Government of **Western Australia**
Department of **Transport**

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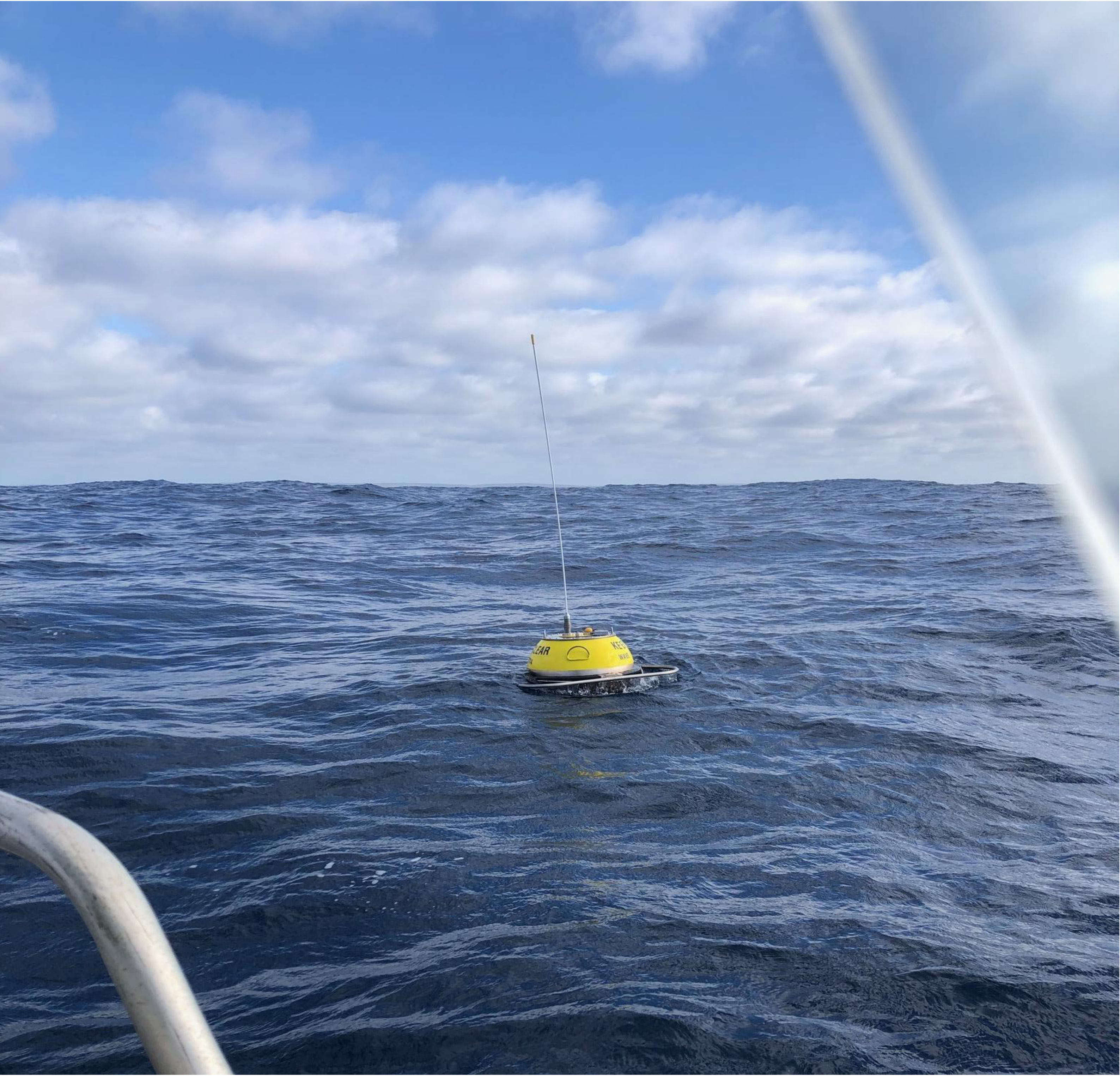
Geraldton Wave Data Summary

2023-24



Technical Report

September 2024

Geraldton Wave Data Summary 2023-24

Prepared for Department of Transport

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1	06/08/2024	SK	First draft issued for review	FL, SCF
2	29/08/2024	SK	Updates and added analyses	FL, SCF
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Amendment record

This guidelines document is reviewed to ensure its continuing relevance to the systems and process that it describes. A record of contextual revisions is listed in the following table.

Page No.	Context	Revision	Date

Contents

Acknowledgements

Sincere gratitude is extended to the Tides and Waves, Coastal Information, and Maritime Division of the Department of Transport for their invaluable advice, provision of access to the Geraldton wave and tide data, and the field photographs used in this report.

The CoastWA project is generously supported by grants from the Department of Transport (Coastal Adaptation and Protection grants) and the Western Australian Planning Commission (Coastal Management Plan Assistance Program and Coastwest). Acknowledgement is also given to the Batavia Coast Maritime Institute for their collaboration during the Geraldton wave buoy deployment.

Glossary

Accelerometer: A device used to measure the acceleration experienced by an object. In wave buoys, the accelerometer monitors both vertical and horizontal motions, capturing the buoy response to the movement of the ocean surface.

Biofouling: The accumulation of marine organisms on any part of a vessel's hull, internal seawater systems, or any equipment or spaces attached to or onboard the vessel.

Calibration: Verifying and correcting the precision of an instrument by comparing its measurements to a known standard.

Fast Fourier Transform (FTT): A computational algorithm used in spectral analysis to efficiently calculate the Fourier coefficients from a given time series.

Mean Period (T_m): The average period of the energy spectrum, calculated as T_m = 1 / average frequency of the spectrum.

Peak Period (T_p): The period corresponding to the peak of the energy spectrum, calculated as $T_p = 1 / f_p$, where f_p is the frequency at which the spectral density is maximum.

Percentage Exceedance: The proportion of time, expressed as a percentage, that a specific value is surpassed.

Percentage Occurrence: The proportion of time, expressed as a percentage, that a specific value or range of values is observed.

Pitch: The movement of a wave buoy along its transverse axis (y-axis), characterized by the rising and falling of its forward and aft ends.

Quality Assurance: Procedures implemented to guarantee that the collected data meets the highest possible standards of accuracy and reliability.

Quality Control: Procedures used to verify and maintain the accuracy and reliability of data that has already been collected.

Receiver: A shore-based device designed to receive incoming wave signals.

Record Interval: The duration between successive recordings, 30 minutes for directional data.

Roll: The movement of a wave buoy along its longitudinal axis (x-axis), resulting in a side-to-side rocking motion.

Sea Waves: Oceanic waves created locally by wind blowing over the water's surface. Their characteristics depend on the fetch (the length of the water body), the wind duration, and the wind speed. Sea waves usually have short wavelengths and a disordered appearance. In spectral wave data analysis for the region, sea waves are classified as those with a period of less than 8s.

Significant Wave Height (H_s): The average height of the highest 33 percent of waves recorded. In spectral analysis, it is calculated using the formula: $H_s=4\sqrt{m_o}$, where m_0 is the zeroth spectral moment.

Spectral Analysis: A mathematical technique that transforms a waveform into its frequency spectrum. To determine the wave height spectrum, a Fast Fourier Transform is used. For analysing the wave direction spectrum, on-buoy processing employs north, west, and vertical displacements to perform a Fourier analysis, which yields the wave direction.

Swell Waves: Oceanic waves generated at distant locations and traveling long distances, arriving locally with consistent and generally long wavelengths. In spectral wave data analysis for the region, swell waves are characterized by a period greater than 8 seconds.

Wave Direction: The compass direction from which ocean waves approach a specific location.

Wave Height: The vertical distance between the trough and the crest of a wave.

Wavelength (L): The horizontal distance between consecutive wave troughs or crests, representing the length of one complete wave cycle.

Wave Period (T): The time required for one complete wavelength to pass a reference point, usually measured between successive troughs or crests.

Wave Buoy: A floating instrument designed to measure variations in water levels caused by ocean wave

1. Introduction

The Department of Transport (DoT) operates a network of nine wave stations along the Western Australian (WA) coast, including locations at Esperance, Bremer Bay, Albany, Cape Naturaliste, Mandurah, Rottnest Island, Cottesloe, Jurien Bay, and Geraldton (**Figure 1**). These wave buoys provide vital data that support a wide range of purposes at both the state and national levels, including coastal engineering and adaptation projects, recreational activities, research, weather forecasting, and understanding long-term trends related to sea-level rise and climate change phenomena. This data is extensively utilized by DoT coastal management, private consultants, academic and research institutions, the general public, state and federal departments and agencies, and occasionally by entities outside of Australia.

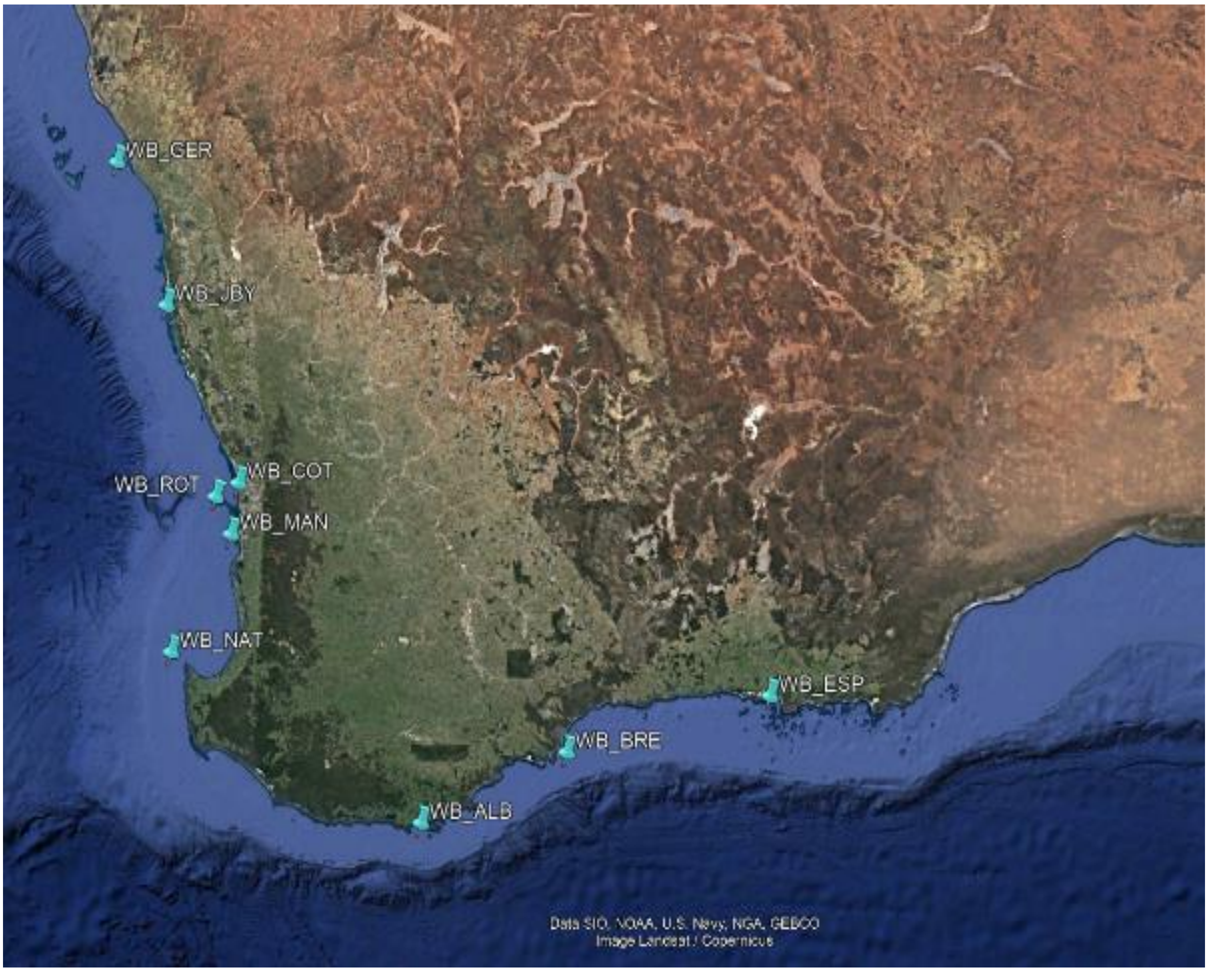


Figure 1. Locations of active wave measurement stations as shown on the DoT's web portal. (https://www.transport.wa.gov.au/imarine/download-tide-wave-data.asp)

The first wave buoy was deployed at Fremantle (33° 03' 44" S, 115° 43' 28" E) on June 5, 1974, and remained in operation until February 24, 1975. Initially, non-directional wave buoys were used to measure wave heights and periods, with data recorded every six hours. Early data collection faced challenges such as continuity issues and seasonal gaps. Over time, there have been significant improvements in the wave data collection industry, which have enabled directional wave data recording with significantly improved reliability, quality, and detail (Stephen, et al., 2005).

Historical wave data is essential for various applications, including coastal engineering, environmental research, and the design and development of coastal infrastructure. Real-time wave data is also critical for managing extreme weather events, supporting state emergency services and the Bureau of Meteorology (BOM). Additionally, wave data aids in navigation for shipping, informs recreational marine activities, and contributes to scientific and educational research.

1.1. CoastWA project

The WA Coastal Zone Management Program was administered by the Department of Planning and Heritage. In 2021, this program was expanded and enhanced through the introduction of CoastWA, which was designed to further assist coastal land managers in planning, managing, and adapting to coastal hazards. CoastWA aims to ensure sustainable land use and development along the coast by addressing the findings and recommendations from the assessment of coastal erosion and inundation hotspots in WA (WA.gov.au, 2024).

In 2017/18, the DoT commissioned a study to determine regionally appropriate design storm events for assessing coastal erosion risk in Southwest Western Australia. One of the study's key recommendations was to introduce offshore wave buoys in Geraldton and Bremer Bay/Hopetoun, where wave measurement data was previously unavailable. As part of the CoastWA initiative, which comprises five key elements, the third focuses on wave data collection. Under this element, funding has been allocated to purchase two new wave rider buoys, which have now been deployed at Geraldton and Bremer Bay to fill the existing data gaps and enhance coastal hazard management.

1.2. Site selection

The installation of the offshore wave buoy at Geraldton, a key initiative under CoastWA, provides near real-time data on wave height, period, and direction. This deployment marks the first use of a Directional Wave Radar (DWR) at the Geraldton site, significantly enhancing the region's capabilities for wave data collection and monitoring. The location of the Geraldton wave station is shown in **Figure 2**, with a detailed description provided in **Table 1**.

Table 1. Description of Geraldton site

Location	Geraldton Directional Wave buoy
Location Latitude	28° 54.924'S (28.9154°S)
Location Longitude	114° 23.000'E (114.3833°E)
Deployment Depth	42 m
Deployment Date	22/03/2023

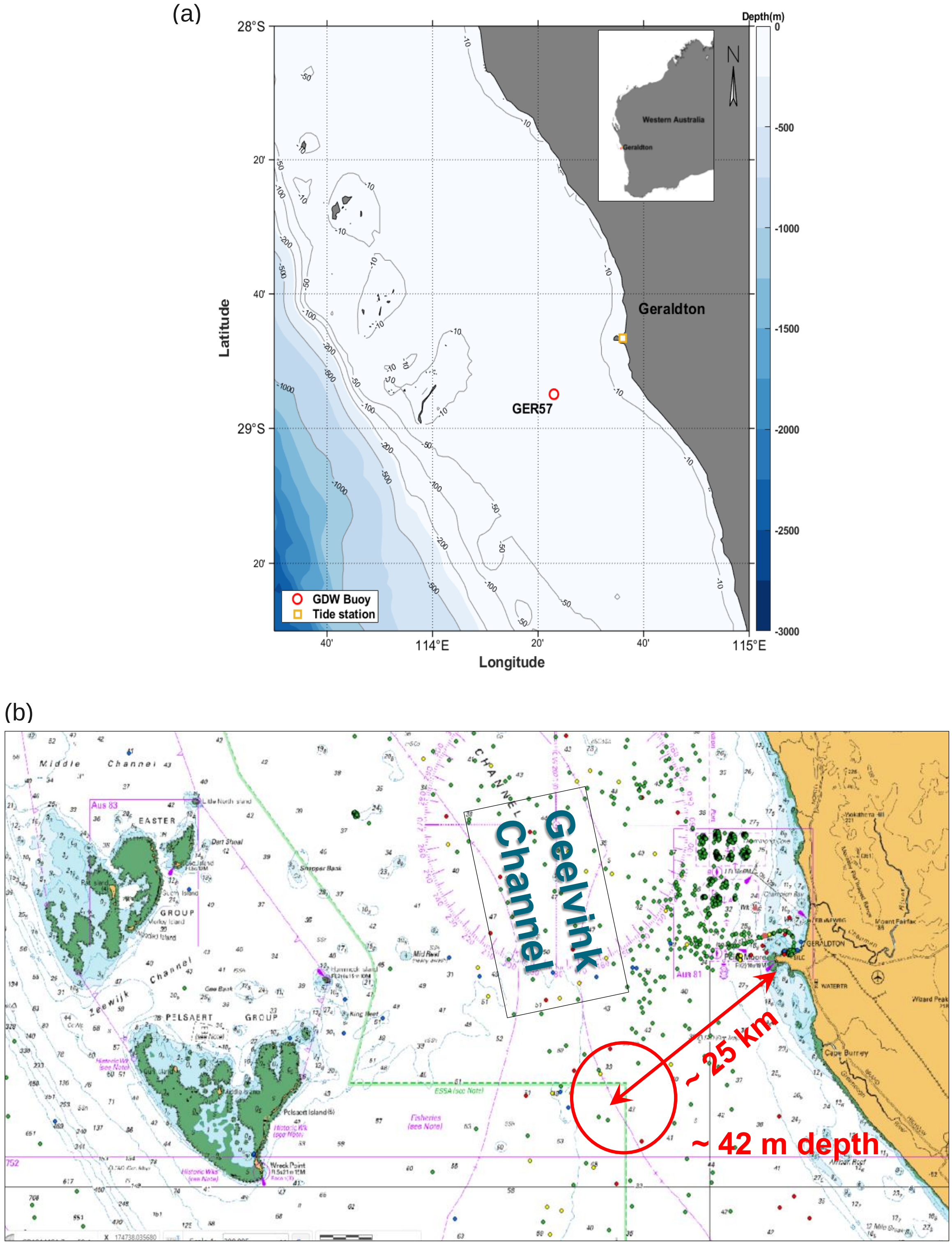


Figure 2. (a) Location of Geraldton Directional Wave Buoy and Tide station. (b) A chart displaying the Geraldton site.

1.3. Considerations for wave buoy site selection

When selecting a location for wave buoy deployment near the Port of Geraldton, several critical factors were considered to ensure minimal interference with port operations. The port is equipped with numerous instruments for meteorological and oceanographic measurements, so it was essential to avoid any interference with these systems, including potential magnetic or radio signal disturbances. Additionally, vessel traffic density in the area was analysed to prevent disruptions to port activities (**Figure 3a**). While the ideal distance for wave buoy deployment is typically around 50 km from the shore station, a site 25 km offshore was chosen to meet these requirements. Oceanographic Information personnel conducted site investigations in Geraldton from February 16-18 to identify suitable locations for shore stations and Batavia Coast Maritime Institute was selected to ensure an uninterrupted line of sight between the buoy and the shore station (**Figure 3b**).

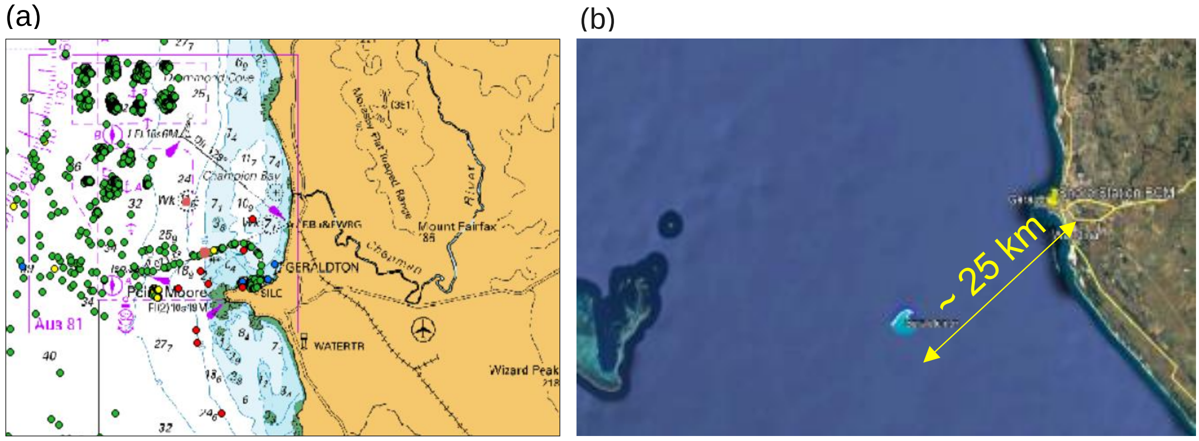
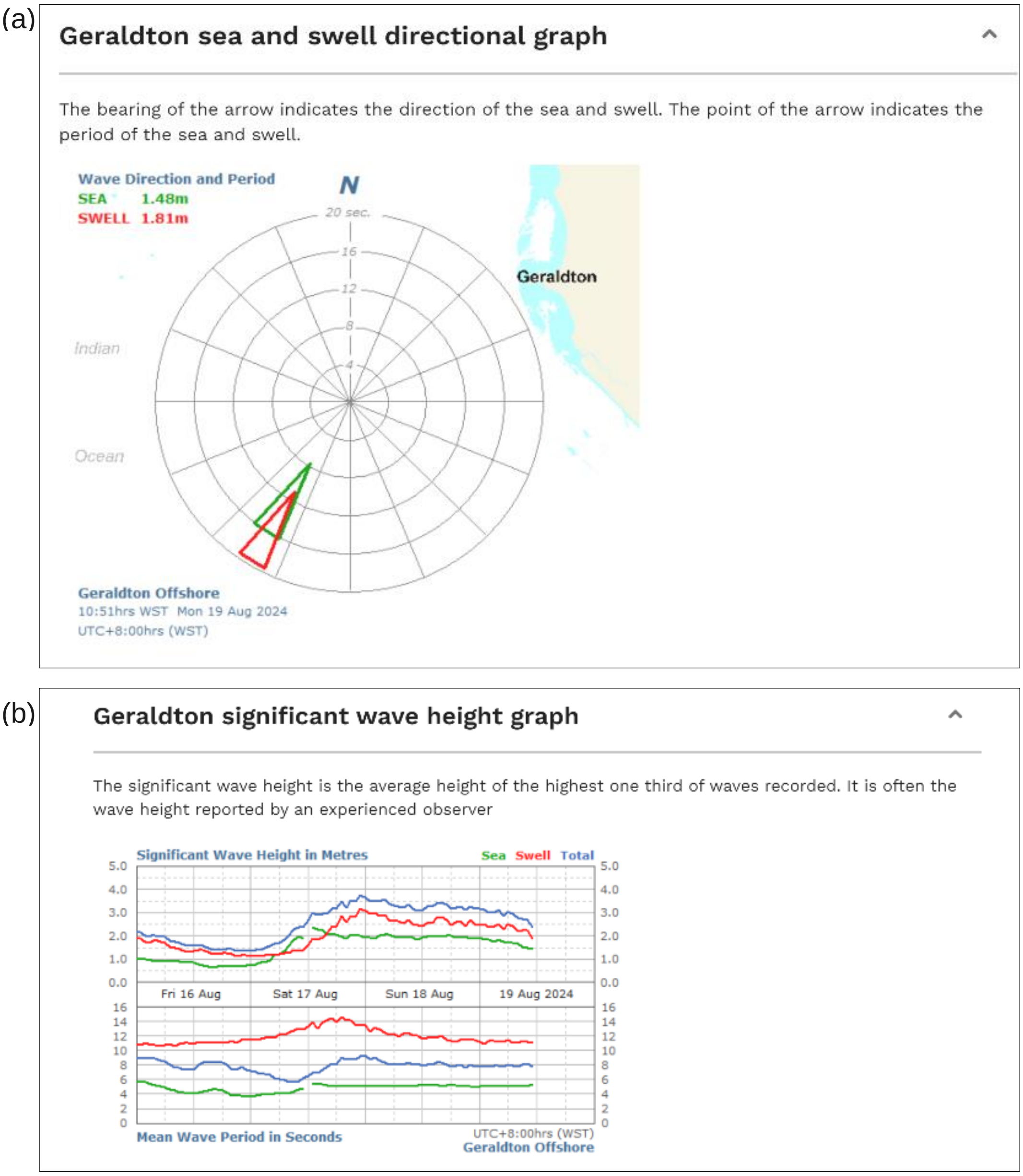


Figure 3. (a) A chart showing vessel traffic density in the area. (b) Locations of the Geraldton Directional Wave (GDW) Buoy and the shore station at the Batavia Coast Maritime Institute.

1.4. Real-time wave data

The data collected by Geraldton wave buoys is accessible on the DoT website providing near real-time wave information (https://www.transport.wa.gov.au/imarine/geraldton-wave-data.asp). This includes graphical representations of sea and swell wave directions, as well as significant wave height and period for Geraldton, which are updated approximately every 30 minutes (**Figure 4**). The near real-time wave data is sourced directly from the recording sites, and the graphical outputs are generated for the website using software developed by Tremarfon Pty Ltd.



(a)

Geraldton sea and swell directional graph

The bearing of the arrow indicates the direction of the sea and swell. The point of the arrow indicates the period of the sea and swell.

(b)

Geraldton significant wave height graph

The significant wave height is the average height of the highest one third of waves recorded. It is often the wave height reported by an experienced observer

Figure 4. Snapshots of real-time data displayed on the DoT website for the Geraldton wave station. (a) Geraldton sea and swell directional graph; (b) Geraldton significant wave height and period graph.

1.5. Purpose of the report

This report presents an analysis of the most recent directional wave data collected from the Geraldton wave station between April 01, 2023, and March 31, 2024, including a systematic dataset of wave heights, periods, and directional data that enable an in-depth examination of Geraldton wave characteristics.

2. Wave buoy

The wave measuring system is comprised of six main components, extending from the anchor weight on the sea floor to the top of the HF antenna (**Figure 5**). This system features the Datawell Directional MK III Waverider, a high-precision instrument manufactured in the Netherlands. It offers centimetre-level accuracy in measuring wave height and a 5-degree resolution for wave direction. Data from the Wave rider is transmitted HF radio signals, ensuring reliable and real-time communication of wave conditions. A description of the wave buoy instrument is provided in **Table 2**.

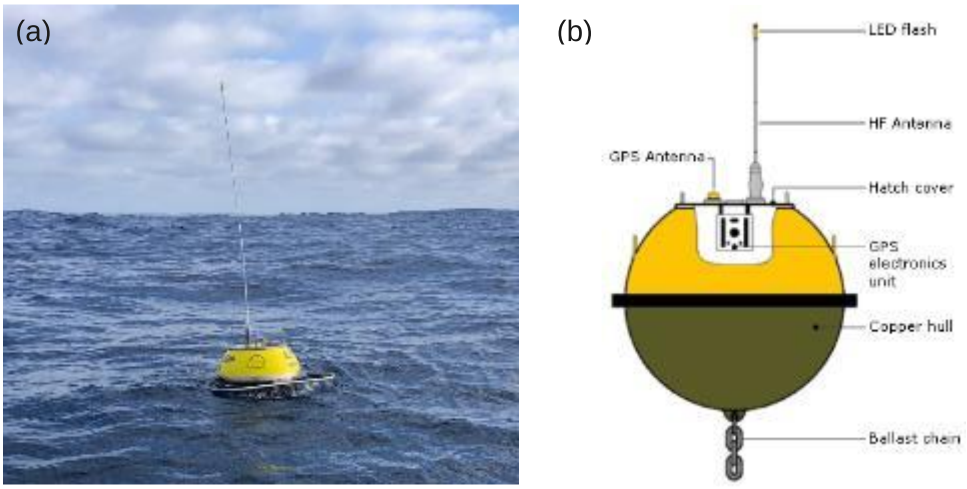


Figure 5. Components of a wave buoy system: (a) DoT wave buoy; (b) Diagram of inner and outer components (QGOV, 2024)

Table 2. Description of the Instrument

Instrument Type	Directional
Instrument Make	Datawell
Instrument Model	Directional Wave Rider MK III
Diameter	0.7m diameter
Material	Cunifer 10
Receiver Make	Datawell
Receiver Model	RX-C Receiver
Sampling frequency	1.28Hz

2.1. Wave buoy calibration

Prior to deployment, the wave buoy is calibrated using a calibration arm at Marine Operation Centre (MOC). The buoy is mounted on an arm that rotates to simulate wave conditions with a height of two meters (**Figure 6**). This arm can rotate through various periods, including 7-8 seconds, 10 seconds, 15 seconds, and 20 seconds. The system compares the measured wave heights and periods against the simulated values, examining any discrepancies between them. If necessary, calibration factors are computed from these discrepancies and applied during data processing to ensure accuracy of wave data.

The buoy accelerometer, which stays vertically aligned, is essential for measuring pitch and roll, and helps convert data from additional sensors into a fixed North-East-Vertical reference frame, as described by Gerritzen (1993). To maintain accuracy, wave buoys are calibrated both before and after deployment. According to Datawell recommendations, the DWR-MkIII and WR-SG models should be recalibrated every six years (Datawell, 2017).

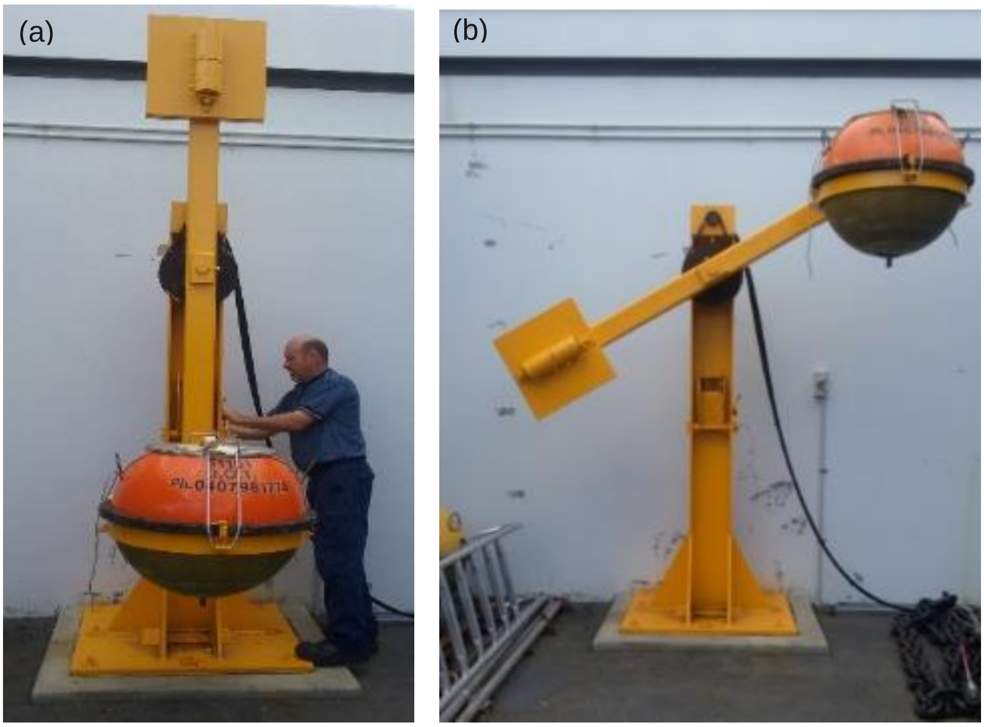


Figure 6. Wave buoy calibration using the calibration arm at the DoT's Marine Operations Centre (MOC).

2.2. Wave buoy preparation

The mooring configuration for the directional wave buoy, detailed in **Figure 7**, adheres to the manufacturer's specifications to ensure precise measurement of wave parameters.

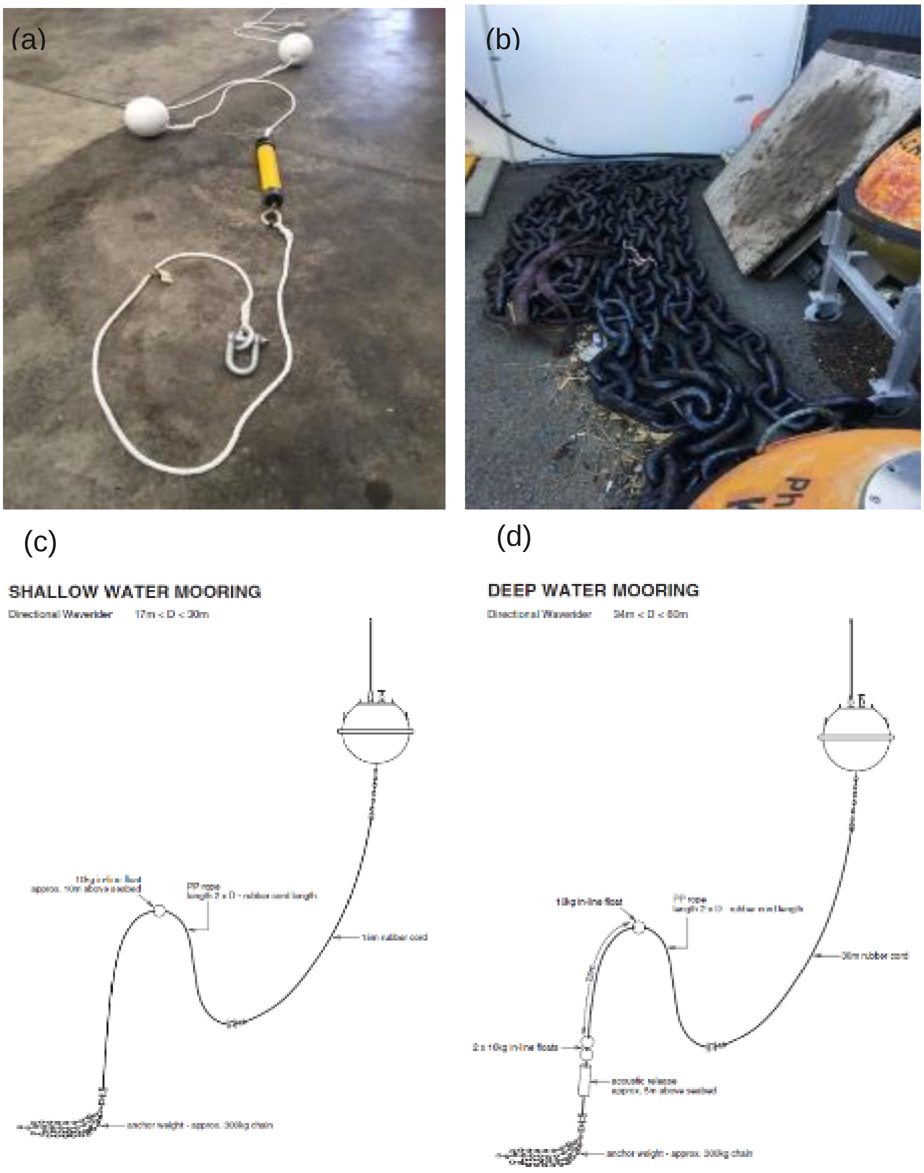


Figure 7. Mooring layout for the Directional Wave buoy: (a) Polypropylene rope with floats; (b) 300 kg anchor weight; (c) Shallow water mooring (Datawell, 2017); (d) Deep water mooring (Datawell, 2017).

The mooring system begins with an anchor weight, ideally composed of scrap chain, followed by a polypropylene rope equipped with floats. Specifically, the mooring includes an anchor weight and incorporates a rubber shock cord and a rope. This arrangement is designed to provide the necessary flexibility for the buoy to accurately track wave motion. A detailed description of the components of wave buoy mooring is given in the **Table 3**.

Table 3. Components of the wave buoy mooring

Mooring component	Description
Anchor chain	300 kg anchor weight with 36 mm stud link chain
Rubber shock code	Diameter of 27 mm rubber cord; length of 15 m for shallow water; 30m for deep water mooring
Polypropylene rope	Rope length is twice that of the rubber cord length
Two floats	A 10 kg in-line float for shallow water mooring, plus two additional 10kg floats for deep water mooring to ensure adequate buoyancy in ejecting the mooring line
Acoustic release	A remotely operated mechanical hook used to eject the entire mooring line except the anchor chain

2.3. Deployment

All procedures are in accordance with the manufacturer's guidelines to ensure precise and secure buoy deployment (Datawell, 2017). To deploy the buoy, position the ship at the designated location and reverse into the current to prevent the mooring line from interfering with the propeller. Lower the buoy from a height of approximately 3 meters, ensuring that the line has sufficient slack to avoid inverting the buoy. Gradually release the line as the buoy drifts away from the vessel, then deploy the anchor weight. Continue reversing the ship until it is sufficiently distanced from both the buoy and mooring line to avoid entanglement (**Figure 8**).

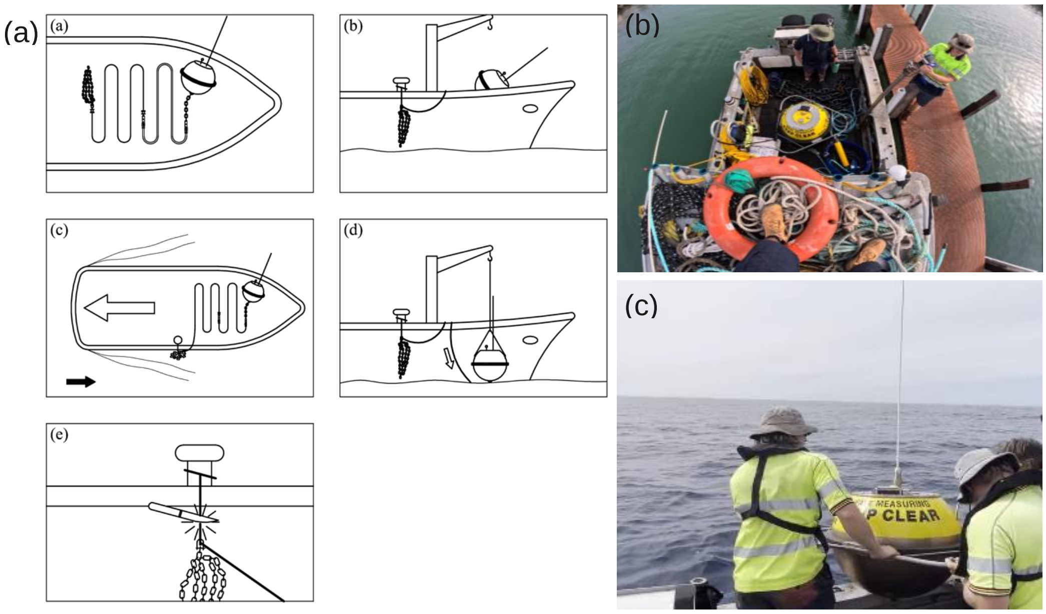


Figure 8. Buoy deployment: (a) Diagram illustrating the procedure (Datawell, 2017); (b) Buoy onboard at Geraldton before deployment; (c) Buoy deployment in progress at Geraldton.

2.4. Recovery

The recommended procedure for buoy recovery involves first retrieving the buoy, then the rubber cord, and finally the clump weight, which should be lifted using the polypropylene rope (Datawell, 2017). The rubber cord should not be used for lifting the mooring. Given that the rubber cord poses the greatest risk during recovery, it is essential to avoid stretching it to ensure safety.

2.5. Maintenance

Routine maintenance of the wave buoy is conducted annually. The procedure includes biofouling removal, instrumentation checks, servicing, and battery and mooring replacement (**Figure 9**). Even during short deployments, buoys accumulate biofouling, salt crystals, bird deposits, and sustain physical damage. While functionality remains largely unaffected, biofouling can increase drag forces. For buoys with temperature sensors, keeping the mooring eye free of marine growth is essential for optimal performance. Biofouling can be effectively removed using a standard pressure washer at 150 bars, which is also suitable for buoys equipped with solar panels (Datawell, 2017).

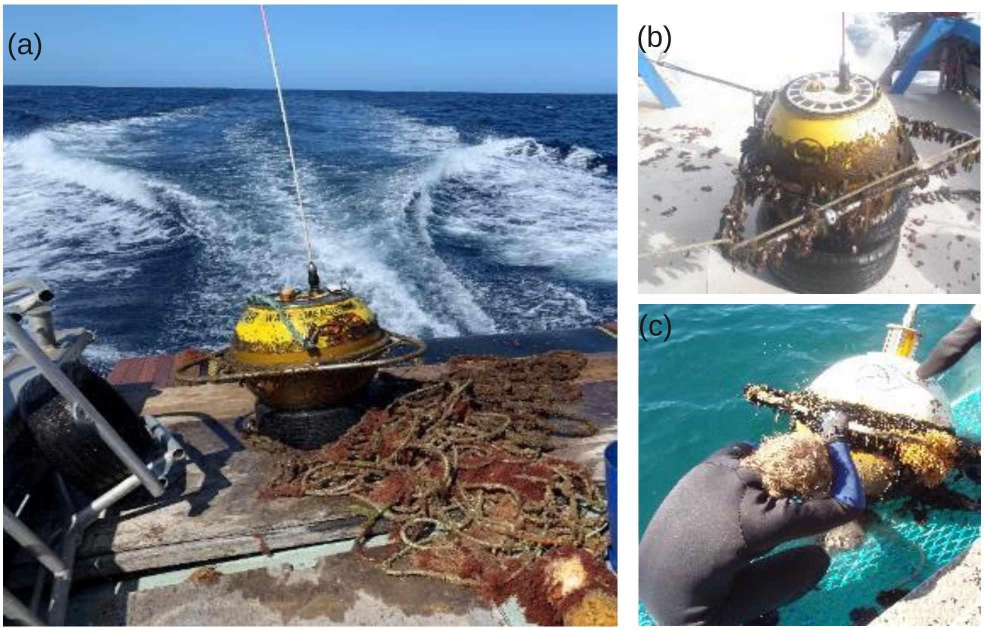


Figure 9. Recovery of the DoT buoy: (a) Buoy onboard after recovery; (b) Buoy covered with biofouling after recovery; (c) Removal of biofouling.

2.6. Safety measures of the wave buoy

After deploying the wave buoy, several precautions have been implemented to prevent the wave buoy from a drifting. The rubber cord used for mooring is prone to breakage, as even a small cut can lead to significant failure due to the cord's expansion. The fishing activities near the wave buoy can potentially damage the mooring line.

To enhance safety of the wave buoy, a warning sign indicates a 100-meter clearance zone around the buoy, stating, **KEEP CLEAR**. Additionally, a GPS tracker is mounted on the buoy hatch to monitor any drifting beyond a 500-meter diameter watch circle. The wave buoy is also equipped with a drifting alarm system to alert of any movement outside the designated area (watch circle). Furthermore, to improve the durability of the mooring system, a dyneema core rope has been integrated with the polypropylene rope, which is an additional measure currently employed in the Albany wave buoy.

3. Wave buoy data collection

The Wave Buoy data collection process at the DoT consists of several key steps. Initially, data measurements are obtained through the wave buoys. The on-buoy processed wave data are subsequently transmitted to a receiver located at the shore station, and then transmitted to the Wave PC at the DoT’s Marine Operations Centre (MOC). Following this, the processed and quality-controlled data are made available on DoT external website and archived within the DoT's database. A flowchart illustrating the wave data collection process at DoT is presented in **Figure 10**.

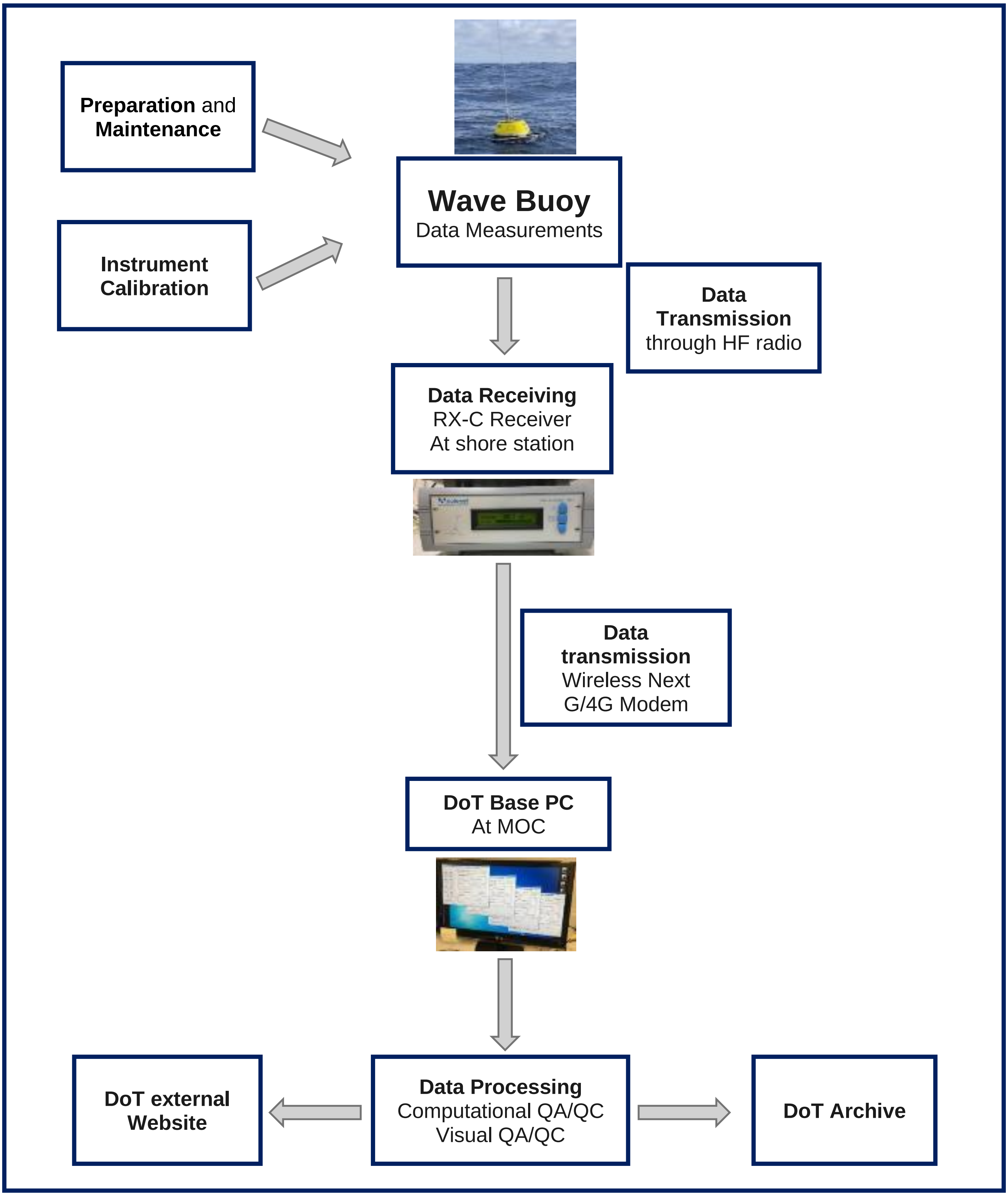


Figure 10. Flowchart illustrating the process of wave data collection within the DoT.

3.1. Data receiving

The directional buoy transmits processed directional data to a shore receiving station every 30 minutes, using Fourier analysis of the raw data as outlined by Datawell (2017). This processed data provides wave direction information at half-hour intervals. The RX-C, a dedicated HF link receiver with an Ethernet port and built-in embedded web server, offers flexibility and remote monitoring capabilities. The Batavia Coast Maritime Institute was selected as the shore station (**Figure 11**), among other proposed locations, due to its 100% line-of-sight with the buoy, ensuring reliable data transmission.

Figure 11. Data receiving setup at the Geraldton Shore station: (a) Receiving antenna on the roof; (b) The Batavia Coast Maritime Institute; (c) RX-C receiver in a cupboard; (d) Exterior of the cupboard; (e) DoT name tag on the cupboard with contact numbers.

4. Data measurement

Waves are present in all bodies of water and result from the orbital motion of water particles. They vary from long-period waves like tides, driven by the Sun and Moon's gravitational forces, to short wavelets caused by wind. Wave energy spans periods from 12 hours to 0.5 seconds, with a significant portion in the 0.5 to 30-second range, known as wind waves (**Figure 12**). At a given location, the wave environment often includes a mix of locally generated wind waves and long-period swell waves from distant storms.

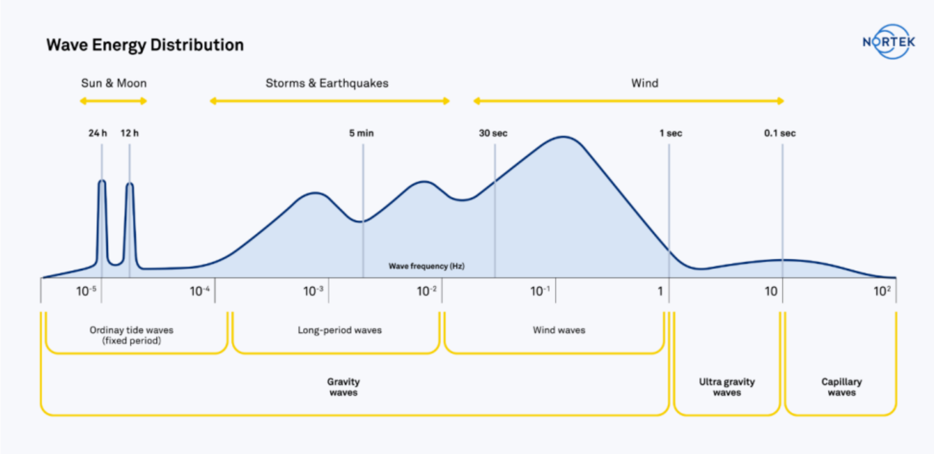


Figure 12. Types of surface waves and their generating forces, with blue shading indicating the relative energy of each frequency; more shading signifies greater energy (Source: Nortek).

Estimating wave parameters involves analysing the time series of sea surface displacement from a single measurement point to assess deviations from the mean water level. This process, known as the zero-crossing method, identifies individual waves by noting where the displacement crosses the mean level, thus defining the start and end of each wave. Wave characteristics, including period and height, are then determined from these crossings (**Figure 13**).

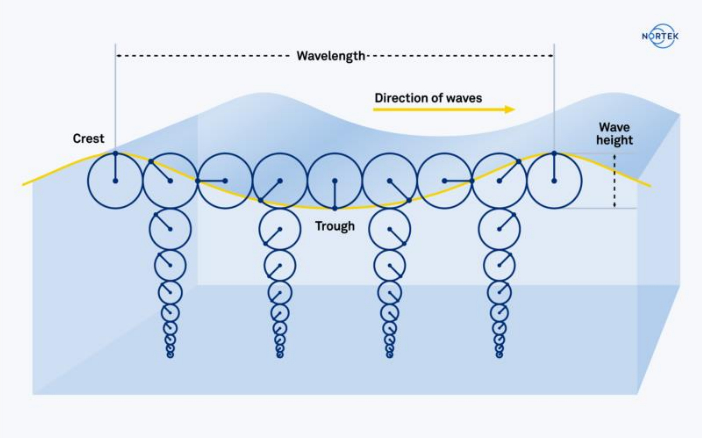


Figure 13. Wave parameters of an individual wave (Source: Nortek).

Significant wave height (Hs) is calculated as the average height of the highest 33 percent of waves recorded, while the Mean Period (Tm) represents the average period of all waves. Many wave-measuring instruments, however, lack the capability to directly measure surface displacement. Instead, these measure related properties such as pressure or velocity and infer sea state through spectral analysis. Spectral analysis yields parameters such as significant wave height (Hs), spectral peak period (Tp), and spectral mean period (Tm). To differentiate between sea and swell waves, a wave period threshold of 8 seconds is used (DPI, 2009). Waves with periods less than 8 seconds are classified as sea waves, while those with periods exceeding 8 seconds are identified as swell waves. This categorization allows for a detailed analysis that includes the Hs, Tp, and Tm for both sea and swell waves (**Figure 14**).

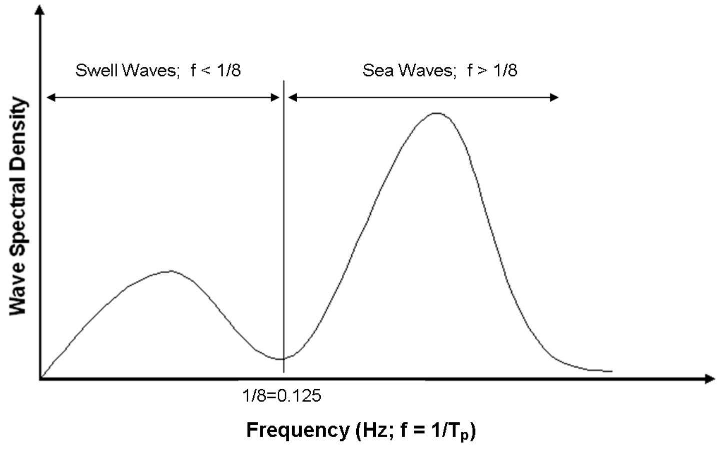


Figure 14. Wave spectrum showing swell and sea wave peaks, with an 8-second period (0.125 Hz) threshold for classification (Source: DPI, 2009).

4.1. Wave height

The DWR-MkIII uses a single accelerometer mounted on a gravity-stabilized platform to measure the vertical motion (heave) of the buoy. This accelerometer detects up-and-down movements, which are then processed through filtering and double integration to determine the wave height. The buoy follows the orbital motion of the water due to the equivalence between the mass of the buoy and the displaced water, ensuring precise wave monitoring (Datawell, 2017).

4.2. Wave direction

The DWR-MkIII buoy measures wave direction by combining fixed accelerometer data with heave motion and a compass. It uses an orbital following system to track the two-dimensional horizontal component of wave motions. However, mooring forces can cause deviations in the buoy movement, requiring a resilient mooring line for accuracy.

Wave direction is determined by correlating the buoy horizontal and vertical motions. Two perpendicular accelerometers measure horizontal movement, while pitch and roll sensors account for tilts using electromagnetic coupling with a coil on a stabilized platform (**Figure 15**). A fluxgate compass converts the data to north-west coordinates. The DWR-MkIII sensor package captures eight observables: three accelerations (Ax, Ay, Av), three magnetic field strengths (Hx, Hy, Hz), pitch, and roll, all referenced to specific axes for precise data collection (Datawell, 2017).

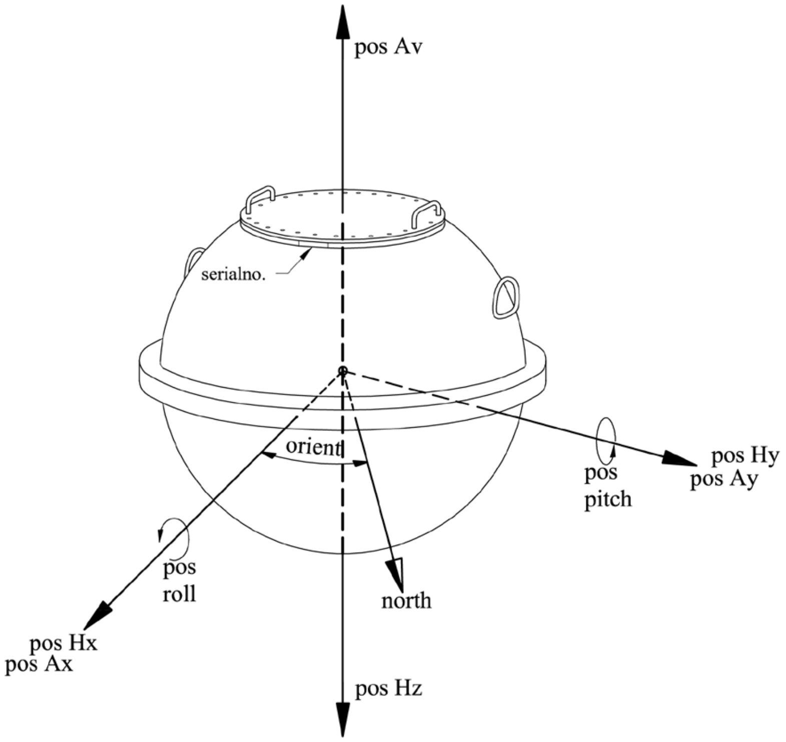


Figure 15. Definition of the axes and coordinate signs for the DWR-MkIII motion sensors, including the x, y, z, and vertical axes used for measuring accelerations, pitch, and roll (Source: Datawell, 2017).

5. Data processing

Raw data transmitted to the Marine Operations Centre (MOC) undergoes analysis using the Wave-by-Wave analysis, and Fast Fourier Transform (FFT) methods. The Wave-by-Wave analyses are used exclusively for quality control, while the FFT method calculates the energy spectrum. Directional data is derived from the 30-minute on-board processed data. The manual (Datawell, 2017) provides an in-depth description of the on-board data processing procedures.

6. Quality controlling and archiving

6.1. Computational quality controlling

The raw data is decoded and converted into ASCII files, generating parameters specific to the DoT. Automatic quality control is then conducted, and plots are produced for the DoT website.

6.2. Visual quality controlling

After a month of data collection and computational quality control, the Oceanographic Services team conducts a visual quality control review. This review involves plotting and examining the data and comparing it with information from nearby wave buoys to detect any anomalies. During this process, spikes are removed, and significant wave height values are verified. Data with uncertain validity is retained, while only those values clearly identified as erroneous are discarded. All detected errors and the corrective actions taken are documented to ensure data quality and facilitate future traceability. Additionally, any major events or issues affecting data capture are noted.

6.3. Data archiving

Following computational and visual quality control, the data is archived by the DoT for internal use. The data is provided to other users upon request.

7. Data analysis

The Quality controlled data were analysed using MATLAB to produce plots in this report. Geraldton wave data recovery monthly percentages for the year 2023 are listed in the **Table 4**. The data spanned from 00:21:00 on 01 April 2023 to 23:51:00 on 31 March 2024.

Table 4. Monthly percentage of directional wave data recovery at Geraldton in 2023-24.

Months	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Valid data percentage	99.31	95.90	99.93	99.87	97.58	**100.00**	99.40	99.51	99.26	99.26	99.43	99.06

Annual valid data percentage: **99.03**

During a twelve-month period in 2023-24 at Geraldton, the data recovery rates fluctuated across the various months. The highest recovery rate of 100% was recorded in September, indicating that all data was successfully recovered during this month. In contrast, the lowest recovery rate was 95.90%, observed in May. This reduction in recovery was partly due to equipment malfunctions, which also affected the data recovery process in August. The equipment failures during these months led to temporary disruptions in data collection, resulting in lower overall recovery rates compared to other months.

7.1. Wave and water level time series

Time series plots were produced for wave heights and tide water levels (**Figure 16**). The four subplots were plotted at first including the total significant wave height (Hs) and total mean period (Tm). For the second the swell significant wave height and mean period. For the third sea significant wave height and mean period. The fourth subplot was the corresponding water level measurements and residuals (Observed water level minus the predicted water level) for the tide gauge located in Geraldton. These plots enable a clear comparison of the contributions of sea, swell, and water levels during significant events. **Table 5** presents a summary of the total, swell, and sea wave statistics for Geraldton over a twelve-month period from 01 April 2023 to 31 March 2024.

Table 5. Summary of total, swell, and sea wave statistics at Geraldton from 01 April 2023 to 31 March 2024.

Months	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
Total Hs (m)	2.1	1.6	2.2	2.5	2.2	2.4	2.1	1.9	2.0	2.1	2.0	2.1	2.1
Swell Hs (m)	1.6	1.3	1.8	2.2	1.9	1.9	1.4	1.3	1.3	1.4	1.4	1.6	1.6
Sea Hs (m)	1.3	0.9	1.2	1.1	1.0	1.2	1.5	1.4	1.5	1.6	1.4	1.4	1.3
Total Tm (s)	7.5	7.4	8.0	9.2	8.9	8.5	6.9	6.8	6.6	6.5	6.8	7.2	7.5
Swell Tm (s)	11.6	12.1	11.7	12.5	12.3	12.1	11.5	10.9	10.9	10.8	10.6	11.5	11.5
Sea Tm (s)	4.7	4.2	4.7	4.8	4.6	4.8	4.8	4.9	4.9	4.9	5.0	4.7	4.8
Total Tp (s)	12.8	13.2	12.9	13.8	13.9	13.5	11.8	11.0	10.7	10.8	10.8	12.4	12.3
Swell Tp (s)	13.1	13.3	13.1	14.2	13.9	13.6	12.7	11.7	11.5	11.6	11.2	12.7	12.7
Sea Tp (s)	6.9	6.2	7.0	7.1	7.1	7.0	6.7	7.2	6.9	7.0	7.2	6.8	6.9
Swell Dir (º)	223	219	220	226	225	228	223	219	217	222	219	223	222
Sea Dir (º)	204	189	209	217	213	212	200	205	197	203	203	199	204

The annual mean offshore significant wave height (Hs) was measured at 2.1 m, the annual mean wave period (Tm) was 7.5 s, and the annual mean peak period (Tp) was 12.3 s at Geraldton. These measurements align with earlier studies of the offshore wave climate by Lemm et al. (1999), DPI (2009), and Roncevich et al. (2009).

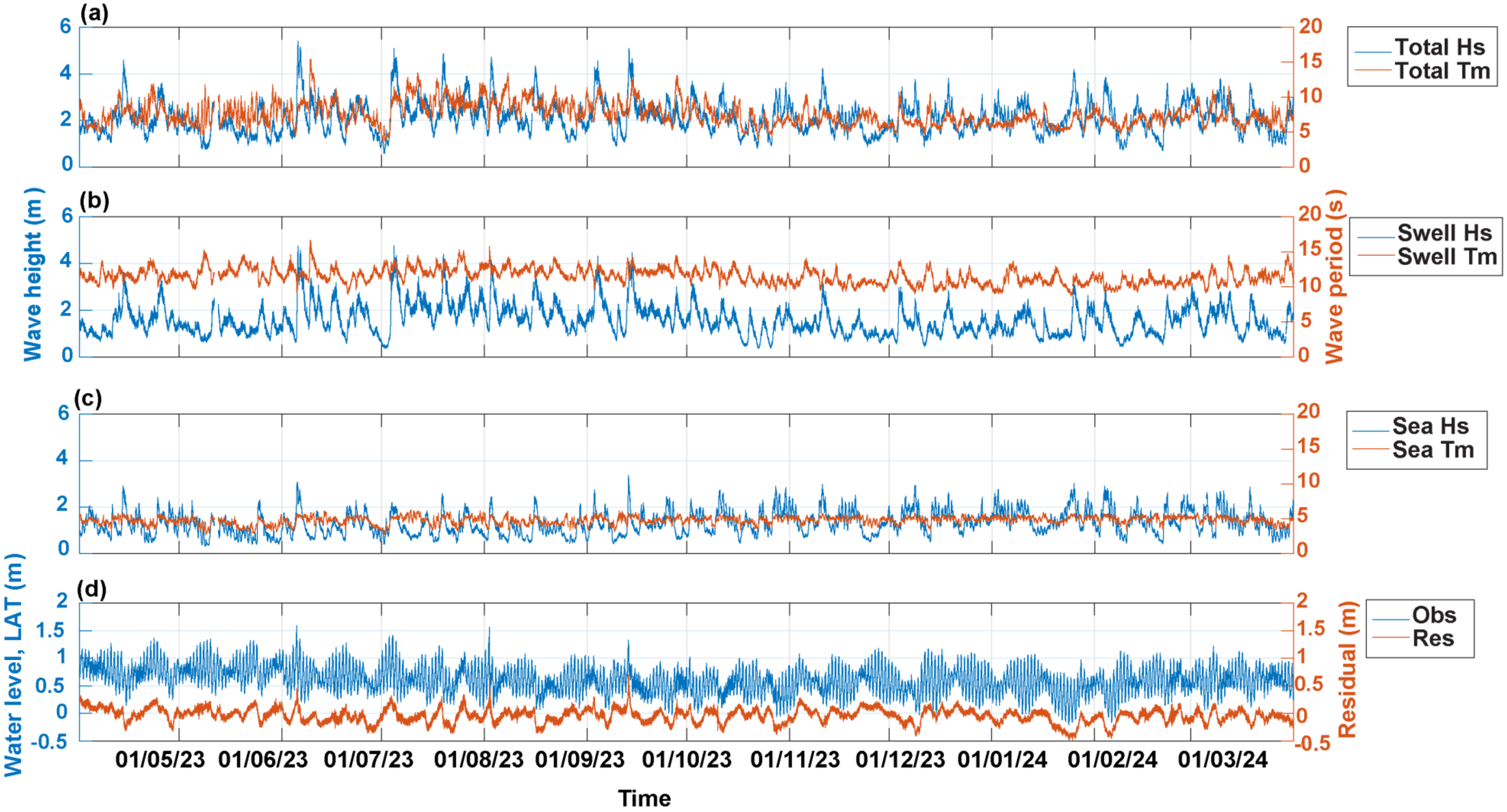


Figure 16. Time series plot of significant wave heights (Hs) and mean period (Tm) for total, swell, and sea wave data, along with observed and residual water levels from 01 April 2023 to 31 March 2024 at Geraldton. (Datum: Geraldton Lowest Astronomical Tide (LAT) 0.07m, unit: meters.)

7.2. Wave height distribution

All total significant wave height data were binned to find the occurrence and exceedance distribution from 01 April 2023 to 31 March 2024 (**Figure 17**). Then produced a histogram and cumulative frequency plot (red line). The wave height bins used were for significant wave heights from 0 metres to 10 metres with ranges of 0 metres to 0.2 metres; followed by 0.4 metre bin intervals for 0.2 metres to 9.8 metres; and then 9.8 metres to 10.0 metres. These plots are shown in Appendix B. The distribution of wave height variations by month was assessed by plotting the data for each calendar month, with the resulting plots provided in Appendix B.

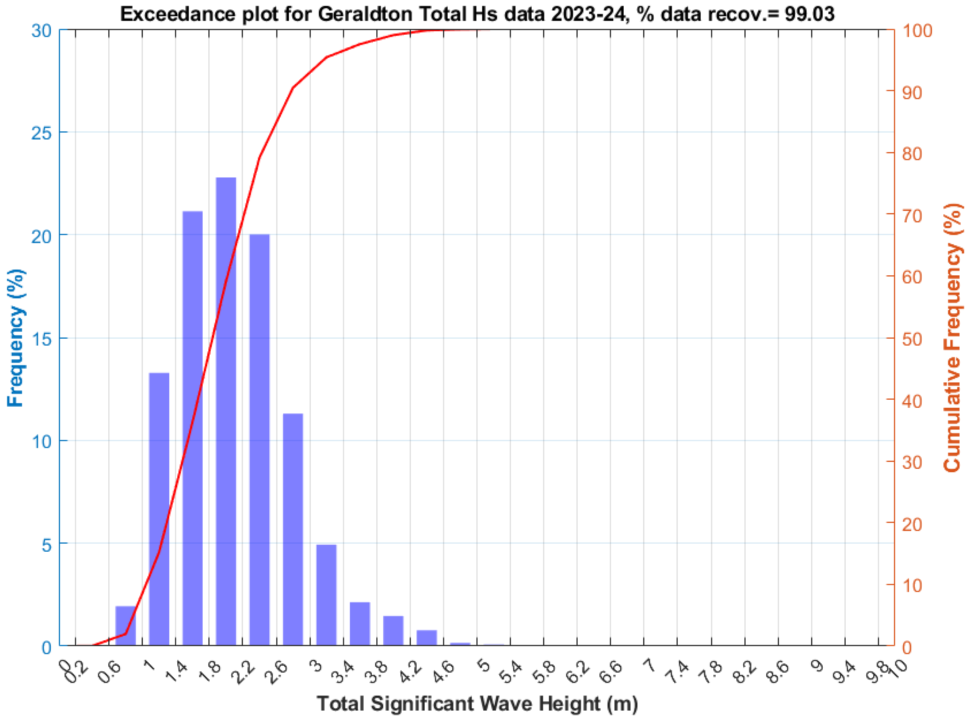


Figure 17. Occurrence and exceedance distribution of total significant wave height (Hs) from 01 April 2023 to 31 March 2024 for Geraldton wave data.

7.3. Wave period distribution

The distribution of peak wave periods from 01 April 2023 to 31 March 2024 was examined through the preparation of histogram and cumulative frequency plots showing the occurrence and exceedance of the peak period (Tp) for total wave data (**Figure 18**). The peak period data was binned for 0 second to 30 second peak periods with bin ranges of 1 second (0:1:30). Changes in the monthly distributions of peak periods was examined through the production of plots for all data from a month. These plots are shown in Appendix C.

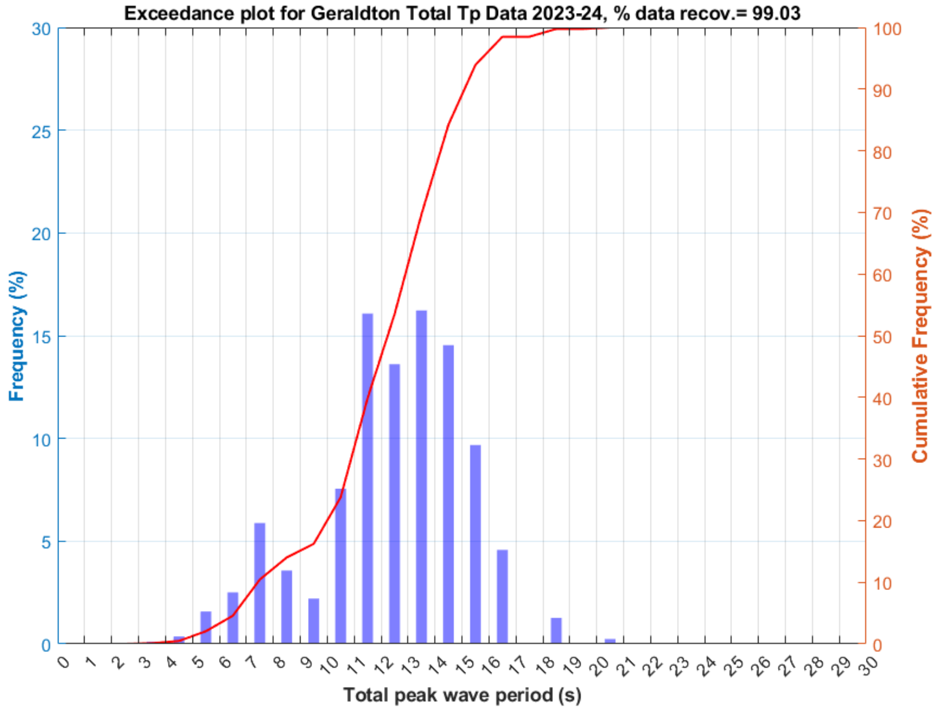


Figure 18. Peak period (Tp) occurrence and exceedance distribution from 01 April 2023 to 31 March 2024 for Geraldton wave data.

7.4. Joint wave height and period distribution

To investigate the joint occurrence of wave heights and periods, cross plots were generated illustrating the relationships between significant wave height and peak period (**Figure 19**), as well as between significant wave height and mean period (**Figure 20**). In addition, joint distributions were produced to indicate the percentage joint frequency of occurrence for these parameters: one for significant wave height and peak period (**Table 6**) and another for significant wave height and mean period (**Table 7**). The bin intervals for wave height and period in Table 6 and 7 were set at 0.25 meters and 2 seconds, respectively.

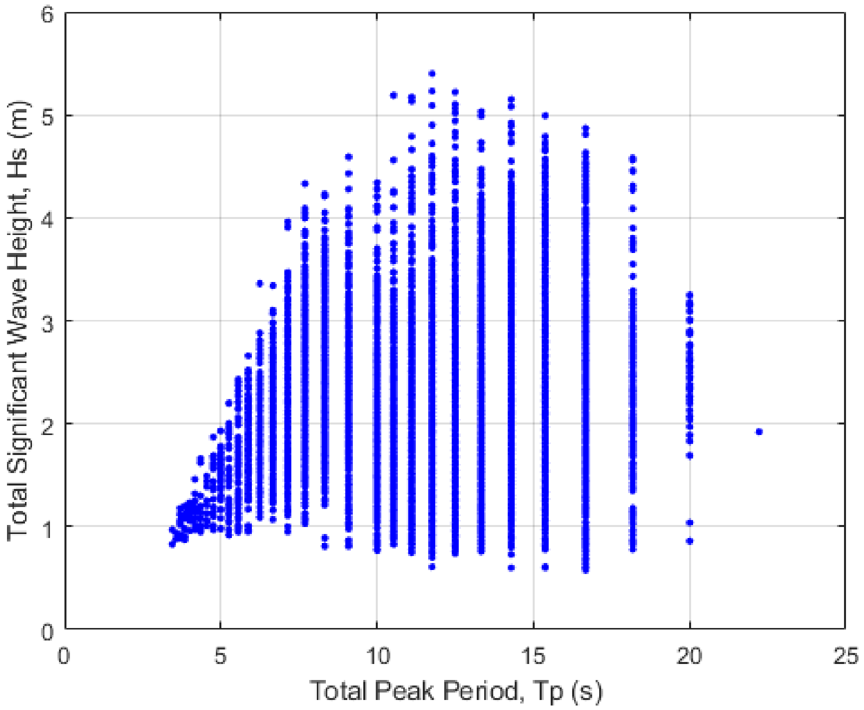


Figure 19. Over twelve-months period a cross plot of total significant wave height (Hs) versus total peak period (Tp) for Geraldton wave data from 01 April 2023 to 31 March 2024.

Table 6. Percentage joint occurrences of total significant wave height (Hs) and total peak period (Tp) for Geraldton wave data from 01 April 2023 to 31 March 2024. (Note. Red is used to indicate the highest percentage, followed by yellow, green, and blue for the lowest percentage).

Total significant wave heights Hs (m)	Total peak period Tp (s)												
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	TOTAL
0-0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.25-0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5-0.75	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.02	0.07	0.00	0.00	0.00	0.13
0.75-1	0.00	0.06	0.12	0.01	0.06	0.75	0.35	0.24	0.18	0.07	0.01	0.00	1.84
1-1.25	0.00	0.06	0.33	0.13	0.07	3.43	1.73	0.68	0.09	0.06	0.01	0.00	6.58
1.25-1.5	0.00	0.00	0.39	0.69	0.14	3.67	3.52	2.10	0.30	0.07	0.00	0.00	10.89
1.5-1.75	0.00	0.00	0.45	1.04	0.57	3.79	4.64	2.55	0.53	0.14	0.01	0.00	13.72
1.75-2	0.00	0.00	0.32	1.36	0.67	3.62	4.98	3.28	0.51	0.20	0.02	0.01	14.97
2-2.25	0.00	0.00	0.23	1.40	1.02	2.41	4.32	3.79	0.37	0.14	0.03	0.00	13.69
2.25-2.5	0.00	0.00	0.09	1.65	1.06	2.06	3.98	3.58	0.55	0.11	0.04	0.00	13.13
2.5-2.75	0.00	0.00	0.01	0.84	0.55	1.60	2.78	2.67	0.48	0.16	0.05	0.00	9.14
2.75-3	0.00	0.00	0.00	0.67	0.63	0.87	1.53	1.79	0.51	0.12	0.03	0.00	6.14
3-3.25	0.00	0.00	0.00	0.32	0.43	0.49	0.88	1.21	0.29	0.09	0.03	0.00	3.75
3.25-3.5	0.00	0.00	0.00	0.20	0.26	0.37	0.42	0.69	0.12	0.02	0.01	0.00	2.08
3.5-3.75	0.00	0.00	0.00	0.05	0.18	0.15	0.24	0.41	0.13	0.02	0.00	0.00	1.17
3.75-4	0.00	0.00	0.00	0.03	0.07	0.12	0.20	0.51	0.15	0.03	0.00	0.00	1.11
4-4.25	0.00	0.00	0.00	0.02	0.04	0.12	0.13	0.34	0.13	0.01	0.00	0.00	0.79
4.25-4.5	0.00	0.00	0.00	0.01	0.01	0.08	0.06	0.22	0.09	0.02	0.00	0.00	0.50
4.5-4.75	0.00	0.00	0.00	0.00	0.01	0.05	0.03	0.07	0.06	0.01	0.00	0.00	0.22
4.75-5	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.01	0.00	0.00	0.00	0.08
5-5.25	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.02	0.00	0.00	0.00	0.00	0.07
5.25-5.5	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
5.5-5.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.75-6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	0.00	0.11	1.94	8.39	5.78	23.63	29.84	24.21	4.57	1.27	0.24	0.01	100.00

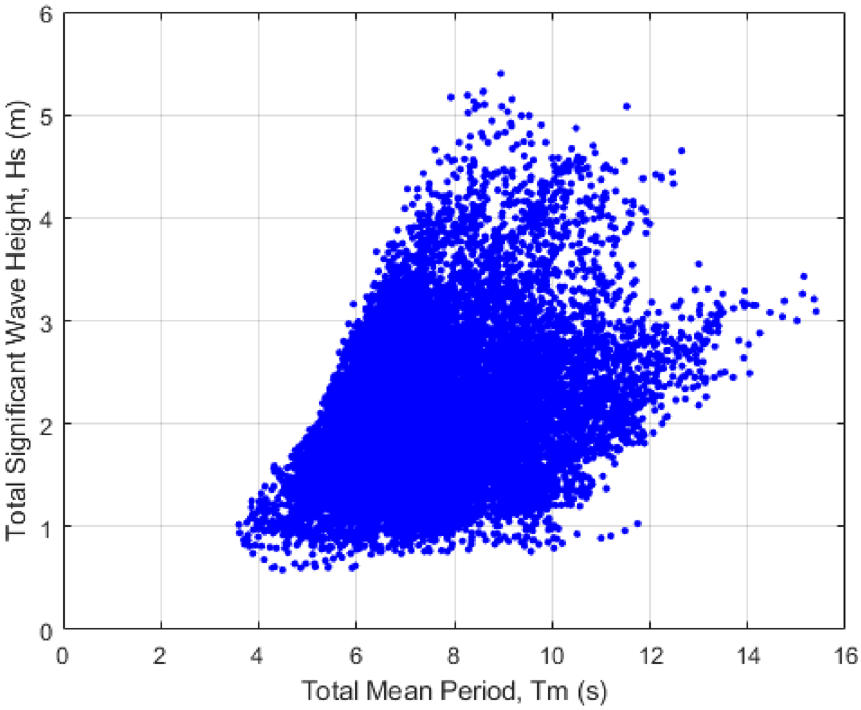


Figure 20. Over twelve-months period a cross plot of total significant wave height (Hs) versus total mean period (Tm) for Geraldton wave data from 01 April 2023 to 31 March 2024.

Table 7. Percentage joint occurrences of total significant wave height (Hs) and total mean period (Tm) for Geraldton wave data from 01 April 2023 to 31 March 2024. (Note. Red is used to indicate the highest percentage, followed by yellow, green, and blue for the lowest percentage).

Total significant wave heights Hs (m)	Total mean period Tm (s)								
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	TOTAL
0-0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.25-0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5-0.75	0.00	0.01	0.11	0.01	0.00	0.00	0.00	0.00	0.13
0.75-1	0.00	0.07	0.66	0.86	0.20	0.06	0.00	0.00	1.84
1-1.25	0.00	0.06	1.69	3.71	1.07	0.05	0.00	0.00	6.58
1.25-1.5	0.00	0.01	3.54	4.44	2.57	0.33	0.00	0.00	10.89
1.5-1.75	0.00	0.00	3.63	6.66	2.84	0.59	0.00	0.00	13.72
1.75-2	0.00	0.00	2.66	7.90	3.41	0.99	0.01	0.00	14.97
2-2.25	0.00	0.00	2.08	6.69	3.55	1.32	0.05	0.00	13.69
2.25-2.5	0.00	0.00	1.30	6.87	3.59	1.18	0.18	0.01	13.13
2.5-2.75	0.00	0.00	0.30	5.33	2.28	0.97	0.25	0.00	9.14
2.75-3	0.00	0.00	0.09	3.53	1.57	0.69	0.25	0.01	6.14
3-3.25	0.00	0.00	0.01	2.07	1.18	0.32	0.13	0.05	3.75
3.25-3.5	0.00	0.00	0.00	1.01	0.80	0.24	0.02	0.01	2.08
3.5-3.75	0.00	0.00	0.00	0.48	0.53	0.15	0.01	0.00	1.17
3.75-4	0.00	0.00	0.00	0.34	0.56	0.20	0.01	0.00	1.11
4-4.25	0.00	0.00	0.00	0.16	0.41	0.22	0.00	0.00	0.79
4.25-4.5	0.00	0.00	0.00	0.04	0.25	0.18	0.03	0.00	0.50
4.5-4.75	0.00	0.00	0.00	0.02	0.10	0.09	0.01	0.00	0.22
4.75-5	0.00	0.00	0.00	0.00	0.07	0.01	0.00	0.00	0.08
5-5.25	0.00	0.00	0.00	0.01	0.06	0.01	0.00	0.00	0.07
5.25-5.5	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
5.5-5.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.75-6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	0.00	0.14	16.08	50.12	25.07	7.59	0.94	0.07	100.00

The offshore wave climate in Geraldton is illustrated by joint distributions of significant wave height versus peak period (**Table 6**) and significant wave height versus mean period (**Table 7**). The table of significant wave height versus peak period indicates a higher percentage of waves with significant heights ranging from 1.25 to 3 meters and peak periods between 12 and 15 seconds. Meanwhile, the table of significant wave height versus mean period reveals that significant wave heights of 1.5 to 3 meters are typically associated with mean wave periods ranging from 6 to 8 seconds.

7.5. Wave height directional analysis

To examine the relationship between wave height and direction, wave roses for directional sea and swell wave data from 01 April 2023 to 31 March 2024 were produced and are shown in **Figure 21** (**Table 8**) and Figure 22 (**Table 9**). Additionally, the monthly variations in the relationship between wave height and direction were analysed by creating monthly wave roses (Appendix D) for significant wave heights of both sea and swell. The wave height data was binned in 0.5 metre intervals from 0 metres to 6 metres and the direction data was divided in to 16 subdivisions for wave height and direction wave roses.

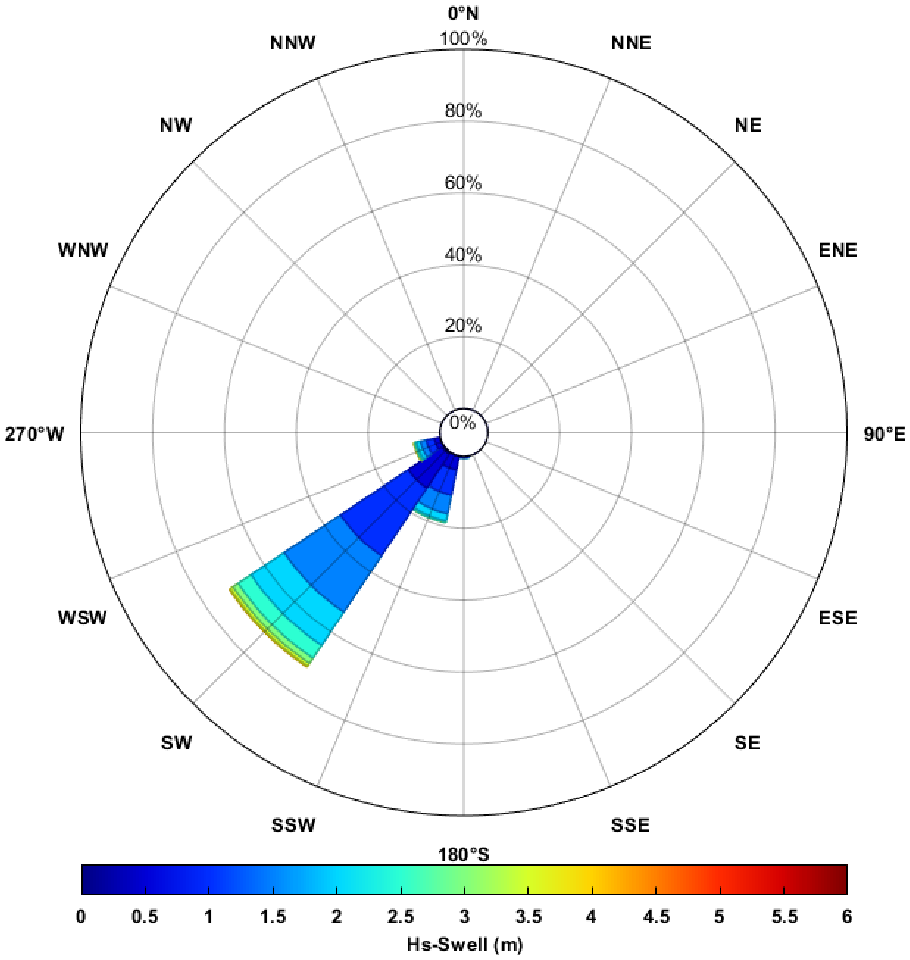


Figure 21. Over twelve-months period wave rose for significant wave height and direction of swell waves recorded at Geraldton from 01 April 2023 to 31 March 2024.

Table 8. Percentage occurrence of swell significant wave height versus swell wave direction from 01 April 2023 to 31 March 2024. (Note. Data recovery= 99.03%, and red is used to indicate the highest percentage, followed by yellow, green, and blue for the lowest percentage).

Direction Interval	Avg. Direction	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-Inf	TOTAL
348.75, 11.25	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11.25, 33.75	22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
33.75, 56.25	45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
56.25, 78.75	67.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
78.75, 101.25	90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
101.25, 123.75	112.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
123.75, 146.25	135	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
146.25, 168.75	157.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
168.75, 191.25	180	0.01	0.06	0.19	0.17	0.09	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.54
191.25, 213.75	202.5	0.15	3.79	7.13	5.29	2.04	0.53	0.04	0.01	0.01	0.00	0.00	0.00	0.00	18.98
213.75, 236.25	225	0.59	11.34	22.69	18.84	11.11	4.30	1.75	0.94	0.30	0.02	0.00	0.00	0.00	71.88
236.25, 258.75	247.5	0.14	1.55	2.32	1.62	1.12	0.46	0.14	0.18	0.09	0.00	0.00	0.00	0.00	7.63
258.75, 281.25	270	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
281.25, 303.75	292.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
303.75, 326.25	315	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
326.25, 348.75	337.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0, 360	TOTAL	0.89	16.75	32.33	25.92	14.35	5.32	1.93	1.13	0.40	0.02	0.00	0.00	0.00	**99.03**

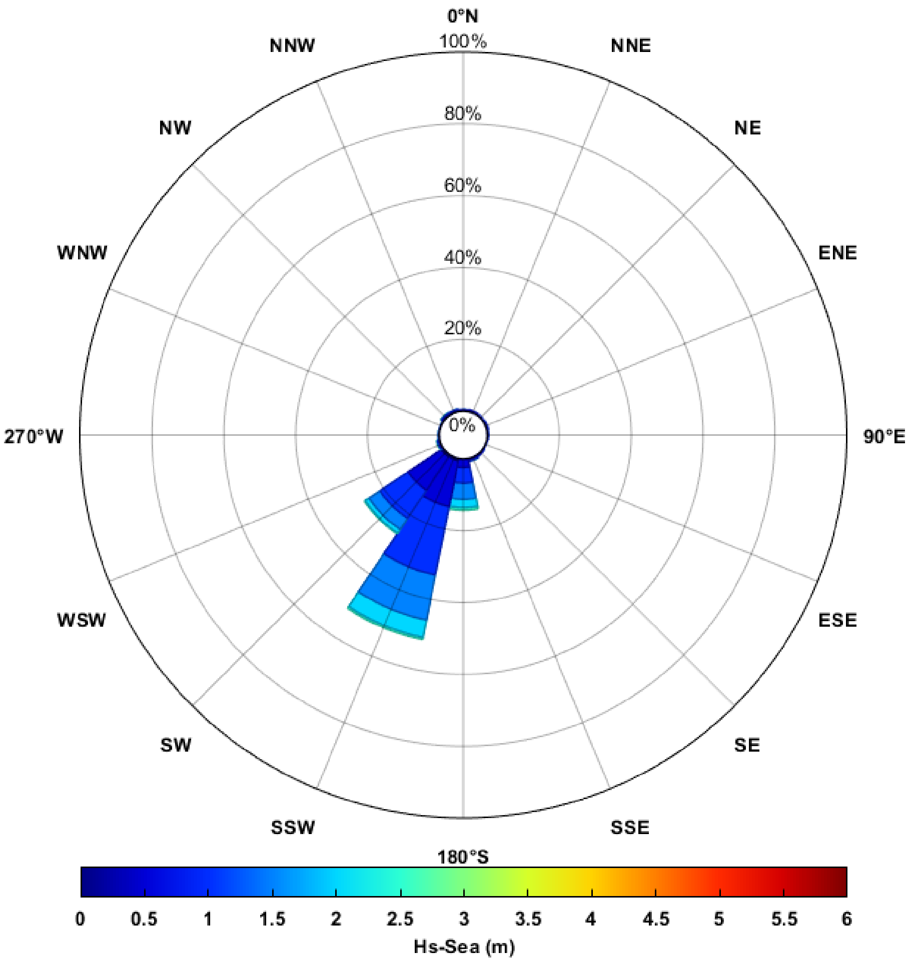


Figure 22. Over twelve-months period wave rose for significant wave height and direction of sea waves recorded at Geraldton from 01 April 2023 to 31 March 2024.

Table 9. Percentage occurrence of sea significant wave height versus sea wave direction from 01 April 2023 to 31 March 2024. (Note. Data recovery= 99.03%, and red is used to indicate the highest percentage, followed by yellow, green, and blue for the lowest percentage).

Direction Interval	Avg. Direction	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-Inf	TOTAL
348.75, 11.25	0	0.03	0.18	0.19	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45
11.25, 33.75	22.5	0.03	0.38	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52
33.75, 56.25	45	0.00	0.20	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42
56.25, 78.75	67.5	0.00	0.21	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
78.75, 101.25	90	0.04	0.15	0.14	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36
101.25, 123.75	112.5	0.00	0.09	0.09	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18
123.75, 146.25	135	0.01	0.34	0.15	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
146.25, 168.75	157.5	0.00	0.38	0.44	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.90
168.75, 191.25	180	0.04	2.27	4.41	4.52	2.29	0.74	0.01	0.00	0.00	0.00	0.00	0.00	0.00	14.27
191.25, 213.75	202.5	0.57	13.05	19.43	12.80	4.92	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.37
213.75, 236.25	225	0.66	11.14	9.47	3.68	1.25	0.23	0.01	0.00	0.00	0.00	0.00	0.00	0.00	26.44
236.25, 258.75	247.5	0.09	0.13	0.40	0.13	0.11	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.94
258.75, 281.25	270	0.02	0.11	0.06	0.07	0.01	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32
281.25, 303.75	292.5	0.01	0.05	0.08	0.05	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.22
303.75, 326.25	315	0.02	0.32	0.31	0.18	0.02	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.91
326.25, 348.75	337.5	0.06	0.22	0.39	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73
0, 360	TOTAL	1.57	29.21	36.14	21.66	8.63	1.73	0.08	0.00	0.00	0.00	0.00	0.00	0.00	**99.03**

7.6. Wave period directional analysis

Wave roses were produced for sea and swell using mean wave period and direction data in 2023 to examine the relationship between mean wave period and direction (**Figure 23**; **Table 10**, **Figure 24**; **Table 11**). Monthly variation of wave period with direction was examined through the production of monthly wave period and direction wave roses. Plots are shown in Appendix D. The direction data was divided in to 16 subdivisions for the mean wave period and direction wave roses. Swell mean wave period data was binned in two second intervals for periods of 8 seconds to 20 seconds and sea mean wave period data was binned in one second intervals for periods of 0 seconds to 8 seconds.

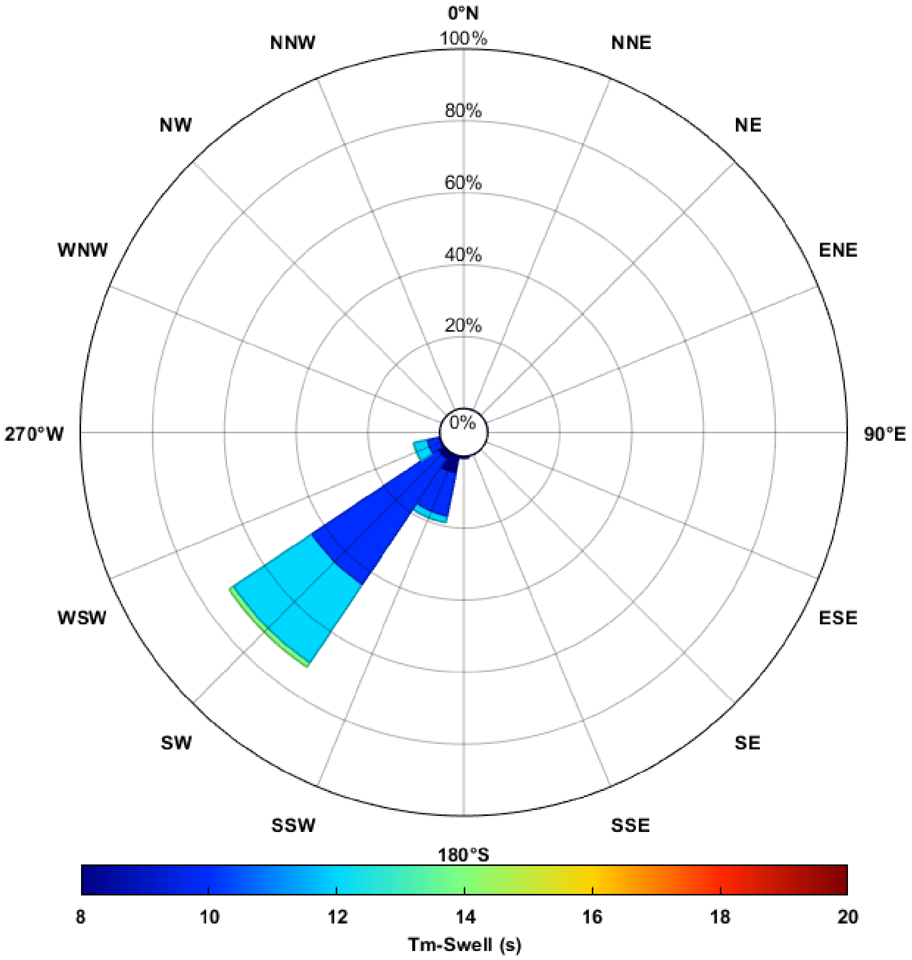


Figure 23. Over twelve-months period wave rose for mean wave period and direction of swell wave data collected at Geraldton from 01 April 2023 to 31 March 2024.

Table 10. Percentage occurrence of swell mean period versus swell wave direction from 01 April 2023 to 31 March 2024. (Note. Data Recovery= 99.03%, and red is used to indicate the highest percentage, followed by yellow, green, and blue for the lowest percentage).

Direction Interval	Avg. Direction	8-10	10-12	12-14	14-16	16-18	18-20	20-Inf	TOTAL
348.75, 11.25	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11.25, 33.75	22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
33.75, 56.25	45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
56.25, 78.75	67.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
78.75, 101.25	90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
101.25, 123.75	112.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
123.75, 146.25	135	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
146.25, 168.75	157.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
168.75, 191.25	180	0.26	0.28	0.00	0.00	0.00	0.00	0.00	0.54
191.25, 213.75	202.5	4.72	12.24	1.98	0.04	0.00	0.00	0.00	18.98
213.75, 236.25	225	1.82	42.30	26.22	1.52	0.02	0.00	0.00	71.88
236.25, 258.75	247.5	0.15	3.57	3.81	0.10	0.00	0.00	0.00	7.63
258.75, 281.25	270	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
281.25, 303.75	292.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
303.75, 326.25	315	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
326.25, 348.75	337.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0, 360	TOTAL	6.96	58.39	32.01	1.66	0.02	0.00	0.00	**99.03**

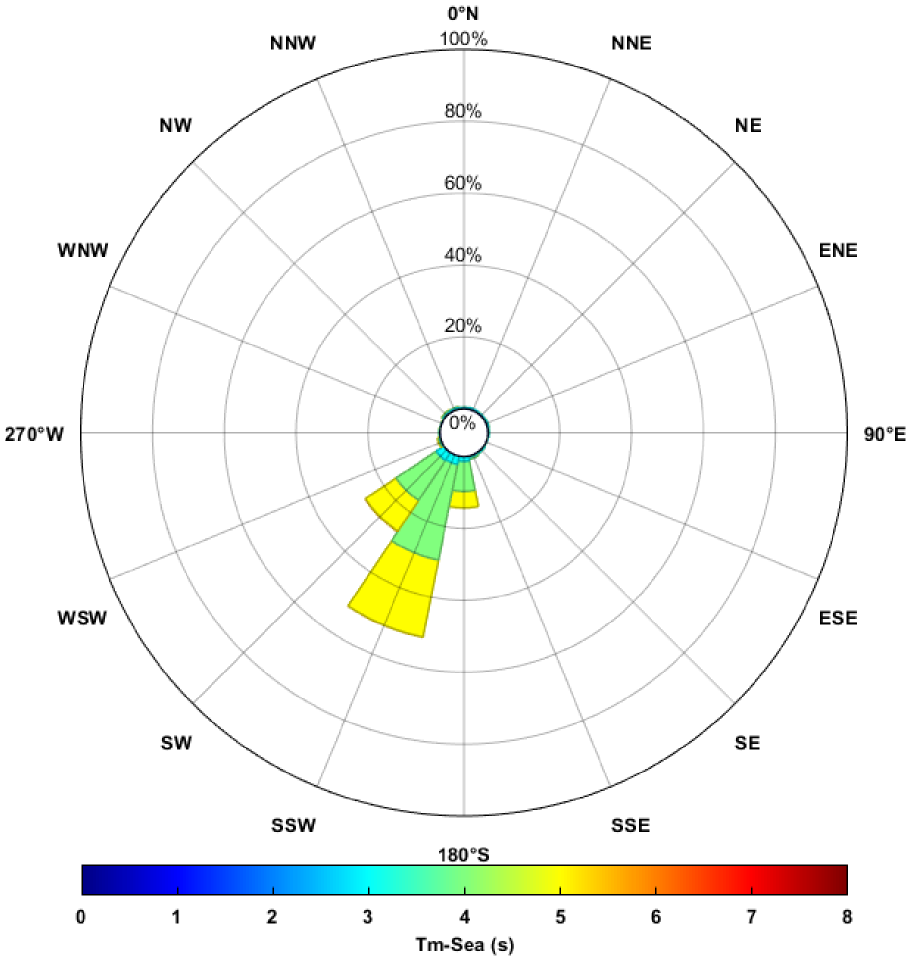


Figure 24. Over twelve-months period wave rose showing mean wave periods and directions of sea waves collected at Geraldton from 01 April 2023 to 31 March 2024.

Table 11. Percentage occurrence of sea mean period versus sea wave direction from 01 April 2023 to 31 March 2024. (Note. Data recovery= 99.03%, and red is used to indicate the highest percentage, followed by yellow, green, and blue for the lowest percentage).

Direction Interval	Avg. Direction	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-Inf	TOTAL
348.75, 11.25	0	0.00	0.00	0.01	0.36	0.08	0.00	0.00	0.00	0.00	0.45
11.25, 33.75	22.5	0.00	0.00	0.06	0.45	0.01	0.00	0.00	0.00	0.00	0.52
33.75, 56.25	45	0.00	0.00	0.01	0.36	0.05	0.00	0.00	0.00	0.00	0.42
56.25, 78.75	67.5	0.00	0.00	0.01	0.42	0.07	0.00	0.00	0.00	0.00	0.50
78.75, 101.25	90	0.00	0.00	0.04	0.24	0.08	0.00	0.00	0.00	0.00	0.36
101.25, 123.75	112.5	0.00	0.00	0.00	0.14	0.04	0.00	0.00	0.00	0.00	0.18
123.75, 146.25	135	0.00	0.00	0.00	0.37	0.13	0.00	0.00	0.00	0.00	0.50
146.25, 168.75	157.5	0.00	0.00	0.00	0.36	0.54	0.01	0.00	0.00	0.00	0.90
168.75, 191.25	180	0.00	0.00	0.00	1.27	8.34	4.65	0.00	0.00	0.00	14.27
191.25, 213.75	202.5	0.00	0.00	0.00	2.32	27.15	21.86	0.05	0.00	0.00	51.37
213.75, 236.25	225	0.00	0.00	0.00	2.61	13.38	10.33	0.11	0.00	0.00	26.44
236.25, 258.75	247.5	0.00	0.00	0.00	0.17	0.35	0.42	0.00	0.00	0.00	0.94
258.75, 281.25	270	0.00	0.00	0.01	0.16	0.09	0.06	0.00	0.00	0.00	0.32
281.25, 303.75	292.5	0.00	0.00	0.00	0.06	0.14	0.03	0.00	0.00	0.00	0.22
303.75, 326.25	315	0.00	0.00	0.03	0.34	0.47	0.07	0.00	0.00	0.00	0.91
326.25, 348.75	337.5	0.00	0.00	0.05	0.39	0.28	0.01	0.00	0.00	0.00	0.73
0, 360	TOTAL	0.00	0.00	0.21	10.02	51.20	37.44	0.17	0.00	0.00	**99.03**

In the analysed data, swell waves predominantly approach from the southwest (SW: 225°), accounting for approximately 72% of occurrences. A smaller proportion, around 19%, arrive from the south-southwest (SSW: 202.5°). These swell waves generally have significant wave heights between 0.5 and 3 meters, with mean periods ranging from 8 to 14 seconds. Sea waves, on the other hand, about 51% of them come from the south-southwest (SSW: 202.5°), and 26% approach from the southwest (SW: 225°). The significant wave heights for sea waves typically range from 0.5 to 2 meters, with mean periods between 3 and 6 seconds.

7.7. Large wave events

The threshold for large wave events (storm events) at the wave buoy locations was established using a statistical approach (Li et al., 2011; 2012; Wandres, et al., 2017).

Storm peak threshold (Hs_storm_peak) = mean + 2SD

Storm duration threshold (Hs_dur) = mean + SD

(The mean and standard deviation (SD) of significant wave height Hs from 01 April 2023 to 31 March 2024).

Commonly used thresholds for defining large wave events vary by study location, such as Hs > 4 m (Lemm et al., 1999) and Hs > 4.09 m (Li et al., 2011). Three criteria to define a large wave event (storm event), must be met simultaneously for wave height (Li, et al., 2011; 2012). First, at least one recording must exceed the storm peak threshold (Hs_storm_peak). Second, storm duration is the period during which recordings exceed the duration threshold (Hs_dur). This is shown in **Figure 25**, which is sourced from Li et al. (2011). Third, the interval between consecutive storms must be at least 30 hours from peak to peak; otherwise, they are considered part of the same storm. Additionally, the break between storms must be at least 3 hours; otherwise, it is seen as a continuation of a single storm.

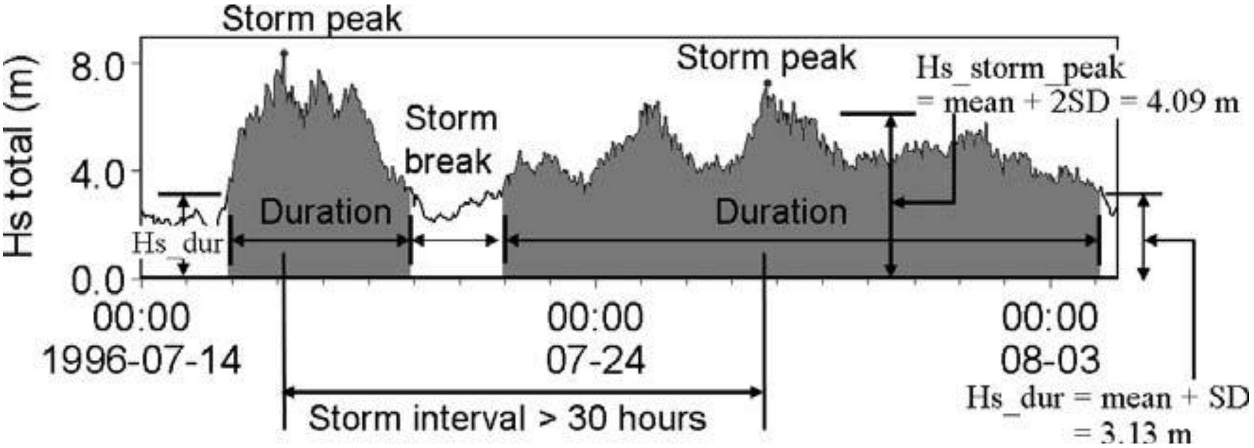


Figure 25. Diagram illustrating the threshold for large wave events (Source: Li, et al., 2011).

The analysis of the Geraldton wave buoy dataset identified the thresholds for significant wave events, with Hs_storm_peak=3.48 m and Hs_dur=2.79 m. During the observed period, 24 large wave events (not shown) were recorded at the Geraldton location; however, only the top 15 events are displayed in **Table 12**; and only the top 10 events are shown in **Figure 26**. Additionally, the residual water level (non-tidal water level) is shown using DoT tidal data, which was derived by subtracting the predicted tides from the observed water levels at Geraldton (**Figure 16**,**Figure 26**).

Table 12. Top 15 large wave events determined at Geraldton ranked by significant wave height from 01 April 2023 to 31 March 2024.

Large wave Events	Start time	End time	Hs_storm_peak (m)	Hs_dur (hr)	Tp (s)	Direction	Residual level (m)	Rank
1	13-Apr-2023 20:21:00	15-Apr-2023 11:51:00	4.59	39.5	9.09	222	-0.30	6
2	05-Jun-2023 11:51:00	07-Jun-2023 16:51:00	5.40	53.0	11.76	231	0.46	1
3	03-Jul-2023 20:21:00	06-Jul-2023 13:21:00	5.08	65.0	14.29	232	0.32	3
4	19-Jul-2023 02:21:00	20-Jul-2023 21:51:00	4.87	43.5	16.67	232	0.30	4
5	25-Jul-2023 17:21:00	27-Jul-2023 17:51:00	3.90	48.5	16.67	235	0.08	11
6	02-Aug-2023 16:21:00	04-Aug-2023 05:21:00	4.72	37.0	11.76	212	0.66	5
7	15-Aug-2023 13:51:00	17-Aug-2023 08:51:00	4.34	43.0	10.00	224	-0.36	8
8	03-Sep-2023 00:51:00	05-Sep-2023 10:51:00	4.55	58.0	15.38	225	0.29	7
9	13-Sep-2023 02:51:00	15-Sep-2023 15:51:00	5.09	61.0	11.76	233	0.69	2
10	10-Nov-2023 14:51:00	12-Nov-2023 01:21:00	4.23	34.5	13.33	226	-0.24	9
11	08-Dec-2023 16:21:00	09-Dec-2023 06:51:00	3.75	14.5	8.33	188	-0.41	15
12	18-Dec-2023 14:51:00	19-Dec-2023 04:51:00	3.81	14.0	9.09	204	-0.01	13
13	25-Jan-2024 01:21:00	27-Jan-2024 02:21:00	4.18	49.0	15.38	219	-0.37	10
14	03-Feb-2024 16:51:00	05-Feb-2024 07:21:00	3.86	38.5	9.09	195	-0.30	12
15	08-Mar-2024 18:21:00	10-Mar-2024 07:21:00	3.79	37.0	11.76	218	-0.14	14

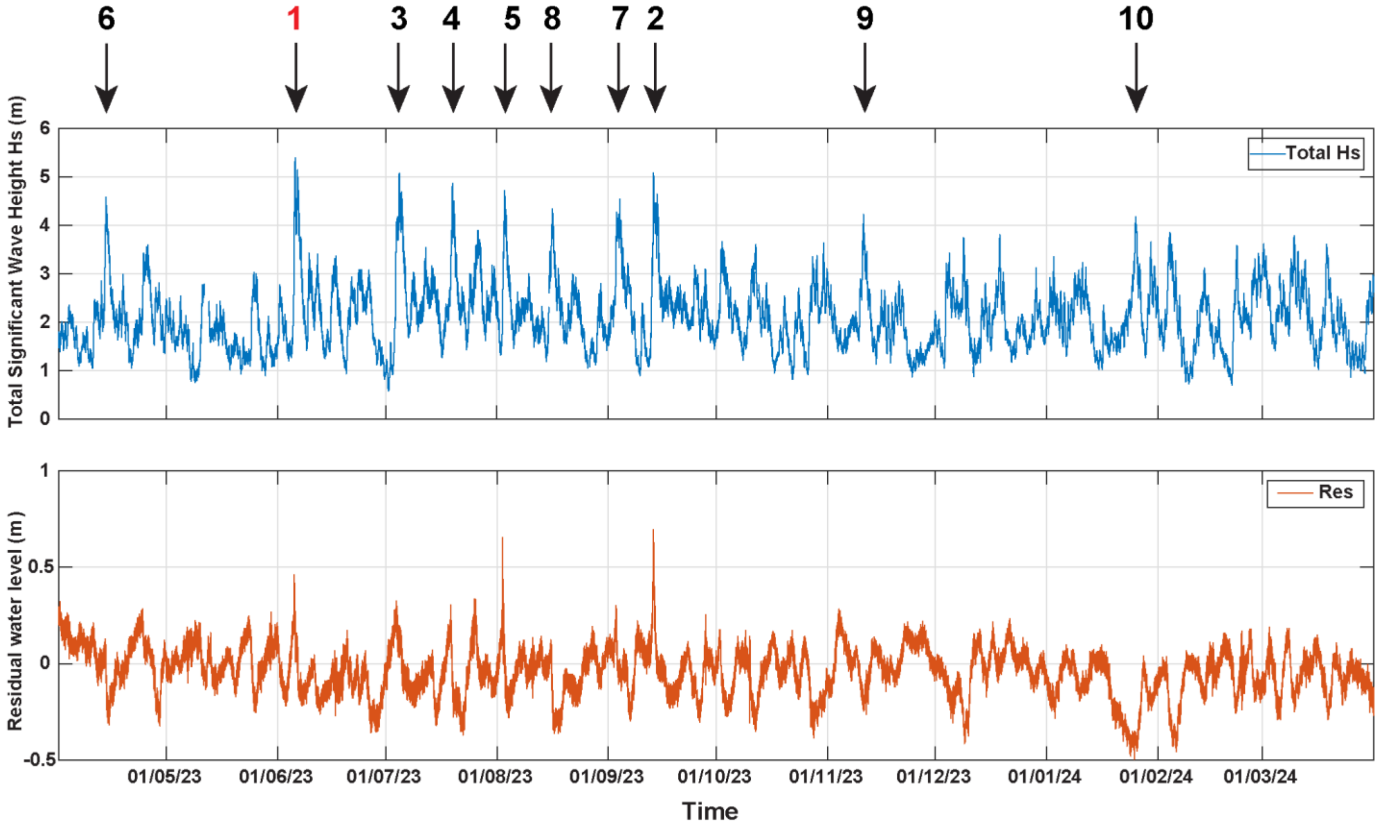


Figure 26. Time series plot of total significant wave height (Hs) and residual water levels for Geraldton from 01 April 2023 to 31 March 2024. Black arrows indicate the rank of identified large wave events of top 10 events (refer to Figure 16 for detailed wave information at this location).

8. Conclusions

A comprehensive understanding of wave parameters and their annual fluctuations is essential for the effective management and operation of coastal and offshore industries. Such understandings are crucial for anticipating changes in wave climate and informing operational and strategic decisions. From 01 April 2023 to 31 March 2024, wave heights, periods, and directional data were collected at Geraldton, enabling a detailed analysis of the distribution and intra-annual variability of these wave characteristics. This dataset also allows for the examination of how wave height and period vary with direction throughout the period. The current findings are consistent with previous research in the southwest Western Australian region. The offshore wave climate in this region is characterized by a south to southwest swell dominated waves. Geraldton, identified as one of three inundation hotspots in the CoastWA initiative, is particularly significant for this analysis. The data collected will contribute to understanding of coastal risks in this critical area, including the impacts of identified storm events. This information will be influential in developing effective strategies for managing coastal erosion and inundation, thereby supporting sustainable land use and development along the coast.

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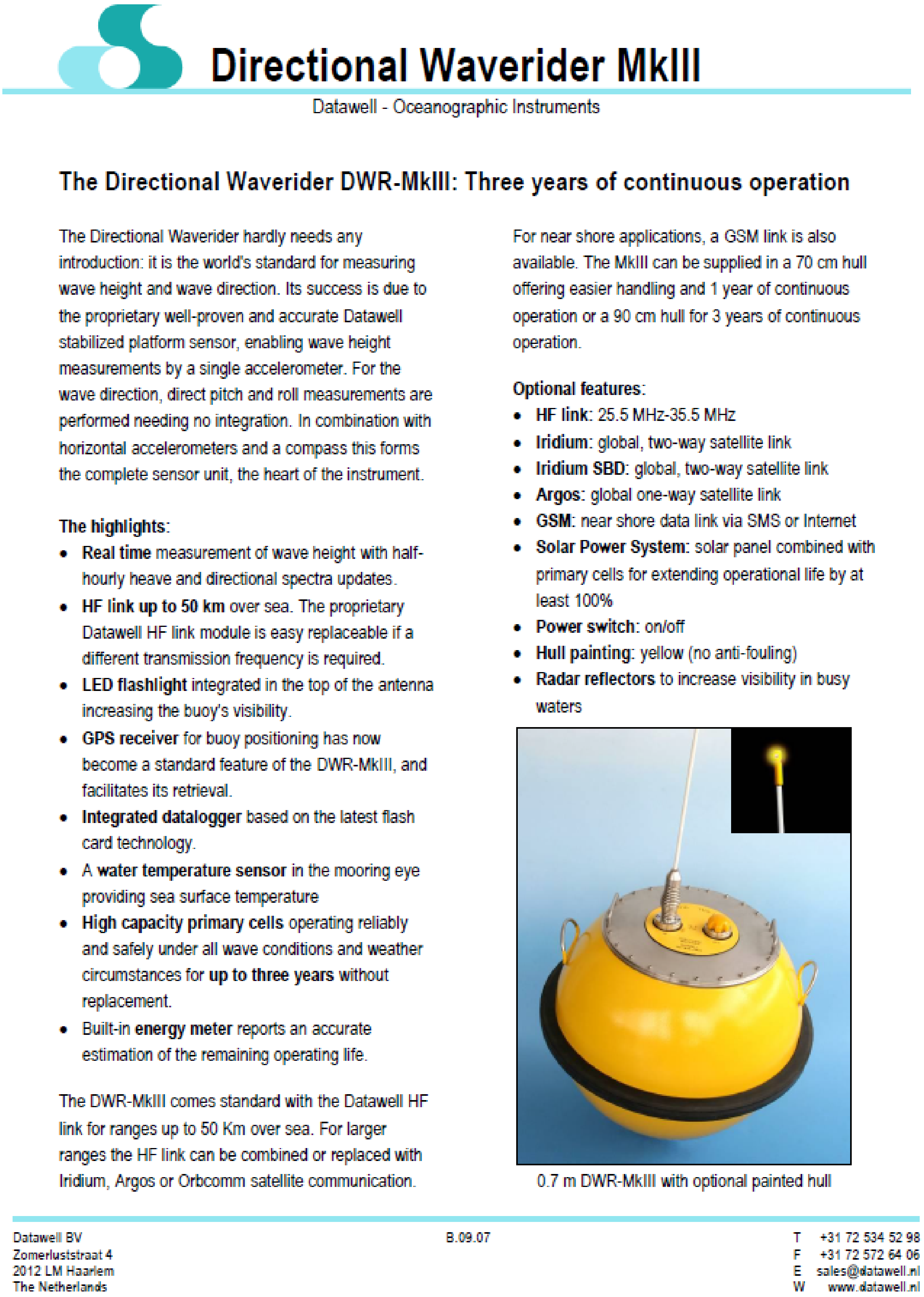
Appendix A: Wave buoy technical specifications



Directional Waverider MkIII

Datawell - Oceanographic Instruments

The Directional Waverider DWR-MkIII: Three years of continuous operation

The Directional Waverider hardly needs any introduction: it is the world's standard for measuring wave height and wave direction. Its success is due to the proprietary well-proven and accurate Datawell stabilized platform sensor, enabling wave height measurements by a single accelerometer. For the wave direction, direct pitch and roll measurements are performed needing no integration. In combination with horizontal accelerometers and a compass this forms the complete sensor unit, the heart of the instrument.

The highlights:

- **Real time** measurement of wave height with half-hourly heave and directional spectra updates.
- **HF link up to 50 km** over sea. The proprietary Datawell HF link module is easy replaceable if a different transmission frequency is required.
- **LED flashlight** integrated in the top of the antenna increasing the buoy's visibility.
- **GPS receiver** for buoy positioning has now become a standard feature of the DWR-MkIII, and facilitates its retrieval.
- **Integrated datalogger** based on the latest flash card technology.
- A **water temperature sensor** in the mooring eye providing sea surface temperature
- **High capacity primary cells** operating reliably and safely under all wave conditions and weather circumstances for **up to three years** without replacement.
- Built-in **energy meter** reports an accurate estimation of the remaining operating life.

The DWR-MkIII comes standard with the Datawell HF link for ranges up to 50 Km over sea. For larger ranges the HF link can be combined or replaced with Iridium, Argos or Orbcomm satellite communication. For near shore applications, a GSM link is also available. The MkIII can be supplied in a 70 cm hull offering easier handling and 1 year of continuous operation or a 90 cm hull for 3 years of continuous operation.

Optional features:

- **HF link**: 25.5 MHz-35.5 MHz
- **Iridium**: global, two-way satellite link
- **Iridium SBD**: global, two-way satellite link
- **Argos**: global one-way satellite link
- **GSM**: near shore data link via SMS or Internet
- **Solar Power System**: solar panel combined with primary cells for extending operational life by at least 100%
- **Power switch**: on/off
- **Hull painting**: yellow (no anti-fouling)
- **Radar reflectors** to increase visibility in busy waters

0.7 m DWR-MkIII with optional painted hull

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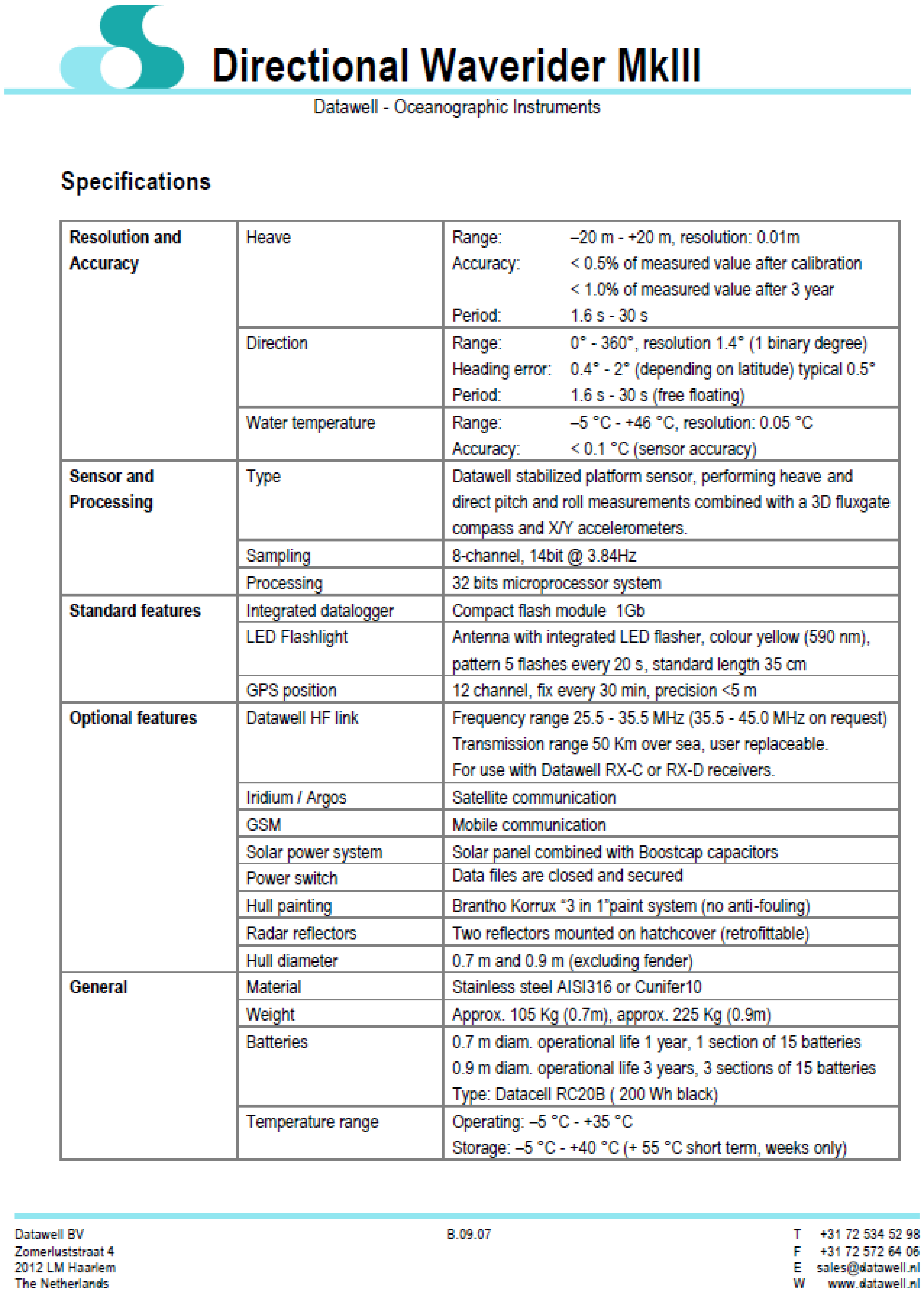

Directional Waverider MkIII

Datawell - Oceanographic Instruments

Specifications

Resolution and Accuracy	Heave	Range: –20 m - +20 m, resolution: 0.01m Accuracy: < 0.5% of measured value after calibration < 1.0% of measured value after 3 year Period: 1.6 s - 30 s
	Direction	Range: 0° - 360°, resolution 1.4° (1 binary degree) Heading error: 0.4° - 2° (depending on latitude) typical 0.5° Period: 1.6 s - 30 s (free floating)
	Water temperature	Range: –5 °C - +46 °C, resolution: 0.05 °C Accuracy: < 0.1 °C (sensor accuracy)
Sensor and Processing	Type	Datawell stabilized platform sensor, performing heave and direct pitch and roll measurements combined with a 3D fluxgate compass and X/Y accelerometers.
	Sampling	8-channel, 14bit @ 3.84Hz
	Processing	32 bits microprocessor system
Standard features	Integrated datalogger	Compact flash module 1Gb
	LED Flashlight	Antenna with integrated LED flasher, colour yellow (590 nm), pattern 5 flashes every 20 s, standard length 35 cm
	GPS position	12 channel, fix every 30 min, precision <5 m
Optional features	Datawell HF link	Frequency range 25.5 - 35.5 MHz (35.5 - 45.0 MHz on request) Transmission range 50 Km over sea, user replaceable. For use with Datawell RX-C or RX-D receivers.
	Iridium / Argos	Satellite communication
	GSM	Mobile communication
	Solar power system	Solar panel combined with Boostcap capacitors
	Power switch	Data files are closed and secured
	Hull painting	Brantho Korrux "3 in 1"paint system (no anti-fouling)
	Radar reflectors	Two reflectors mounted on hatchcover (retrofittable)
	Hull diameter	0.7 m and 0.9 m (excluding fender)
General	Material	Stainless steel AISI316 or Cunifer10
	Weight	Approx. 105 Kg (0.7m), approx. 225 Kg (0.9m)
	Batteries	0.7 m diam. operational life 1 year, 1 section of 15 batteries 0.9 m diam. operational life 3 years, 3 sections of 15 batteries Type: Datacell RC20B (200 Wh black)
	Temperature range	Operating: –5 °C - +35 °C Storage: –5 °C - +40 °C (+ 55 °C short term, weeks only)

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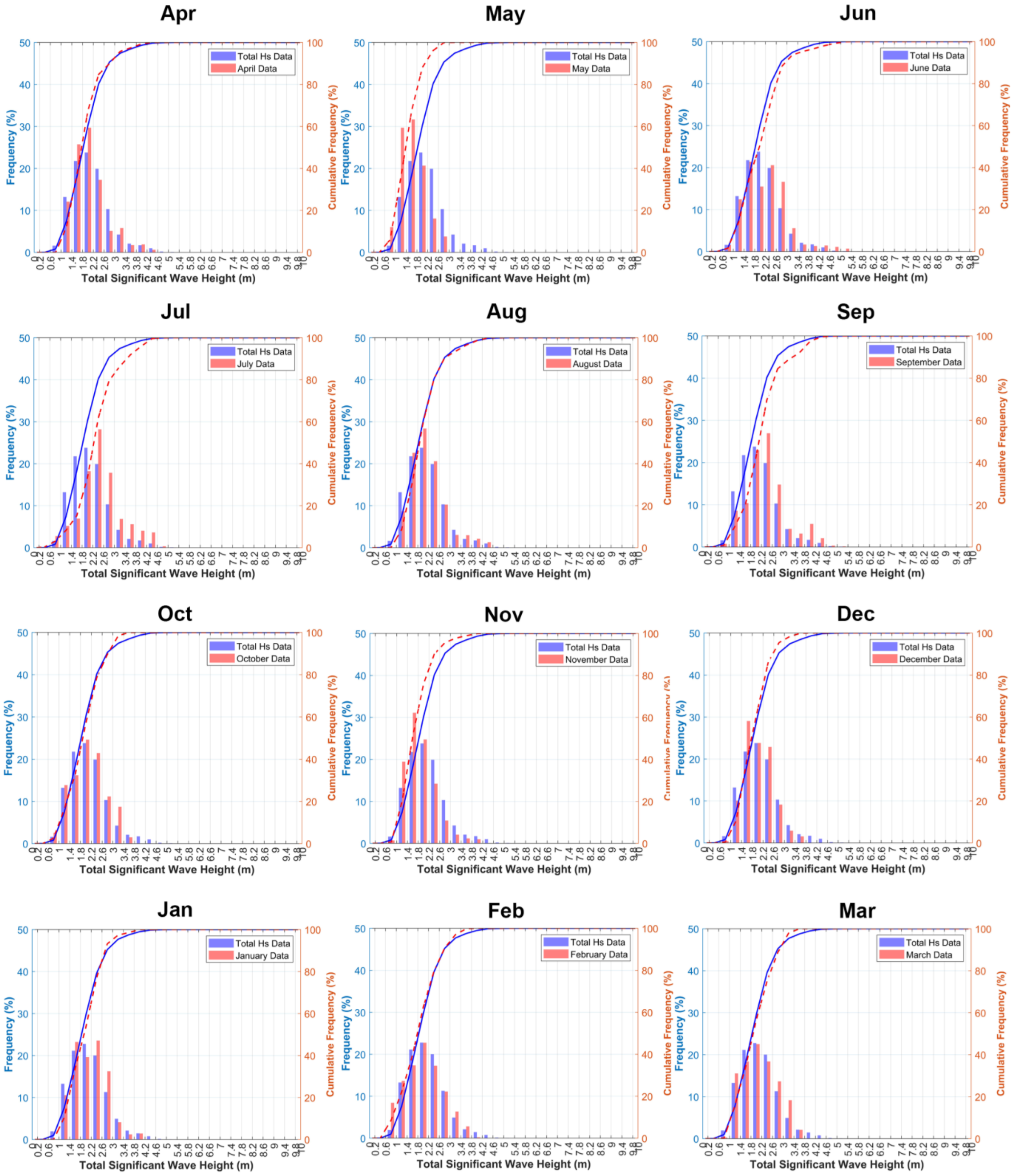
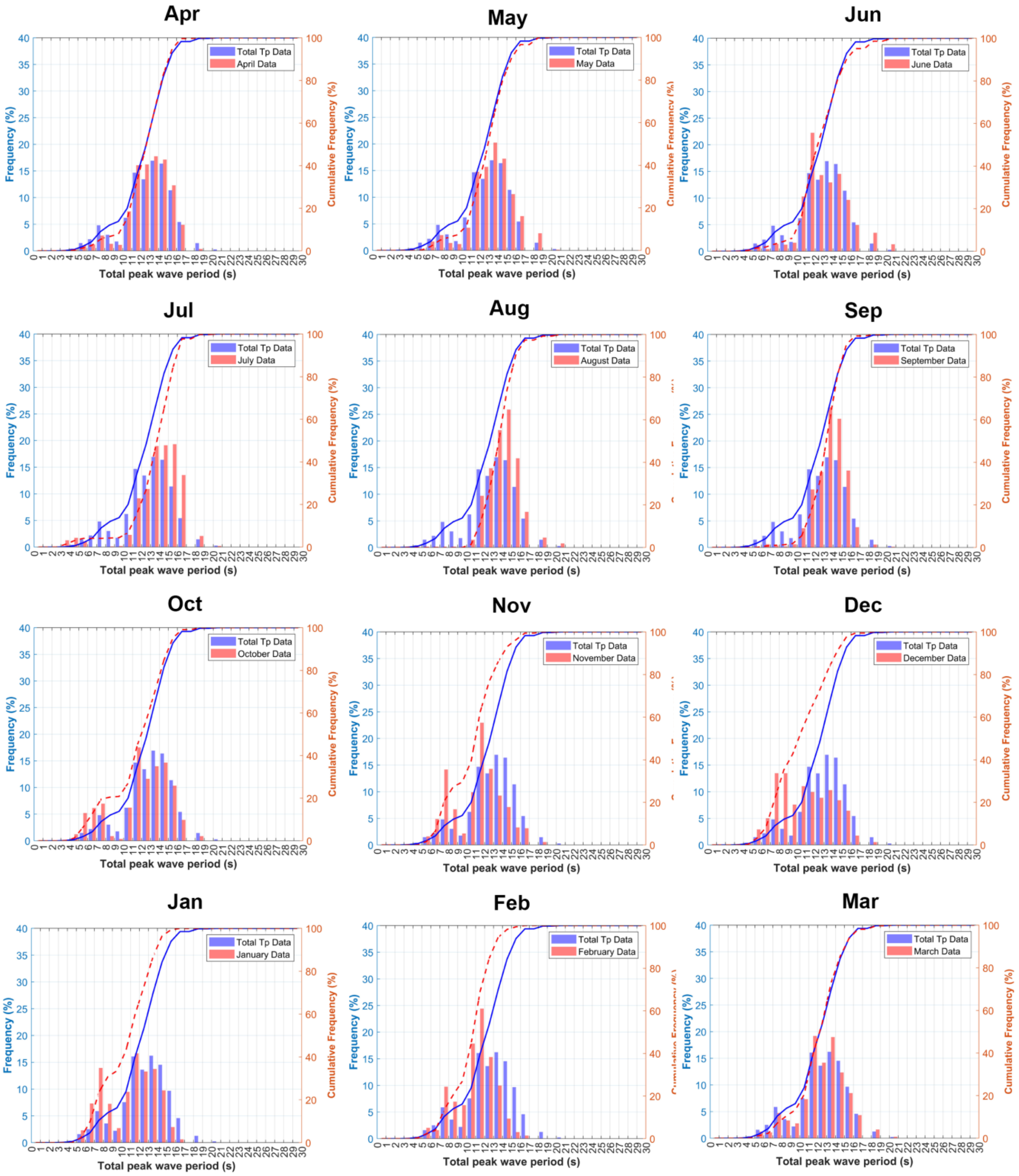
Appendix B: Monthly variations of Hs

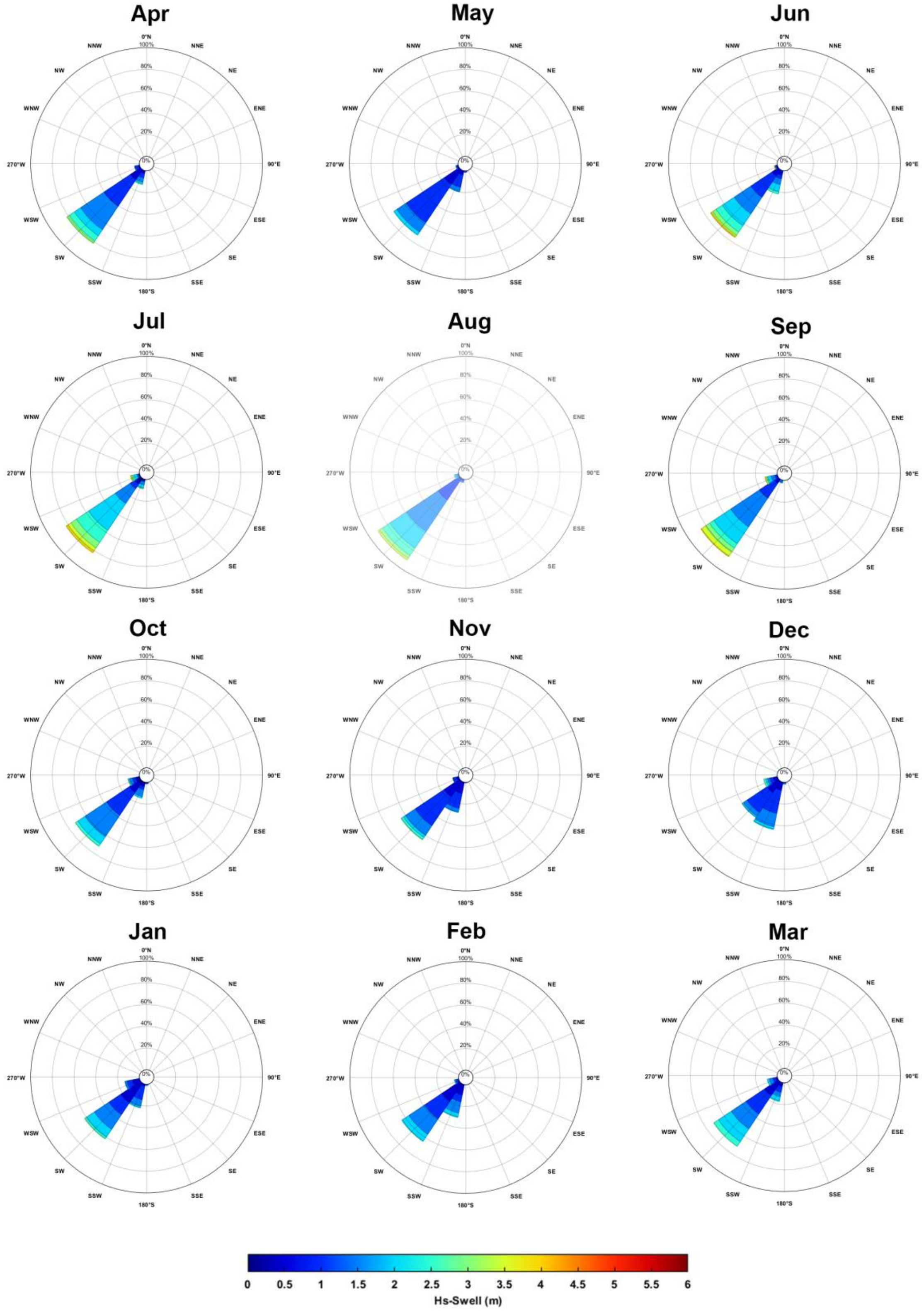


Appendix C: Monthly variations of Tp

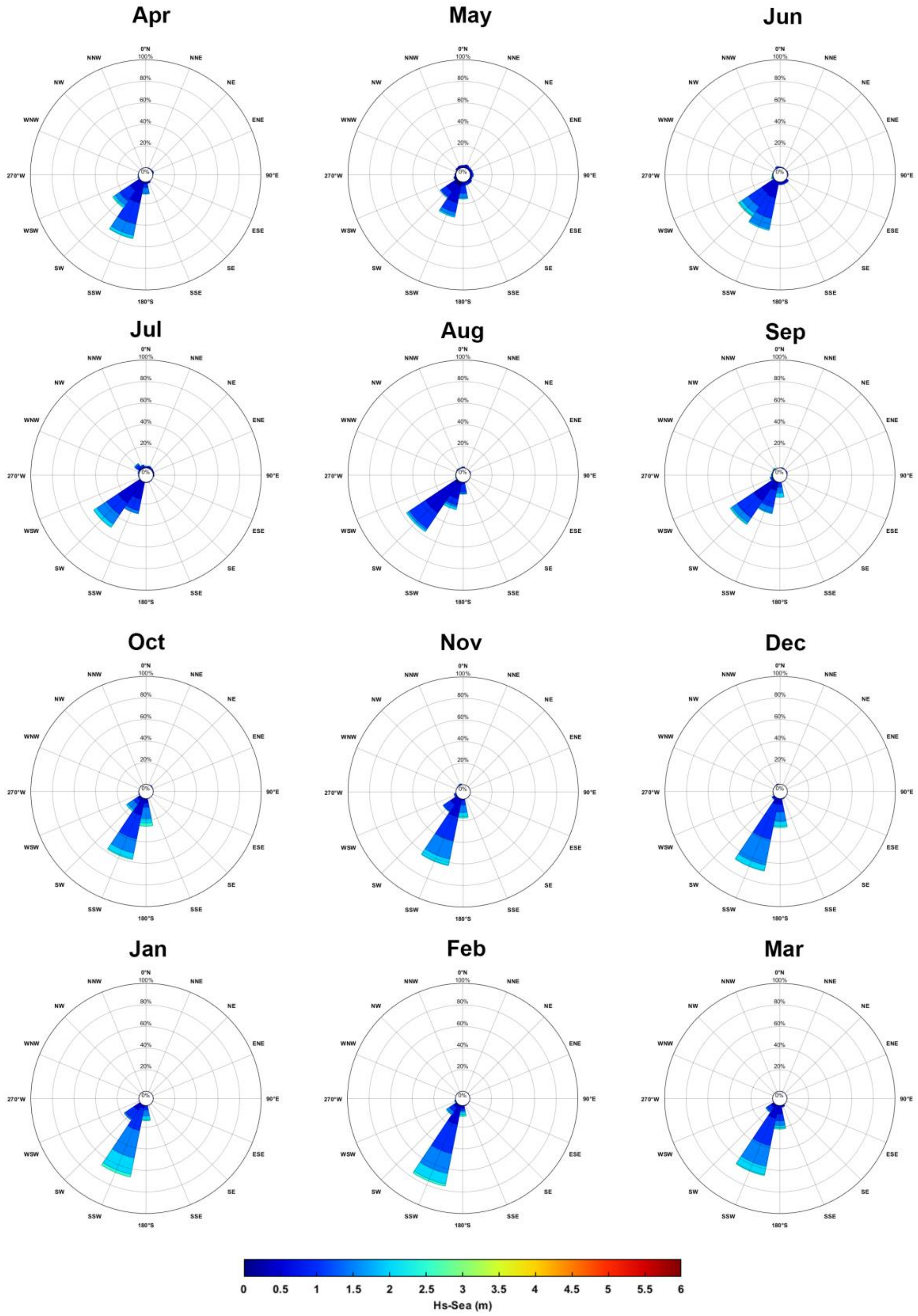


Appendix D: Monthly variations of Hs

Swell waves



Sea Waves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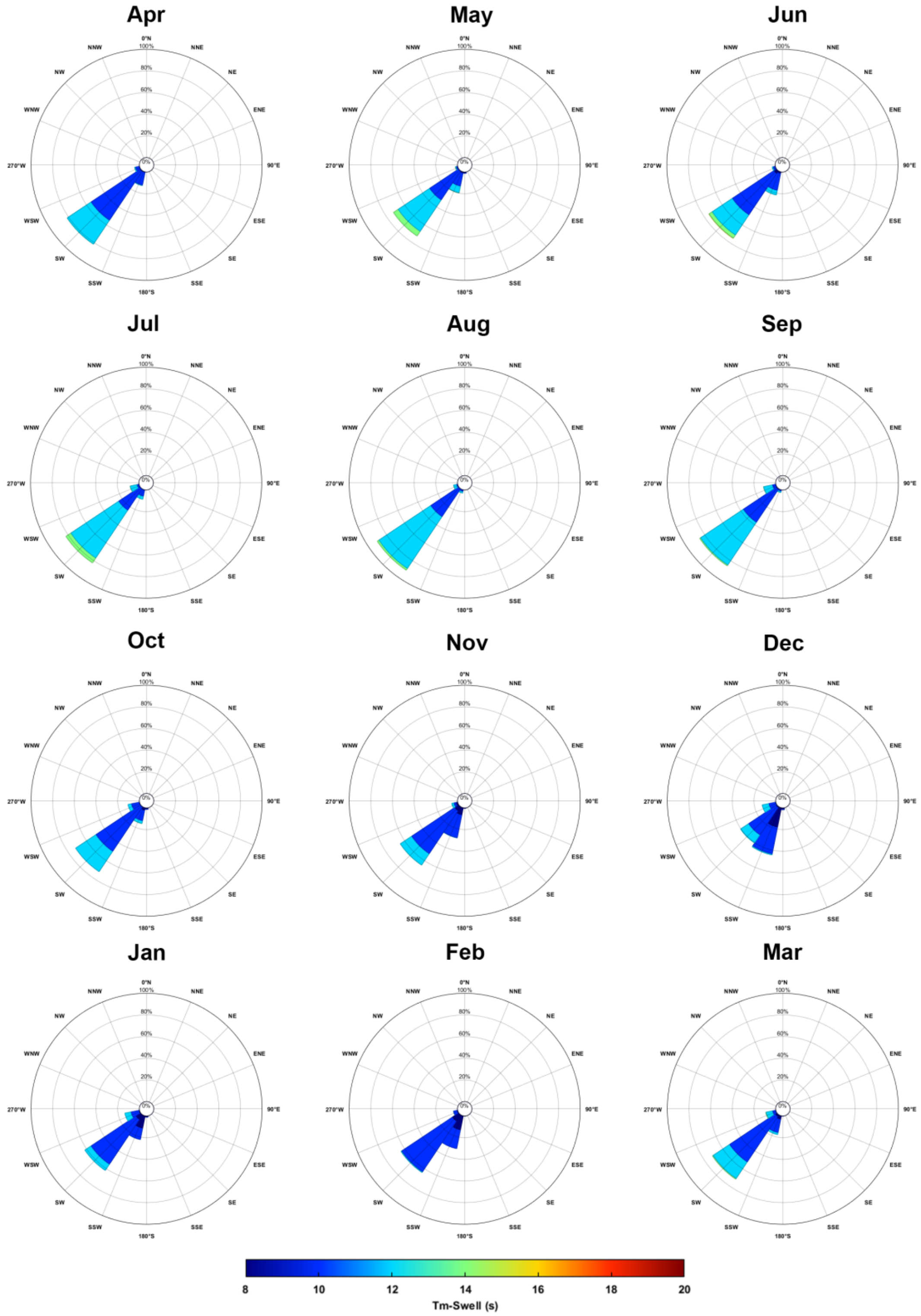
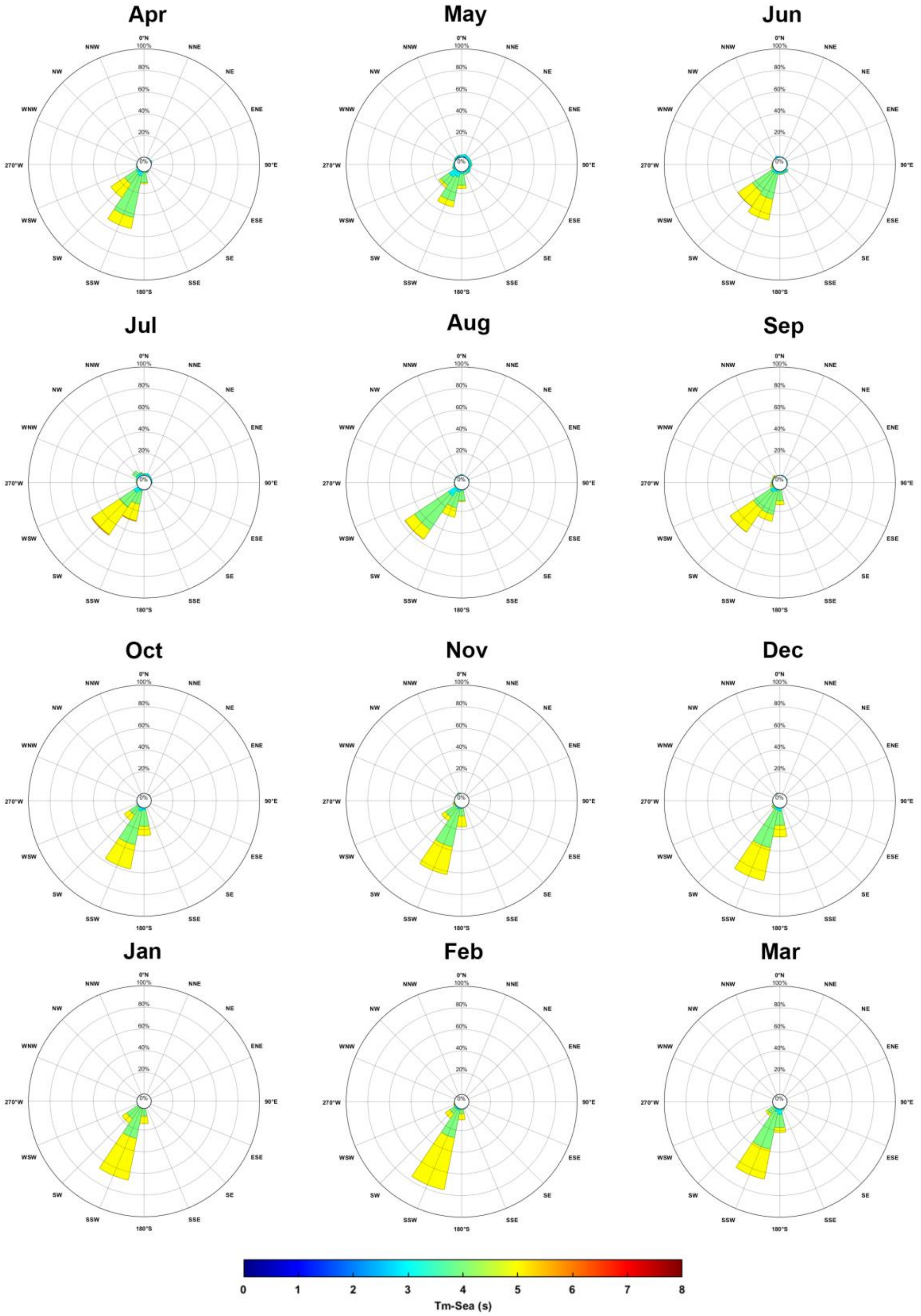
Hs-Sea (m)

Appendix E: Monthly variations of Tm

Swell waves



Sea Waves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