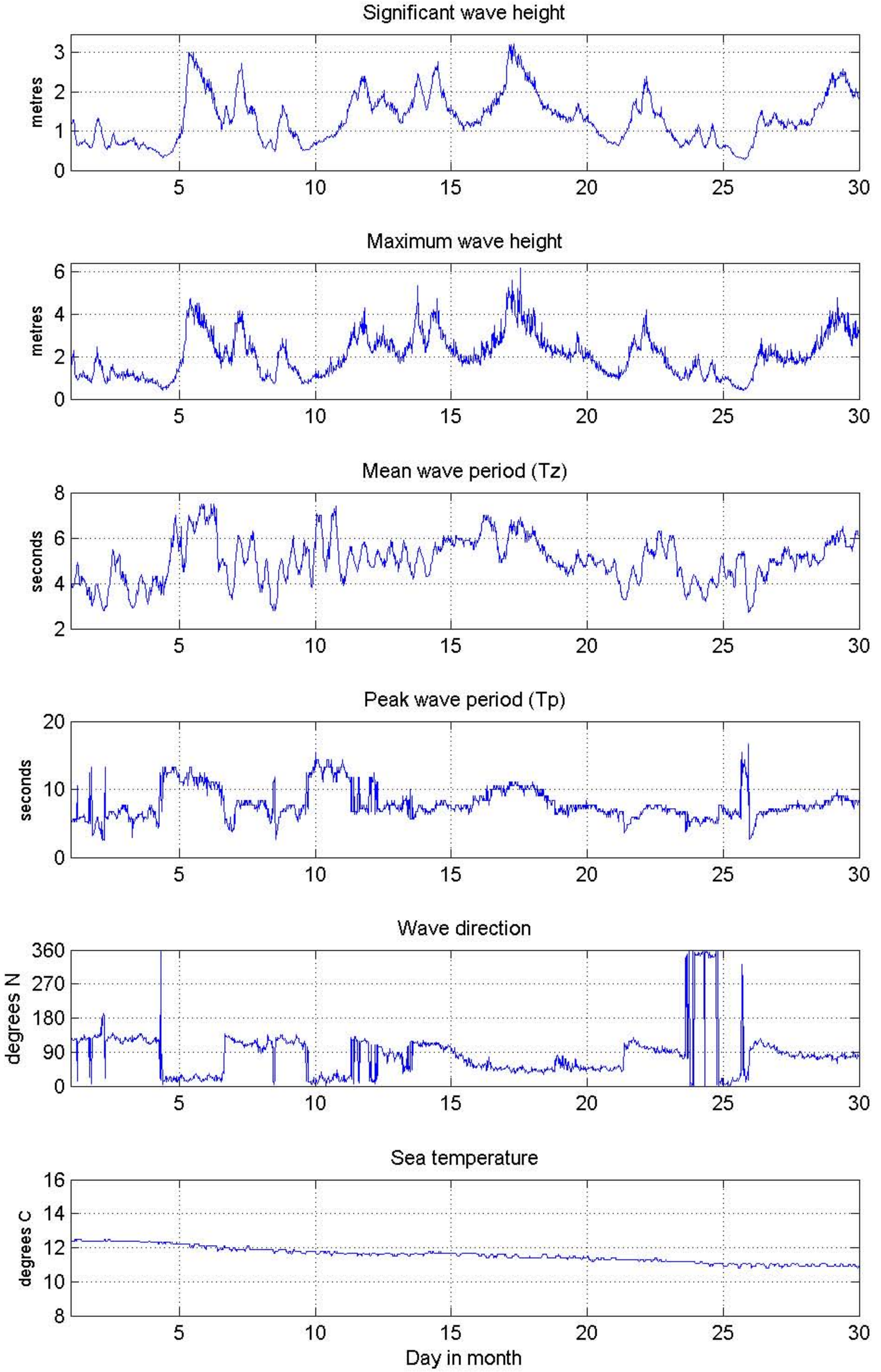
Scarborough - September 2014



Scarborough - October 2014



Scarborough - November 2014



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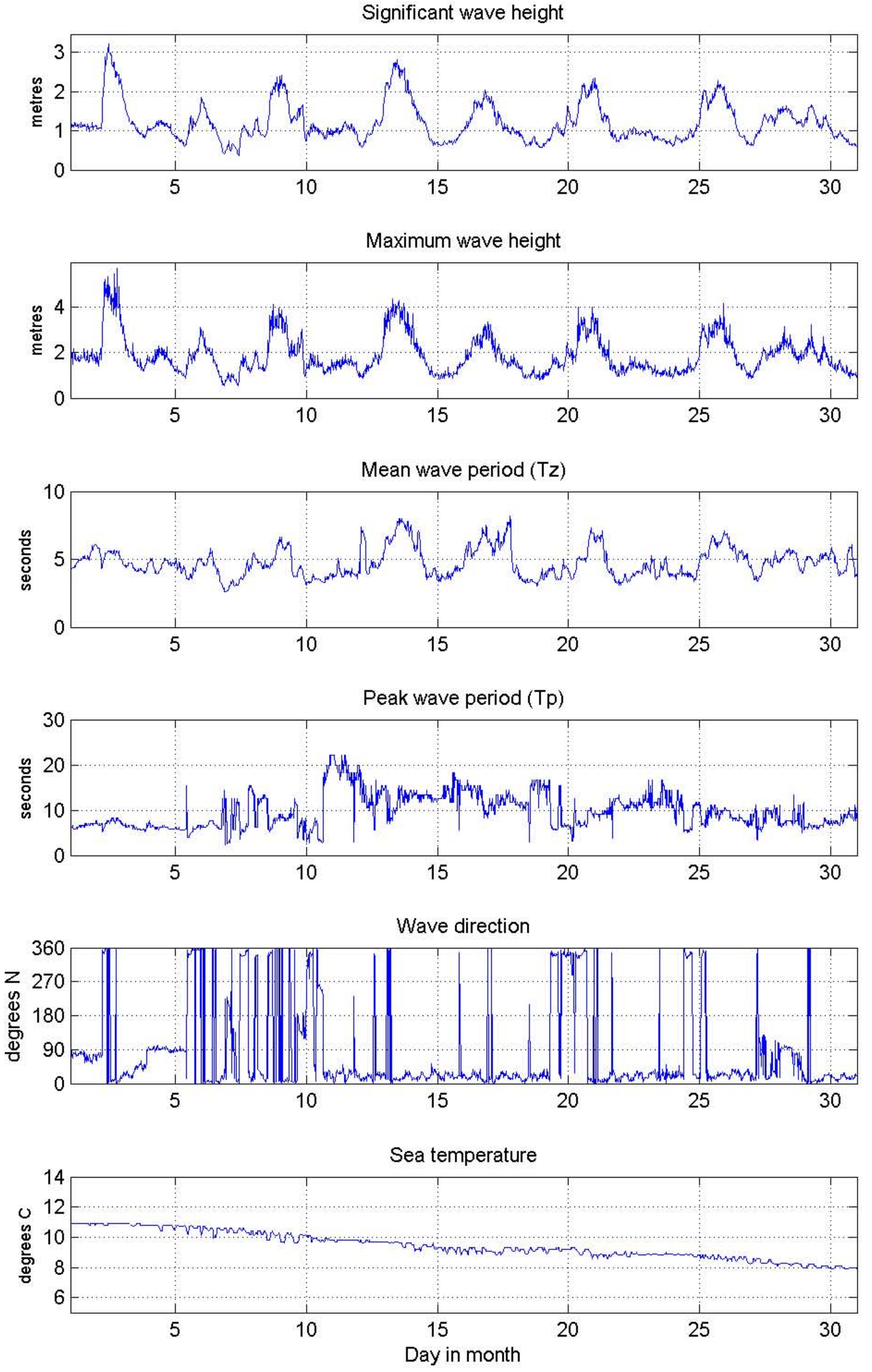

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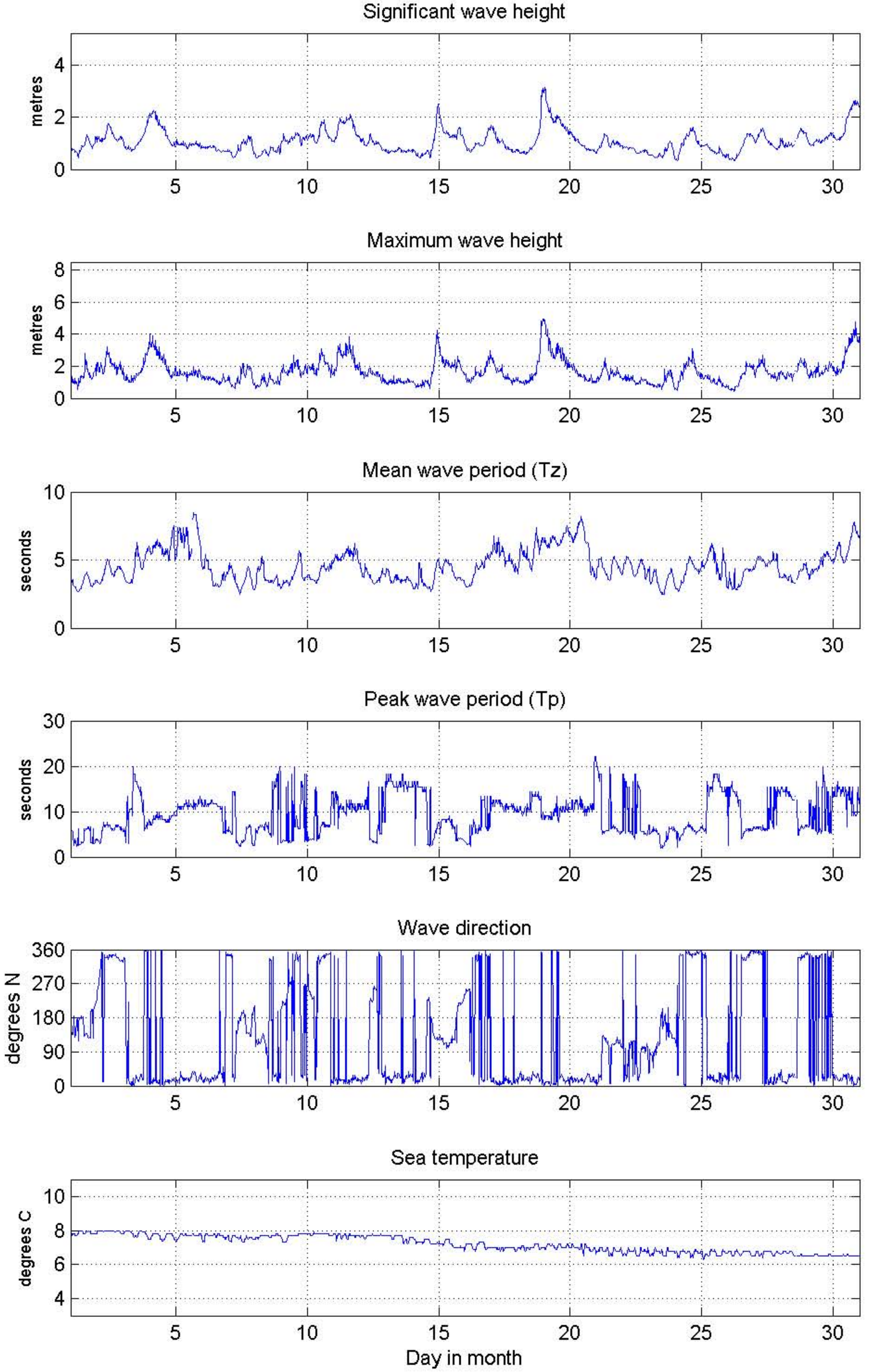

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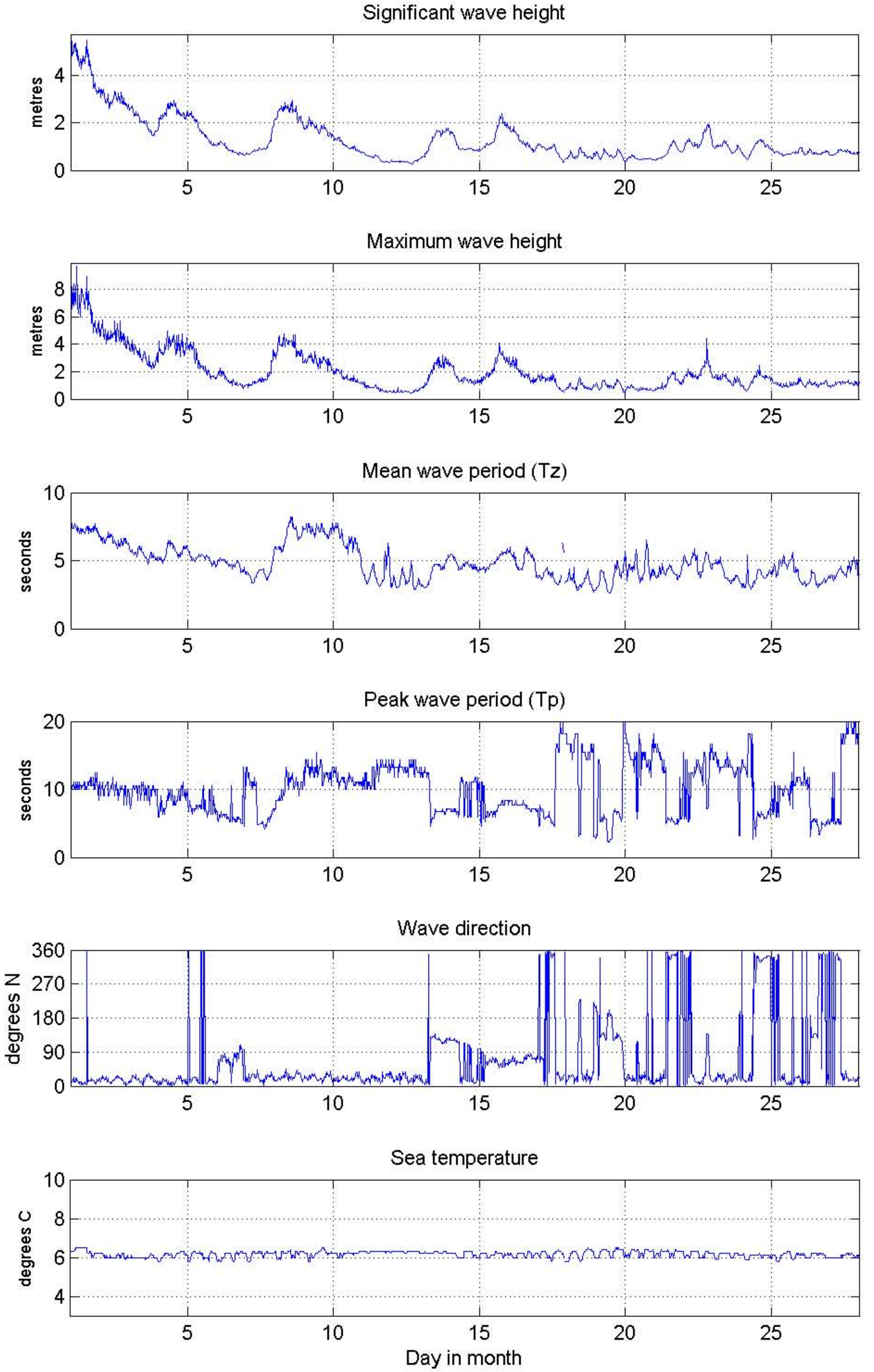
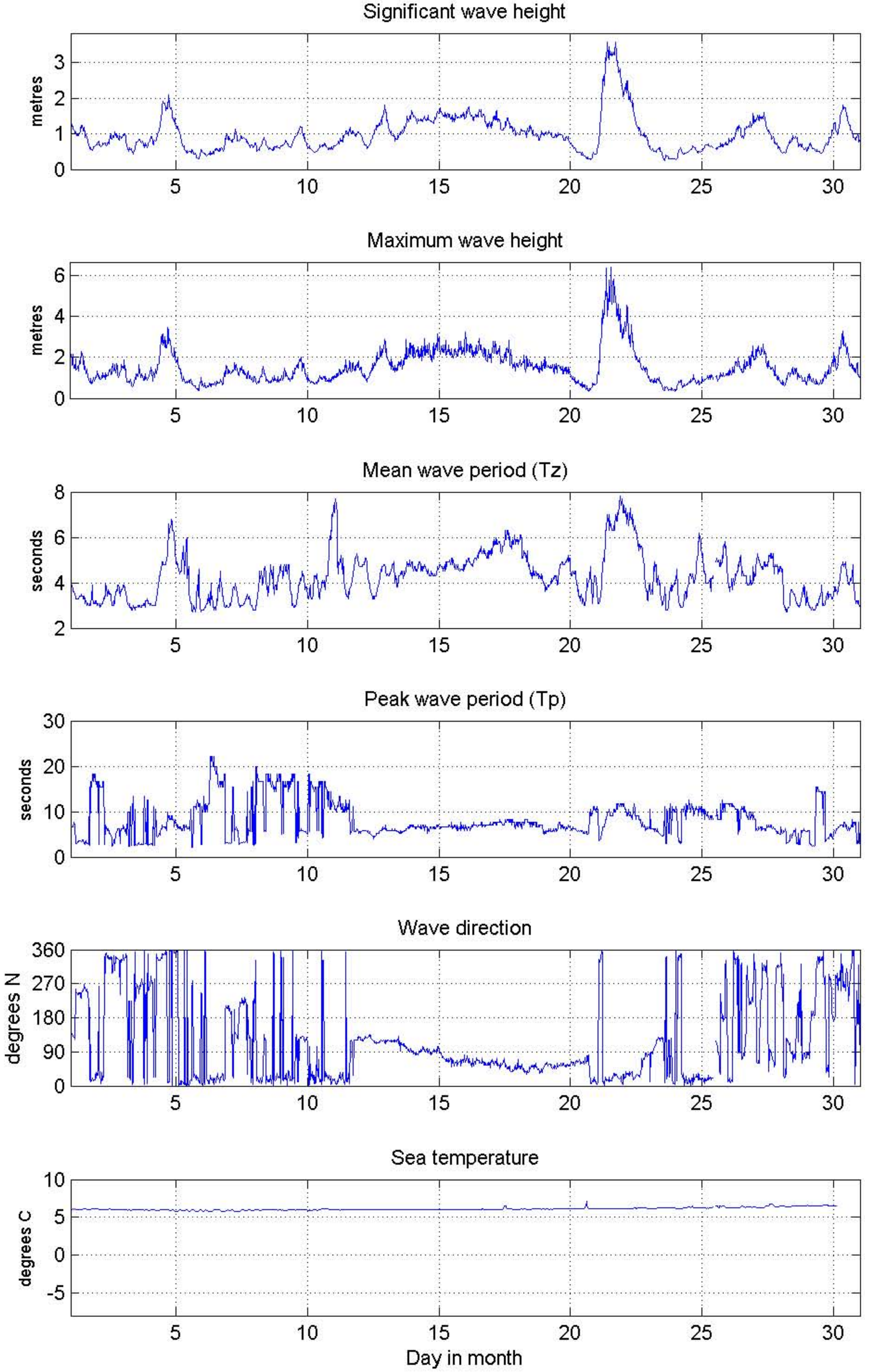


Scarborough - March 2015



Appendix E

Annual reports on Scarborough and Whitby tide gauges

Scarborough Tide Gauge

Location

OS: 504898E 488622N
WGS84: *Latitude:* 54° 16' 56.990"N *Longitude:* 00° 23' 25.0279"W

Instrument Type

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
88	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.

Measurements

The pressure transducer samples at 4Hz. Tidal elevations are derived, every 10 minutes, as the 40 second average of the 4Hz 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	3.40	04-Jan-2014 18:00	-2.39	06-Jan-2014 02:00
February	3.19	02-Feb-2014 17:50	-2.16	02-Feb-2014 11:20
March	3.12	03-Mar-2014 17:30	-2.22	03-Mar-2014 11:40
April	2.92	01-Apr-2014 17:10	-2.27	28-Apr-2014 22:00
May	2.67	17-May-2014 05:30	-2.32	14-May-2014 22:20
June	2.78	16-Jun-2014 06:10	-2.35	15-Jun-2014 12:00
July	3.05	15-Jul-2014 05:50	-2.42	16-Jul-2014 13:10
August	3.25	13-Aug-2014 05:20	-2.49	13-Aug-2014 12:20
September	3.20	10-Sep-2014 04:10	-2.54	11-Sep-2014 12:00
October	3.25	09-Oct-2014 04:00	-2.34	08-Oct-2014 10:00
November	-	-	-	-
December	2.98	23-Dec-2014 17:00	-2.34	26-Dec-2014 01:10

Month	Surge maxima		Surge minima	
	Value (m)	Date/Time	Value (m)	Date/Time
January	0.64	04-Jan-2014 14:50	-0.72	24-Jan-2014 23:50
February	0.59	28-Feb-2014 00:00	-0.52	12-Feb-2014 23:40
March	1.09	14-Mar-2014 23:50	-0.61	08-Mar-2014 17:00
April	0.61	13-Apr-2014 08:20	-0.20	16-Apr-2014 00:30
May	0.45	06-May-2014 20:50	-0.31	03-May-2014 06:20
June	0.37	19-Jun-2014 06:10	-0.08	17-Jun-2014 09:10
July	0.43	05-Jul-2014 06:00	-0.10	19-Jul-2014 07:20
August	0.44	10-Aug-2014 13:00	-0.26	03-Aug-2014 16:30
September	0.46	26-Sep-2014 14:00	-0.21	03-Sep-2014 13:50
October	1.16	21-Oct-2014 20:20	-0.41	22-Oct-2014 17:30
November	-	-	-	-
December	0.98	10-Dec-2014 03:10	-1.00	09-Dec-2014 16:50

Month	Mean Level	
	No. of days	Elevation (OD)
January	31	0.313
February	28	0.381
March	31	0.369
April	30	0.315
May	31	0.258
June	30	0.281
July	31	0.337
August	31	0.354
September	30	0.356
October	29	0.457
November	0	-
December	31	0.423

Highest values in 2014			
Extreme		**Surge**	
Elevation (OD) *(Surge component)*	Date/Time	Value (m)	Date/Time
3.40 *(0.51)*	04-Jan-2014 18:00	1.16	21-Oct-2014 20:20
3.25 *(0.11)*	13-Aug-2014 05:20	1.09	14-Mar-2014 23:50
3.25 *(0.09)*	09-Oct-2014 04:00	1.03	14-Mar-2014 23:40
3.23 *(0.07)*	10-Oct-2014 04:40	1.02	21-Oct-2014 22:40
3.20 *(0.02)*	10-Sep-2014 04:10	0.98	10-Dec-2014 03:10
3.19 *(0.25)*	02-Feb-2014 17:50	0.92	10-Dec-2014 02:10
3.17 *(-0.10)*	11-Sep-2014 05:10	0.80	08-Mar-2014 00:20
3.17 *(0.09)*	14-Aug-2014 06:10	0.68	09-Mar-2014 07:00
3.14 *(0.06)*	12-Aug-2014 04:40	0.64	04-Jan-2014 14:50
3.12 *(0.21)*	03-Mar-2014 17:30	0.62	04-Jan-2014 13:40

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%

***** 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.

Acknowledgement

Tidal predictions were produced using the TASK windows edition software, kindly provided by the Marine Data Products team at the UK National Oceanography Centre (Liverpool).

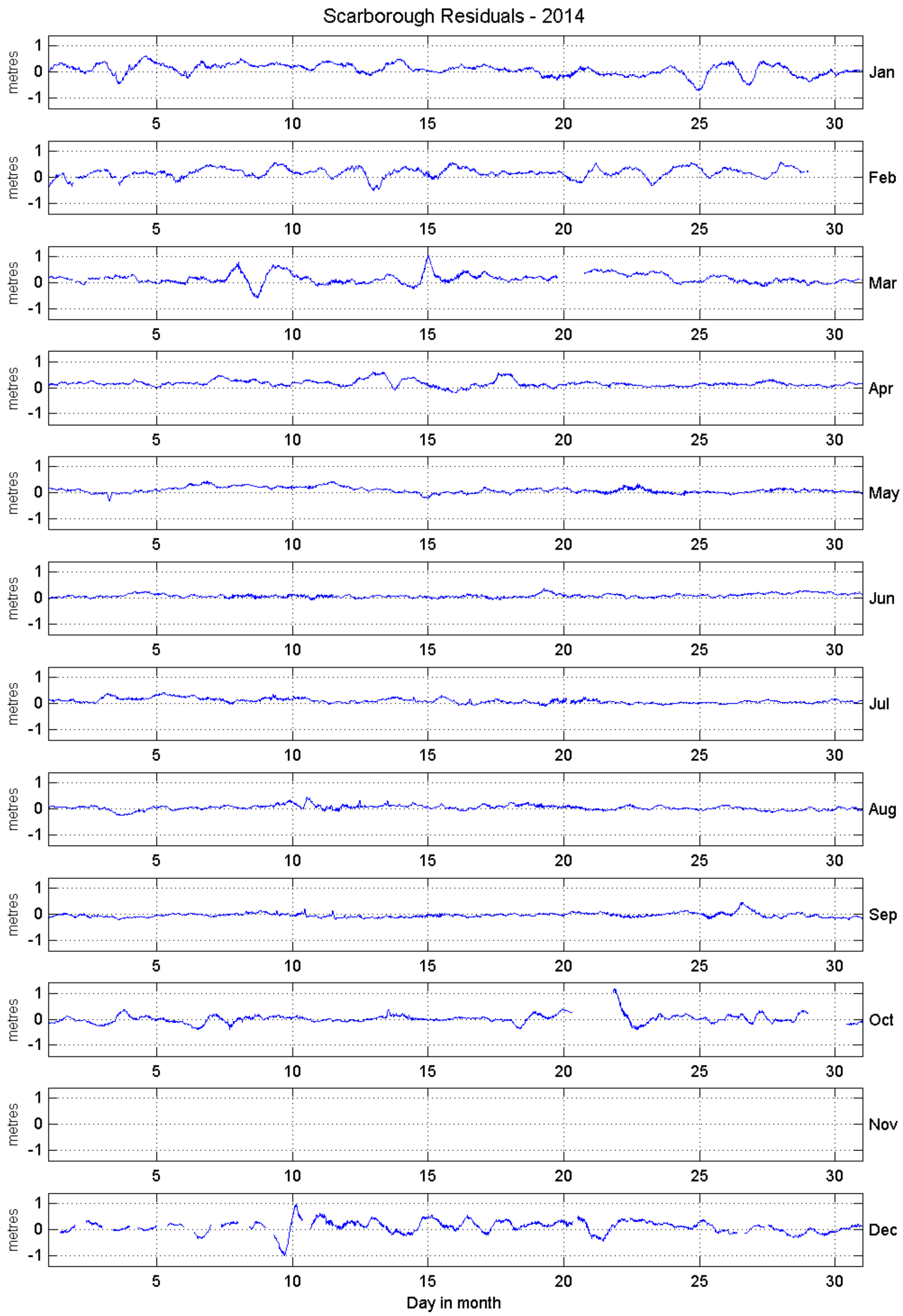


Figure 1: Scarborough residuals for 2014

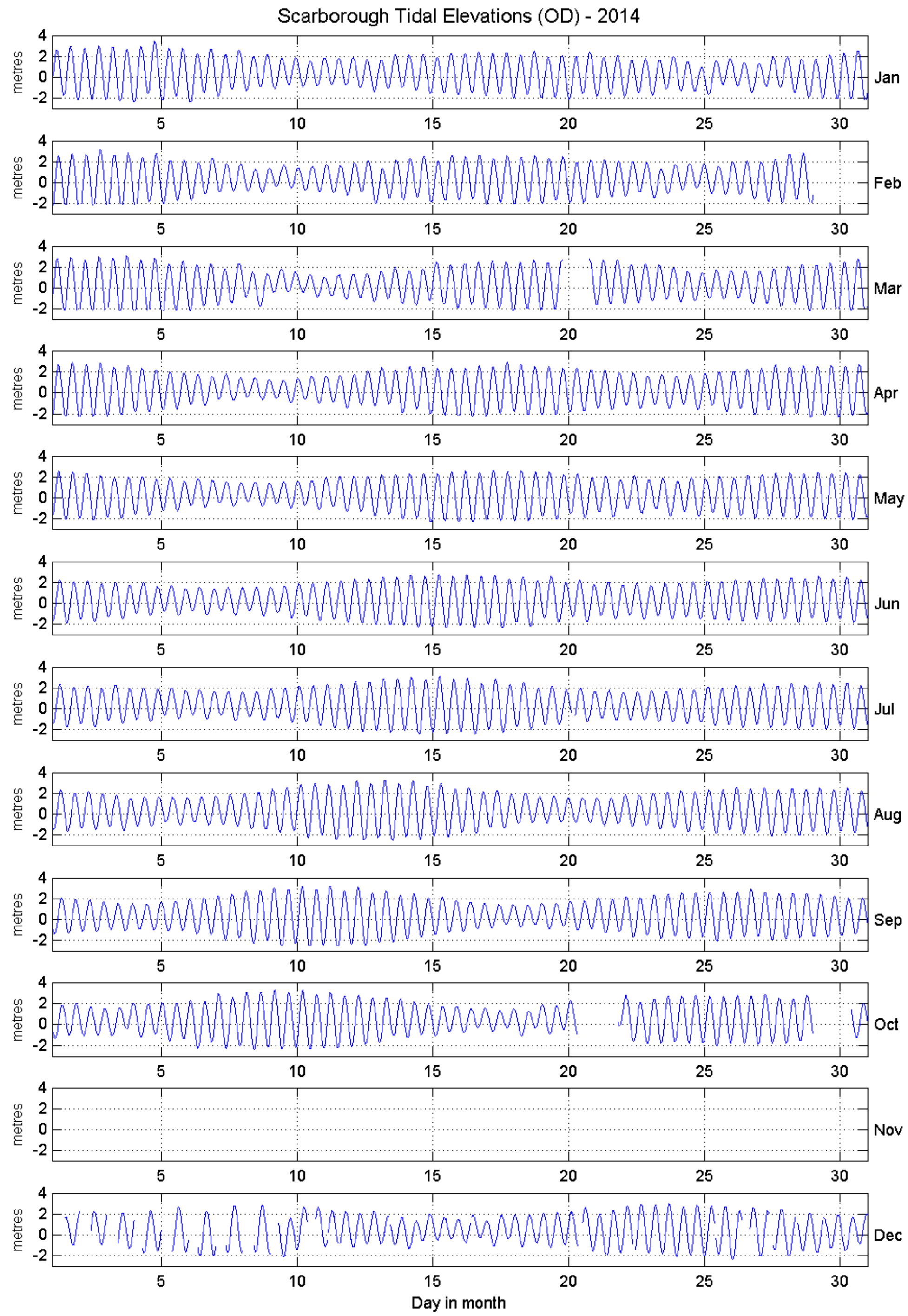


Figure 2: Scarborough tidal elevations for 201 relative to Ordnance Datum

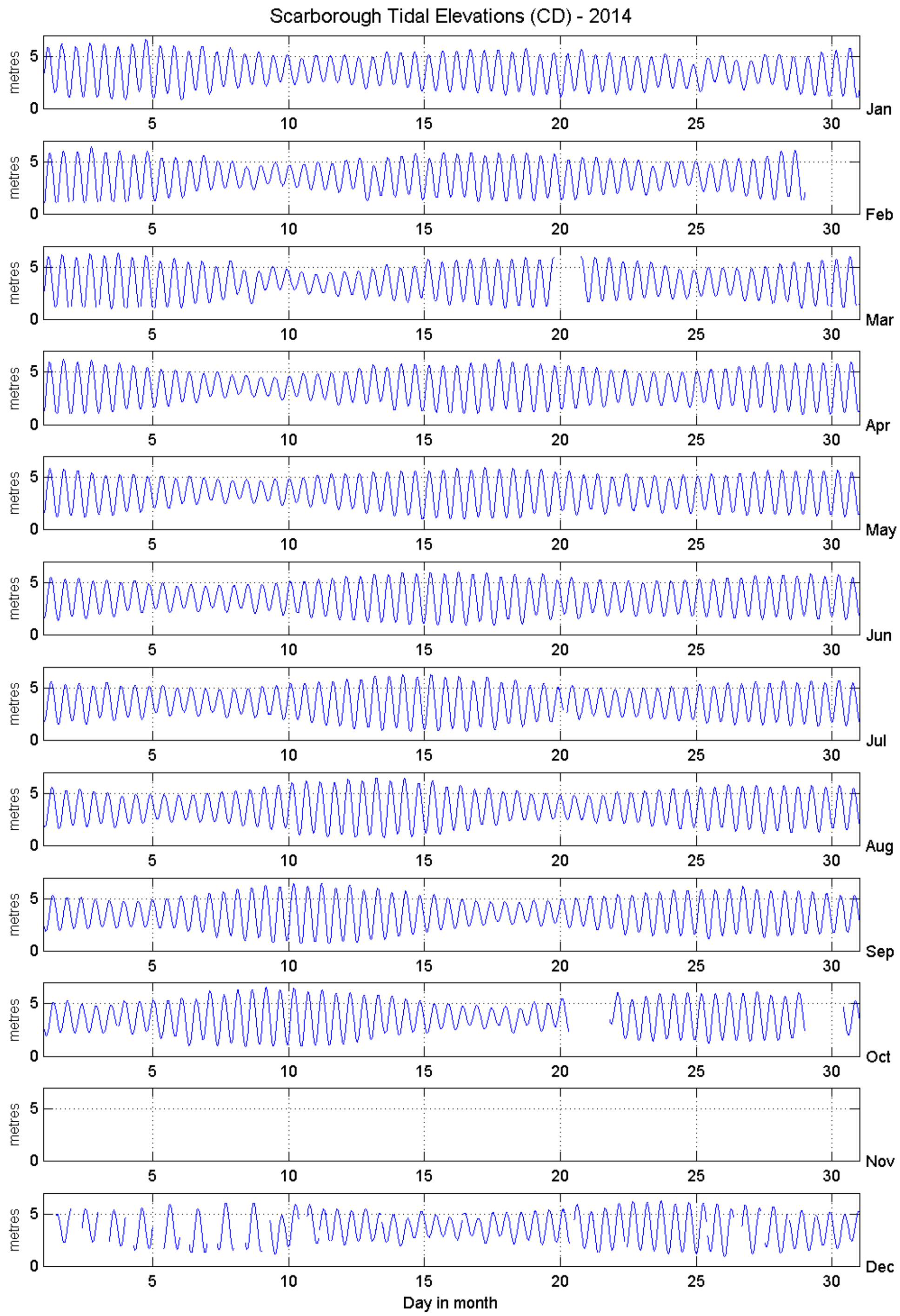


Figure 3: Scarborough tidal elevations for 2014 relative to Chart Datum

Whitby Harbour Tide Gauge

Location

OS: 489842E 511247N
WGS84: *Latitude:* 54° 29' 19.0731"N *Longitude:* 00° 36' 52.6886"W

Instrument Type

Valeport Tidemaster (Drück Pressure Transducer)

Benchmarks

Benchmark	*Description*
TGBM = 4.453m 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. The tide gauge transducer is fixed to a weighted stainless steel strop located in a stilling well.

Data Quality

Recovery rate (%)	Sample interval
95	10 minutes

Service history

The gauge was first deployed on 8 May 2013 and is serviced at 6-monthly intervals.

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 s 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	2.50	31-Jan-2014 03:50	-2.93	31-Jan-2014 22:40
February	3.09	02-Feb-2014 17:40	-2.93	01-Feb-2014 23:20
March	3.02	03-Mar-2014 17:20	-2.75	01-Mar-2014 22:20
April	2.82	01-Apr-2014 17:00	-2.40	15-Apr-2014 22:20
May	2.55	17-May-2014 05:20	-2.32	14-May-2014 21:50
June	2.67	16-Jun-2014 05:50	-2.47	15-Jun-2014 11:30
July	2.92	15-Jul-2014 05:40	-2.63	16-Jul-2014 12:50
August	3.15	13-Aug-2014 05:20	-2.72	12-Aug-2014 11:10
September	3.10	10-Sep-2014 04:20	-2.77	10-Sep-2014 10:40
October	3.14	09-Oct-2014 03:50	-2.44	08-Oct-2014 09:40
November	2.91	08-Nov-2014 04:20	-2.40	06-Nov-2014 09:20
December	2.92	23-Dec-2014 16:40	-2.44	26-Dec-2014 00:40

Month	Surge maxima		Surge minima	
	Value (m)	Date/Time	Value (m)	Date/Time
January	0.31	27-Jan-2014 08:50	-0.84	24-Jan-2014 21:00
February	0.45	24-Feb-2014 17:50	-0.67	13-Feb-2014 00:40
March	0.87	14-Mar-2014 23:30	-0.72	08-Mar-2014 15:40
April	0.46	18-Apr-2014 00:00	-0.29	16-Apr-2014 00:20
May	0.31	11-May-2014 13:10	-0.30	15-May-2014 00:00
June	0.29	19-Jun-2014 06:20	-0.19	17-Jun-2014 15:10
July	0.28	04-Jul-2014 23:40	-0.17	23-Jul-2014 17:50
August	0.39	10-Aug-2014 13:00	-0.32	03-Aug-2014 17:30
September	0.47	26-Sep-2014 12:30	-0.22	03-Sep-2014 16:30
October	1.06	21-Oct-2014 20:20	-0.38	22-Oct-2014 17:00
November	0.31	02-Nov-2014 17:10	-0.41	06-Nov-2014 20:50
December	0.78	10-Dec-2014 02:40	-0.93	09-Dec-2014 17:10

Month	Mean Level	
	No. of days	Elevation (OD)
January	16	0.151
February	28	0.301
March	31	0.256
April	30	0.271
May	31	0.226
June	30	0.257
July	31	0.304
August	31	0.324
September	30	0.319
October	31	0.426
November	30	0.376
December	31	0.387

Highest values in 2014			
Extreme		Surge	
Elevation (OD) *(Surge component)*	Date/Time	Value (m)	Date/Time
3.15 *(0.16)*	13-Aug-2014 05:20	1.06	21-Oct-2014 20:20
3.14 *(0.13)*	10-Oct-2014 04:30	0.95	21-Oct-2014 22:20
3.14 *(0.13)*	09-Oct-2014 03:50	0.87	14-Mar-2014 23:30
3.10 *(0.07)*	10-Sep-2014 04:20	0.83	14-Mar-2014 23:00
3.09 *(0.17)*	02-Feb-2014 17:40	0.78	10-Dec-2014 02:40
3.06 *(0.13)*	14-Aug-2014 06:00	0.78	10-Dec-2014 01:50
3.04 *(-0.04)*	11-Sep-2014 05:00	0.63	07-Mar-2014 22:50
3.03 *(0.11)*	12-Aug-2014 04:30	0.54	11-Dec-2014 00:10
3.02 *(0.12)*	03-Mar-2014 17:20	0.48	11-Dec-2014 04:10
2.96 *(0.07)*	02-Mar-2014 16:40	0.48	09-Mar-2014 06:10

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%

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.

Acknowledgement

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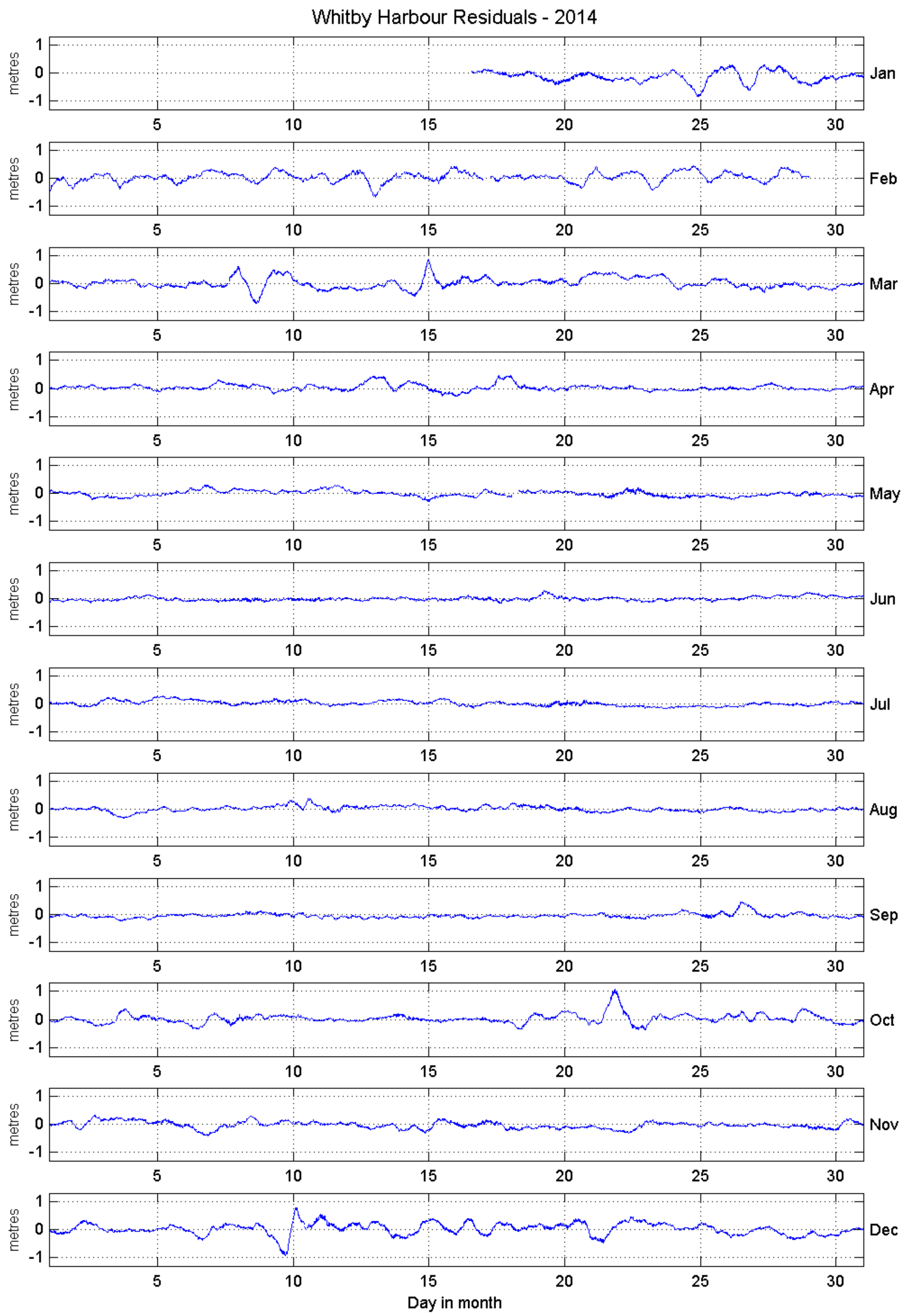


Figure 1: Whitby Harbour residuals for 2014

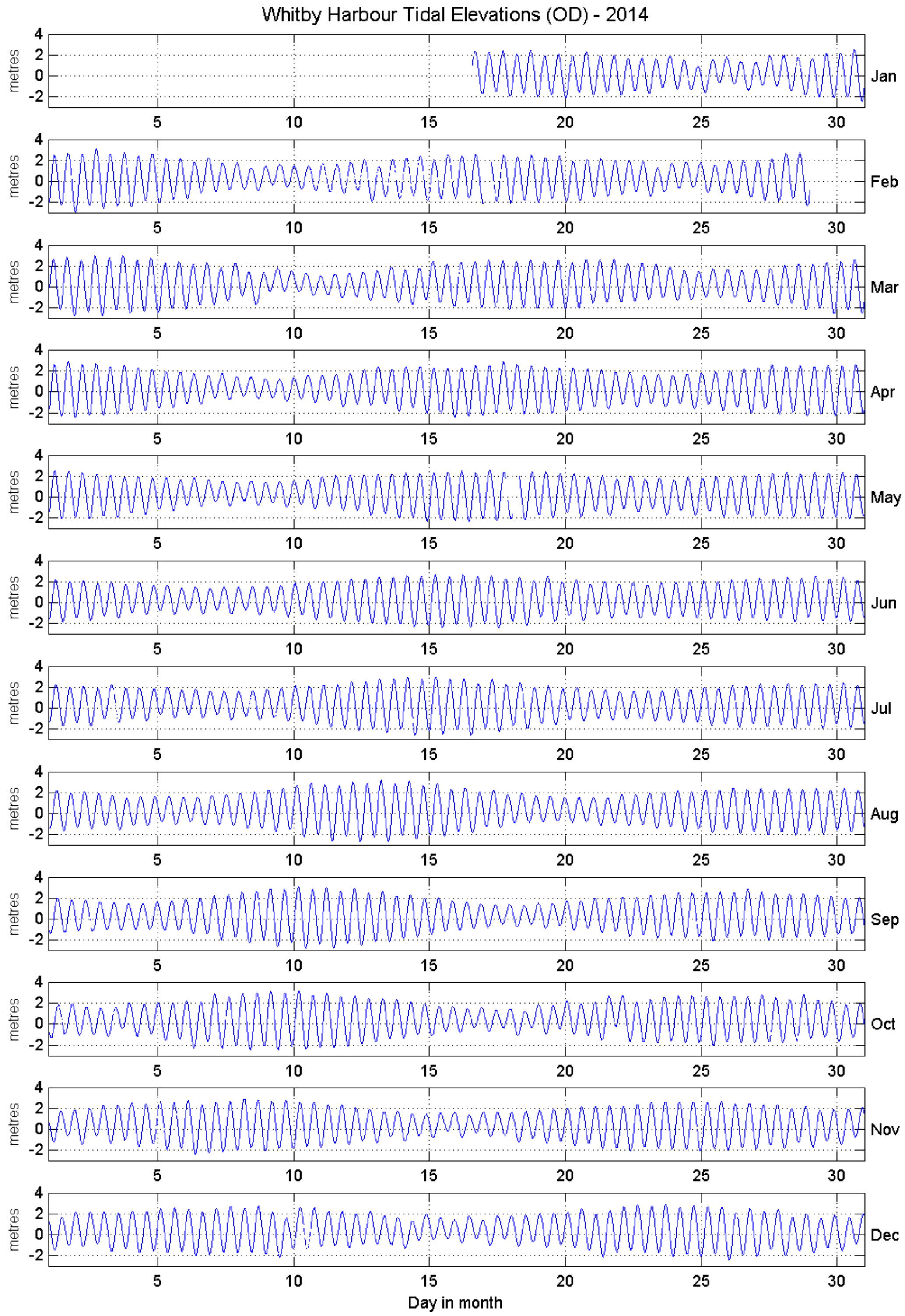


Figure 2: Whitby Harbour tidal elevations for 2014 relative to Ordnance Datum

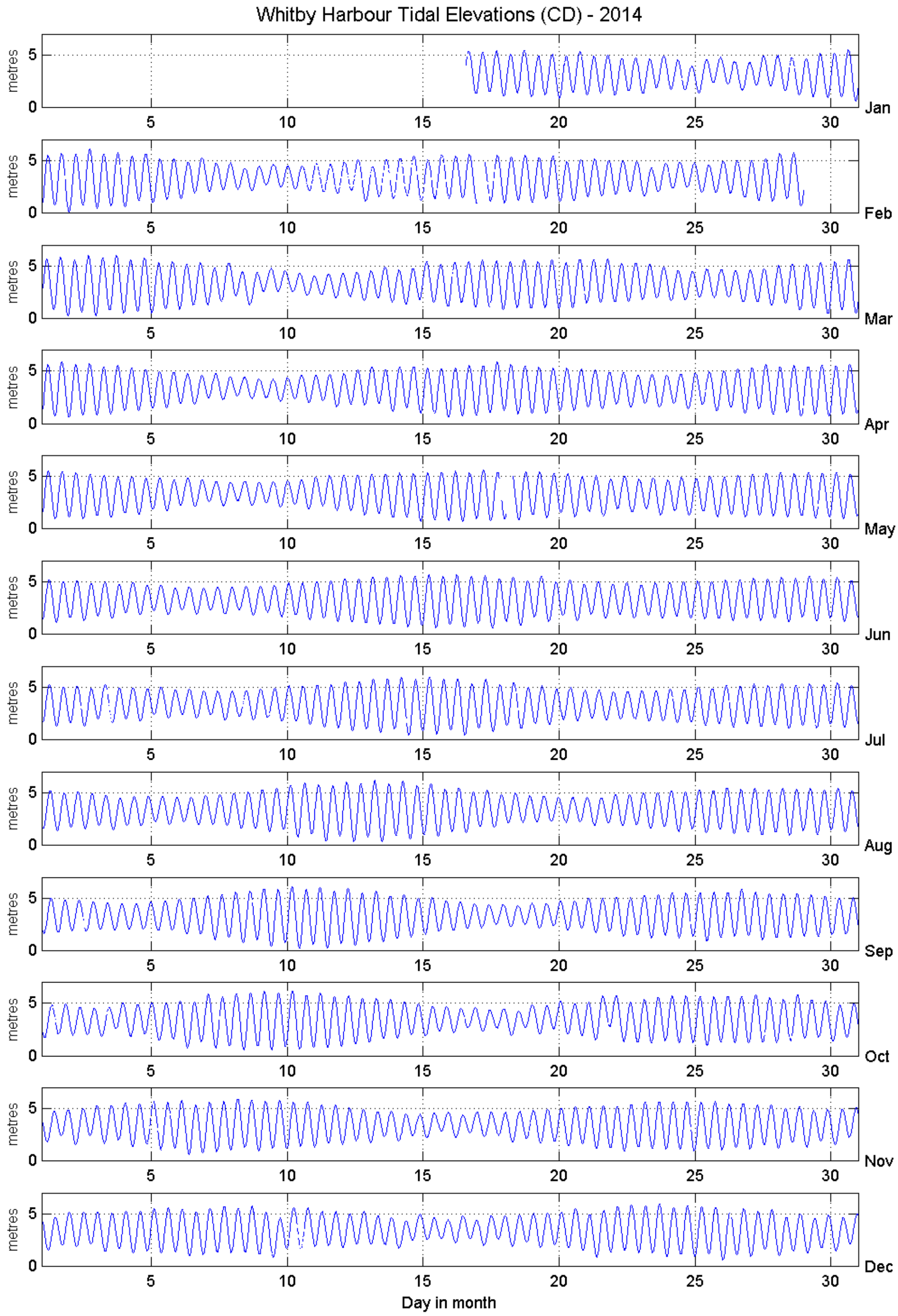


Figure 3: Whitby Harbour tidal elevations for 2014 relative to Chart Datum

Appendix F

Fugro report on instrument deployments

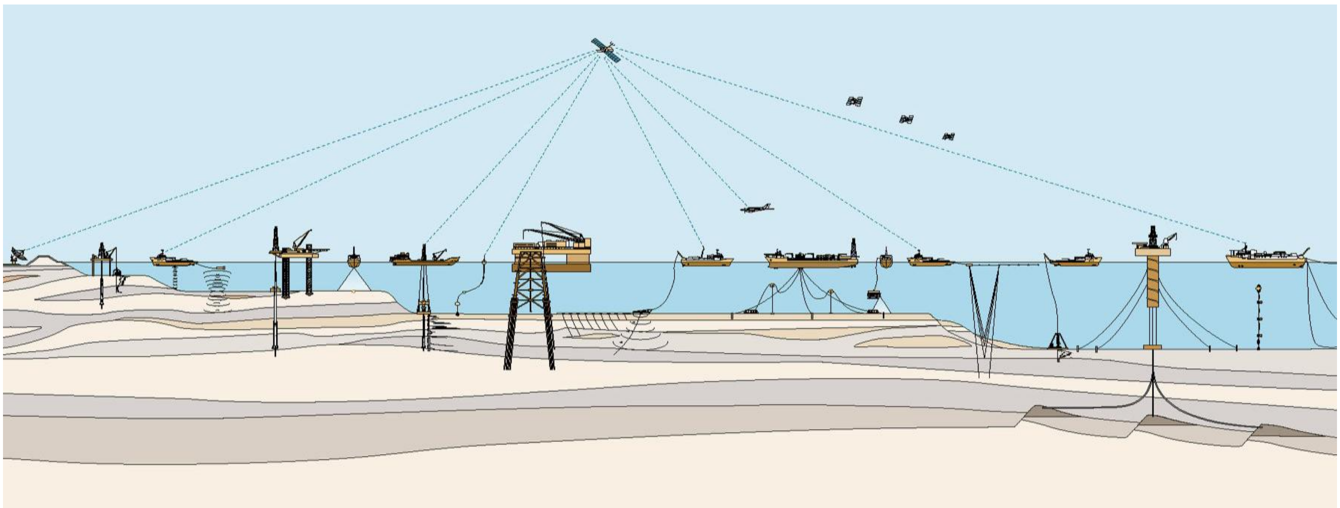
THE NATIONAL NETWORK OF COASTAL MONITORING PROGRAMMES

CELL 1 NORTHEAST REGIONAL COASTAL MONITORING FRAMEWORK

HYDRODYNAMIC SERVICES

November 2013 to June 2014 Reports

1	13/J/1/01/2131/1510	Chloe Bodemeaid	Andrew Gowland	Robin Newman	25/07/2014
Rev	**Description**	**Prepared**	**Checked**	**Approved**	**Date**



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REPORT ISSUE PAGE

This table contains a record of reports given during Phase I of the Northeast Regional Coastal Monitoring Framework.

Fugro EMU reference J/1/01/2131

Report Issue Number	Period Covered	Date	Authoriser's Signature
1	December 2012 to June 2013	30/08/2013	
2	November 2013 to June 2014	25/07/2014	

Authorisation Page

North East Reports: November 2013 to June 2014

Document Release and Authorisation Record			
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1. INTRODUCTION

The National Network of Strategic Regional Coastal Monitoring Programmes (NNSRCMP) owns and maintains a network of real time metocean data acquisition instruments around the coast of the England. The project is funded by local and national government agencies with the purpose that the data is used for coastal engineering, defence, planning and flood forecasting. The data is provided in real time to aid decision makers and input into warning systems, it is also stored and maintained for long term trend analysis.

Fugro EMU's involvement in the project is to ensure reliable data is collected for and provided to the NNSRCMP. A fundamental part of this is to regularly service the equipment, and respond to faults. Following each maintenance visit, or other works, a report is written by the field personnel. These have been collated for the months November 2013 to June 2014 and form section 2 of this report. *Reports from future works will be issued as an amendment to this report.*

Each report is site specific and usually relates to either the shore station or the metocean instrumentation. The objective of these reports is to provide fieldwork feedback to the client on the work undertaken, the condition of the equipment, any spare equipment used and recommendations for the future.

Each report typically includes information regarding:

- Date of works
- Whether the work was scheduled or unscheduled
- Surveyor(s) who completed the works
- The purpose of the visit
- Equipment details i.e. serial numbers, radio frequencies
- Condition of the equipment i.e. biofouling levels, paintwork, mooring, antennas
- List of spare equipment used during the work
- Recommendations for the next service visit, or for the site overall
- Battery voltage(s) and estimated remaining battery life (where available and applicable)
- Position of the equipment
- Any other comments

These reports are sent to Scarborough Borough Council (SBC) who act as lead authority for the Northeast regional area known as Coastal Cell 1. The reports contain a list of client owned stock which were used on deployment in the field. SBC have an agreement with the Channel Coastal Observatory (CCO) for spares and stock replenishment where SBC will replace items used during field work. This report includes both scheduled and unscheduled operations; scheduled work is included in the original contract price whereas unscheduled work is charged separately according to the unscheduled costs set out in the contract. The unscheduled work is typically a response to unforeseen issues which arise throughout the course of the project.

2. REPORTS

Section 2 comprises of both scheduled and unscheduled reports.

2.1 Whitby adrift

Whitby Directional WaveRider Buoy (DWR)		
Date of visit	17/11/2013	Unscheduled
Surveyor(s)	Duty personnel: Tom Latter-Stapley Field personnel: Catherine Boorer and Matthew Davison	
Purpose of visit	Response to adrift situation. On arrival to the most recent transmitted position the buoy was discovered approximately 1Km off position and tethered by its mooring.	
Serial numbers	Hull: 30891 Top Plate: 70282-01 Electronics: E70282-01	
Frequency	34.5875 MHz	
Biofouling	Recovery: 55 % cover	Redeployment: 5 % cover
Paintwork	Recovery: 100 % cover	Redeployment: 100 % cover
Mooring	The site where the buoy had settled was approximately 50m deep. Retrieval was attempted but unsuccessful. A second attempt was made to retrieve the mooring during which the upper bungee parted and the lower mooring lost. A full new mooring was made up and deployed on the licenced position.	
GPS Antenna	Good condition	
HF Antenna	No signs of water ingress. The light was not flashing in the correct sequence Fl(5)20s(Y), and so was replaced and brought back for testing.	
Triangle	Evidence of an impact was clear as the triangle was bent. Rope was also found attached to the triangle and removed.	
List of spares used/components replaced	1 x HF antenna, 2 x triangle anodes, 5 x Datawell SS shackles, 5 x large split pins, 2 x 15m mooring bungees, 1 x 26m riser line, 2 x 10Kg pellet floats, 1 x 3Kg pellet float, 2 x PP terminals, 4 x small split pins, 1 x clump weight, 1 x SS clump weight chain	
Length of riser line	26 m	
Site recommendations	The old HF antenna to be sent to Datawell for repair.	
Battery voltage	Not checked	
Remaining battery life	Not checked	
Position	54° 30.310' N, 000° 36.485' W	
Comments	The coastguard was informed about the incident and a field team in the Humber area was mobilised to respond to the situation.	

DWR recovered on board showing bent triangle and rope spliced through triangle

2.2 Scarborough adrift

Scarborough Directional WaveRider Buoy (DWR)		
Date of works	20/11/2013	Unscheduled
Surveyor(s)	Duty personnel: Chloe Bodemeaid	
Purpose of works	Response to adrift situation	
Work done/completed	At 17:44 the first out of range warning was received. Duty personnel monitored the transmitted positions following the buoy which was travelling SSE. The coastguard was kept up to date and a vessel mobilised from Scarborough to retrieve the buoy. At approximately 22:40 the buoy was recovered beyond Filey spit. Initial reports back revealed the upper part of mooring was still attached to buoy which had broken/worn through at the lower part of the riser line.	
Comments	The DWR was taken to Scarborough harbour for storage until a field team could perform full checks.	

DWR recovered on board showing condition following adrift situation

2.3 Scarborough redeployment

Scarborough Directional WaveRider Buoy (DWR)		
Date of visit	17/12/2013	Scheduled
Surveyor(s)	Chloe Bodemeaid and Sarah Watt	
Purpose of visit	Redeployment of DWR following AWOL	
Serial numbers	Hull: 30892 Top Plate: 70283-01 Electronics: 70283-01	
Frequency	34.6125 MHz	
Biofouling	Recovery: 50 % cover	Redeployment: 5 % cover
Paintwork	Recovery: 95 % cover	Redeployment: 95 % cover
Mooring	New mooring was configured and deployed. Two extra 3 kg pellet floats were added to the riser line to increase buoyancy of the rope.	
GPS Antenna	Good condition	
HF Antenna	Good condition; light working, response to daylight sensor	
Triangle	Good condition; seaweed biofouling removed	
List of spares used/components replaced	1 x triangle anode, 3 x large split pins, 1 x 30 m mooring bungee, 1 x 48 m riser line, 1 x 10 kg pellet float, 3 x 3 kg pellet floats, 2 x PP terminals, 4 x small split pins, 1 x clump weight, 1 x SS clump weight chain	
Length of riser line	48 m	
Site recommendations	It is recommended the riser line be switched from polyprop rope to a combined metal and rope riser to increase durability.	
Battery voltage	20.8 V	
Remaining battery life	76 Weeks	
Position	54° 17.616' N, 000° 19.072' W	
Comments	None	

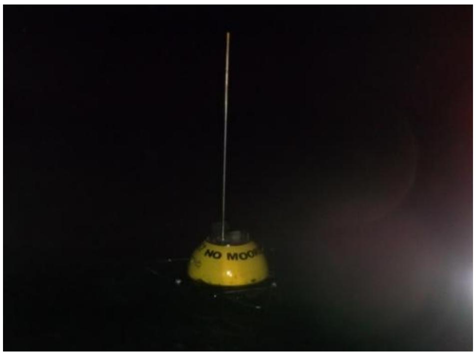
DWR on site prior to service


Serviced DWR redeployed, pellet float visible

2.4 Newbiggin

Newbiggin Directional WaveRider Buoy (DWR)		
Date of visit	14/01/2014	Scheduled
Surveyor(s)	Andrew Gowland and Sam Stevens	
Purpose of visit	Scheduled service	
Serial numbers	Hull: 30893 Top Plate: 70284-01 Electronics: 70284-01	
Frequency	35.2875 MHz	
Biofouling	Recovery: 75 % cover	Redeployment: 5 % cover
Paintwork	Recovery: 95 % cover	Redeployment: 95 % cover
Mooring	Full mooring recovered to deck. During operations the riser rope frayed near to the upper PP terminal so was cut and re-terminated. Full mooring was cleaned and both pellet floats were visible on departure.	
GPS Antenna	Good condition	
HF Antenna	Good condition; light working, response to daylight sensor	
Triangle	Good condition; limited biofouling	
List of spares used/components replaced	3 x triangle anodes, 2 x small split pins, 2 x large split pins	
Length of riser line	26.5 m reduced to 26 m	
Site recommendations	Re-circulate NTM due to proximity of fishing gear (Update: this was re-issued on the 27/01/2014)	
Battery voltage	19.0 V	
Remaining battery life	99 Weeks	
Position	55° 11.117' N, 001° 28.706' W	
Comments	Lobster pot was deployed very close to buoy and may present a risk of entanglement with the mooring. Buoy excursion will need to be monitored to ensure this has not occurred.	

DWR on-board prior to swap out


DWR redeployed on site

2.5 Whitby

Whitby Directional WaveRider Buoy (DWR)		
Date of visit	14/01/2014	Scheduled
Surveyor(s)	Andrew Gowland and Sam Stevens	
Purpose of visit	Scheduled service	
Serial numbers	Hull: 30891 Top Plate: 70282-01 Electronics: 70282-01	
Frequency	34.5878 MHz	
Biofouling	Recovery: 95 % cover	Redeployment: 5 % cover
Paintwork	Recovery: 95 % cover	Redeployment: 95 % cover
Mooring	Both mooring bungees and 10 kg pellet floats recovered, all in good condition with minimal biofouling. Both pellet floats visible upon departure.	
GPS Antenna	Good condition	
HF Antenna	Good condition; light working, response to daylight sensor	
Triangle	Good condition	
List of spares used/components replaced	1 x triangle anode, 2 x large split pins	
Length of riser line	26 m	
Site recommendations	As approved by Robin Siddle; new combi-riser to be purchased	
Battery voltage	21.2 V	
Remaining battery life	75 Weeks	
Position	54° 30.313' N, 000° 36.441' W	
Comments	None	

DWR on-board prior to service

DWR following service and redeployment

2.6 Whitby adrift

Whitby Directional WaveRider Buoy (DWR)		
Date of works	05/05/2014	Unscheduled
Surveyor(s)	Duty personnel: Chloe Bodemeaid	
Purpose of works	Response to adrift situation	
Work done/completed	Whitby DWR sent the first out of range warning at 12:08. After three off location messages were received the buoy was confirmed to be drifting and the coastguard was informed of its trajectory. At 14:00 the Whitby Harbour Watch Keeper was informed of the situation and he informed us that a local fishing vessel (*Stoney Broke*) had recovered the wave buoy and brought it back to harbour. The mooring was severed at the end of the lower bungee.	
Comments	The DWR was taken to Whitby harbour for storage until redeployment.	

Recovered DWR at Whitby harbour

2.7 Whitby redeployment (new mooring)

Whitby Directional WaveRider Buoy (DWR)		
Date of visit	12/05/2014	Scheduled
Surveyor(s)	Andrew Gowland and Sarah Watt	
Purpose of visit	Response to adrift situation and scheduled service	
Serial numbers	Hull: 30891 Top Plate: 70282-01 Electronics: E70282-01	
Frequency	34.5875 MHz	
Biofouling	Recovery: 75 % cover	Redeployment: 5 % cover
Paintwork	Recovery: 95 % cover	Redeployment: 95 % cover
Mooring	The mooring had been cut through the lower bungee. The upper bungee was in good condition so was reused. On arrival to the licenced position the old riser line was located and retrieved. A new mooring was laid on site as agreed with SBC using a combined rope/steel riser, a new A3 pellet float for increased buoyancy to offset combi riser and a galvanised swivel.	
GPS Antenna	Good condition	
HF Antenna	Good condition: no signs of water ingress, daylight sensor working	
Triangle	The triangle showed a sign of impact as one corner was slightly bent upwards, but there was no water ingress.	
List of spares used/components replaced	2 x triangle anodes, 3 x 3.25 T Green pin shackles, 1 x galvanised swivel, 1 x Dyneema rope, 3 x large cable ties, 1 x 15 m mooring bungees, 1 x 26 m combi riser line, 1 x A3 pellet float, 1 x galvanised clump weight chain and rope, 3 x large split pins	
Length of riser line	26 m (combi riser)	
Site recommendations	None	
Battery voltage	19.6 V (Datawell estimate)	
Remaining battery life	58 Weeks (Datawell estimate)	
Position	54° 30.301' N, 000° 36.454' W	
Comments	On arrival the DWR was removed from the Whitby Fish Market and visually inspected for damage. All appeared to be in good condition with minor damage to the triangle, buoy and radar reflectors.	

 **Recovered DWR during inspection and service**	 **New mooring laid out on deck pre-deployment**

2.8 Newbiggin

Newbiggin Directional WaveRider Buoy (DWR)		
Date of visit	12/05/2014	Scheduled
Surveyor(s)	Andrew Gowland and Sarah Watt	
Purpose of visit	Scheduled service	
Serial numbers	Hull: 30893 Top Plate: 70284-01 Electronics: E70284-01	
Frequency	35.2875 MHz	
Biofouling	Recovery: 70 % cover	Redeployment: 5 % cover
Paintwork	Recovery: 100 % cover	Redeployment: 100 % cover
Mooring	The entire mooring was in good condition	
GPS Antenna	Good condition	
HF Antenna	Good condition; daylight sensor working	
Triangle	The triangle has an impact zone on one side	
List of spares used/components replaced	1 x large split pin, 1 x information display poster for shore station	
Length of riser line	26 m	
Site recommendations	None	
Battery voltage	21.6 V (Datawell estimate)	
Remaining battery life	82 Weeks (Datawell estimate)	
Position	55° 11.117' N, 001° 28.706' W	
Comments	Fishing gear very close to licenced position	

DWR during service

DWR showing impact zone

2.9 Scarborough adrift incident

Scarborough Directional WaveRider Buoy (DWR)		
Date of works	31/05/2014	Unscheduled
Surveyor(s)	Duty personnel: Sarah Watt	
Purpose of works	Response to adrift incident	
Work done/completed	At 16:12 on 31/05/2014 the first out of range warning was received. Following three off location messages the duty response procedure began; the coastguard was informed and a vessel was arranged for recovery. The trajectory of the buoy was SSE. The *Providence* from Bridlington was able to secure the buoy on board and return to harbour by approximately 10 pm. The mooring appeared to be severed approximately 25 m along the bungee.	
Comments	The DWR was taken to Bridlington harbour for storage until redeployment.	

Severed bungee from recovered DWR indicating cutting

2.10 Scarborough redeployment (new mooring)

Scarborough Directional WaveRider Buoy (DWR)		
Date of visit	03/06/2014	Scheduled
Surveyor(s)	Chloe Bodemeaid and Catherine Boorer	
Purpose of visit	Redeployment of DWR complete with new mooring design	
Serial numbers	Hull: 30892 Top Plate: 70283-01 Electronics: E70283-01	
Frequency	34.6125 MHz	
Biofouling	Recovery: 60 % cover	Redeployment: 5 % cover
Paintwork	Recovery: 95 % cover	Redeployment: 95 % cover
Mooring	As agreed with SBC a new mooring design was deployed. The single 30 m bungee was buoyed using a larger float (A3). A meter long Dyneema rope then joined the bungee to the combi rope via a galvanised swivel. The previous remaining mooring was recovered and the clump weight reused.	
GPS Antenna	Good condition	
HF Antenna	Good condition; light working, response to daylight sensor	
Triangle	Good condition extra anode attached	
List of spares used/components replaced	1 x triangle anode, 1 x 30 m mooring bungee, 1 x A3 pellet float, 1 x Dyneema rope, 3 x 3.25 T Green pin shackles, 1 x galvanised swivel, 1 x 48 m combi riser line, 1 x galvanised clump weight chain and rope, 3 x large split pins, 3 x large cable ties	
Length of riser line	48 m	
Site recommendations	None	
Battery voltage	19 V	
Remaining battery life	56 Weeks	
Position	54° 17.610' N, 000° 19.057' W	
Comments	A Notice to Mariners was re-issued following redeployment on the 09/06/14.	

DWR recovered following AWOL

Deployed DWR onsite

2.11 Whitby tide gauge

Whitby Tide Gauge		
Date of visit	05/06/2014	Scheduled
Surveyor(s)	Chloe Bodemeaid and Catherine Boorer	
Purpose of visit	Valeport tide gauge service	
Inspection of transducer	The cabling and stilling well were in good condition	
Inspection of Telemetry system	UHF antenna was in good condition, telemetry to receiver station confirmed	
Telemetry	Valeport UHF telemetry	
Inspection of electronics and housing	Good condition	
List of spares used/components replaced	No spares required	
Site recommendations	SBC have issued a IT request to install phone line for remote access	
Position	50° 35.652' N, 004° 50.061' W	
Comments	Tidal dips were taken at 1600h for half an hour to compare tide gauge readings.	

Receiving computer for the tide gauge in Watch keepers office

UHF telemetry antenna

2.12 Whitby adrift incident

Whitby Directional WaveRider Buoy (DWR)		
Date of works	26/06/2014	Unscheduled
Surveyor(s)	Duty personnel: Sarah Watt	
Purpose of works	Response to adrift situation	
Work done/completed	Whitby DWR came off its mooring at approximately 08:00am. Following a succession of out of range warnings the duty procedure began. The Watch Keeper at Whitby Harbour informed duty personnel that the DWR had been recovered by a vessel (assumed to be "*Never can Tell*") and was returned to Whitby Harbour by 14:00 hours.	
Comments	The DWR was taken into Whitby fish market at the harbour for storage.	

Recovered DWR at Whitby harbour. Picture courtesy of Doug Shannon (Whitby Deputy Harbour Master)

Appendix G

CCO Reports
Newbiggin and Whitby wave buoys

Newbiggin Directional Waverider Buoy

Location	
OS	433321 E 587999 N
WGS84	*Latitude:* 55° 11.110' N *Longitude:* 01° 28.696' W
Instrument type	
Datawell Directional Waverider Mk III	
Water depth	~18m CD

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

Location of buoy (Google mapping)

Data Quality

Recovery rate (%)	Sample interval
100	30 minutes

Monthly Averages - 2014

All times are GMT

Month	H_s (m)	T_p (s)	T_z (s)	Dir. (°)	SST (°C)	No. of days
January	1.59	8.7	5.6	90	7.2	31
February	1.24	7.4	4.7	113	6.5	28
March	0.93	8.1	4.4	91	6.8	31
April	0.88	7.2	4.4	75	7.9	30
May	0.89	6.9	4.5	69	9.7	31
June	0.81	6.6	4.6	59	13.2	30
July	0.56	5.4	3.9	81	14.2	31
August	0.81	6.8	4.4	79	13.9	31
September	0.63	6.8	4.3	69	13.9	30
October	1.05	7.0	4.6	96	12.7	31
November	1.47	8.1	5.2	89	11.2	30
December	0.80	10.2	4.8	66	8.9	31

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)
19-Jan-2014 20:00	4.22	11.8	8.7	70	0.50	HW +3	3.9	-0.39	-0.23
05-Feb-2014 07:00	3.93	9.1	6.5	124	2.25	HW	4.0	0.11	0.14
29-Jan-2014 08:00	3.76	8.3	6.6	103	-1.80	HW +6	3.5	-0.37	-0.18
17-Nov-2014 10:30	3.64	10.0	6.9	66	1.42	HW -1	2.3	0.12	0.17
27-Mar-2014 01:30	3.54	10.5	6.9	68	1.32	HW +1	2.9	-0.15	-0.10

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	-	3.26	3.04	2.71	2.27	1.88	10-Oct-2013 18:30	4.15
2014	3.76	3.27	3.01	2.73	2.24	1.86	19-Jan-2014 20:00	4.22

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

Distribution plots

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

- Annual time series of H_s (red line is 3m storm threshold)
- Wave rose (percentage of occurrence of Direction vs. H_s) for all measured data
- Percentage of occurrence of H_s, T_p, T_z and Direction for 2014
- Incidence of storm waves for 2014. Storm events are defined using the Peaks-over-Threshold method. The highest H_s of each storm event is shown
- Joint distribution of all parameters for all measured data, given as percentage of occurrence

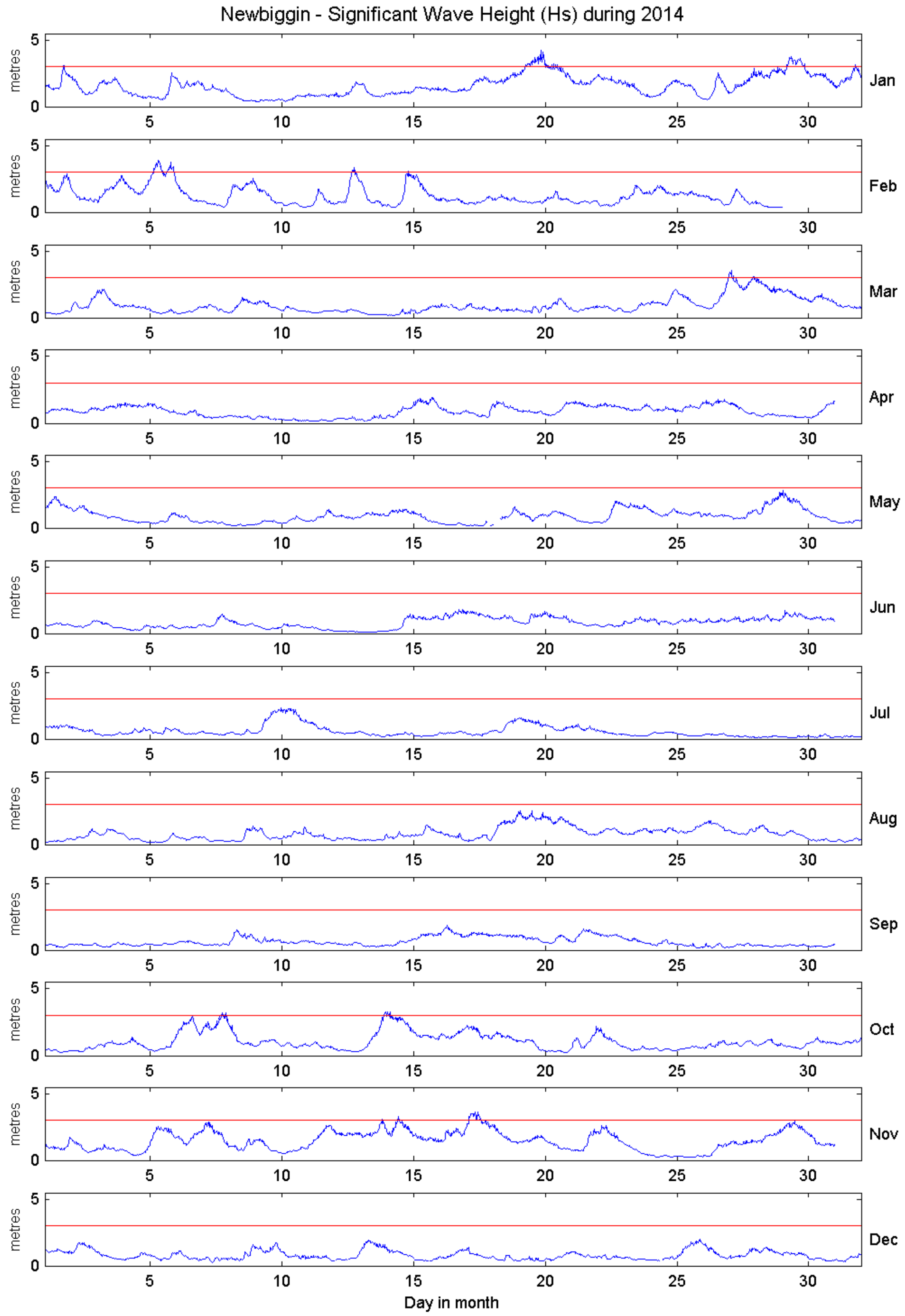
General

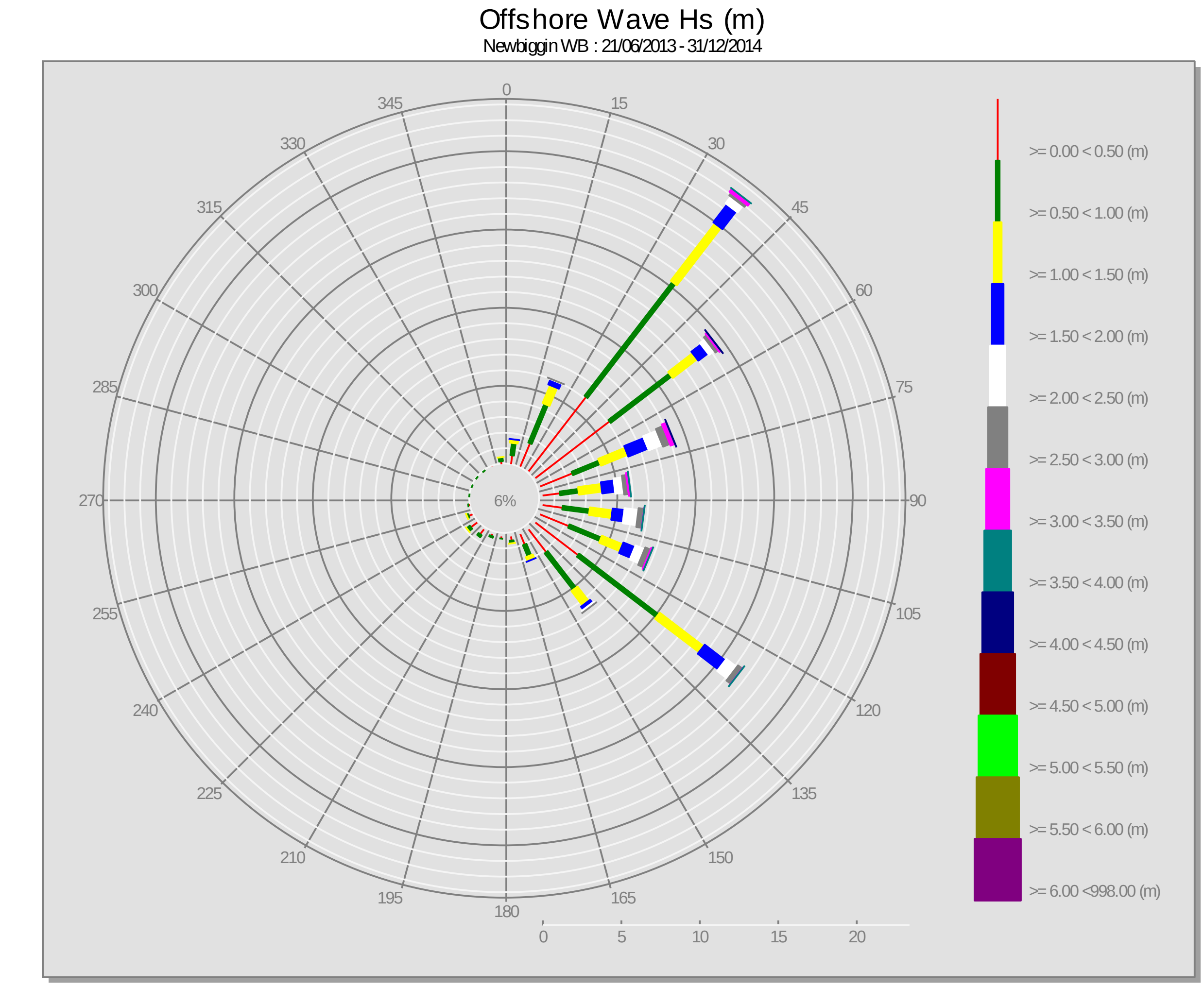
The buoy, owned by Scarborough Borough Council, was deployed on 21 June 2013, at which time the magnetic declination at the site was 2.2° west, changing by 0.18° east per year. A DWR had previously been deployed at this location from 20 May 2010 to 04 February 2011.

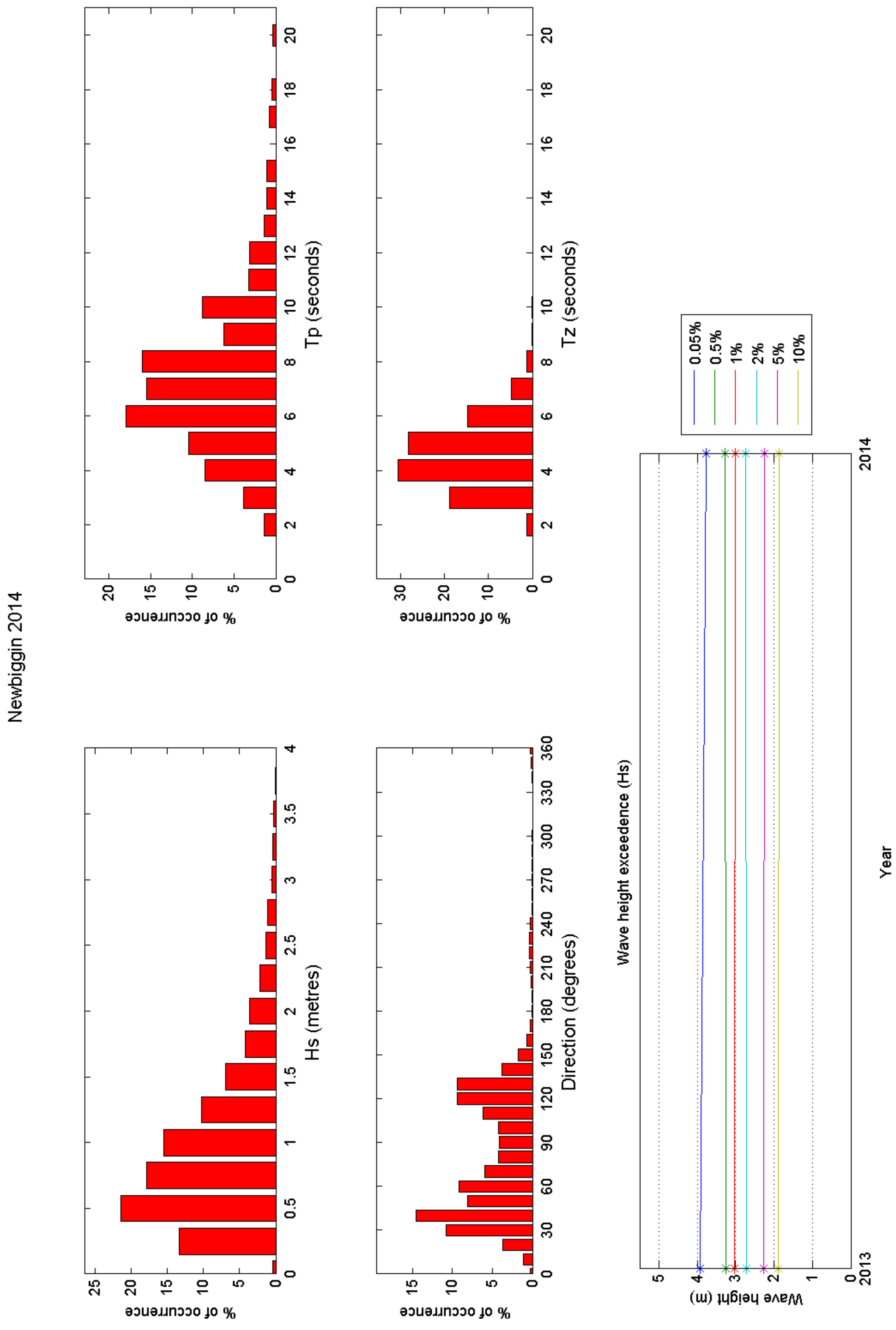
Acknowledgements

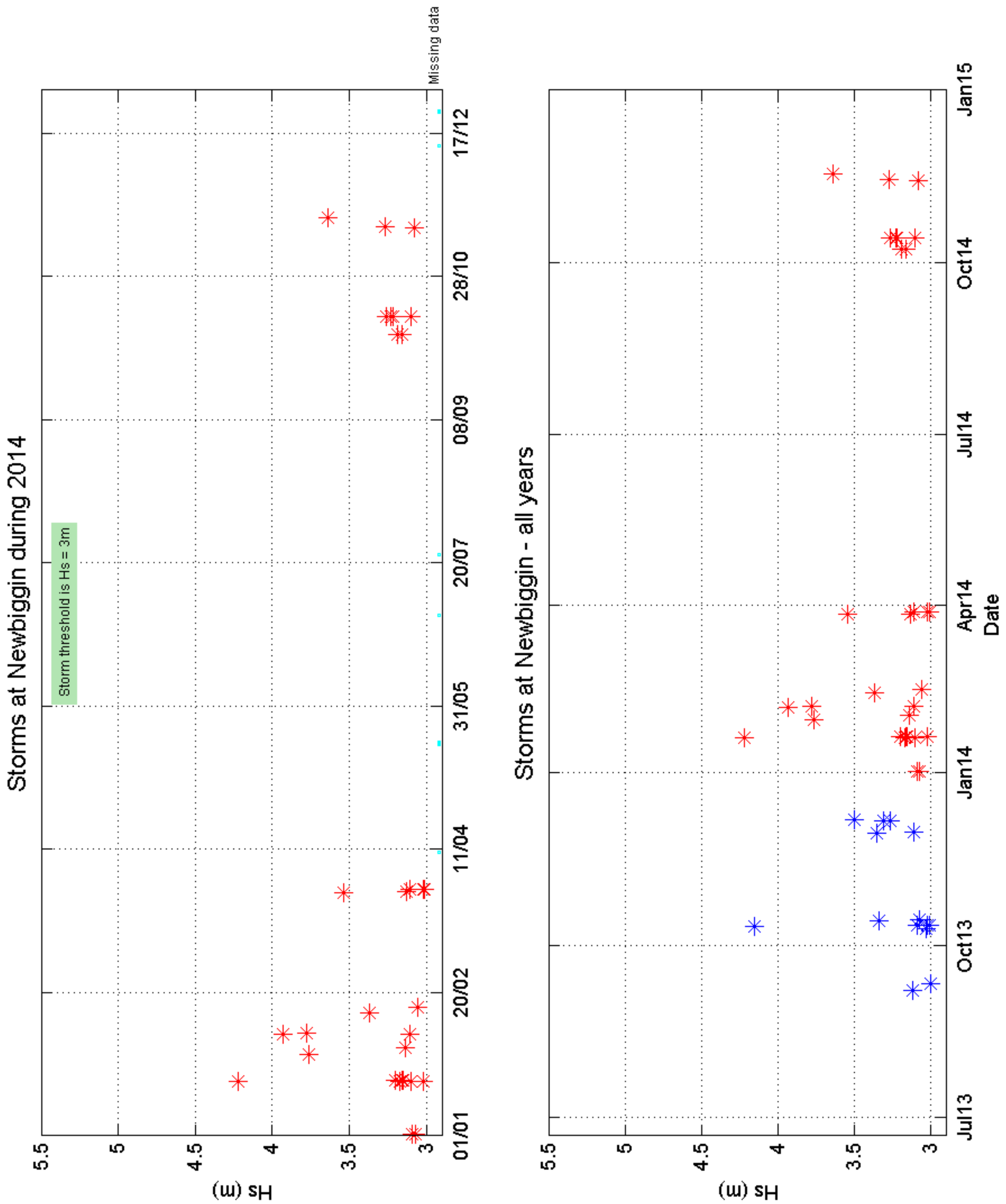
Tidal data were supplied by the British Oceanographic Data Centre as part of the function of the National Tidal and Sea Level Facility, hosted by the Proudman Oceanographic Laboratory and funded by DEFRA and the Natural Environment Research Council.

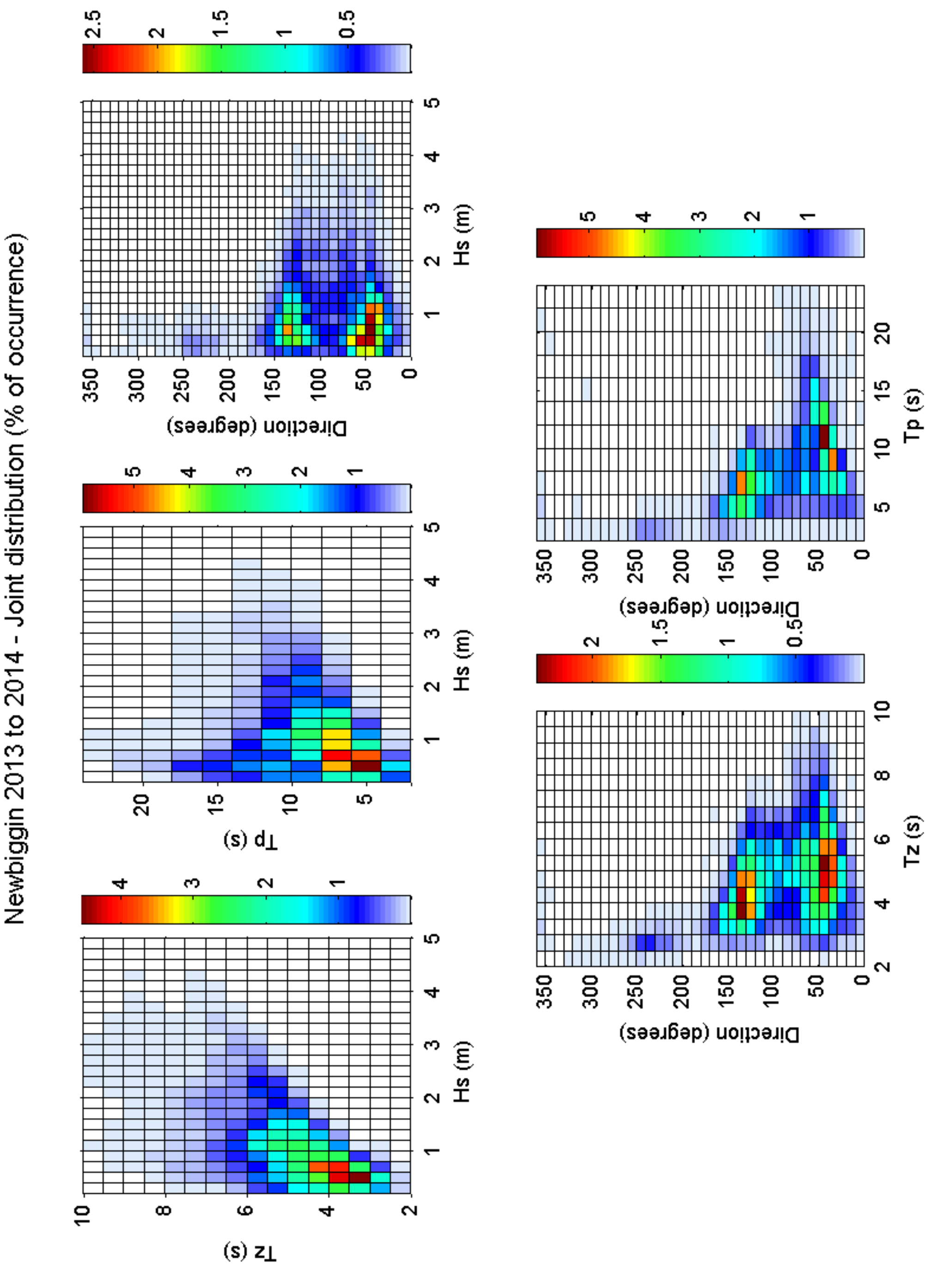
** Tidal information is obtained from the nearest recording tide gauge (the National Network gauge at North Shields). The surge shown is the residual at the time of the highest Hs. The maximum tidal surge is the largest positive surge during the storm event.*


Newbiggin - Significant Wave Height (Hs) during 2014
metres
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Day in month


Offshore Wave Hs (m)
Newbiggin WB : 21/06/2013 - 31/12/2014
0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
330
345
6%
0
5
10
15
20
>= 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 2014
% of occurrence
Hs (metres)
Tp (seconds)
Direction (degrees)
Tz (seconds)
Wave height exceedence (Hs)
Wave height (m)
Year
0.05%
0.5%
1%
2%
5%
10%


Storms at Newbiggin during 2014
Storm threshold is Hs = 3m
Missing data
Hs (m)
5.5
5
4.5
4
3.5
3
01/01
20/02
11/04
31/05
20/07
08/09
28/10
17/12
Storms at Newbiggin - all years
Hs (m)
Jul13
Oct13
Jan14
Apr14
Jul14
Oct14
Jan15
Date



Newbiggin 2013 to 2014 - Joint distribution (% of occurrence)
Tz (s)
Hs (m)
Tp (s)
Hs (m)
Direction (degrees)
Hs (m)
Direction (degrees)
Tz (s)
Direction (degrees)
Tp (s)

Whitby Directional Waverider Buoy

<table>
<tr><th colspan="2">Location</th><td rowspan="5"></td><td rowspan="5">
</td></tr>
<tr><td>OS</td><td>490233 E 513103 N</td></tr>
<tr><td>WGS84</td><td>Latitude: 54° 30.314' N
Longitude: 00° 36.482' W</td></tr>
<tr><th colspan="2">Instrument type</th></tr>
<tr><td colspan="2">Datawell
Directional Waverider Mk III</td></tr>
<tr><th>Water depth</th><td>~17m CD</td><td>Buoy in situ off Whitby beach. Photo courtesy of Fugro EMU Limited</td><td>Location of buoy (Google mapping)</td></tr>
</table>

Data Quality

Recovery rate (%)	Sample interval
93	30 minutes

Monthly Averages - 2014

All times are GMT

Month	H_s (m)	T_p (s)	T_z (s)	Dir. (°)	SST (°C)	No. of days
January	1.21	9.3	5.6	74	6.9	30
February	0.85	8.2	4.5	94	6.3	27
March	0.92	9.4	4.7	74	6.8	31
April	0.92	7.4	4.7	81	7.8	30
May	1.02	8.4	5.2	45	9.7	24
June	0.81	7.3	4.6	57	12.6	25
July	0.49	5.2	3.7	116	15.9	20
August	0.94	7.3	4.7	89	14.5	31
September	0.72	7.5	4.8	67	14.2	30
October	0.93	8.7	4.9	80	12.8	31
November	1.22	8.6	5.4	75	11.3	30
December	1.14	10.0	4.9	80	8.6	31

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)
14-Oct-2014 05:30	4.10	8.3	6.5	53	1.44	HW -2	3.3	0.20	0.33
19-Jan-2014 19:30	3.74	10.0	8.2	69	1.51	HW +1	4.1	-0.27	-0.15
21-Oct-2014 23:30	3.71	10.5	6.9	4	1.44	HW -3	2.9	0.96	1.20
29-Jan-2014 15:00	3.57	9.1	6.8	70	2.20	HW	4.2	-0.13	0.01
17-Nov-2014 04:30	3.43	11.1	6.9	44	-0.20	HW +5	2.3	0.30	0.32

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	-	4.76	4.43	3.93	2.98	2.19	10-Oct-2013 20:00	6.26
2014	3.74	3.16	2.81	2.53	2.12	1.75	14-Oct-2014 05:30	4.10

** i.e. 5 % of the H_s values measured in 2013 exceeded 2.98 m*

Distribution plots

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

- Annual time series of H_s (red line is 3.25m storm threshold)
- Wave rose (percentage of occurrence of Direction vs. H_s) for all measured data
- Percentage of occurrence of H_s, T_p, T_z and Direction for 2014
- Incidence of storm waves for 2014. Storm events are defined using the Peaks-over-Threshold method. The highest H_s of each storm event is shown
- Joint distribution of all parameters for all measured data, given as percentage of occurrence

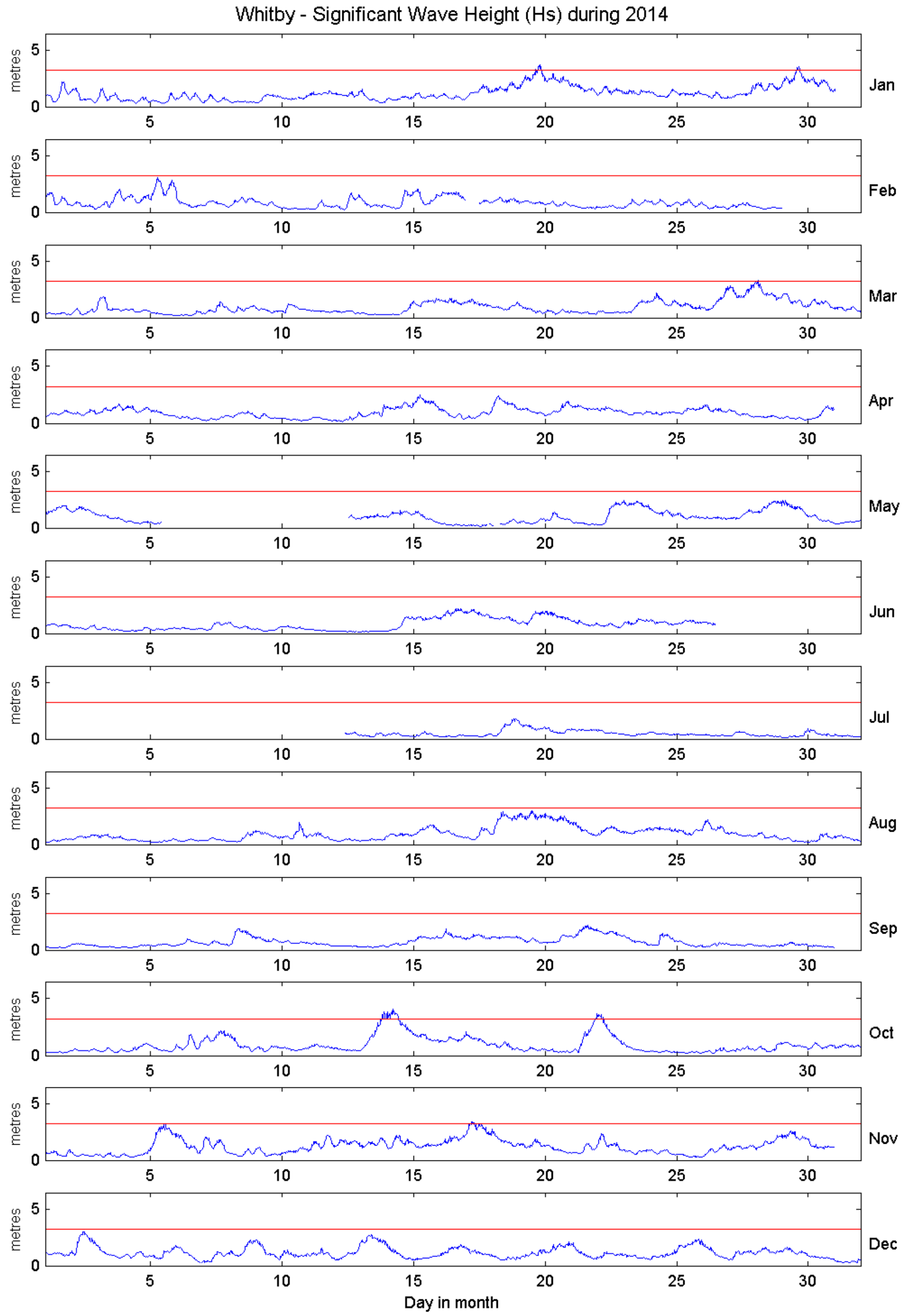
General

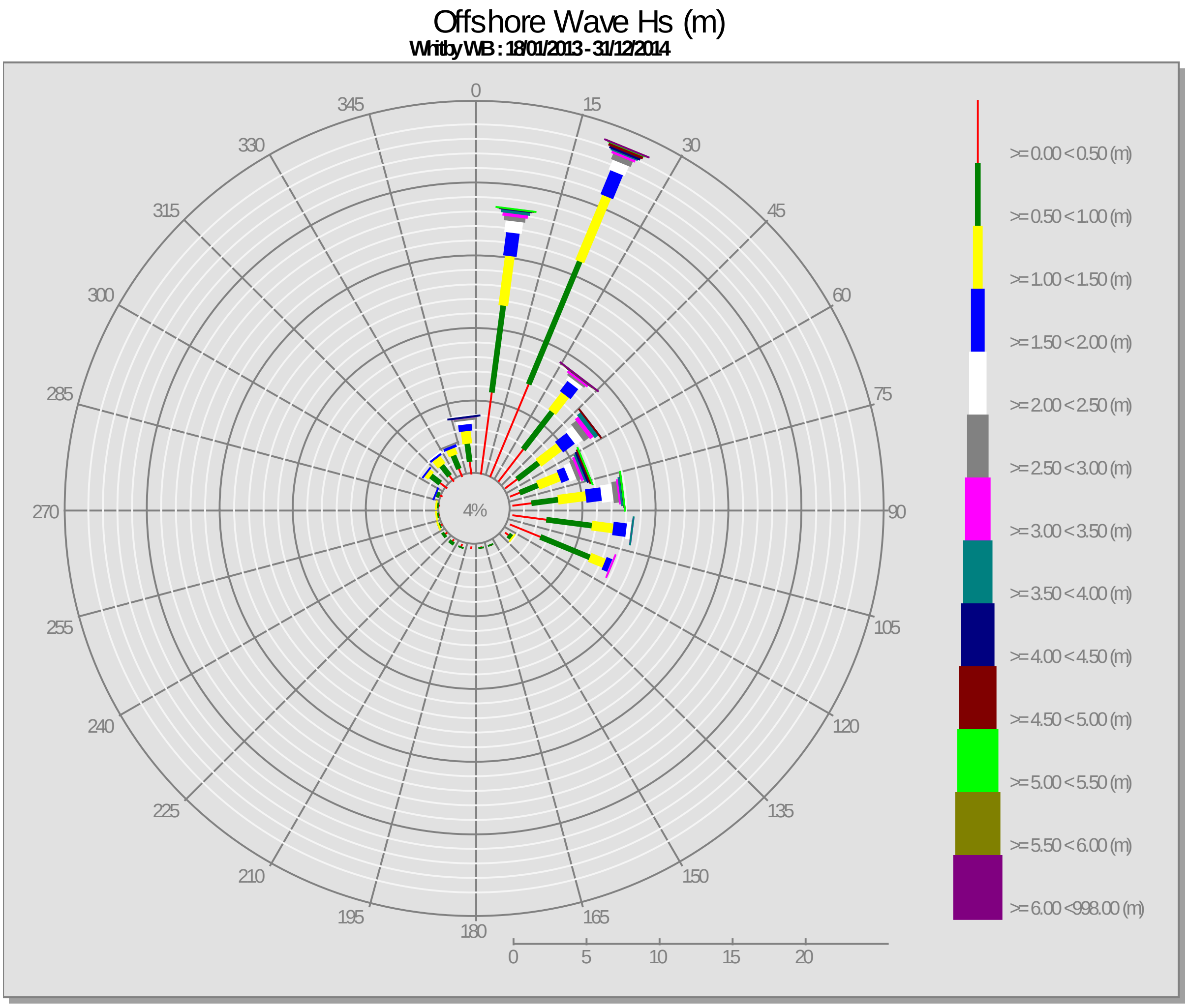
The buoy, owned by Scarborough Borough Council, was deployed on 18 January 2013, at which time the magnetic declination at the site was 1.8° west, changing by 0.18° east per year.

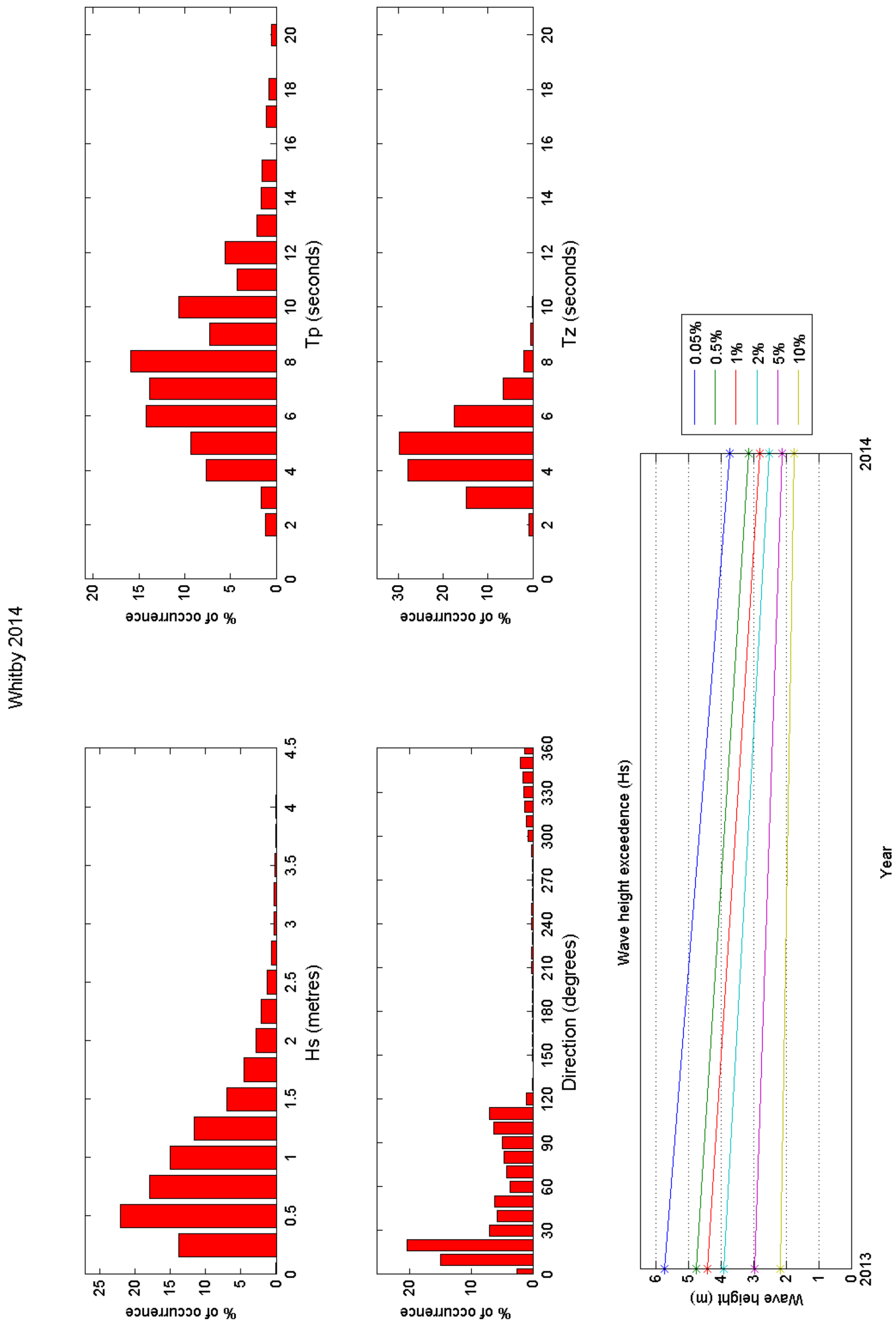
Acknowledgements

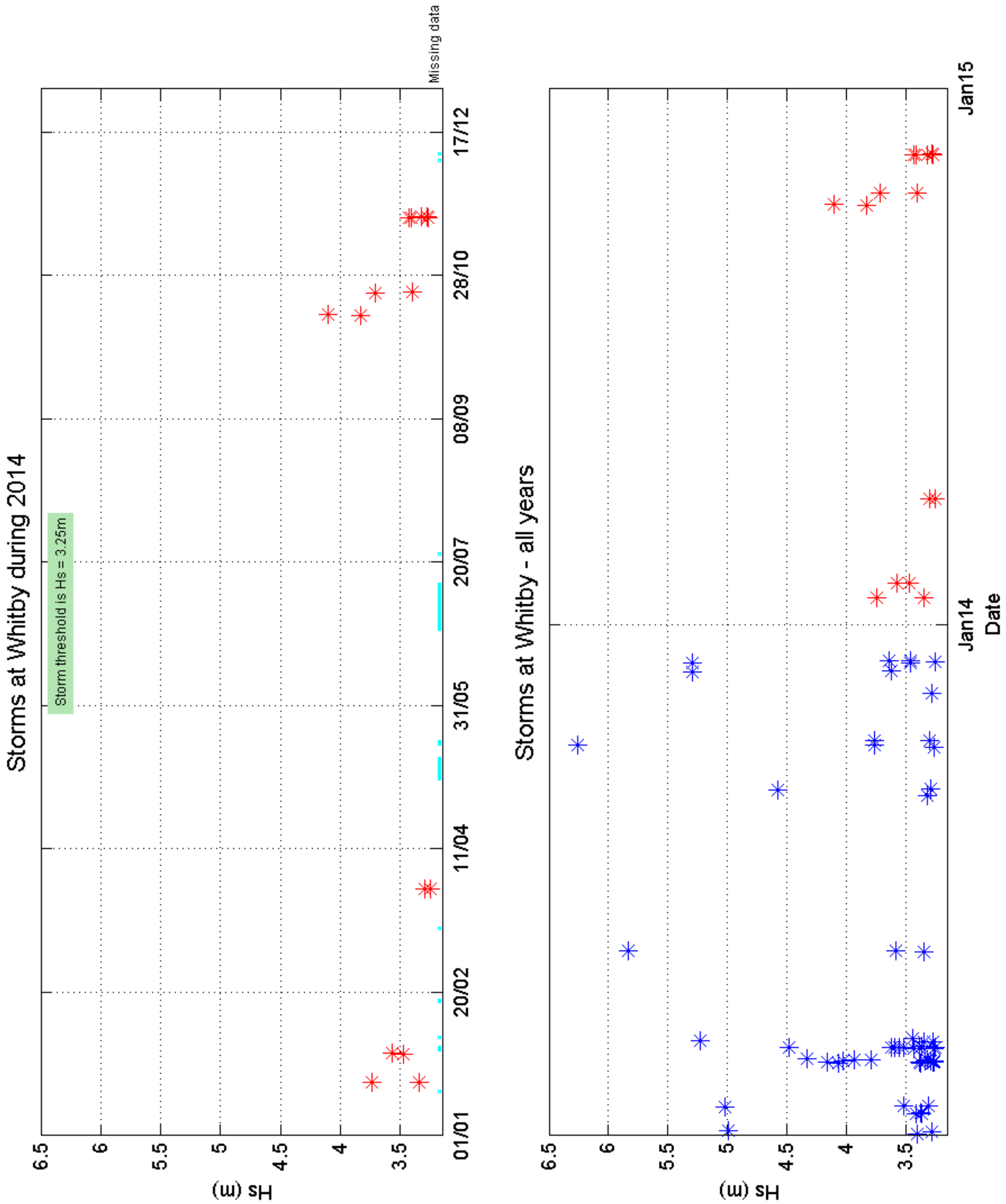
Tidal data were supplied by the British Oceanographic Data Centre as part of the function of the National Tidal and Sea Level Facility, hosted by the Proudman Oceanographic Laboratory and funded by DEFRA and the Natural Environment Research Council.

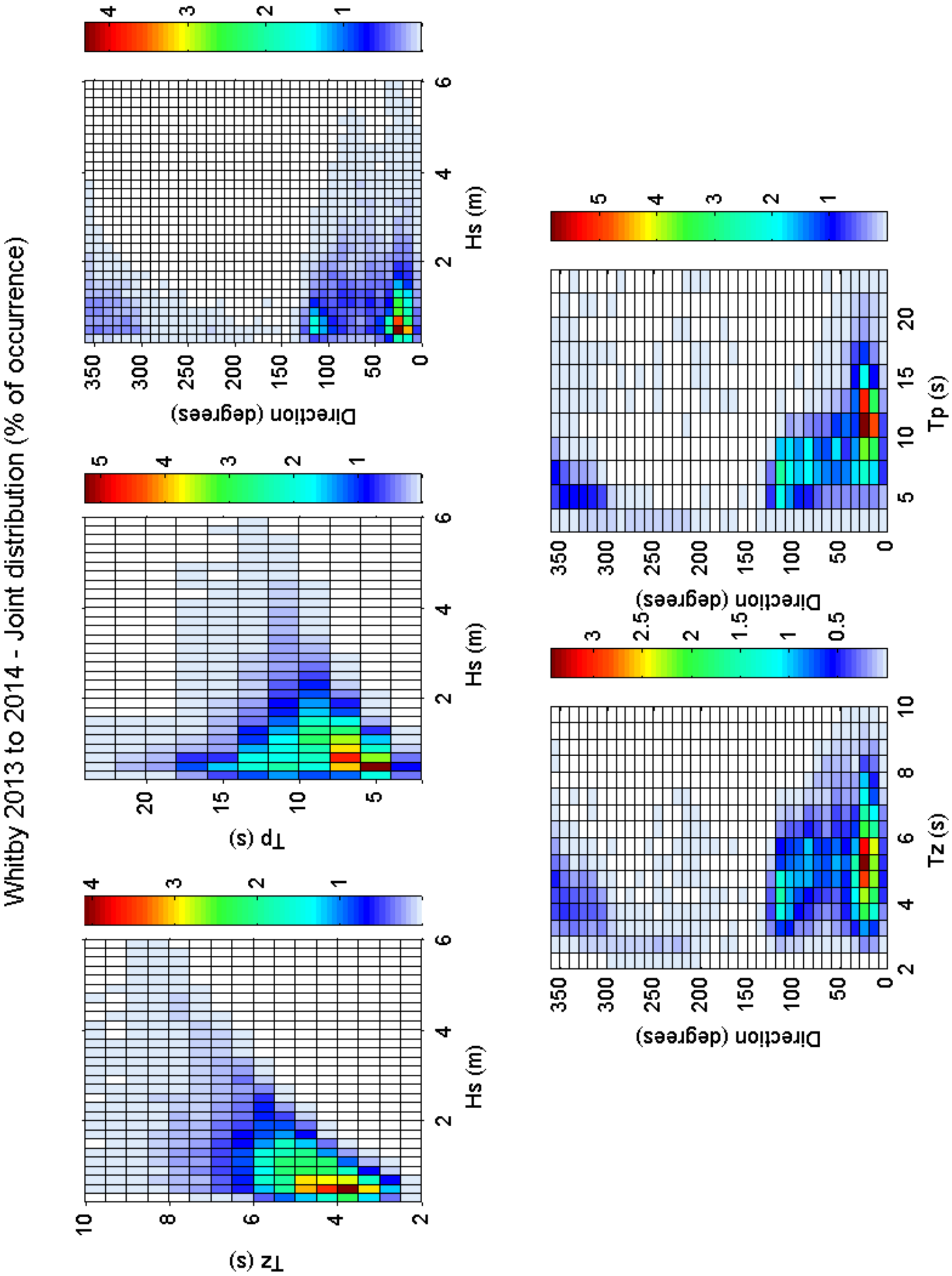
** Tidal information is obtained from the nearest recording tide gauge (the National Network gauge at Whitby). The surge shown is the residual at the time of the highest Hs. The maximum tidal surge is the largest positive surge during the storm event.*


Whitby - Significant Wave Height (Hs) during 2014
metres
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Day in month


Offshore Wave Hs (m)
Whitby WB : 18/01/2013 - 31/12/2014
0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
330
345
4%
0 5 10 15 20
>=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 2014
% of occurrence
Hs (metres)
Tp (seconds)
Direction (degrees)
Tz (seconds)
Wave height exceedence (Hs)
Wave height (m)
Year
2013
2014
0.05%
0.5%
1%
2%
5%
10%


Storms at Whitby during 2014
Storm threshold is Hs = 3.25m
Missing data
Hs (m)
6.5
6
5.5
5
4.5
4
3.5
01/01
20/02
11/04
31/05
20/07
08/09
28/10
17/12
Storms at Whitby - all years
Hs (m)
Jan14
Jan15
Date


Whitby 2013 to 2014 - Joint distribution (% of occurrence)
Tz (s)
Hs (m)
Tp (s)
Hs (m)
Direction (degrees)
Hs (m)
Direction (degrees)
Tz (s)
Direction (degrees)
Tp (s)

Appendix H
Environment Agency briefing on high tides in 2014/2015

High tides during 2014/15

Increase in the number and size of high tides

9 July 2014

High astronomic tides (also known as "spring tides") will be at their greatest over the next 18 months. This is because September 2015 is the point in a natural 19 year cycle when the sun, moon and earth align to exert the greatest force on the tides in the UK.

The increase in the size and number of high natural tides this coming winter means that there is a small, but elevated, increase in risk of coastal flooding this winter.

However, the weather conditions that generate a tidal surge, or extreme waves on the west and south coasts, will continue to be the dominant factors influencing coastal flood risk.

Why are the tides so high this winter?

An astronomic tide is the regular and predictable movement of water caused by the way that the earth, sun and moon move in relation to each other. The astronomic tides are notably high during 2014 and 2015 because we are reaching the peak of the 18.6 year tidal cycle in September 2015. This peak sees the position of the earth, sun and moon align such that they combine to create a greater than average force over the tides. This means they are higher than the average for the 18.6 year period.

When are the tides notably high this autumn and winter?

Over the course of autumn and winter 2014/15, notable high natural tides will occur along all parts of the UK coastline, but particularly on:

- August 12th and 13th
- September 10th and 12th (the highest astronomic tide for 14/15)
- October 9th and 10th
- January 22nd and 23rd
- February 20th and 21st.

High astronomic tides alone do not cause a significant coastal flood risk. Significant coastal flooding on the east coast is dependent on the combined effect of high natural tides and weather generated tidal surge and wave conditions.

High astronomic tides can pass without incident, but even a moderately high astronomic tide when combined with a large coastal storm can result in severe widespread flooding. This was the case on 5th December 2013. The highest natural tide of 2013 ocurred between 21st and 23rd August and passed without incident.

How do the tides compare to last winter and other years?

The table below shows tide levels for 2013 to 2015.

It shows that the highest natural tide in 2015 is between 8 and 21 cm higher than experienced in 2013 on the east coast. This increase in the difference in the underlying astronomic tide is important but less significant than weather effects on tide levels. All tide levels are either increased or decreased by the effects of the weather creating a tidal surge. Typically the difference in water level caused by the weather can be between 20-30cm. **On the 5th December the tidal surge increased the water level by up to 2m**.

		Maximum natural high tide levels (tide level without weather generated surge)			
Site	Site representative of	Highest tide 2013	5th December 2013	Highest tide 2014	Highest tide 2015
North Shields	Northern North Sea	2.95	2.79	3.11	3.13
Immingham	Humber	3.88	3.61	4.07	4.09
Lowestoft	Southern North Sea	1.38	1.19	1.42	1.45
Dover	SE Coast	3.39	3.25	3.55	3.6
Plymouth	South Coast	2.67	2.61	2.82	2.83
Hinkley Point	SW Bristol Channel	6.75	6.47	7.05	7.12
Liverpool	NW Coast	5.11	4.97	5.18	5.44

Of greater significance in preparing for possible coastal flooding in the coming winter is the frequency of higher than normal tides rather than the height of the highest tide of each year.

The frequency of high tides at North Shields is used to highlight this point. A sea level of 2.9m at North Shields will result in the closure of the Hull Barrier which protects 19000 properties. The frequency of natural high tides alone (without any consideration of surge) above this threshold is shown in the table below.

Frequency of tides above 2.9m threshold	**2013**	**2014**	**2015**
North Shields	3	13	15

The increased frequency of high tides does not mean that widespread or frequent coastal flooding will occur over 2014/15. The weather conditions that create a coastal surge or extreme wave conditions will remain the dominant factor.

Our response and readiness

In preparation for the high tide cycle we are updating our internal incident management procedures to build in learning from the winter floods and are also ensuring our incident management rosters are robust around these high tide periods. Our local Flood Resilience teams will be sharing this briefing with Local Resilience Forums to ensure our partners are well briefed and aware. A fuller statement on our wider readiness for winter is in preparation as part of the national recovery piece.

customer service line
03708 506 506

incident hotline
0800 80 70 60

floodline
0345 988 1188
0845 988 1188

www.gov.uk/environment-agency