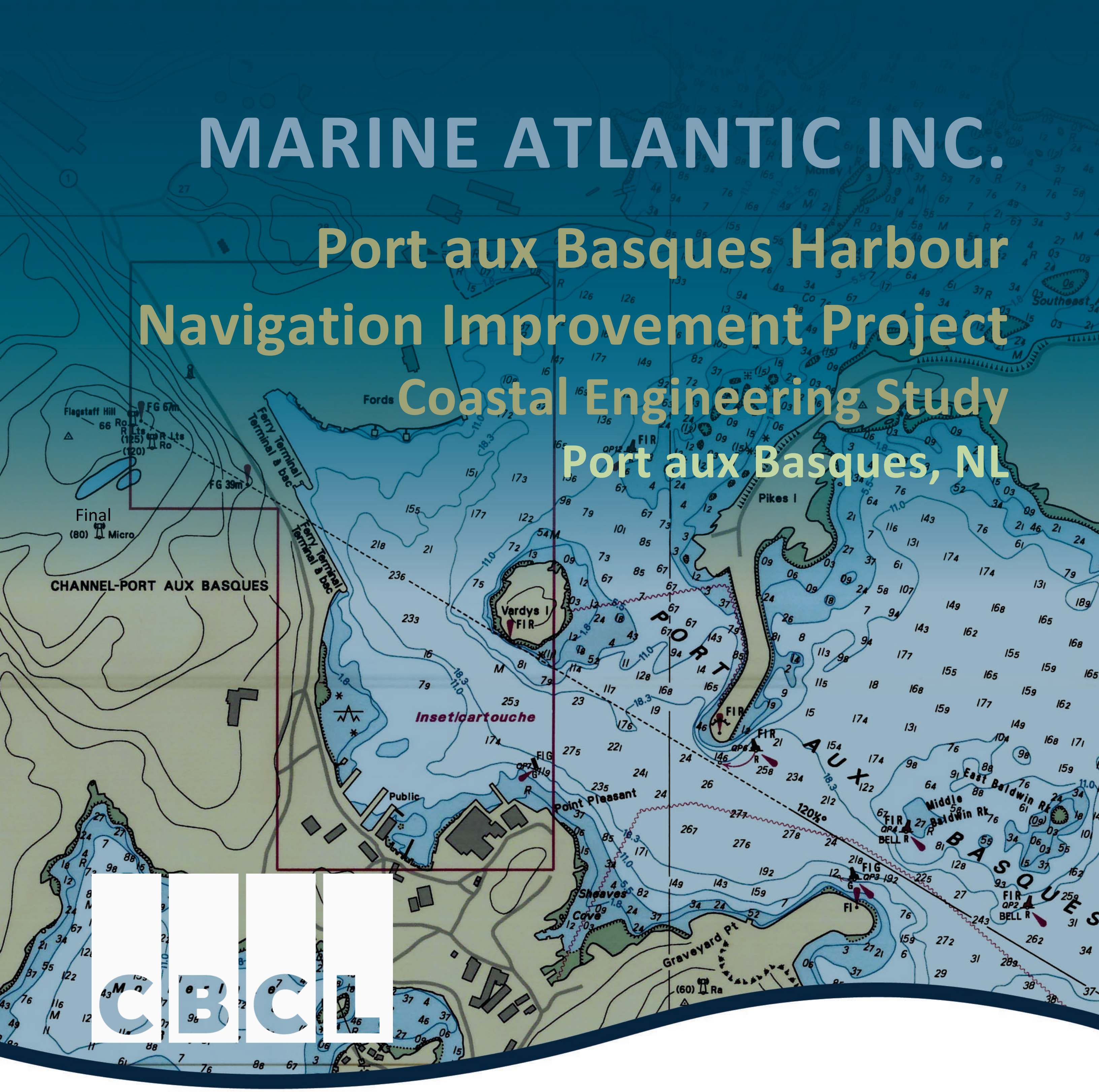

MARINE ATLANTIC INC.

Port aux Basques Harbour Navigation Improvement Project

Coastal Engineering Study

Port aux Basques, NL

CBCL

Marine Atlantic
Marine Atlantique

202479.04 • Final Report • February 2021

	Final Report	L. Campbell	19 Feb 2021	V. Leys E. Gomes
	Draft Report	L. Campbell	4 Nov 2020	V. Leys E. Gomes
Issue or Revision		**Reviewed By:**	**Date**	**Issued By:**

CBCL

Final Report: 202479.04

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19 February 2021

Mr. Steve Giorno
Operations Program Manager
Marine Atlantic Inc.
65 Memorial Drive
Sydney, NS B2A 0B9

Dear Mr. Giorno:

RE: Coastal Engineering Study for Navigation Improvements at Port-aux-Basques Harbour, NL

This report presents the final results for the CBCL Coastal Engineering Study for Navigation Improvements at Port-aux-Basques Harbour. We look forward to your comments.

Yours very truly,

CBCL Limited

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Project No: 202479.04

Contents

Appendices

Chapter 1 Introduction

1.1 Background

Marine Atlantic Incorporated (MAI) is proposing to complete a navigation improvement project within the Port aux Basques (PAB) Harbour, in Newfoundland and Labrador (the Project). The objective of this project is to improve navigation conditions for the MAI fleet with the realignment of the existing approach to eliminate a narrow and shallow area at Baldwin's Rock and the complete removal of Vardy's Island to establish a turning basin within the inner harbour. The construction works primarily involves drill and blast operations with dredge (excavation) and placement of inert rock in a manner that maximizes beneficial use.

As part of the evaluation process for the project, a coastal engineering study was completed to understand the existing coastal environment and changes that may result if the project was implemented. This report presents the study findings which includes the outcomes of stakeholder consultation sessions conducted with the MAI Masters in June and July 2020. As key stakeholders, input from the MAI Captains was solicited to help assess the implications of changes within the harbour as a result of the Project and to confirm our understanding of local physical environmental conditions and operational constraints.

1.2 Objectives

The present Coastal Engineering Study fulfills the following objectives:

- Collect baseline oceanographic data during storm conditions.
- Calibrate hydrodynamic and wave models to existing conditions.
- Assess changes to harbour hydrodynamic and wave regime as a result of the proposed project.
- Assess coastal engineering solutions for beneficial use of dredged material as well as mitigation of potential negative impacts of the project on wave action in the harbour.

Figure 1.1: Departing Ferry passing Pikes Island Breakwater, looking South.
https://www.youtube.com/watch?v=4c4VHkH8_Y4&feature=youtu.be

Chapter 2 Coastal Processes Monitoring

2.1 Harbour Wave and Current Observations

On December 9, 2019, CBCL personnel deployed a series of monitoring equipment in the harbour at Port-aux-Basques, including:

- One (1) Teledyne Sentinel Acoustic Doppler Current Profiler (ADCP) for collecting directional wave and current profiles.
- Four (4) RBR pressure gauges for collecting non-directional wave parameters.

The instrumentation was deployed in the locations presented in Figure 2.1. All instruments were installed using bottom mounted anchor systems in the form of a steel frame for the ADCP (Figure 2.2) and concrete blocks for the RBR gauges (Figure 2.3). All instrumentation was retrieved on 23 January, 2020, for a total of 45 days of data collection. Following retrieval of the instruments, the data was downloaded and post-processed for presentation of results.

The ADCP was deployed at a water depth of 10.5 m behind the breakwater within the harbour. This location as chosen primarily for the following reasons:

- Location outside the navigation channel.
- Observation of currents around Vardy's Island – With the objective of the present study in mind, placing the ADCP behind the breakwater would provide observations of currents within the harbour for improved model calibration results in this area. Outside meteorological conditions for modeling purposes can be obtained through external sources including models and observations.

The ADCP was configured to collect data ensembles at the following intervals:

- Wave data every 30 minutes.
- Current profiles every 15 minutes.

Post-processing of the wave data was completed at an averaging interval of 5 minutes. Measured wave parameters are presented in Figure 2.4 including significant wave height (Hs), peak wave period (Tp), and mean wave direction.

Figure 2.1: Deployed instrument locations in Port-aux-Basque Harbour.

Figure 2.2: ADCP Deployment Setup.

Figure 2.3: RBR Pressure Gauge Anchor Setup.

Table 2.1: Instrument Deployment Locations

	Instrument	Easting UTM21	Northing UTM21	Approx. Depth
1	WG RBR 41486	339542	5271595	6 m CD
2	WG RBR 41485	339250	5271873	7 m CD
3	WG RBR 200081	339099	5271851	6.5 m CD
4	WG RBR 42043	339048	5271601	6 m CD
5	ADCP	339118	5271250	7.3 m CD

Current ensembles were collected every 15 minutes at a 0.3 m bin size up to the water surface. Current profile time series for water speed and current direction through the deployment period are shown in Figure 2.5. Current speeds recorded by the ADCP below the top 1 m of the water surface remain relatively low through the duration of observations, peaking during a wave event on 17 December. The ADCP recorded several events where surficial currents reach at least 0.5 m/s.

To investigate the amount of tidal influence on the measured current speeds and directions, scatter plots were produced for varying depths within the water column. The dots represent the directional components (travelling towards) of the current measurements on a polar scatter plot. On these plots, the more uniform data points are located, the more tidal influence is present in the signal. Conversely, more scattered data points represent a higher influence of wind and wave generated currents near the surface. The polar scatter plots in Figure 2.6 indicate the currents within the lower part of the water column are largely dominated by tidal forcing. Near-surface currents exhibit stronger variability due to influence from winds and waves.

The four RBR pressure gauges were deployed off various wharves and mooring dolphins within the harbour. The gauges were each deployed in water depths ranging from 7.5 to 8.5 m and configured to collect data ensembles every 20 minutes. Figure 2.7 presents time series of wave parameters derived from each wave gauge over the duration of deployment.

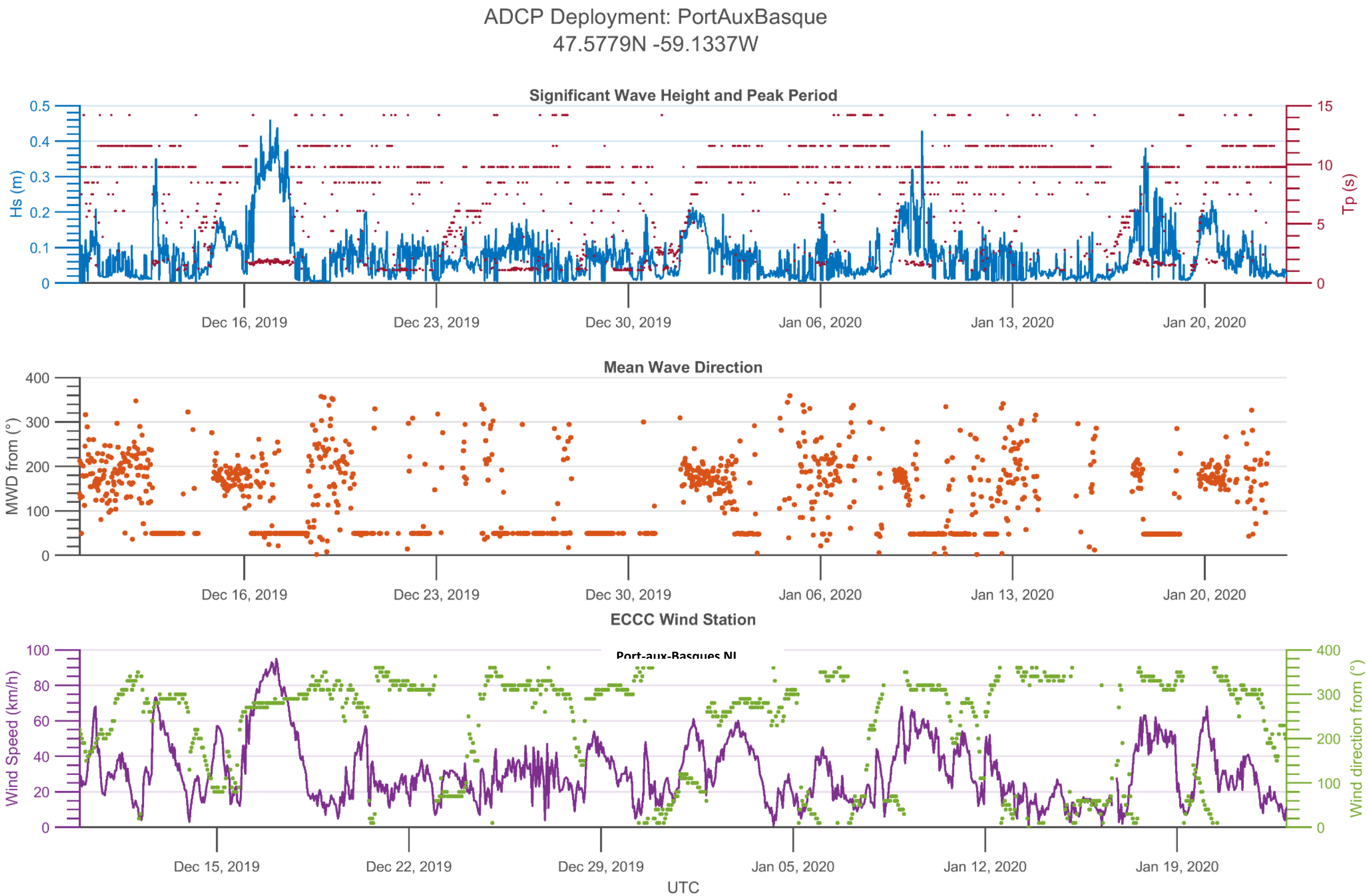


Figure 2.4: Measured Currents, Wave Heights at ADCP and Winds from ECCC Weather Station.

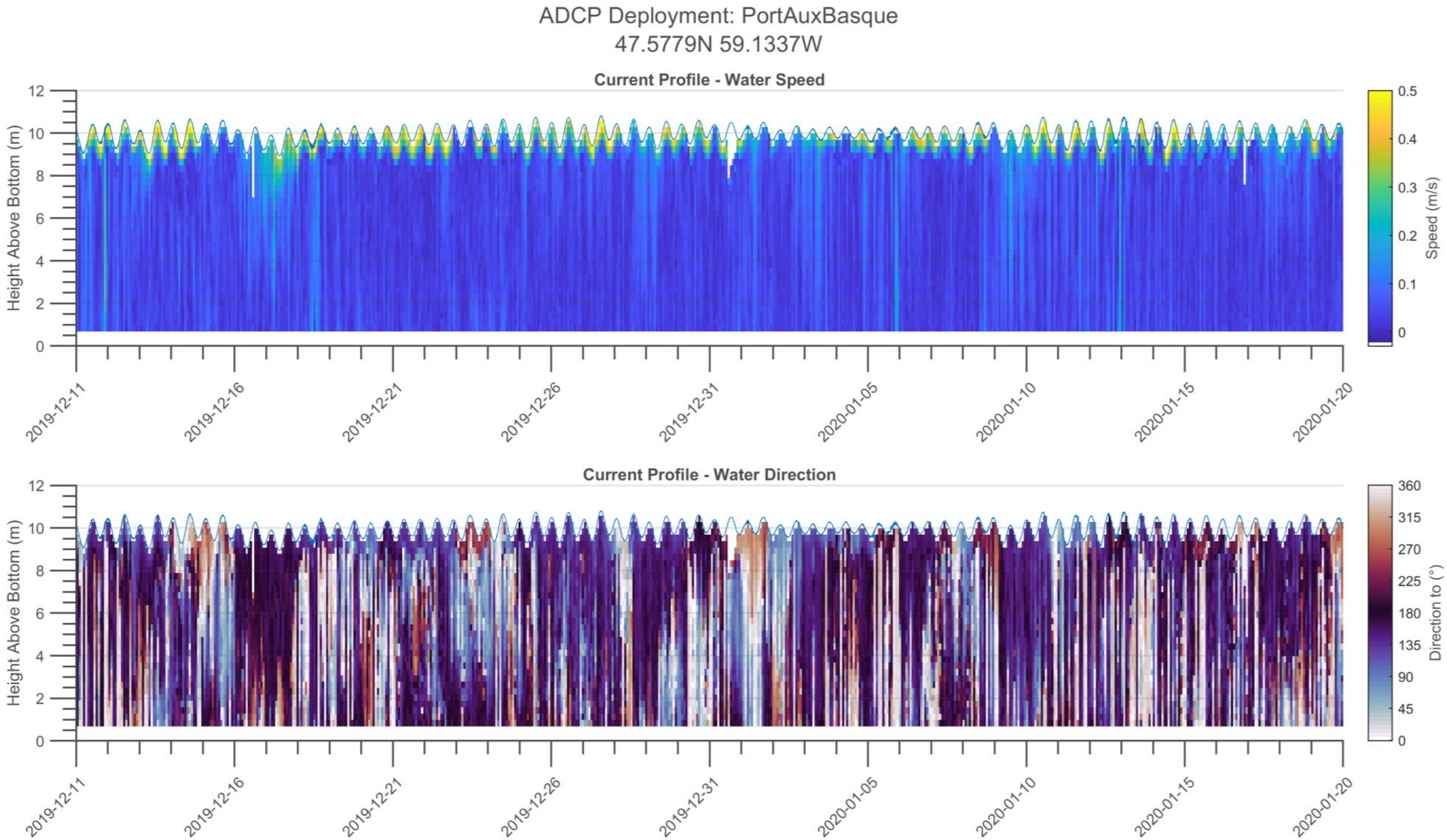


Figure 2.5: Current Profile Time Series of a) Current Speed; and b) Current Direction (to).

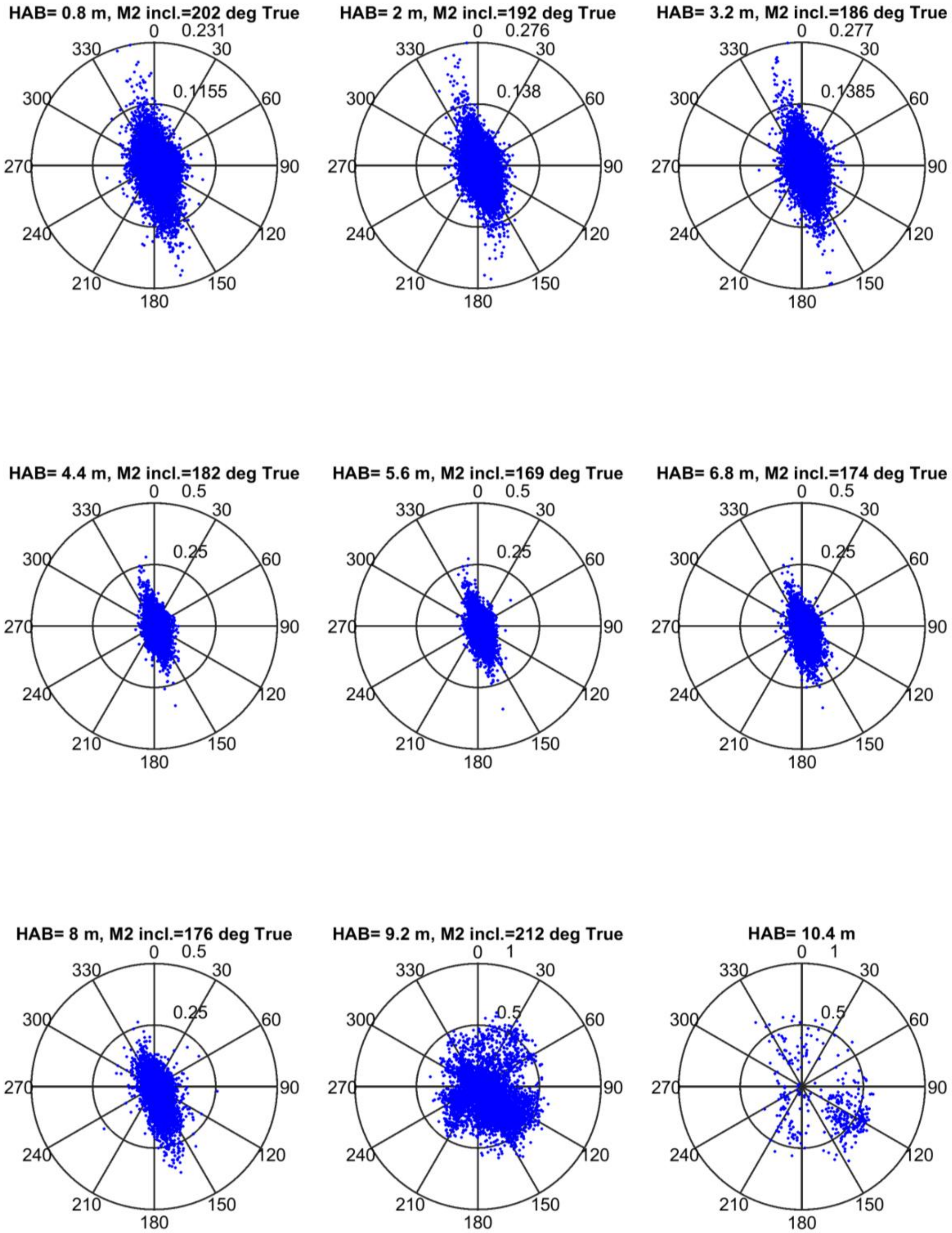


Figure 2.6: Current Scatter Plots at Varying Levels within the Water Column. Level is Referenced as the Height Above Bottom (HAB) up to a Maximum of 10.4 m.

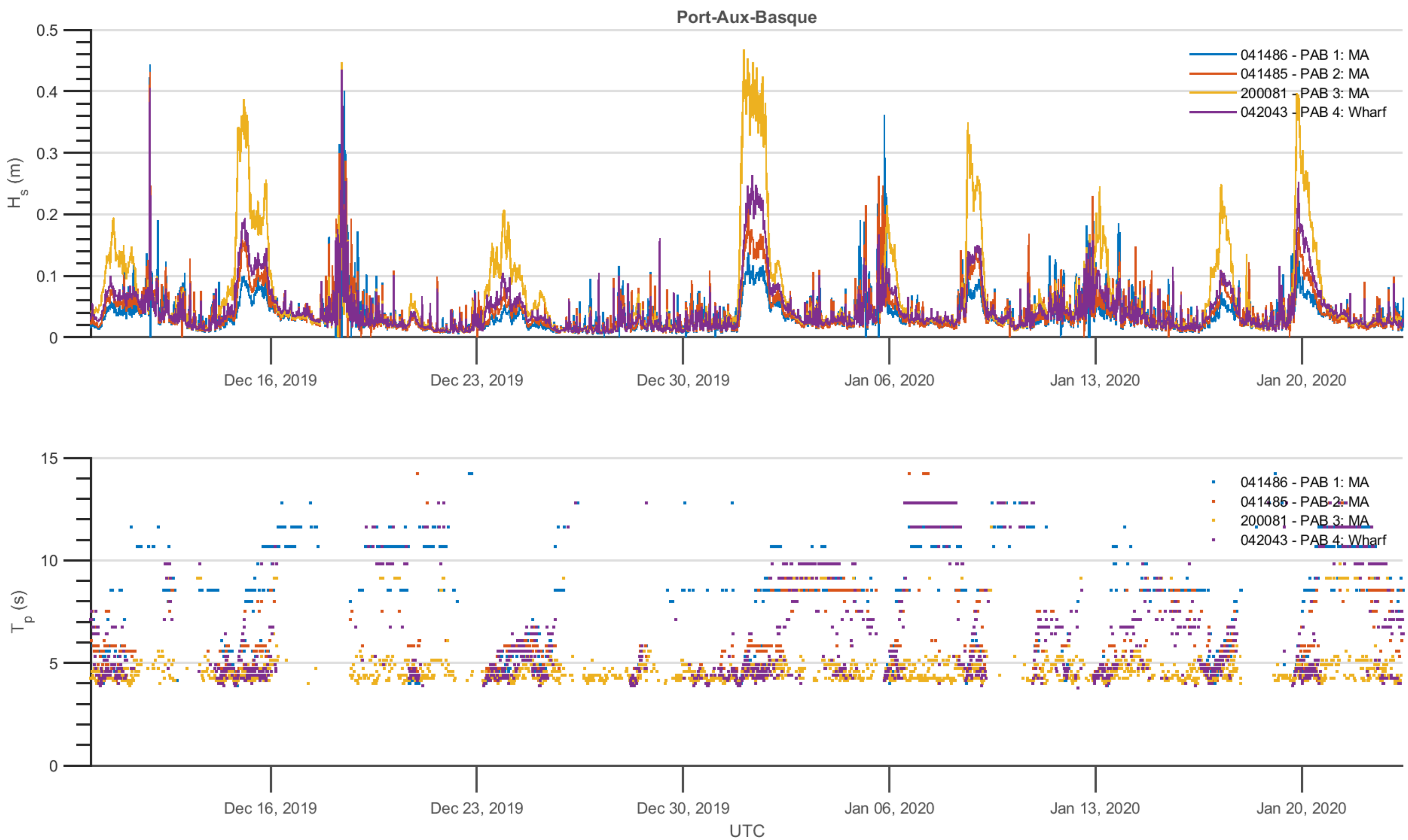


Figure 2.7: Time series of wave parameters measured by pressure gauges; a) Significant Wave Height; and b) Peak Wave Period.

2.2 Wind Observations

2.2.1 Data Sources

Wind observations were obtained from 2 sources:

- Port-aux-Basques weather station operated by Environment and Climate Change Canada (ECCC)
- SmartAtlantic Wave buoy observations offshore Port-aux-Basques at 47° 33.7705' N, 59° 006.0239'W (see www.smartatlantic.ca/station_alt.html?=portauxbasques)

We verified that the data from the two sources are in good agreement. Winds during this period primarily were approaching from the west and northern directions. High wind speeds frequently reaching 50 km/h (14 m/s) were observed (Figure 2.8), with the peak wind speed recorded as 95 km/h (26.3 m/s) at the ECCC station on 17 December 2019.

2.2.2 Wave Events

As shown on Figure 2.8, The most exposed wave gauge (#3) close to the MAI Dock #1 recorded high wave events during instances of sustained easterly winds such as 15 Dec or 1 Jan storms blowing swell into the harbour. The largest wind speed recorded was from the west (17 Dec), which did not cause immediate wave agitation at the dock. A low frequency harbour oscillation was triggered towards the end of the storm on 18 Dec when winds shifted to the NW, resulting in an apparent 0.4 m wave height for which the period was much longer than swell or wind waves. Harbour oscillation is discussed in the next section.

2.2.3 Wind Impact on Ferry Operations

MAI initially communicated to CBCL the following general operational constraints:

- Winds over 35 kts (65 km/hr or 18 m/s) is the current typical limitation in PAB assuming normal vessel operations. The limit is 25 kts (46 km/hr or 13 m/s) if there are vessel issues i.e. thrusters not operational.
- Northwest (NW) and Southwest (SW) directions represent the winds of biggest concern once the ship is inside the harbour, because they tend to blow the ship towards Vardy's Island, particularly as it manoeuvres a 180° turn at slow speed between the island and the dock.
- The vessel turning maneuver to berth vessels is the biggest limitation. Given the very limited room for manoeuvring around the island, there is presently no room for error and the Captains indicated that wind speed over 30 kts are a concern from NW and SW. Departure is less concerning because there are no sharp turns in the trajectory.

The MAI Captains stressed that the above thresholds are only indicative, and operational decisions are made based on the Captains experience dealing with a complex array of parameters involving ship, wind conditions in the harbour, as well as offshore wave and wind conditions. MAI provided CBCL operational records for Dec 2019-Jan 2020, including the timing of 9 weather related delays or cancellations. The events were plotted alongside wind observations from the ECCC weather stations (Figure 2.8). There was one instance of cancellation coinciding with observed wind speed between 25 and 30 kts. All other instances were for wind speed exceeding 30 (or 35) kts. Long-term wind trends pertaining to operational thresholds are discussed further in the following section.

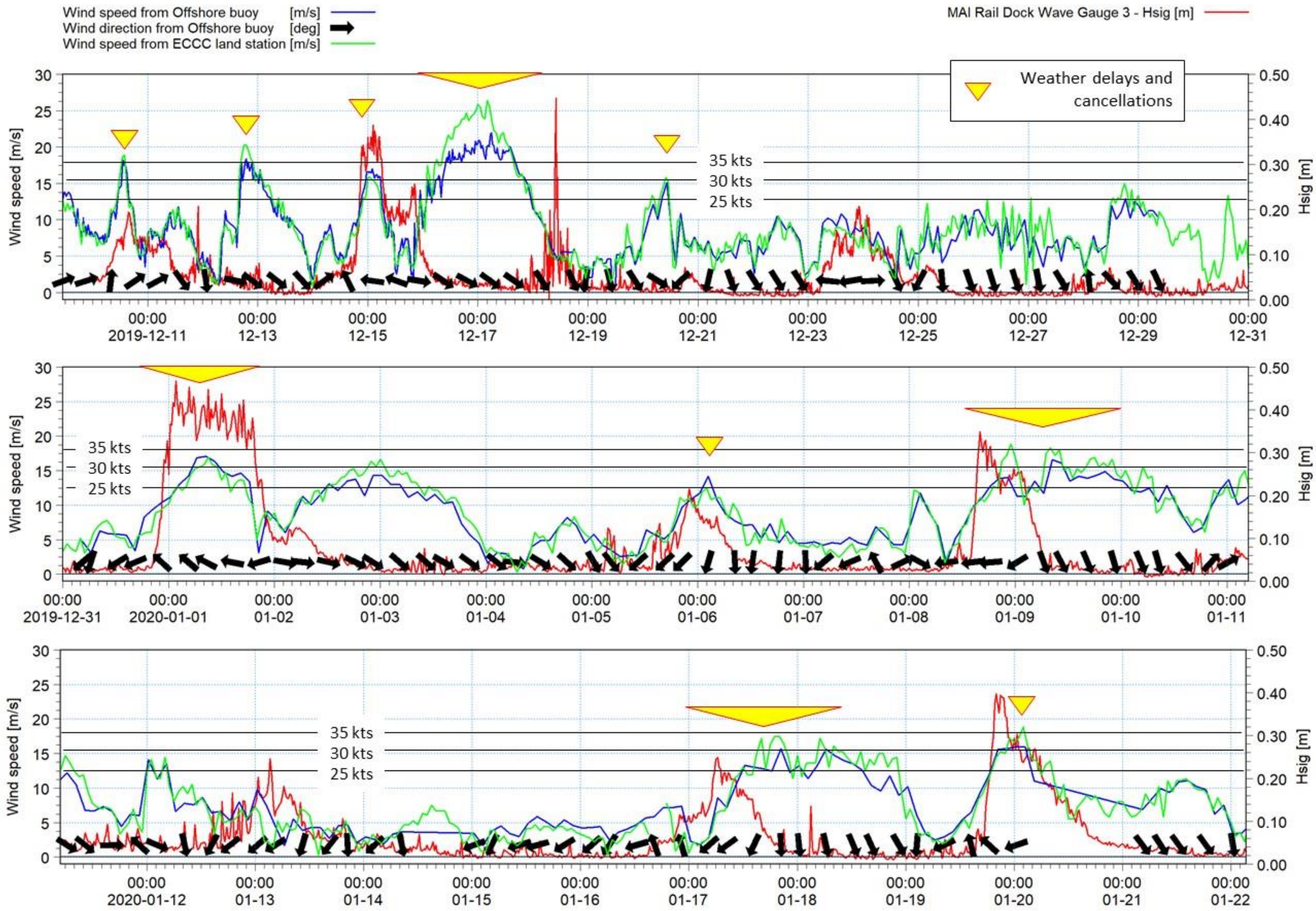


Figure 2.8: Observed Wind Speed, Direction and Wave Heights vs. at MAI Dock No. 2 (Wave Gauge #3).

2.3 Long-Term Wind Trends

2.3.1 Historical Trends

Summary statistics from the offshore wind and wave climate from the MSC50 hindcast (1954-2018) are provided in Appendix A. We verified that the MSC50 data is in good agreement with the recent SmartAtlantic wave buoy observations (2013-present) off Port-aux-Basques. Wind roses based on the long-term MSC50 offshore wind hindcast (Figure 2.9 and Appendix A) show that the strongest winds are from the WNW, which is a limiting factor for navigation as outlined in Section 2.2.3. Annual and seasonal exceedances of wind speed were investigated for the historical period 1954-2018 covered by the MSC50 hindcast. Results are presented in the following Figures, with the following conclusions:

- There is a clear annual trend towards increase frequency of wind speed between 20 and 40 kts (Figure 2.10 and Figure 2.11);
- The increasing annual trend is stronger for the higher range of wind speeds examined (30-40 kts) than for the lower range of wind speeds (15-25 kts);
- The annual trend is driven by stronger trend in the fall and particularly winter seasons; and
- The increasing trend for the 30, 35 and 40 kt threshold occurs predominantly in from the SW, W and NW directions (Figure 2.12), which correspond the most sensitive directions for Ferry operations.

2.3.2 Climate Change Outlook

The uncertainty associated with wind in climate modelling is high. The IPCC indicates that winds are modelled with "low confidence" (IPCC, 2013). Processes impacting winds are complex, with different processes having contrasting effects. Changes are therefore difficult to project and are anticipated to be non-linear. The main processes driving potential changes in winds are as follows:

- A change in the location of regional storm tracks (e.g., northward movement of extratropical cyclones);
- The displacement and intensification of mid-latitude westerlies; and
- The potential increase in local convection caused by heating of the ground surface.

Studies have indicated wind gusts are expected to increase with climate change. For NL, a study by Cheng and Lopes (2014) suggests a possible increase in gusts of 20-40% to the period 2080-2100 for gusts of 70 km/hr (38 kts). Gusts above the highest thresholds (90 km/hr or 48 kts) are expected to increase the most (up to 100%). While future wind climate projections come with high uncertainty, recent trends point to an increase in high wind conditions. The possibility of a stormier future should be accounted for in infrastructure planning and design. The proposed navigation project is intended to increase MAI operations' resiliency to storm conditions.

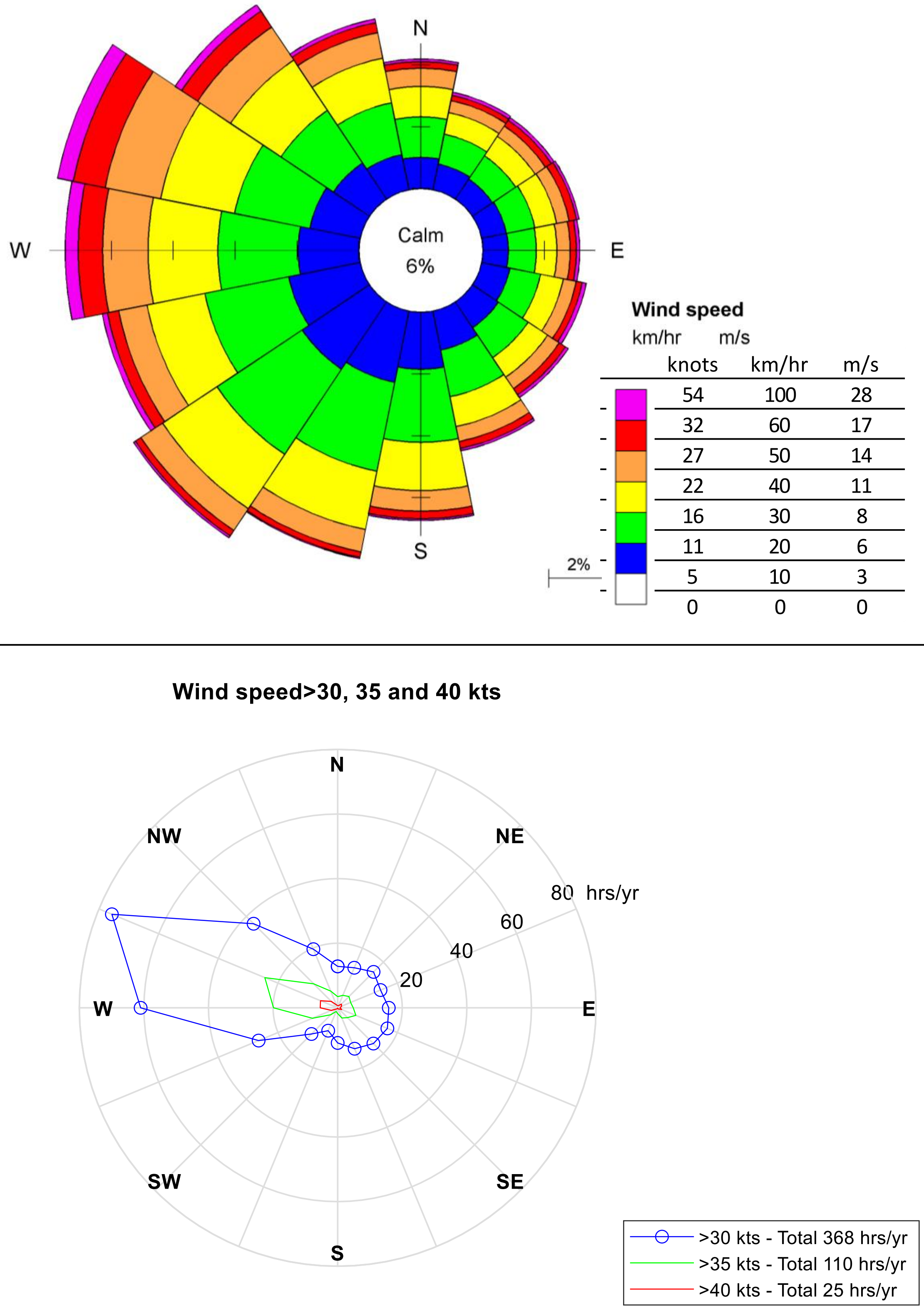


Figure 2.9: Annual Wind Directional Statistics with Percent Occurrence (top) and Exceedence (bottom)
Typical Ferry Navigation Thresholds are 30 to 40 kts

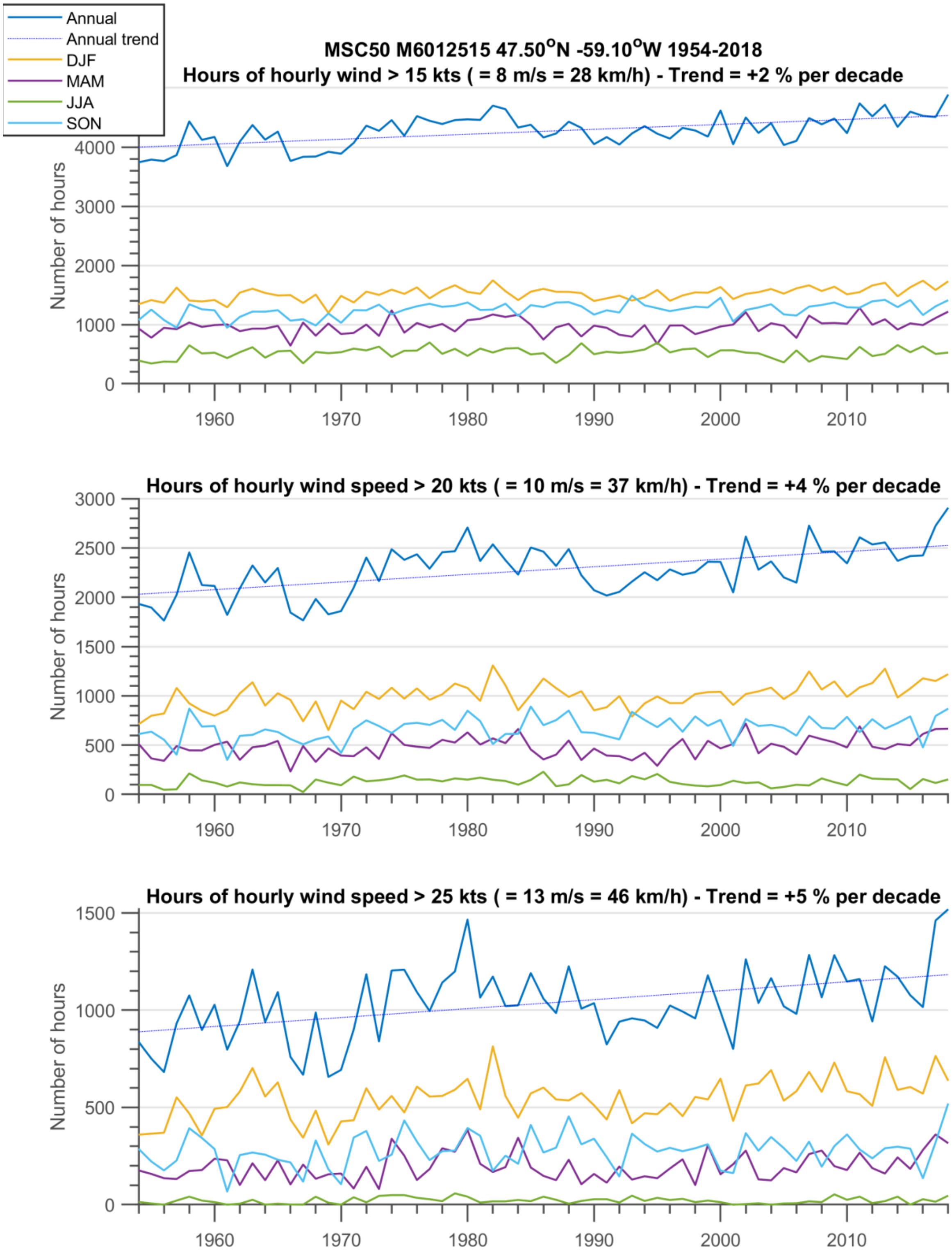


Figure 2.10: Annual and seasonal historical exceedances for hourly wind speed of 15, 20 and 25 kts at 10 m height above sea level from MSC50 hindcast.

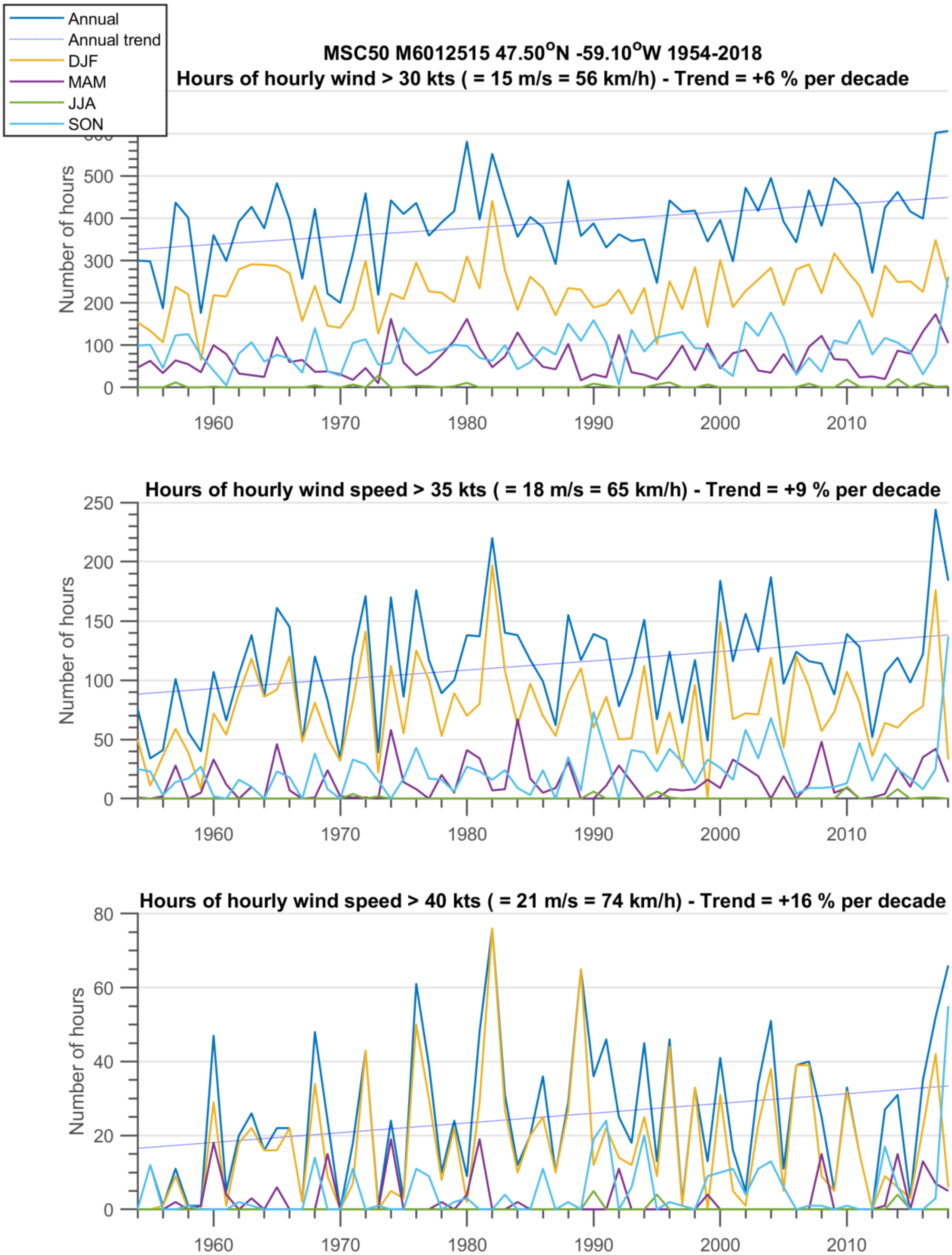


Figure 2.11: Annual and seasonal historical exceedances for hourly wind speed of 30, 35 and 40 kts at 10 m height above sea level from MSC50 hindcast.

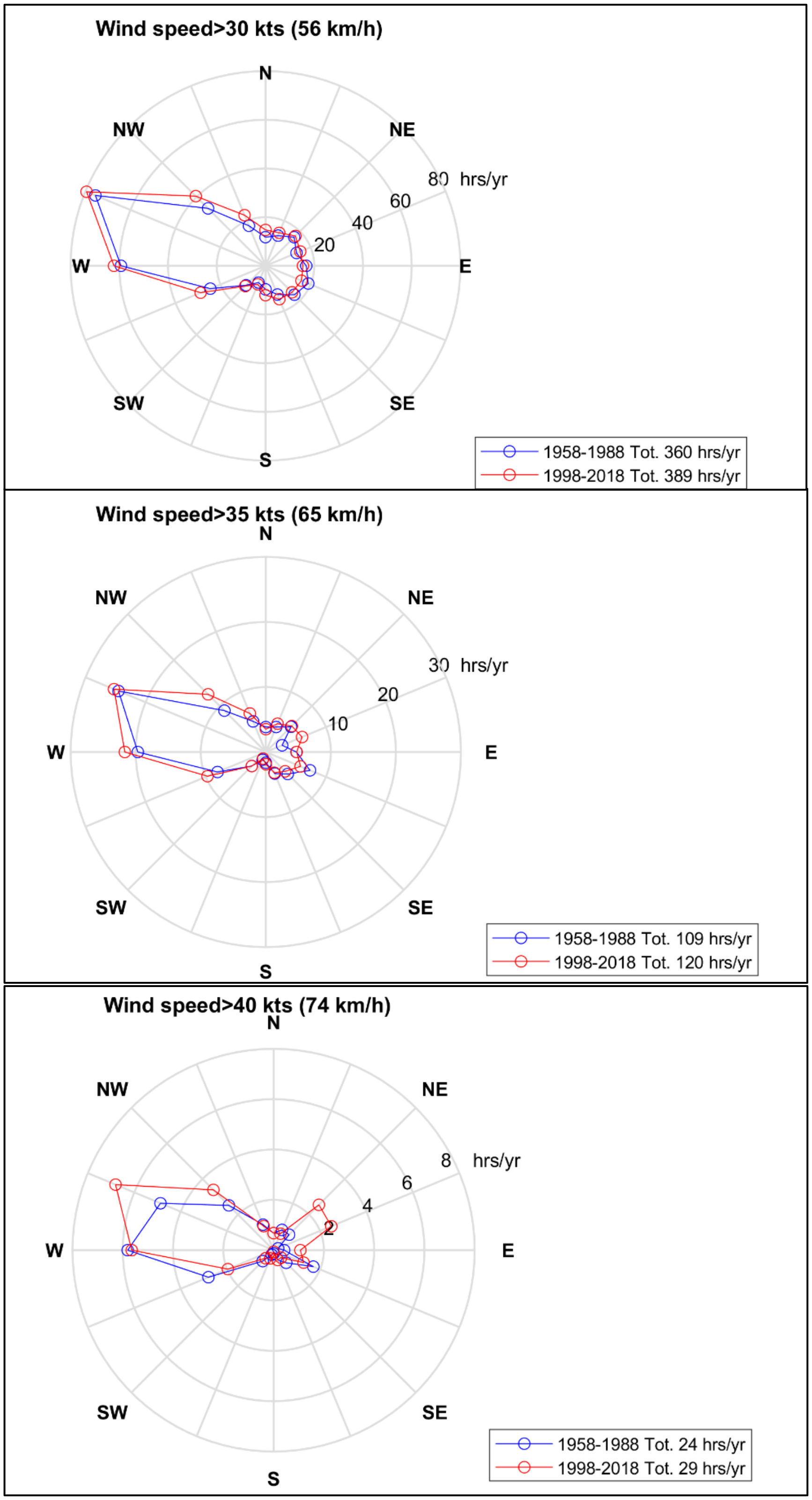


Figure 2.12: Historical Trend in Directional Distribution of Hourly Wind Speed greater than 30, 35 and 40 kts (top, middle, bottom plots).

2.4 Water Levels

2.4.1 Tides and Storm Surge

A DFO tide gauge has been in operation at Port-aux-Basques since 1959. Local astronomical tides are semi-diurnal, with two high waters and two low waters occurring during each 25-hour lunar day. Tidal levels are listed in Table 2.2. Extreme values of total water levels were derived from analysis of storm peaks over the measurement period (CBCL, 2014).

Table 2.2: Water Levels in PAB

Extreme Values by Return Period [years]	m Chart Datum	m CGVD28	m CGVD2013
100-yr	2.74	1.64	1.14
50-yr	2.67	1.57	1.07
10-yr	2.52	1.42	0.92
5-yr	2.46	1.36	0.86
2-yr	2.37	1.27	0.77
1-yr	2.31	1.21	0.71
Tidal Elevations as Published by CHS			
Higher High Water Large Tide	2.0	0.9	0.4
Higher High Water Mean Tide	1.7	0.6	0.1
Mean Water Level	1.2	0.1	-0.4
Lower Low Water Mean Tide	0.6	- 0.5	-1.0
Lower Low Water Large Tide	0.3	- 0.8	-1.3

2.4.2 Harbour Oscillation (Seiche)

An internal harbour oscillation triggered by storm activity, i.e. seiche, is evident in the tide gauge data during the monitoring period. Its typical amplitude during a storm is 0.2 to 0.4 m, with a typical period of 20 min (Figure 2.13). The seiche affects the inner area of the harbour behind the breakwaters.

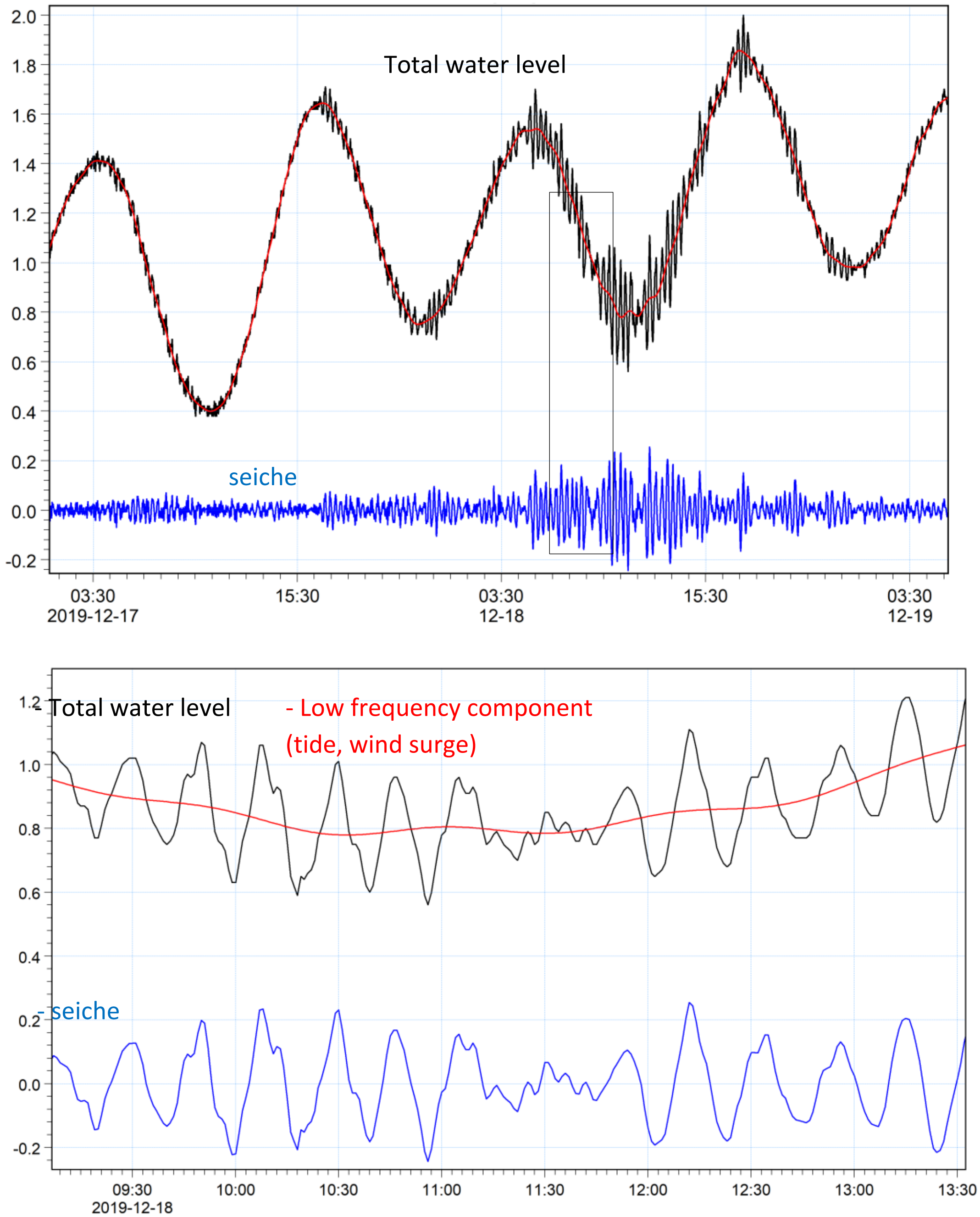


Figure 2.13: Sample DFO Tide Gauge Observations during Monitoring Period Showing Harbour Seiche.

2.5 Seiche Currents

The seiche has implications in terms of currents throughout the harbour. This is evidenced in the field observations (Figure 2.14):

- Calculated significant wave height Hs in the wave gauges is high (0.4 m) on Dec 18 when the wind is coming from the land direction (Northwest). The ‘Hs’ indicated by the wave gauge instruments is actually a low-frequency seiche amplitude, not wind waves.
- High oscillating currents in ADCP on Dec 18. The strongest current velocities observed at the site are due to the seiche. The tidal component of the currents is negligible. This is expected,

because the relatively small area of Port-aux-Basques Harbour requires a relatively steep water level variation in order to generate significant currents in and out of the entrance. The water level gradients are steeper with the seiche than with the tide, hence the stronger currents.

2.6 Summary of Observations

Port-aux-Basques Harbour is relatively protected from coastal storms, which has allowed the development of the small craft harbour and Ferry Terminal. The observations collected during a stormy period from 9 Dec 2019 to 23 Jan 2020 indicated:

- High wave agitation at the docks (in excess of 0.3 m significant wave height) during periods of southwest storm winds, as well as Northeast wind wave generated across the harbour.
- Presence of low-frequency harbour oscillation (seiche) triggered during storms. The seiche manifests itself a long-period wave 0.2 to 0.4 m high, with a typical period of 20 min. This causes peak current speeds in excess of 0.2 m/s at the current meter observation site. Such speeds are still relatively low, albeit much higher than the tidal component of the current with is negligible inside the harbour.

To complement the observations collected for the 2019-2020 monitoring period, long-term trends were examined for high wind speed, which is the governing parameter for Ferry operations. Recent trends point to an increase in high wind conditions. The possibility of a stormier future should be accounted for in infrastructure planning and design. The proposed navigation project is intended to increase MAI operations' resiliency to storm conditions.

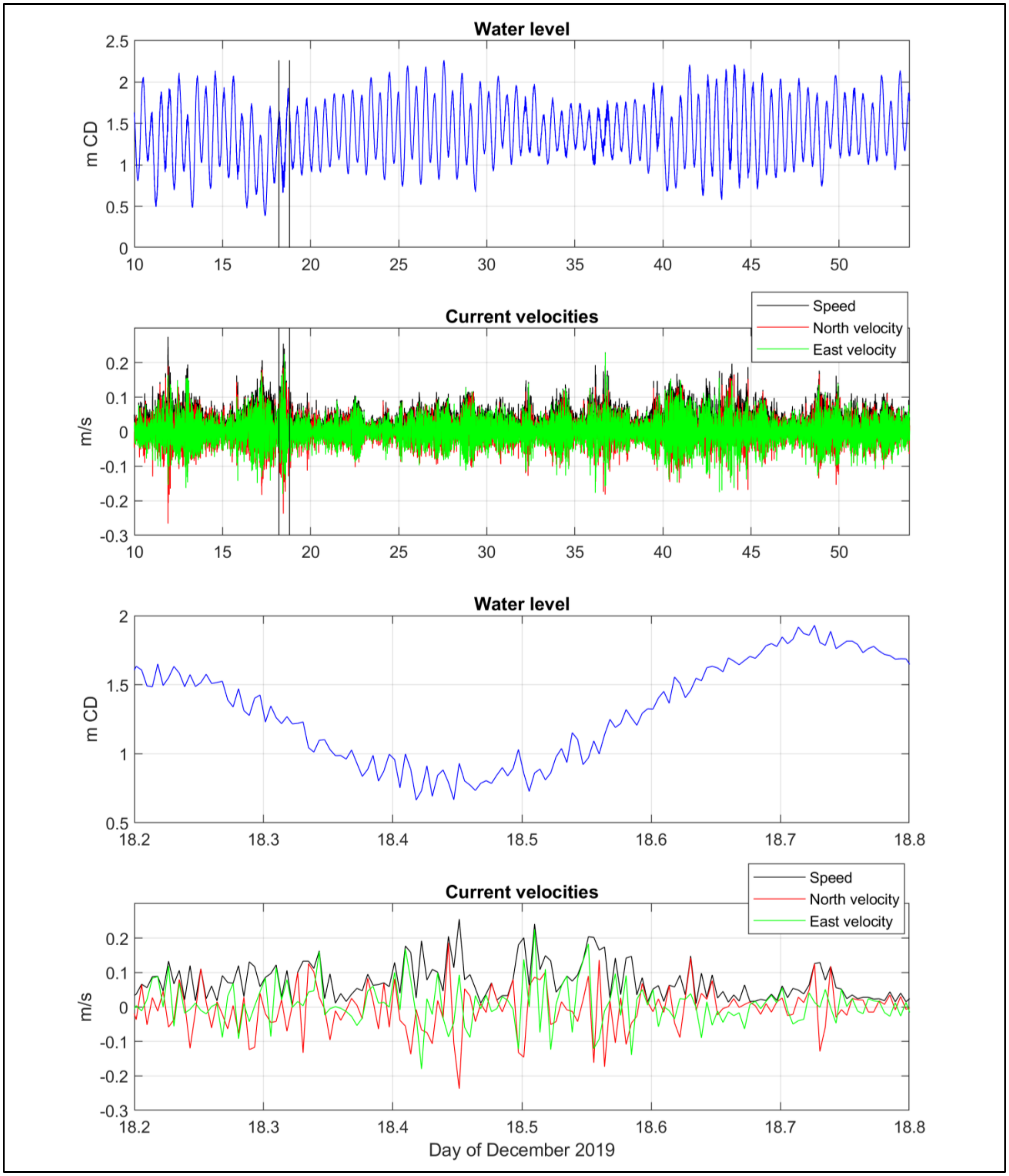


Figure 2.14: Water Levels and Depth-Average Currents from ADCP during NW Wind Storm Triggering Harbour Oscillation.

Chapter 3 Modeling of Existing Conditions

3.1 Methodology

CBCL's DHI MIKE21 model used in previous studies was updated and calibrated based on the recent field measurements. This model is a regional model that resolves hydrodynamics (HD) and spectral waves (SW), with high resolution on the harbour. The model was prepared by first creating a bathymetric grid. The grid contained the newly prepared multibeam bathymetric data from the survey completed by Canadian Seabed Research (CSR) for Marine Atlantic, in addition to nautical charts in locations without survey data. The model uses a triangular unstructured mesh, which is beneficial due to its ability to resolve the nearshore with smaller grid cells relative to deeper, offshore areas (Figure 3.1).

Additional high-resolution harbour wave modelling used a Phase-Resolving model to investigate wave agitation within the basin associated with swell waves. Model type and application areas are summarized in Table 3.1, with associated key inputs and outputs.

Table 3.1: Summary of Models Applied in the Present Study

Area of Application	Model	Objective	Inputs & Calibration	Outputs
Regional wave transformation, Wind wave growth.	Spectral wave model DHI MIKE21 SW.	Nearshore transformation and wind wave growth up to harbour entrance.	MSC50 hindcast, wave gauge and wind observations	Wave climate at harbour entrance, NE wind waves.
Harbour wave agitation from swell and long waves.	Phase-resolving wave model DHI MIKE21 BW.	Evaluate swell agitation and local reflection against wharves	Wave climate at harbour entrance and wave gauge observations.	Harbour wave agitation
Water levels and tidal currents.	Hydrodynamic model MIKE21 HD.	Water levels and current speed.	Water level observations from ADCP and DFO tide gauge	Water levels and currents at the harbour.

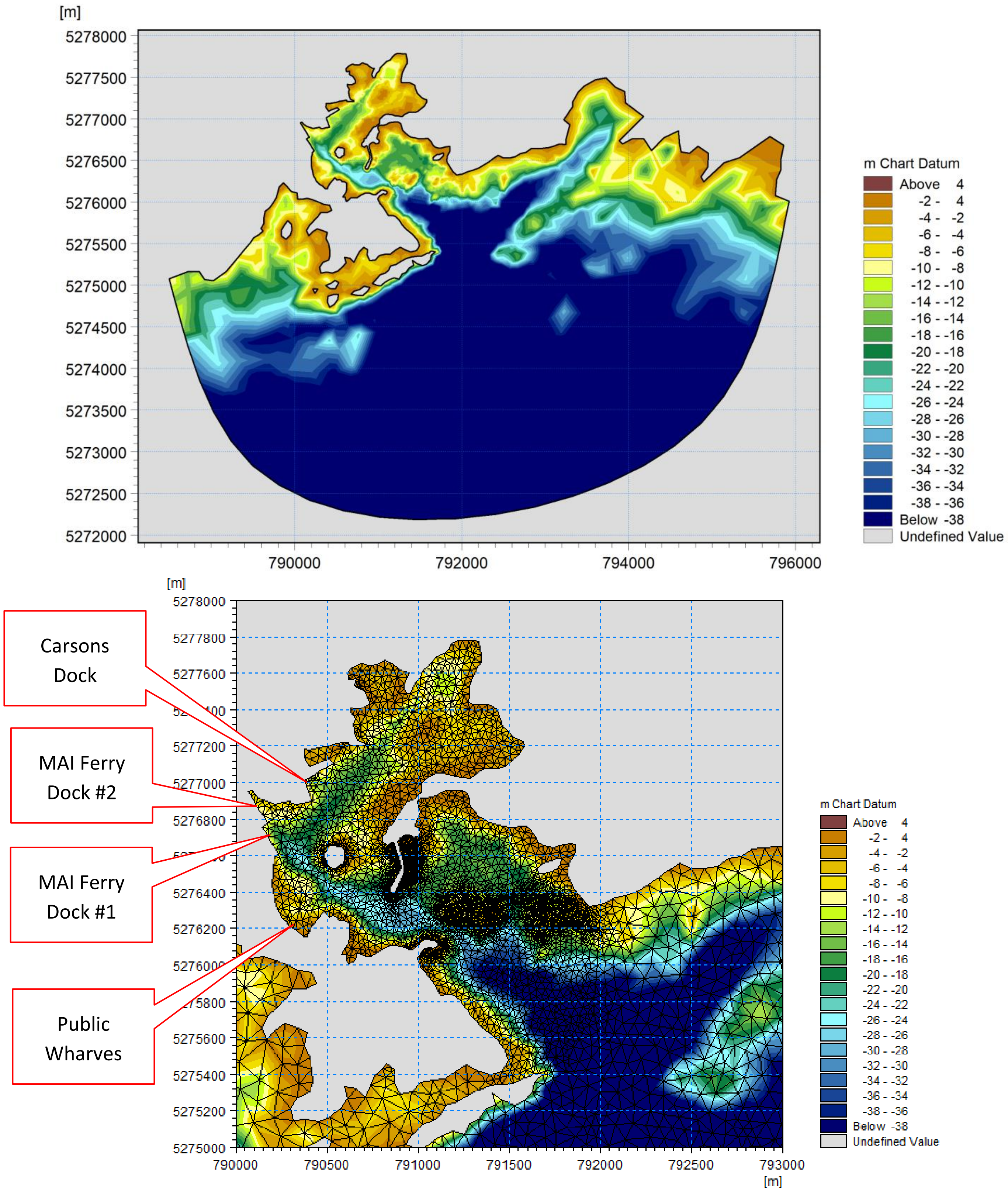


Figure 3.1: MIKE21 Model Domain with High-Resolution Mesh on Project Area.

3.2 Hydrodynamic Model

3.2.1 Water Level Boundary Conditions

To generate offshore water level boundary conditions, Port-aux-Basques tide gauge observations were modified to include the full tidal signal, plus the seiche component scaled down to 4% of its amplitude observed by the tide gauge in the harbour. The boundary scaling factor of the seiche was a calibration parameter, determined to obtained a balanced model representation of the water levels and currents in the HD model.

3.2.2 Calibrated Model Results

Modeled versus observed water levels and currents are shown in Figure 3.2 and Figure 3.3, respectively. The primary objective of the HD calibration is to get an acceptable representation of currents. The general range of modeled current speed is within 10% of observations, based on mean current speed for Dec 15-19, which is an appropriate metric for measuring the general amount of current energy in the system. The model correctly reproduces the 20-min seiche amplitude and its associated water level and current signatures during the largest storm event (Dec 18). The seiche amplitude is somewhat underestimated during calmer periods, likely due to approximations in the wind fields and boundary water levels.

Snapshots of modeled seiche currents (ebb and flood) are shown on Figure 3.4. The areas with moderately higher currents (~0.3 m/s, i.e. 0.6 kts) are predominantly around the breakwater ends, and do not represent a concern for navigability due to the relatively low current speed.

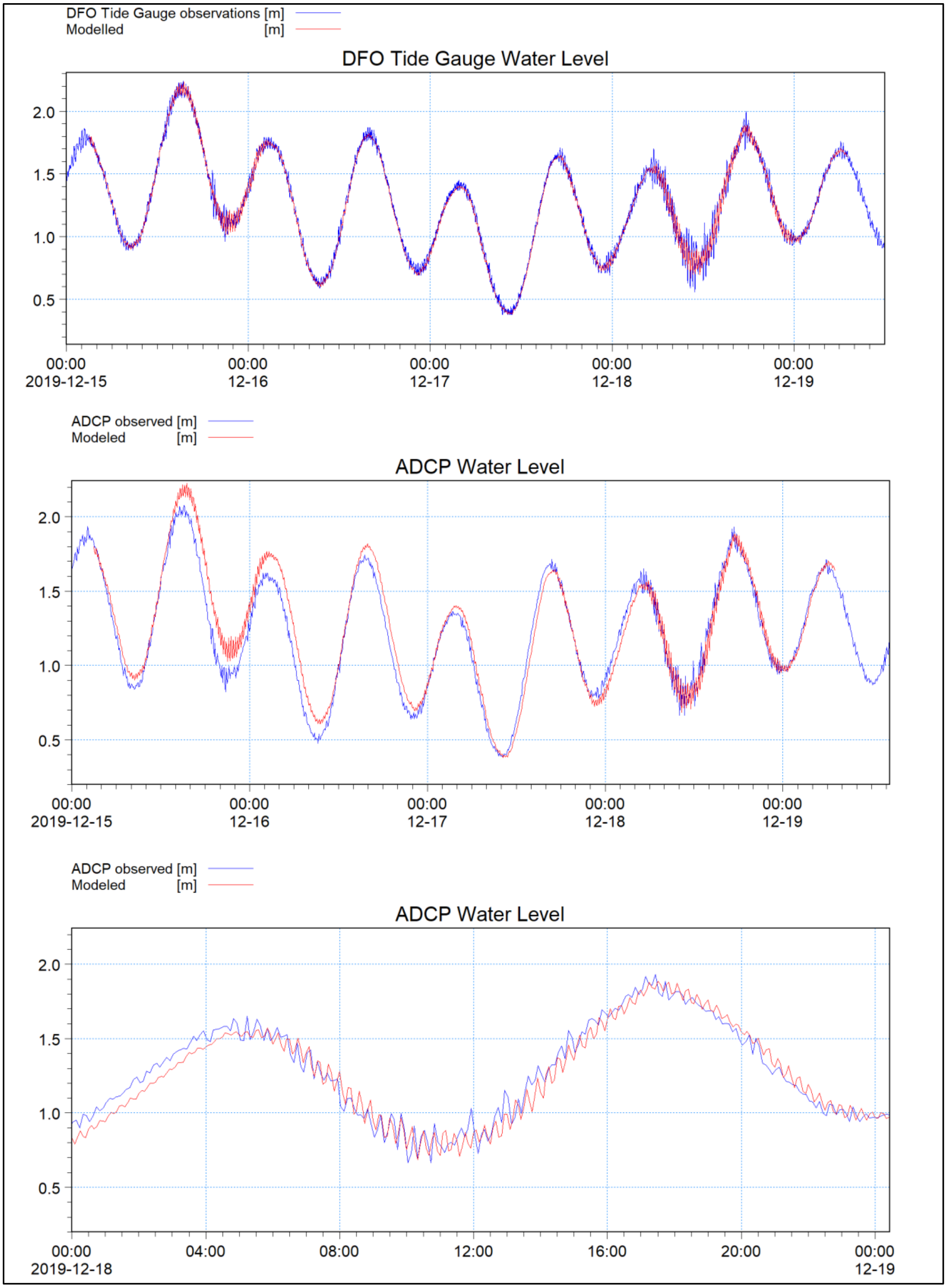


Figure 3.2: Hydrodynamic Model Calibration – Water Levels.

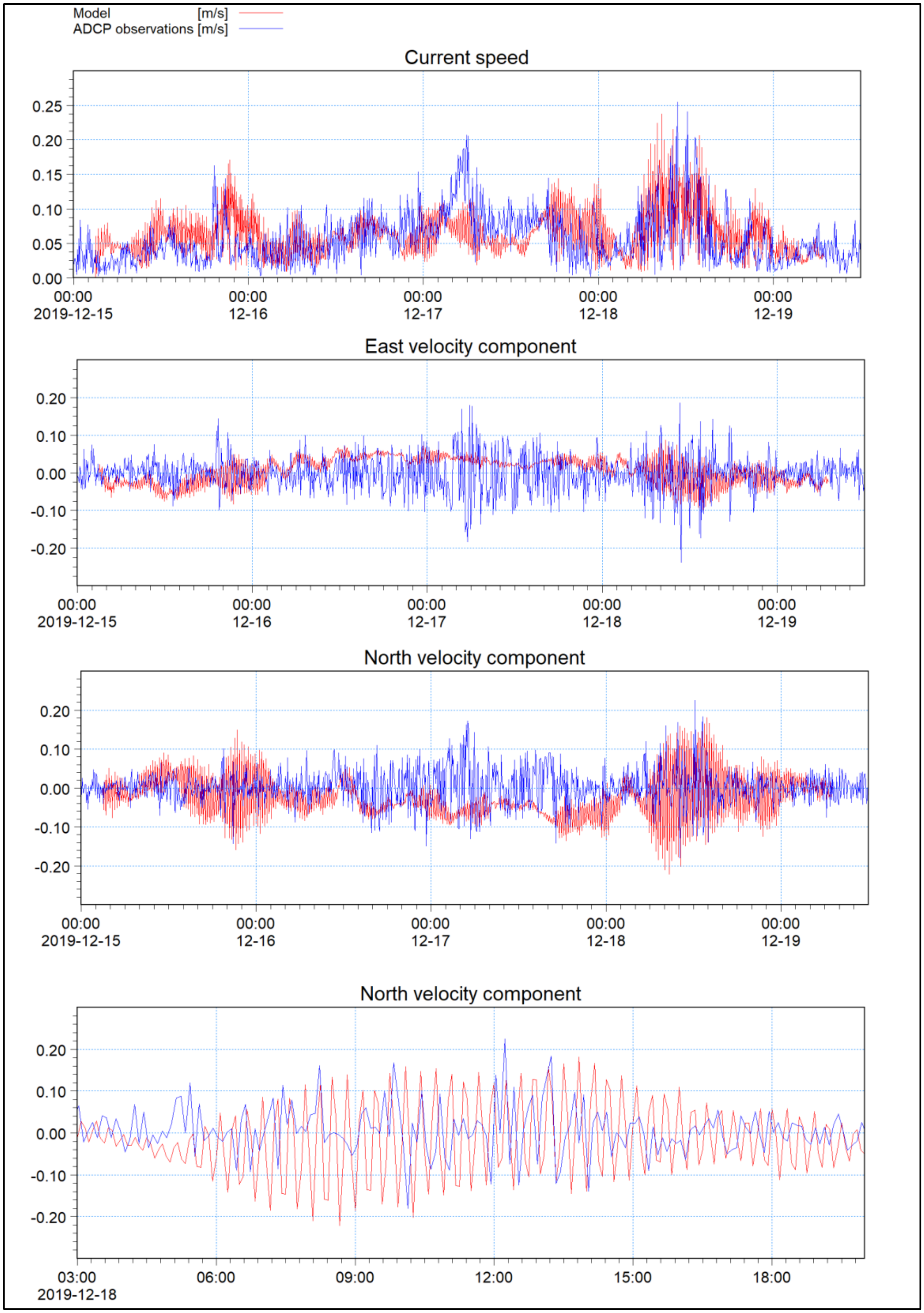


Figure 3.3: Hydrodynamic Model Calibration – Currents.
Model confidence interval is ±10% based on mean current speed.

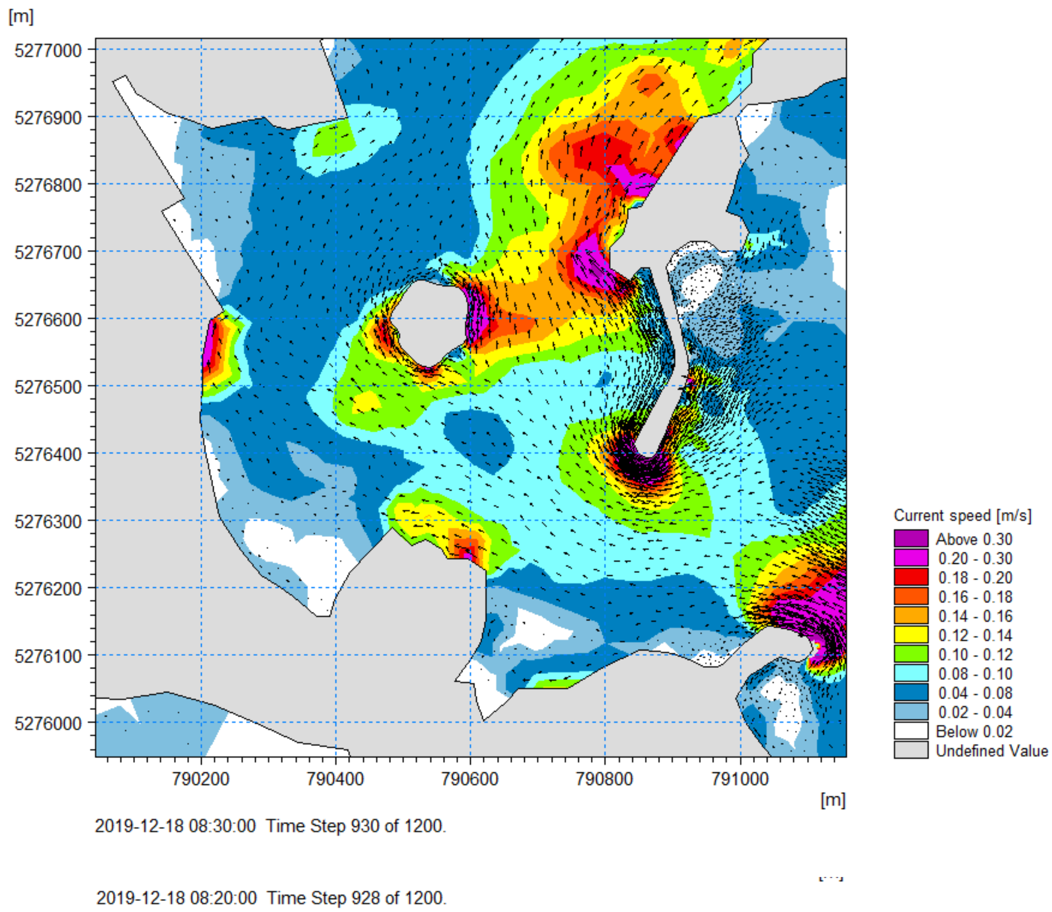


Figure 3.4: Snapshots of Modeled Seiche Currents (ebb-top, and flood-below).

3.3 Wave Models

3.3.1 Regional Spectral Wave Model

Model Description – The computationally efficient MIKE21 SW model was used in fully spectral mode with a quasi-stationary time-domain approach (i.e., steady state). The model simulates the following physical phenomena:

- Refraction and shoaling due to depth variations.
- Dissipation due to depth-induced wave breaking – A typical breaking coefficient of 0.8 was assumed (i.e. the ration of breaking wave height / water depth).
- Dissipation due to bottom friction (a typical bottom roughness of 0.04 m was assumed).
- Dissipation due to white-capping.
- Non-linear wave-wave interaction.
- Wind-wave growth (the uncoupled formulation recommended by DHI for small-scale coastal applications was used).

Boundary Conditions – The offshore wave data was obtained from the ERA5 wave hindcast, which is a dataset containing hourly wind and wave data provided by the European Centre for Medium-Range Weather Forecasts (ECMWF). The ERA5 data provides the hourly significant wave height and peak period over time at an offshore location. Tests were also conducted with offshore observations from the SmartAtlantic wave buoy as boundary conditions. Results between ERA5 and buoy boundary conditions were found to be comparable. However significant variation in the buoy's wave directionality was found to somewhat increase calibration uncertainty, hence the choice of ERA5 data.

Calibration - The regional spectral wave model was calibrated for 2 major storms on Jan 01 and Jan 20 2020. With boundary conditions described previously, the wave model was calibrated to the observations from the wave gauge data and the ADCP by adjusting two parameters:

- the surface wind stress coefficient of Charnock (1955), to a value of 0.005 (this is reduced from previous CBCL desktop modeling studies where we had used the default 0.01); and
- the reflection coefficients from the coastline, adjusted to 0.4 (for the Ferry Terminal area, this is reduced from previous CBCL modeling where we had used a conservative 0.9 for the vertical wharves).

This provided a reasonable fit to most observations, in particular to the most exposed wave gauge 3 at the end of the MAI Dock No. 1 for the highest wave height recorded on 01 Jan 2020. A snapshot of the model at the peak of this storm is shown on Figure 3.5. Calibration time-series plots are provided in Appendix B.

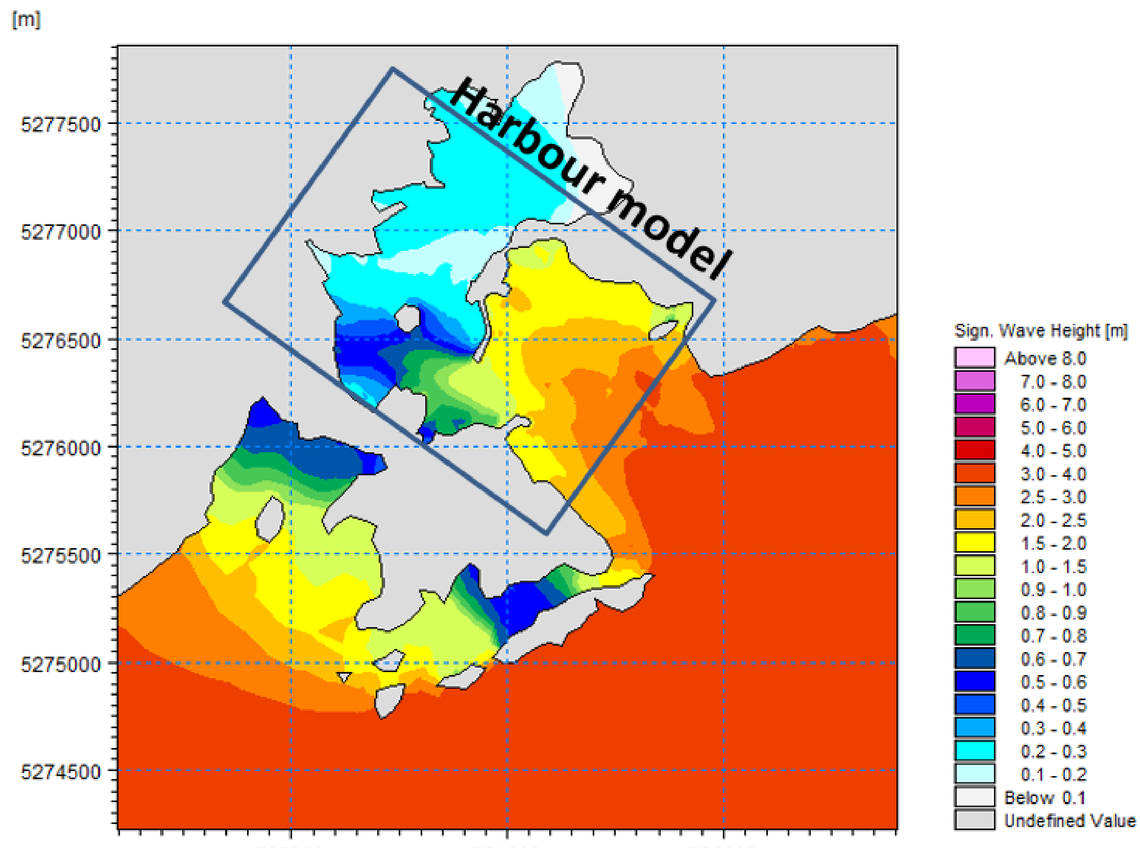


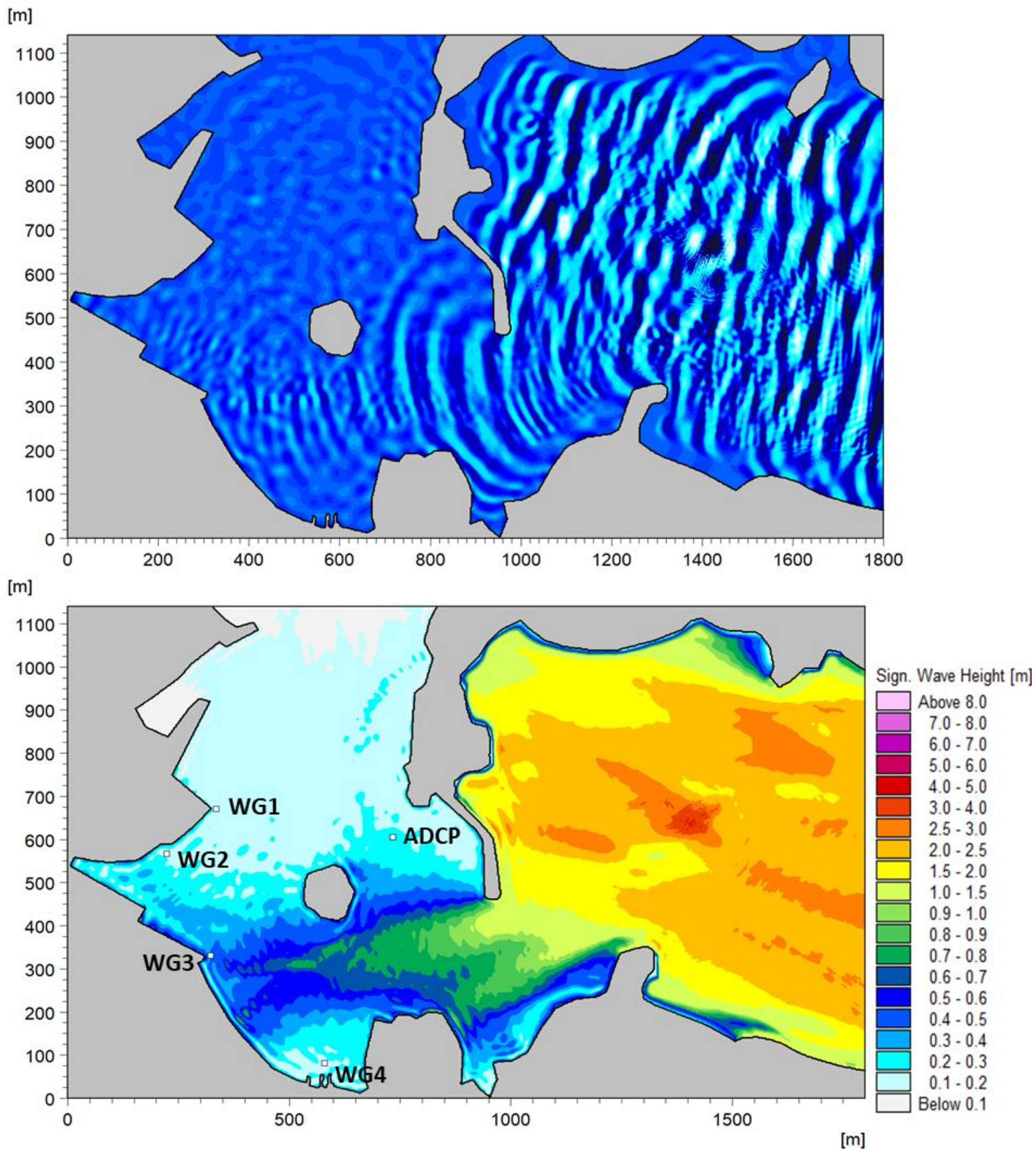
Figure 3.5: Regional Wave Model Storm Peak, 1 Jan 2020.
Boundary Conditions: 33 kts SE wind

3.3.2 PHASE-RESOLVING HARBOUR WAVE MODEL

MIKE21 Boussinesq Waves (BW) model, which resolves individual waves and multiple reflections was used to simulate the pattern of wave propagation into the harbour in a more accurate manner than the spectral model. The BW model is best suited to model diffraction, multiple reflections and long period wave action. The results of this modelling are presented on **Figure** 3.6.

The BW harbour model was calibrated by refining incoming wave angles and adjusting reflection coefficients along the shoreline and within the basin for peak storm conditions on 1 January 2020. Wave conditions or the high resolution model domain were input based on calibrated SW Regional wave model results from the domain boundary location. The calibration was focused on WG3, which is the most exposed wharf with a measured Hs of 0.4 m on 1 Jan 2020.

During meetings with Captains in the course of June-July 2020, it was confirmed that the wave model results were realistic. It was also confirmed that present wave agitation at the Ferry dock was not considered problematic, and has not been a cause of downtime or delay to the operations. The wind is the governing parameter.



	WG1	WG2	WG3	WG4
Measured Hs [m]	0.10	0.16	0.40	0.22
Modeled Hs [m]	0.16	0.15	0.41	0.18
Error [%]	61%	-5%	3%	-16%

Figure 3.6: Calibrated Harbour Wave Model Storm Peak, 01 Jan 2020.

Chapter 4 Modeling of Future Conditions

4.1 Future Layout

Blasted, excavated, and dredged materials will be transported to the Pikes Island Breakwater and the Pikes Island infill area for beneficial reuse. The majority of the dredged rock will be placed in the designated Pikes Island infill area. To understand future conditions post infilling, the infill was added to the hydrodynamic and wave models for simulations. Results are presented in the following sections.

It is noted that the infill layout is still subject to be adjusted, pending final design. The final layout will be checked with the coastal models to ensure minimal impacts. Contract requirements will require that the coastal impacts of the final layout will not significantly differ from those presented in the following model results.

4.2 Storm Currents

Results for peak seiche currents are presented in Figure 4.1. The model indicates that the removal of the island and infill would cause the path of the peak currents to shift further east inside the harbour. The currents would remain relatively weak and are not expected to cause significant scour or sedimentation in the basin, given that rock is the prevailing bottom type. Conditions within the navigation channel are not expected to change significantly, and no impacts are foreseen on operations.

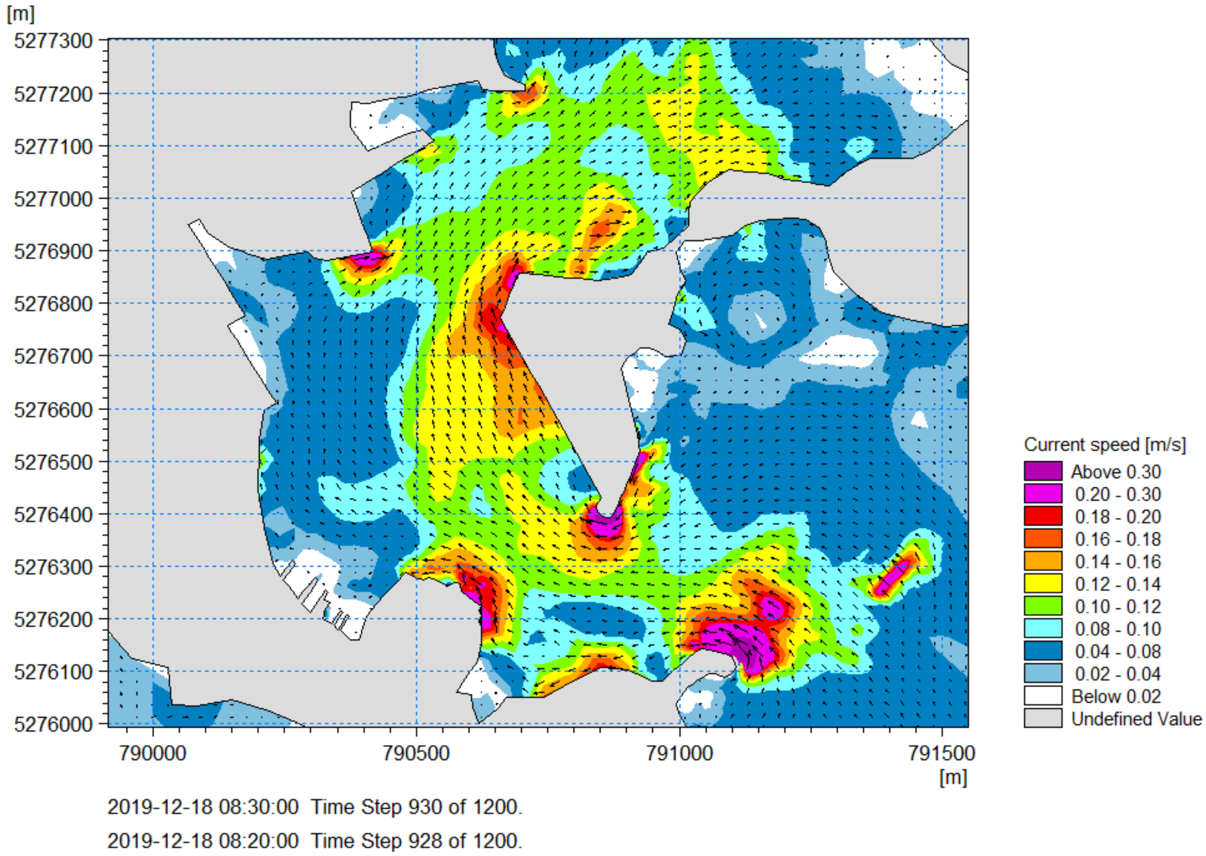


Figure 4.1: Snapshots of Modeled Seiche Currents (ebb-top, and flood-below) After Island Removal and Infill.

4.3 Wave Conditions

4.3.1 Southeast Swell

Figure 4.2 presents modeled wave agitation for the 1-year return storm conditions from the SE. Conclusions are as follows:

- Island removal (middle plot) will increase SE wave agitation at the MAI docks relative to existing conditions (top plot);
- Addition of the infill in the back of the Pikes Island Breakwater (bottom plot) is not expected to cause significant changes in SE wave agitation relative to the Island Removal-only scenario (middle plot); and
- With island removal and infill (middle and bottom plots), wave conditions at MAI Dock 2 are expected to become comparable to existing conditions (top plot) at MAI Dock No. 1.

4.3.1.1 Feedback from Captains

As part of the information meetings with MAI Captains, these results were presented for discussion. Captains indicated that present wave agitation at Dock 1 was not considered problematic, and has not been a cause of downtime or delay to the operations. As a result, there was no consensus on the maximum tolerable wave height at the dock, since that limit has not been experienced due to wind being the governing operational limitation.

There is variability in the significant wave height along the docks due to wave reflection patterns. Representative modeled wave height values were selected at a point approximately mid-distance along the dock, and half a vessel width away from the site to produce a wave height vs. SE wind speed Chart in Figure 4.3. This chart was developed to support discussion with Captains on whether wave agitation may become problematic in relation to wind speed, which is currently the governing parameter for Ferry delays or cancellations. It was presented to the Captains that wave conditions at MAI Dock 2 are expected to become comparable to existing conditions at MAI Dock No. 1.

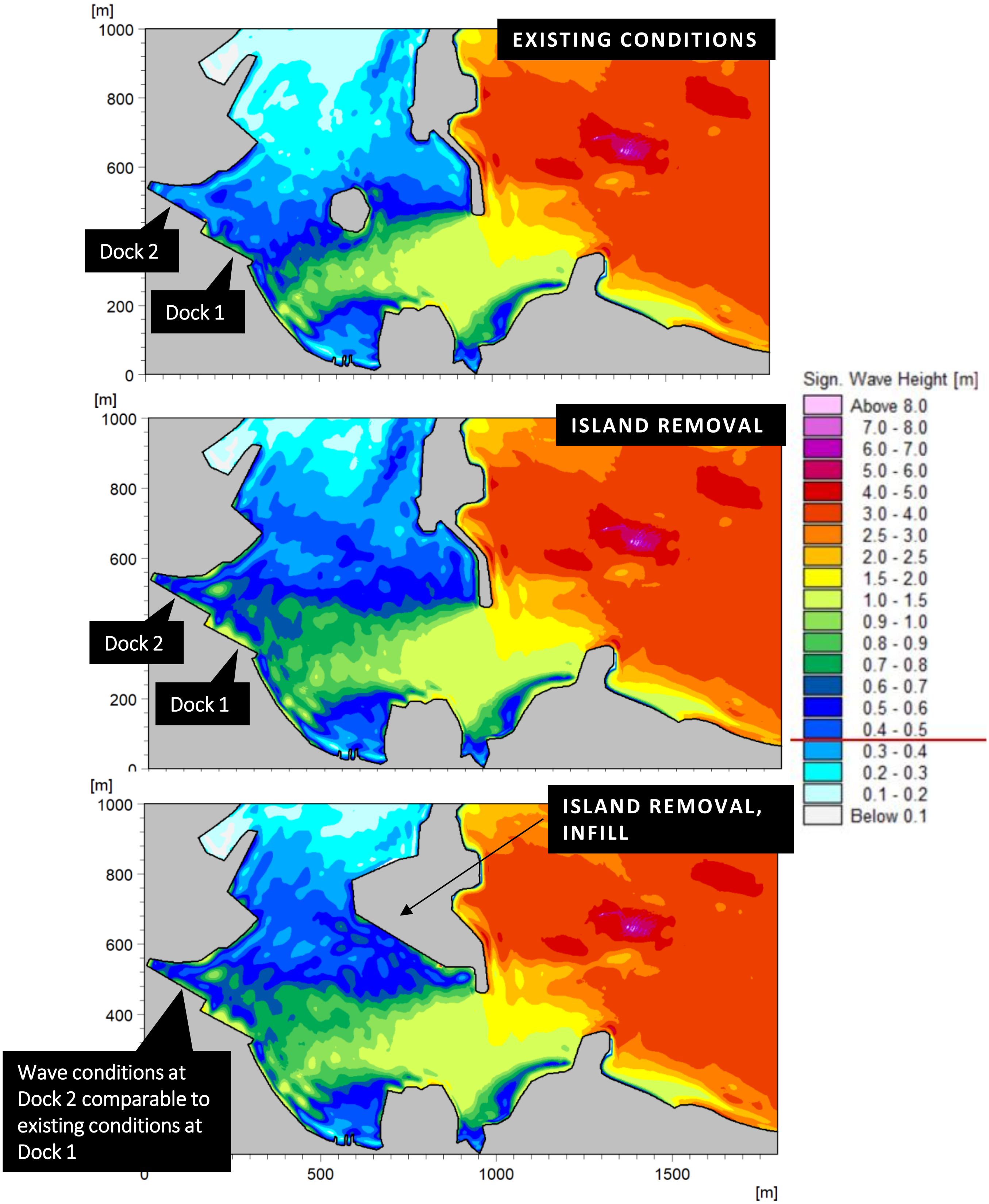


Figure 4.2: Modeled 1-Year Return Wave Agitation from SE Storm for Existing Conditions (top), after Removal of Vardy's Island (middle) and Infill (bottom).

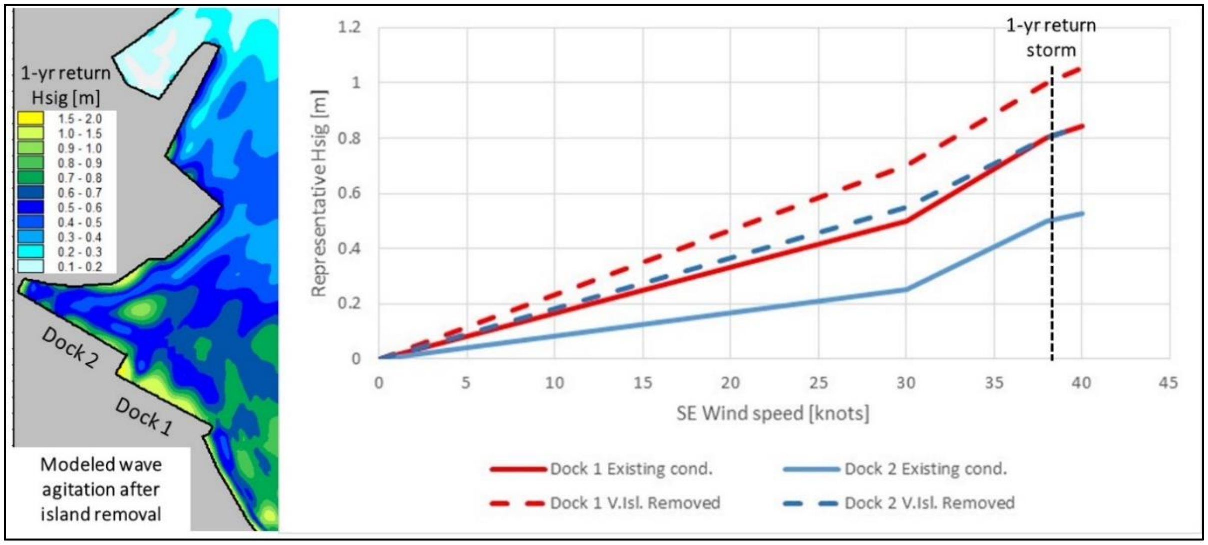


Figure 4.3: Modeled Existing and Future Representative Wave Agitation vs. SE Wind Speed at MAI Docks.

4.3.1.2 Wave Height Thresholds

Significant wave height thresholds cited by the World Association for Waterborne Transport Infrastructure (PIANC 1995) for car ferries range from 0.4 to 0.6 m. The existing wave agitation at the dock occasionally exceeds 0.4 m, with no concerns raised by Captains. Therefore, the upper end of the PIANC values, i.e. 0.6 m, may be more representative, and would be associated with SE wind speeds of 25 to 32 kts for future scenario at Dock 1 and 2, respectively. These wind speeds are close to the existing typical wind threshold of 30-35 knots. Therefore, it is unlikely that future wave agitation may become the governing parameter under strong but less frequent SE wind conditions.

The above conclusion was essentially confirmed by Captains upon presentation of these results, i.e. stating that future Dock 2 wave conditions would become comparable to existing conditions at Dock 1. Captains have indicated that:

- The wind is expected to remain the governing parameter, as the projected increases in wave height were not deemed to have the potential to disrupt operations.
- The increase in wave agitation could be mitigated by improving mooring systems, including but not limited to the addition of a stern stop and bow dolphin at Dock 1.
- Under future conditions, Dock 2 is expected to remain the preferred berthing location, with Dock 1 used only during instances of maintenance work being performed at Dock 2.

4.3.1.3 Shoreline Erosion

Erosion typically occurs when action from ocean swell impacts an erodible shoreline made of soft sediment or brittle rock. The model indicates that the area of moderately increased swell action will be along the shoreline to the northwest of the island, which is already protected with either armour stone or hard structures and wharves. Therefore, there are no concerns that the removal of the island may lead to greater shoreline erosion.

4.3.2 Northeast Wind Waves

Vardy's Island presently provides partial sheltering to the Town wharves from NE wind waves. The spectral wave model was used to assess conditions for locally generated wind waves from the Northeast (Figure 4.4). The removal of Vardy's Island would have increased NE wave agitation at the town wharves relative to existing conditions. However, the effect is expected to be mitigated by the new infill, to the point that the future wave agitation at the Town wharves is not expected to exceed existing conditions.

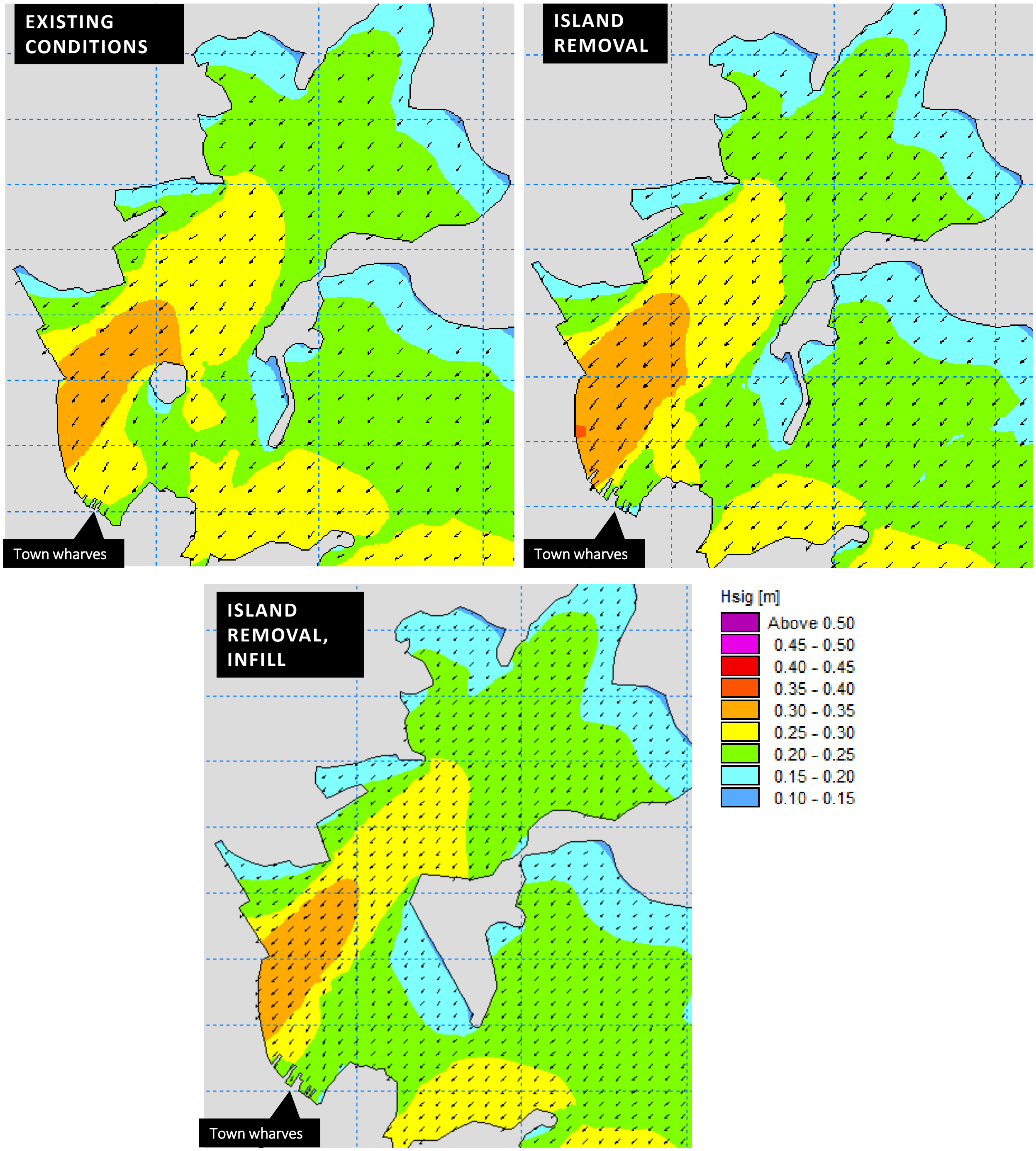


Figure 4.4: Modeled 1-Year Return Wave Agitation from Northeast Storm for Existing Conditions (top left), after Removal of Vardy's Island (top right) and Infill (bottom).

4.4 Potential for Bed Sediment Movement

This section presents a preliminary examination of how the project may affect bottom sediment movement through modeled changes to bed shear stresses. Bed shear stresses are commonly used to assess the mobilization of sediment on the bed layer.

The bed shear stresses can be compared to the critical bed shear stress thresholds of various sediment to predict if the movement of sediment will occur (US Geological Survey, 2008). The bed shear stress is a reliable output as it is based on hydrodynamic parameters that have higher confidence than sediment parameters. The peak shear stresses, which occur with peak storm currents, are compared for current conditions and the proposed design (Figure 4.5). The maps can indicate the type of sediment mobilization that will occur during these occurrences.

The grain size distributions detailed in the Marine Sediment Program Report indicated that Northeast of the Town Wharves, the sediment is primarily composed of sand, with some clay and gravel. The locations and median grain sizes of the sediment samples are illustrated in Figure 4.6. The median grain size (D_{50}) is commonly used to characterize the type of sediment, as labeled in this figure. Movement of sediment Northeast of the Town Wharves due to harbour hydrodynamics is not likely to occur because the sediment's critical shear stress for mobilization is generally higher than the ambient peak bed shear stresses, i.e. the sediment is too coarse for ambient currents to carry. Areas of likely sediment movement include the breakwater head perimeters, as well as the area between Vardy's Island and Pikes Island breakwater. There is potentially additional sediment movement along the navigation channel due to Ferry propwash.

The removal of Vardy's Island and addition of infill at the breakwater is not expected to cause a significant change overall in the peak bed shear stresses, and therefore sediment movement inside the harbour.

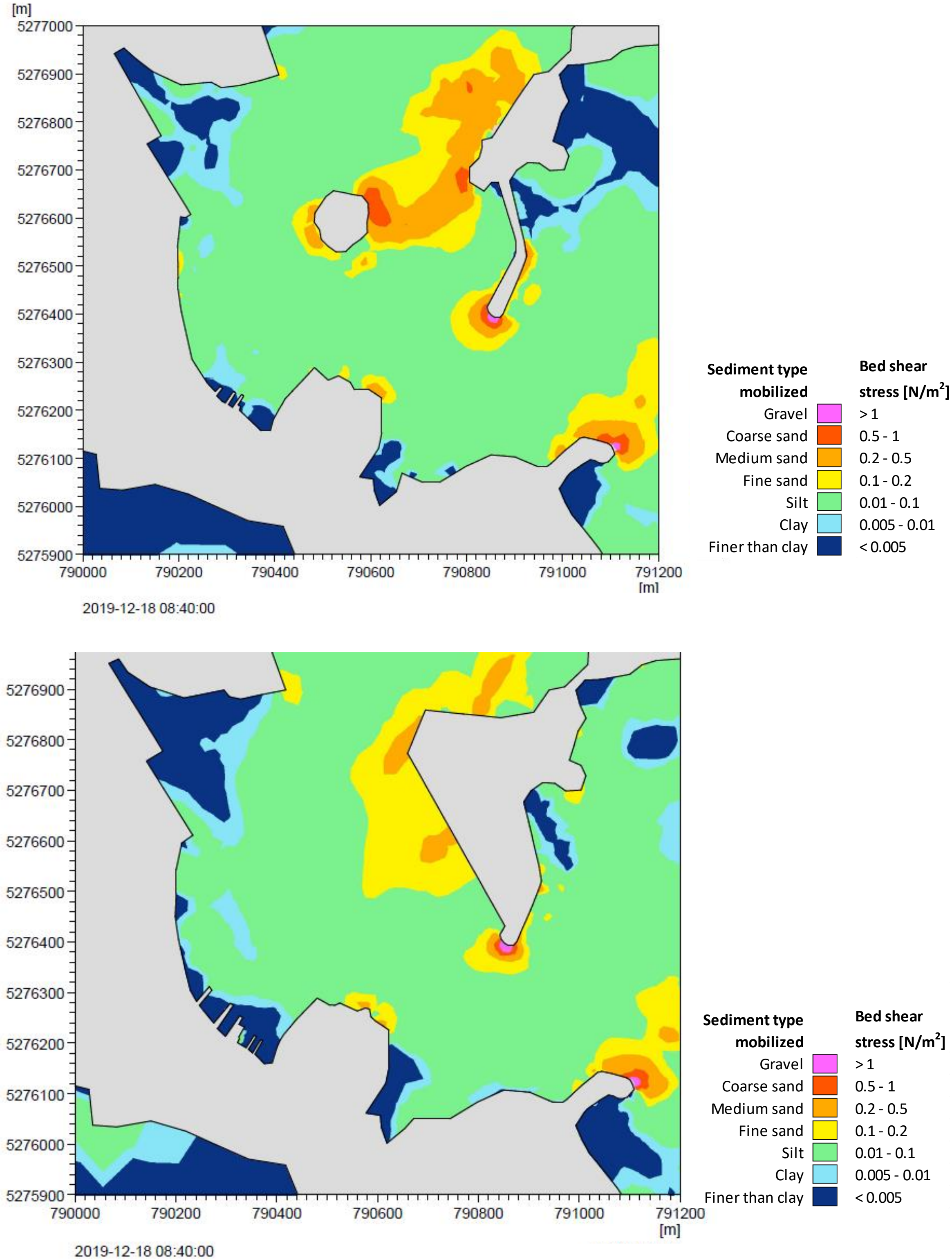


Figure 4.5: Modelled peak bed shear stresses for existing (top) and future (bottom) conditions based on the thresholds for various sediment types.

Note: Based on hydrodynamic model of flows and harbour oscillation, not including effect of waves which would be significant outside the harbour and in shallow breaking zones.

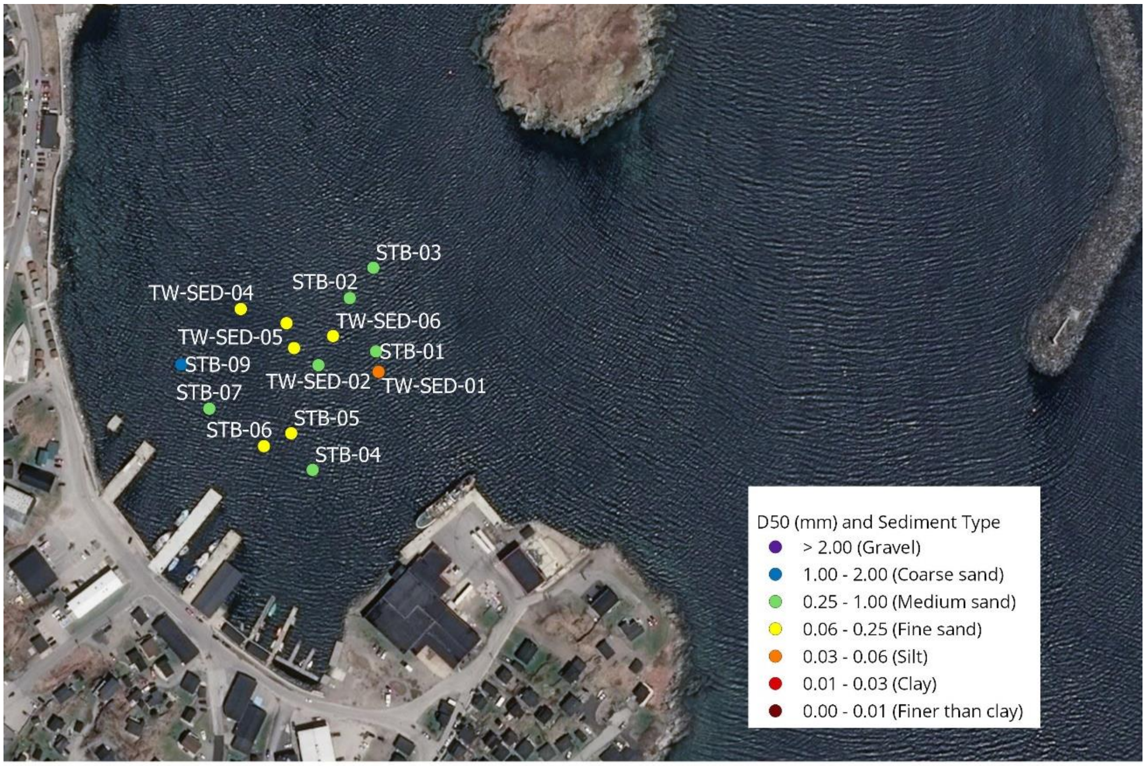


Figure 4.6: Median grain size and sediment type for samples taken during the marine sediment sampling program.

Chapter 5 Concept Design for Breakwater Repairs

5.1 Context

As part of the overall project planning for MAI's operations, completed condition assessments of infrastructure were completed including Pikes Island and Graveyard Point Breakwaters. The previous CBCL studies (2014, 2018) identified the Pikes Island breakwater as needing repairs in the relatively near-term. The Graveyard Point breakwater to the South is deemed to have a sufficient reserve of armour stone to simply warrant continued monitoring for the foreseeable future.

Recommendations from 2014 Report included:

- Continued monitoring, which led to the 2018 drone survey assessment showing significant damage along the Pikes Island Breakwater trunk (Figure 5.1), in addition to the lee side slope being unprotected and prone to significant damage in the event of a large overtopping event;
- Recommended repairs to the Pikes Island Breakwater include the following steps:
    1. Side-casting armour stone from the crest to the damaged front slope, and replacing the crest stone with new stones; and
    2. Repair entire back slope.

5.2 Pikes Island Concept Repair Option

Traditional breakwater design involves the determination of a required armour stone grading and slope based on design wave conditions and desired damage level, with the objective of minimizing require rock quantities. However, the available rock grading from local quarries is not clear at the planning stage. These circumstances, combined with the severe wave conditions, would typically call for a 'berm breakwater' design. A berm breakwater involves using a thicker covering of armour stone layers in the wave attack zone, determined by the gradation of the available material. A berm design typically requires smaller armour stone but in greater quantity than a conventional 2-layer armour stone design. The final cross-section allows for practical construction considerations and post-construction reshaping to a flatter stable slope.

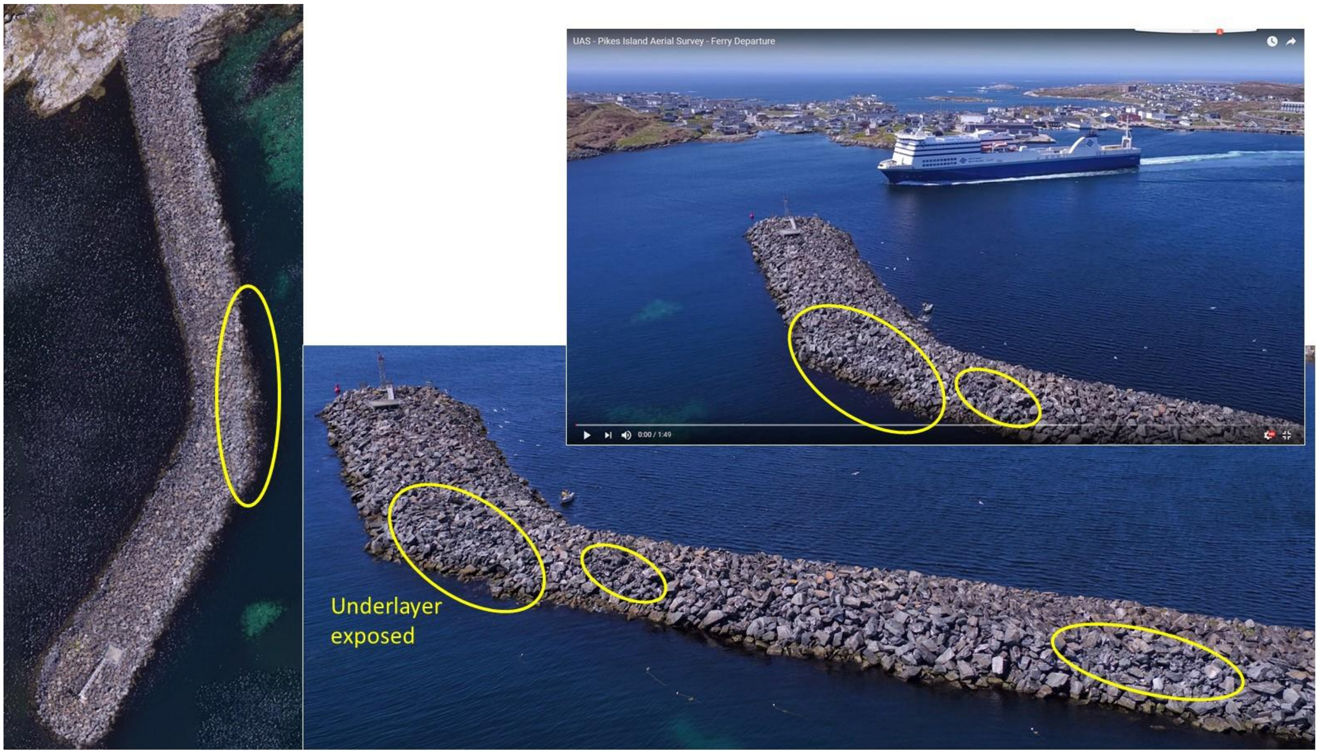


Figure 5.1: Pikes Island Breakwater Damage from 2018 Drone Survey.

Guidelines for geometrical design of berm breakwater are available from Van der Meer and Sigurdason (2016), along with preliminary design calculation tools. A concept level cross-section is shown on Figure 5.2. The design is based on the following assumptions:

- Design wave conditions Hs = 3.8 m, Tp = 12.4 s
- Use of 3 rock classes (0.3-1, 1-3, and 3-5 tonne rock)
- Assumed mass density or rock 2,650 kg/m^3
- New crest elevation 8.0 m CD
- Berm width ~12 m
- Partly reshaping type of berm breakwater.

The breakwater repair design will be dependent on available rock type and quantities.

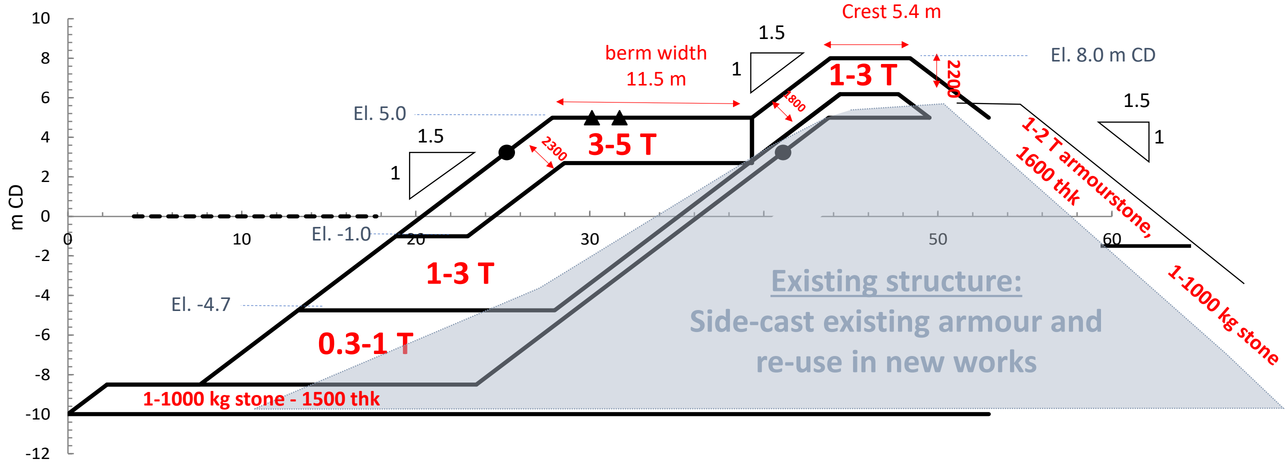


Figure 5.2: Concept-Level Cross-Section for Pikes Island Breakwater Repair.

Chapter 6

Summary and Conclusions

A coastal engineering study was completed to support design and impact assessment of MAI's proposed navigation improvement project at Port-aux-Basques. Winter 2019-2020 field observations were used to calibrate a hydrodynamic and wave model of the harbour.

Wave conditions are expected to change at MAI docks following removal of Vardy's Island and completion of an infill area along Pikes Island breakwater. Wave conditions at the less exposed MAI Dock No. 2 are expected to become comparable to existing conditions at the more exposed Dock No. 1. Captains have indicated that this does not represent a significant concern, for the following reasons:

- The wind is expected to remain the governing parameter, as the projected increases is wave height were not deemed to have the potential to disrupt operations.
- The increase in wave agitation could be mitigated by improving mooring systems, including but not limited to the addition of a stern stop and bow dolphin at Dock 1.
- Under future conditions, Dock 2 is expected to remain the preferred berthing location, with Dock 1 used only during instances of maintenance work being performed at Dock 2.

The removal of Vardy's Island would have increased NE wave agitation at the town wharves relative to existing conditions. However, the effect is expected to be mitigated by the new infill, to the point that the future wave agitation at the Town wharves is not expected to exceed existing conditions.

Historical trends in wind speed point to an increase in high wind conditions. The possibility of a stormier future with climate change must be accounted for in infrastructure planning and design. The proposed navigation project is intended to increase MAI operations' resiliency to high wind conditions, which will remain the limiting operational parameter.

Finally, the dredging operations will result in large quantities of rock available for beneficial use as infill. The project also represents an opportunity to repair damage to the Pikes Island breakwater. Based on potential limitations on large rock sizes from local quarries, a 'berm breakwater' design concept was developed. The proposed design involves using a thicker covering of armour stone layers in the wave attack zone, determined by the gradation of the available material. The final cross-section will allow for practical construction considerations and post-construction reshaping to a flatter stable slope. The design will progress as updated information becomes available on available rock type and quantities.

Chapter 7

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Offshore Wind and Wave Climate

Figure A.1: MSC50 Offshore Hindcast Site (M6012515, at 47.5N 59.1W, 1954-2018) and SmartAtlantic Wave buoy[1] (47° 33.7705' N, 59° 006.0239'W, 2013-Present).

[1] https://www.smartatlantic.ca/station_alt.html?=portauxbasques

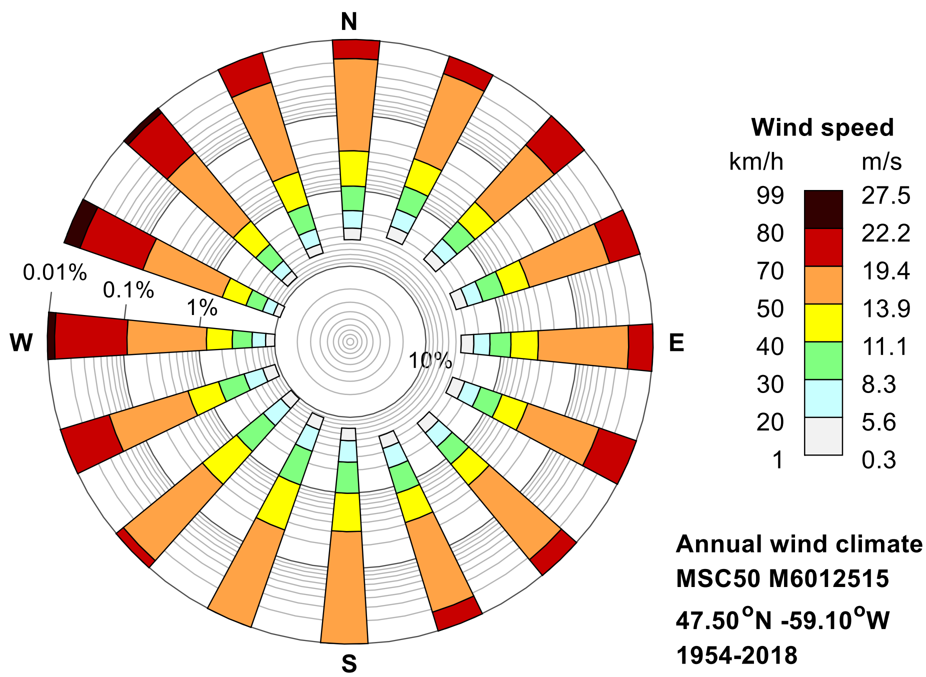


Figure A.2: Annual Directional Frequencies of Wind Speed

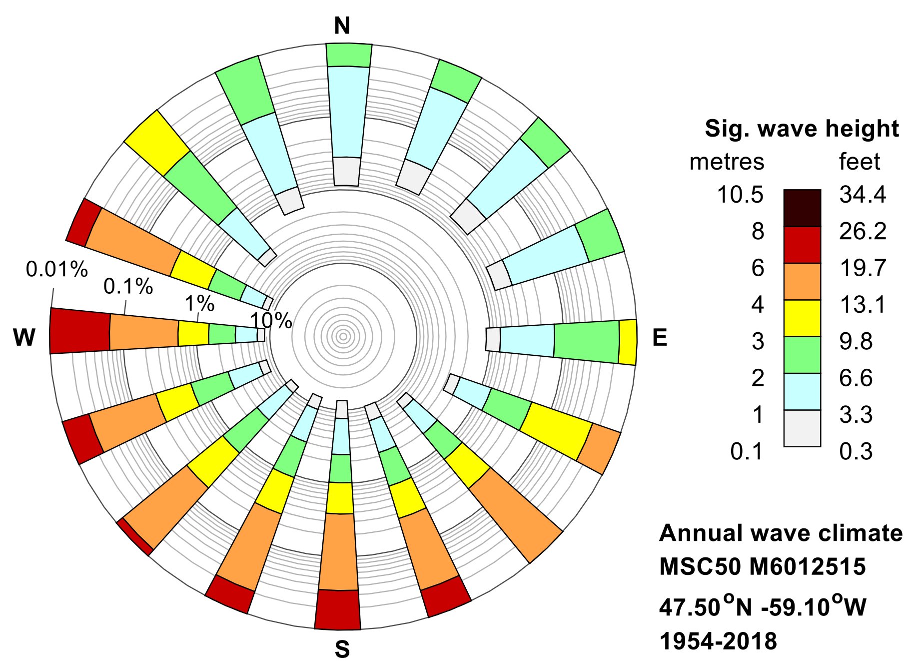


Figure A.3: Annual Directional Frequencies of Significant Wave Heights

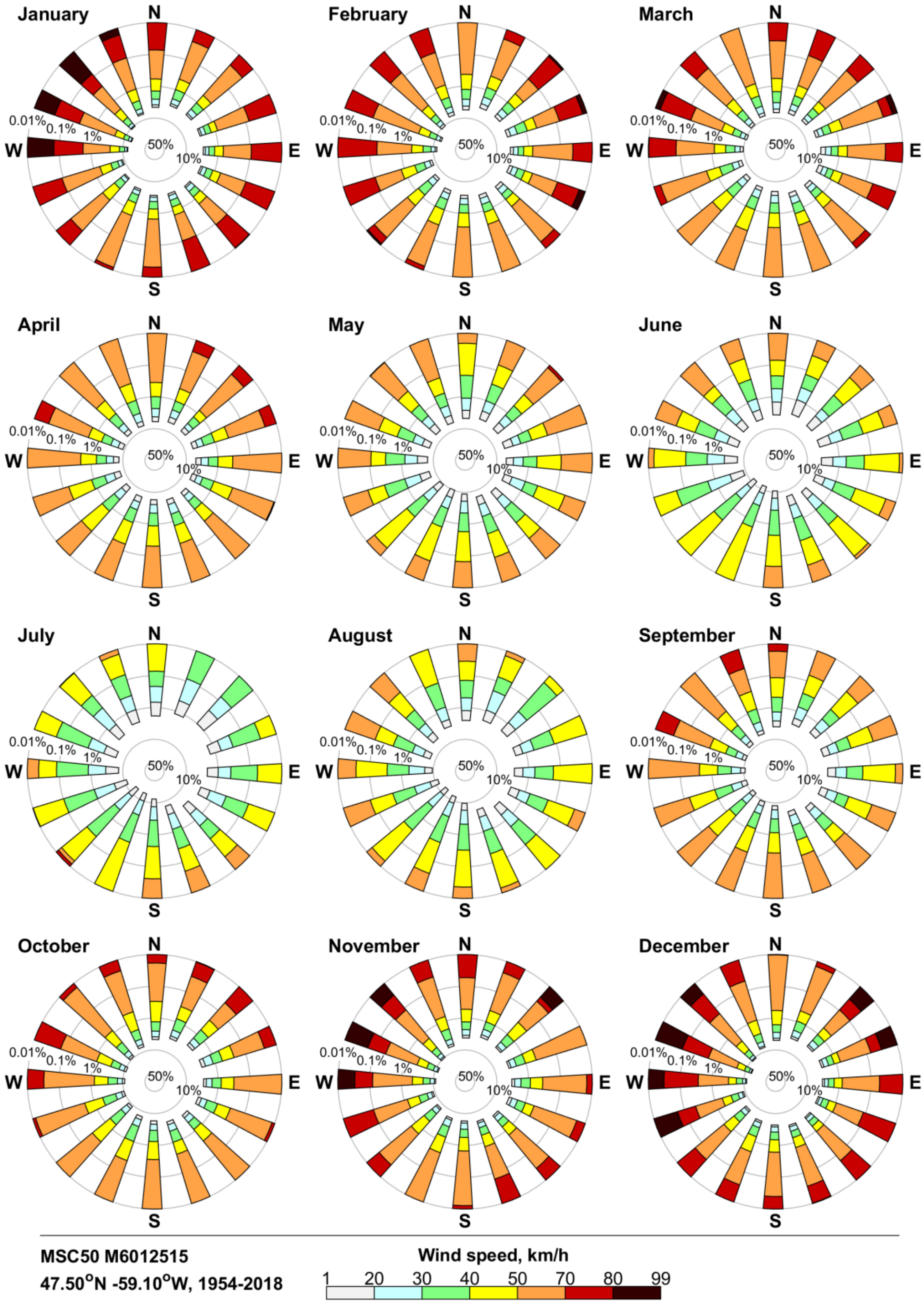


Figure A.4: Monthly Directional Frequencies of Wind Speed

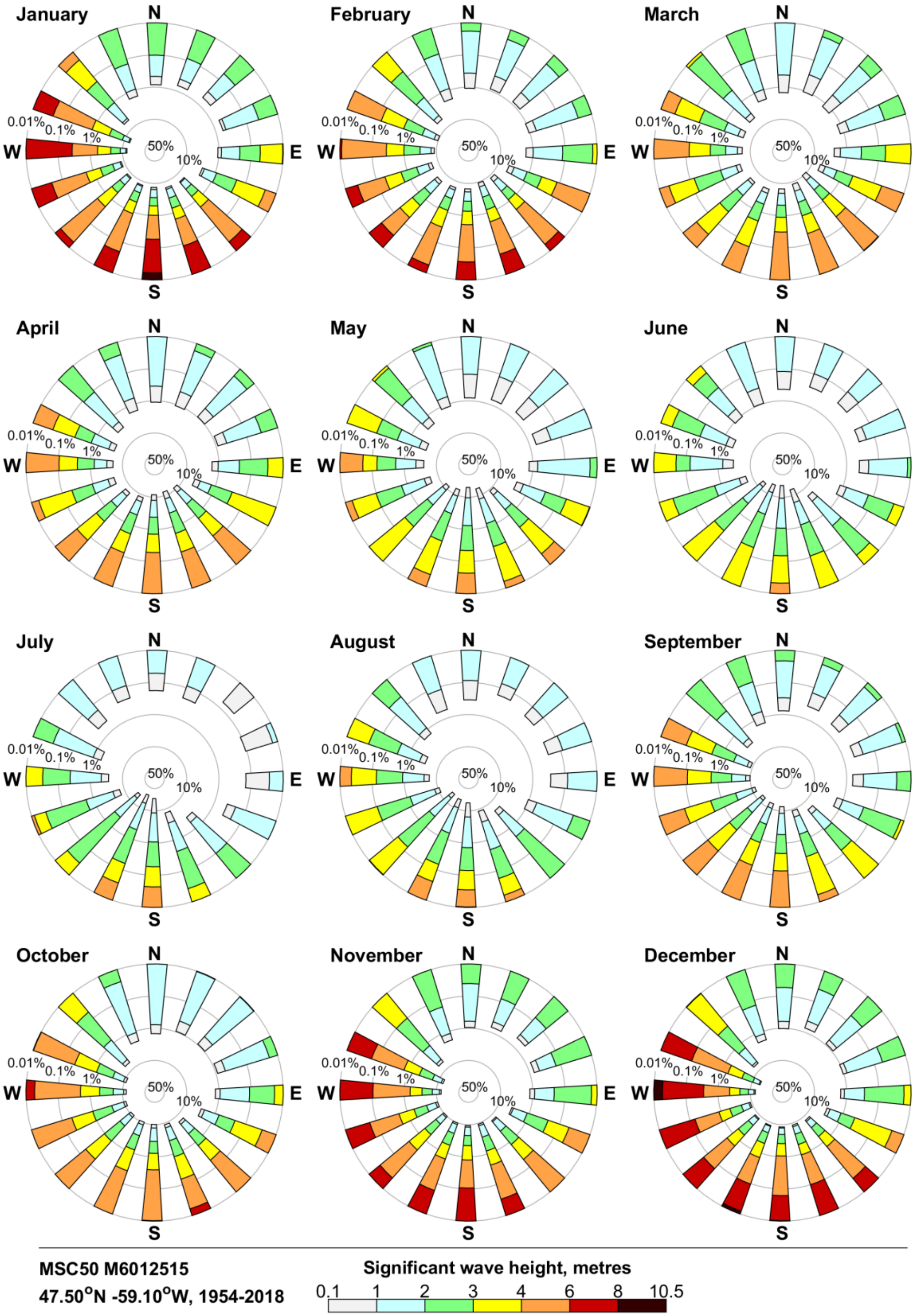
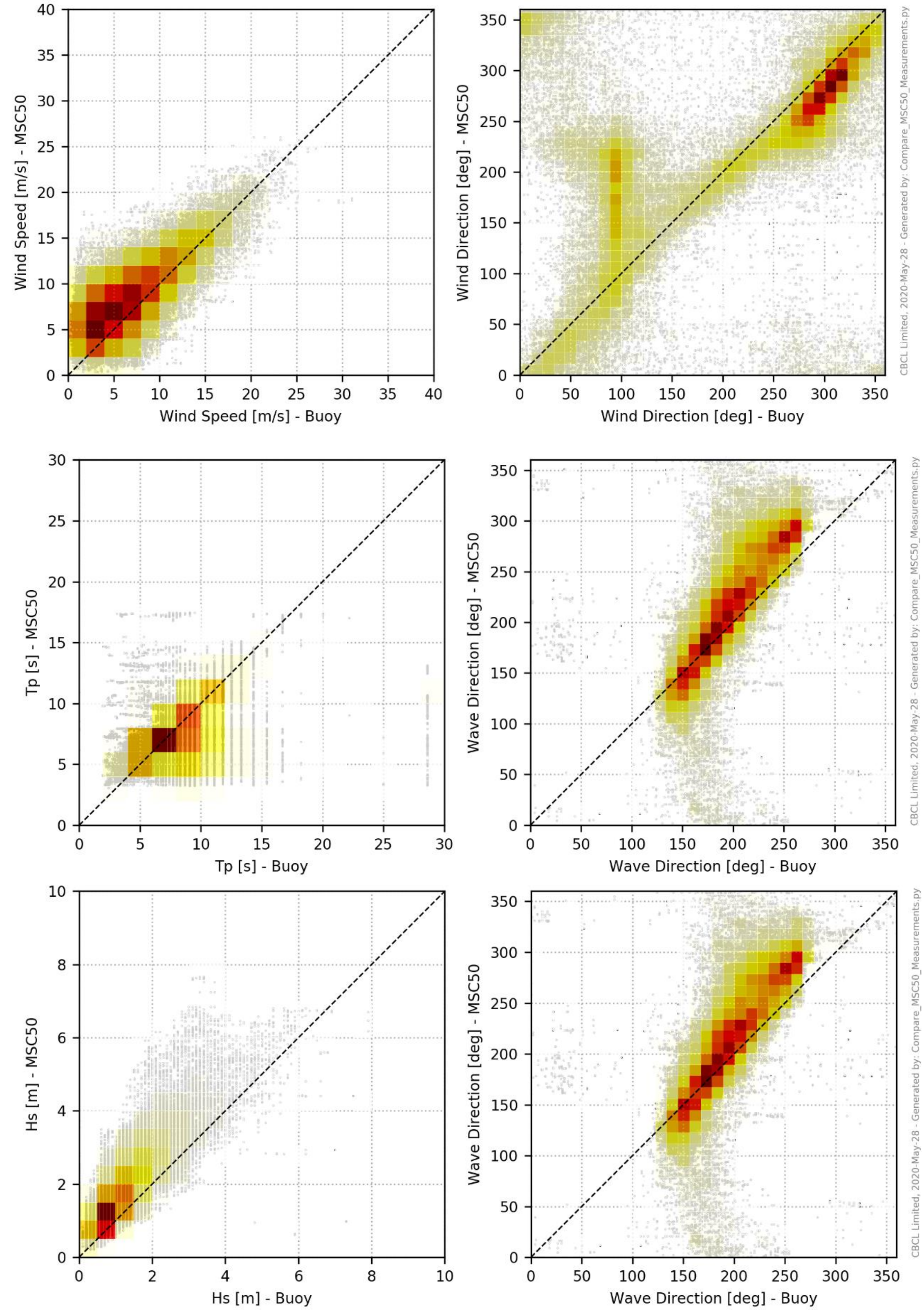


Figure A.5: Monthly Directional Frequencies of Significant Wave Heights

Table A.1 Extreme Values from MSC50 M6012515 (1954-2018)

Dir.	RP (years)	Hs (m)	Tp (s)	Hourly Wind Speed (m/s)	(kts)
N	1	2.1	8.8	18.1	35
	10	3.1	10.8	21.7	42
	25	3.4	11.4	22.8	44
	50	3.7	11.8	23.6	46
	100	3.9	12.2	24.4	47
NE	1	2	7.9	18.5	36
	10	3	10.4	22.6	44
	25	3.3	11.1	23.8	46
	50	3.6	11.6	24.6	48
	100	3.9	12	25.4	49
E	1	2.8	8.6	19.7	38
	10	3.7	9.8	22.7	44
	25	4	10.1	23.6	46
	50	4.2	10.4	24.3	47
	100	4.4	10.6	25	49
SE	1	5.2	10.7	19.4	38
	10	6.8	11.9	22.8	44
	25	7.5	12.2	24.3	47
	50	7.9	12.5	25.5	50
	100	8.4	12.7	26.7	52
S	1	6.1	11	18.4	36
	10	7.8	12.3	21.7	42
	25	8.9	13	23	45
	50	9.9	13.5	23.9	46
	100	11	14	24.9	48
SW	1	5.4	10.7	18.5	36
	10	7.1	11.1	22.6	44
	25	7.6	11.2	24.1	47
	50	8	11.3	25.2	49
	100	8.4	11.3	26.4	51
W	1	5.8	10.8	21	41
	10	7.3	11.3	23.9	46
	25	7.8	11.5	24.9	48
	50	8.2	11.6	25.5	50
	100	8.6	11.7	26.2	51
NW	1	3.7	10.7	20.4	40
	10	5.5	11.8	24.2	47
	25	6.1	12.1	25.6	50
	50	6.5	12.3	26.7	52
	100	7	12.5	27.7	54

Comparison MSC50 – PAB Offshore wave buoy[2] (2013-2018)

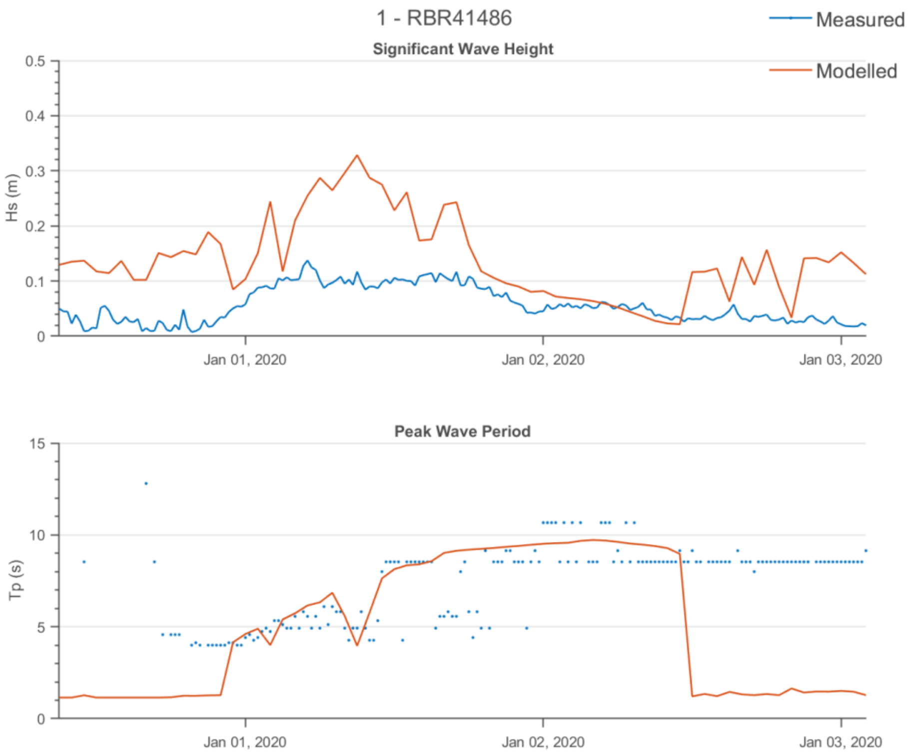


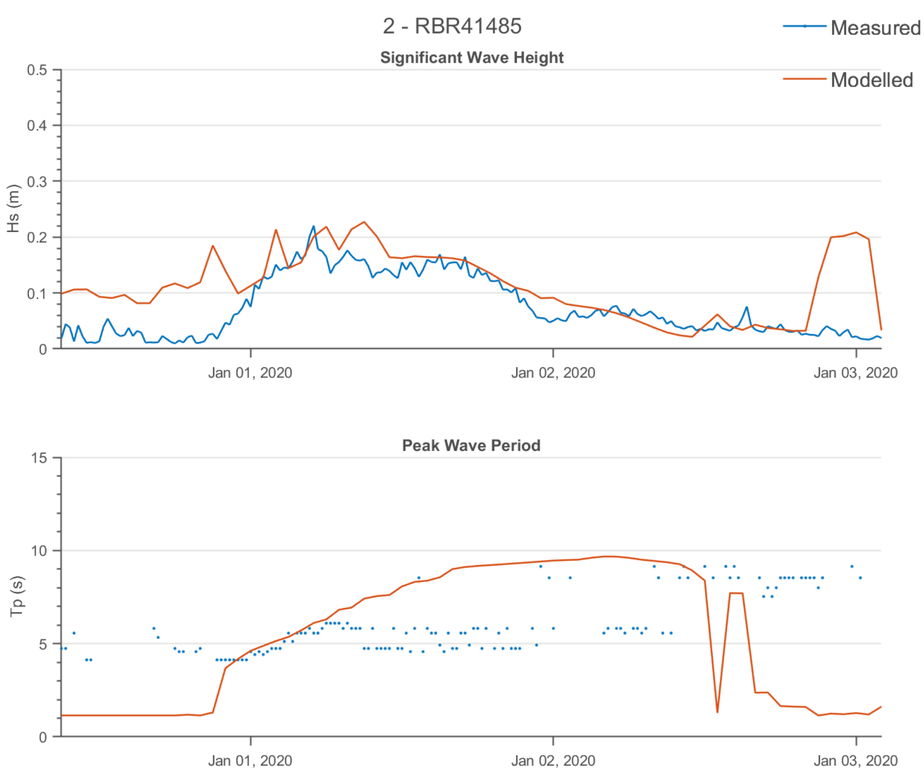
[2] https://www.smartatlantic.ca/station_alt.html?=portauxbasques

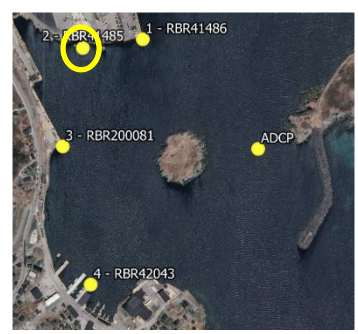
APPENDIX B

Regional Spectral Wave Model Calibration Plots

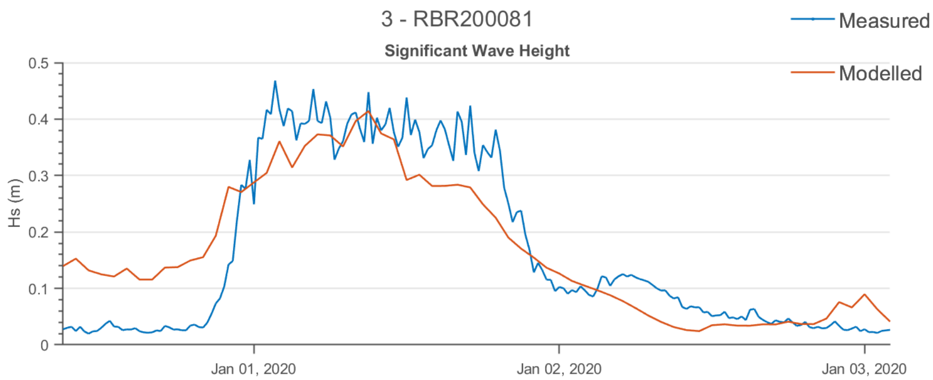
SW Spectral Wave Model Calibration, 01 Jan 2020 Storm

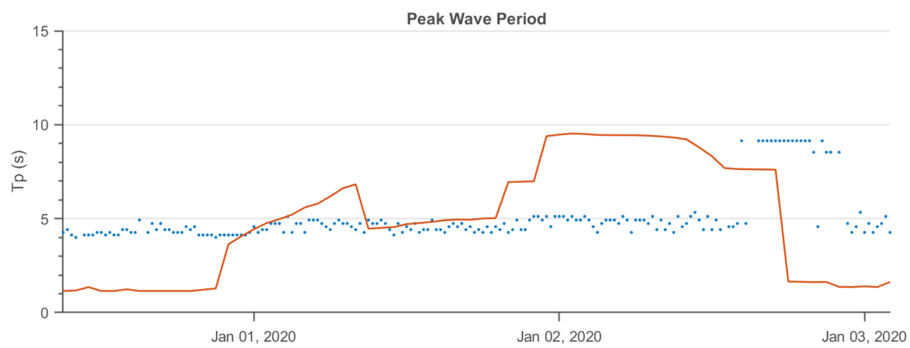


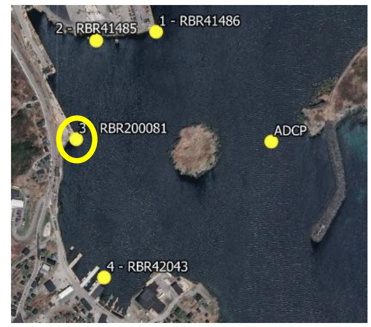


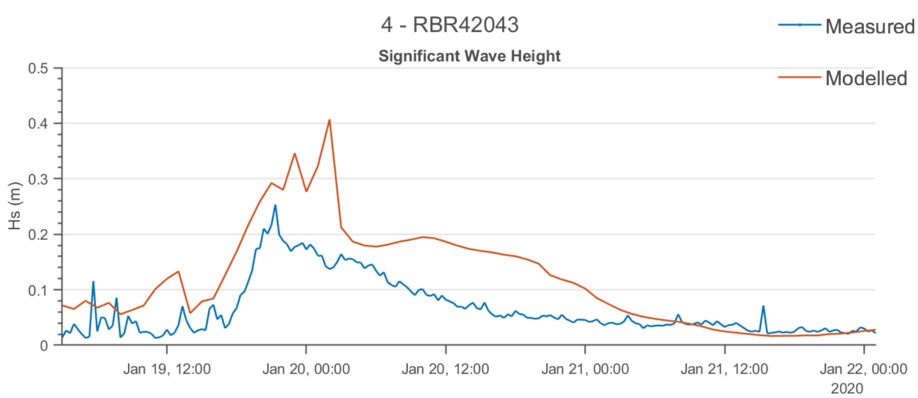


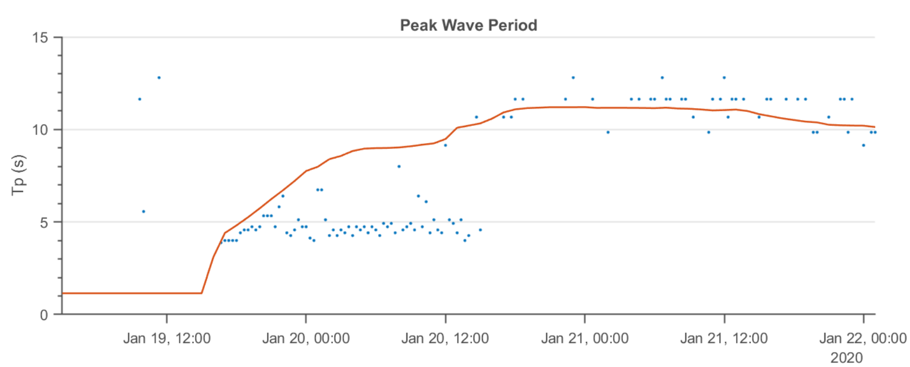
SW Spectral Wave Model Calibration, 01 Jan 2020 Storm



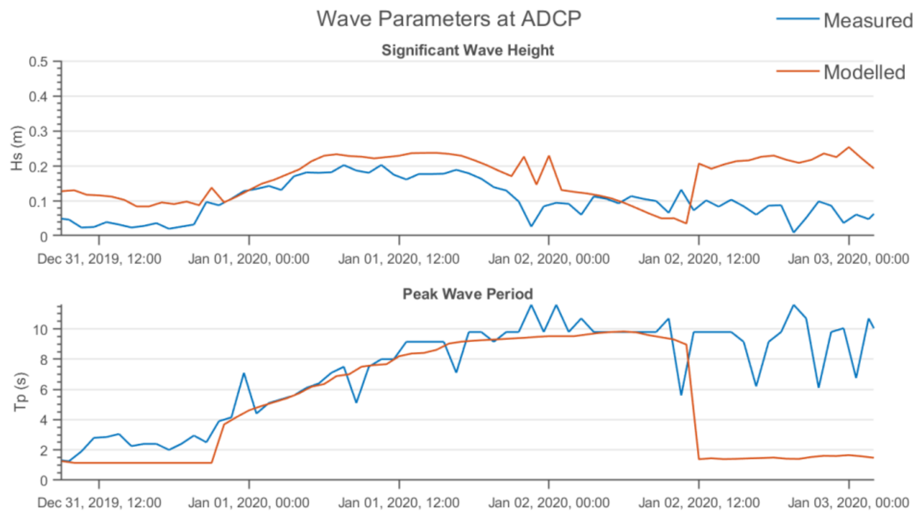




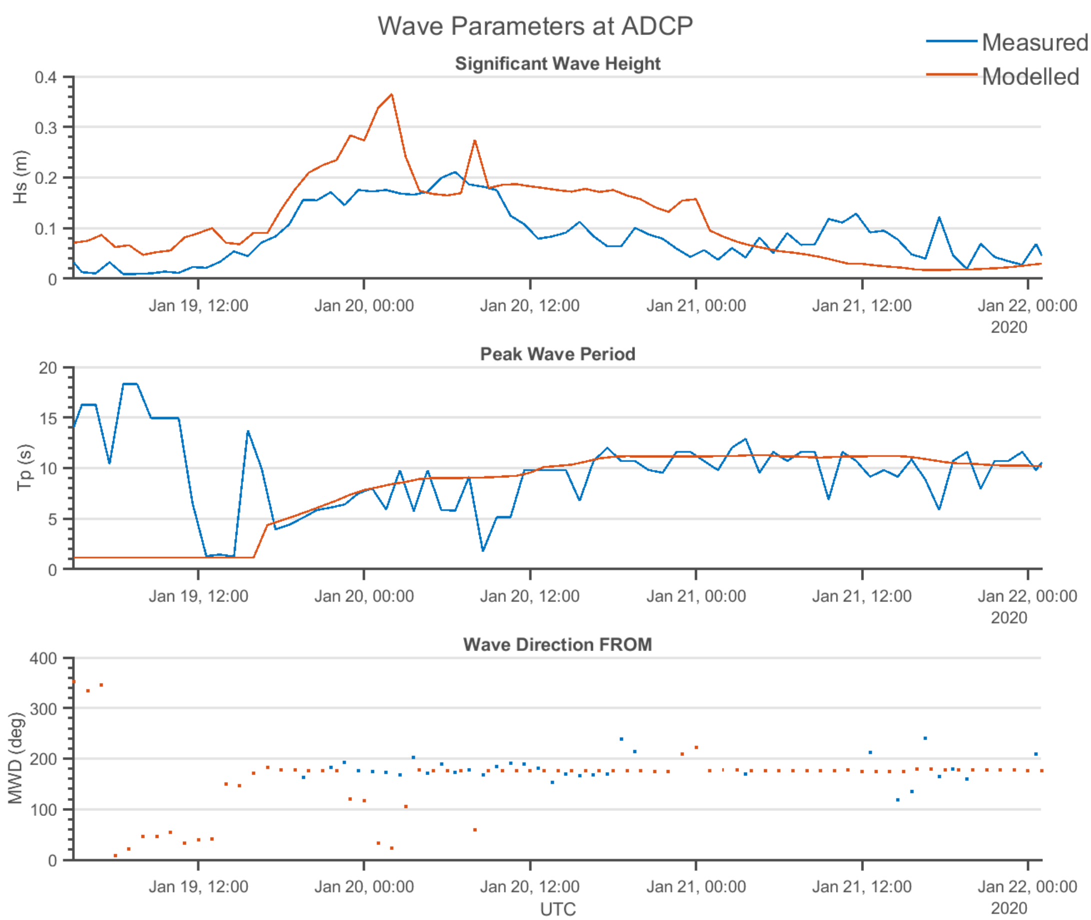




SW Spectral Wave Model Calibration, 01 Jan 2020 Storm



SW Spectral Wave Model Calibration, 20 Jan 2020 Storm



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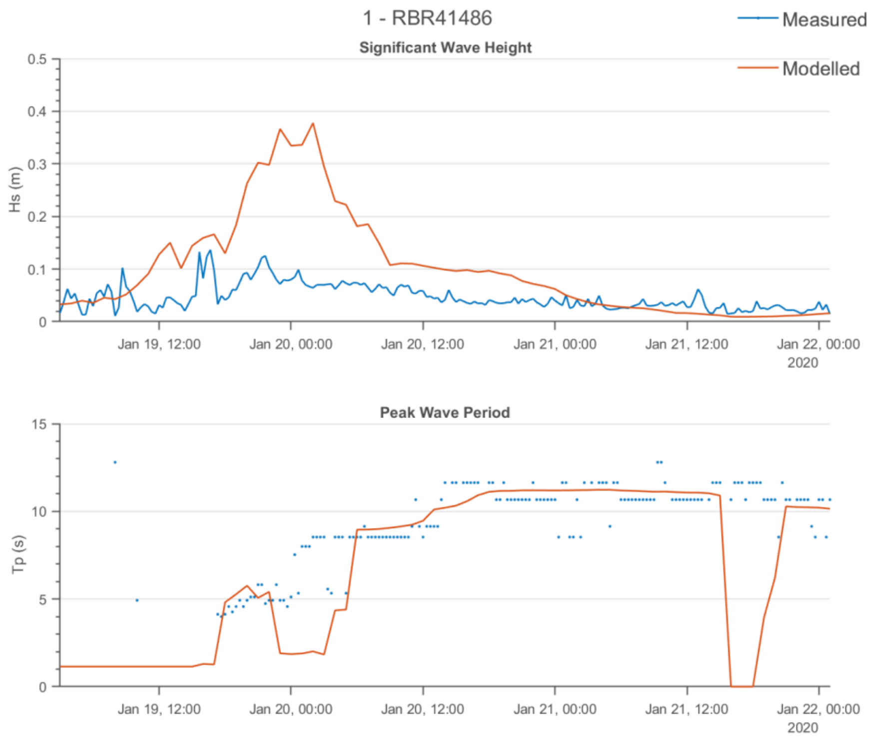

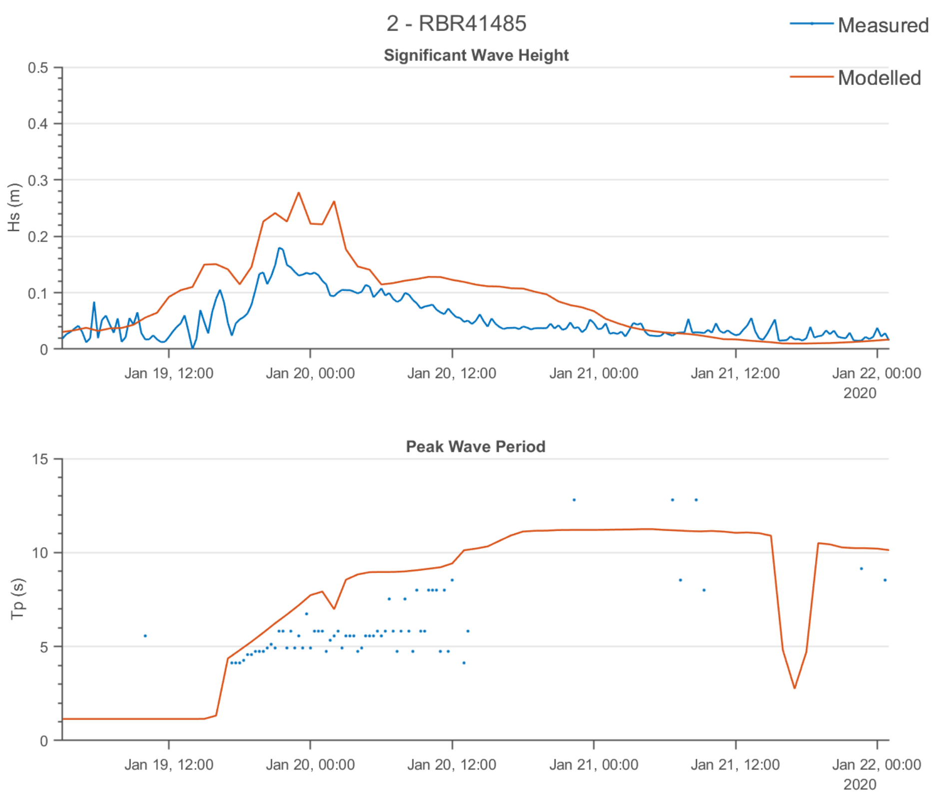

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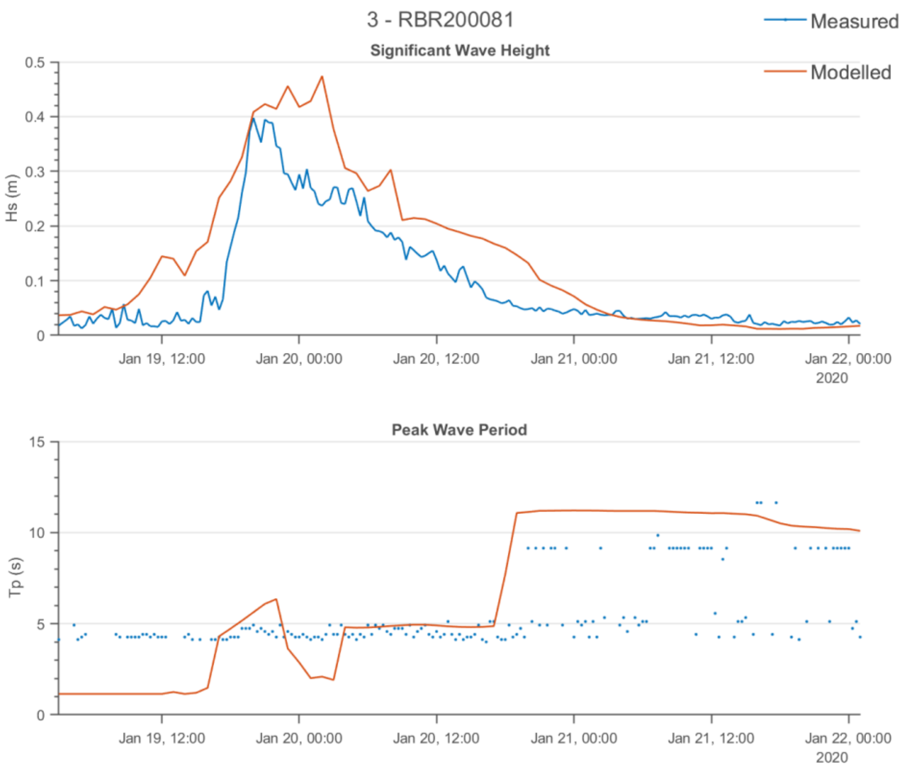

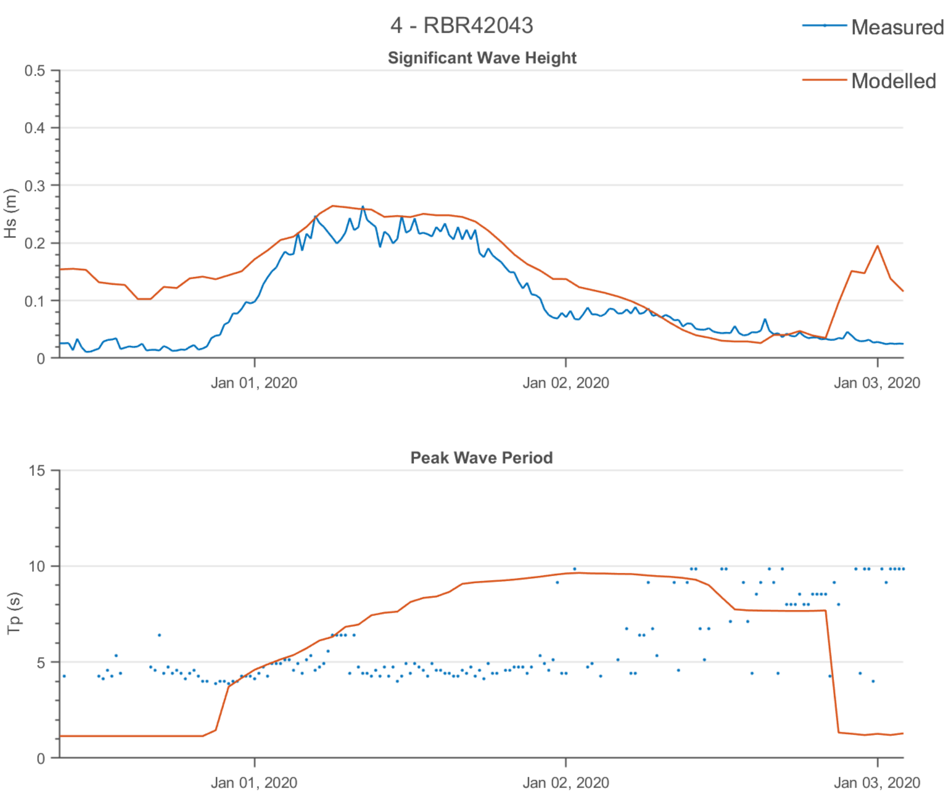

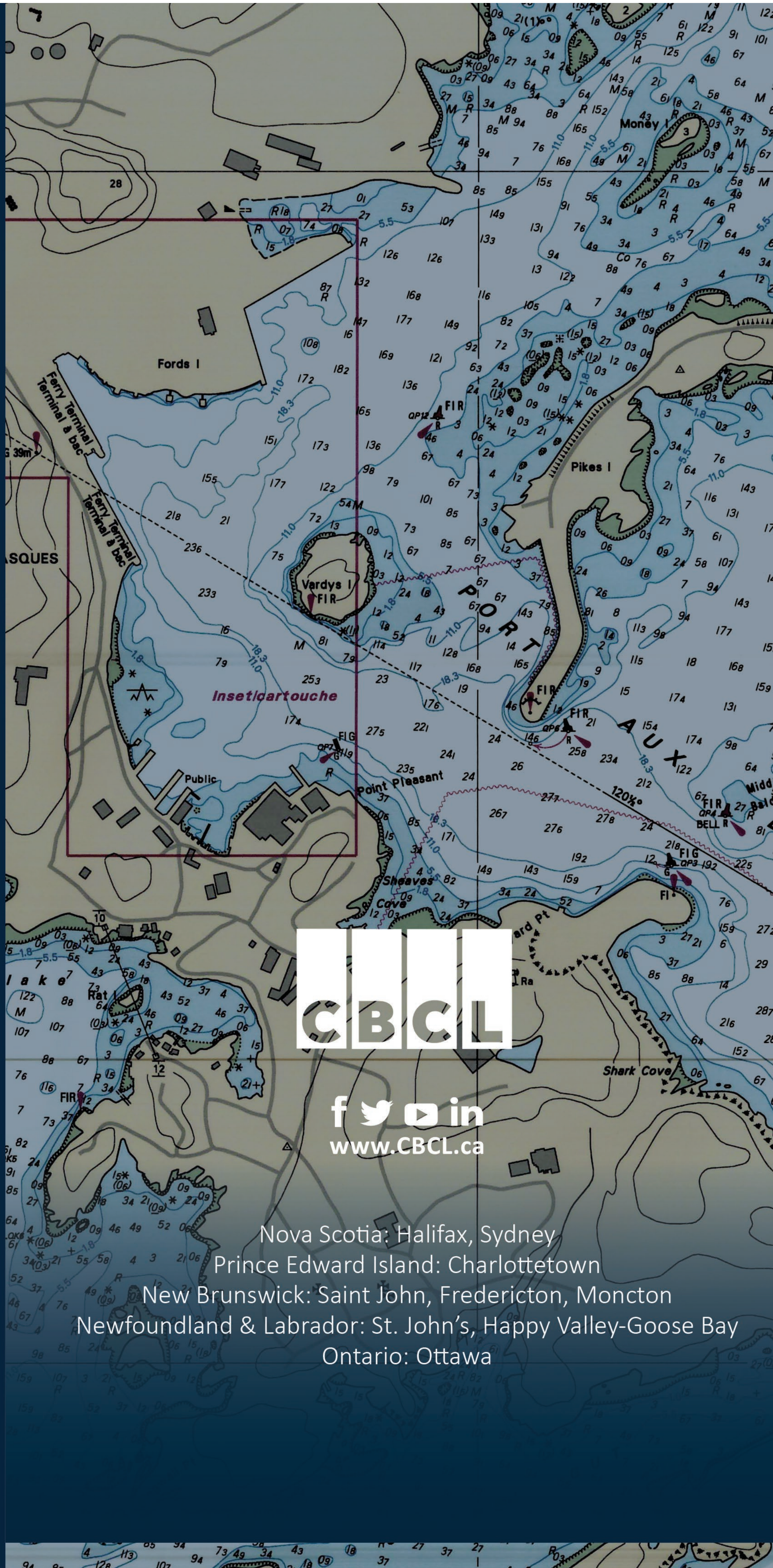

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