Williamstown Maritime Precinct Wave, Wash and Surge Study - Stage 3 Mitigation Options Assessment

Report

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Synopsis	This BMT report documents Stage 3 of the study conducted for Parks Victoria, Victoria State Government, on monitoring, data analysis, modelling, and assessment of high-level options to mitigate damaging wave, wash and surge intermittently experienced at the Williamstown Maritime Precinct. Stage 3 focuses on advanced analysis of collected data, comparative assessment of potential mitigation measures, and recommendations.
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Executive Summary

The Williamstown Maritime Precinct – Wave, Wash and Surge Study (this study) is concerned with ‘wave, wash and surge’ events intermittently experienced and reported by stakeholders at the Williamstown Maritime Precinct, southwest of Melbourne, Victoria. The study, commissioned by Parks Victoria (PV) and the Department of Transport (DoT), Victoria State Government, involves monitoring, data analysis, and identification of high-level options to mitigate the ‘wave, wash and surge’, which are regarded as both inconvenient and damaging by local stakeholders. The study comprises three stages, namely: Stage 1 – Data Collection; Stage 2 – Data Analysis; and Stage 3 – Potential Mitigation Options.

This report documents the findings of Stage 3 – Potential Mitigation Options, it covers further advanced analysis of the data collected during previous stages, general characterisation of the wave climate in the study area, development of a comparative assessment framework for evaluation of mitigation measures to the ‘wave, wash and surge’ events, which was informed by engagement with key stakeholders from PV, DoT and local marinas and yacht clubs. The outcome of this assessment process is a set of recommendations ranked by their overall score, considering effectiveness (likelihood) and consequence criteria, for mitigating the risk posed by the vessel generated wake and surge on berthed vessels.

Building on the previous stages of the study, key findings of the additional data analysis completed in Stage 3 include:

- The wave climate that is naturally occurring in the Williamstown Maritime Precinct results in conditions that do not conform with the Australian Standards for Marina Design. The results of a calibrated and validated spectral wave model of wind sea waves for the broader Port Phillip Bay and Hobsons Bay propagating to Williamstown, indicate significant wave height extremes of 0.78m and 0.55m for the 50year and 1year average return interval (ARI), exceeding the criteria recommended in the Standard. Further, annual probabilities of occurrence of 1.4%, 3.0% and 4.35% for significant wave heights greater than 0.3m for short period waves (<2s), 0.3m for longer period waves (>2s) and 0.15m for longer period waves (>2s), respectively, all exceed the recommendations from the Standard for good wave climate in marinas.
- The naturally occurring wind and wave conditions in the study area result in moored boat motions of variable amplitude. For typical/ambient conditions these motions are generally of lesser amplitude than those caused by marine traffic, as observed in this study. More severe or extreme weather conditions, however, can result in extreme boat motions and impact to infrastructure, which have not been the focus of this study.
- The wave climate of the Williamstown Maritime Precinct is further degraded by the frequent occurrence of wake and surge generated by vessel transits through and around the study area, with wave heights that at times exceed those recommended in the Standard (i.e., 0.15m for “beam” seas and 0.3m for “head” and “oblique” seas).
- Wake and surge generated by vessels transiting through and around the study area were analysed, using the measured data to characterise the wave properties close to the source vessels (where the wake is generated) and the affected area (i.e., marinas, yacht clubs and public piers). It was found that different vessels produce a distinctive wake pattern or “signature” at the source, with four types of vessels characterised: 1. Fast ferries (i.e., catamaran design), 2. Large (commercial) ships with deep draught (e.g., cargo, tanker, cruise ship, etc), 3. Tugs, and 4. Small to medium motorboats (not included in other categories). However, despite distinctive wake signatures of the various vessel types at the source, the properties of the propagated wake waves observed in the affected areas are not too dissimilar, which is attributed to the physics of the wave propagation process. In

practical terms, this means that wake and surge from different vessel types affect the study area in a similar way.

- Expanding on the detection of ‘wave, wash and surge’ events, the acceleration data collected from the boat motion sensors was further analysed using a dynamic threshold algorithm. This confirmed the frequent occurrence of ‘surge’ boat motions that have been reported by the local stakeholders prior and during this study. Peak accelerations recorded during the surge motions were between 1.5 and 2.0m/s^2. The data analysis indicated that these surge motions occurred in the vast majority of the detected events, in conjunction with the roll angular motions, and hence these surge events had already been accounted for in the catalogue of events previously developed during Stage 2.
- Looking at the timeseries of properties of propagated wake wave package and the response motions of moored boats measured, it is inferred that the surge motions are initiated by the leading waves of the propagated package, which are characterised by having smaller wave height but larger wavelength and period (i.e., a relatively longer wave that travels faster in the water). In contrast the subsequent waves in the propagated package have larger wave height but smaller wavelength and period (i.e., relatively shorter, and steeper waves), which in turn are associated with initiation and prolongation of the angular (e.g., roll and pitch) motions.

A comparative assessment framework was developed for the evaluation of potential mitigation measures to the events. The framework integrates data outcomes and insights from the monitoring and analysis program, and incorporated input from engagement with stakeholders. The framework was developed following the principles of multi-criteria analysis and risk management, and as such it considers the likelihood (of effectiveness) and the consequences (either positive benefit or negative detriment) along with a comprehensive set of social, economic, environmental, and other criteria. Based on the two mitigation strategies identified as viable in the previous stage of the study, namely: “Reducing the generation of wake as the main cause of the events, i.e., operational control measures, such as managing vessel transit and speed limits” and “Local reduction of effects of the incident waves (including wake waves) on the boats and infrastructure”, a list of 14 potential mitigation measures was prepared with consideration of input from the stakeholders:

- Operational control measures
  - Education and enforcement of speed control / limit of Recreational Boats
  - Education and enforcement of speed control / limit of Fast Ferries
  - Education and enforcement of speed control / limit of Tugs and Pilot boats and Port Tenders
  - Education and enforcement of speed control / limit of large commercial (e.g., Cargo, Tanker, and Cruise Ship) vessels
  - Education and enforcement of speed control / limit of Small – Medium Commercial Vessels (excluding Tug and Pilot vessels)
  - Creation and/or modification of 5 knot zone
  - Restriction of vessels
- Reduce local effect measures
  - Redistribution of moored boats
  - Damping devices
  - Improvement of fendering systems
  - Repair and replacement of joints in marinas and yacht clubs’ infrastructure
  - Spacing boats within local marinas and yacht clubs
  - Re-alignment of berths within marinas and yacht clubs
  - Wave attenuation at the marina scale

The potential mitigation measures were then evaluated and scored using the comparative assessment framework, and then ranked based on the overall scores obtained as a product of the effectiveness (likelihood) and consequence scores. The evaluation and scoring process was further informed and “calibrated” by direct engagement with key stakeholders including government agencies (PV and DoT), local yacht clubs and marinas (Royal Yacht Club of Victoria, Hobsons Bay Yacht Club, The Anchorage Marina, Royal Victorian Motor Yacht Club, Savages Wharf Marina, and Blunt’s Boatbuilders), as well as Port Phillip Ferries. There is an element of overlap in some of the mitigation measures, (e.g., the speed control / limit of either recreation boats and small to medium commercial boats and the modification of the 5-knot zone), however, it is noted that each measure was assessed and ranked individually. In general, the comparative assessment results indicate that the “operational control measures” rank higher than the “local reduction of effects” measures. In more detail, the results show:

- The five best ranked measured are: 1. Creation or modification of 5 knot zone, i.e., extend the 5kt speed limit from the foreshore to the channel boundary of the Williamstown channel; followed by 2. Education and enforcement of speed control / limit of recreational boats; 3. Education and enforcement of speed control / limit of Fast Ferries; 4. Wave attenuation at the local marina scale; and 5. Education and enforcement of speed control / limit of large commercial vessels.
- The four worst ranked measures are: 13. Spacing boat berths within the local marinas (this measure is considered not viable by the local marinas and yacht clubs, based on their direct feedback); 12. Repair, replacement and maintenance of joints / piles in marinas’ infrastructure, e.g., pontoons, jetties (this measure is already part of the maintenance program of the local marinas and yacht clubs, based on their direct feedback); and 11. Education and enforcement of speed control / limit of small to medium commercial vessels (this measure becomes somewhat redundant if the measure ranked 1st is applied). Further, the measure of restriction of vessels was discarded as it was rendered as non-feasible at this point in time (and thus automatically ranked 14th).
- A set of three other measures ranked 8th in a tied ranking, these are: Redistribution of boats within marinas, i.e., large boats moored next to smaller ones; Damping devices, e.g., “rider poles”; mooring springs, etc., aimed to avoid contact; and Improvement of fendering systems, i.e., aimed to minimise impact when contact occurs. These measures have, to some extent, already been trialled / implemented by the local marinas and yacht clubs and found to be of limited effectiveness, based on their direct feedback.

The comparative assessment provides direction regarding the relative effectiveness of each mitigation. The following is a list of recommendations in priority order, with consideration of the overall scores, which account for effectiveness (likelihood) and consequence criteria.

1. Modification, i.e., extension, of a 5kt zone speed limit from the Williamstown foreshore to the channel boundary of the Williamstown channel, including navigational aids and signage, and an education campaign targeting the main users of this area, namely recreational boats and small to medium sized commercial vessels.
2. Undertake speed controlled trials and route changes on Fast Ferries to test avoiding the critical speeds (e.g., 17-20kt) to determine the best low wash and wake operating conditions for these ferries. Consideration in the trials should be given to rapid versus slow accelerating and decelerating, in line with the vessel design and capacity.
3. Explore implementation of education and enforcement of speed control / limit of large commercial vessels e.g., cargo, tankers, cruise ships) as well as port support vessels (e.g., tugs, pilot boats and port tenders), in collaboration and engagement with VPCM / Ports Victoria, the Harbour Master, and their teams.
4. The marinas, yacht clubs and foreshore businesses plan for future wave attenuation at a local scale to provide wave protection suitable for each of their facilities.

5. Re-alignment of berths within the marinas (likely to only be feasible if/when marinas are refurbished / upgraded and may not be feasible nor viable for all marinas).

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1 Introduction

1.1 Project Background and Objectives

The Williamstown coast in Hobsons Bay, southwest of Melbourne, hosts numerous recreational, community and commercial boating facilities, with more than 500 moored vessels at local jetties, marinas, yacht clubs and in open water. In recent years concern has developed over increasing frequency of events characterised by water motions that excite the movement of some moored boats, marina, and infrastructure to the point of some damage to the vessels and infrastructure. These motions have been described by local stakeholders to be independent of ambient wind and wave conditions and hypothesised to be associated with vessels in transit through the surroundings of the immediate marina areas.

The Williamstown and Port Melbourne dredged channels pass within 0.5km to 2.0km of the Williamstown Maritime Precinct, respectively (Figure 1.1). These channels provide access for a wide range of vessels to/from Port Melbourne, Station Pier in Hobsons Bay and within the Yarra River. Passage of these vessels is expected to generate a spectrum of wake and surge which propagates into the Williamstown Maritime Precinct, some of which may be associated with the events of concern.

This study is concerned with monitoring, data analysis, and assessment of high-level options to mitigate damaging ‘wave, wash and surge’ intermittently experienced at the Williamstown Maritime Precinct.

This report summarises Stage 3 of the study, which includes advanced analysis of collected data, comparative assessment of potential mitigation measures, and recommendations.

Figure 1.1 Location of Williamstown Maritime Precinct in relation to primary navigation channels

1.2 Stage 3 Overview

The data collected during Stage 1 of the study, has been further analysed to a) understand the wave properties within the Williamstown Maritime precinct, b) characterise wake pattern or "signature" of different type of transiting vessels and the properties of wake waves at the source of generation and as these propagate in the study area; and c) better understand the difference between "surge" events and the "roll" events catalogued during Stage 2 of the study. All these additional analyses help inform the identification and assessment of potential mitigation measures.

From the data analysis conducted to date, a comparative assessment framework has been developed and a number of mitigation measures were identified and assessed in this Stage 3 of the study. These measures are based on the two high-level mitigation strategies identified as viable in the previous Stage 2 of the study, namely, "Reducing the generation of wake as the main cause of the events, i.e., operational control measures, such as managing vessel transit and speed limits" and "Local reduction of effects of the incident waves (including wake waves) on the boats and infrastructure", with consideration of input from the stakeholders.

The mitigation measures assessed in this report are grouped into two main high-level strategies as previously identified and described herein:

1. Operational Control Measures (i.e., reducing or stopping the generation of wake as the main cause of the events)
    a. Education and enforcement of speed control / limit of Recreational Boats
    b. Education and enforcement of speed control / limit of Fast Ferries transiting
    c. Education and enforcement of speed control / limit of Tugs, Pilot boats and Port Tenders
    d. Education and enforcement of speed control / limit of large commercial (e.g., Cargo, Tanker, and Cruise Ship) vessels
    e. Education and enforcement of speed control / limit of Small – Medium Commercial Vessels
    f. Creation and/or modification of 5 knot zones
    g. Restriction of vessels
2. Reduce Local Effect Measures (i.e., better protection within the Maritime Precinct from the effect of incident wake waves)
    a. Redistribution of boats (e.g., large moored next to small)
    b. Damping devices (e.g., “rider poles”, mooring springs, etc.), aimed to avoid and minimise contact
    c. Improvement of fendering systems, aimed to minimise impact when contact occurs
    d. Repair and replacement of joints in marinas and yacht club infrastructure (e.g., pontoons and jetties)
    e. Spacing boats within local marinas and yacht clubs
    f. Re-alignment of berths within marinas and yacht clubs
    g. Wave attenuation at the marina scale

2 Analysis

Building on from data analysis completed in previous stages of the study, additional analyses were conducted in this Stage 3 to better understand the following aspects:

1. The wave climate in the Williamstown Maritime precinct is studied using observations from the data collected and model data. Wave properties are then compared against the "good wave climate" criteria from Australian Standard for Marina Design (AS 3962:2020), with consideration of both the naturally occurring waves and the added effect of wake waves from marine traffic.
2. Are there differences in the wake produced by different vessels? How does that affect the motion of boats (and eventually events) in the marinas within the study area?
3. Are "surge" events different events to the "roll" events detected and analysed during Stage 2? Does further analysis of surge events add to the comprehension of the boat motions and effects to infrastructure in the marinas?

2.1 Wave climate

Wave climate in the Williamstown Maritime precinct is studied and compared with an available guideline from the Australian Standard for Marina Design (AS 3962:2020). To characterise the wave climate, wave data from two separate sources i) a spectral wave transformation model (SWAN) wave hindcast developed by BMT, and ii) observations collected during the first stage of this study are analysed and compared with the criteria for good wave climate provided by the referred guidelines.

2.1.1 Marina guidelines

For marinas to be safe for the berthing and protection of vessels, the Australian Standard for Marina Design (AS 3962:2020, see https://www.standards.org.au/) recommends a wave height criteria for "good" wave climate (see Table 2.1).

Table 2.1 Criteria for a "good" wave climate in marinas (Source: Australian Standard for Marina Design, AS 3962:2020)

Direction and peak period of design harbour wave	Significant wave height H_S	
	Wave event exceeded once in 50 years	Wave event exceeded once a year
Head seas less than 2 s	Conditions not likely to occur during this event	Less than 0.3 m wave height
Head seas greater than 2 s	Less than 0.6 m wave height	Less than 0.3 m wave height
Oblique seas greater than 2 s	Less than 0.4 m	Less than 0.3 m wave height
Beam seas less than 2 s	Conditions not likely to occur during this event	Less than 0.3 m wave height
Beams seas greater than 2 s	Less than 0.25 m wave height	Less than 0.15 m wave height
NOTE For criteria for an "excellent" wave climate multiply wave height by 0.75, and for a "moderate" wave climate multiply wave height by 1.25. For vessels of less than 20 m in length, the most severe wave climate should satisfy moderate conditions. For vessels larger than 20 m in length, the wave climate may be more severe.		

2.1.2 Wave modelling

A spectral wave transformation model (SWAN) was used to hindcast wave properties in the Williamstown Maritime precinct over a 5-year period from 2017 to 2022. SWAN (Booij et al., 1999) is a third-generation spectral wave model, which is capable of simulating the generation of waves by wind, dissipation by white capping, depth-induced wave breaking, bottom friction and wave-wave interactions in both deep and shallow waters. SWAN simulates wave/swell propagation in two-dimensions, including shoaling and refraction due to spatial variations in bathymetry and currents. This is a global industry standard modelling package that has been applied with reliable results to many investigations worldwide.

Data sets used in the wave model

Bathymetry

Bathymetric data were obtained from the Victorian Coastal Digital Elevation Model (VCDEM 2017), in which spatial resolution is provided down to 10 m. These data can be downloaded from the Australian Ocean Data Network (AODN, https://portal.aodn.org.au).

Wind

Australian Bureau of Meteorology (BoM) weather stations record a variety of characteristics of the weather including wind speed and direction. The observations from stations covering the regional area of Port Phillip Bay have been used in this study. Figure 2.1 shows the available stations in the region.

Figure 2.1 BoM weather station locations covering the Port Phillip Bay

Wave

The Port Phillip Bay wave monitoring program started in December 2020 as a part of the broader Victorian Coastal Monitoring Program (VCMP). A total of 6 buoys have been deployed in the Bay and have continued records of waves until now. Werribee Buoy is the best spatially related buoy in the network to the Study area. Figure 2.2 represents the locations of the buoys deployed in Port Phillip Bay.

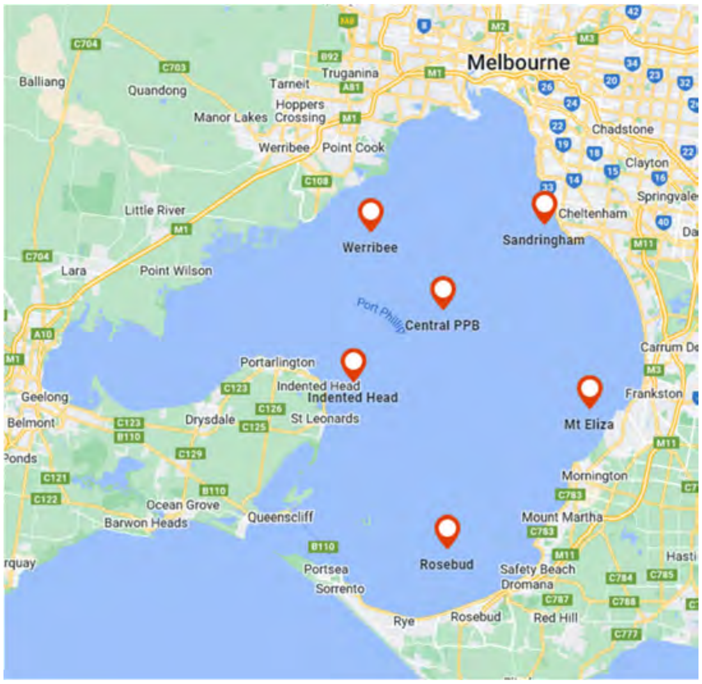

Figure 2.2 Locations of wave buoys in Port Phillip Bay from the VCMP (www.vicwaves.com.au)

Tide

The global tidal information is based on the integration of approximately 5000 tidal stations and 17 years of satellite radar altimeter measurements into depth average global and regional tidal models (2DH model) developed at BMT. For the area of interest, the model resolution is approximately 1 minute. The tidal model provides tidal current harmonics (u, v components) as well as harmonics of surface elevation, from which predicted time series of levels and currents can be generated. The model includes the M2, S2, N2, K2, K1, O1, P1 and Q1 harmonic constituents, from which 12 more minor constituents are inferred.

Model Setup

The SWAN wave model setup and development involved a number of investigations, followed by calibration, and validation to optimise the simulation results in regard to the Werribee Buoy's wave observations.

Spatial Representation

The wave model domain is a regional structured grid covering Port Phillip Bay with a resolution of 500m (Figure 2.3).

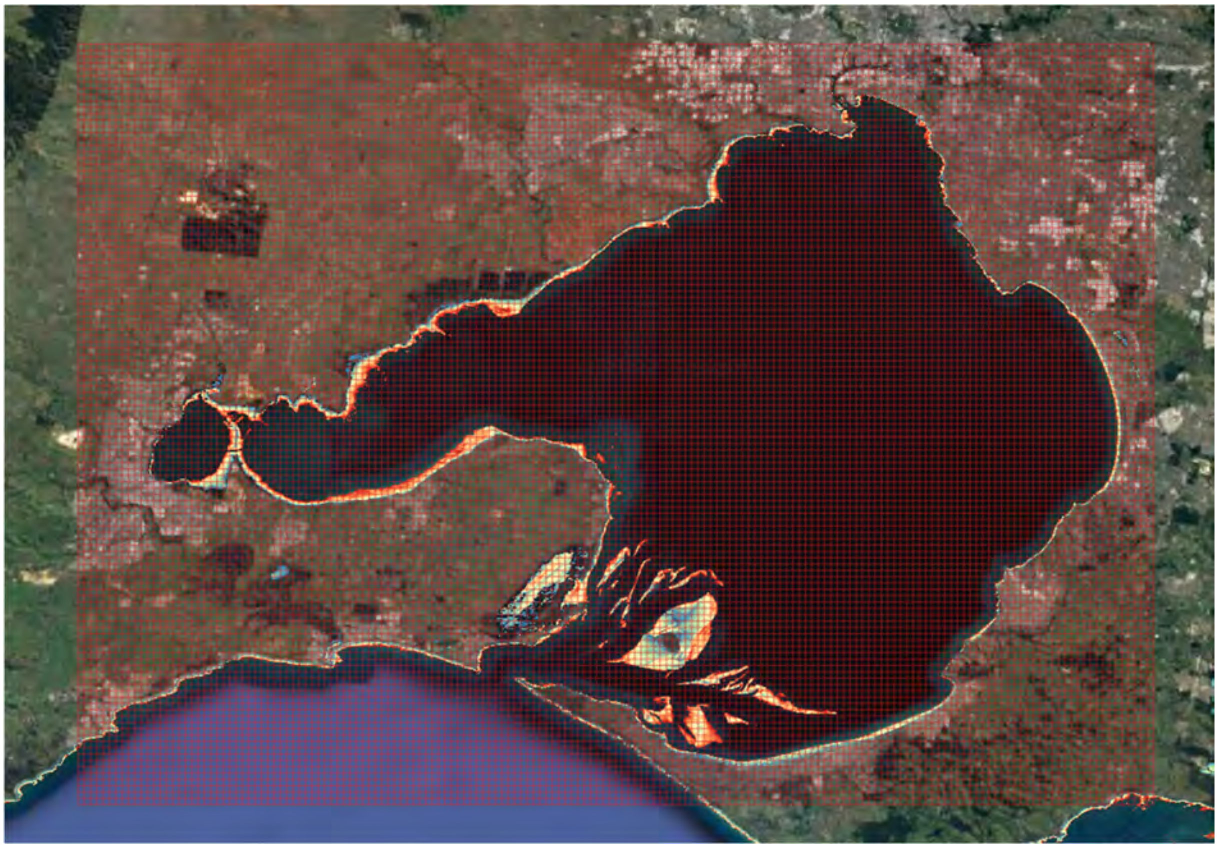

Figure 2.3 Wave model grids

Boundary Conditions

The model's wind field is an interpolated wind field based on four BoM weather stations (Fawkner Beacon, South Chanel Island, Avalon Airport and Laverton RAAF) in Port Phillip Bay. The interpolation method is non-linear radial basis function (RBF) interpolation. The water level was applied as a non-stationary constant level change derived from BMT tidal model. In the case of Swell, the geomorphology of the Bay prevents swell from penetrating into the Bay, particularly for the area of interest in this study; therefore, no open boundary swell condition was imposed in the model.

Model Validation

The hindcast data have been validated against wave observations for the year 2021 from the Werribee buoy. A close investigation of the results showed that the model provides a good representation of waves in the Bay and can capture all the main weather events recorded by the Werribee Buoy for the validation period. Figure 2.4 and Figure 2.5 present the comparison of sample time windows of the wave timeseries from the model hindcast and Werribee Buoy observations.

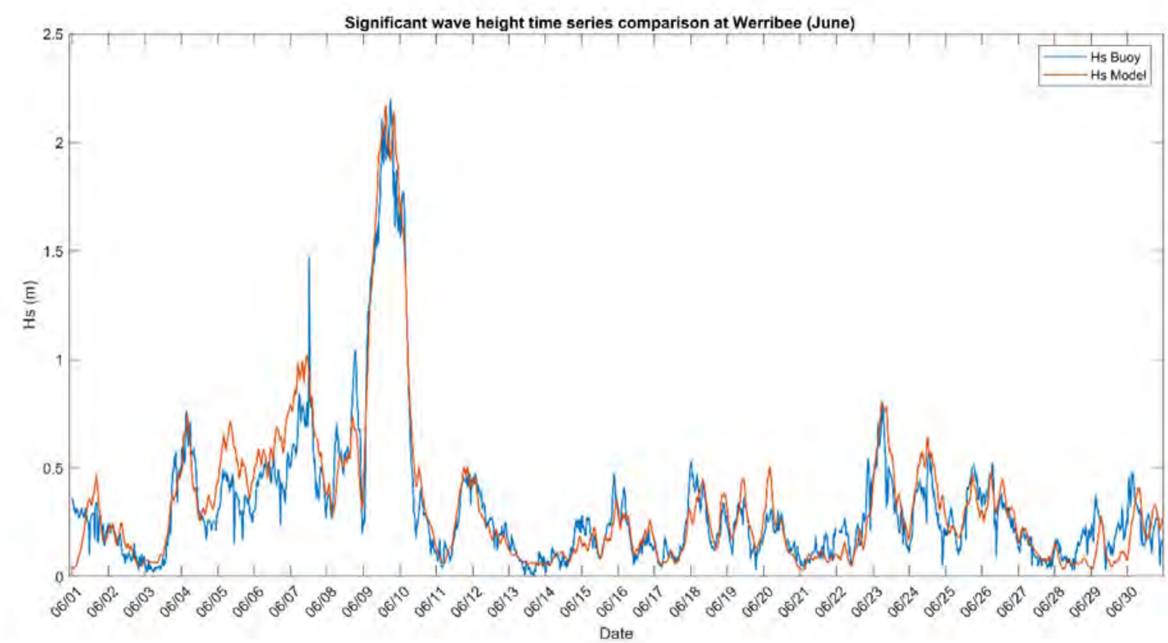

Figure 2.4 Wave timeseries from Werribee buoy (blue) and model hindcast (orange) for June 2021

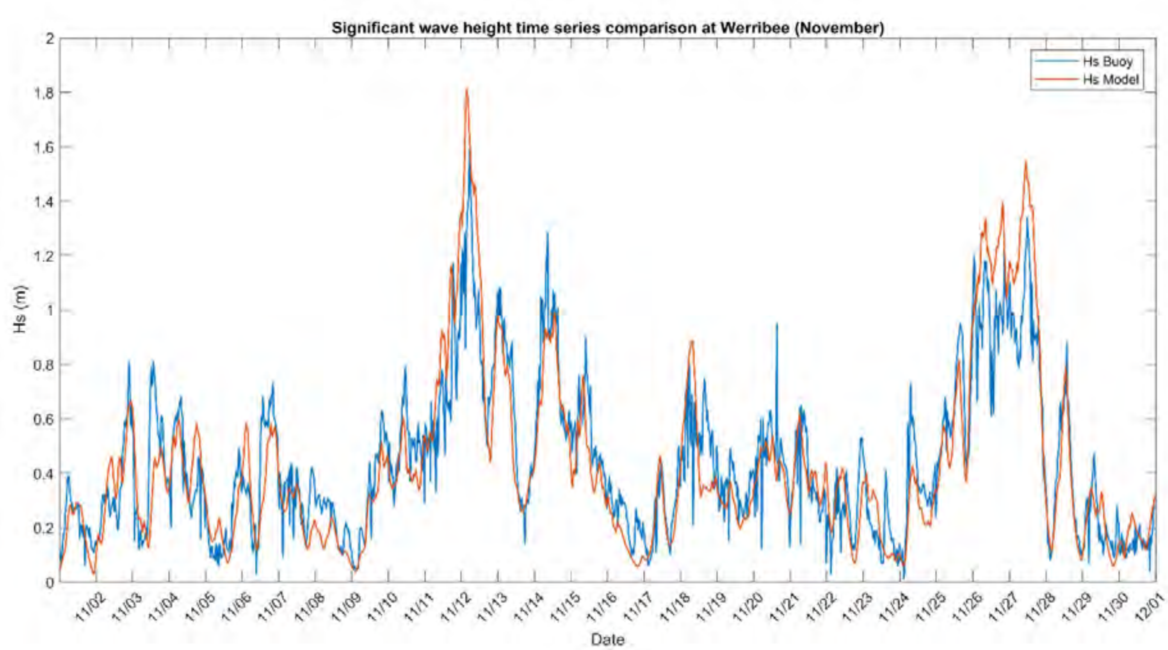

Figure 2.5 Wave timeseries from Werribee buoy (blue) and model hindcast (orange) for November 2021

The probability of exceedance of significant wave height from buoy observations and model hindcast is shown in Figure 2.6.

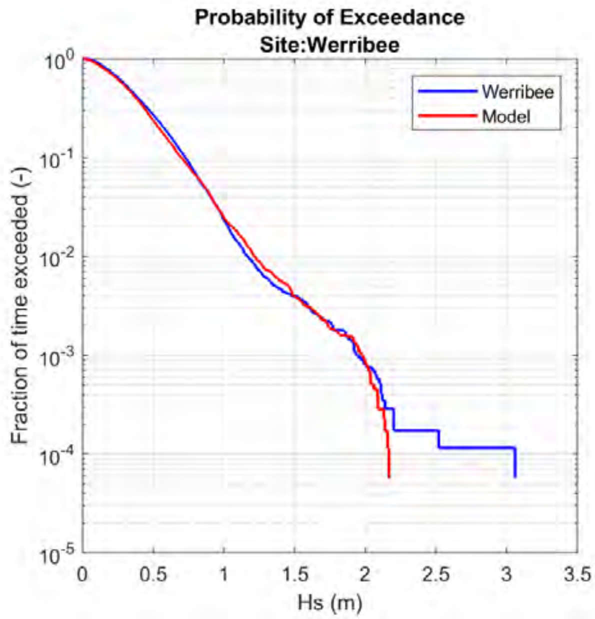

Figure 2.6 Probability of exceedance of model hindcast significant wave height and collocated Werribee Buoy observations

Figure 2.7 to Figure 2.9 present annual and monthly wave roses from the model hindcast and buoy observations at the Werribee buoy location.

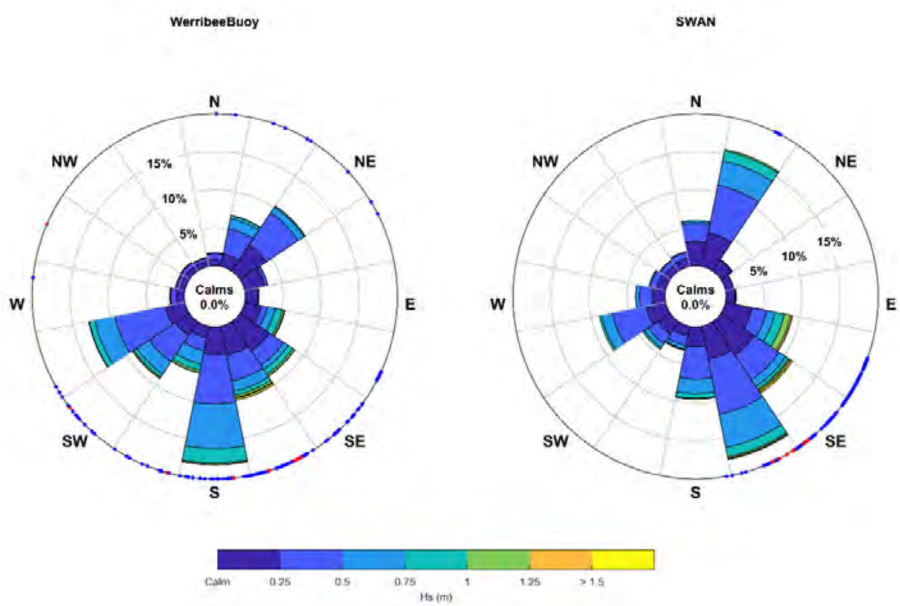

Figure 2.7 All-year Wave roses from buoy (left) and model hindcast (right).

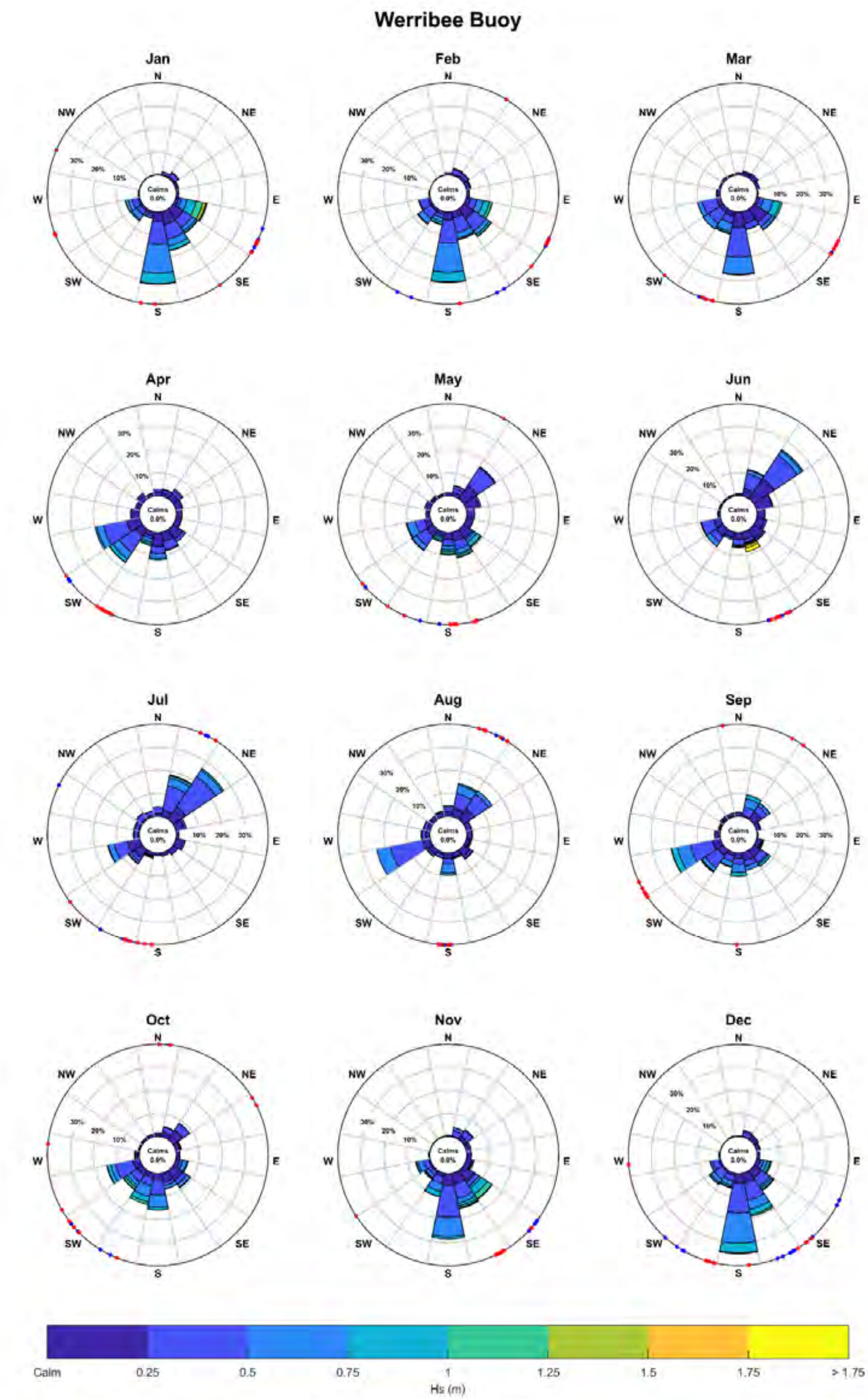

Figure 2.8 Monthly Wave roses from buoy observations.

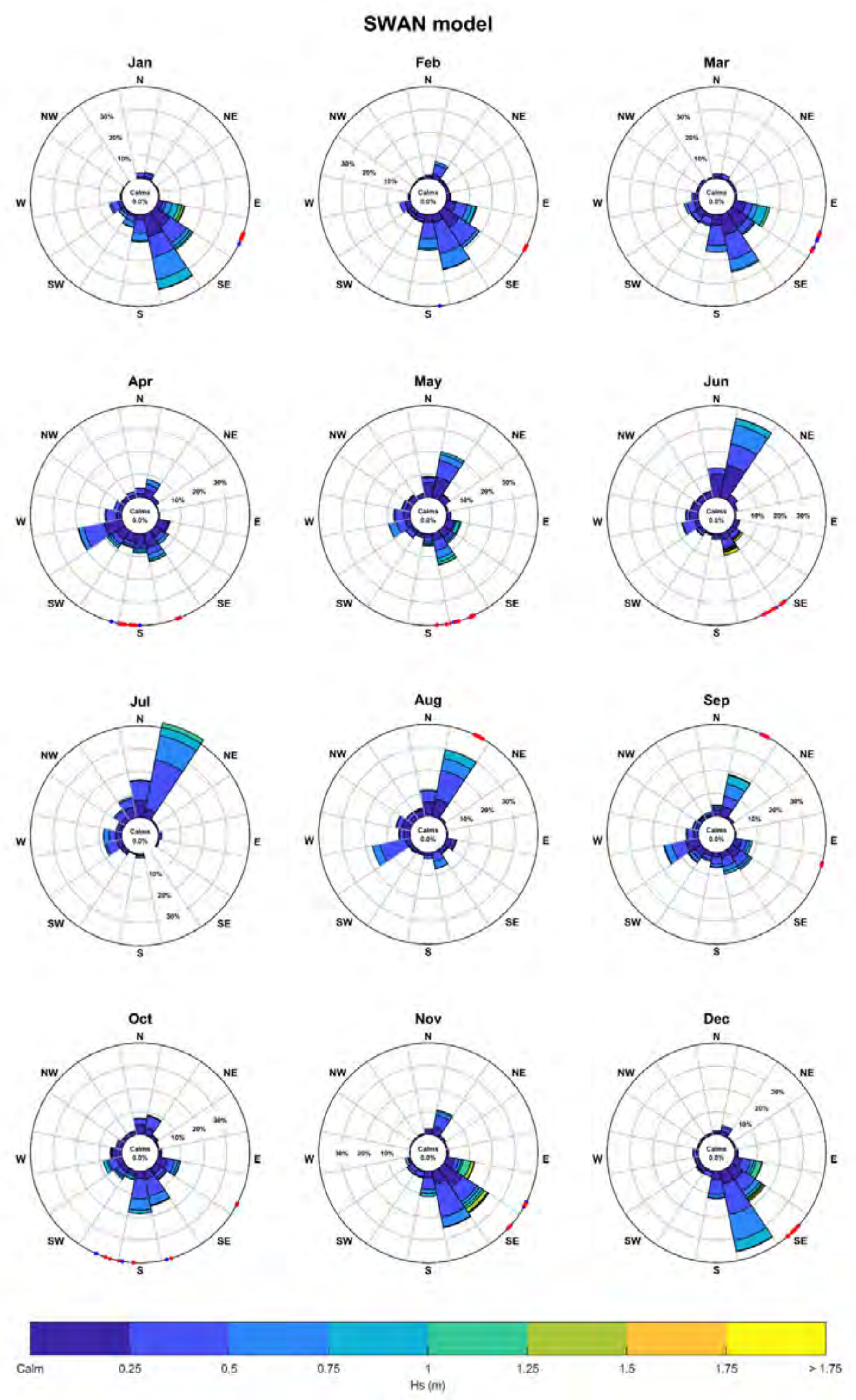

Figure 2.9 Monthly Wave roses from model hindcast.

Model outputs

Wave climate at five different points around the Williamstown Maritime Precinct (as shown in Figure 2.10) were extracted from the wave model grid. Wave model outputs at Point1 (P1, the closest point to most of the marinas) are further analysed.

Note, the model provides simulation of wave conditions without accounting for wake waves produced by vessel passage and marine traffic.

Figure 2.10 SWAN wave model output points around the study area

Table 2.2 shows the results of an Extreme Value Analysis (EVA) for significant wave heights (Hs) at Point1. EVA is a method used to estimate the probability of occurrence of Hs that are more extreme. Regardless of the wave direction, in comparison with the guidelines provided in Table 2.1, extreme wave height both in 1-year and 50-year, average return interval (ARI) or return period, exceed 0.3m with values up to 0.55 in 1-year and up to 0.78 in 50-year return periods, which indicate no compliance with the criteria for "good" wave climate for marinas.

Table 2.2 Extreme return values of significant wave height at P1

Wave Direction (coming from)			Return Period (year)								
			1	2	5	10	20	50	100	200	500
337.5	22.5	N	0.37	0.39	0.41	0.43	0.45	0.48	0.50	0.52	0.55
22.5	67.5	NE	0.34	0.36	0.39	0.40	0.42	0.45	0.47	0.49	0.51
67.5	112.5	E	0.38	0.44	0.49	0.52	0.54	0.57	0.59	0.61	0.63
112.5	157.5	SE	0.55	0.60	0.65	0.69	0.73	0.78	0.81	0.84	0.89
157.5	202.5	S	0.49	0.54	0.60	0.64	0.68	0.73	0.77	0.80	0.85
202.5	247.5	SW	0.30	0.32	0.34	0.35	0.36	0.38	0.39	0.40	0.41
247.5	292.5	W	0.31	0.33	0.35	0.36	0.37	0.39	0.40	0.41	0.42
292.5	337.5	NW	0.30	0.32	0.34	0.35	0.36	0.38	0.39	0.40	0.41
Omni Direction			0.55	0.60	0.65	0.69	0.73	0.78	0.81	0.84	0.89

Table 2.3 shows the joint percentage of occurrence of conditions in significant wave height (Hs) interval and peak wave period (Tp) interval. When comparing these to the guidelines in Table 2.1, for Tp less than 2s, ~1.4% of wave heights exceed 0.3m and for Tp more than 2s, ~3% of waves heights exceed 0.3m and ~4.35% of wave heights exceed 0.15m, which further indicate no compliance with the criteria for “good” wave climate for marinas.

Table 2.3 Percentage of occurrence of conditions in Hs interval and Tp interval

Significant Wave Height (m)		Peak Wave Period (s)													Total
		0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	
0.70	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.65	0.70	0	0	0	0	0	0.011	0.005	0	0	0	0	0	0	0.016
0.60	0.65	0	0	0	0	0	0.007	0.009	0	0	0	0	0	0	0.016
0.55	0.60	0	0	0	0	0	0.007	0.016	0	0	0	0	0	0	0.023
0.50	0.55	0	0	0	0	0.018	0.021	0.025	0	0	0	0	0	0	0.064
0.45	0.50	0	0	0	0	0.037	0.078	0.007	0	0	0	0	0	0	0.121
0.40	0.45	0	0	0	0.002	0.178	0.146	0	0.002	0	0	0	0	0	0.329
0.35	0.40	0	0	0	0.116	0.794	0.107	0.002	0.009	0	0	0	0	0	1.029
0.30	0.35	0	0	0	1.276	1.422	0.039	0.025	0.007	0	0	0	0	0	2.768
0.25	0.30	0	0	0	4.555	0.755	0.039	0.021	0.002	0	0.002	0	0	0	5.374
0.20	0.25	0	0	0.009	8.507	0.306	0.043	0.005	0	0.002	0	0.005	0.002	0	8.879
0.15	0.20	0	0	0.988	11.841	0.087	0.011	0.027	0.053	0.009	0.002	0.007	0	0	13.025
0.10	0.15	0	0	13.255	5.244	0.034	0.069	0.292	0.235	0.016	0.002	0.005	0	0	19.152
0.05	0.10	0	0	14.951	0.794	0.187	1.031	1.232	0.153	0.027	0.002	0	0	0	18.378
0.00	0.05	0	0	16.402	5.091	4.315	3.124	1.038	0.502	0.249	0.075	0.030	0.002	0	30.828
Total		0	0	45.605	37.425	8.133	4.733	2.704	0.963	0.304	0.084	0.046	0.005	0	100.000

2.1.3 Wave observations

To better understand the wave conditions at the study area, wave measurements recorded using a wave array instrument deployed during stage 1 were reviewed. The timeseries of measured wave height and period for a sample period of 2 months in February 2021 and March 2021 are shown in Figure 2.11. The data shows that wave heights exceed the AS 3962:2020 recommend criteria for “good” wave climate of 0.3m and more so 0.15m on numerous occasions during the 2 month sample period. Note that the continuous timeseries shown in Figure 2.11, incorporates both the wind generated waves, i.e., ambient conditions, and the wake waves from marine traffic around the study area.

Moored boat motions associated with naturally occurring wind and wave conditions

Figure 2.12 shows wind conditions measured by the Victorian Port Corporation (Melbourne) (VPCM) at Breakwater Pier presented for each month between December 2020 and April 2021 compared to the daily number of detected roll events categorised to six maximum amplitudes of measured roll motions (same categories as analysed and presented in the Stage 2 Report of this Study) i.e., i) less than 5°, ii) between 5° and 10°, iii) between 10° and 15°, iv) between 15° and 20°, v) between 20° and 25°, and vi) more than 25°. The figure indicates that there is no marked association between the number of detected events and the background wind and wave ambient conditions (that naturally occur in the area), i.e., event detections were independent of whether ambient wind and wave conditions were calm or rough sea state. In turn, this validates that the dynamic threshold algorithm, purposely developed in this Study, for boat motion event detection has been effective on adjusting the detection to the background conditions occurring at the time of events; in other words, the algorithm successfully detects the wake and surge induced motions regardless of the background sea state throughout the data collection period (refer to the Stage 2 Report for further details on the method and algorithm applied).

In despite of the above, naturally occurring wind and wave conditions do induce motion of moored boats in the Williamstown Maritime Precinct. Two examples of wind generated waves at the study area are shown in Figure 2.13 and Figure 2.15 (see Figure 2.14 and Figure 2.16 for recorded accelerations – refer to Section 2.2 for the explanation of spectrogram plots). Each figure covers a representative 30-minute time period selected to present examples of high wind speeds, no vessel passage, and no event detection when the dynamic threshold algorithm was applied. Wind speeds of ~20knots and ~30knots were recorded during these examples on 1 March 2021 and 11 April 2021, respectively. The maximum roll motion amplitude measured was approximately 5 degrees in the first example and 7 degrees in the second example, and wave heights generally remained below 0.2m in both examples, that is still in excess of 0.15m requirement for “good” wave climates in marinas for beam seas direction and peak period of design harbour wave greater than 2s.For comparison, an example detected event triggered by the wake waves and surge from marine traffic is shown in Figure 2.17 (see Figure 2.18 for recorded accelerations and spectrogram plots). The event, that was detected on 8 April 2021 at 10:33am, led to a maximum roll amplitude of 19.6 degrees with wave heights of more than 0.4m. These examples demonstrate that naturally occurring wind and wave ambient conditions do result in moored boat motions, however, these motions tend to be less pronounced than some of those recorded from wash, wake and surge induced events. These examples further demonstrate the effectiveness of the algorithm and methodologies used for event detection and analysis purposes developed in this Study.

Nevertheless, it is worth noting that naturally occurring extreme wind and wave conditions, e.g., storm related, such as those described in Table 2.2 above, can lead to extreme boat motions and loads on marina infrastructure, and thus potentially result in high impact, damage and risk to assets and people. The detailed analysis of extreme conditions and associated risk/impact is beyond the scope of this Study, but it is noted that local stakeholders, including yacht club members and marina berth holders and personnel, have commented on damaging and threatening storm events occurring in the past and affecting different sections of the foreshore and marinas depending on the prevalent direction of specific storms.

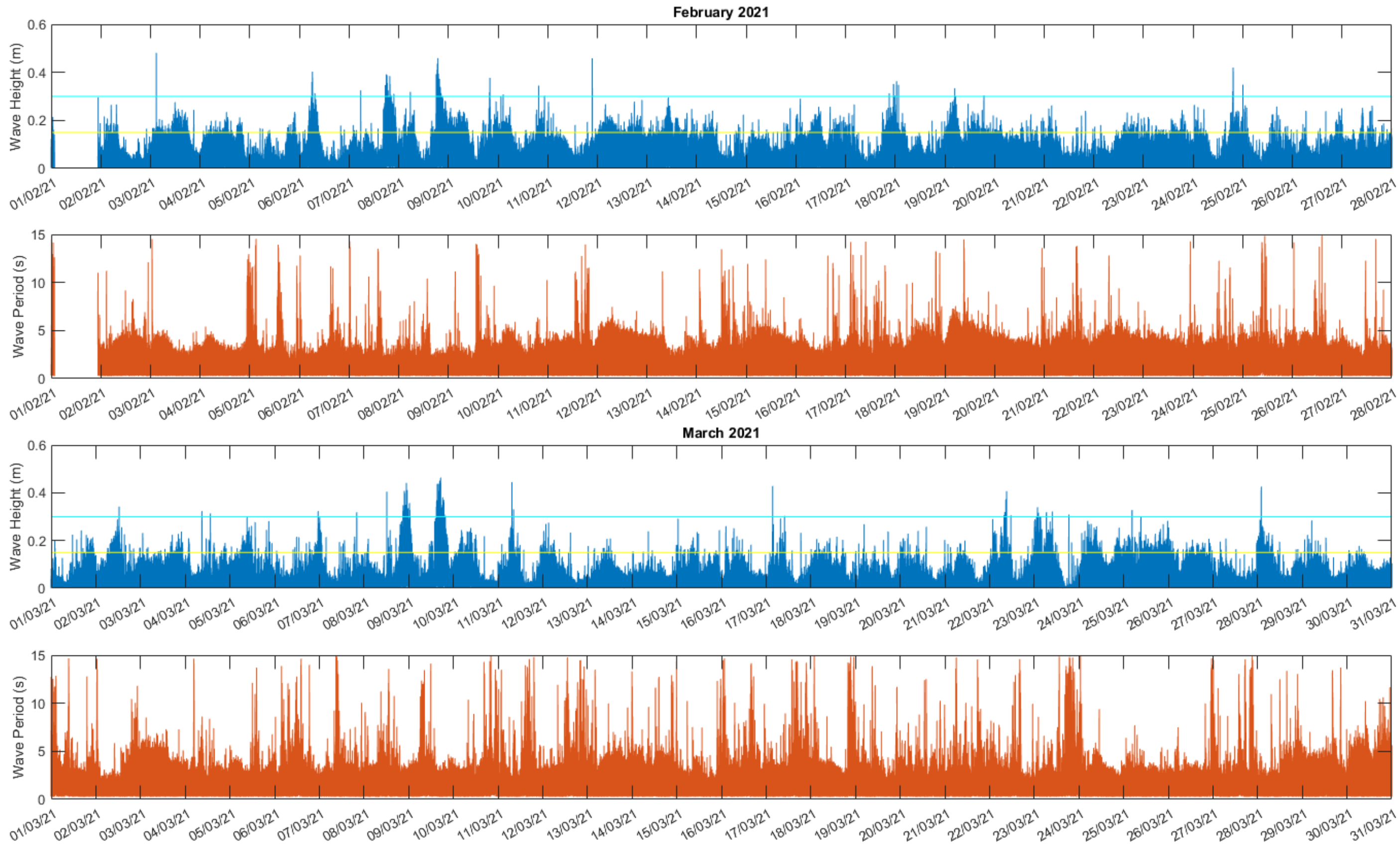

Figure 2.11 Measured wave height and period in February 2021 and March 2021 (the yellow and cyan lines represent the 0.15m and 0.30m wave heights recommended in AS 3962:2020 for "good" wave climate in marinas and boating facilities, refer to section 2.1.1 for further context)

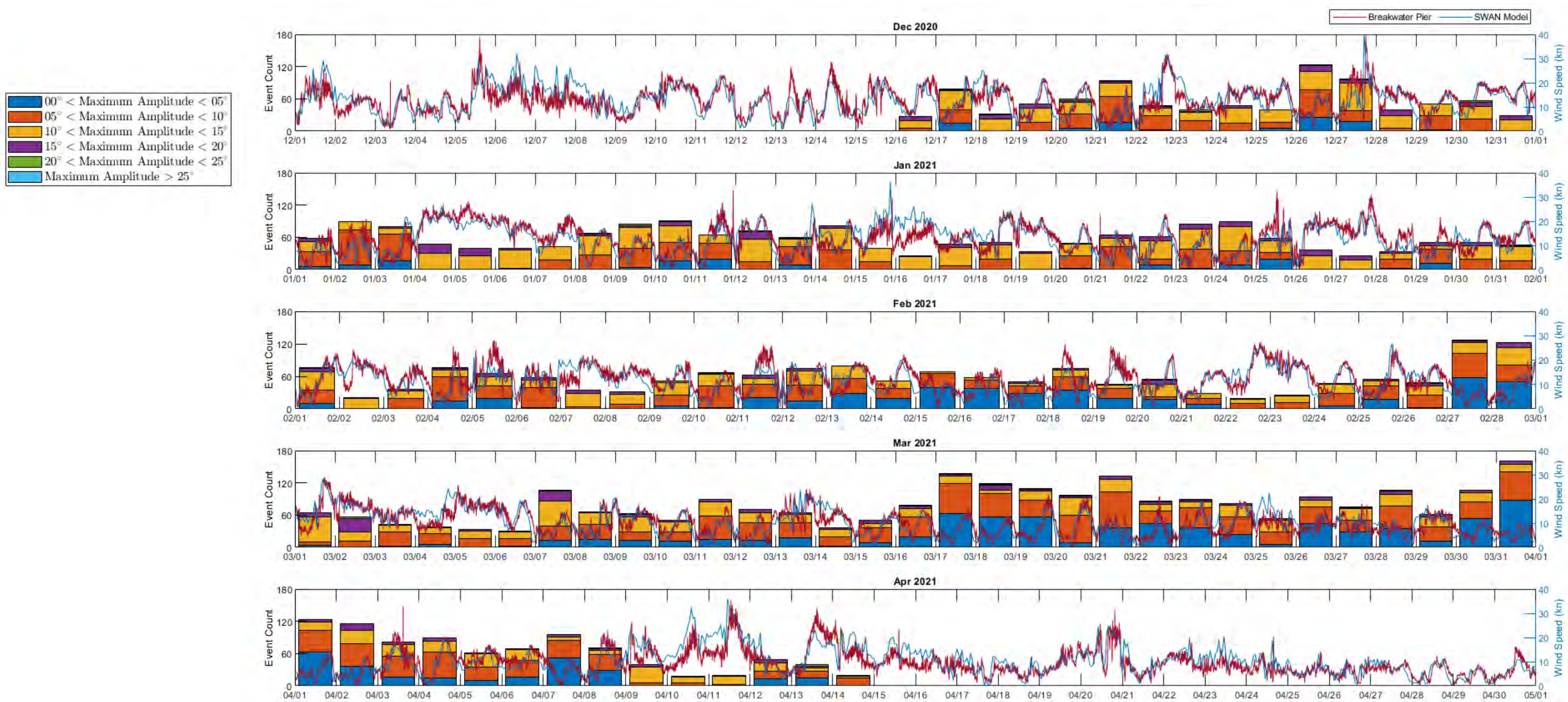

Figure 2.12 Measured wind at Breakwater Pier compared to detected roll events categorised by the evens' maximum roll amplitude

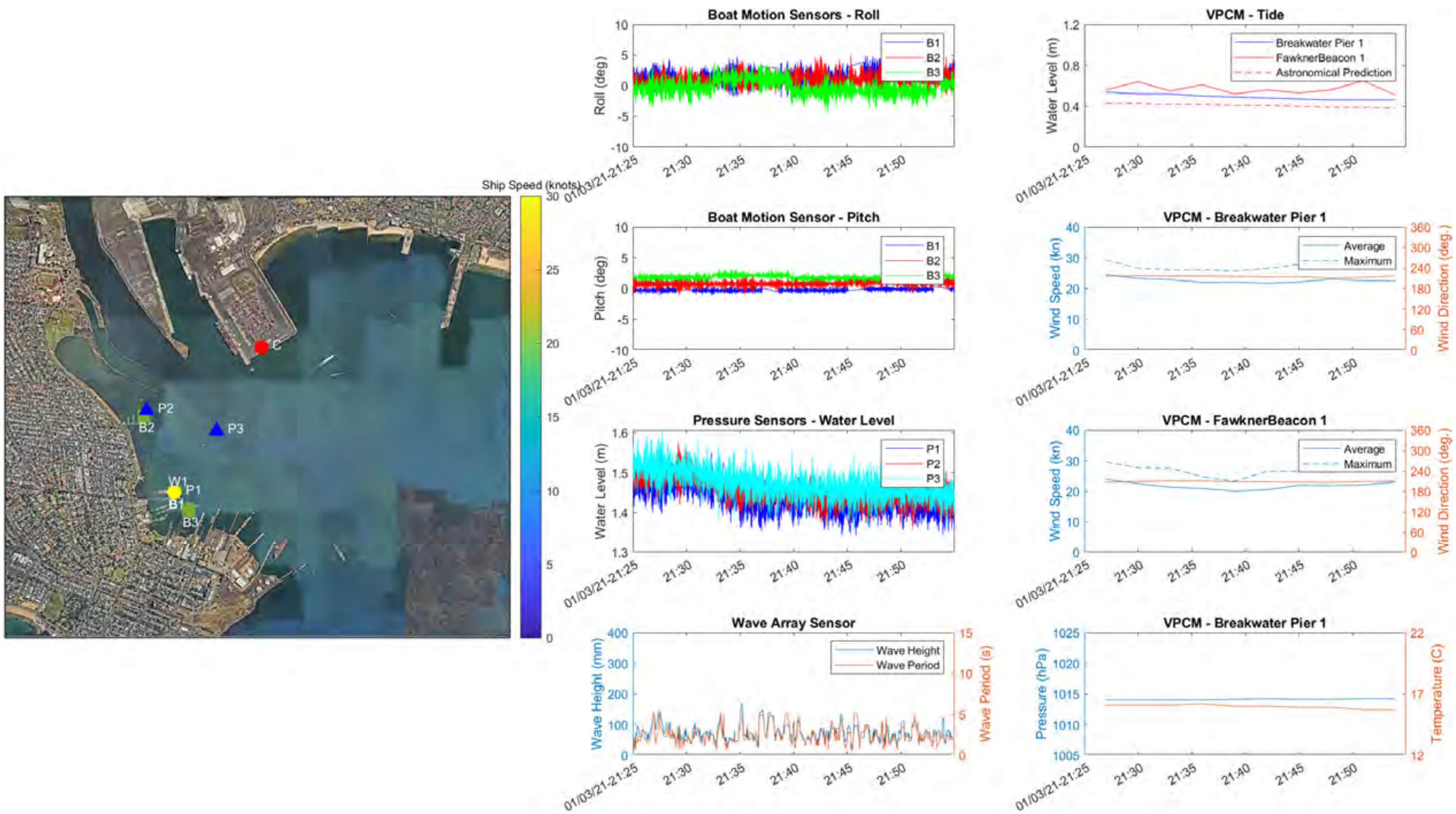

Figure 2.13 Summary diagnostic plot of marine traffic, metocean conditions and moored boat motions on 1 March 2021 from 21:25 to 21:55

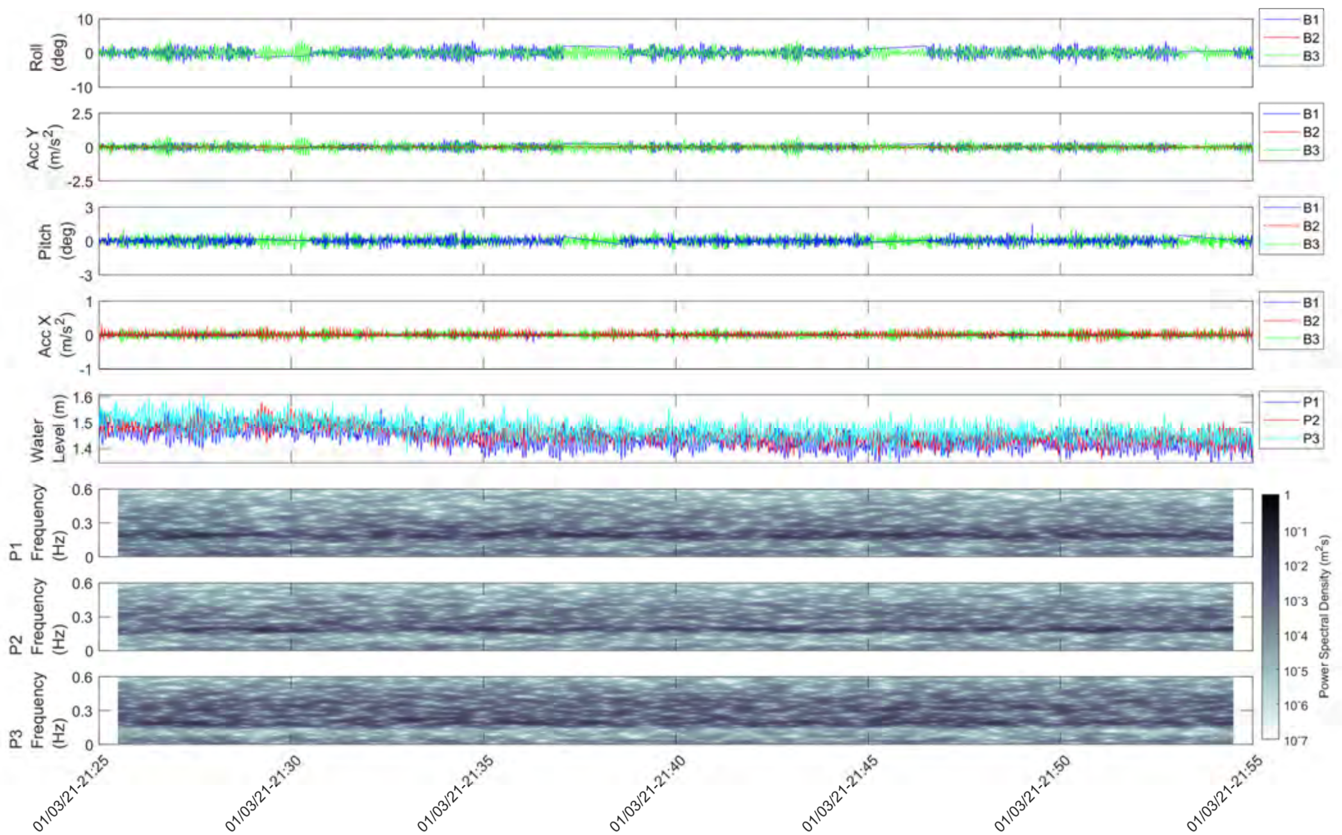

Figure 2.14 Spectrogram plot for metocean condition and boat motion accelerations on 1 March 2021 from 21:25 to 21:55

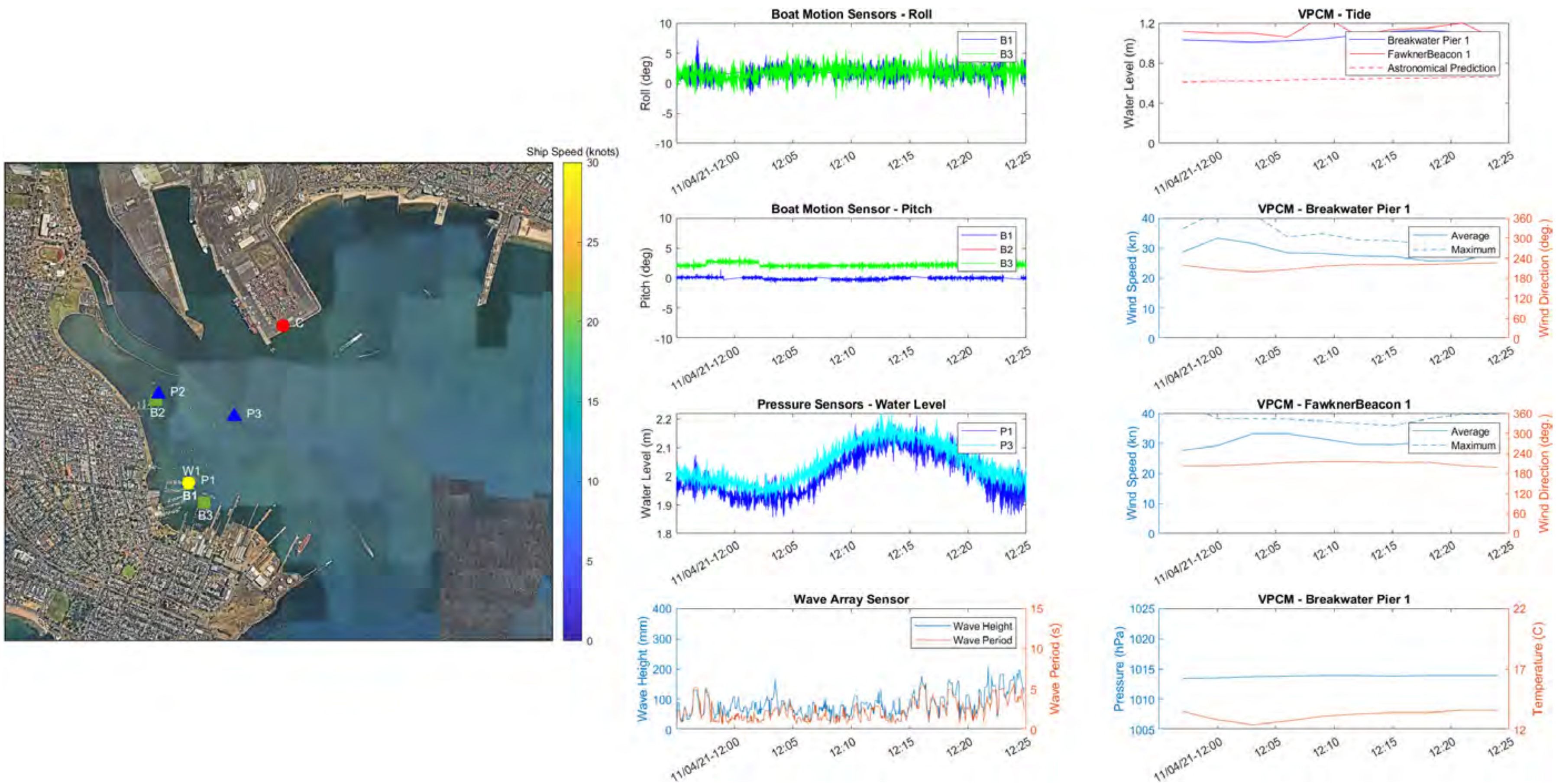

Figure 2.15 Summary diagnostic plot of marine traffic, metocean conditions and moored boat motions on 11 April 2021 from 11:55 to 12:25

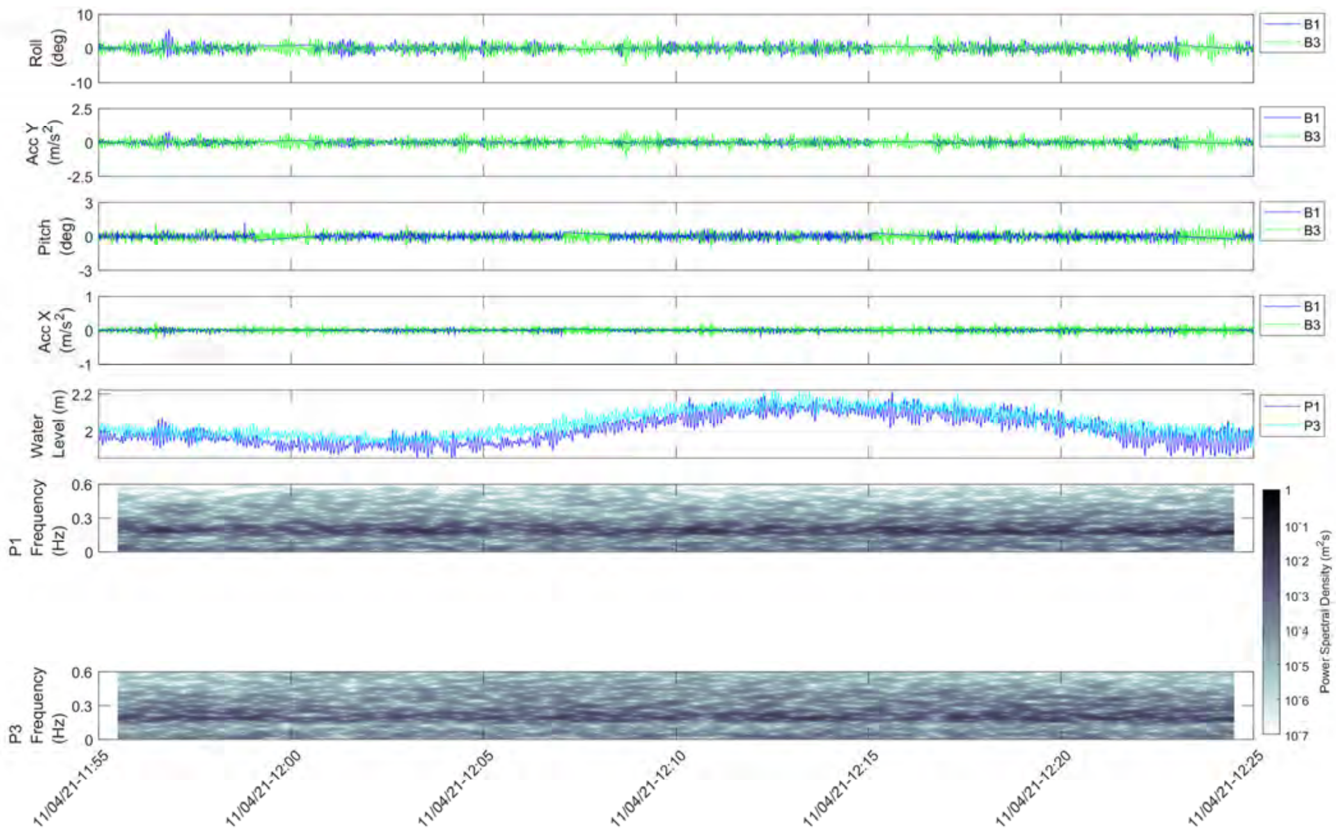

Figure 2.16 Spectrogram plot for metocean conditions and boat motion accelerations on 11 April 2021 from 11:55 to 12:25

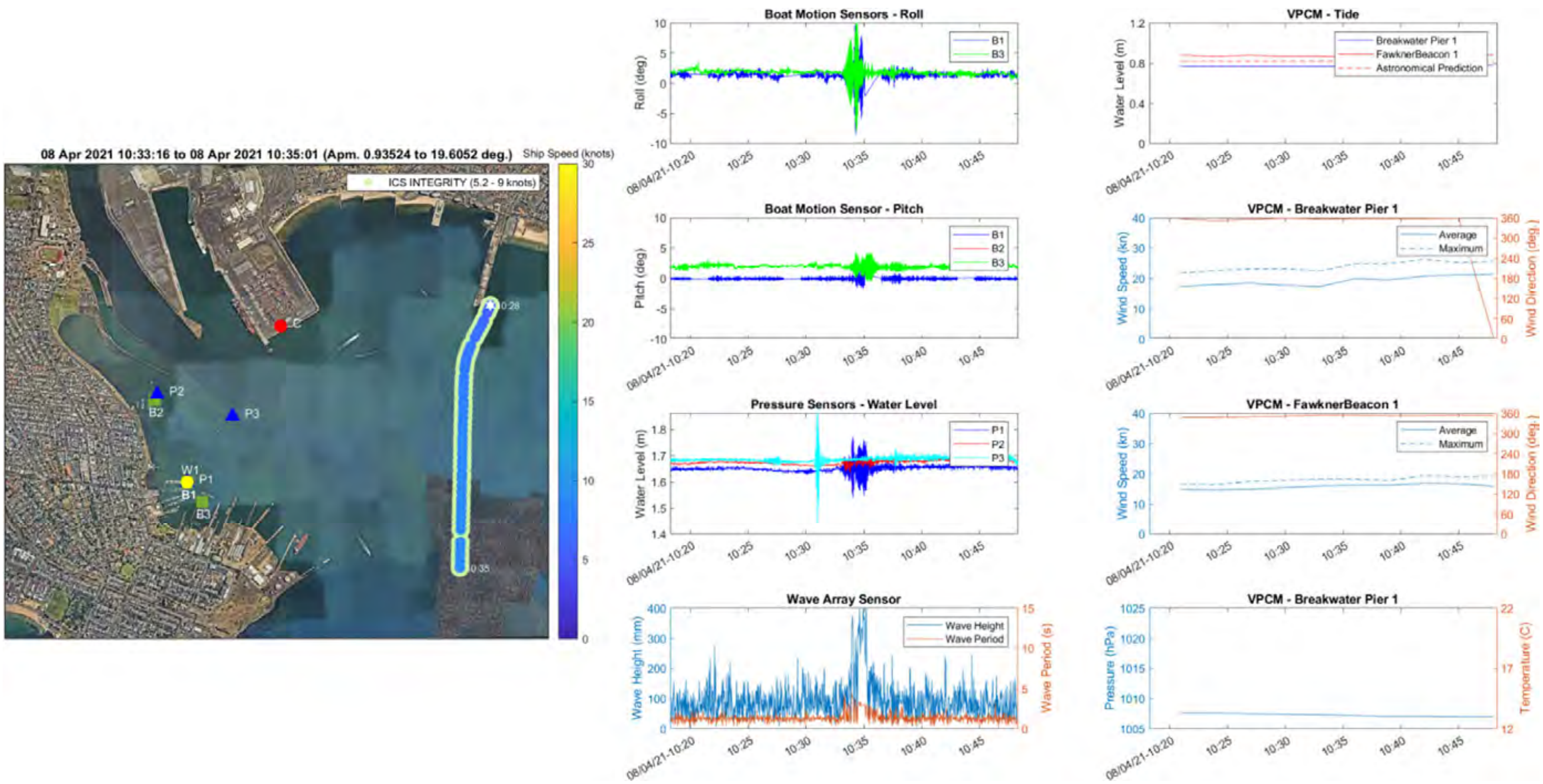

Figure 2.17 Summary diagnostic plot for a roll event of 19.6-degree maximum amplitude detected on 8 April 2021 at 10:33am

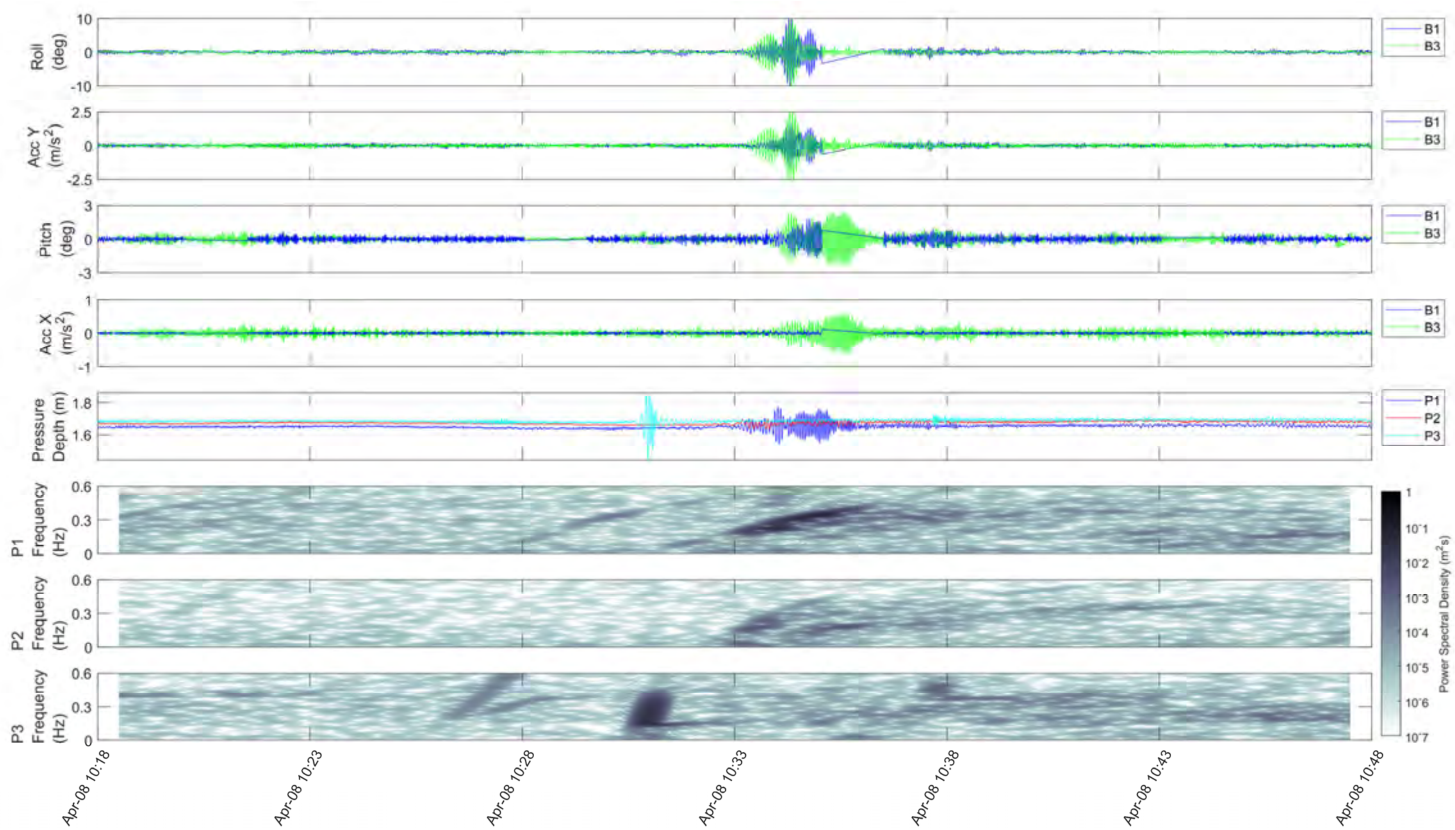

Figure 2.18 Spectrogram plot for metocean conditions and boat motion accelerations on 8 April 2021 from 10:18 to 10:48

2.2 Characterisation of vessel wake patterns

To further analyse different wake patterns (or "signature") from different vessel types typically transiting in the study area, a selection of catalogued events were analysed, including preparation of spectrogram plots.

The spectrogram plots are a visual representation of the wave signal strength recorded by the pressure sensors (P1, P2, and P3) that show how the energy level of the signal (shown as the Power Spectral Density – PSD) varies over time in different frequency bands.

The wave characteristics, significant wave height Hs and significant wave period Ts, were derived using the OCEANLYZ 2.0 algorithm. The algorithm used, adopts the zero-crossing method to analyse the timeseries data in distinct bursts of time. For this analysis, based on sensitivity testing, 36 burst of 50 seconds were used for each of the half hour intervals plotted in the diagnostic plots and then replotted for the 14 minutes surrounding the detected event and associated vessel passage. The wavelength associated with the significant wave period was further derived, following the assumption of shallow water conditions.

The vessel passages of four main categories of vessels, based on the different vessel size and hull design of vessels associated with events (as opposed to vessel functional type) listed below were studied, and an example of a detected event associated with each type is presented.

1. Fast ferries, i.e., catamaran demi hull design
2. Large (commercial) vessels, i.e., with deep draught
3. Port support vessels, i.e., tugs
4. Small to medium motorboats (not included in other categories)

2.2.1 Catamaran Demi Hull Vessels – Fast Ferries

An example of a detected event where there was a fast ferry travelling through the study area is the event detected on 16 March 2021 from 08:05. As described in the stage 2 report this was also one of the events reported by local stakeholders (a boat owner/user of the Savages Wharf marina) and it was characterised by having a maximum amplitude of 15.9° roll on the B3 sensor (RYCV), 13.4° and 4.1° on the B1 (HBYC) and B2 (The Anchorage) sensors, respectively.

Figure 2.19, shows, from the AIS data, the Bellarine Express on an inbound transit and passing the pressure sensors, P3 and P1, shortly before the event was detected by the boat motion sensors. Note, additionally, prior to this event, the plots in Figure 2.19 and Figure 2.20 show another event that was detected on all three boat sensors that occurred from 07:56 and was associated with the other fast ferry, the Geelong Flyer and a cargo ship.

The spectrogram plots in Figure 2.20 distinctly show the wake signature of both fast ferries. The P3 sensor, closest to the channel, shows sharp fluctuations in water level, i.e., wake waves associated with the passage of the ferries for a relatively short duration, which are reflected on the spectrogram plot as a 'chirping' signal (frequency increase) observed as a 'dark shade' (peak PSD of approximately 1 m^2s). The P1 sensor, located closer to the boat motion sensors B1 and B3 sensors shows the propagation of the wake waves with less prominent fluctuations in water level occurring over a longer duration, and again reflected in a longer and clear 'chirp' (frequency increase) in the spectrogram plot (the dark shade, again with a peak PSD of approximately 1 m^2s). Similarly, the P2 pressure sensor, the one located furthest north, although less distinct, shows a smaller fluctuation in the water level, starting later and this is reflected in the lighter shading, weaker and longer chirping on the spectrogram, with peaks in PSD of approximately 10^{-3}-10^{-2} m^2s.

Figure 2.21 shows the statistical wave properties for this event from the pressure sensor measurements. The significant wave period slightly increases as sensor P3 as the ferry passes and then the wave height increases. As the wake waves propagate from the source vessel (the fast ferry in this case) towards the marinas area, the diverging waves which contain a mixture of wavelengths get gradually separate (because in water longer waves travel faster than the slower ones), this is reflected in the period of the wake waves observed at P1, which increases/peaks together with wavelength at the outset of the motion of moored boats in the marinas, initially causing a surge motion that is followed shortly after by the increase in wave height causing roll and pitch motions.

This sequence of wave properties and boat motions is as expected as both ferries are travelling inbound (towards Melbourne) and the B2 motion sensor (located northward at the Anchorage) was the last to register the boat motions in this case. The boat motions recorded include roll (more than 15 degrees at B3, ~10 degrees at B1, and less than 5 degrees at B2) and pitch (~5 degrees at B2 and less than 1 degree at B1 and B3) movements that also excites acceleration-x (~0.1ms2 at B2 in the direction of bow-stern) and acceleration-y (up to 2ms2 at B3 in the direction of port and starboard side).

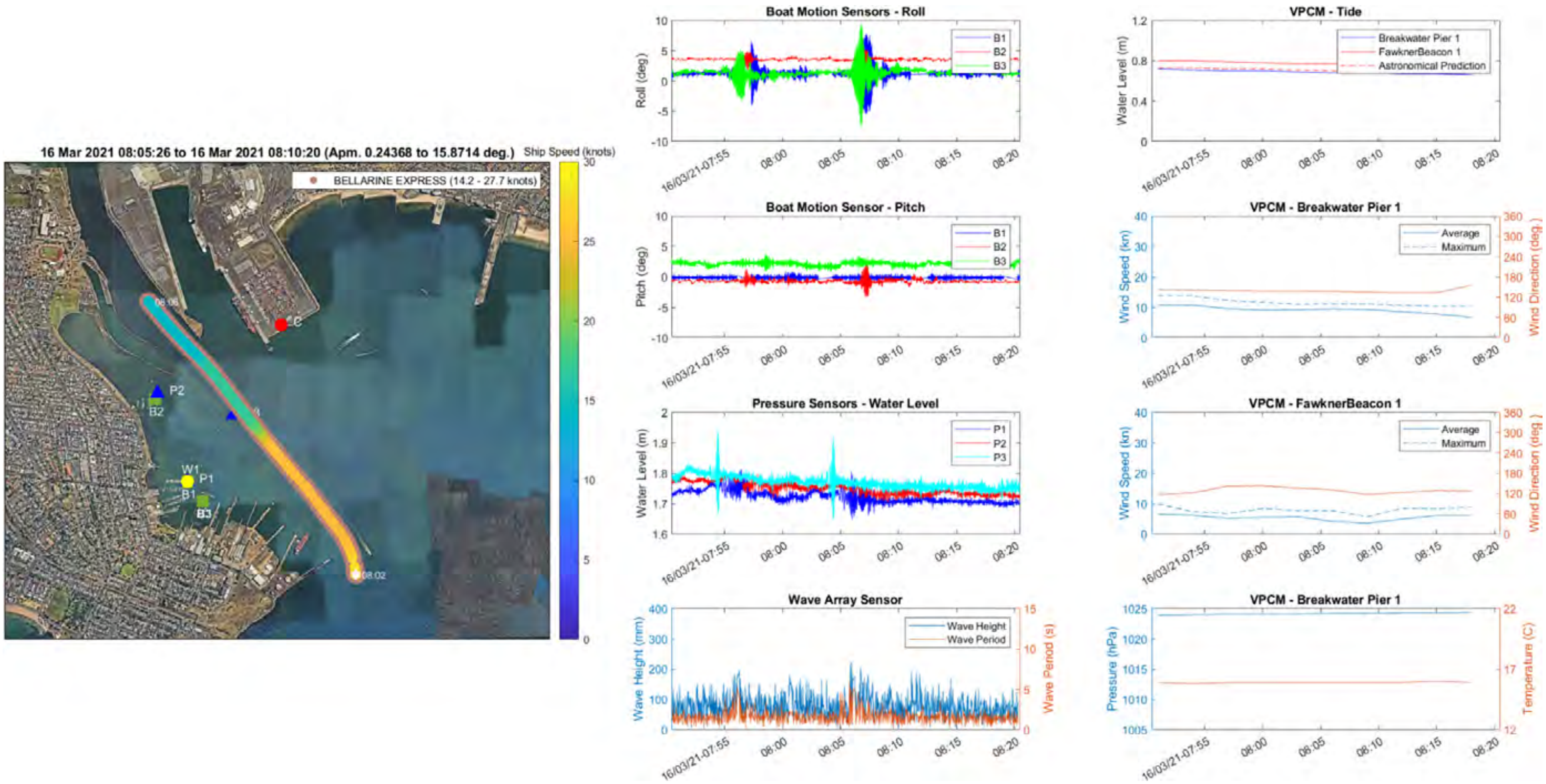

Figure 2.19 Summary diagnostic plot for an example event detection with only a Fast Ferry associated

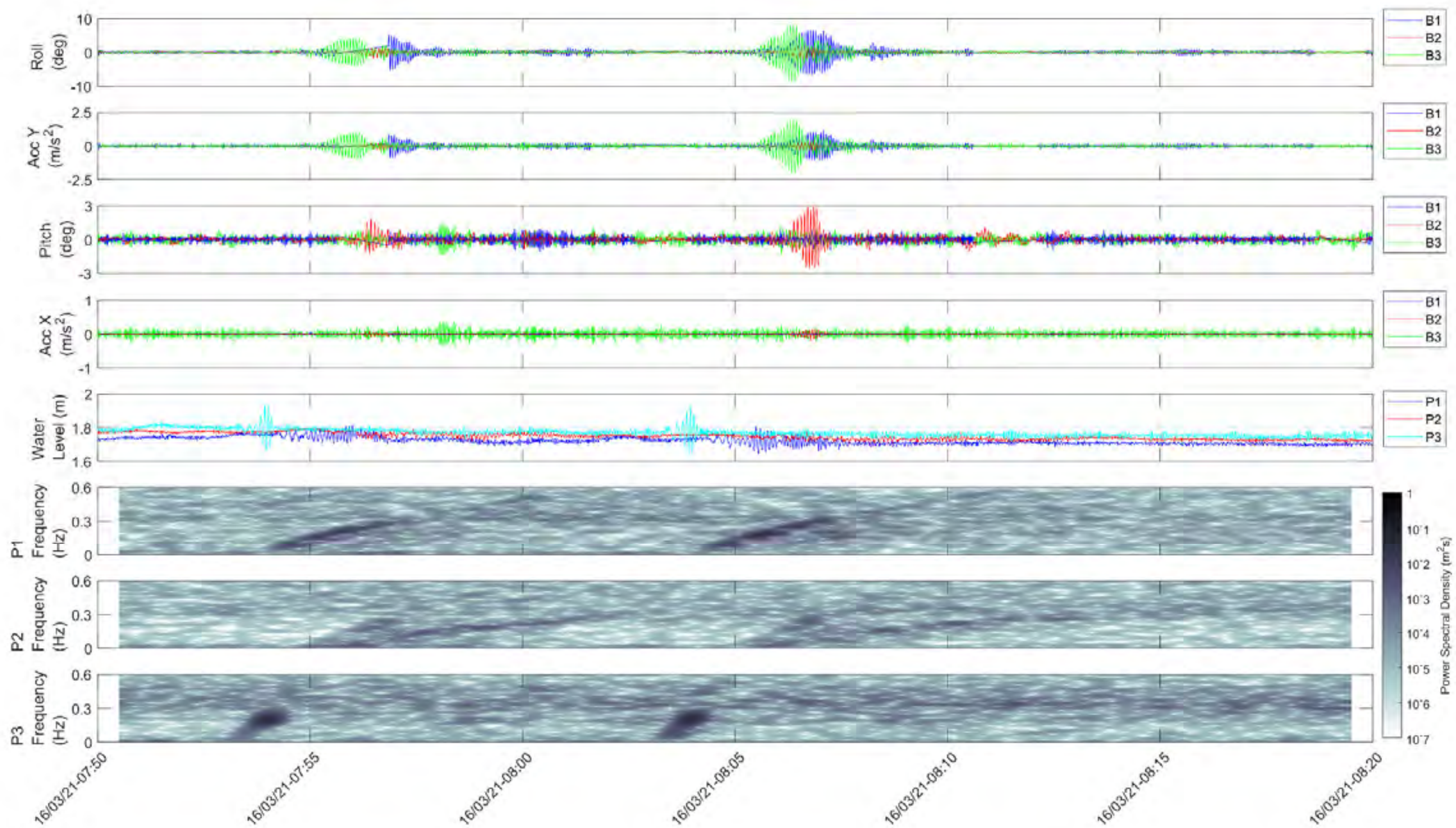

Figure 2.20 Spectrogram and diagnostic plot for an example event detection with only a Fast Ferry associated

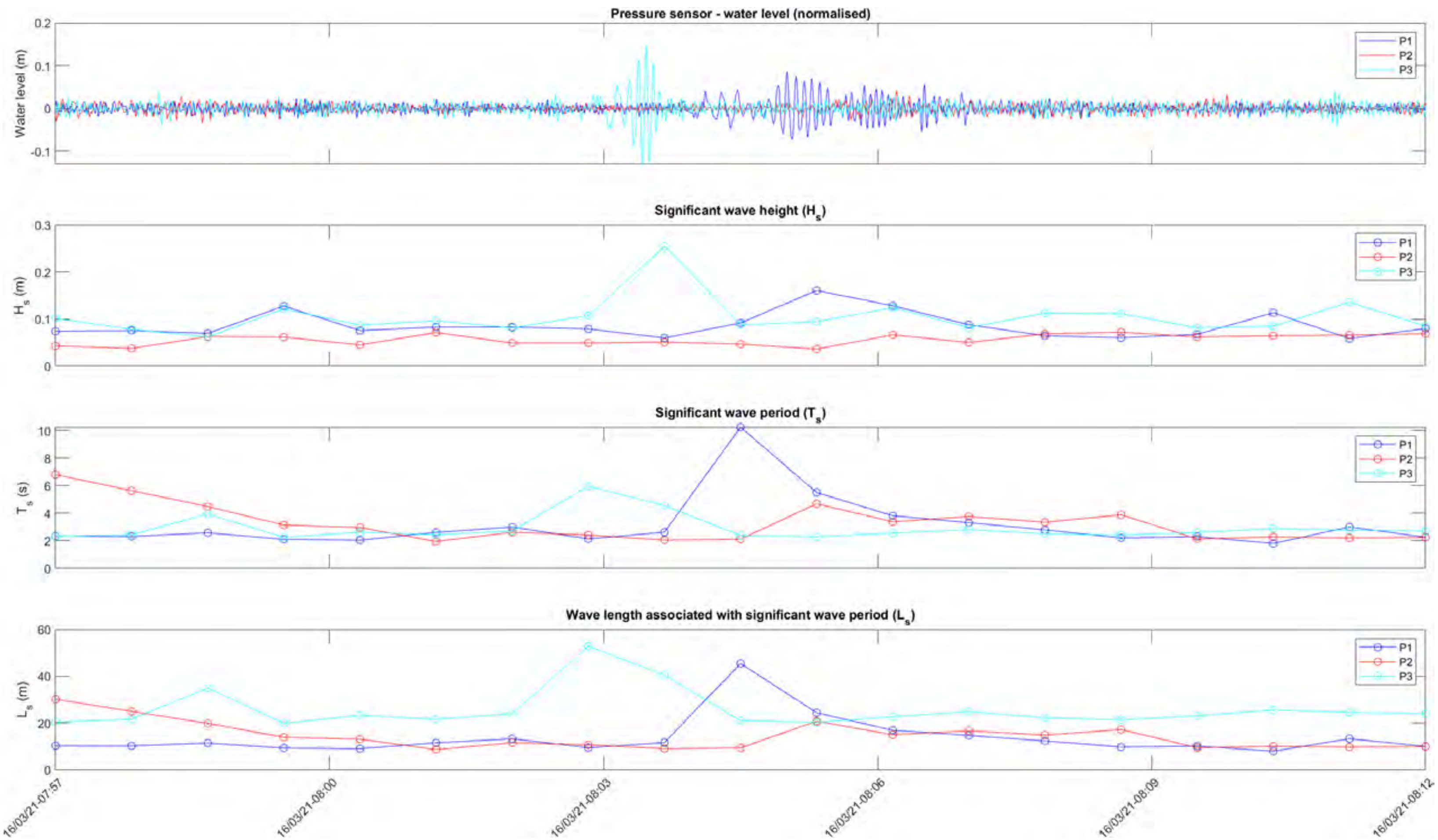

Figure 2.21 Wave characteristics determined from the pressure sensors for an example event detection with only a Fast Ferry associated

2.2.2 Large commercial vessels with deep draught – Cargo, Tanker Vessels, and Cruise Ships

Cargo and Tanker vessels as well as Cruise ships are large vessels with a deep draught monohull, transiting in and out of the several docks and piers around the Port of Melbourne, e.g., Webb Dock, Breakwater Pier, Station Pier, and other docks up the Yarra. Several observations from the data collected indicate that when these large vessels pass close to a pressure sensor, i.e., P3 by the Williamstown channel, a characteristic water 'draw' is observed whereby the displacement of these vessels causes a temporary drop in the water level (ranging approximately 0.10 – 0.30 m). This is captured in the form of a large 'V' shape in the water level data and a clear corresponding signal in the spectrogram. If the vessels do not pass close enough to the pressure sensor the distinct signal is less evident, indicating that the disturbance in the water level and associated wake quickly dissipate with distance. Similarly, if these large, deep vessels are moving very slowly then the signal may be less pronounced or not show in the data recorded by the pressure sensor.

An example of a detected event where there was a Tanker (the Haruna Express) transiting outbound (coming from the Yarra mouth) through the area of interest, with a clear event detected on 28 March 2021 at 15:32. Figure 2.22 shows the vessel passing very close to the P3 pressure sensor at a speed of between 8.4 and 8.9 knots. The water level signal from the pressure sensor (Figure 2.22 and Figure 2.23) show the large 'V' shape change in water level as recorded by the P3 sensor followed by a large change in water level at P1 but not the large water draw. This is also reflected in the spectrogram where the P3 sensor shows two long 'dark lines' at approximately 0.3Hz which are present but slightly less pronounced in the spectrogram for the P1 sensor.

A pitch movement of ~5.5 degrees has been recorded at B3 at ~15:30 that coincides with acceleration-x (surge motion) peaks of more than $0.5ms^{-2}$ recorded by the same sensor. A few minutes later, a high amplitude roll event (with maximum amplitude more than 16 degrees) was recorded at B1, coinciding with a peak in acceleration-y (sway motion) of more than $1ms^{-2}$.

Figure 2.24 shows the statistical wave properties for this event from the pressure sensor measurements, at P3 (by the Williamstown channel) a substantial increase in significant wave period and the associated wavelength is observed, followed by a relatively small increase in the significant wave height. As the diverging wake waves get gradually separated and propagate towards the marinas the period and wavelength at P1 increase, which is associated with the observed surge and sway motions. In this case, the increased period is sustained at P1 for a few minutes before returning to normal background periods. The initial increase in significant wave period is shortly followed by an increase in the significant wave height, which in turn is associated with the roll motions detected.

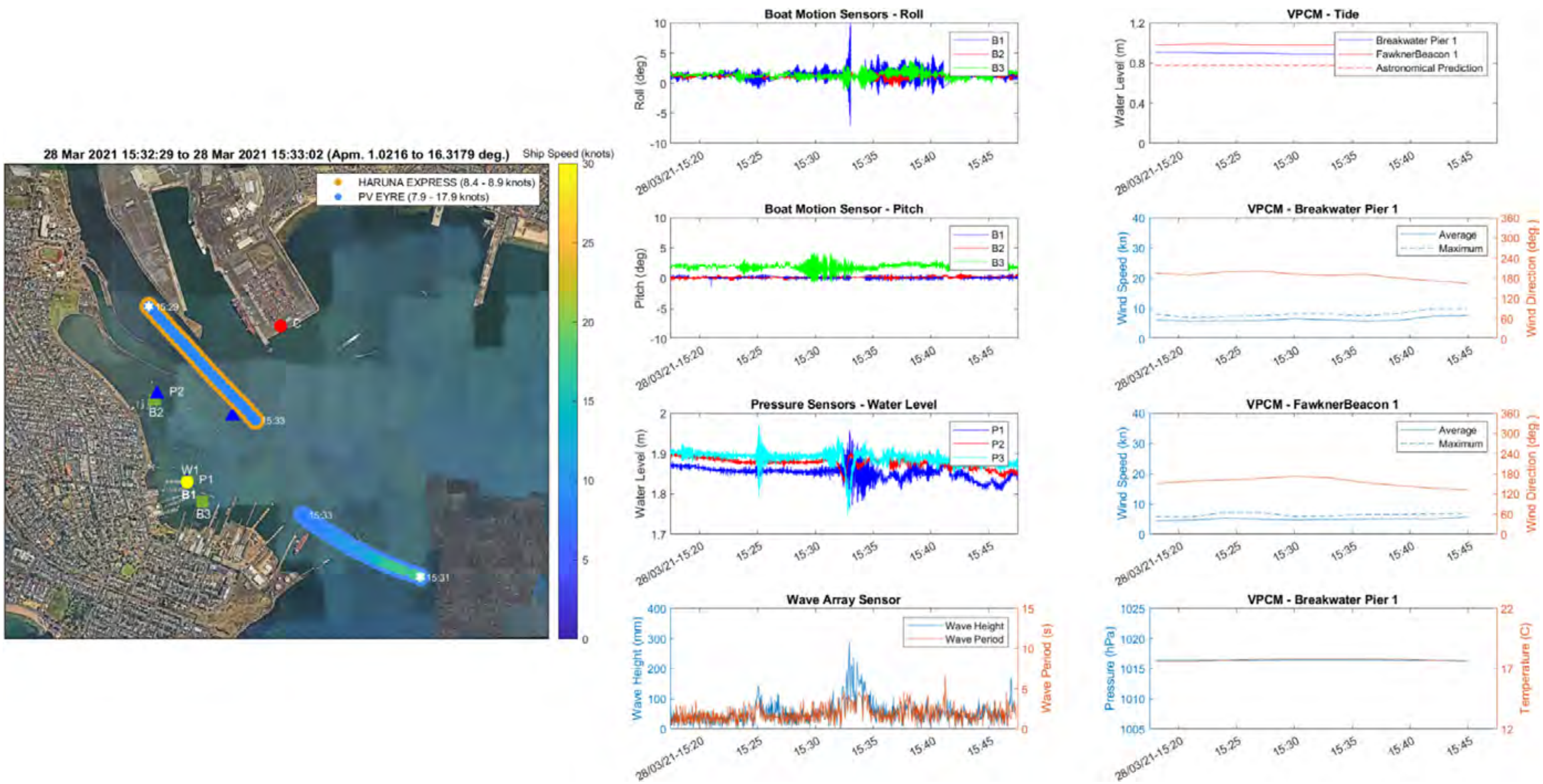

Figure 2.22 Summary diagnostic plot for an example of an event detection with a passing Tanker vessel

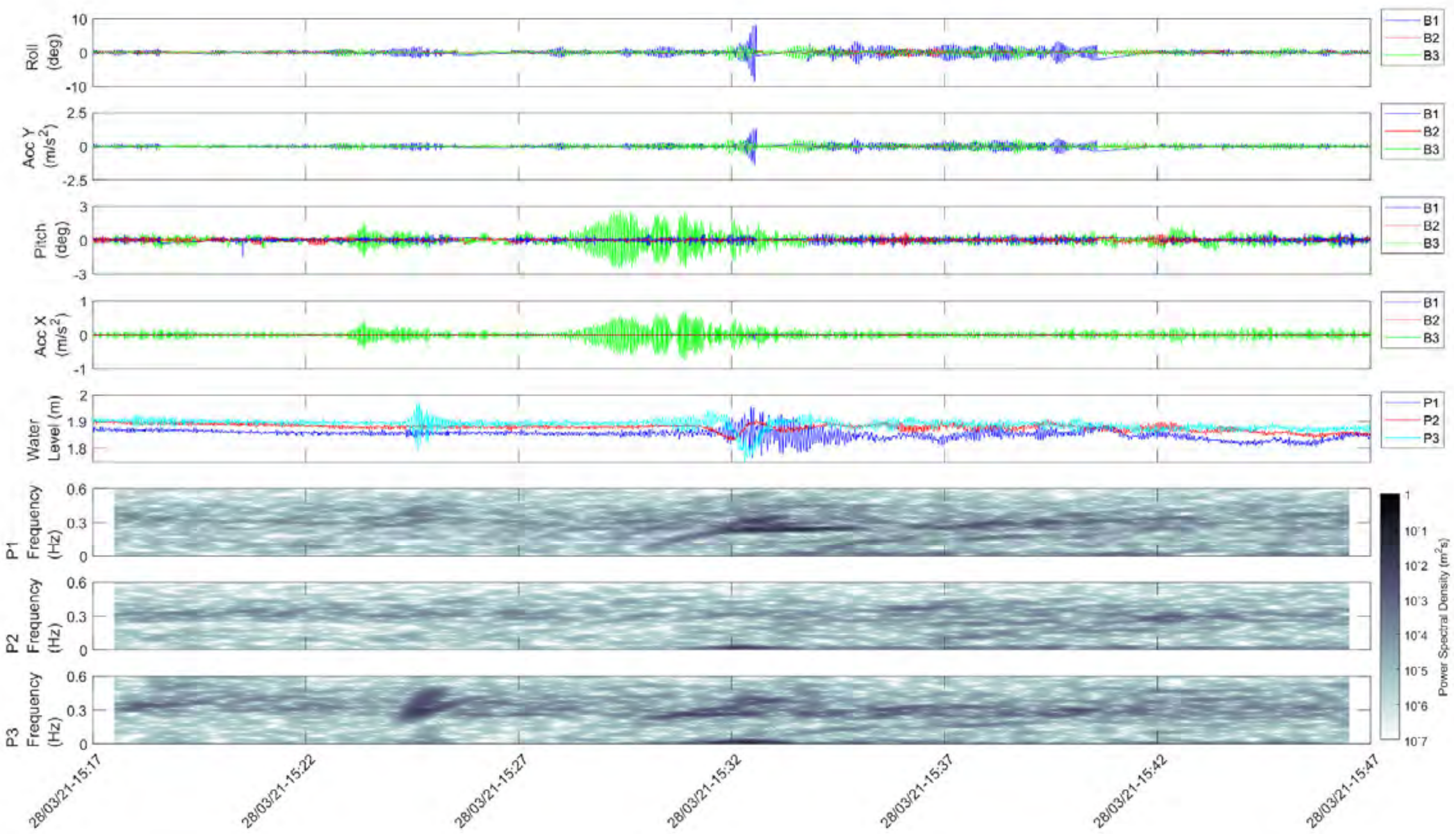

Figure 2.23 Spectrogram and diagnostic plot for an example event detection with a passing Tanker vessel

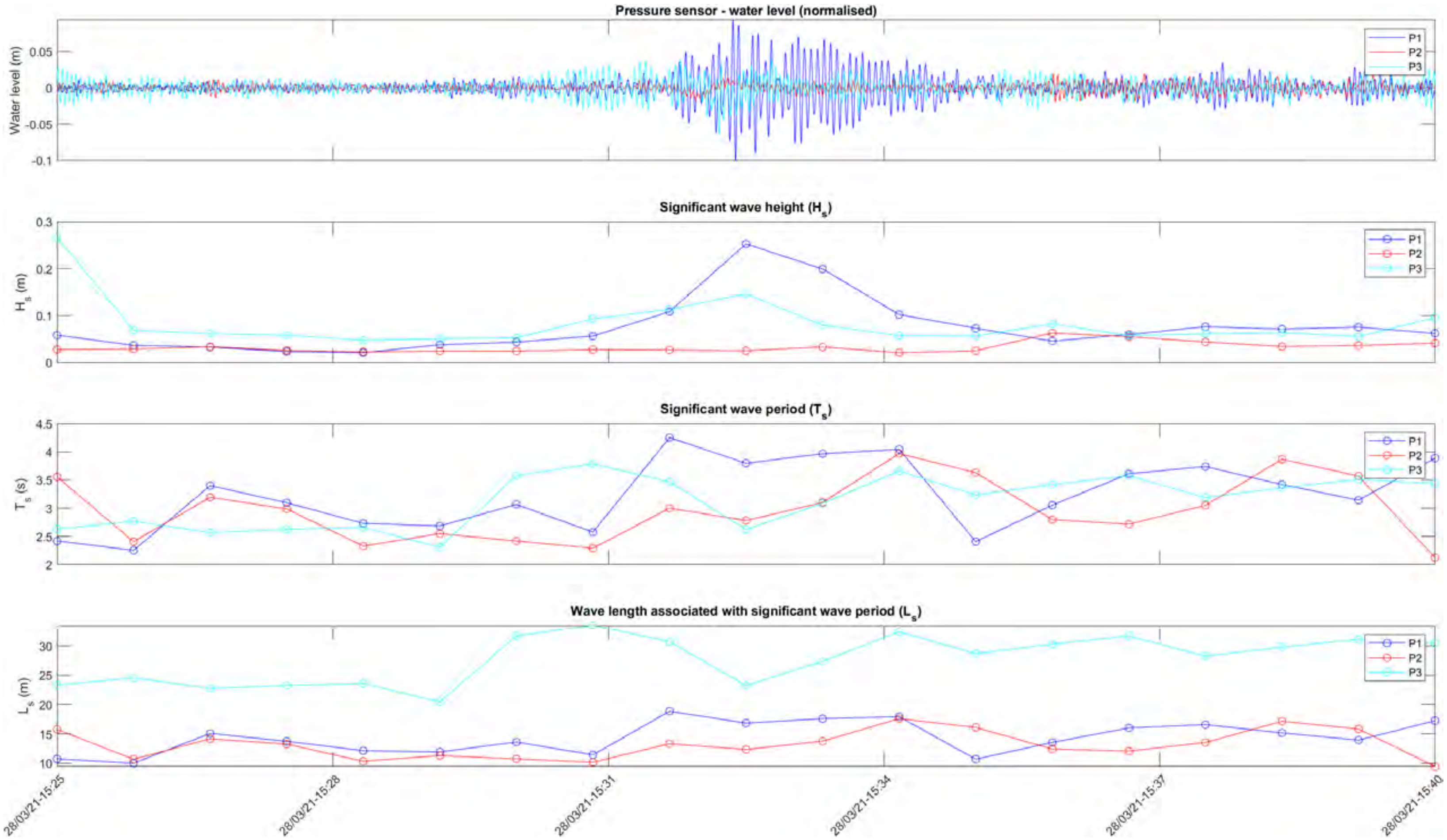

Figure 2.24 Wave characteristics determined from the pressure sensors for an example event detection with a passing Tanker vessel

2.2.3 Port support vessels – Tugs

The main types of port support vessels operating in the study area are tugs, pilot vessels and port tenders. Out of these, tugs are the most active and distinct given their propulsion system and ways of operating; hence, this subsection focusses on a couple of examples detected events associated with tug movements.

In the first example, the passage of a tug led to an event on 2 April 2021 at 13:25, Figure 2.25 shows the tug moving around Webb Dock. The water level plot from the pressure sensors (Figure 2.25 and Figure 2.26) show a change in water level recorded by the P1 (at around 13:25) followed by a smaller change in the water level recorded at sensor P3. This is also reflected in the spectrogram plot that shows 'chirps' with increased PSD up to 10^{-3} m^2s at P1 (with a frequency range of close to 0 to 0.6Hz) and up to $10^{-4}m^2s$ at P3 (with frequencies ranging between 0.2 and 0.6Hz).

A clear 10 degrees amplitude roll motion is recorded at B1 coinciding with acceleration-y (sway motion) of approximately $1ms^{-2}$ peaks. Nevertheless, no clear excess pitch or acceleration-x movements are recorded at any of the boat motion sensors. Despite less pronounced than in previous examples,, Figure 2.27 shows similar features of the wave characteristics in that the significant wave period and wavelength increase (although to lesser values, meaning shorter waves travelling slightly slower than in previous examples), this is shortly followed by the increase of wave height, particularly at P1 as the wake waves diverge and propagate further from the source and at the outset of sway and roll motions detected at B1.

Another example event of this category occurred on 9 April 2021 at 12:17 as shown in Figure 2.28 and Figure 2.29. Two tugs transit through the Williamstown channel, within approximately 1 minute of each other and inbound to Webb Dock, causing spikes in water level recorded by all pressure sensors and most clearly by P1 (noting that background conditions at the time of the event indicate winds of 15-20 knots that would have resulted in a 'choppy' sea state). Those conditions and the tug wake wave signal are also reflected in the spectrogram plots that show background PSD ranging between $10^{-4}m^2s$ and $1m^2s$ at frequencies around 0.3Hz for all three pressure sensors and 'chirps' of $1m^2s$ PSD at P1 at about 12:18, a few minutes after the tugs passed through the channel.

High amplitude roll motions (more than 15 degrees) are recorded first at B3 and then at B1 as the tugs pass them while travelling inbound. These movements are mirrored in acceleration-y excitements in B3 and B1 with values exceeding $1ms^{-2}$ (see Figure 2.29). Similar to the previous example, no clear excess pitch or acceleration-x movements are detected at any of the boat motion sensors during this event. Figure 2.30 also shows the same features of wave characteristics associated with the passage of the tugs, with all three pressure sensors showing increase in wave period and length, this being more accentuated at P3 close to the channel, followed by increase of wave height particularly at P1, which in turn relate to the roll motions recorded by the motion sensors B3 and B1.

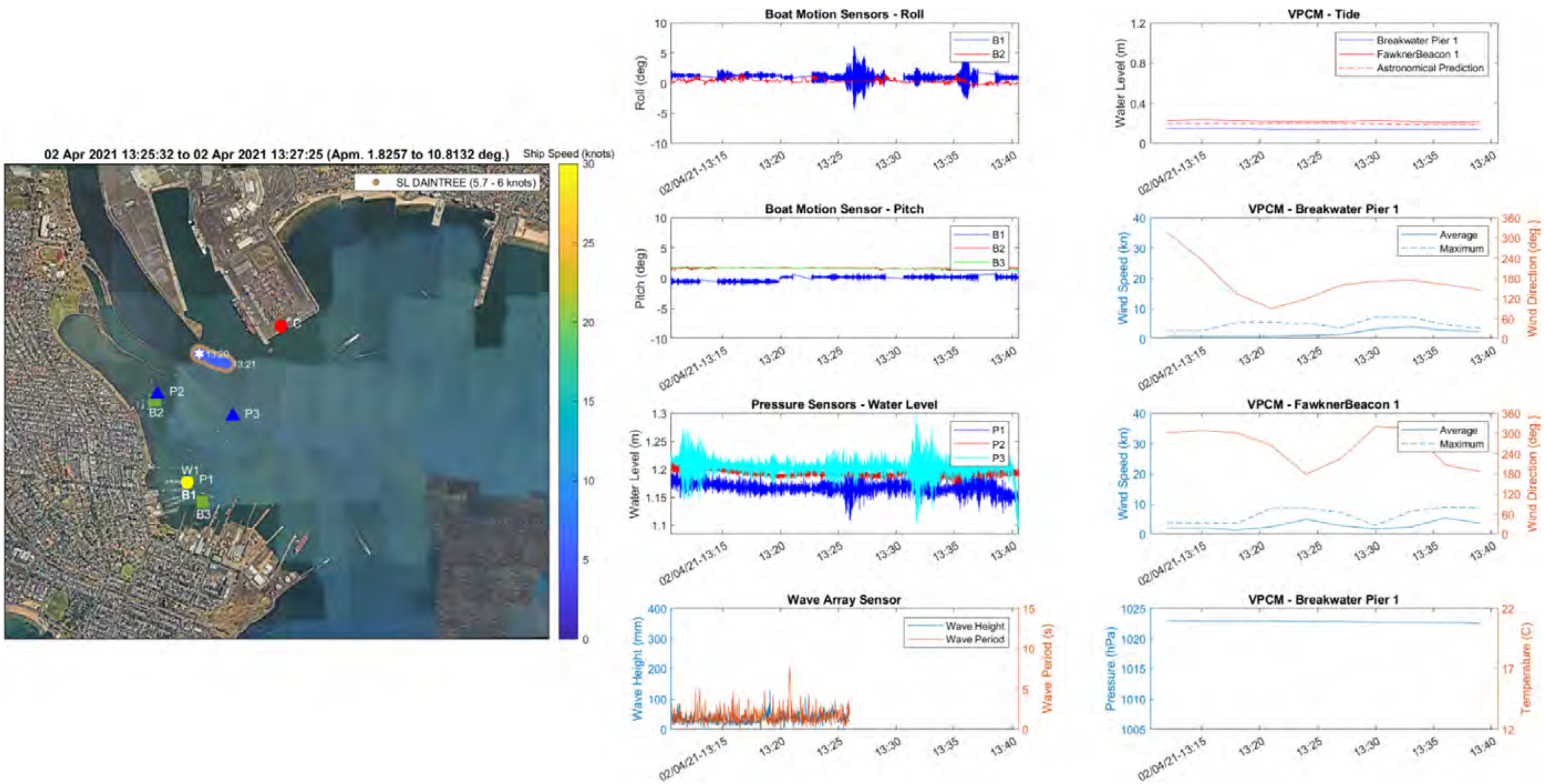

Figure 2.25 Summary diagnostic plot for example 1 of an event detection with only a Tug associated

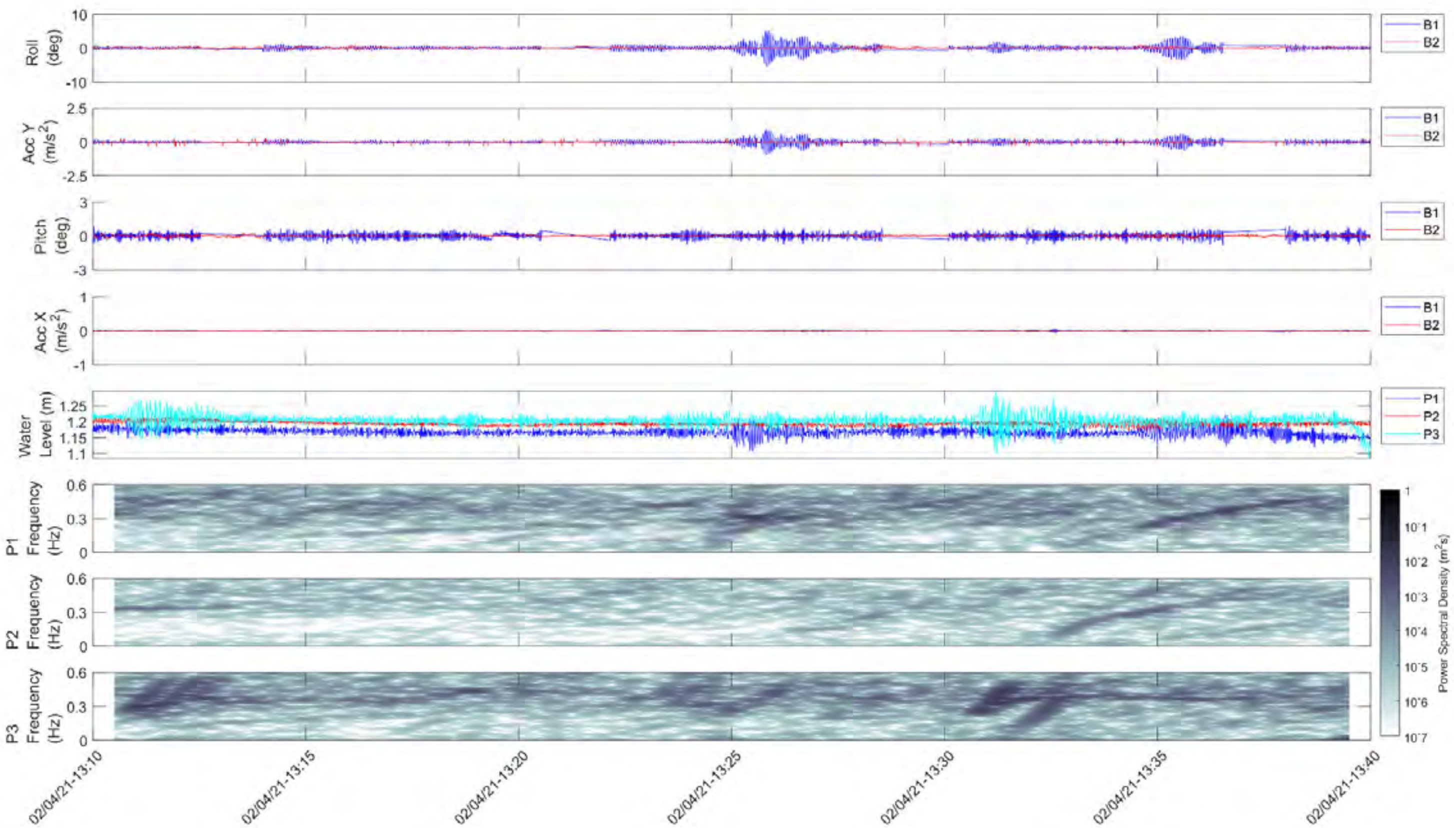

Figure 2.26 Spectrogram and diagnostic plot for example 1 of an event detection with only a Tug associated

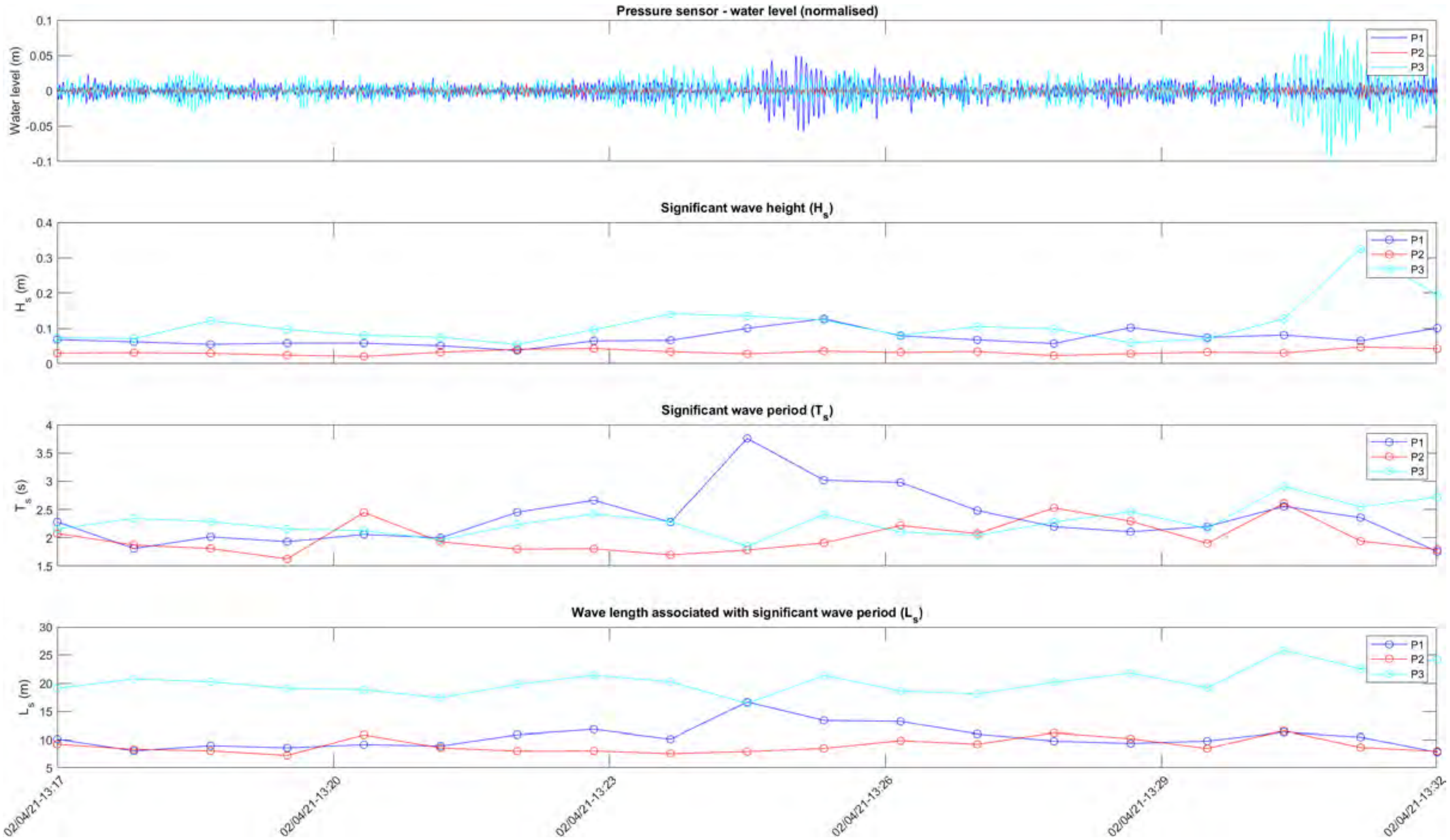

Figure 2.27 Wave characteristics determined from the pressure sensors for example 1 of an event detection with only a Tug associated

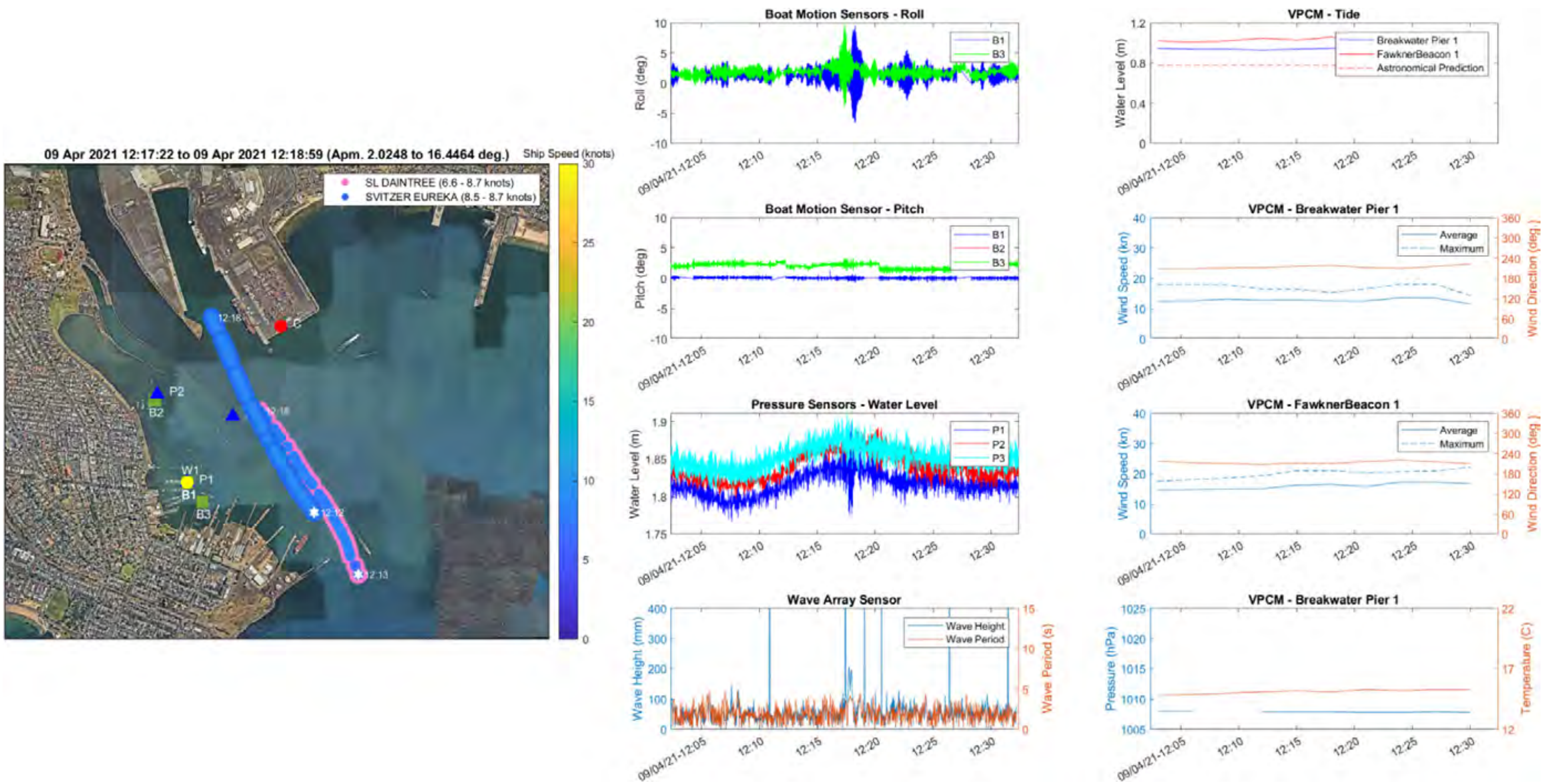

Figure 2.28 Summary diagnostic plot for example 2 of an event detection with only Tugs associated

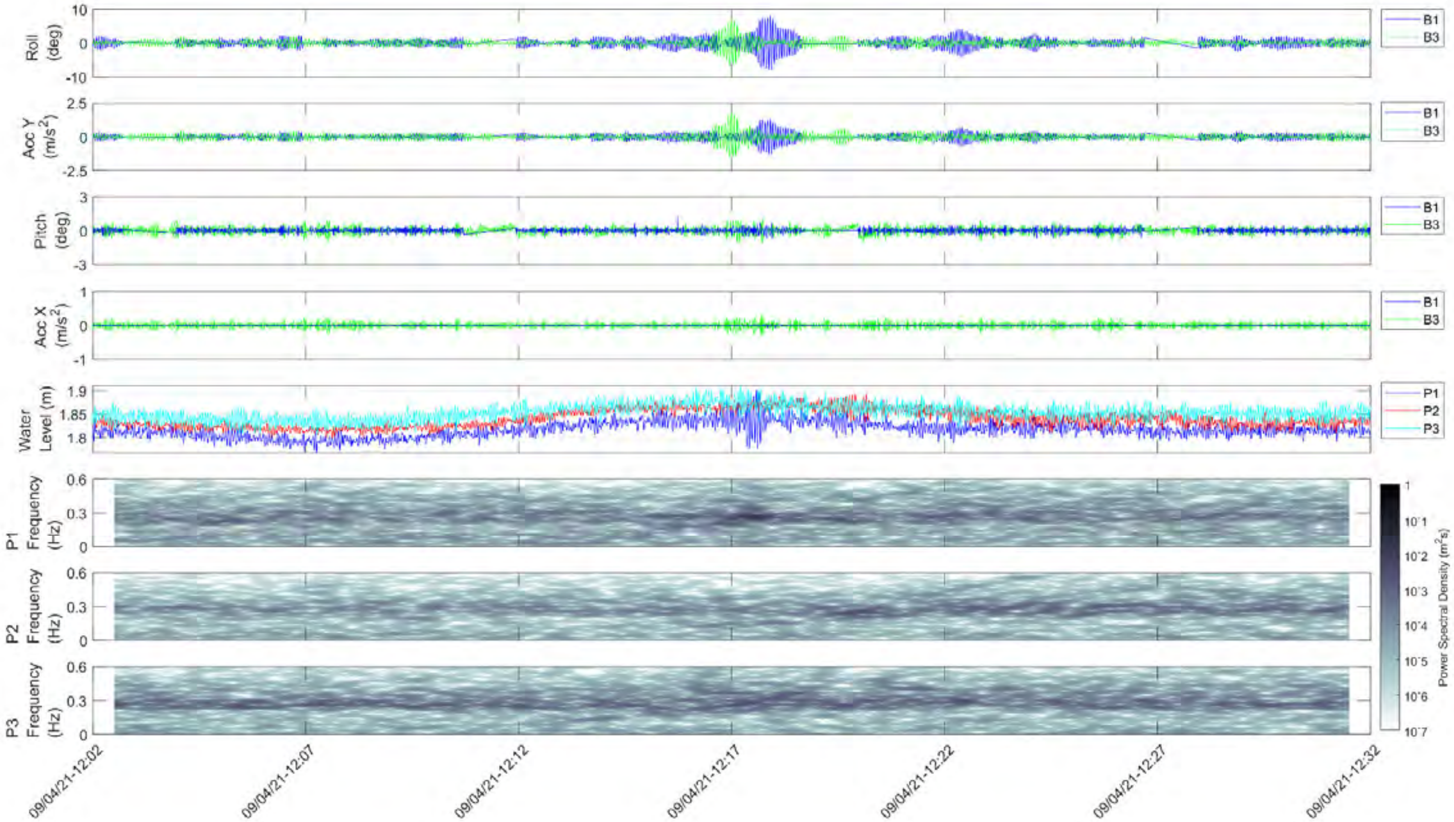

Figure 2.29 Spectrogram and diagnostic plot for example 2 of an event detection with only Tugs associated

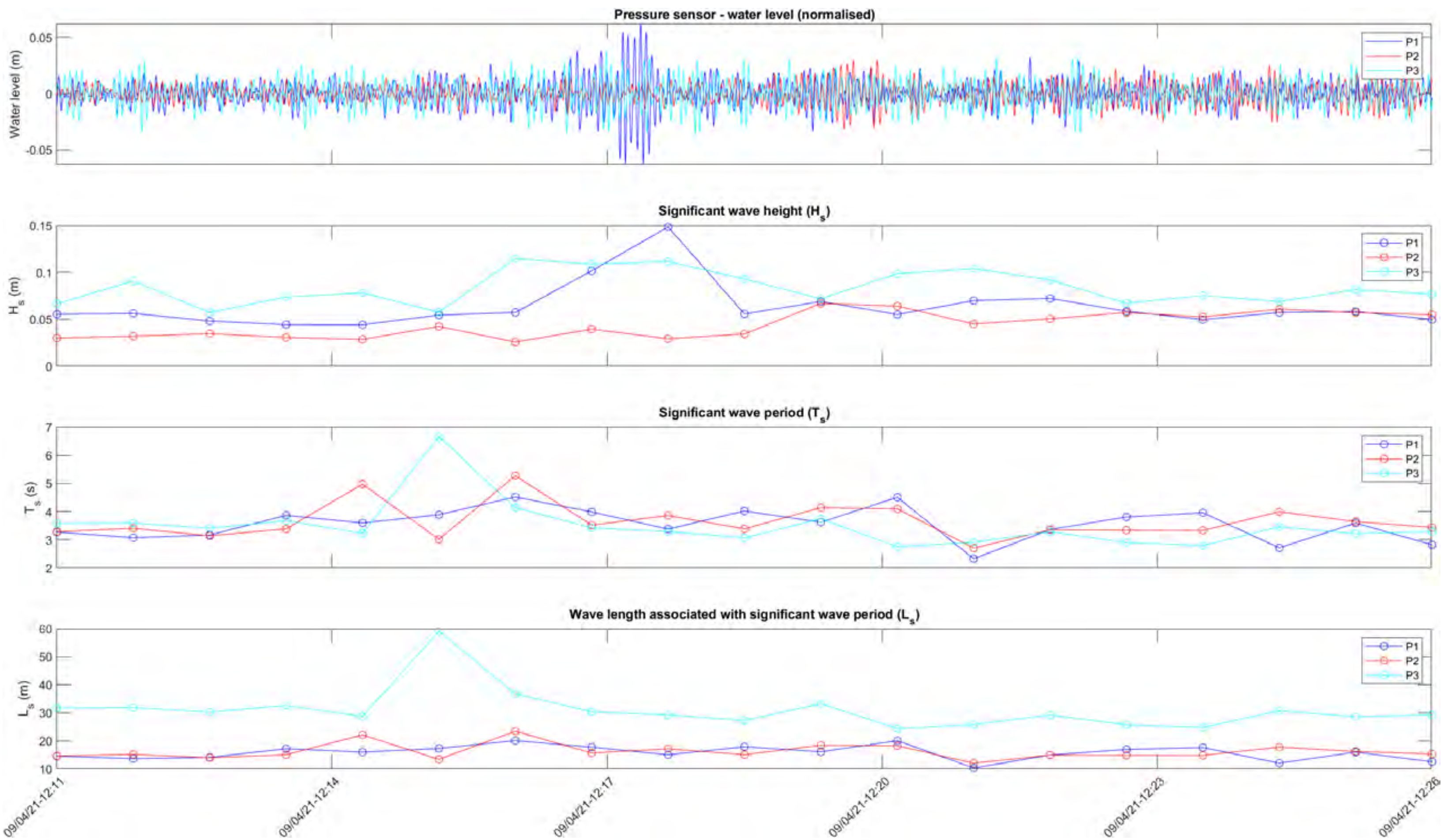

Figure 2.30 Wave characteristics determined from the pressure sensors for example 2 of an event detection with only a Tug associated

2.2.4 Small to medium motorboats (not included in other categories)

Small to medium motorboats, typically of monohull design, with and without AIS often transit through the study area producing wake waves that have been associated with events. A couple example events of this type are showcased in this subsection. These example events took place when a 31.1m yacht has been transiting through the channel on 21 December 2020 at 17:29 and on 11 March 2021 at 12:00 as shown in Figure 2.31 and Figure 2.34, respectively. In both events P3 is the first instrument to more prominently record the vessel passages, showing up to ~0.4m spikes in water level, i.e., wake waves close to the source. In the event on 21 December 2020, the propagates wake waves were recorded by P1 and P2 within a few minutes after P3. This is also reflected in the spectrogram plots (see Figure 2.32) that shows high PSD (~1ms^2 or more) starting at ~17:27 for P3 and slightly lower PSD (up to 10^{-1}ms^2) starting at ~17:30 for P1 and P2. For the event on 11 March 2021, P1 has also recorded small changes in water level, i.e., wake waves, a few minutes after P3. Although, there is no clear wave signal recorded by P2. For this event though, 'chirps' of increased frequency in PSD of P3 at ~11:54 and P1 at ~11:58 are also evident in the spectrogram plots shown in Figure 2.35.

In the first for these examples on 21 December 2020, roll movements were detected first at B3 (more than 15 degrees) and then B1(approximately 10 degrees) while the yacht travels inbound. The roll movements at B3 and B1 are accompanied by sway motions with acceleration-y peaks that exceed 2ms^{-2} at B3 and up to 1ms^{-2} at B1. On the other hand, in the second example on 11 March 2021, roll movements are of relatively small amplitude remaining below 3 degrees, while fluctuations in the pitch and acceleration-x, i.e., surge motions, were recorded, particularly at B3 (see Figure 2.35).

The statistical wave properties plots for the 21 December 2020 event, shown in Figure 2.33, shows a large increase in the wave height at pressure sensor P3, with a lower increase in period. The diverging wake waves then propagate to sensors P1 and P2 where the usual increase in wave period and associated wavelength are seen before the increase in height. At P2 although there is an obvious increase in period the increase in wave height is less obvious.

The statistical wave properties plots for the 11 March 2021 event in Figure 2.36 shows a more distinct change in the wave height at pressure sensor P3 as the motorboat passes but not much change in period or wavelength and as such, the propagation to the P1 and P2 sensors in the marinas areas is less evident, highlighting the variability of the amplitude of events.

2.2.5 Summary of wake pattern observations

Analysis of the wake wave patterns, or 'signature', recorded by the three pressure sensors in the Williamstown Maritime precinct shows that different types/size of vessels produce a different wake. However, the analyses also show that the wake waves produced by different vessel types tend to diverge with the mixture of wavelengths and periods gradually getting separated (because in water longer waves travel faster than the slower ones) as the waves propagate. This is typically the case for vessels transiting along the Williamstown channel, with the leading wake waves in a package commonly showing at the P1 and P2 pressure sensors, closer to the marinas, longer period, and wavelength, shortly followed by waves of lower period but of slightly larger height, in comparison than at P3 closest to the channel and thus to the wake source.

Although the wake wave pattern may be more dissimilar at the source for various vessel types and sizes, these differences become less prominent by the time the waves propagate and reach the Williamstown Maritime precinct, and so the potential effect to boats and marina infrastructure is likely to be similar, regardless of the source of the wake waves.

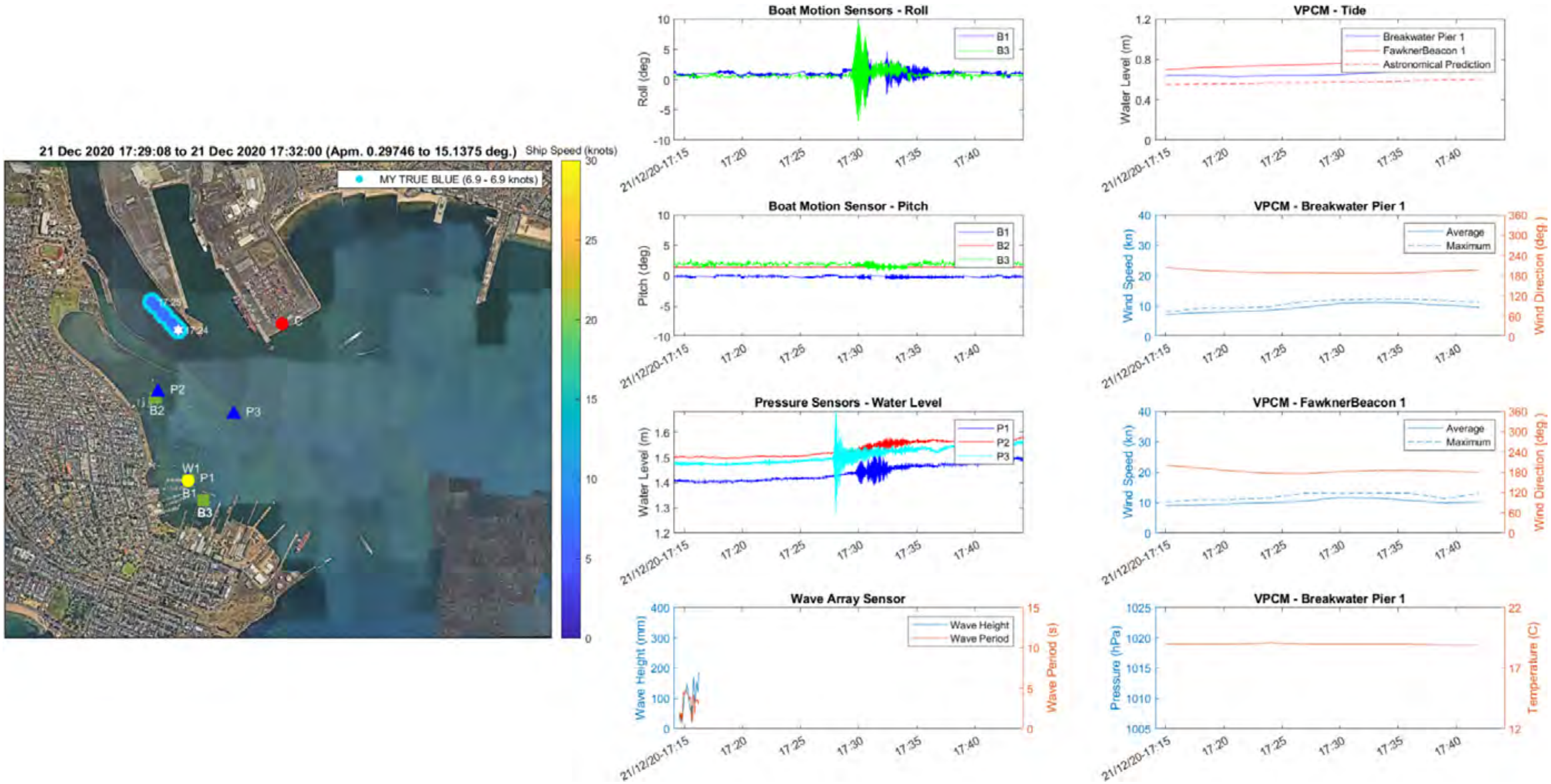

Figure 2.31 Summary diagnostic plot for example 1 event detection with a motorboat (Pleasure Craft) associated

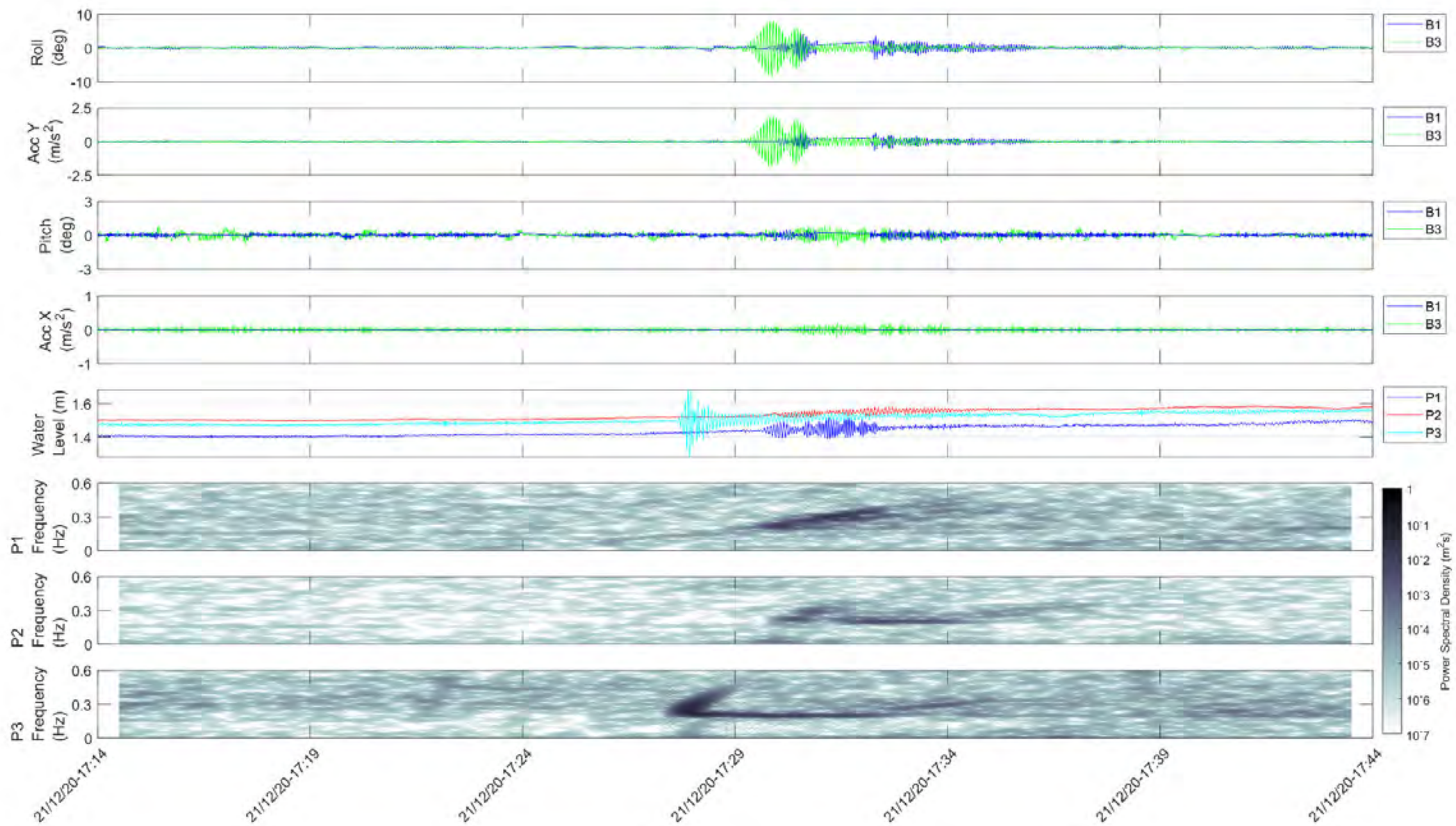

Figure 2.32 Spectrogram and diagnostic plot for example 1 event detection with a motorboat (Pleasure Craft) associated

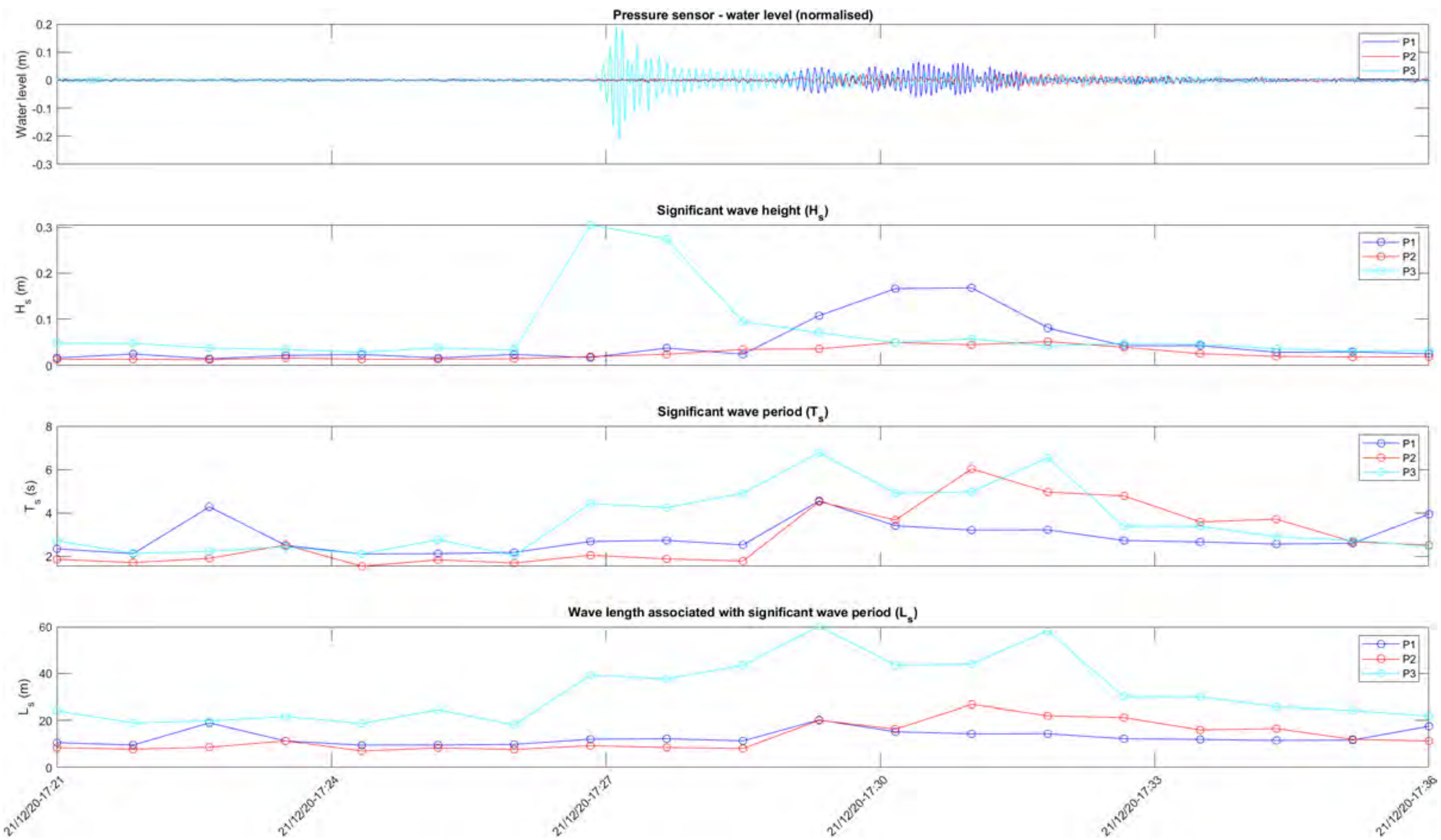

Figure 2.33 Wave characteristics determined from the pressure sensors for example 1 event detection with a motorboat (Pleasure Craft) associated

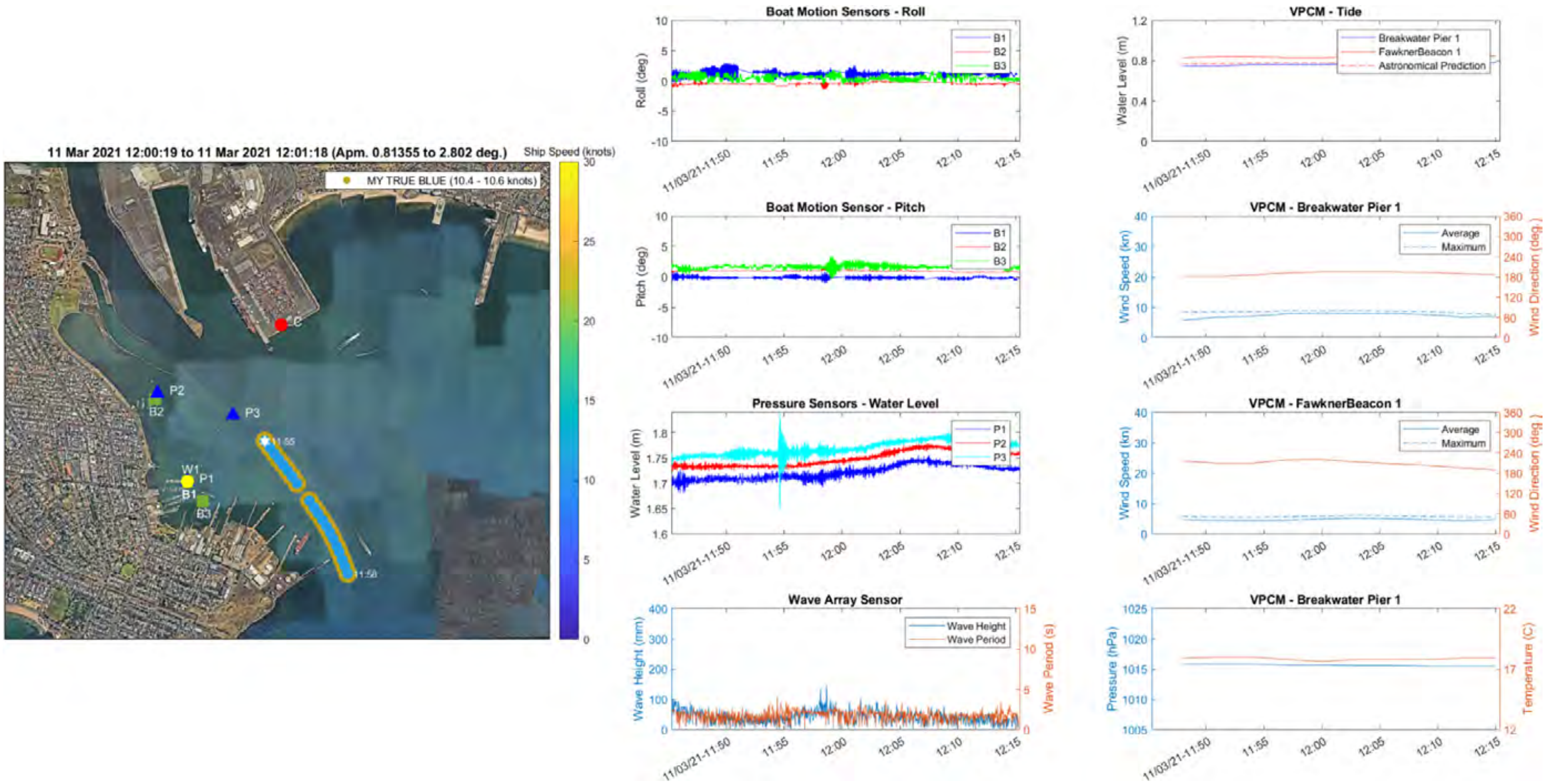

Figure 2.34 Summary diagnostic plot for example 2 event detection with a motorboat (Pleasure Craft) associated

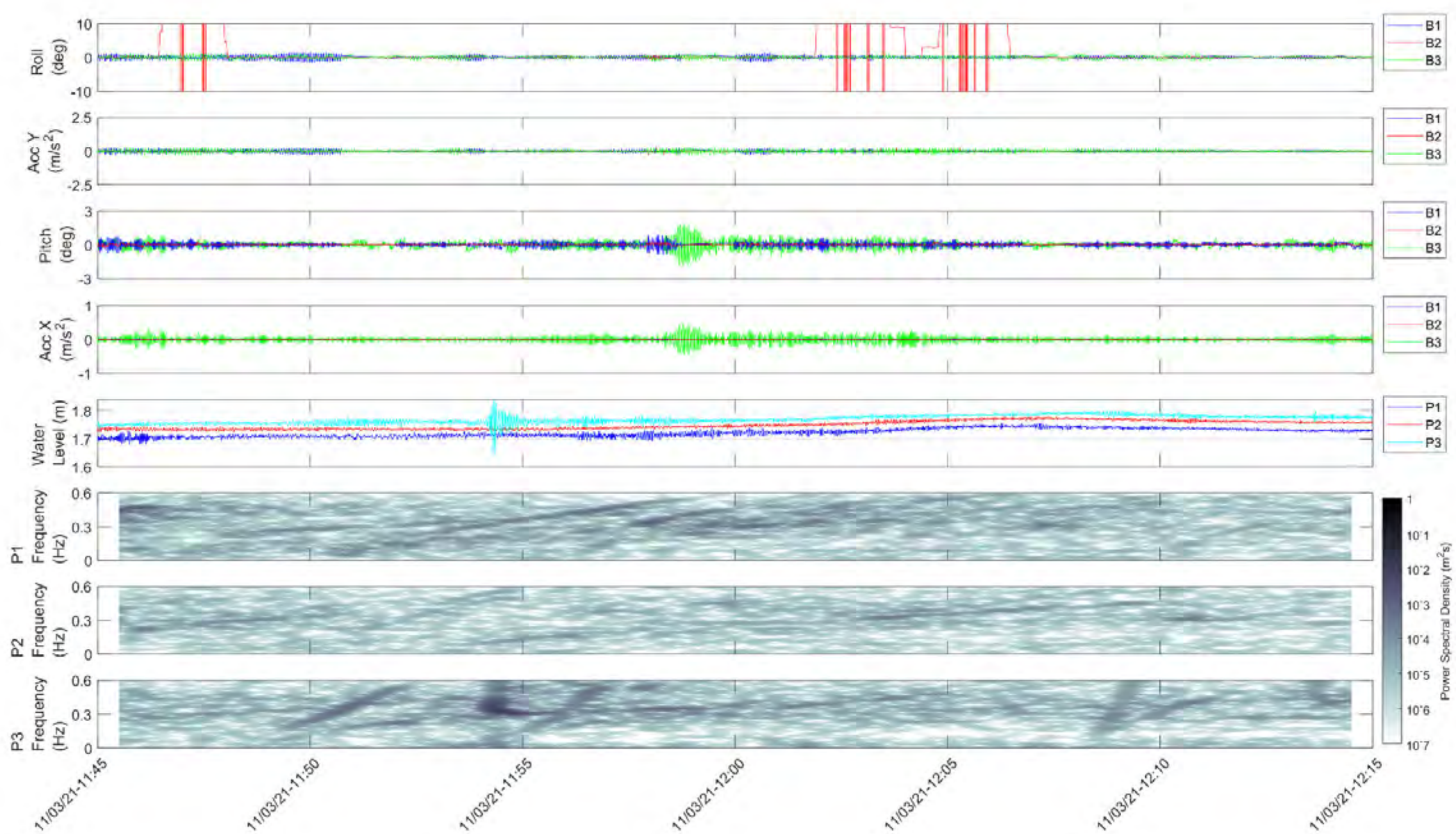

Figure 2.35 Spectrogram and diagnostic plot for example 2 event detection with a motorboat (Pleasure Craft) associated

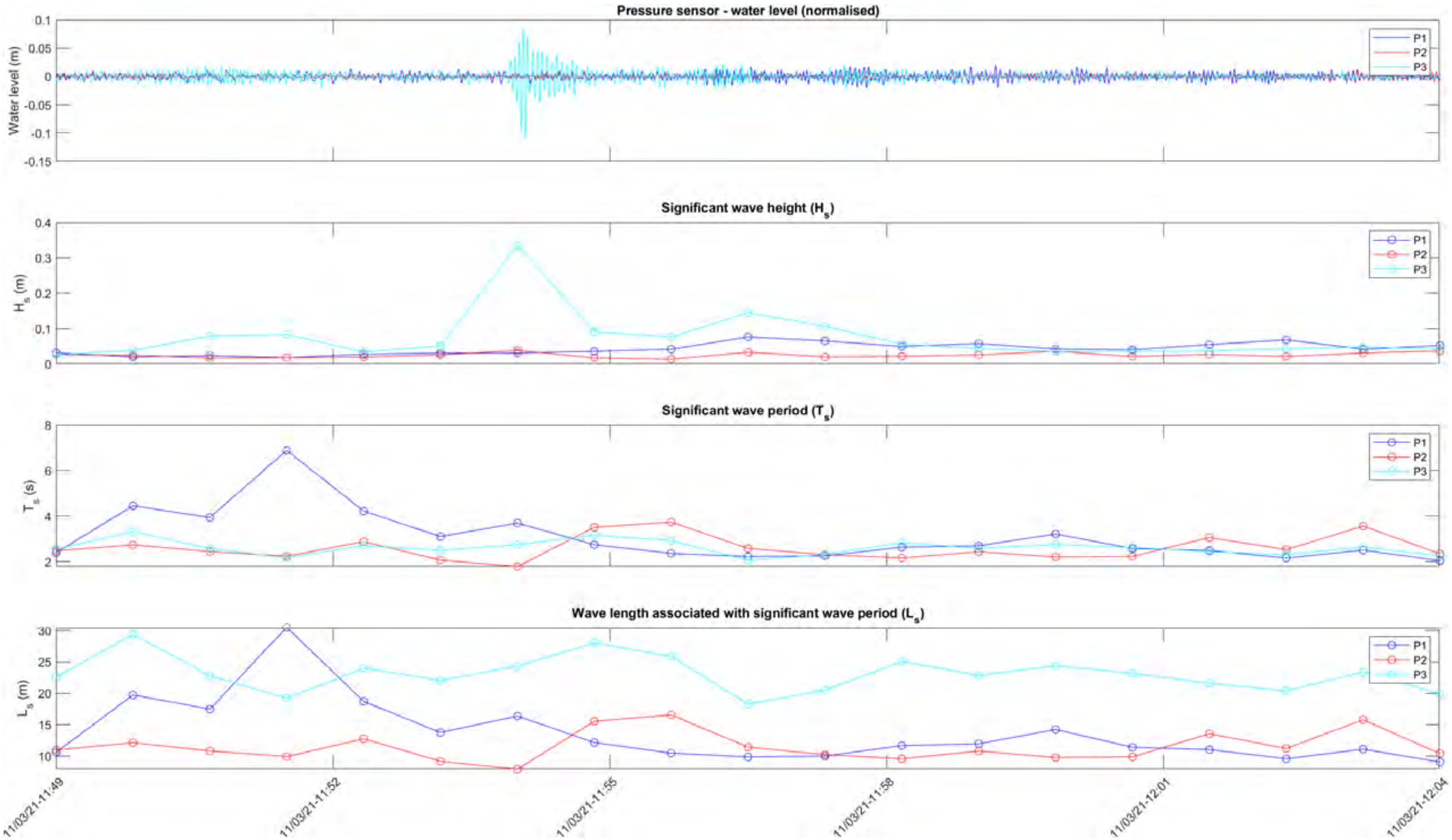

Figure 2.36 Wave characteristics determined from the pressure sensors for example 2 event detection with a motorboat (Pleasure Craft) associated

2.3 Surge events

It has been repeatedly reported, by local yacht clubs and marinas within the Williamstown Maritime Precinct before and during the previous stages of this study, that in addition to 'roll' motions 'surge events' occur in the area in association with the passage of vessels. Stakeholders reported and described some of these as "surges that knock people off their feet" that sometimes were "experienced while not much wake was observed". These events were of great concern to some of the local yacht clubs and marinas in particular. They were reported to "cause damages to yacht decks and fittings due to the pull of mooring lines [and in some cases] break the mooring lines" threating safety, boats, infrastructure, and businesses. Therefore, additional analyses of the measured data were conducted to better understand these motions and are presented in this section of the report.

In response to metocean and environment forces, i.e., wind, waves and currents, a moored boat moves in six degrees of freedom: three translations: heave, surge, and sway, and three (angular) rotations: pitch, roll, and yaw, in reference to its centre of gravity (see Figure 2.37). In a surge motion, the boat moves in the direction of the bow or stern, i.e., translating along its longitudinal axis, and 'pushing and/or pulling" it on that direction. Based on general and fundamental physic principles, the force (F) exerted as a 'push or pull' on the boat (or any object) due to the surge motion can be described as the product of the acceleration (a) on the boat and its mass (m): F=ma. Acceleration is defined as the rate of change in boat's velocity over time with velocity being the rate at which the boat changes its position.

In the case of wind generated waves such as the selected examples with high wind presented in Section 2.1.3, maximum accelerations along the x-axis (boat's longitudinal axis) generally remain below 0.05m/s^2 (see examples in Figure 2.14 and Figure 2.16). However, maximum x-axis accelerations in the presence of wake waves are generally higher by about one order of magnitude, ranging from ~0.5m/s^2 up to values above 1.5m/s^2 in several detected events (see examples in Figure 2.18, Figure 2.40 and Figure 2.43; and summary list in Table 2.4). To put this in context, the force exerted to a boat of mass 8,000kg moving back and forth with an acceleration of 0.05m/s^2 experiences a force of approximately 400 Newtons. This force is elevated to 4,000 Newtons for acceleration of 0.5m/s^2 and 12,000 Newton for acceleration of 1.5m/s^2. Whilst the forces exerted by a single surge motion are generally well below the breaking load of mooring lines, these motions and loads may contribute to fatigue failure over time due to their cyclic nature and due to intermittent but more frequent occurrence due to increased marine traffic.

2.3.1 Detection of 'surge' events induced by vessel passage

To identify boat 'surge' events, the acceleration response measured by the three boat motion sensors deployed during the first stage of this study were further analysed. The sensors were deployed on three representative yachts moored within three different locations at the Williamstown Maritime Precinct: B1 at Hobsons Bay Yacht Club (HBYC), B2 at the Anchorage Marina, and B3 at the Royal Yacht Club of Victoria (RYCV).

A similar methodology to the roll event detection, involving a dynamic threshold algorithm to 'filter' the background conditions, was used to analyse the acceleration records and to identify the surge events, with a focus on the x-axis acceleration signal for surge motions. In this regard, 'surge events' are defined as energetic responses of the moored boat to the transient disturbance of the water they are in (see diagram in Figure 2.38). In summary, the algorithm involved x-axis acceleration timeseries were decomposed into individual cycles using a zero-up-crossing method that yields to the characteristics of individual cycles e.g., amplitude. Then, using the peaks-over-threshold technique, the resulting time series of cycle amplitudes was filtered using a temporally varying threshold derived from the distribution of cycle amplitudes over a 30-minute time window. Instances in which four or more sequential cycles exceeded the dynamic threshold were marked as 'events' (refer to Stage 2 report for further method description and details).

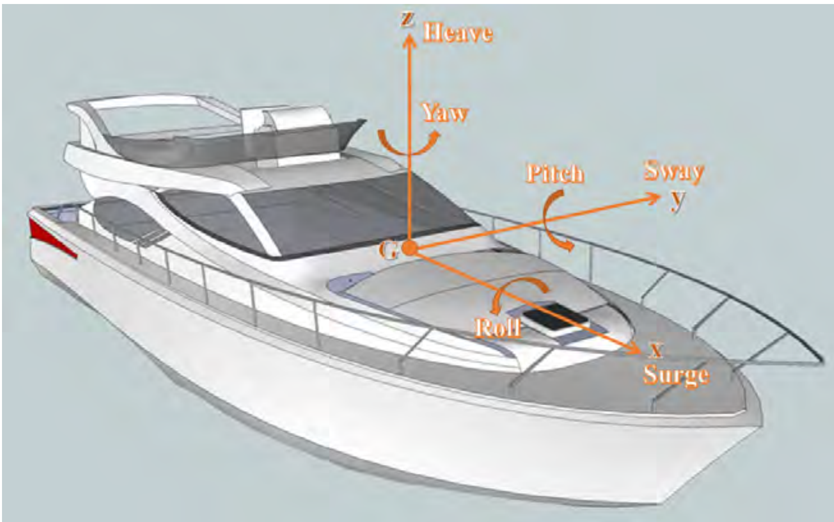

Figure 2.37 Schematic showing six degrees of freedom for boat motion

Figure 2.38 Diagrammatic representation of 'surge' motions of a vessel, back and forth along the bow-stern direction

From the results of the above-described analysis, key events in which the maximum x-axis acceleration exceeded 1.5m/s^2 were identified as high acceleration amplitude events and looked into further detail. In total, 17 high acceleration amplitude events, i.e., 'surge' were detected (see Table 2.4). Among them, 8 were caused with vessel passages with No AIS, 5 were associated with Fast Ferries (Fast Ferry only, and Fast Ferry + other), and the rest were caused by other vessel passage categories, i.e., Pilot Vessel (only), Tug (only), Cargo (only), and Tug + large ship (cargo/tanker). Importantly, the results indicate that all these surge events occurred within a few minutes of a detected roll event. The collocated roll events, of variable maximum roll amplitudes ranging between 2.18 and 19.25 degrees, and of variable duration that in most cases was longer than the surge duration (although this is partly attributable to the detection algorithms and thresholds used in the analyses).

An example 'surge' event is presented below, with diagnostic and spectrogram plots shown in Figure 2.39 and Figure 2.40, respectively. This surge event had a maximum x-axis acceleration of 1.59m/s^2 and maximum roll amplitude of 4.23 degrees and was caused by the passage of a Fast Ferry with a maximum speed of 23.8knots recorded in the AIS data.

Another example surge event that was reported by stakeholders from Savages Marina (report No. 4 as referred in Stage 2 report), is also described in Table 2.5. Figure 2.42 shows the summary diagnostic plot of this event, and spectrogram plots together with the timeseries of recorded accelerations are shown in Figure 2.43. In this event, multiple vessel passages were recorded in the AIS data, with the event boat motions' of up to 5 degrees roll at Hobsons Bay Yacht Club (approximately 150m north of Savages Marina) that coincided with a maximum x-axis acceleration of over 1.75m/s^2 at the same location.

The initiation of the angular (e.g., roll and pitch) and translational (e.g., surge and sway) motions of moored boats in association with wake waves can be explained when considering the process of wake propagation and the properties of the resulting incoming waves. As wake waves diverge from the source of production, e.g., vessels transiting through the study area including the navigational channel represented by P3 in Figure 2.41 and Figure 2.44, the mixture of wavelengths and periods in a wake 'package' gradually get separated due to the fact that longer waves travel faster in water than shorter, slower ones. This makes the longer and faster waves leading the package (generally of lower height) very difficult to detect by the naked eye but of physical properties and shape (i.e., wavelength, height and steepness) such that a slight inclination in the water surface takes place over a length of order of magnitude comparable to the size of moored vessels in the marinas, which in turn initiates the translational, surge and sway motions, e.g., wavelength of approximately 20 to 40 m as shown at P1 and P2 in the examples in Figure 2.41 and Figure 2.44. The leading longer waves are shortly followed by shorter, slower, and slightly higher waves that propagate behind in the package with lower period that makes moored boats resonate and initiates the angular (e.g., roll) motions.

Despite the difference in the mechanism that initiates the roll and surge motions (explained above), the analysis of the measured data, and several examples presented in this report, show clearly that these motions generally coincide along the timeframe associated with the propagation of wake waves of vessels transiting around. Therefore, mitigation strategies would apply to both roll and surge events, and thus, in general mitigation measures should target to either control wake generation as a source of the disturbances or reduce the effect of the motions induced by the propagation of wake waves within the Williamstown Maritime Precinct.

Table 2.4 High amplitude surge events with collocated roll events detected from measured boat motions

No.	Surge Event Detection			Roll Event Detection			Start Time Difference (minutes)	Vessel Passages Category
	Start Time	Duration (s)	Max. Amplitude (m/s2)	Start Time	Duration (s)	Max. Amplitude (deg.)		
1	2020-Dec-23 14:59:11	34.86	2.09	2020-Dec-23 14:54:51	72.56	2.18	5	Pilot Vessel (only)
2	2020-Dec-28 17:45:47	21.75	1.58	2020-Dec-28 17:47:35	39.92	10.21	2	Cargo (only)
3	2020-Dec-30 11:03:55	22.92	1.59	2020-Dec-30 11:00:05	113.55	4.23	3	Fast Ferry (only)
4	2020-Dec-31 13:00:29	34.03	1.68	2020-Dec-31 13:00:08	216.85	19.25	0	No AIS
5	2021-Jan-01 18:02:45	34.90	2.15	2021-Jan-01 18:00:17	305.24	11.61	2	Fast Ferry (only
6	2021-Jan-11 16:46:54	38.99	1.62	2021-Jan-11 16:39:37	76.97	5.33	7	No AIS
7*	2021-Jan-11 18:32:49	38.28	1.76	2021-Jan-11 18:32:57	73.17	5.66	0	Fast Ferry + other
8	2021-Jan-21 20:52:34	22.23	2.07	2021-Jan-21 20:51:53	70.18	10.80	1	Tug + large ship (cargo/tanker)
9	2021-Jan-25 15:19:26	34.88	1.61	2021-Jan-25 15:17:58	98.00	5.60	2	No AIS
10	2021-Feb-10 15:19:44	54.34	1.55	2021-Feb-10 15:17:51	50.21	5.52	2	Tug (only)
11	2021-Feb-28 19:14:37	64.12	1.72	2021-Feb-28 19:14:48	35.90	2.98	0	Fast Ferry + other
12	2021-Mar-01 09:31:33	24.92	1.65	2021-Mar-01 09:31:00	51.62	3.80	0	No AIS
13	2021-Mar-03 12:12:47	55.65	2.14	2021-Mar-03 12:05:03	49.08	3.06	7	No AIS
14	2021-Mar-12 10:41:26	29.83	1.79	2021-Mar-12 10:39:43	97.26	2.65	2	No AIS
15	2021-Mar-25 16:22:34	41.21	1.65	2021-Mar-25 16:22:21	207.31	8.79	0	No AIS
16	2021-Apr-03 11:06:17	30.33	2.06	2021-Apr-03 11:07:18	94.48	5.84	1	Fast Ferry + other
17	2021-Apr-08 19:27:42	27.17	1.59	2021-Apr-08 19:27:18	70.91	4.01	0	No AIS

*** Event reported by local stakeholder (see Table 2.5)**

Table 2.5 Details of a stakeholder reported event for an example surge event including information reported and analysis of measured, AIS and metocean data

No.	Date	Time (Local Time)	Location	Reported via	Remarks	Observed in measured data		Max roll amplitude (degrees)	Vessel passing (Yes/No)	Vessel types	Vessel max speed (kts)	Vessel Inbound/Outbound	Wind	Wind dir	Tide	
4	11-Jan-21	18:34	Savages Marina	Email	A strong surge experienced in the marina. Not much wake was observed, a North/South underwater surge led to the incident. A large incoming ship OOCL DUBAI doing 9 knots on the Eastern side of the channel and the outgoing Bellarine Express doing 21.5 knts on the western side between channel (markers 21 and 19) were noticed.	Yes	18:34:42 - 18:37:11	5.0	AIS	Fast Ferry Cargo - Hazard D Tug Tug Tug	25.3 9.6 9.8 8.3 8	Outbound Inbound Inbound Inbound Inbound	Strong	NNW	0.19	↓

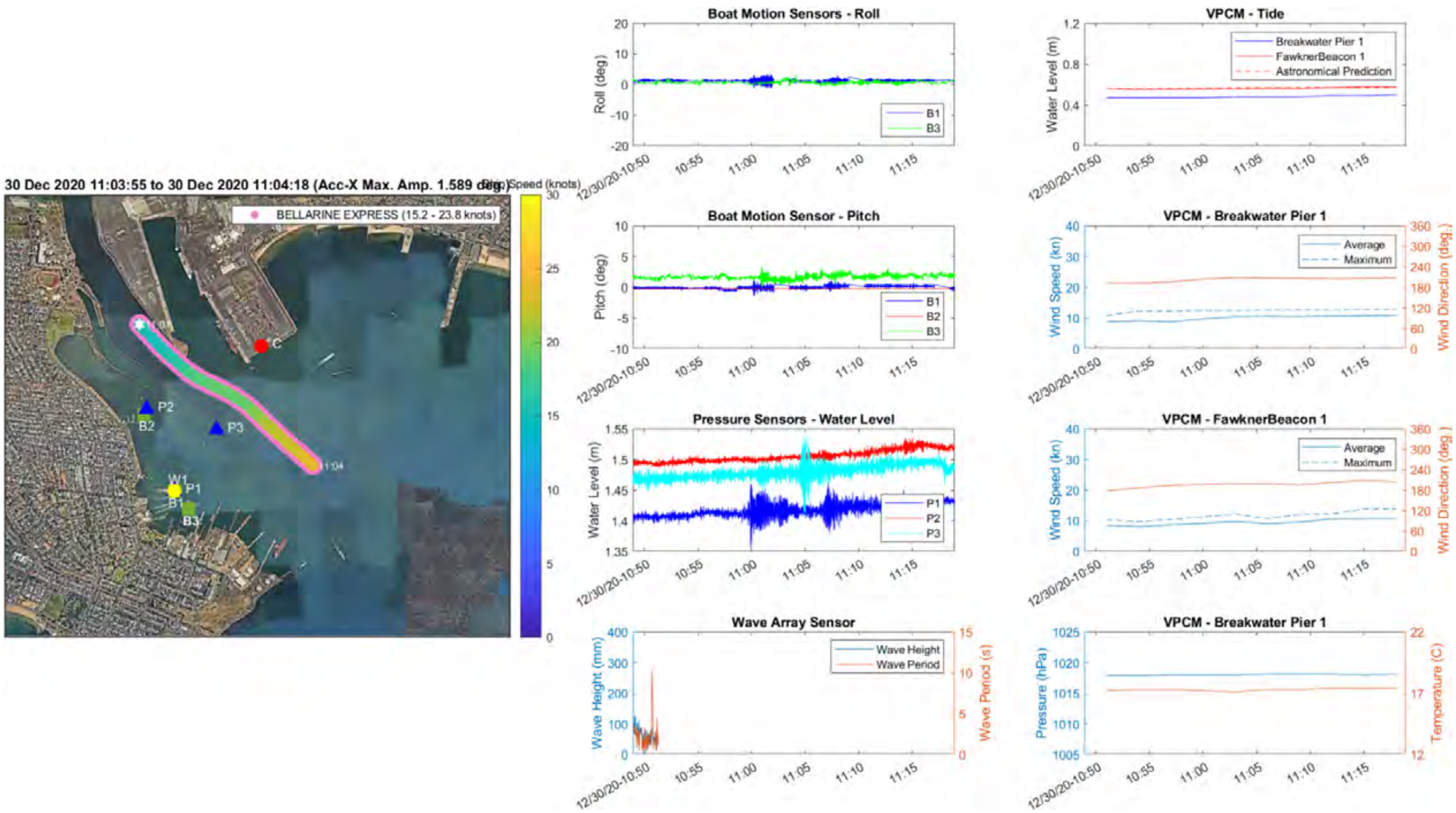

Figure 2.39 Summary diagnostic plot for an example surge event (event No. 3 listed in Table 2.4)

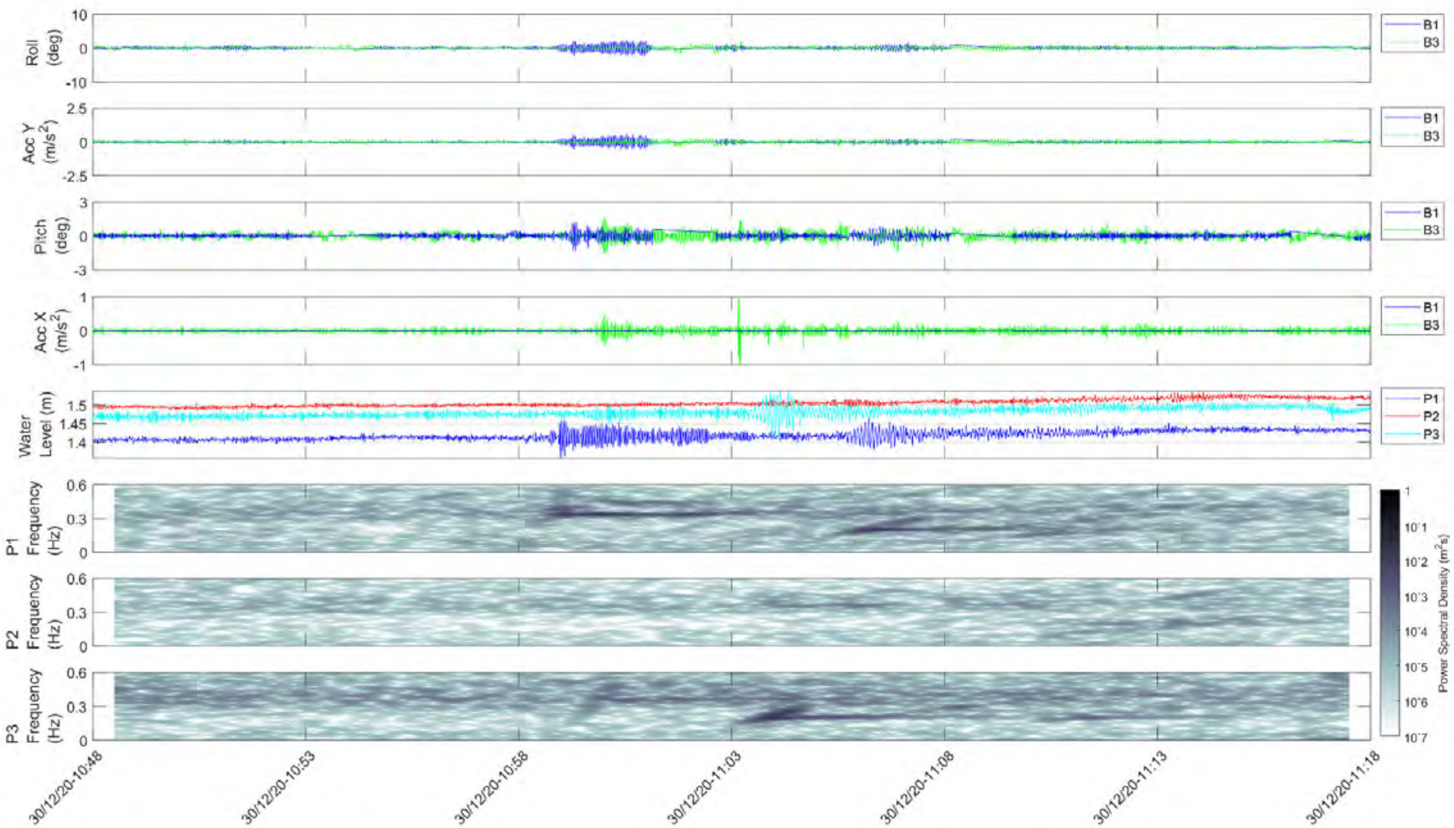

Figure 2.40 Spectrogram plot for an example surge event (event No. 3 listed in Table 2.4)

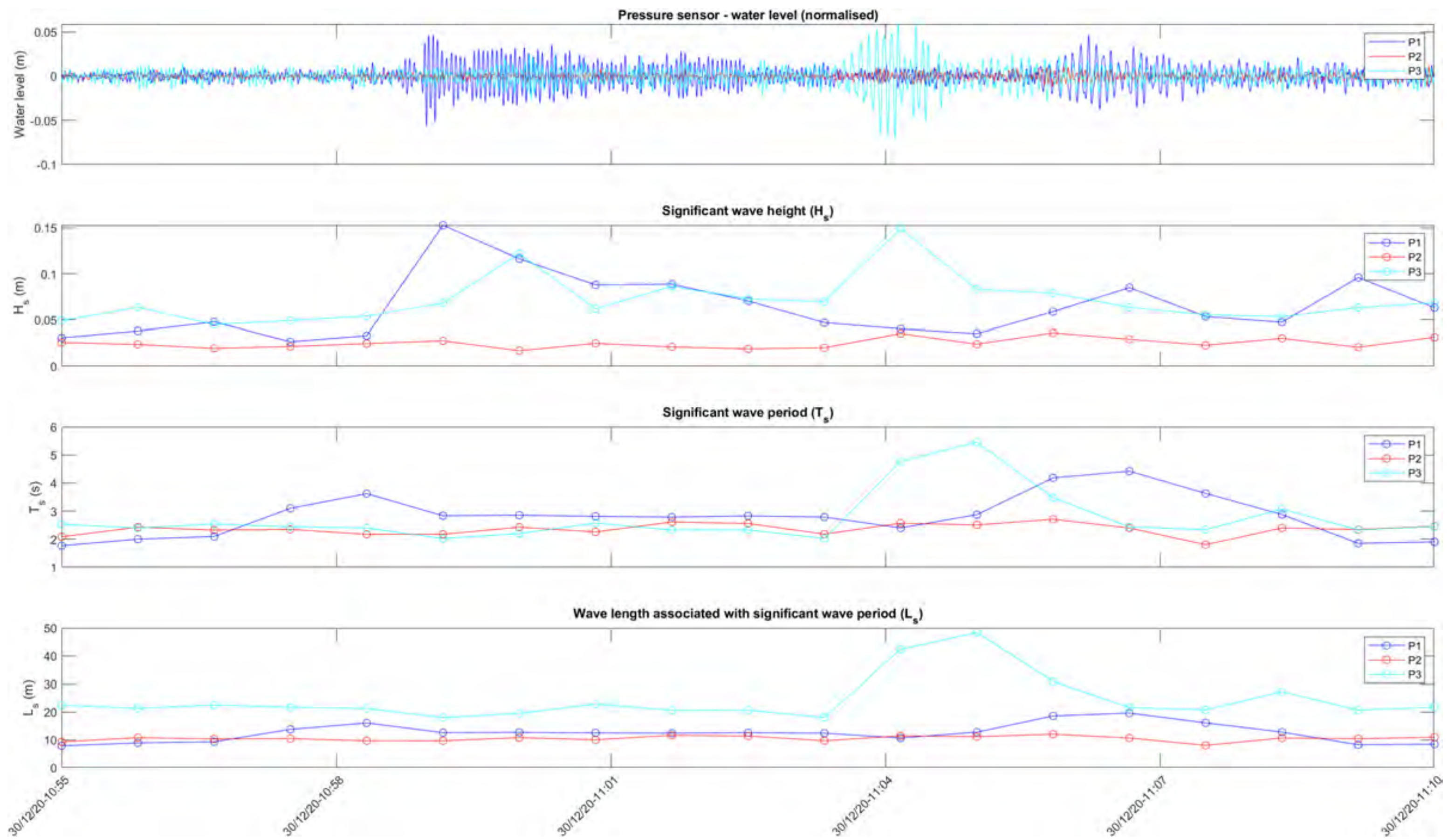

Figure 2.41 Wave characteristics determined from the pressure sensors for an example surge event (event No. 3 listed in Table 2.4)

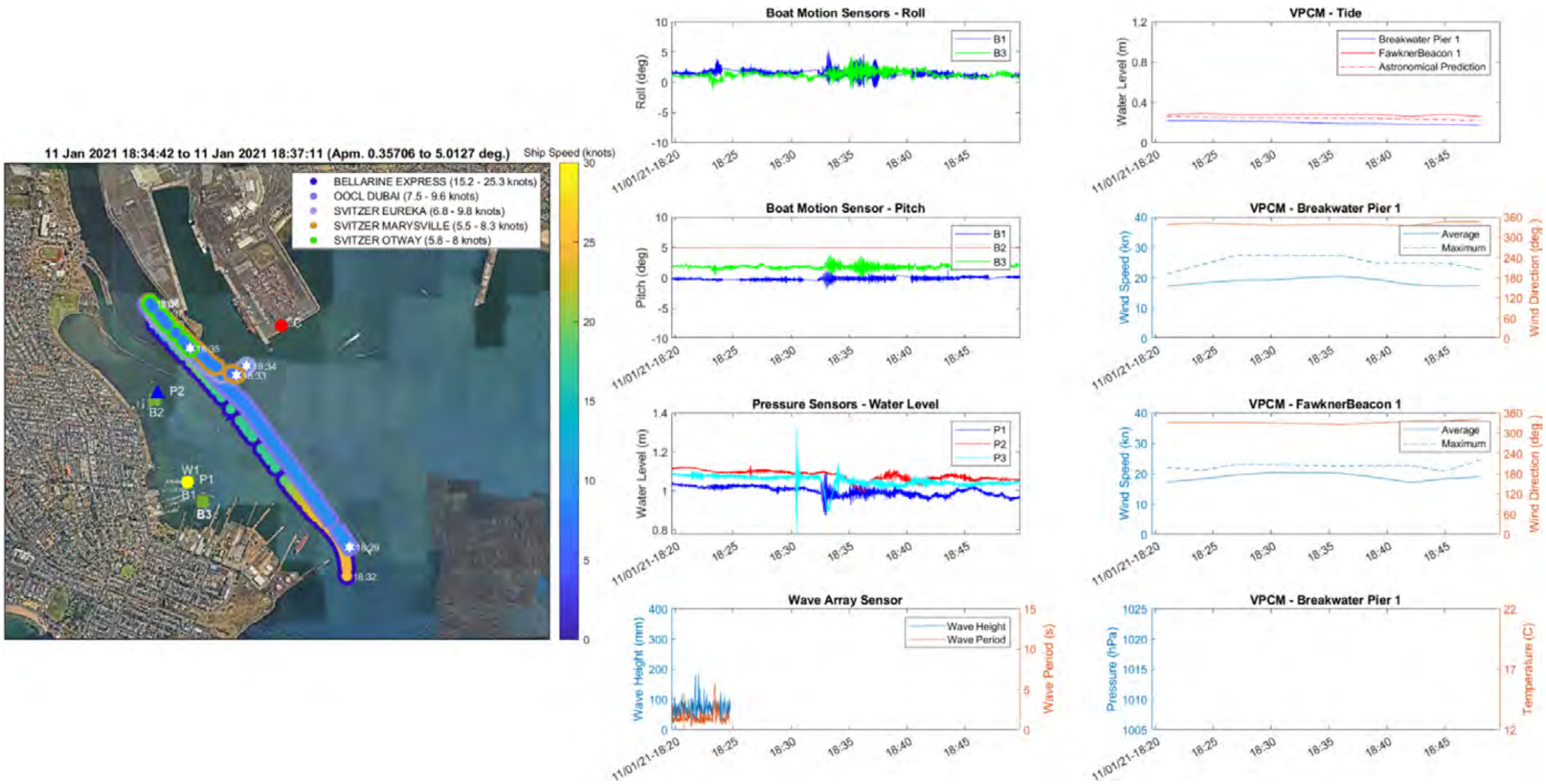

Figure 2.42 Summary diagnostic plot for a reported surge event (event No. 7 listed Table 2.4 and further described as report No 4 in Table 2.5)

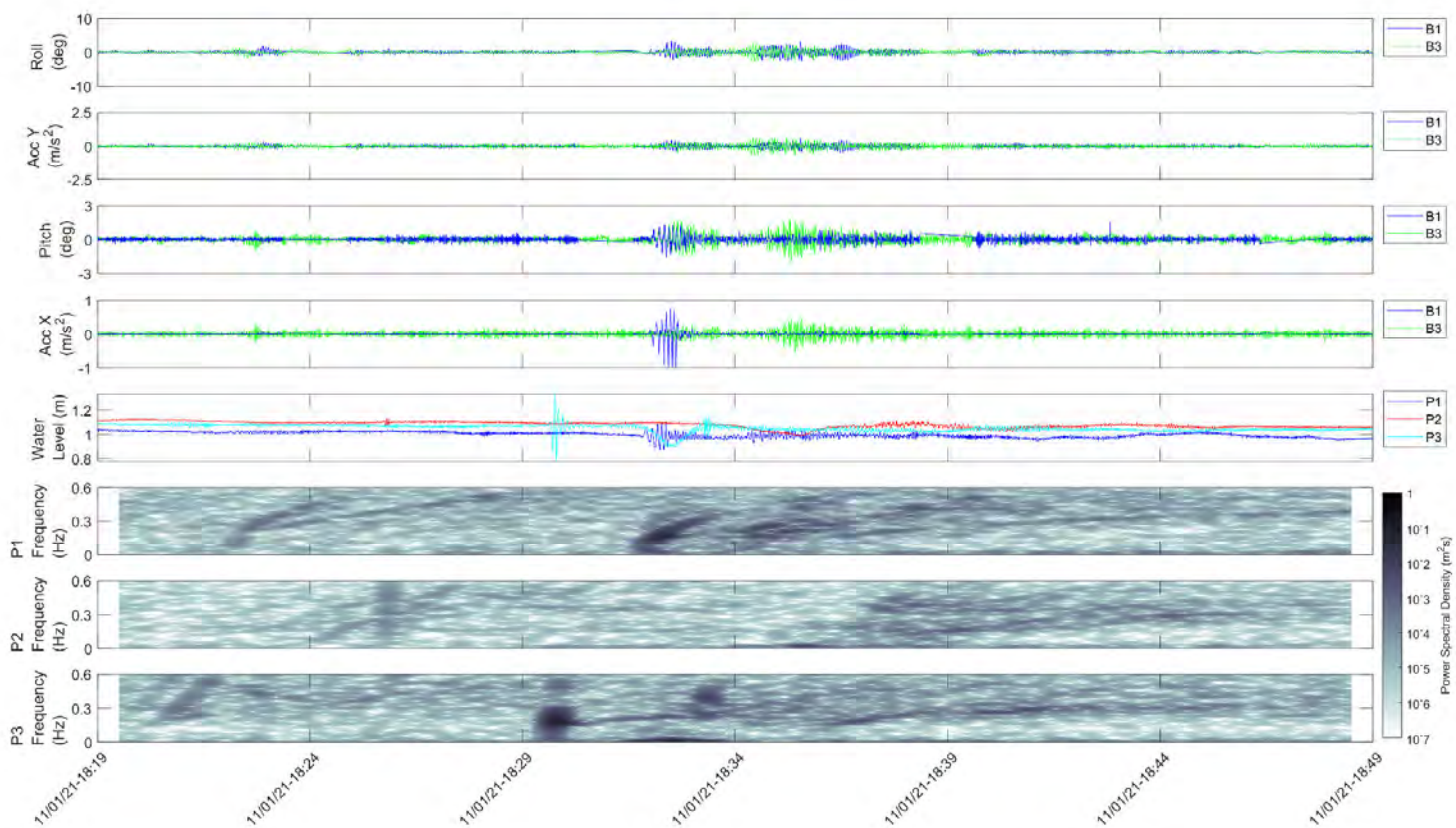

Figure 2.43 Spectrogram plot for a reported surge event (event No. 7 listed Table 2.4 and further described as report No 4 in Table 2.5)

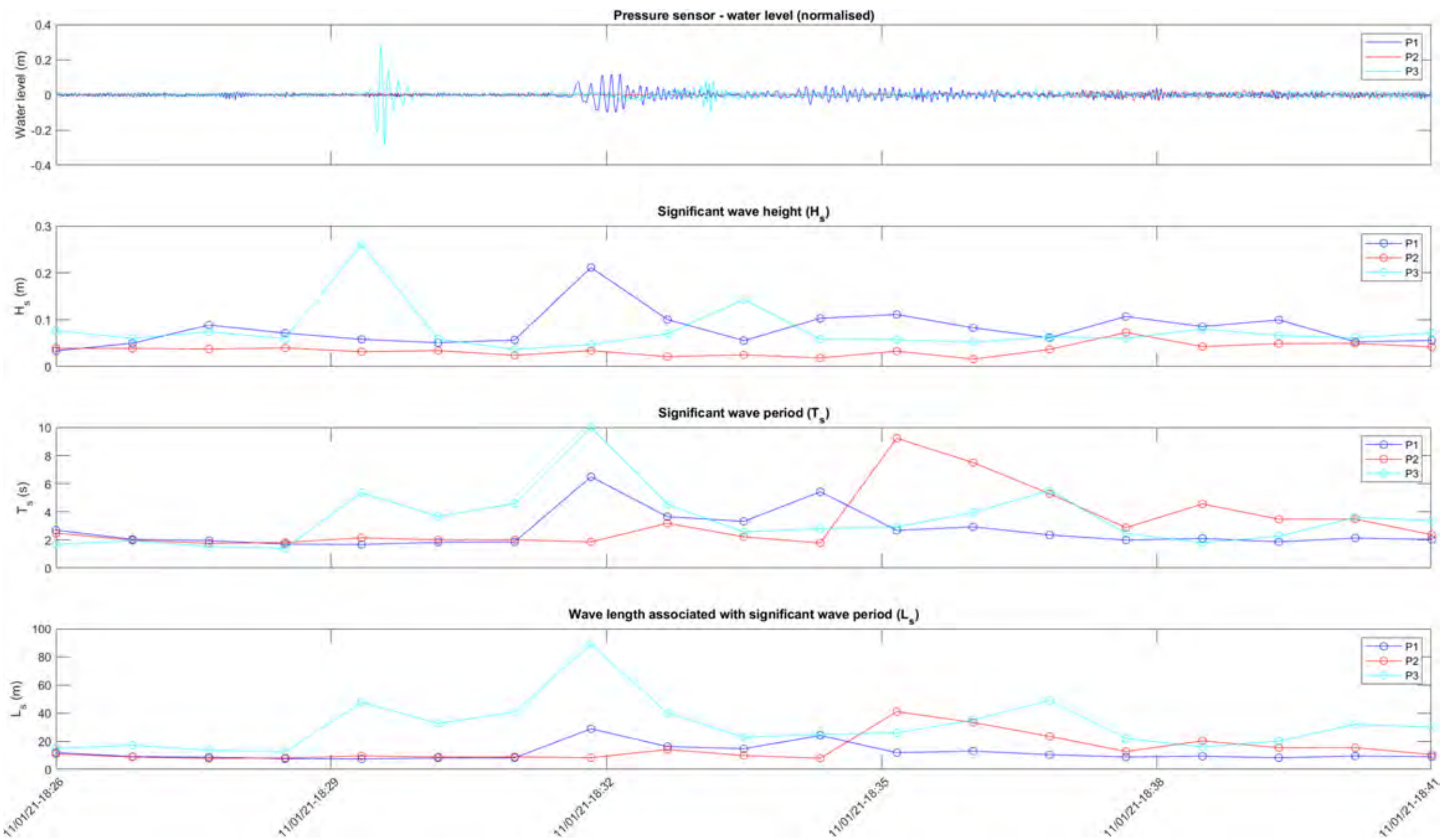

Figure 2.44 Wave characteristics determined from the pressure sensors for a reported surge event (event No. 7 listed Table 2.4 and further described as report No 4 in Table 2.5)

3 Stakeholder Engagement

As part of this Stage 3 of the Study, BMT along with Parks Victoria, visited and conducted 'one-on-one' engagement sessions with several of the local stakeholders, namely yacht clubs, marinas, and businesses within the Williamstown Maritime Precinct, as well as with Port Phillip Ferries. The objective of the visits was to gain insight into staff, operators, owners, and berth holder concerns, to better understand what damage and safety issues have been previously identified as a result of vessel wake, wave, wash and surge events along with, any mitigation measures that have been previously implemented or trialled locally by the stakeholders. Additionally, feedback was sought from these local stakeholders regarding the mitigation measures included in the Comparative Assessment Framework (Section 4).

Table 3.1 lists the stakeholders that were engaged along with the primary contact and the date visited.

Table 3.1 List of marinas visited by BMT and PV during the stage 3 assessment

Stakeholder	Contact person met	Context	Date visited
Royal Yacht Club of Victoria (RYCV)	General Manager	RYCV was one of the marinas where the data collection was undertaken. The general manager was given an update on the Stage 2 results and questioned about the experiences and mitigation specific to the marina.	5 May 2022
Hobsons Bay Yacht Club (HBYC)	Club Manager	HBYC was one of the marinas where the data collection was undertaken. The club manager was given an update on the Stage 2 results and questioned about the experiences and mitigation specific to the marina. May 2022	5 May 2022
The Anchorage	Marina Manager	The Anchorage was one of the marinas where the data collection was undertaken. The marina manager was given an update on the Stage 2 results and questioned about the experiences and	19 May 2022

Stakeholder	Contact person met	Context	Date visited
		mitigation specific to the marina.	
Royal Victorian Motor Yacht Club (RVMYC)	Commodore	The commodore was given an update on the project to date and questioned about the experiences and mitigation specific to the marina.	19 May 2022
Blunt's Boatbuilders	Owner	The owner was given an update on the project to date and questioned about the experiences and mitigation specific to his boat yard and wharf.	19 May 2022
Savages Wharf	Director Relationship Manager	The director and relationship manager were given an update on the project to date and questioned about the experiences and mitigation specific to his boat yard and marina.	23 May 2022
Port Phillip Ferries	CEO Operations Manager Consultant	The CEO, operations manager, and consultant were given an update on the project to date and specifically the results and statistics from Stage 2. The meeting included discussions on vessel speeds, acceleration/deceleration and the scope of stage 3 of the project.	2 June 2022

To aid the discussion and consistency of the engagement the meetings, with the exception of Port Phillip Ferries and Blunt's Boatbuilders, included a brief, structured, questionnaire. Copies of notes taken during the engagement visits, against this questionnaire are included in Annex A of this report.

3.1 Feedback from stakeholders in the Williamstown Maritime Precinct

The feedback received from the stakeholders during the engagement visits in the Williamstown Maritime Precinct, in relation to the 'wave, wash and surge' events is summarised in four categories below:

- Cause
- Safety Incidents
- Damage
- Concerns

3.1.1 Cause

The general perception by most of the stakeholders in the Williamstown maritime Precinct is that Port Phillip Ferries are believed to be one of the main causes of the surge events worsening in recent years. Additionally, it is widely believed by the stakeholders that the number of events experienced in the marinas, has increased since the Port Phillip Ferries commenced Fast Ferry services. It was commented on that the wider arc taken by some of the Fast Ferries' operators, helps reduce the wake that propagates into the precinct; however, this was not a consistent comment from all stakeholders.

When shown summary statistics from Stage 2 of this study, which indicate different percentage of events detected in association with various vessels during the data collection period, all the marinas' representatives agreed that actually a variety of vessels often pass through the study area (including small to medium motorboats either private or commercial, large commercial ships and support vessels, and other), transiting at speeds that do produce wake waves that propagate into their facilities causing events, in addition to the Fast Ferries. There was commentary indicating that often "people on their boats exceed the no-wash speed limit of 5knots around the marinas". Although the association of cause of events was consistent, there was some contradictions on whether the wake propagation is worse at high or low tide.

3.1.2 Safety Incidents

It was widely acknowledged that the 'wave, wash and surge' events constitute a safety risk to people in the marinas, particularly as events occur inadvertently and "take by surprise" people on moored and berthed boats. However, when further queried about safety incidents, there were no specific reports of actually injury being incurred and reported to date. A couple of incidents categorised as a 'near miss' have been reported to the marina and club managers, and there was commentary that this "happens a few times per year".

3.1.3 Damage

Although, anecdotally, there is a lot of mention of damage, there were only a few specific incidents where damage was identified and linked to a 'wave, wash and surge' event. It was acknowledged that repeated events cause general 'wear and tear' and fatigue of materials and structural elements in the marinas, which can reduce the lifespan of infrastructure, but this is very hard to quantify.

A few marinas reported having to replace or repair 2-3 piles per year, as well as mooring attachments and fenders. However, there was acknowledgement of marina and yard managers that this is the result of the combination of aged facilities, which in their view gets aggravated by the recurrent 'wave, wash and surge' events.

The majority of the damage to masthead wind instruments is suspected to be due to 'mast clashing' caused by 'wave, wash and surge' events, however, the damage to the masthead wind instruments is usually found after the damage has occurred. Masts clashing and damage to instruments occurring during a 'wave wash and surge' event has actually only been witnessed a few times. Most marinas reported that wind instruments get damaged (requiring repairs and/or replacement), in this fashion 2-3 times per year, sometimes more, within each marina, despite the marinas trying to relocate vessels or stagger the boats so that the masts are not aligned. Furthermore, there have also been some instances of damage to the actual masts of sailing yachts which is seen as a great concern by the local stakeholders, not only because of the cost associated with this type of damage but because of the potential safety risk that this poses to people who could go sailing without knowing of damage "and could find themselves in real trouble out at sea".

3.1.4 Concerns

The main concerns identified by the stakeholders in the Williamstown Maritime Precinct, was that events will continue to occur, damage and/or injury will then likely occur and that it is not feasible and too costly for the marinas to mitigate the effect themselves.

3.2 Feedback from Port Phillip Ferries

Port Phillip Ferries are concerned that they are anecdotally being held responsible for the wake waves being experienced in the Williamstown Maritime Precinct.

They have conducted their own research into wake generated by their vessels and determined that 18-20 knots is the worst speed for the ferries to travel at, when trying to minimise wash. They say, “at 25 knots the boats are planing and causing minimal wash”. Additionally, they advised that the ferries are designed and intended to accelerate and decelerate very quickly, i.e., over a boat’s length, rather than gradually to also minimise wake and wash generation.

When shown summary data and example events recorded during the previous stages of this study, Port Phillip Ferries commented that they have since their inception and are willing to continue cooperating with the authorities to help manage the issues.

BMT have not reviewed the research conducted and data collected by Port Phillip Ferries and therefore cannot give further comment.

4 Comparative Assessment Framework

To conduct an objective evaluation of potential mitigation options to the 'wave, wash and surge' events, a comparative assessment framework has been purposely developed in collaboration with Parks Victoria. The framework follows principles of Multi-Criteria Analysis (MCA) as well as Risk Assessment and Management.

Using the developed framework, each of the mitigation measures are compared in the context of their relative performance to minimise the defined risk events, with consideration of likelihood (effectiveness) and consequence (effect). Although mitigation measures can be implemented individually, in combination or in a staged approach, the framework rates each measure independently of all other mitigation measures.

The comparative assessment was then completed using the framework for the mitigation measures among the high-level strategies identified in during Stage 2 of this study and further described below. However, the framework is designed so that other measures can be assessed at a later stage should alternative strategies or measures become apparent.

4.1 Mitigation Strategies and Measures

Mitigation measures are the controls or changes that can potentially be implemented to reduce or stop the 'wave, wash and surge' events from either occurring or having an effect on the Williamstown Maritime Precinct.

During Stage 2, six potential mitigation strategies/scenarios were listed at high level, of these, two mitigation strategies were identified as viable by PV and DoT at this point in time, namely: "Reducing the generation of wake as the main cause of the events, i.e., operational control measures, such as managing vessel transit and speed limits" and "Local reduction of effects of the incident waves (including wake waves) on the boats and infrastructure".

Generally, Operation Control Measures are intended to eliminate or substantially reduce the production of the wake waves causing the events, whereas the Reduce Local Effect Measures are intended to ease or lessen the impact that the waves have without stopping the production of the wake waves. Comprised in these two categories, a list of 14 potential mitigation measures was prepared with consideration of input from the stakeholders and are further described below.

The mitigation measures are generally independent from each other, meaning that each measure could be implemented in isolation or multiple measures can be implemented simultaneously, and therefore each measure is assessed in its own merit (relative to other measures).

4.1.1 Operational Control Measures

The Operational Control Measures identified and assessed in this Stage 3 report are:

a. Education and enforcement of speed control / limit of recreational boats

b. Education and enforcement of speed control / limit of Fast Ferries

c. Education and enforcement of speed control / limit of Tugs and Pilot boats

d. Education and enforcement of speed control / limit of large commercial (e.g., Cargo, Tanker, and Cruise Ship) vessels

e. Education and enforcement of speed control / limit of small – medium commercial vessels (excluding Tug and Pilot vessels)

f. Creation and/or modification of 5 knot zone

g. Restriction of vessels

Education and enforcement of speed control / limit of recreational boats

This control measure consists of determining the most appropriate speed limit (which may be as is), educating the public and enforcing the speed limits for recreational boats. Currently recreation vessels, in the enclosed waters of Hobsons Bay, as per Victorian waterways and also detailed in the Victorian Recreational Boating Safety Handbook, are subject to a 5-knot speed limit when within:

- 50 m of a person, vessel, wharf, jetty, slipway, diving platform or boat ramp on coastal and enclosed waters
- 100 m of a dive flag
- within 200 m of the water's edge unless specifically excluded by Notice or where designated for other purposes within 50 m of any wharf, jetty, slipway, diving platform or boat ramp
- when passing through a recognized anchorage for small vessels.

These rules generally form part of the Vessel Operating and Zoning Rules (VOZR). The illustration in the Parks Victoria Port Phillip Recreation Boating Guide (7th edition, June 2019), as shown in Figure 4.1, depicts the 200m distance from the shore but does not clearly illustrate the other rules. The combined area will vary slightly depending on the location of vessels or persons in the water at any given time, but the general area presently subject to the combined 5 knot rules above is shown in Figure 4.2.

As the vast majority of recreational boats do not carry an AIS transmitter, there is no available data to easily show the speeds that recreation boats are travelling at in different areas. However, from discussions with the stakeholders it is clear that there is significant uncertainty about the extent of the 5-knot limit. Due to the combination of rules, as shown in Figure 4.2, the combined area has an irregular shape and does not have a marked boundary on the water i.e., there are no navigational aids to help users determine where the 5-knot speed limit applies.

Additionally, both stakeholders and BMT have witnessed boats travelling over 5knots, and causing wake, close to the marinas and local jetties. Hence, this proposed measure would seek to control this.

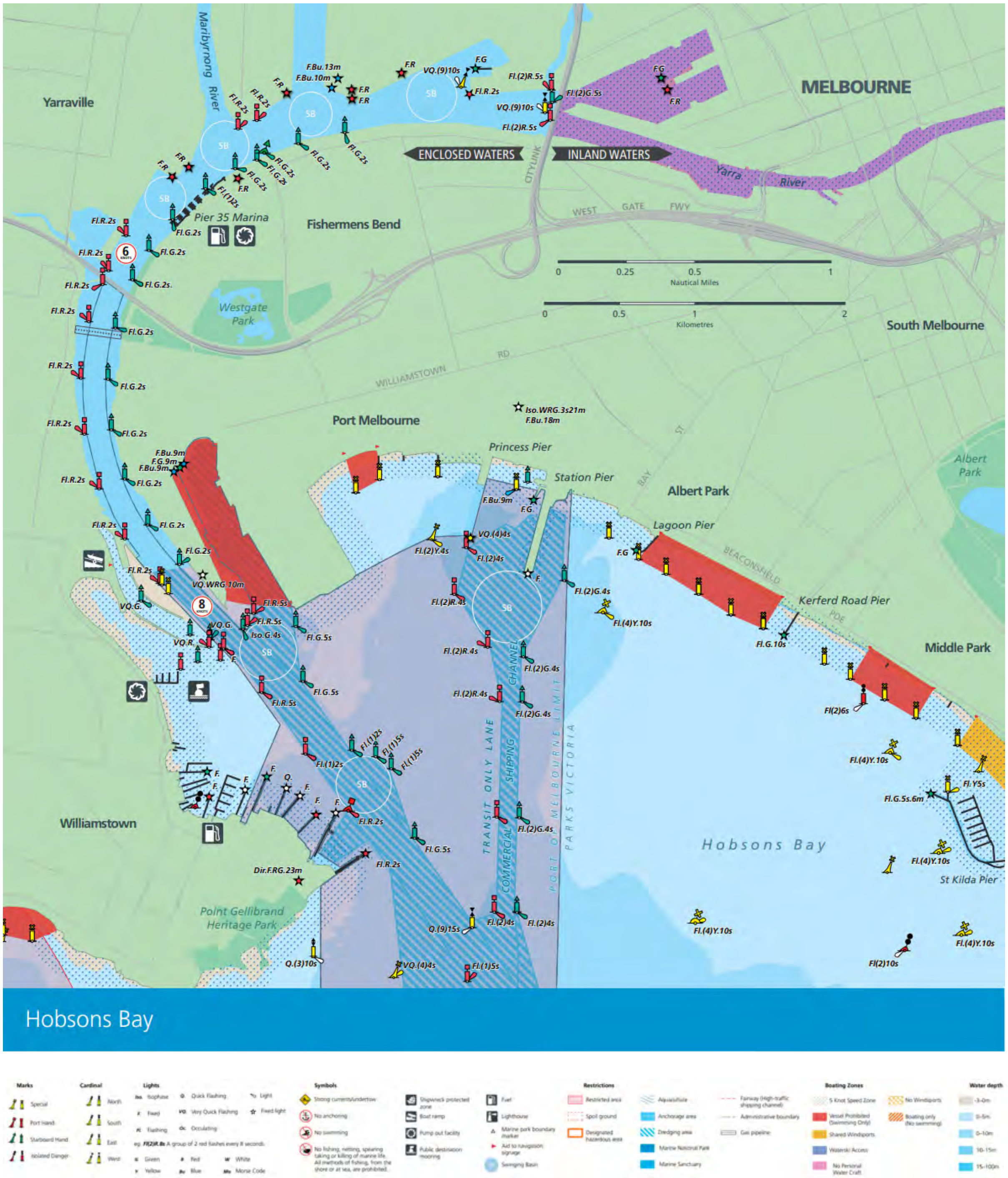

Figure 4.1 Illustration of boating rules in Hobson Bay, sourced from the Parks Victoria Port Phillip Recreation Boating Guide (7th edition, June 2019)

Figure 4.2 General area presently subject to the combined 5 knot rules (indicative figure prepared by BMT for this report)

Education and enforcement of speed control / limit of fast ferries

This control measure consists of determining and enforcing alternative speed limits, and potentially a slightly altered route for the Fast Ferries, (namely the Geelong Flyer and Bellarine Express, operated by Port Phillip Ferries), for the section of their service transiting through the Williamstown channel in Hobsons Bay, past the Williamstown Maritime Precinct.

It is our understanding, based on communications from Parks Victoria and VPCM, that currently the Ferries are subject to a 25knot speed limit from Breakwater Pier to the entrance of the Yarra at Beacons 23 / 24. Noting, upstream from the Yarra entrance to the Westgate Bridge their limit is 15 knots and out in the bay from Breakwater Pier the limit is 30 knots (although, legally there is no limit to speeds some section outside the Port of Melbourne waters in the bay). Further, within the study area, Port Phillip Ferries have agreed with the Harbour Master directions to a 'self-controlled' limit of 18 knots between Beacons 19 / 20 and Beacons 23 / 24 (see Figure 4.3).

Figure 4.3 Diagram to show the 25-knot zone and voluntarily agreed 18-knot zone in the Williamstown channel

From the data analysed in this study, Figure 4.4 shows each of the Fast Ferry transits associated with detected events, the speed and location at each AIS transmission, either inbound or outbound to/from Melbourne/Victoria Harbour. The plots show that whilst passing by the Williamstown Maritime Precinct between beacons 19/20 and 23/24, the Ferries are most commonly travelling between 17 and 20 knots.

During the stakeholder engagement, Parks Victoria and BMT met with Port Phillip Ferries. They informed that 18 knots (and actually a range of about 18-20 knots) is the “worst speed” for their vessels to travel at when trying to minimise the production of wake, and that at 25 knots the boats are planning and producing substantially less wake.

Alternative speed limits to minimise the wake production by Fast Ferries in the study area could therefore either be above or below the agreed 18 knots, in the channel,

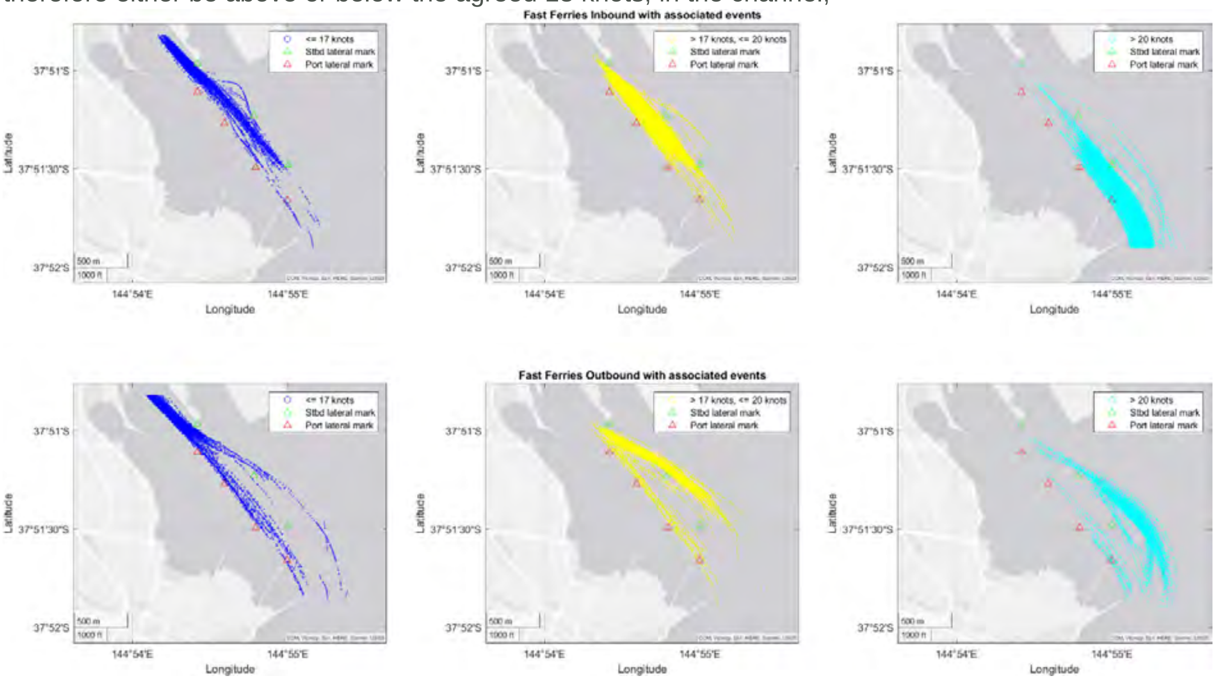

Figure 4.4 Vessel speed and location recorded in the AIS data during the collection period, for Fast Ferry passages associated with detected events

Education and enforcement of speed control / limit of Tugs and Pilot boats

This control measure consists of determining the most appropriate speed limit (which may be as is), educating the operators of port support vessels (such as Tugs and Pilot boats), and enforcing the speed limits for the Tugs, Pilot boats, Port Tenders and other port support vessels.

Currently, the Harbour Masters Directions for the waters operated by the Port of Melbourne dictate that:

- vessels with a LOA of 35m or more but less than 50m, have the following speed limits:
  - 8 knots in the Williamstown Channel north of Breakwater Pier
  - 10 knots in the Port of Melbourne Channel north of the Junction
  - 10 knots between Breakwater Pier and Channel Beacon 9 (to the south)
- vessels with a LOA of less than 35m are subject to the general speed limits and safety distances specified in the VOZR of 5knots:
  - within 50 m of a person in the water
  - within 100 m of a vessel or buoy on which a dive flag is displayed, or a rigid replica of that dive flag
  - within 50 m of another vessel except where both vessels are engaged in competition or training
  - within 200 m of the water's edge
  - within 50 m of a wharf, jetty, slipway diving platform or boat ramp
  - passing through a recognised anchorage for small craft

It should, however, be noted, that Tugs and Pilots have an important role in guiding vessels into the Port of Melbourne and minimum speeds may be required to maintain steerage of large, heavy vessels.

Figure 4.5 shows each AIS transmission by tugs, pilot boats and port tenders associated with detected events recorded during the data collection period. The plot show that speeds up to 25knots occurred and often speed of these boats exceeds 8 knots within the study area.

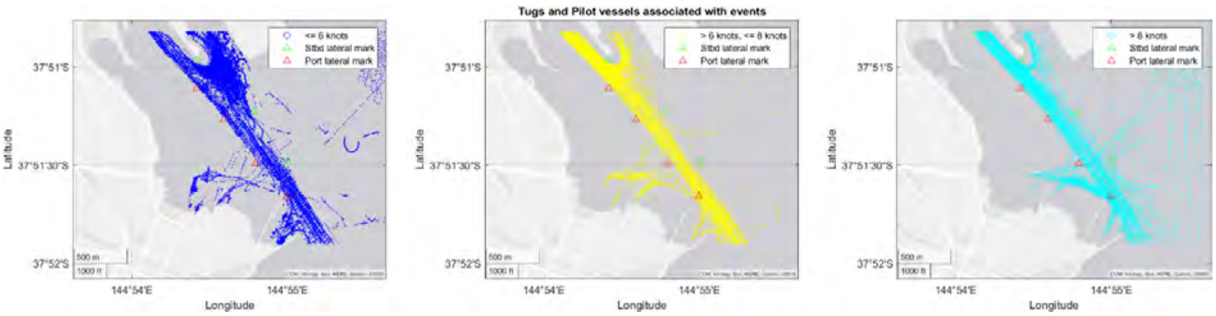

Figure 4.5 Tug and Pilot vessel AIS data during the window timeframes of detected events

Education and enforcement of speed control / limit of large commercial vessels (e.g., Cargo, Tanker, and Cruise Ship)

This control measure consists of determining the most appropriate speed limit (which may be as is), educating operators, and enforcing the speed limits for the large Commercial vessels such as Cargo, Tanker, and Cruise Ships.

Currently, the Harbour Masters Directions for the waters operated by the Port of Melbourne dictate that:

- vessels with a length overall (LOA) of 50m or more, with a draught less than 11.6m have the following speed limits:
  - 8 knots in the Williamstown Channel north of Breakwater Pier
  - 10 knots in the Port of Melbourne channel north of the Junction
  - 10 knots between Breakwater Pier and Channel Beacon 9 (to the south)
- vessels with a LOA of 50m or more, with a draught of 11.6m or more have individual speed limits based on dynamic under keel clearance (DUKC) calculations or determined by Melbourne VTS where DUKC calculations are not available
- vessels with a LOA of 35m or more but less than 50m, have an 8-knot speed limit
  - 8 knots in the Williamstown Channel north of Breakwater Pier
  - 10 knots in the Port of Melbourne channel north of the Junction
  - 10 knots between Breakwater Pier and Channel Beacon 9 (to the south)
- vessels with a LOA of less than 35m are subject to the general speed limits and safety distances specified in the VOZR

It should be noted that minimum speeds may be required for large, heavy vessels to maintain their steerage.

Figure 4.6 shows, each AIS transmission by large commercial vessels associated with detected events recorded during the data collection period, for inbound and outbound movements from / to Port of

Melbourne. The data shows that large commercial vessels exceed the 8-knot speed in a number of these events.

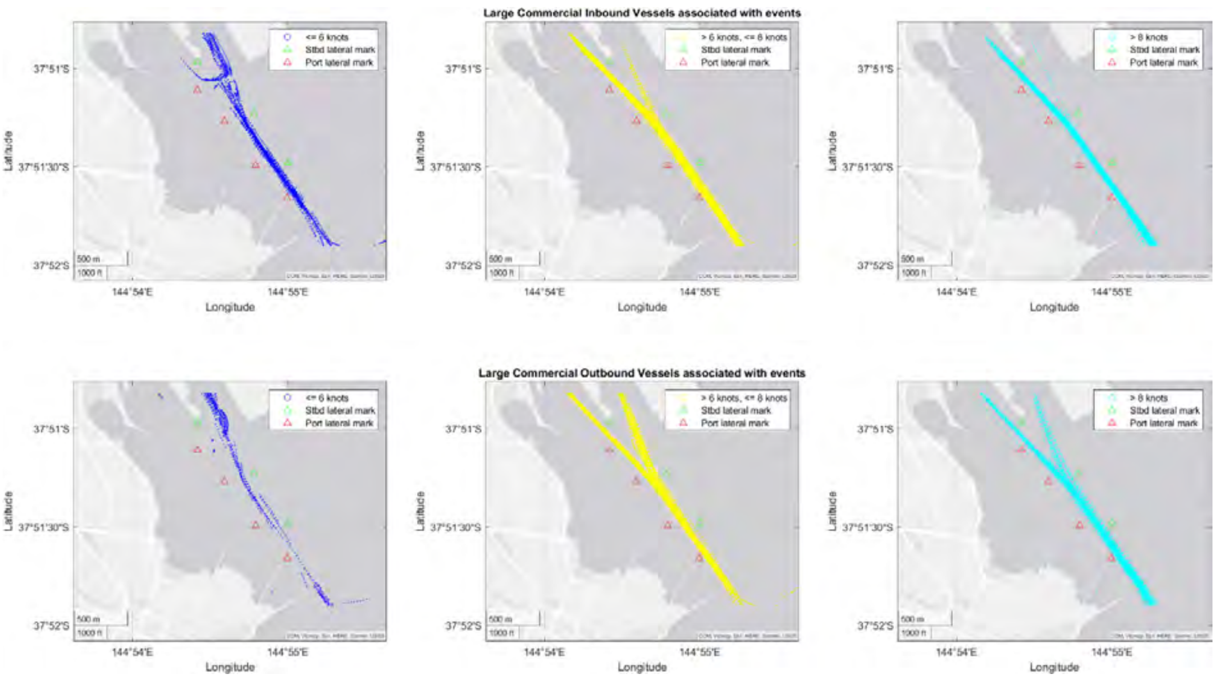

Figure 4.6 Vessel speed and location recorded in the AIS data during the collection period, for Large Commercial Vessels associated with detected events

Education and enforcement of speed control / limit of small – medium commercial motorboats (excluding those accounted in other categories, e.g., port support vessels)

This control measure consists of determining the most appropriate speed limit (which may be as is), educating operators, and enforcing the speed limits for small to medium commercial motorboats, that operate or transit through the study area.

Currently, the Harbour Masters Directions for the waters operated by the Port of Melbourne dictate that vessels with a LOA of less than 35m are subject to the general speed limits and safety distances specified in the VOZR.

It should be noted that exceptions may be required for police and search and rescue (SAR) vessels.

There are only a few recordings of small to medium sized commercial vessels in the AIS data (because these type and size of vessels are not required to carry AIS and often opt to not do so). Figure 4.7 shows the speed and location that have been captured in the AIS data for the data collection period. The plot shows that some of these vessels are travelling over 8 knots within the Williamstown Channel, north of Breakwater Pier and within the waters operated by the Port of Melbourne.

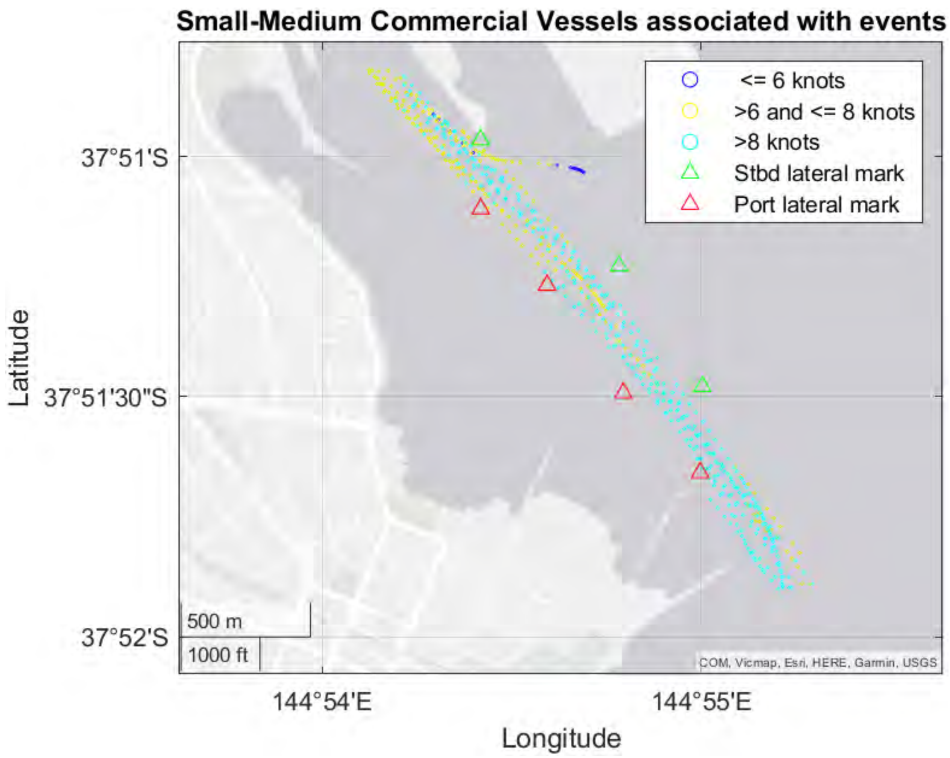

Figure 4.7 Vessel speed and location recorded in the AIS data during the collection period, for Small-Medium Commercial vessels (excluding SAR) associated with detected events

Creation and/or modification of 5 knot zone.

This control measure consists of modifying the existing zoning in the area. In particular, BMT's technical suggestion is creating / extending a 5-knot zone (the speed at which most boats do not produce wash and wake) from the Williamstown Maritime Precinct's foreshore to the western extent of the Williamstown Channel, i.e., along the port side lateral markers from Breakwater Pier, past the Yarra entrance at the “warmies”. Figure 4.8 shows the proposed area that could be set as a 5-knot zone, in relation to the Port Authority boundary of Port of Melbourne Waters; noting most of the proposed 5 knot zone is in waters where Parks Victoria is the port and waterway manager (under the provisions of the Marine Safety Act).

The suggested 5 knot zone would encompass all the standard waterways rules as detailed in the VOZR and provide much greater clarity in an area that has numerous wharfs, jetties, slipways and boat ramps protruding from the shoreline, along with a number of vessels on swing moorings. It is also suggested that the creation or modification of zoning includes buoyage and or signage which is currently minimal within the waters near to the Williamstown Maritime Precinct.

Figure 4.9 shows the AIS traffic recorded in the area during the data collection period. Although the speed limit is 5 knots within 200m of shore, and 50m of a jetty, the data shows that some boats are arriving and leaving the vicinity of the area at speeds exceeding 8 knots. It is worth further noting that data in this plot only includes vessels with AIS, whereas it is known that a large proportion of the local marine traffic within this area is of small to medium motor boats that do not carry AIS.

Figure 4.8 Area proposed for extension / modification of a 5-knot zone

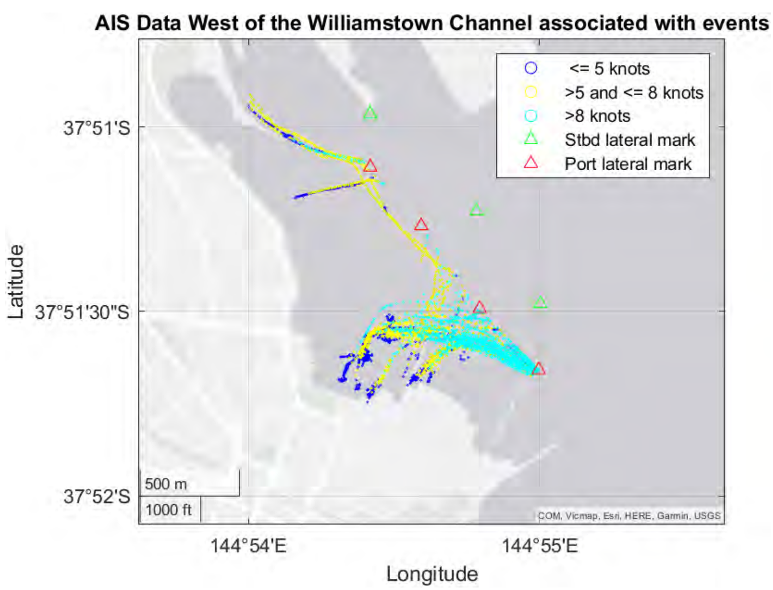

Figure 4.9 AIS data recorded for all vessels in the Williamstown Maritime precinct and to the west of the Williamstown channel during the data collection period

Restriction of vessels

Within Port Phillip Bay there are several zones where vessels are restricted, however in the complex area of Williamstown, at the mouth to the Yarra River, and within the vicinity of the Port of Melbourne, BMT believe that restricting vessels will be a limited option. As such, this option has not been further assessed at this stage.

4.1.2 Reduce Local Effect Measures

The Reduce Local Effect Measures identified and assessed in this Stage 3 report are (at the local scale of each marina):

a. Redistribution of moored boats
b. Damping devices
c. Improvement of fendering systems
d. Repair and replacement of joints in marinas and yacht clubs' infrastructure
e. Spacing boats within local marinas and yacht clubs
f. Re-alignment of berths within marinas and yacht clubs
g. Wave attenuation at the marina scale

Redistribution of moored boats

This control measure consists of moving the vessels of some berth holders to different berths so that larger vessels are moored next to smaller vessels. In particular this allows for larger masts to be alongside smaller ones and with the masts naturally offset due to the length of the vessel.

This measure, however, is somewhat limited by the infrastructure of each marina, as it is not likely to be plausible to change the size (length and width) of individual berths in either pile and jetty or floating pontoon marinas. Similarly larger boats generally have a greater draught, which also limits which berths are appropriate for any particular vessel.

It should also be noted that many of the marinas are already adopting this measure where possible, as heard directly from the marina and yard staff and managers during the stakeholder engagement visits.

Damping devices

This control measure consists of improving, maintaining, or adding additional ways of absorbing the energy from the wake waves to avoid contact between boats or boats and infrastructure. Many of the marinas with piles and jetties already have springs on the mooring lines to help absorb the motion. Other devices are poles (referred by some as "rider poles") that hold the boat away from a dock (see Figure 4.10) although these are generally only appropriate for smaller motor boats and jet skis.

Figure 4.10 Damping device that holds the boat away from the dock

Improvement of fendering systems

This control measure consists of improving fendering systems within each marina to allow boats to touch each other or marina infrastructure without damage occurring. For jetty and pile marinas there is limited fendering systems as most berths in these marinas are designed with the vessel sitting in the centre of the berth with clearance all around. Fendering systems are mainly applicable when a vessel sits directly alongside the jetty pier, alongside a floating pontoon or when vessels are rafted up to each other. Boat owners with these berthing situations generally provide their own fenders tied to their vessel or their regular berth. A number of vessels also already have fendering strips on the pontoons.

Repair and replacement of joints in marinas and yacht club infrastructure (e.g., pontoons and jetties)

This control measure consists of ensuring that marina infrastructure is regularly maintained to a high standard to ensure breakages are minimal. Fatigue to infrastructure has been reported across the Williamstown Maritime Precinct and it is expected that long term fatigue can increase the likelihood of infrastructure failure.

Several marinas in the Williamstown Maritime Precinct have aged infrastructure showing wear and tear signs, whilst a few have been replaced with floating pontoons. However, all the marinas in the precinct reportedly experience issues from wake waves.

Although repair is an ongoing and usual expense for marinas, this mitigation measure would involve a more intense maintenance program above and beyond the business-as-usual approach, noting that replacement of infrastructure can be an exceptionally costly and lengthy process.

Spacing boats within local marinas and yacht clubs

This control measure consists of moving the vessels of some berth holders so that the boats are better spaced. This could include putting smaller boats in larger berths, using alternate berths only or having less berths alongside to allow more spacing between the vessels.

This measure is costly as it reduces potential income and is not feasible if a marina is already operating near full capacity, as heard directly from the marina and yard staff and managers during the stakeholder engagement visits.

Re-alignment of berths within marinas and yacht clubs

This control measure consists of changing the orientation of the marina berths. At present some marinas experience more of a surge (forward and backwards motion) whereas others experience more of a roll (side to side motion) which causes different forces and therefore different damage being incurred. This option proposes that marinas are altered so that boats are berthed at an angle to the predominant direction of incoming waves to incur the least amount of force and damage. This is an expensive option, is restricted by available space and licensed/permitted boundaries and is a lengthy process, only likely to occur when the entire marina infrastructure is replaced, allowing for redesign of a marina; as heard directly from the marina and yard staff and managers during the stakeholder engagement visits.

Wave attenuation at the marina scale

This control measure consists of building/implementing barrier devices local to the boundary of each marina to reduce the wave propagation into each marina. Building new infrastructure is a costly and length process and is limited by available space. A couple of marinas have indicated that although not desirable (to the marina), they are investigating this option.

4.2 Assessment framework

For each level of risk event, associated with the amplitude of events, each mitigation measure is assessed for both the effectiveness at resolving the boat motions experienced and the criteria (effect/consequence) in order to determine an overall score for each of the mitigation measures and conducting a comparative evaluation/assessment of the options. The scores obtained are intended to be indicative at a high level and should be used within the context of the framework.

4.2.1 Risk Events

From the outcomes of Stage 2 of this study, the detected 'wave, wash and surge' events were grouped together into three categories (Small, Medium, and Large) based on the recorded amplitude of the roll motion (with an inherent assumption that greater roll events correlate with greater surge events as observed in examples presented and discussed in section 2.3 above).

- Small amplitude events are those events with a recorded amplitude of 0-5 degrees.
- Medium amplitude events are those events with a recorded amplitude of 5-10 degrees.
- Large amplitude events are those events with a recorded amplitude of greater than 10 degrees.

4.2.2 Likelihood

For each of the risk events the likelihood, is the percentage of the total events for each category of vessel associated with events. For example, small events associated with large commercial shipping is 12.9% of the total detected events and therefore the likelihood is 12.9.

4.2.3 Effectiveness and effectiveness total score

Each Mitigation Strategy is assessed as to how effective it is likely to be in reducing the wave, wash and surge events from each of the categories determined in Stage 2, e.g., small vessels without AIS, fast ferries, large commercial vessels, and so on.

Effectiveness is rated from 0 to 1, where 0 means a mitigation strategy will not aid that category of events at all, and 1 will completely mitigate the risk event for the given category of vessel.

The scoring has considered the feedback from the stakeholder engagement.

The total Effectiveness Score for each mitigation strategy, is the statistical likelihood of the category of vessel for a risk event multiplied by the effectiveness rating given to each category of vessel for each mitigation strategy for the risk event.

4.2.4 Criteria (effect/consequence)

There are four broad categories of effect/consequence considered in the framework and following the "quadruple bottom-line approach": Social (inc. safety and wellbeing), Economic / Financial, Environmental and Other.

Within these categories there are more detail defined criteria, so that each mitigation measure can be assessed on how it affects both users of the Williamstown Precinct and the wider maritime community including the Port operations, boat operators and government agencies.

Criteria are assessed on a rating scale of 3 to -3, where 3 is highly positive, 0 is neutral (neither an effect or consequence), and -3 is a highly negative effect or consequence.

4.2.5 Weighting

For each criterion (effect/consequence) there is a weighting so that some criteria are ranked of higher importance and consequently influence the overall score accordingly. These weighting were determined in consultation with Parks Victoria.

4.2.6 Consequence total score

For each mitigation strategy the consequence total score is the sum of the weighting of each criterion multiplied by the rating given to each criterion.

For the total events the consequence score has been doubled for medium events and tripled for large events to emphasize the severity of the events, and the value of resolve the large amplitude events.

4.2.7 Overall score

The overall score is the Total Effectiveness Score multiplied by the Consequence total score, divided by 100.

The overall score for the total events is the sum of the consequence score for the total events, allowing for the increased factors as detailed above. This represents the overall aggregated performance of each mitigation measure.

5 Comparative Assessment Outcomes

The Operational Control Measures and Reduce Local Effect Measures were assessed using the purposely developed framework. Figure 5.1 shows the summary table detailing the effectiveness score, consequence score and overall score for the 14 options assessed. The full assessment tables for small, medium, and large events are further included in Annex B. See section 4.2 for more information on how the assessment was completed.

In order to interpret the results each mitigation measure has been ranked from highest overall score for total events (based on the combination of effectiveness and consequence score and multipliers for the impact of the medium and large events) to the lowest score.

The ranked order of measures is:

1. Creation/modification of 5 knot zone
2. Education and enforcement of speed control / limit of recreational boats
3. Education and enforcement of speed control / limit of Fast Ferries
4. Wave attenuation at the marina scale
5. Education and enforcement of speed control / limit of large commercial vessels
6. Re-alignment of berths within marinas and yacht clubs
7. Education and enforcement of speed control / limit of tugs and pilot boats
8. Tied ranking: Redistribution of boats
8. Tied ranking: Damping devices
8. Tied ranking: Improvement of fendering systems
11. Education and enforcement of speed control / limit of small to medium commercial vessels
12. Repair, replacement and maintenance of joints, piers in marinas and yacht clubs
13. Spacing boats within local marinas and yacht clubs
14. Restriction of vessels (note this measure was deemed non-feasible at this point in time and thus ranked last by default, therefore it does not appear as a column in the summary assessment tables)

Recommendations of how these rankings can be implemented in a pathway approach is discussed in section 6 below.

Williamstown Maritime Precinct Wave, Wash and Surge Study - Stage 3 - Comparative Assessment of Potential Mitigation Measures

Comparative Assessment of Mitigation Measures based on Effectiveness Likelihood and Multi-criteria Effect (Consequence)			Mitigation Strategy Measures												
			Operational Control Measures						Reduce Local Effect Measures						
Summary of Scores			Education and enforcement of speed control / limit of recreational boats	Education and enforcement of speed control / limit of Fast Ferries	Education and enforcement of speed control / limit of Tugs and Pilot boats	Education and enforcement of speed control / limit of large commercial (Cargo, Tanker, Cruise) vessels	Education and enforcement of speed control / limit of small commercial vessels	Creation / modification of 5 knot zone, i.e., extend the 5kt limit to the channel boundary	Redistribution of boats. Large moored next to small.	Damping devices (e.g. Rider poles; Mooring springs, etc) (i.e., avoiding contact)	Improvement of fendering systems (i.e., minimising impact when touching)	Repair, replacement and maintenance of joints / piles in marinas and yacht clubs infrastructure (e.g. pontoons, jetties)	Spacing boats within local marinas and yacht clubs	Re-alignment of berths within marinas and yacht clubs	Wave attenuation at the marina scale
SMALL Amplitude Events -	Effectiveness Score	60.7	21.7	9.4	7.4	15.6	2.9	27.5	18.2	18.2	18.2	18.2	24.3	30.3	36.4
	Consequence Score	100.0	17.0	18.0	22.0	10.0	25.0	33.0	8.0	8.0	8.0	2.0	0.0	-7.0	10.0
	Overall Score		**3.7**	**1.7**	**1.6**	**1.6**	**0.7**	**9.1**	**1.5**	**1.5**	**1.5**	**0.4**	**0.0**	**-2.1**	**3.6**
MEDIUM Amplitude Events -	Effectiveness Score	31.1	8.7	8.3	2.9	8.0	1.2	10.9	6.2	6.2	6.2	6.2	9.3	12.4	15.6
	Consequence Score	100.0	17.0	18.0	22.0	10.0	25.0	33.0	8.0	8.0	8.0	2.0	0.0	13.0	10.0
	Overall Score		**1.5**	**1.5**	**0.6**	**0.8**	**0.3**	**3.6**	**0.5**	**0.5**	**0.5**	**0.1**	**0.0**	**1.6**	**1.6**
LARGE Amplitude Events -	Effectiveness Score	8.2	0.9	3.4	0.8	2.2	0.1	1.2	0.8	0.8	0.8	0.8	1.6	2.5	3.3
	Consequence Score	100.0	37.0	38.0	42.0	30.0	45.0	53.0	8.0	8.0	8.0	2.0	0.0	13.0	10.0
	Overall Score		**0.3**	**1.3**	**0.3**	**0.7**	**0.0**	**0.6**	**0.1**	**0.1**	**0.1**	**0.0**	**0.0**	**0.3**	**0.3**
TOTAL of Events -	Effectiveness Score	100.0	31.3	21.1	11.1	25.8	4.2	39.6	25.2	25.2	25.2	25.2	35.2	45.2	55.2
	Consequence Score	300.0	162.0	168.0	192.0	120.0	210.0	258.0	48.0	48.0	48.0	12.0	0.0	58.0	60.0
	Overall Score		**50.7**	**35.4**	**21.3**	**31.0**	**8.9**	**102.2**	**12.1**	**12.1**	**12.1**	**3.0**	**0.0**	**26.2**	**33.1**
	Rank Based on Overall Score		**2**	**3**	**7**	**5**	**11**	**1**	**8**	**8**	**8**	**12**	**13**	**6**	**4**
	Recommended Timing/Priority Pathway for Implementation (based on judgement of benefit vs effort involved)		*****	**2**	******	**3**	*****	**1**		**#**		**##**	**###**	**5**	**4**

* This measure is somewhat redundant if 1 is implemented

** This measure is somewhat redundant if 1 and 4 are implemented

These measures have been already trialed / implemented by the local marinas and yacht clubs to some extent (based on their direct feedback)

This measure is part of the maintenance program of the local marinas and yacht clubs (based on their direct feedback)

This measure is considered not viable by the local marinas and yacht clubs (based on their direct feedback)

Figure 5.1 Summary and outcomes of the comparative assessment of potential mitigation measures

6 Conclusions and Recommendations

Building on from the previous two stages of this Study, advanced data analysis allowed BMT to develop further insights during Stage 3, including the following key findings:

- The wave climate that is naturally occurring in the Williamstown Maritime Precinct results in conditions that do not conform with the Australian Standards for Marina Design. The results of a calibrated and validated spectral wave model of wind sea waves for the broader Port Phillip Bay and Hobsons Bay propagating to Williamstown, indicate significant wave height extremes of 0.78m and 0.55m for the for 50year and 1year average return interval (ARI), exceeding the criteria recommended in the Standard. Further, annual probabilities of occurrence of 1.4%, 3.0% and 4.35% for significant wave heights greater than 0.3m for short period waves (<2s), 0.3m for longer period waves (>2s) and 0.15m for longer period waves (>2s) respectively, all exceed the recommendations from the Standard for good wave climate in marinas.
- The naturally occurring wind and wave conditions in the study area result in moored boat motions of variable amplitude. For typical/ambient conditions these motions are generally of lesser amplitude than those caused by marine traffic, as observed in this study. More severe or extreme weather conditions, however, can result in extreme boat motions and impact to infrastructure, which have not been the focus of this study.
- The wave climate of the Williamstown Maritime Precinct is further degraded by the frequent occurrence of wake and surge generated by vessel transits through and around the study area, with wave heights that at times exceed those recommended in the Standard (i.e., 0.15m for “beam” seas and 0.3m for “head” and “oblique” seas).
- Wake and surge generated by vessels transiting through and around the study area were analysed, using the measured data to characterise the wave properties close to the source vessels (where the wake is generated) and the affected area (i.e., marinas, yacht clubs and public piers). It was found that different vessels produce a distinctive wake pattern or “signature” at the source, with four types of vessels characterised: 1. Fast ferries (i.e., catamaran design), 2. Large (commercial) ships with deep draught (e.g., cargo, tanker, cruise ship, etc), 3. Tugs, and 4. Small to medium motorboats (not included in other categories). However, despite distinctive wake signatures of the various vessel types at the source, the properties of the propagated wake waves observed in the affected areas are not too dissimilar, which is attributed to the physics of the wave propagation process. In practical terms, this means that wake and surge from different vessel types affect the study area in a similar way.
- Expanding on the detection of ‘wave, wash and surge’ events, the acceleration data collected from the boat motion sensors was further analysed using a dynamic threshold algorithm. This confirmed the frequent occurrence of ‘surge’ boat motions that have been reported by the local stakeholders prior and during this study. Peak accelerations recorded during the surge motions were between 1.5 and 2.0m/s2. The data analysis indicated that these surge motions occurred in the vast majority of the detected events, in conjunction with the roll angular motions, and hence these surge events had already been accounted for in the catalogue of events previously developed during Stage 2.
- Looking at the timeseries of properties of propagated wake wave package and the response motions of moored boats measured, it is inferred that the surge motions are initiated by the leading waves of the propagated package, which are characterised by having smaller wave height but larger wavelength and period (i.e., a relatively longer wave that travels faster in the water). In contrast the subsequent waves in the propagated package have larger wave height but smaller wavelength and period (i.e., relatively shorter, and steeper waves), which in turn are associated with initiation and prolongation of the angular (e.g., roll and pitch) motions.

Based on the two mitigation strategies identified as viable in the previous stage of the study, namely, “Reducing the generation of wake as the main cause of the events, i.e., operational control measures, such as managing vessel transit and speed limits” and “Local reduction of effects of the incident waves (including wake waves) on the boats and infrastructure”, a list of 14 potential mitigation measures was prepared with consideration of input from the stakeholders.

The potential mitigation measures were then evaluated and scored using the comparative assessment framework, and then ranked based on the overall scores obtained as a product of the effectiveness (likelihood) and consequence scores. The evaluation and scoring process was further informed and “calibrated” by direct engagement with key stakeholders including government agencies (PV and DoT), local yacht clubs and marinas (Royal Yacht Club of Victoria, Hobsons Bay Yacht Club, The Anchorage Marina, Royal Victorian Motor Yacht Club, Savages Wharf Marina, and Blunt’s Boatbuilders), as well as Port Phillip Ferries. There is an element of overlap in some of the mitigation measures, (namely the speed control / limit of either recreation boats and small to medium commercial boats and the modification of the 5-knot zone) but these were assessed and ranked individually. In general, the comparative assessment results indicate that the “operational control measures” rank higher than the “local reduction of effects” measures. In more detail, the results show:

- The five best ranked measured are: 1. Creation or modification of 5 knot zone, i.e., extend the 5kt speed limit from the foreshore to the channel boundary of the Williamstown channel; followed by 2. Education and enforcement of speed control / limit of recreational boats; 3. Education and enforcement of speed control / limit of Fast Ferries; 4. Wave attenuation at the local marina scale; and 5. Education and enforcement of speed control / limit of large commercial vessels.
- The three worst ranked measures are: 13. Spacing boat berths within the local marinas (this measure is considered not viable by the local marinas and yacht clubs, based on their direct feedback); 12. Repair, replacement and maintenance of joints / piles in marinas’ infrastructure, e.g., pontoons, jetties (this measure is already part of the maintenance program of the local marinas and yacht clubs, based on their direct feedback); and 11. Education and enforcement of speed control / limit of small to medium commercial vessels (this measure becomes somewhat redundant if the measure ranked 1st is applied). Further, the measure of restriction of vessels was discarded as it was rendered as non-feasible at this point in time (and thus automatically ranked 14th).
- A set of three other measures ranked 8th in a tied ranking, these are: Redistribution of boats within marinas, i.e., large boats moored next to smaller ones; Damping devices, e.g., “rider poles”; mooring springs, etc., aimed to avoid contact; and Improvement of fendering systems, i.e., aimed to minimise impact when contact occurs. These measures have, to some extent, already been trialled / implemented by the local marinas and yacht clubs and found to be of limited effectiveness, based on their direct feedback.

The comparative assessment provides direction regarding the relative effectiveness of each mitigation. The following is a list of recommendations in priority order, with consideration of the overall scores, which account for effectiveness (likelihood) and consequence criteria.

1. Modification, i.e., extension of a 5kt speed limit from the foreshore to the channel boundary of the Williamstown channel, including navigational aids and signage, and an education campaign targeting the main users of this area, namely recreational boats and small to medium sized commercial vessels.
2. Undertake speed controlled trials and route changes on Fast Ferries to test avoiding the critical speeds (e.g., 17-20kt) to determine the best low wake operating conditions for the ferry. Consideration in the trials should be given to rapid versus slow accelerating and decelerating, in line with the vessel design and capacity.

3. Explore implementation of education and enforcement of speed control / limit of large commercial vessels e.g., cargo, tankers, cruise ships in collaboration and engagement with VPCM / Ports Victoria, the Harbour Master, and their team.
4. The marinas, yacht clubs and foreshore business plan for future wave attenuation at a local scale to provide wave protection suitable for each of their facilities.
5. Re-alignment of berths within the marinas (likely to only be feasible if/when marinas are refurbished / upgraded, and may not be viable for all marinas)

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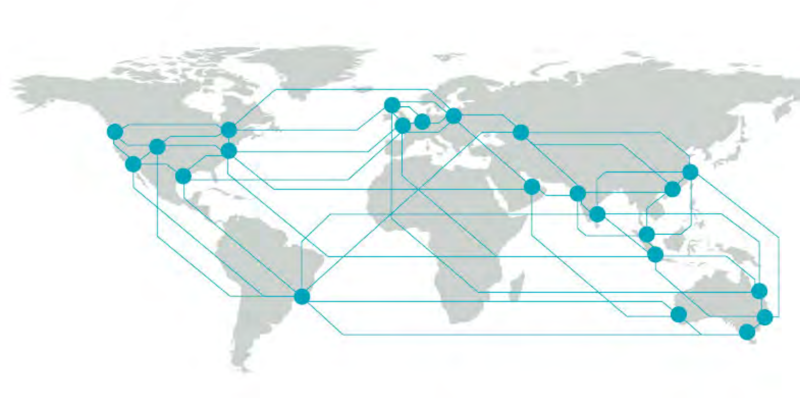

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