Open Sea Operating Experience to Reduce Wave Energy Costs

Technical Note

Processing of Bottom-Pressure Sensor Data (2018)

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EXECUTIVE SUMMARY

This document describes the processing of bottom-pressure data collected by an RBR Virtuoso instrument deployed some 200 m upwave of the Mutriku wave power plant, offshore the Basque Coast, Northern Spain. This is the second deployment of this sensor within the OPERA project. Data was collected February to mid-April 2018. Data collected by the RBR pressure sensor in a previous deployment (November 2016 to February 2017) was made available on the web via ZENODO (DS_Wave_Mutriku, v1.0).

While no other sensor data is available at the moment to validate this analysis, values of surface elevations and sea-state variables are in the ranges expected. Preliminary checks also show consistency in the various statistical variables such as spectral or time-domain significant wave heights and wave periods. The wave data appears adequate to begin the analysis of the Mutriku power plant power performance.

The time series of sea-states will be made available on the web via ZENODO (DS_Wave_Mutriku, v2.0).

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1. INTRODUCTION

This document describes the processing of bottom-pressure data collected by an RBR Virtuoso instrument deployed some 200 m upwave of the Mutriku wave power plant, offshore the Basque Coast, Northern Spain. This is the second deployment of this sensor within the OPERA project. Data was collected February to mid-April 2018.

The objective is to obtain data of wave elevation, relative to the resting surface height, of sufficient accuracy to analyse the power performance of the wave power plant. Accuracy of the order of 1 cm is more than adequate for this purpose.

Basic sensor specifications from the manufacturer are reproduced below (the RBR virtuoso has similar specifications to the RBR duo, except it does not record temperature).

Specifications

Physical

Power:	8 or 16 3V CR123A cells
Communication:	True USB and RS-232/485
Storage:	~30M readings
Clock accuracy:	± 60 seconds/year
Size:	~260 or 395mm x Ø63.5mm
Weight:	960g in air, 430g in water
Housing:	Plastic

Tide

Averaging rate:	>1s, 1 to 6Hz
Averaging duration:	1s to 24h
Sampling period:	1s up to 24h

Waves

Burst rate:	>1s, 1 to 6Hz
Samples per burst:	512 to 32768

Pressure

Range:	20/50m (dBar)
Accuracy:	±0.05% full scale
Resolution:	<0.001% full scale
Time Constant:	<10ms
Drift:	~0.1%/year

Temperature

Range:	-5°C to 35°C
Accuracy:	±0.002°C
Resolution:	<0.00005°C
Time Constant:	~1s (~0.1s option available)
Drift:	~0.002°C/year



FIGURE 1.1: RBR VIRTUOSO SPECIFICATIONS

2. POSITION OF THE SENSOR

The sensor was deployed by Bilbao-based marine contractor Commercial Diving Activity late January 2018.

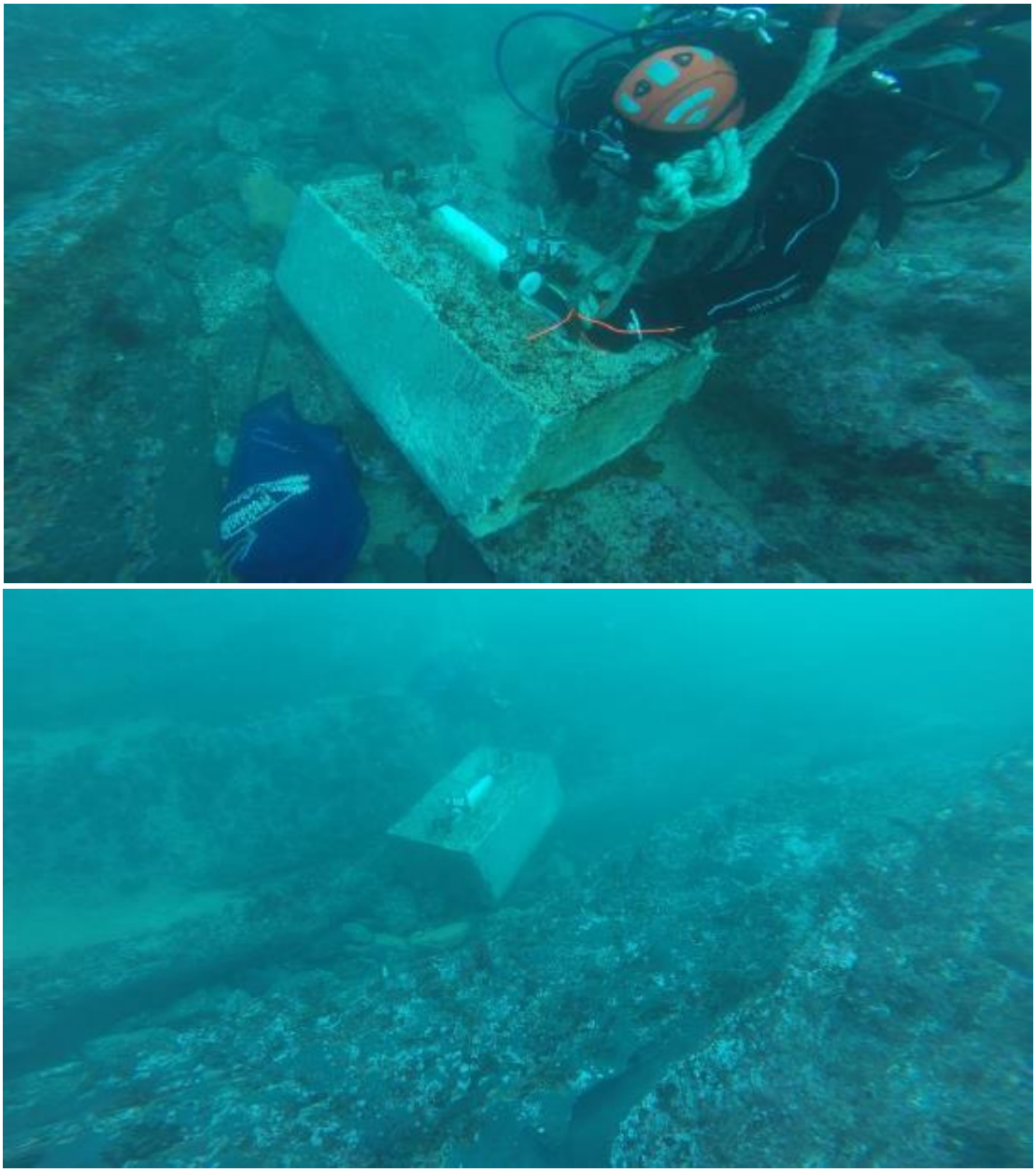


FIGURE 2.1: PHOTOGRAPHS OF SENSOR DEPLOYMENT (CDA)

From GPS readings, the position of the sensor deployment is evaluated to be as follows:
Latitude: 43°18'51.59"N
Longitude: 2°22'33.99"W



FIGURE 2.2: SENSOR DEPLOYMENT LOCATION (SATELLITE VIEW: GOOGLE EARTH)

The distance from the new deployment to the Mutriku plant's front wall is some 202 m at the centre, 215 m at the eastern end and 220 m at the western end.

3. COLLECTED DATA

Data is available from January 22 to April 19, but the first useful hourly record is on January 31st at 1PM, and the last useful hourly record is on April 18 at noon (some 20 minutes of useful data may be useful after 1 PM on that day).

The RBR logger stopped logging unexpectedly early. This failure has been communicated to the supplier and is being investigated.

The first few lines and last few lines of data are shown for illustration

Time,Pressure,Sea pressure,Depth
2018-01-22 14:24:38.000,10.2300071,0.0975071,0.0967120
2018-01-22 14:24:38.500,10.2301552,0.0976552,0.0968588
2018-01-22 14:24:39.000,10.2301849,0.0976849,0.0968883
2018-01-22 14:24:39.500,10.2295010,0.0970010,0.0962100
2018-01-22 14:24:40.000,10.2286667,0.0961667,0.0953825
2018-01-22 14:24:40.500,10.2289700,0.0964700,0.0956833
2018-01-22 14:24:41.000,10.2298943,0.0973943,0.0966001
2018-01-22 14:24:41.500,10.2290582,0.0965582,0.0957708
2018-01-22 14:24:42.000,10.2294263,0.0969263,0.0961359

2018-04-19 00:12:36.000,10.1082973,-0.0242027,-0.0240053
2018-04-19 00:12:36.500,10.1081764,-0.0243236,-0.0241253
2018-04-19 00:12:37.000,10.1090443,-0.0234557,-0.0232644
2018-04-19 00:12:37.500,10.1081818,-0.0243182,-0.0241199
2018-04-19 00:12:38.000,10.1074438,-0.0250562,-0.0248519
2018-04-19 00:12:38.500,10.1082800,-0.0242200,-0.0240225
2018-04-19 00:12:39.000,10.1085913,-0.0239087,-0.0237137

4. FILTERING THE TIDAL SIGNAL

4.1 10-MINUTE MOVING MEAN

As is common practice, a 10-minute moving mean is used to average out the wave signal and obtain the tidal signal in the pressure record. 10 minutes will contain typically over 500 wave cycles and gives adequate result for our purpose.

Below is an example of the raw pressure signal in dBa (blue), with the tidal signal (red), for approximately one tide cycle on 5 March 2018.

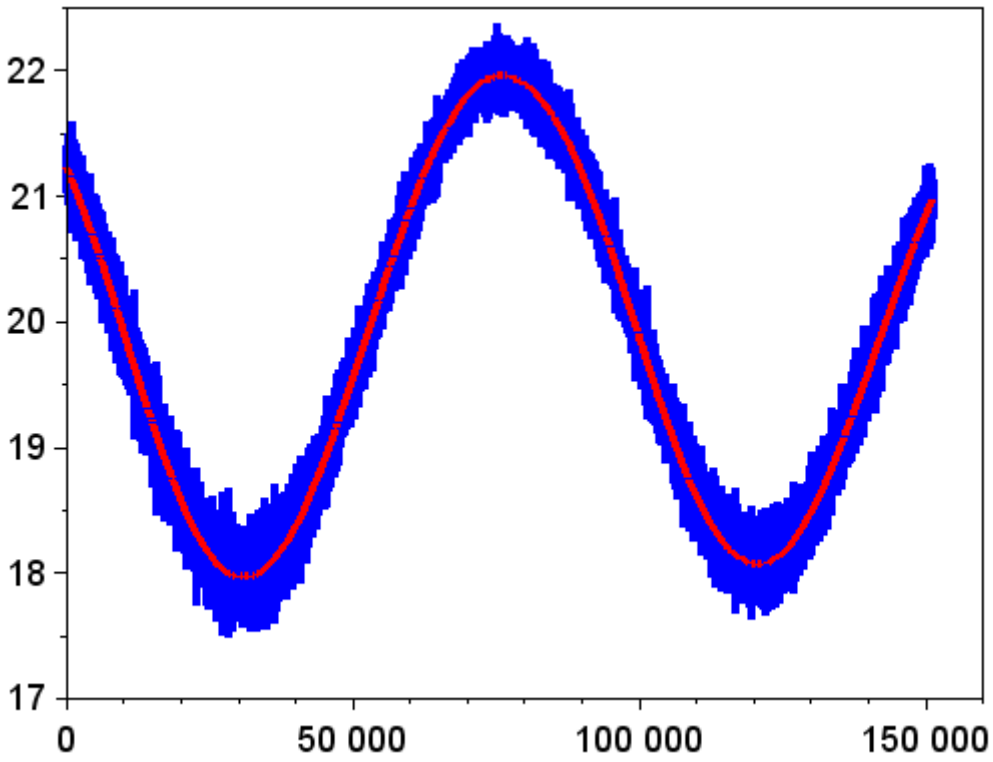


FIGURE 4.1: EXAMPLE OF RAW PRESSURE AND TIDAL SIGNAL

The 10-minute mean tidal signal obtained is shown below. Atmospheric signal has not been corrected for, as it is not necessary for our analysis of wave energy conversion.

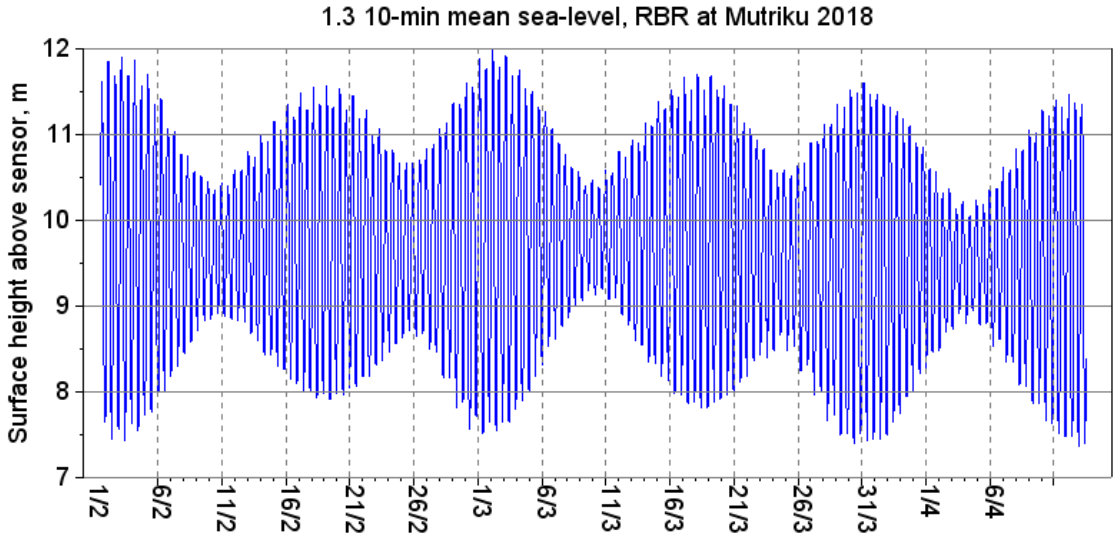


FIGURE 4.2: 10-MINUTE MEAN TIDAL SIGNAL

4.2 OBTAINED WAVE SIGNAL

The tidal signal obtained with the moving mean is then removed from the raw signal to obtain the wave signal.

Example below for a 1-hour record on 5 March 2018, 5-6 AM.

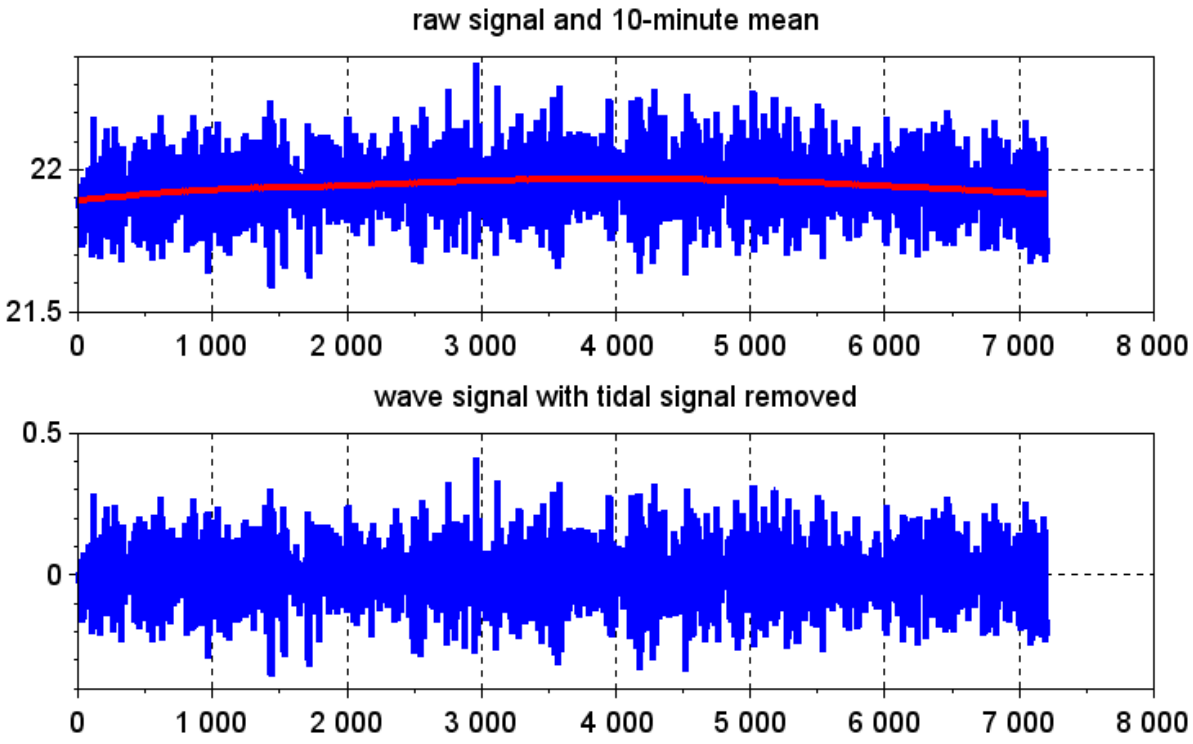


FIGURE 4.3: REMOVAL OF 10-MIN MEAN AND OBTAINED WAVE SIGNAL

5. CONVERSION OF PRESSURES TO WAVE HEIGHTS

5.1 SEAWATER DENSITY

5.1.1 TEMPERATURE

Although there is some interannual variability, a reasonable range for surface temperature for this area in the deployment period is 12-14 °C. For the precision recorded for this study, no further information is required.

Figure below from "Changes in sea surface temperature seasonality in the Bay of Biscay over the last decades (1982–2014)", X. Costoya, M. de Castroa, M. Gómez-Gesteira, F. Santos, Journal of Marine Systems 150 (2015) 91–101.

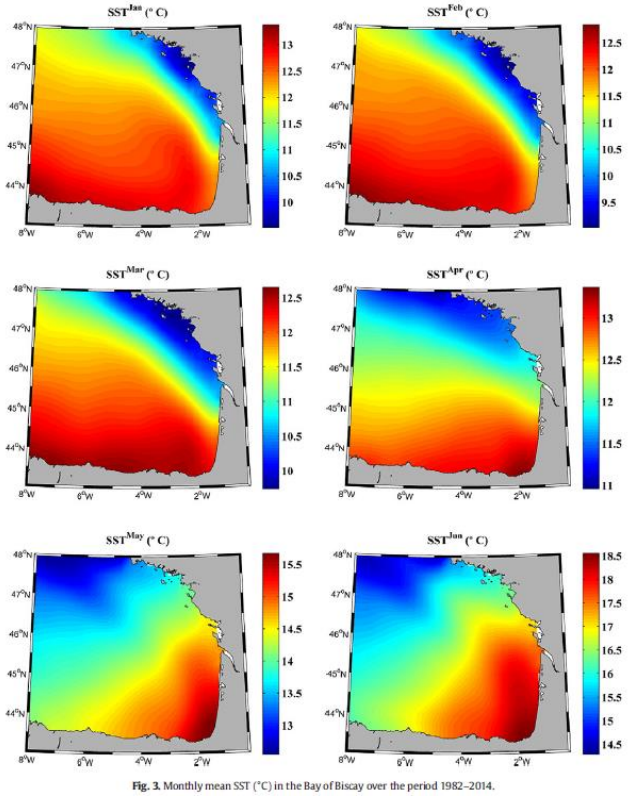


Fig. 3. Monthly mean SST (°C) in the Bay of Biscay over the period 1982–2014.

FIGURE 5.1: SST IN THE BAY OF BISCAY (COSTOYA ET AL. 2015)

5.1.2 SALINITY 34 PSU

Typical values of surface salinity in this area are of the order of 34-36 psu and a relatively constant throughout the year (e.g. below from Bay of Biscay's temperature and salinity climatology, Charraudeau R., Vandermeirsch F.).

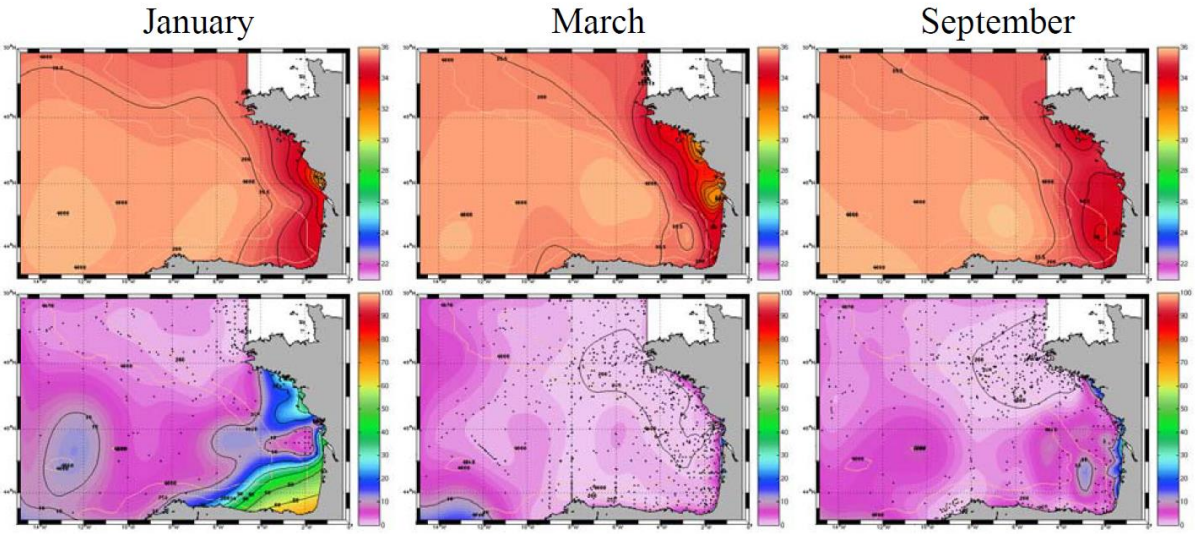


Figure 9: Maps of salinity (top panels) and maps of the confidence in the corresponding estimation (bottom panels), for January, March and September.

FIGURE 5.2: SURFACE SALINITY IN THE BAY OF BISCAY (CHARRAUDEAU AND VANDERMEIRSCH)

5.1.3 TS DIAGRAM AND DENSITY USED

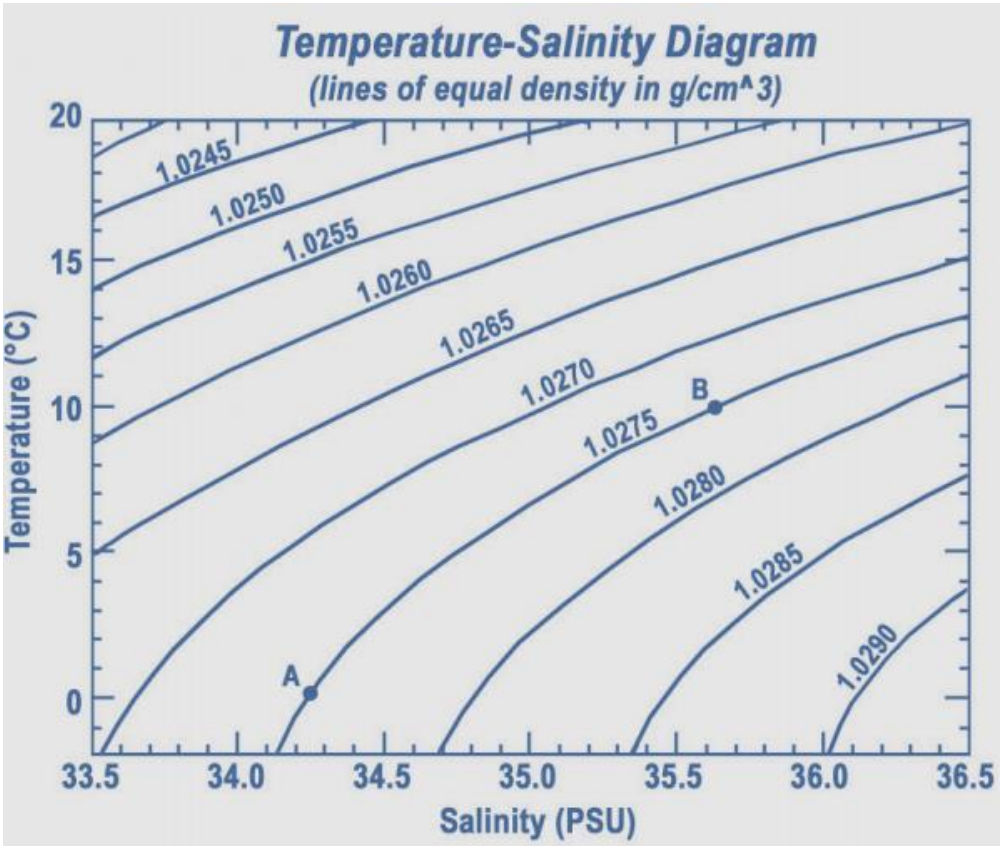


FIGURE 5.3: STANDARD T-S DIAGRAM WITH CONSTANT DENSITY LINES

Variations density of less than 1% are expected over the range of possible temperatures and salinity in Mutriku.

Assuming a density of 1026 kg/m^3 is reasonable based on the temperature and salinity values for this deployment.

5.2 CONVERSION COEFFICIENT

Pressure is hydrostatic in very good approximation in wave motion except in case the sensor is just below a breaking wave (rare for our deployment location).

Hence

$$\eta = \frac{p_{wave}}{\rho g}$$

With ρ = 1026 kg/m^3 and g = 9.81 m/s the correction is negligible on pressure in dBa (below 1%) but is used nonetheless to obtain the wave record.

It is noted that following internal communication with the consortium, further examination of the accuracy of pressure to wave conversion procedure should be considered. For the time being, common oceanographic practice is followed in order to obtain a first set of wave data.

6. SEA-STATE VARIABLES CALCULATION

6.1 SELECTION OF DEGREES OF FREEDOM FOR SPECTRA

As several sea-state variables necessitate spectral calculations basic parameters for the spectral estimates must first be selected.

Common practice in oceanography is to use 16 degrees of freedom (DOF) for spectra based on 2048 records at 2 Hz. This corresponds to 8 sub-records of 256 seconds, or about 10 cycles for very long swell. (Each sub-record gives 2 DOF in exchange for loss of phase information in the power spectrum).

For our hour-long records of 7200 records, we could thus use 28 dof and still have an adequate number of wave cycles, but to get to an even number of data points (for FFT purposes) 24 dof could be used.

For a first batch of sea-states, the commonly used 16 DOF spectra are used.

For convenience for future analysis, the number of DOFs are compared in the following tables. Following figures illustrate the effect of different DOFs on spectra (note, e.g. reduction in peakiness with increased DOF).

Oceanography practice

Record duration	1024	seconds	17.07	minutes
Sampling freq	2			
Data points in record	2048			
Number of DOF	16			
Subrecord duration	128	seconds		
# of 20 s wave cycle	6.4	long wave cycle in subrecord		
Subrecord # samples	256			
Frequency resolution	0.0078	Hz		
Period resol at 10 s	0.8475			
Period resol at 20 s	3.7037			

RBR data DOF selection

Record duration	3600	s
Samling freq	2	Hz
Data points in record	7200	

DOF	# sub-record	Sub-record duration	# data in sub-record	# 20 s wave cycles in subrecord	freq. resolution	period resol at 10 seconds	Period resol at 20 seconds
6	3	1200	2400	60	0.0008	0.08	0.34
16	8	450	900	22.5	0.0022	0.23	0.93
32	16	225	450	11.25	0.0044	0.47	1.95
48	24	150	300	7.5	0.0067	0.71	3.08
50	25	144	288	7.2	0.0069	0.75	3.23

TABLE 6.1: SELECTION OF DEGREES OF FREEDOME FOR SPECTRAL ANALYSIS

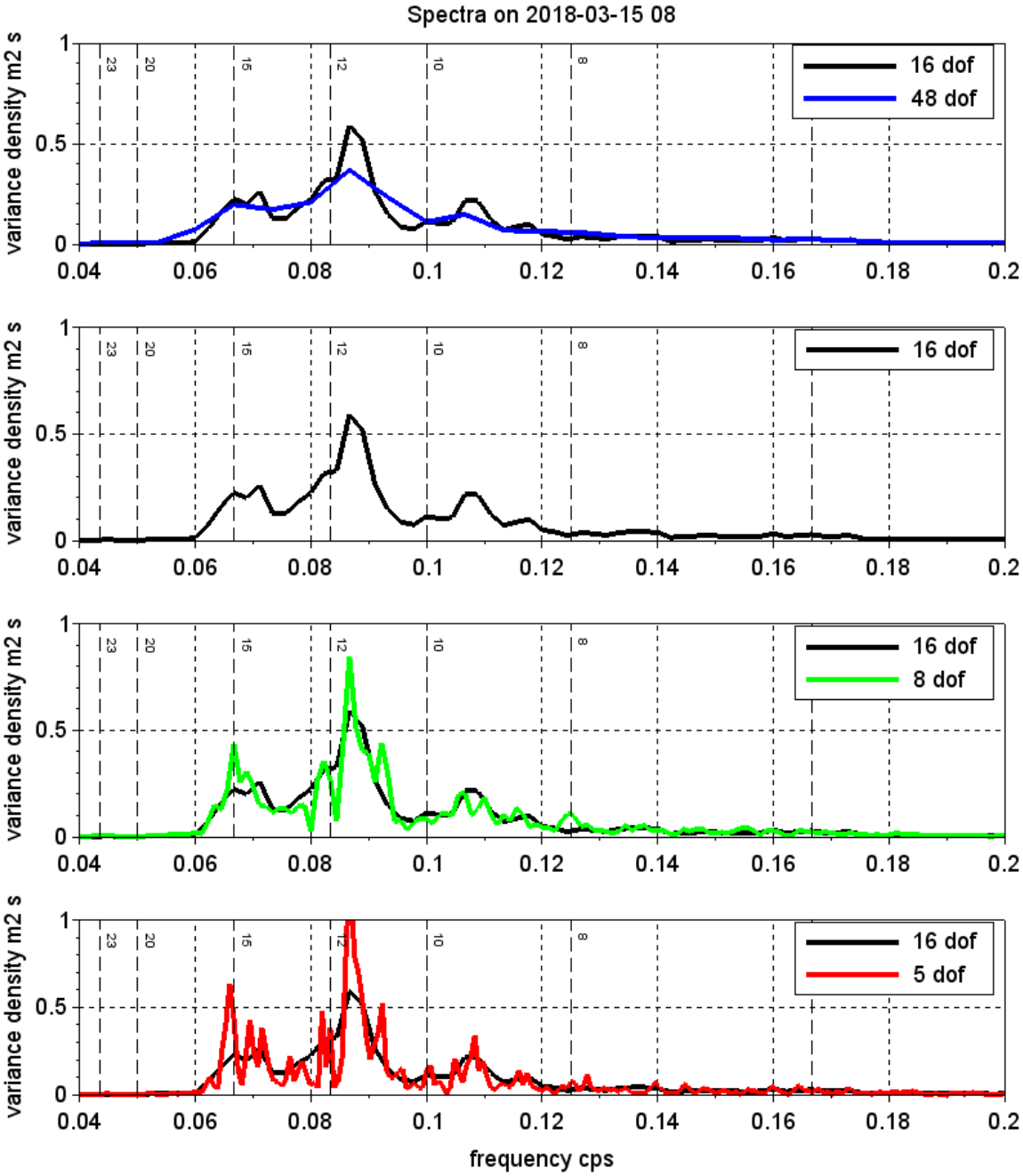


FIGURE 6.1: EXAMPLE OF THE EFFECT OF VARIOUS DEGREE OF FREEDOME IN SPECTRAL ANALYSIS

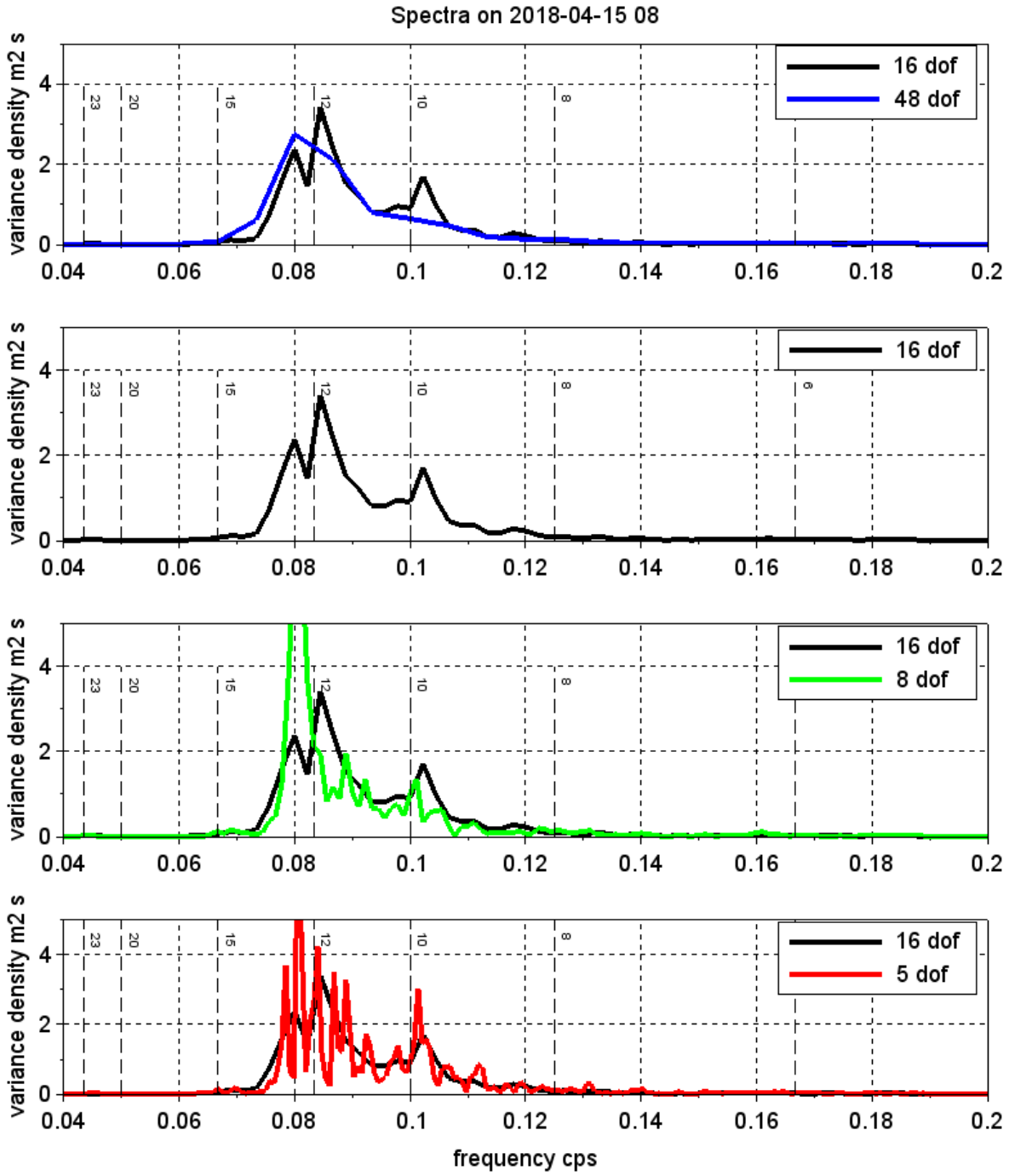


FIGURE 6.2: SAME AS PREVIOUS FIGURE, FOR 15 APRIL

6.2 SIGNIFICANT WAVE HEIGHT, HM0 AND H1/3

The following definition of the spectral significant wave height is used herein. It is consistent with that of e.g. IEC62600-100 on power performance assessment of WECs.

$$H_{m0} = 4\sqrt{m_0}$$

$$m_0 = \int_{f=-\infty}^{f=+\infty} psd(f)\, df = \text{sum of all the variance of the surface elevation}$$

$$\approx \sum_{i=1}^{N} f_n \Delta f \qquad N \text{ spectral components.}$$

$$= \text{sum of all the variance in each frequency band}$$

$$= \text{total variance}$$

$$= \left| (m(t) - |m(t)|)^2 \right| \qquad \text{mean square difference with mean}$$

$$= |m^2(t)| \qquad \text{because mean value is zero by def}$$

$$\approx \frac{1}{N_t} \sum_{i=1}^{N_t} m_i^2 \qquad \text{with } N_t \text{ total number of samples in time domain}$$

Note that $\sqrt{m_0} = \text{r.m.s} = \text{standard deviation } \sigma$

So that $H_{m0} = 4\sigma$

More rigorous and elegant algebra is easily found for these equations, but as depicted above the spectral significant wave height as defined in this analysis is equal to four times the standard deviation of the record of surface elevation.

Also, for most wave records (e.g. Sverdrup and Munk 1946)

$$H_{m0} \approx H_{\frac{1}{3}}$$

It is noted that the significant wave height defined as the mean height of the highest third of waves in the record is thus equal to four times the standard deviation of the surface elevation to a good approximation.

6.3 SIGNIFICANT WAVE HEIGHT AND H110

Wave statistics in the time domain will also be provided.

Graphical illustrations of the time-domain statistics are provided in the following figures for a few selected hourly records.

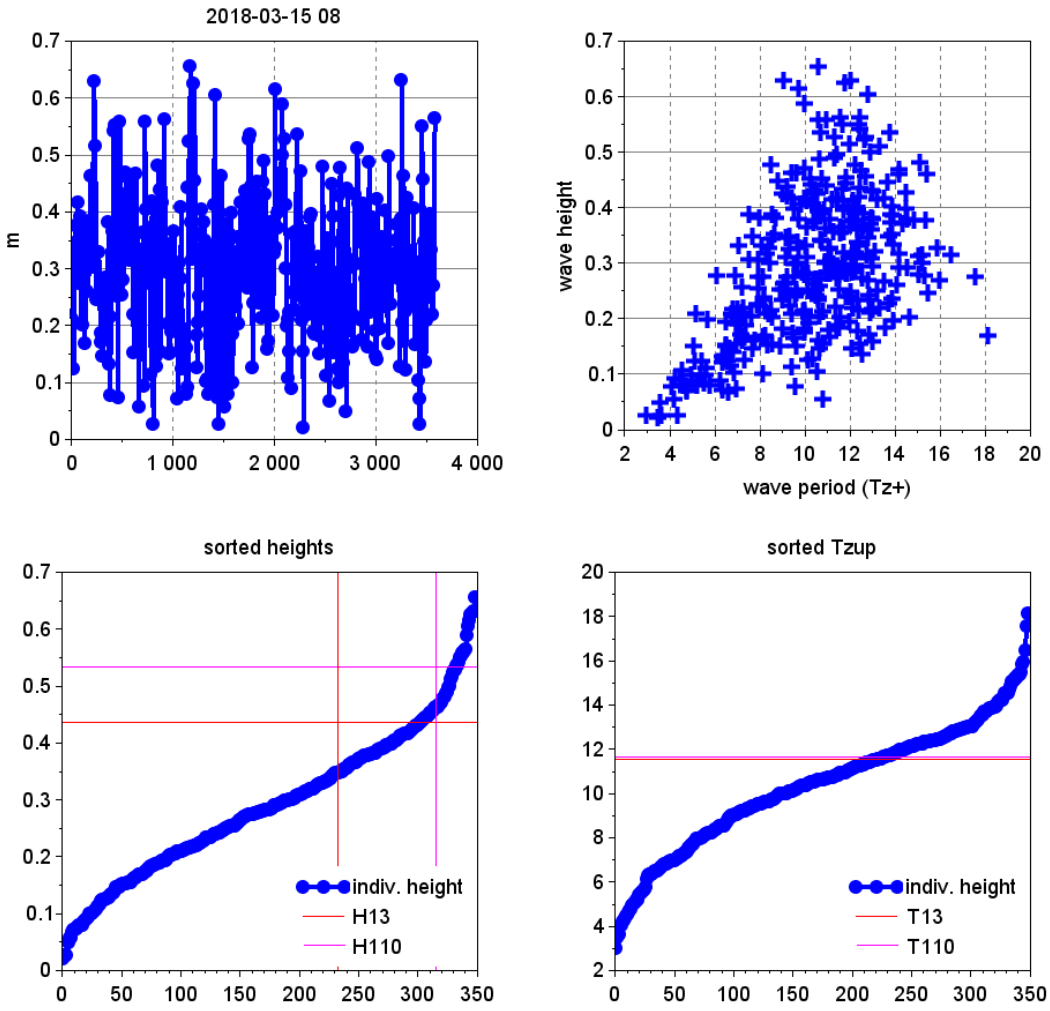


FIGURE 6.3: ILLUSTRATION OF TIME-DOMAIN SEA-STATE VARIABLES CALCULATION

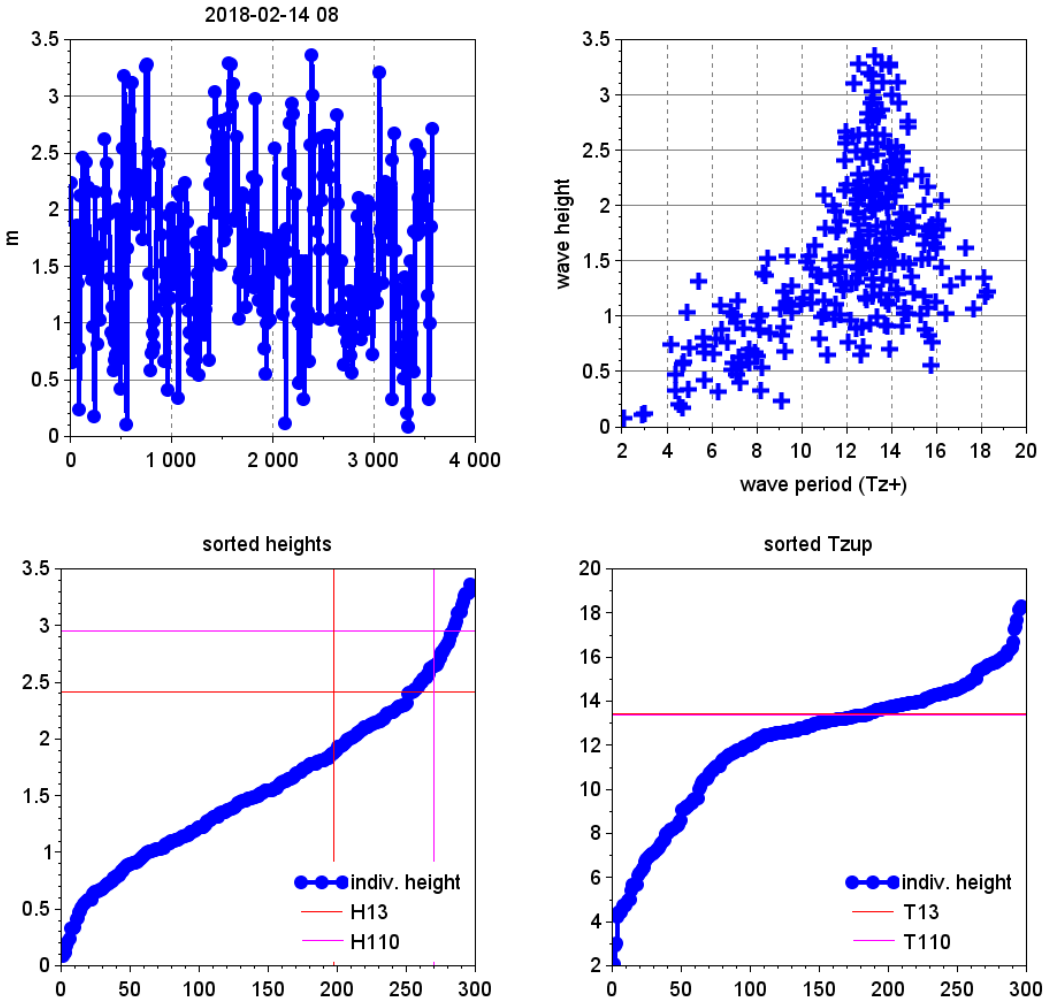


FIGURE 6.4: SAME AS PREVIOUS FIGURE FOR DIFFERENT RECORD

7. RESULTS FOR SEA-STATE VARIABLES

7.1 SPECTRAL SIGNIFICANT WAVE HEIGHT

The time series of spectral significant wave height (H_{m0}) obtained with the method summarized hereto is shown below.

A few storm events have registered Hm0 of over 4.5 m in the measurement period.

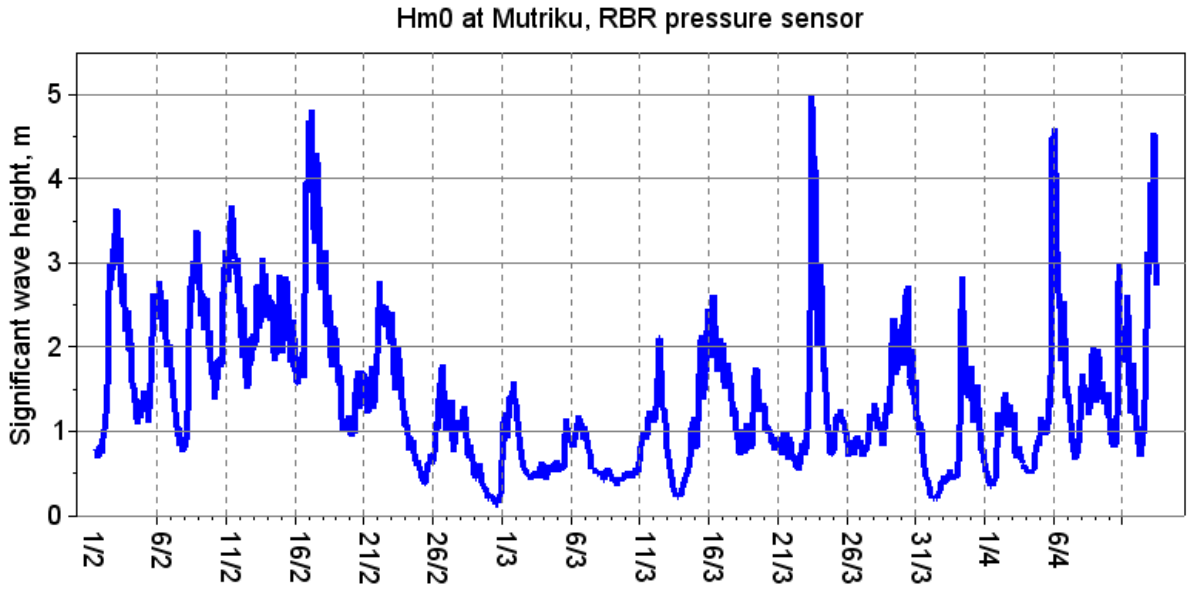


FIGURE 7.1: TIME SERIES OF SPECTRAL SIGNIFICANT WAVE HEIGHT

7.2 SIGNIFICANT WAVE HEIGHT AND SPECTRAL SIGNIFICANT WAVE HEIGHT

The figure below shows the scatter plot of $H_{1/3}$ and H_{m0}.

Agreement between the time-domain evaluation of Hs (mean of the highest 1/3 of the waves) and the spectral analysis is good, as is expected, but not perfect. For larger seas H1/3 tends to be larger than Hm0.

This could be for a number of valid reasons that are not investigated here. Agreement is as good as can be expected suggests that those significant wave heights are of sufficient accuracy for the purpose of T5.3 (wave-by-wave analysis for power performance).

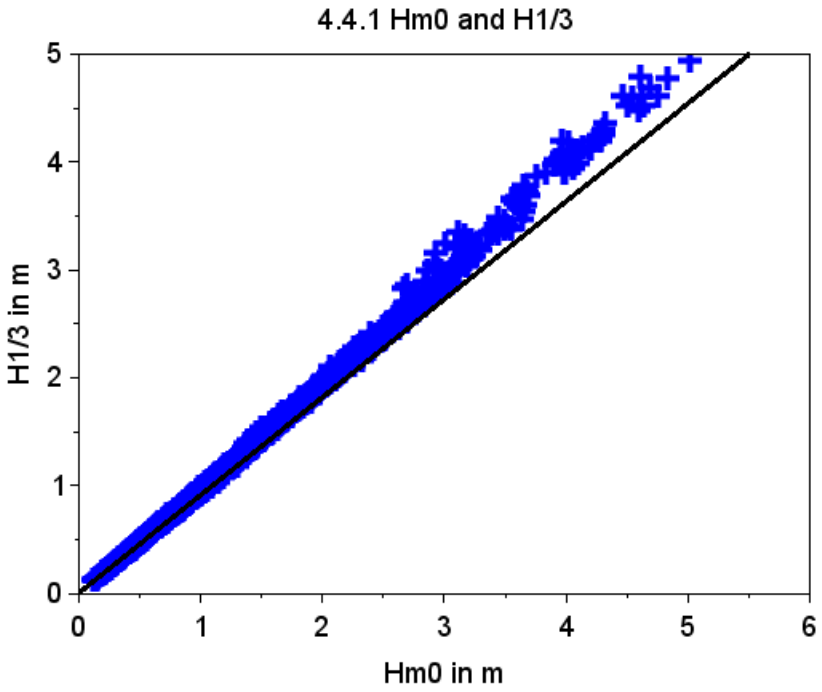


FIGURE 7.2: SPECTRAL AND TIME-DOMAIN SIGNIFICANT WAVE HEIGHTS

7.3 WAVE PERIOD STATISTICS

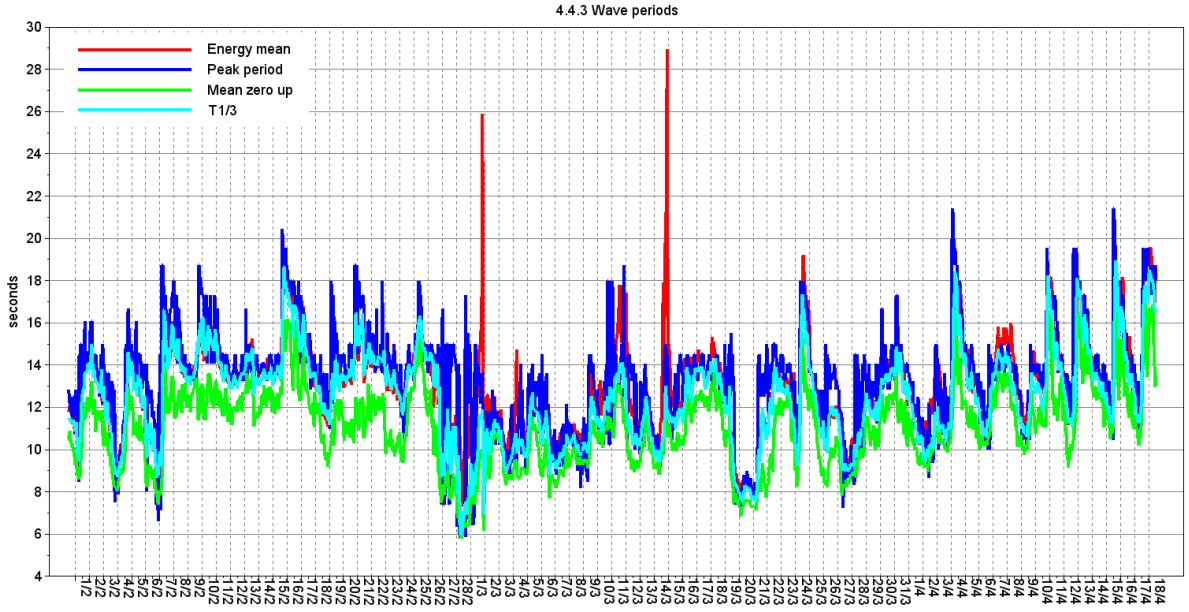


FIGURE 7.3: TIME SERIES OF VARIOUS DEFINITIONS OF WAVE PERIOD

Time series of the energy mean period (IEC62600-100 definition), the peak period, the mean zero-upcrossing period and the mean period of the highest one third of the waves in each hourly record (T1/3).

The two outliers in the energy mean period are due to low frequency noise, possibly due to an atmospheric signal on those days (see following subsection).

7.3.1 OUTLYING LONG TE RECORDS

The time series and spectra of the records with outlying long energy mean periods are provided below for reference.

As may be noted, both records have extremely low wave signal (spectral significant wave height of less than 25 cm), which could explain the relative importance of low frequency noise in the spectrum.

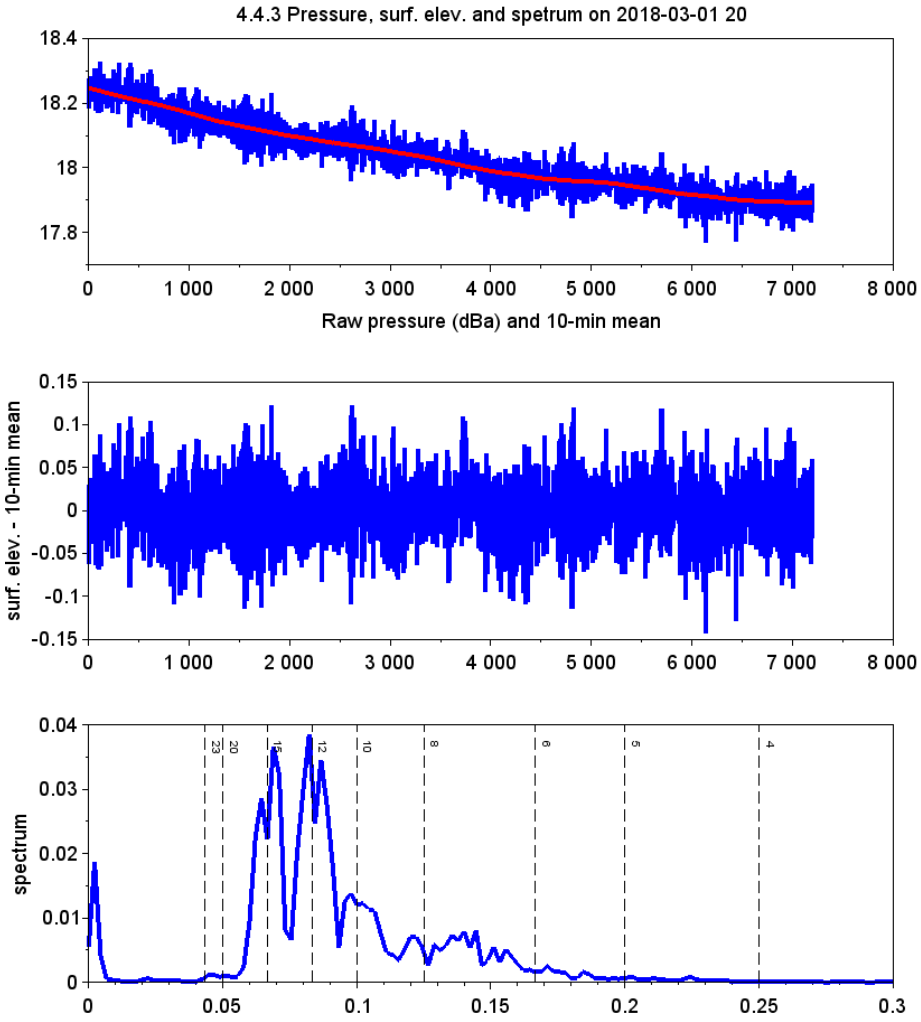


FIGURE 7.4: OUTLYING ENERGY-PERIOD RECORD

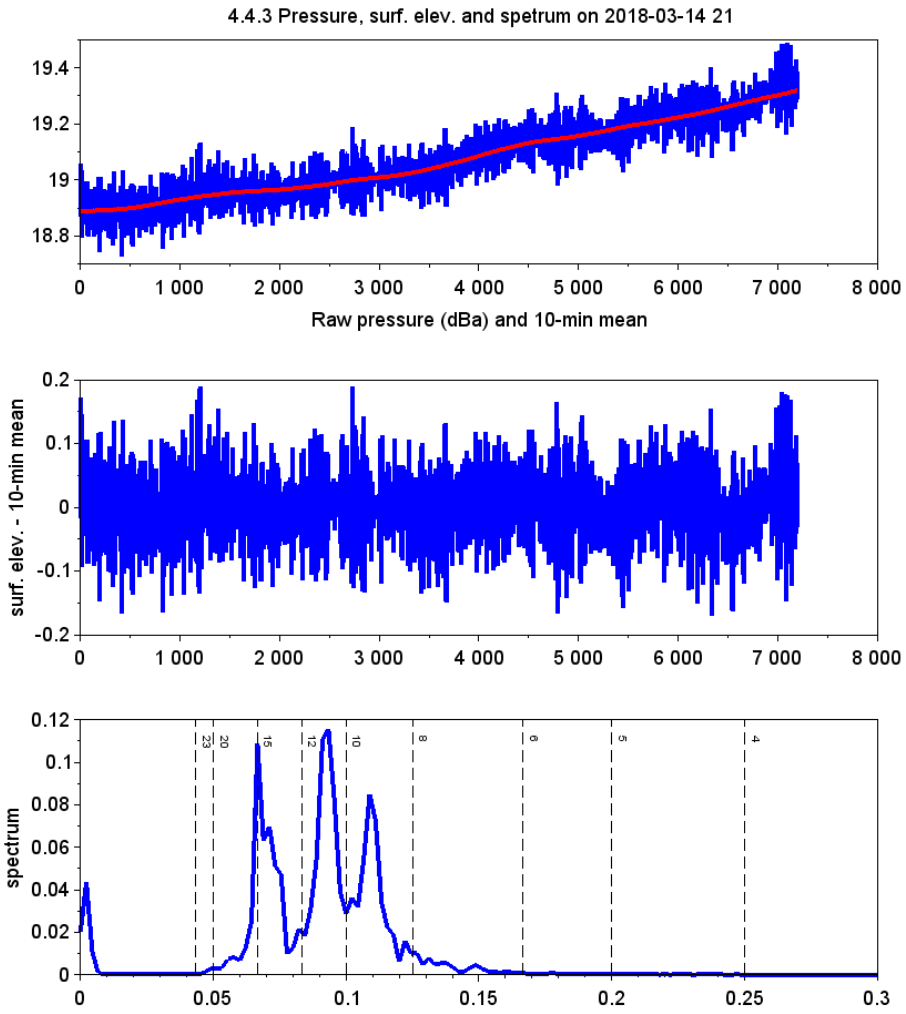


FIGURE 7.5: SAME AS PREVIOUS FIGURE, OTHER OUTLYING RECORD

7.4 SCATTER DIAGRAM

The number of hours for each (H_s, T_e) sea-state in the data collected by the RBR Virtuoso pressure sensor in the January 31 to 18 April 2018 deployment is shown in Table 7.1.

Hs, m (top of bin)	7	8	9	10	11	12	13	14	15	16	17	18	19	20	>20	
>4.5											1					1
4.5											1	4	3			8
4											3	9	4	1		17
3.5									1	4	5	7	7	1		25
3								4	15	11	6	8		1		45
2.5							2	39	42	30	7	8	2			130
2							16	90	41	17	9	5				178
1.5			5	1	4	11	21	120	60	17	6	12	2			259
1		1	23	21	67	90	77	69	45	25	17	5				440
0.5		5	8	58	110	112	97	87	25	6	7	4				519
0			1	7	46	51	65	24	12	7	3	5			5	226
		6	37	87	227	264	278	433	241	117	65	67	18	3	5	
	7	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**>20**	
	Te, s (top of bin)															

TABLE 7.1: NUMBER OF HOURS OF SEA-STATES IN THE BOTTOM PRESSURE SENSOR RECORD, 31 JAN-18 APR 2018

8. CONCLUSIONS

The processing of bottom-pressure data to obtain the wave signal has been described. While no other sensor data is available at the moment to validate this analysis, values of surface elevations and sea-state variables are in the ranges expected. Preliminary checks also show consistency in the various statistical variables such as spectral or time-domain significant wave heights and wave periods.

The wave data appears adequate to begin the analysis of the Mutriku power plant power performance.

The time series of sea-states will be made available on the web via ZENODO.