Queensland Wave Climate

Wave Monitoring Annual Summary
November 2018 – October 2019

Queensland Government

Prepared by: Queensland Government Hydraulics Laboratory, Department of Environment and Science

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Executive Summary

This summary of wave climate in Queensland is prepared annually by the Queensland Government Hydraulics Laboratory (QGHL) of the Department of Environment and Science (DES) Annual wave reports supplement the reporting ability of the QGHL by providing information on wave climates in Queensland. The information presented here summarises the primary analyses of wave data recorded using Datawell Waverider buoys positioned off the Queensland coastline from 01 November 2018 to 31 October 2019.

The wave monitoring program utilises the Waverider system, manufactured by Datawell of the Netherlands, to measure the sea surface fluctuations at each offshore location. Directional Waverider buoys are operated at all sites, except Bundaberg, where a non-directional Waverider buoy is deployed. The directional buoys also record temperature in the bottom of the hull; the temperature record is called Sea Surface Temperature (SST) in Australia.

For all stations, the wave data has been statistically compared to the long-term average conditions at each site. Also provided are brief details of the recording equipment, the methods of handling raw data, quality checks and the type of analyses employed.

The data covers all of the seasonal variations for one year, and includes the tropical cyclone season, which extended from 01 November through to 30 April. This period is also classified as summer while the remainder of the year 01 May to 31 October is classified as winter in these reports.

Tropical cyclone season 2018–2019 experienced several small- and large-scale storm events and tropical cyclones that predominantly stayed well off the East Coast of Australia. TC Oma and TC Owen produced the greatest effect on the Queensland coastline, causing dangerous surf conditions and high winds. The information on severe weather periods and TCs was obtained from the Bureau of Meteorology database.

Introduction

This summary of wave climate in Queensland is one in a series of technical wave reports prepared annually by the Queensland Government Hydraulics Laboratory (QGHL) of the Department of Environment and Science (DES). Annual wave reports supplement the reporting ability of QGHL by providing information on wave climates along the Queensland coast. The information presented here summarises the primary analyses of wave data recorded using Datawell Waverider buoys DWR-MkIII, DWR-G and DWR4 positioned off the Queensland coastline from 01 November 2018 to 31 October 2019.

The data covers all the seasonal variations for one year, and includes the 2018–19 tropical cyclone season, which extends from 01 November through to 30 April. This period is also classed as 'summer' while the remainder of the year (01 May to 31 October) is classed as 'winter' in these reports. For all stations, the wave data collected for the current year is statistically compared to the long-term average conditions at the site. Brief details of the recording equipment, the methods of handling raw data and the type of analyses employed are provided within this report.

Wave monitoring sites

As part of its long-term data collection program, DES has maintained a network of wave recording stations along the Queensland coast since 1968. The network of wave recording stations is grouped into two categories.

Long-term sites: These core sites provide long-term wave climate datasets along the Queensland coast for coastal and disaster management purposes. The stations are fully funded and operated by DES.

Partnership sites: The operation of these sites will vary in duration, and they are associated with specific projects to assess wave conditions or to manage maritime activities. These stations are operated by DES in conjunction with (and jointly funded by) partner agencies.

Table 1 Wave recording stations November 2018 to October 2019

Long-term DES Sites	Partnership Sites	Partners
Brisbane	**Tweed Heads**	Tweed River Entrance Sand Bypassing Project (TRESBP), joint project of Qld & NSW Governments supported by City of Gold Coast
Emu Park	**Gold Coast**	City of Gold Coast
Mackay	**Caloundra**	Port of Brisbane Pty Ltd
Townsville	**North Moreton**	Port of Brisbane Pty Ltd
Cairns	**Mooloolaba**	Department of Transport and Main Roads
Bundaberg	**Gladstone**	Gladstone Ports Corporation
Wide Bay	**Hay Point**	North Queensland Bulk Ports Corp Ltd
	Abbot Point	North Queensland Bulk Ports Corp Ltd
	Weipa	North Queensland Bulk Ports Corp Ltd
	Palm Beach	City of Gold Coast
	Skardon River	Metro Mining LTD (2x buoys)

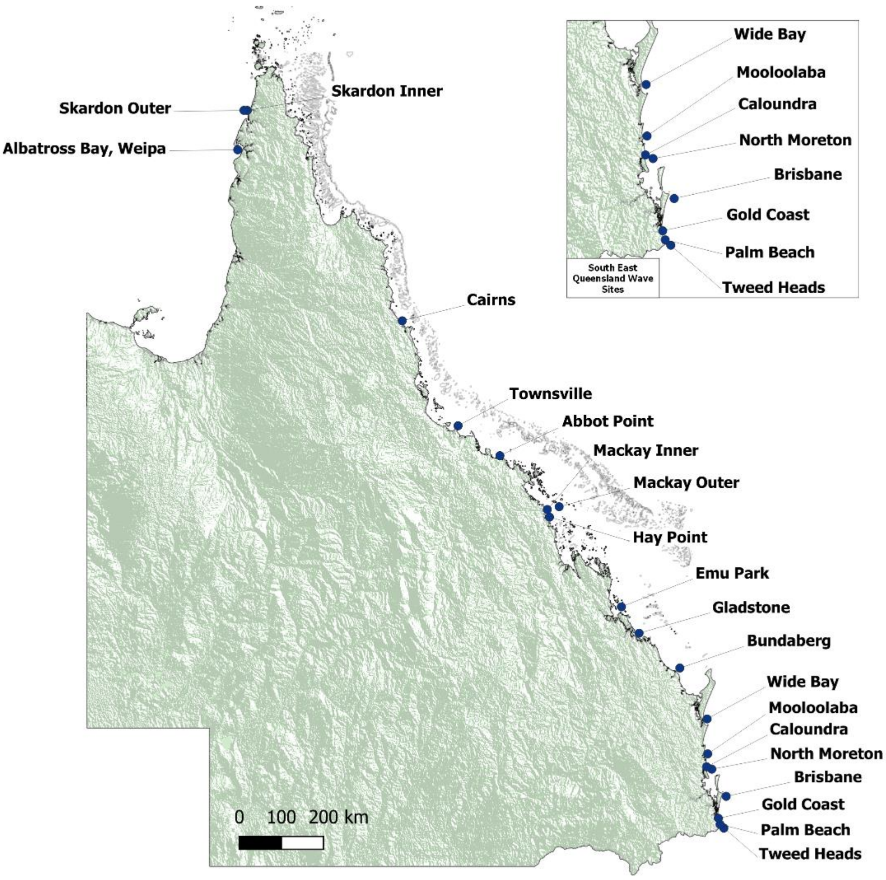


Figure 1 DES wave monitoring sites in Queensland (long-term DES sites)

Table 2 Wave monitoring history: some early (starting 1968) short-term records from the Gold Coast region not listed.

Site	Start date	End date	Restart	Directional start date	Total years	Directional years
Tweed Heads	13/01/1995	-	-	13/01/1995	24.8	24.8
Palm Beach	06/06/2017	-	-	06/06/2017	2.3	2.3
Gold Coast*	21/03/1987	-	-	17/07/2007	32.6	12.3
Brisbane	31/10/1976	-	-	20/01/1997	43.0	22.8
North Moreton Bay	08/03/2010	-	-	08/03/2010	9.6	9.6
Caloundra	01/05/2013	-	-	01/05/2013	6.4	6.4
Mooloolaba	20/04/2000	-	-	11/05/2005	19.5	14.4
Bundaberg	08/09/2015	-	-	08/09/2015	4.1	4.1
Gladstone	23/09/2009	-	-	23/09/2009	10.1	10.1
Emu Park	24/07/1996	-	-	24/07/1996	23.3	23.3

Site	Start date	End date	Restart	Directional start date	Total years	Directional years
Hay Point	24/04/1977	25/05/1987	3/04/1993	31/10/2009	36.7	10.0
Mackay	19/09/1975	-	-	13/03/2002	44.1	17.6
Abbot Point	17/01/2012	-	-	17/01/2012	7.8	7.8
Townsville	20/11/1975	-	-	29/10/2008	43.9	11.0
Cairns	04/05/1975	-	-	26/02/2016	44.4	3.7
Skardon River Inner	06/01/2019	-	-	06/01/2019	0.82	0.82
Skardon River Outer	06/01/2019	-	-	06/01/2019	0.82	0.82
Albatross Bay (Weipa)	22/12/1978	-	-	25/11/2008	40.8	10.9

*some early (starting 1968) short-term records from the Gold Coast region not listed.

Wave monitoring equipment

For the monitoring period documented in this summary report the wave monitoring program utilised the Waverider buoy system manufactured by Datawell of the Netherlands (Datawell, 2010) to measure the sea surface fluctuations at coastal locations. Directional Waverider buoys were in operation at all sites except Bundaberg during the period of this report.

Accelerometer Buoys: DWR-MkIII

The DWR MkIII measures vertical accelerations by means of an accelerometer, placed on a gravity-stabilised platform. This platform is formed by a disk which is suspended in fluid within a plastic sphere placed at the bottom of the buoy. Two vertical coils are wound around the plastic sphere and one small horizontal coil is placed on the platform. The pitch and roll angles are defined by the amount of magnetic coupling between the fixed coils and the coil on the platform. Measuring this coupling gives the sine of the angles between the coils (x and y axes) and the horizontal plane (= platform plane). An additional accelerometer unit measures the forces on the buoy with respect to its horizontal axes.

A fluxgate compass provides a global directional reference with which to orient the buoy. The acceleration values that are relative to the buoy are then transformed into values that are relative to the fixed compass. The measured acceleration values are filtered and double integrated with respect to time to establish vertical displacement values for recording.

Only waves with peak-to-peak frequencies within the range of 0.033–0.64 Hz can be captured by the buoy, due to physical limitations of the system. Wave motion with higher frequencies cannot be followed/ridden properly due to the dimensions of the buoy, while lower frequency waves apply very small acceleration forces that become undetectable.

Accelerometer Buoys: SG non-directional buoy

The directional Waveride buoy SG at Bundaberg operates the same way as the DWR MkIII, but without the wave direction and sea surface temperature data.

Accelerometer Buoys: DWR MK4

The newest addition to the fleet is a directional wave and current Waverider called DWR4, which has an increased sampling frequency, and has a significant increase in resolution (CIU, 2017).

An improvement of the raw displacement (heave) data is achieved by upgrading the on-board capacity of the buoy. This improvement is able to record heave measurements from the accelerometer to 12bit floating point notation.

This is a significant difference compared to the DWR MkIII and DWR-G buoys and ultimately will give a more accurate up and down movement due to the increased frequency of the DWR4, as explained in DSITI (2018).

The spectral scheme is calculated by the overlapping segmented (50 per cent overlap) Welch' method combined with the more commonly used Hann window. The overlapping segments and segment averaging ensure a smoother spectra.

The DWR4 uses online up-crossing wave statistics, which are calculated on the fly. This new method makes use of onshore software and has to be added to the message file. Also, the significant wave height (H_s) is no longer calculated via the commonly used zero up-crossing method but is estimated using root mean square wave height (H_{rms}), $H_{rms}\sqrt{2}$.

The DWR4 is includes a surface current meter which contains three acoustic transducers in the hull of the buoy (Datawell 2017). The current is determined at roughly one meter water depth, by measuring the Doppler Shift of reflected 2 MHz pings. Every 10 minutes, the magnitude and direction of the surface current are measured. The transducers all face 30 degrees down and are 120 degrees laterally apart. Each transducer measures the projection of the current velocity along its axis.

GPS Buoys

The directional Waverider buoys DWR-G at the Tweed Heads, North Moreton Bay, Caloundra, Mooloolaba, Hay Point, and Albatross Bay (Weipa) sites use the GPS satellite system to calculate the velocity of the buoy as it moves with the passing waves. The GPS based Waverider calculates velocity from changes in the frequency of GPS signals according to the Doppler principle. For example, if the buoy is moving towards the satellite the frequency of the signal is increased, and vice-versa. The velocities are integrated through time to determine buoy displacement. The measurement principle is illustrated in Figure 2, which shows a satellite directly overhead and a satellite at the horizon. In practice the GPS system uses signals from multiple satellites to determine three-dimensional buoy motion.

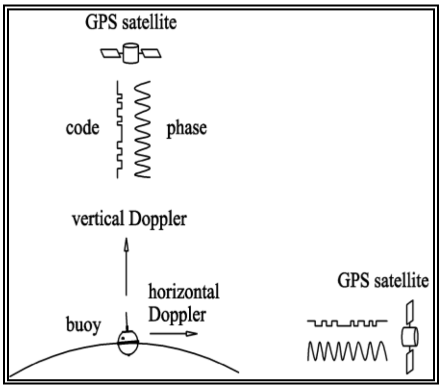


Figure 2 The GPS wave measurement principle (Datawell, 2010)

Data collection

At all wave sites, the vertical buoy displacement representing the instantaneous water level and calculated directional data are transmitted to a receiver station as a frequency modulated high-frequency radio signal. The receiver stations on shore digitise the water level data from each site at 0.78 second intervals (1.28 Hz) and these are stored in bursts of 2,048 points (approximately 26 minutes) to facilitate Fast Fourier Transform (FFT) into a discrete directional wave energy density frequency spectrum. software controls the timing of data recording and processes the data in near real time to provide a set of standard sea-state parameters and spectra. Recorded data and analysis results are transmitted every hour for checking, further processing, and archiving. Data are also stored on-board each buoy as backup should communication of data to the receiver station fail.

Quality checks

Waverider buoys are calibrated before deployment and after recovery. Generally, every buoy is calibrated each 12 months. Accelerometer buoys are calibrated at QGHL using a mechanical 'windmill' buoy calibrator to simulate sinusoidal waves with vertical displacements of 2.7 metres. It is usual to check three frequencies between 0.016–0.25 Hz during a calibration. The following are also checked during the calibration procedure: compass; phase and amplitude response; accelerometer platform stability; platform tilt; battery capacity; and power output.

Calibration of GPS buoys requires being fixed in place on land for a period of several days while recording data. There should be no obstructions between the buoy and the orbiting GPS satellites. A GPS buoy that is in calibration should produce results showing no displacements between records; any differences can be attributed to errors in the transmission signal between the GPS buoy and the orbiting satellites, or to faults in the buoy.

Monthly averaged wave parameters are calculated from the available data and some wave data records may be rejected on the basis of low capture rates. Research (Bacon & Carter, 1991. and Allan & Komar, 2001) has suggested rejecting entire records where less than a certain threshold has been recorded. All Queensland wave-recording sites generally have high-percentage capture rates for the seasonal year and thus minimal bias is introduced into calculations.

Data losses

Data losses can be divided into two categories:

1. losses due to equipment failure
2. losses during data processing from signal corruption.

Common causes of data corruption include radio interference and a spurious, low-frequency component in the water-level signal caused by a tilting platform in the accelerometer-based Waverider buoy.

The various sources of data losses can cause occasional gaps in the data record. Gaps may be relatively short, caused by rejection of data records, or much longer if caused by malfunction of the Waverider buoy or the recording equipment.

Data processing

The wave-recording systems at all sites record data at half-hourly intervals. Raw digitised water level data transmitted from the buoys are analysed in the time domain by the zero up-crossing method (see Appendix A) and in the frequency domain by spectral analysis using FFT techniques to give 128 spectral estimates in bands of 0.01 hertz. The directional information is obtained from initial processing on the buoy, where datasets are divided into sub-sets for FFT analysis. The output from this processing is then transmitted to the shore station, along with the raw data, where it undergoes further analysis using FFT techniques to produce 128 spectral estimates in bands of 0.005 hertz. Temperature is also recorded with an internal sensor imbedded in the hull of the buoy, this data is reported as Sea Surface Temperature (SST) every 30 minutes. The zero up-crossing analysis is equivalent in both the accelerometer and GPS versions. Wave parameters resulting from the time and frequency domain analysis include the following:

Table 3 Parameters involved in the analysis

Parameter	Description
S(f)	Energy density spectrum (frequency domain)
H_s	Significant wave height (time domain), the average of the highest third of the waves in the record
H_{max}	The highest individual wave in the record (time domain)
H_{rms}	The root mean square of the wave heights in the record (time domain)
T_{sig}	Significant wave period (time domain), the average period of the highest third of waves in the record
T_z	The average period of all zero up-crossing waves in the record (time domain)
T_p	The wave period corresponding to the peak of the energy density spectrum (frequency domain)
Dir	The direction (frequency domain) from which the peak period waves (Tp) are coming (in True)
SST	Sea surface temperature (°C) of the buoy hull-bottom.

These parameters form the basis for the summary plots and tables included in this report and critically inform coastal management, engineering and disaster management purposes.

No attempt has been made to interpret the recorded data for design purposes or to apply corrections for refraction, diffraction and shoaling to obtain equivalent deep-water waves.

Major Meteorological events

Five major meteorological events, all tropical cyclones (TCs), occurred during the record period. TCs Owen, Penny, Oma, Trevor and Ann were detected by several buoys along the coast and data was reliably captured and recorded.

A low-pressure system over the Solomon Islands progressed to a tropical low on 29 November 2018. Due to favourable conditions the low developed into TC Owen, the first for the season, but it rapidly weakened to a tropical low on 04 December. Continuing to track west, remnants of Owen crossed Cape York Peninsula and entered the Gulf of Carpentaria, reforming into a tropical cyclone on 11 December. TC Owen then continued west and passed into NT on 13 December before tracking east-southeast across the Gulf of Carpentaria and making landfall on Cape York Peninsula on 15 December. Later the same day TC Owen returned to the Coral Sea and was downgraded to a tropical low.

On 28 December 2018 a tropical low was tracked moving west in the Coral Sea and slowly continued across Cape York Peninsula and into the Gulf of Carpentaria. The low reversed direction and sometime on 31 December 2018 developed into TC Penny and proceeded easterly to cross Cape York Peninsula and was downgraded to a low as it crossed the Cape. TC Penny crossed into the Coral Sea on 02 January 2019 and reformed in favourable conditions as it continued tracking east. TC Penny tracked further east and peaked as a Category 2 on 04 January before being downgraded to a tropical low on 05 January and then slowly tracked back west-southwest towards the coast and make landfall on the 09 January near Bowen.

A tropical low was tracked moving east from 07 February 2019 and formed into TC Oma on 12 February near Vanuatu. Changing direction on 13 February and continuing southwest, Oma intensified to a Category 3 on 19 February to the west of New Caledonia. After continuing southwest OMA was downgraded to a Category 1 on 22 February and was designated a subtropical cyclone on 23 February near Lord Howe Island

A tropical low developed in the Solomon Sea on 11 March 2019 and intensified as it tracked southwest until forming into TC Trevor on 18 March. TC Trevor intensified to a Category 3 before making landfall in the Cape York Peninsula on 19 March and weakened to a Category 1 as it continued west across land before crossing into in the Gulf of Carpentaria on 21 March. In favourable conditions TC Trevor intensified to a Category 4 as it moved southwest and made landfall in the Northern Territory on 23 March and then weakened into a tropical low on 24 March before moving east and back into Queensland on 26 March.

On 07 May 2019 a tropical low had developed near the Solomon Islands and was tracking southwest and entered favourable conditions before turning back eastward on 10 May and later the same day turning back westwards again. TC Ann formed on 11 May and briefly intensified to a Category 2 as it moved west but downgraded to a tropical low on 14 May before making landfall on Cape York Peninsula on 15 May. Ex-TC Ann continued west into the Gulf of Carpentaria and eventually dissipated on 18 May.

Table 4 Tropical Cyclones in the Queensland region during the 2018–2019 season

TC Name	Start Time (AEDT)	End Time (AEDT)	Category	Estimated Minimum MSL Central Pressure (hPa)
Owen	02/11/2018 17:00 pm	17/12/2018 17:00 pm	3	958
Penny	28/12/2018 11:00 am	09/01/2019 11:00 pm	2	987
Oma	12/02/2019 11:00 am	22/02/2019 23:00 pm	2	979
Trevor	18/03/2019 04:00 am	24/03/2019 10:00 am	4	950
Ann	08/05/2019 11:00 am	18/05/2019 23:00 pm	2	993

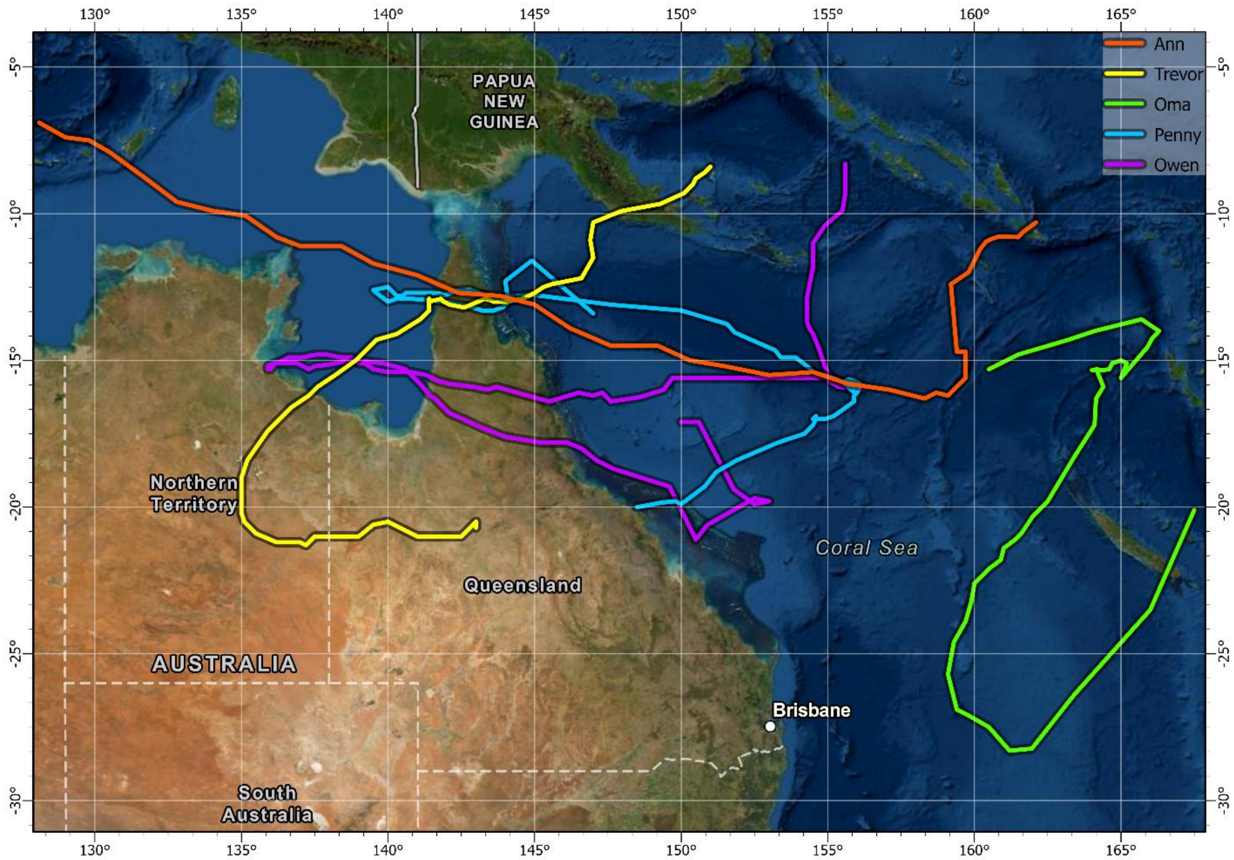


Figure 3 Tropical cyclones affecting Queensland coastline during the 2018–2019 season

Queensland wave climate

Tweed Heads

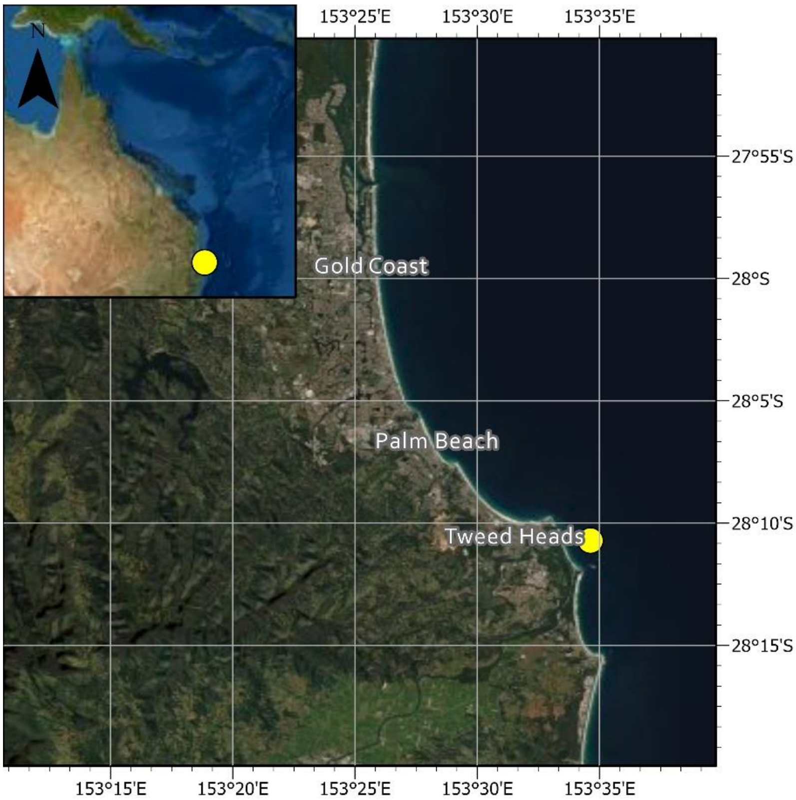


Figure 4 Tweed Heads – Locality plan

Table 5 Tweed Heads – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	13/01/1995	0.36 (years)	377,332	24.44
2018–19	01/11/2018	9.12 (days)	17,082	1

Table 6 Tweed Heads – Buoy deployments during the 2018–19 season

Latitude	Longitude	Type buoy	Depth (m)	Deployed date	Removal date
28° 10.715’ S	153° 34.635’ E	DWR-GPS	25	03/07/2018	15/07/2019
28° 10.575’ S	153° 34.590’ E	DWR4	25	09/06/2017	27/04/2019
28° 10.638’ S	153° 34.595’ E	DWR4	25	27/04/2019	14/09/2019
28° 10.665’ S	153° 34.594’ E	DWR4	25	14/09/2019	current

Tweed Heads – seasonal overview

The Tweed Heads wave site has been operational for nearly 25 years with an overall data return of 98.5 per cent. The data recorded for the period November 2018 to October 2019 was good, with total gaps of 9.12 days, equivalent to 97.5 per cent data return (Table 5). The buoy was replaced twice during the reporting period (Table 6).

The Tweed Heads wave site currently has two wave buoys deployed, to analyse and compare differences between the DWR-G and DWR4 (DSITI, 2018). For the purpose of this report only the data from the DWR4 has been analysed, as both buoys are considered comparable. See

Appendix B Comparison between GPS and Mk4 at Tweed Heads for a comprehensive analysis of the differences between the DWR-G and DWR4 at Tweed Heads for the time period 10/06/2017 – 30/04/2018.

The Tweed Heads GPS wave buoy was exposed to four significant events during the reporting period including tropical cyclone Oma which generated the largest wave conditions for this period. This occurred on 24 February (Table 8), with a significant wave height (H_s) of 4.5 m and a maximum wave height (H_{max}) of 7.1 metres. There were no changes to the highest waves table during this period at Tweed Heads (Table 7).

The daily wave recordings (Figure 5) show the significant meteorological events clearly with numerous other small events throughout the reporting period where maximum wave heights H_{max} exceeded 3 metres. Peak wave periods (T_p) show variation throughout the record, with T_p from less than 5 seconds all the way up to 21 seconds with a more regular T_p around 7 to 9 seconds. June to August show a higher T_p above 10 seconds with drops back to 5 seconds.

The sea surface temperature (SST) measured in the buoy hull showed a range of 18 °C to 27 °C (Figure 6). The SST from mid- to late-January and from mid-February to mid-April was predominantly warm enough for tropical cyclone development, with periodic warm swings in December and the start of January. A low spike below 16 °C seen in mid-September is likely due to a sensor or signal malfunction.

The monthly average H_s (Figure 7) generally fell within one standard deviation (sd) of the long-term mean. Exceptions were seen for December and February where H_s was above 1 sd, and for March where it was below 1 sd.

H_s throughout the 2018–2019 period was generally consistent with historic data, with a slight deviation in wave heights greater than 4 m (Figure 8), more so in winter. The summer months experienced higher waves than winter when H_s was below 1.8 m, then summer and winter exceedances converge at 2.0 m and diverge again with higher summer wave heights in waves over 2.5 metres. Winter months in general experienced lower waves compared to the historical data.

Histograms of the occurrence of H_s (Figure 9) indicate a higher occurrence of waves 1.0–1.2 m, for the winter period, compared to all data. Summer shows waves of size 1.0–1.2 m had a lower occurrence, as did waves sized 2.0–3.0m. A slightly higher occurrence of waves of 0.8–1.0 m can also be noted. All data shows that waves between 2.0 and 3.0 m occurred less throughout the 2018–2019 period. Histograms of the occurrence of T_p (Figure 10) show a varied distribution between the reporting period and historic data for both winter and summer. Winter indicates a T_p between 11 and 13 seconds occurred most frequently while T_p between 7 and 11 seconds occurred less frequently. Summer shows a T_p between 7 and 9 seconds had a higher percentage of occurrence and T_p over 11 seconds a lower occurrence. All data for the most part shows a consistent distribution with historic data.

The ratios between different wave parameters such as H_{max}/ H_s were generally consistent between this reporting period and all the historic data, these are plotted in (Figure 11). The ratio of T_p/T_z and T_p/T_s shows a slightly lower kurtosis for this period compared to the entire record.

The plot of wave direction (Figure 6) show dominant easterly wave directions with infrequent swings to the north-northeast. The dominance of east to east-southeast incident wave direction is reflected in the directional wave rose plot (Figure 12) with the most common H_s of 1.0 to 1.5 metres.

Table 7 Tweed Heads – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	03/05/1996 01:00	7.5	02/05/1996 14:30	13.1
2	28/01/2013 08:30	6.7	28/01/2013 09:00	11.8
3	06/03/2004 01:00	6.1	05/03/2004 23:30	11.1
4	21/05/2009 19:30	5.6	30/06/2005 06:30	9.9
5	04/06/2016 19:30	5.6	05/06/2016 00:30	9.8
6	01/05/2015 22:30	5.5	22/05/2009 07:00	9.7
7	24/05/1999 05:00	5.2	04/03/2006 12:00	9.7
8	04/03/2006 20:30	5.2	25/03/1998 22:30	9.5
9	12/06/2012 10:00	5.2	15/02/1995 15:30	9.3
10	15/02/1995 11:30	5.2	12/06/2012 11:30	9.3

Table 8 Tweed Heads – Significant meteorological events with threshold H_s of 2.4 metres

Date	H_s(m)	H_{max}(m)	Tp(s)	Event
24/02/2019 9:00 Peak Event	4.5	7.1	13	TC Oma was nearest the east coast of Qld on 22 February before returning to a low-pressure system and heading northeast.
20/04/2019 11:00	2.6	4.8	10.4	A low-pressure system developing Solomon Islands and New Caledonia.
30/06/2019 20:30	3	6.1	12.6	Low pressure system moving east from central Australia.
05/07/2019 17:30	3.3	6.1	10	Upper-level trough developed near central Qld around the 4th and interacted with surface troughs over several days.

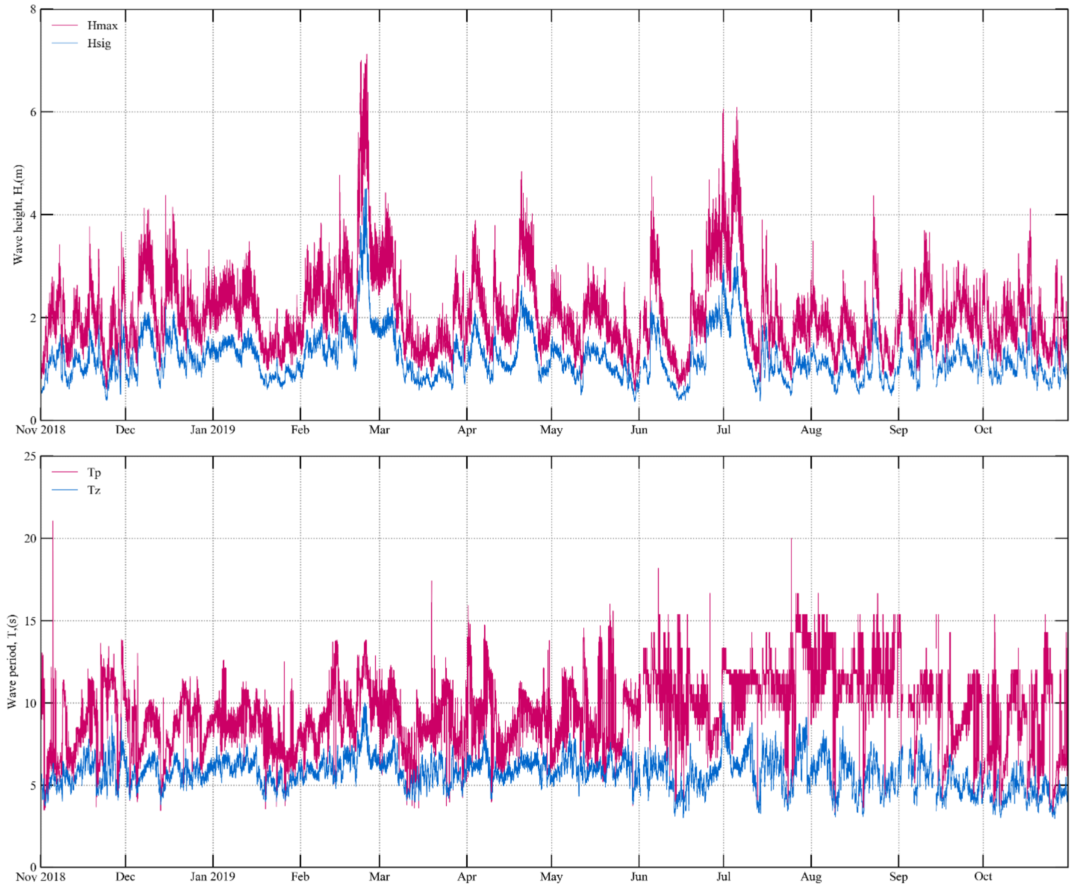


Figure 5 Tweed Heads – Daily wave recordings

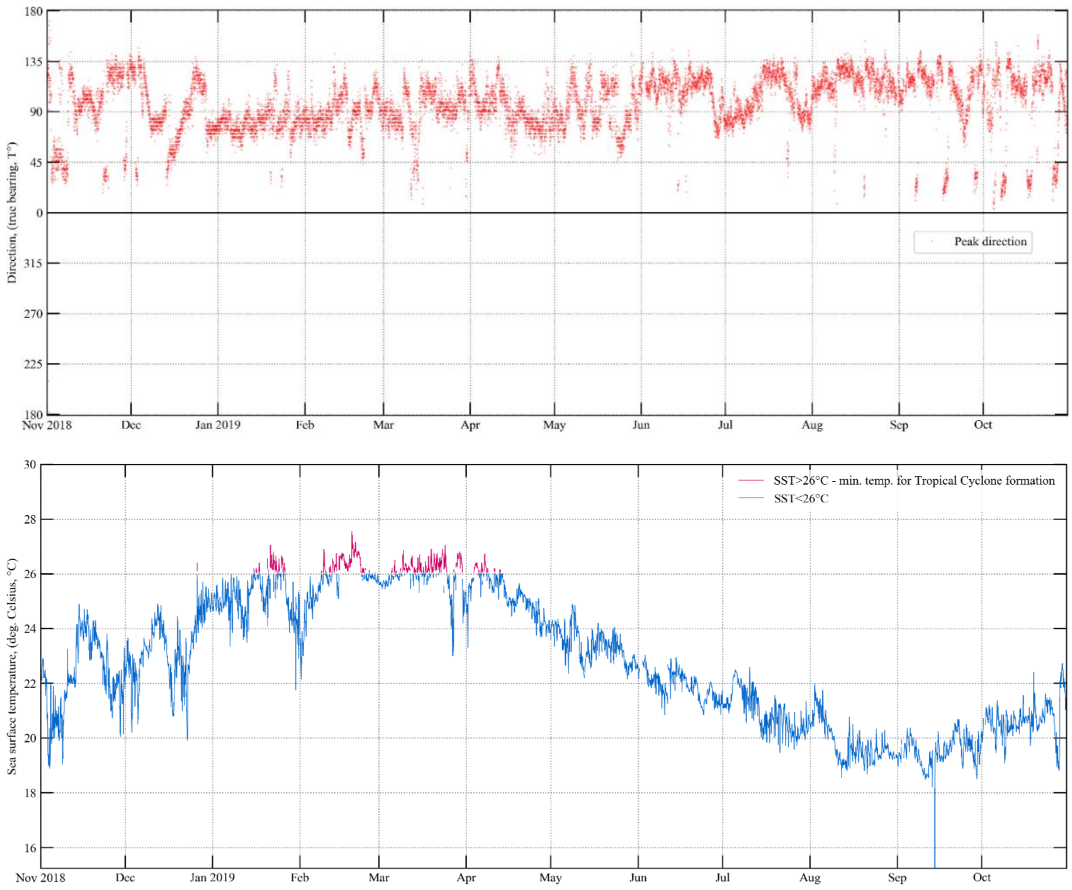


Figure 6 Tweed Heads – Peak wave directions and sea surface temperature

Figure 7 Tweed Heads – Monthly average wave height (H_s) for seasonal year and for all data

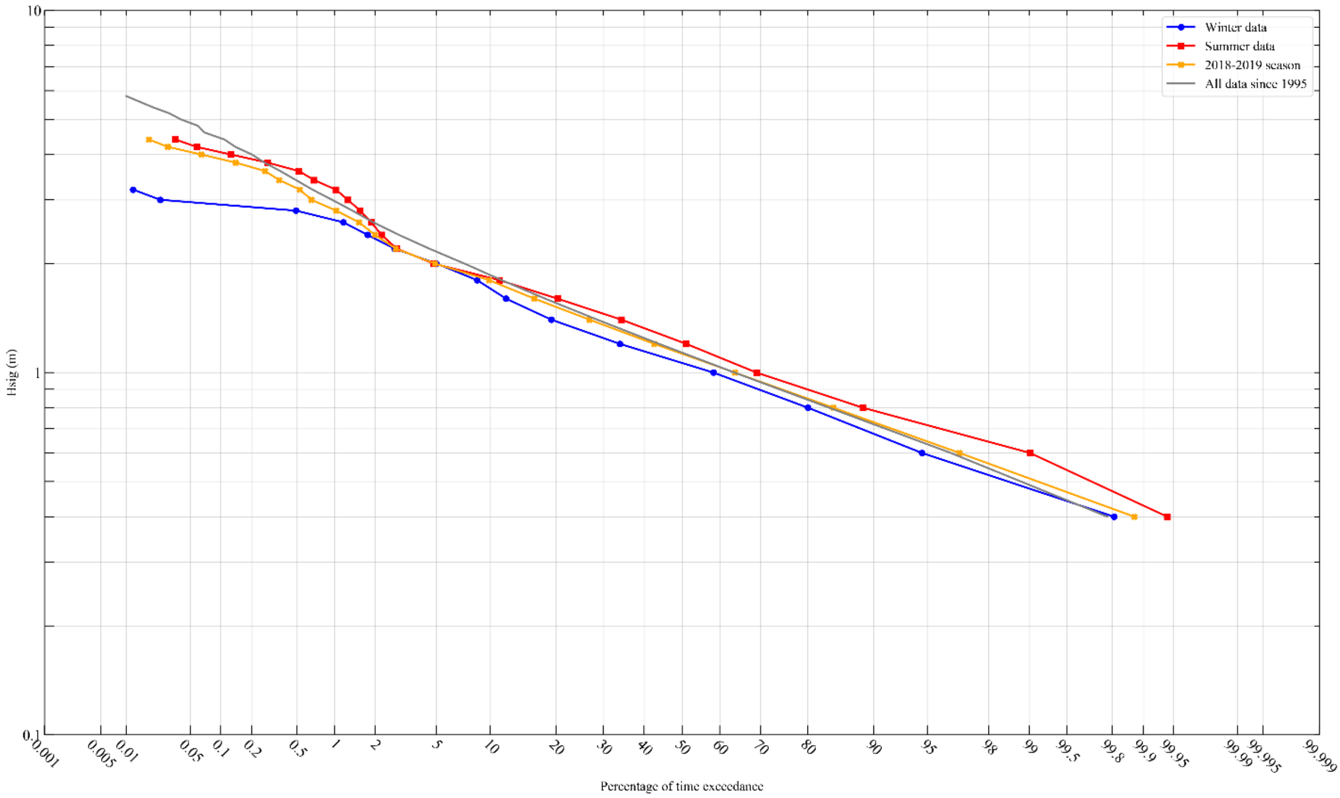


Figure 8 Tweed Heads – Percentage exceedance of wave height (H_s) for all wave periods (T_p)

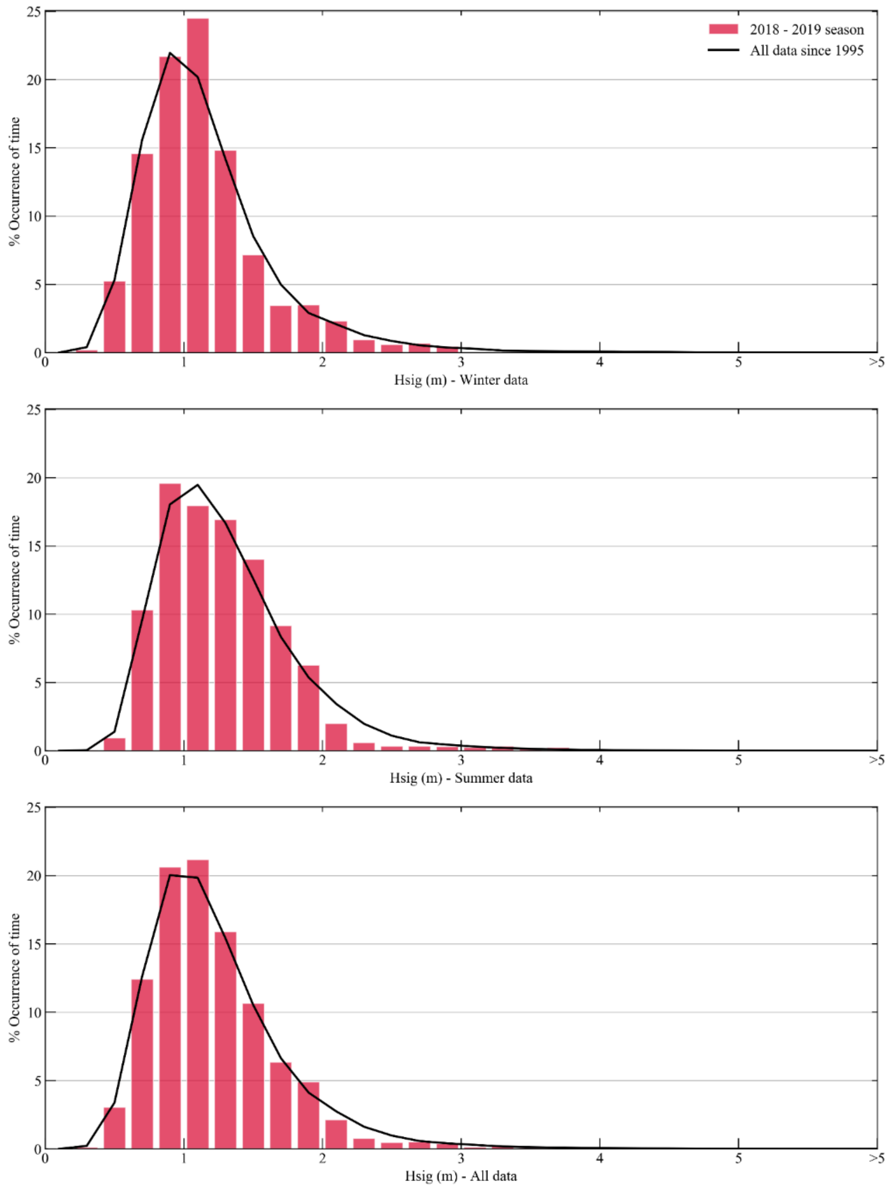


Figure 9 Tweed Heads – Histogram percentage (of time) occurrence of wave heights (H_s)

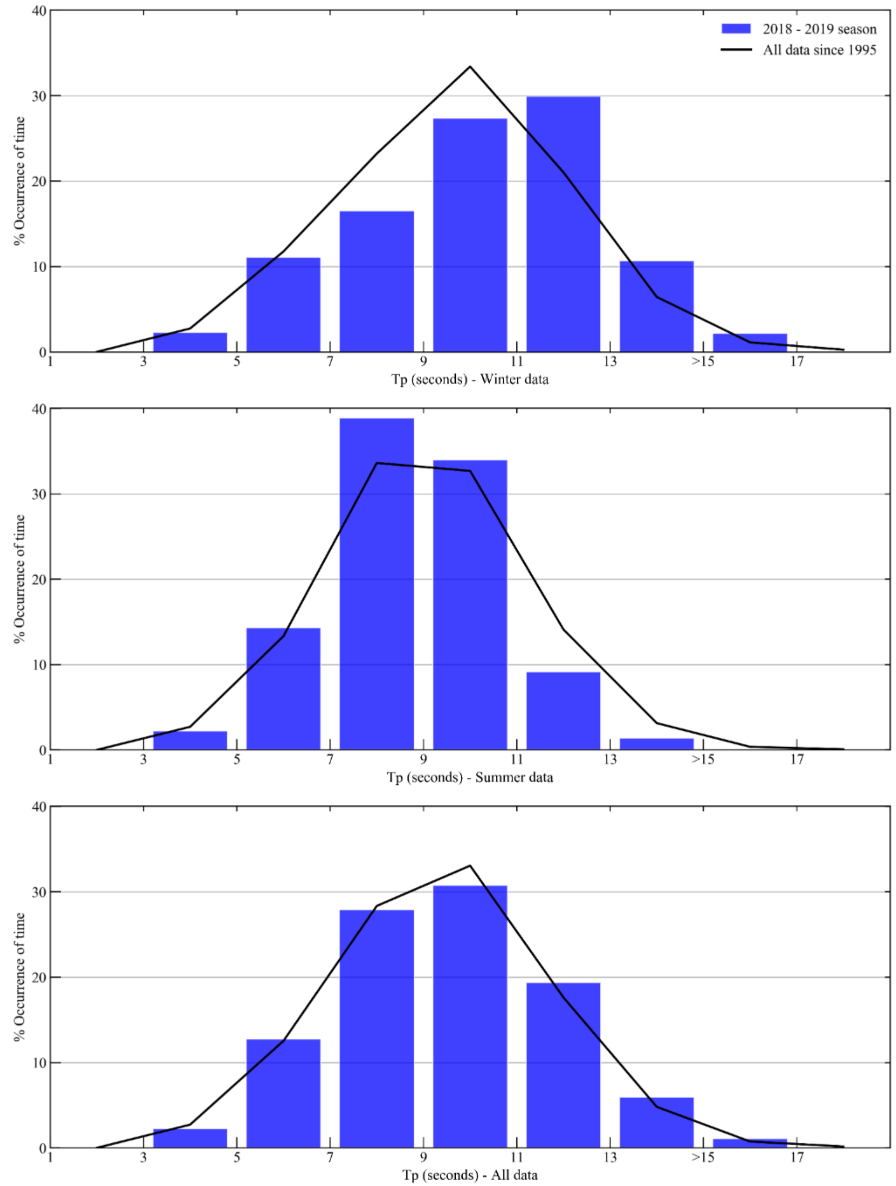


Figure 10 Tweed Heads – Histogram percentage (of time) occurrence of wave periods (T_p)

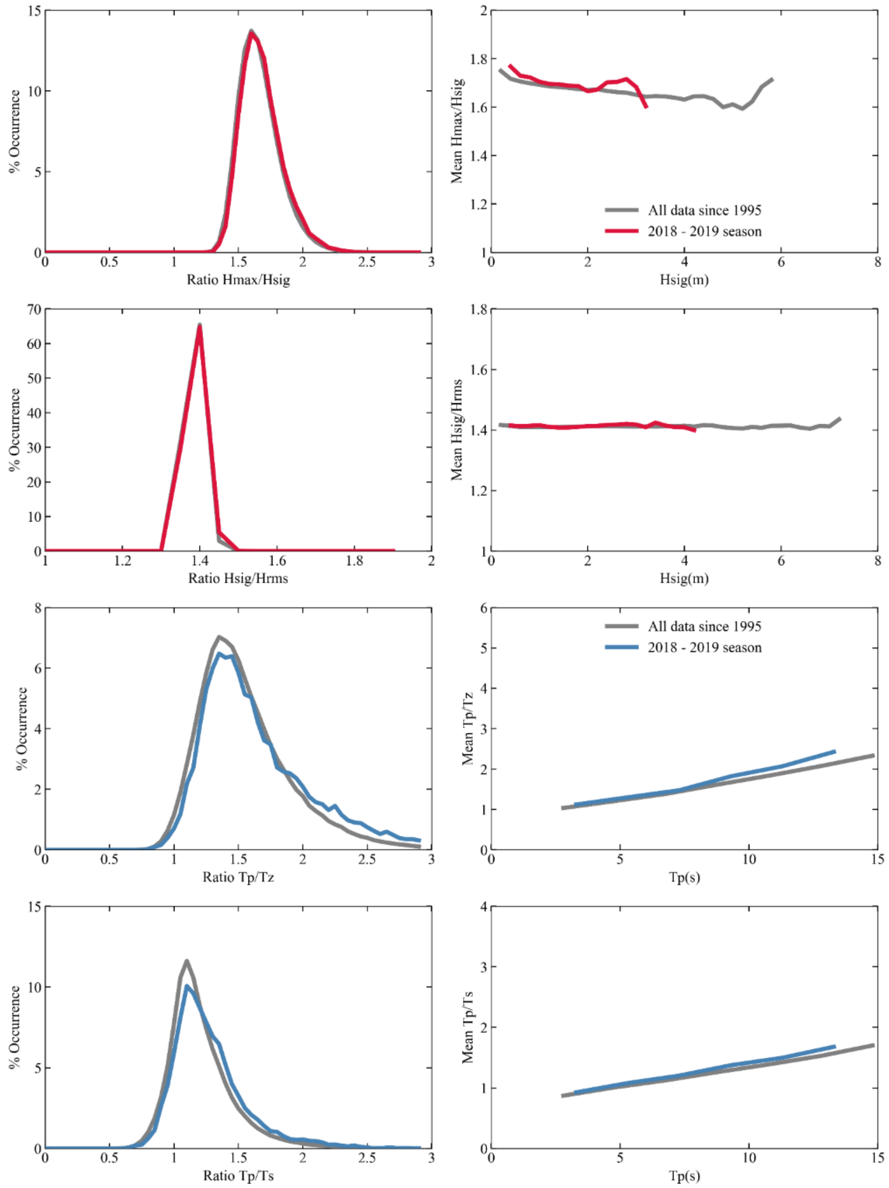


Figure 11 Tweed Heads – Wave parameter relationships

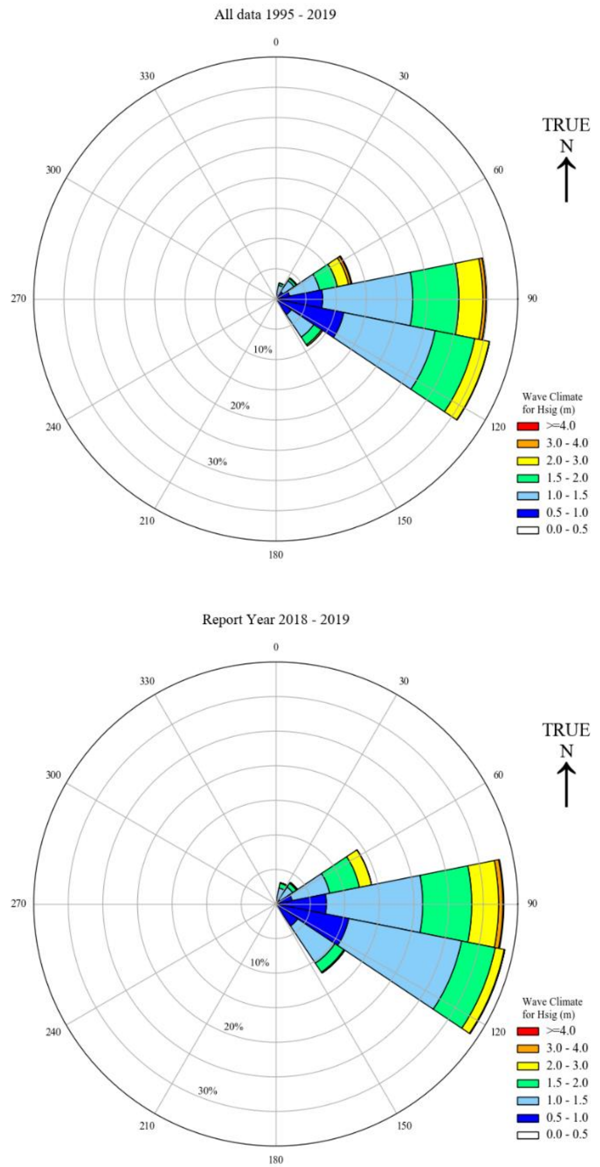


Figure 12 Tweed Heads GPS – Directional wave rose

Palm Beach

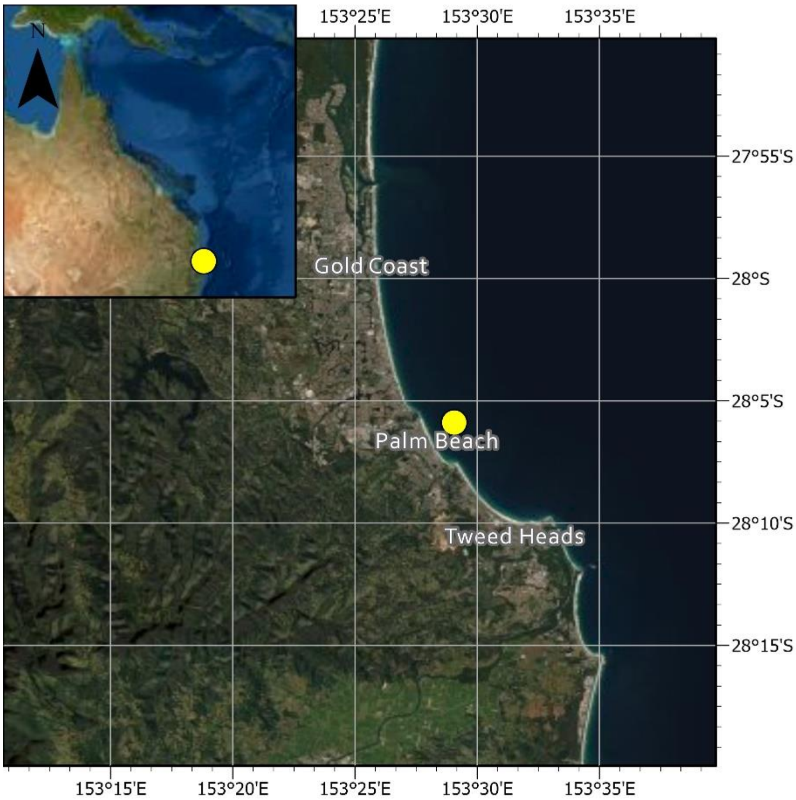


Figure 13 Palm Beach– Locality plan

Table 9 Palm Beach – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	06/06/2017	1.1 years	41,374	2.42
2018–19	01/11/2018	14.05 days	16,799	1

Table 10 Palm Beach – Buoy deployments during the 2018–19 season

Latitude	Longitude	Type buoy	Depth (m)	Deployed date	Removal date
28° 05.895’ S	153° 29.064’ E	DWR4	24	29/08/2018	current

Palm Beach – seasonal overview

The Palm Beach buoy hasn't been in operation for long and this is the first analysis based on limited data. There is also a gap in the data of 14.05 days and hence a 96.15 percent data return for the period of 01 November 2018 to 31 October 2019 (Table 9). The buoy was not replaced during the reporting period.

The Palm Beach Buoy was exposed to three significant meteorological events which are clearly defined in the wave record (Table 12), late March, end of June and early July. All three events have been included in the site's highest waves (Table 11) as this site is has limited historic data.

The time series of wave heights and periods (Figure 14) show the three significant meteorological events clearly with some other events creating lower wave height spikes of between 3 and 4 m H_{max}, throughout the reporting period. Peak wave periods (T_p) are commonly in the 5 to 10 second range with some longer period spikes to 15 seconds. There is an increase in the winter months, most notably August where T_p are longer, from 9 to 16 seconds, for extended time with spikes back to 5 seconds interspersed. A gap in the data is present at the start of January.

The sea surface temperature (SST), measured in the buoy hull showed a range of 19 °C to 27 °C (Figure 15). The SST from January to early April was predominantly warm enough for tropical cyclone development, with periodic warm swings from late November to the start of January.

The monthly average H_s (Figure 16) generally fell within one standard deviation (sd) of the data collected since 2017. Exceptions were noted for July, which was above 1 sd and October where H_s was below 1 standard deviation.

H_s throughout the 2018–2019 period was consistent with the 2017–2018 period data (Figure 17). The summer months experienced higher waves more frequently throughout the period.

Histograms of the occurrence of H_s (Figure 18) indicate a slightly lower occurrence of waves 1.4–1.8 m, for the winter period, compared to 2017–2018 data. Summer shows waves of size 0.8–1.0 m had a higher occurrence, but waves sized 0.2–0.4m had a lesser occurrence. All data from this period shows consistency with the total data set. Histograms of the occurrence of T_p (Figure 19) show a varied distribution between this period and historic data for both winter and summer. Winter indicates a T_p between 11 and 13 seconds occurred more frequently, and between 9 and 11 seconds occurred less frequently. Summer shows a T_p between 7 and 9 seconds and T_p of 9 to 11 seconds had a higher frequency of occurrence. All data for the most part shows a consistent distribution with historic data.

The ratios between different wave parameters such as H_{max}/ H_s were generally consistent between this reporting period and all the historic data, these are plotted in (Figure 20). The ratio of T_p/T_z and T_p/T_s shows a slightly higher kurtosis for this period compared to the entire record.

The plot of wave direction (Figure 15) show dominant easterly wave directions with infrequent swings to the north-northeast. The dominance of east to east-southeast incident wave direction is reflected in the directional wave rose plot (Figure 21) with the most common H_s of 0.5 to 1.0 metres.

Table 11 Palm Beach – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	16/10/2018 01:00	4	15/10/2018 23:30	7.8
2	23/02/2019 20:30	3.7	23/02/2019 20:30	7.3
3	18/02/2018 11:00	3.4	15/03/2018 01:30	6.1
4	15/03/2018 10:30	3	16/10/2017 06:00	6.1
5	13/06/2017 21:00	2.9	5/07/2019 16:00	5.9
6	17/10/2017 15:30	2.8	18/02/2018 23:00	5.6
7	5/07/2019 16:00	2.8	13/06/2017 21:00	5.4
8	7/06/2018 12:00	2.8	29/03/2018 03:30	5.2
9	29/03/2018 03:30	2.7	30/06/2019 23:30	5
10	20/06/2017 06:00	2.6	7/06/2018 08:30	4.9

Table 12 Palm Beach – Significant meteorological events with threshold H_s of 2.5 metres

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
23/02/2019 08:30 Peak Event	3.7	7.3	13.5	TC Oma was nearest the east coast of Qld on 22 February before returning to a low-pressure system and heading northeast.
30/06/2019 11:30	2.6	5	12.9	Low pressure system moving east from central Australia.
05/07/2019 16:00	2.8	5.9	10.2	Upper-level trough developed near central Qld around the 4th and interacted with surface troughs over several days.

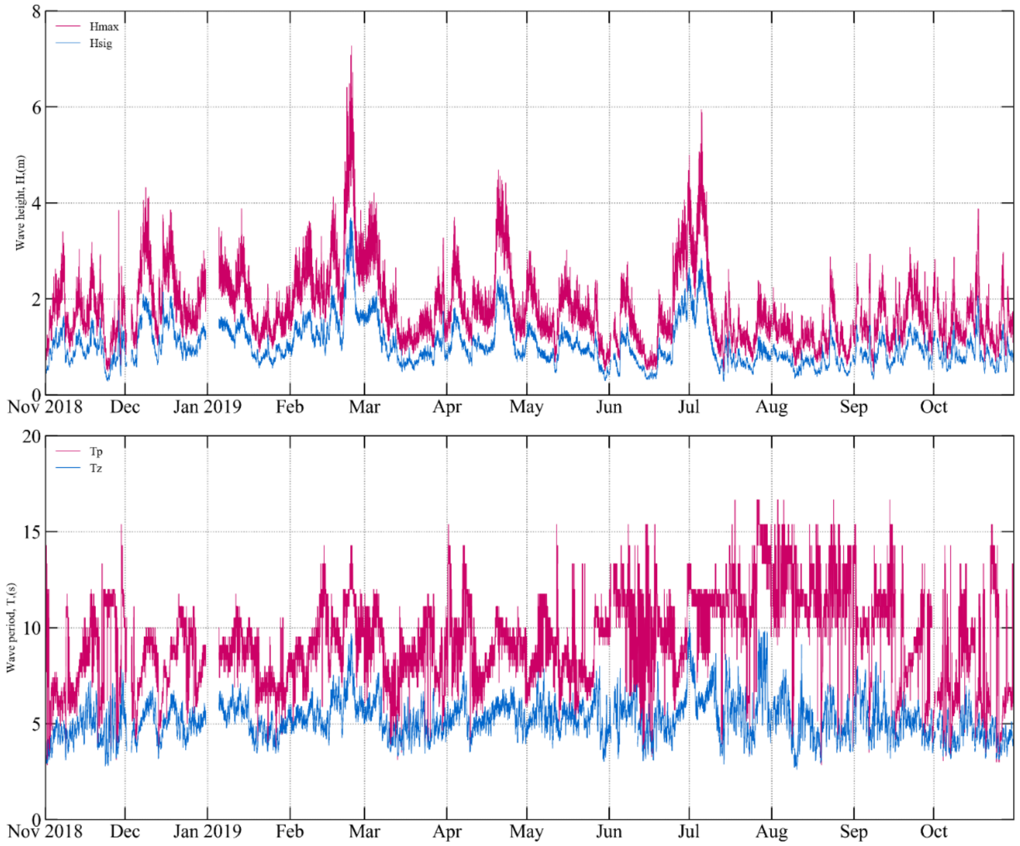


Figure 14 Palm Beach – Daily wave recordings

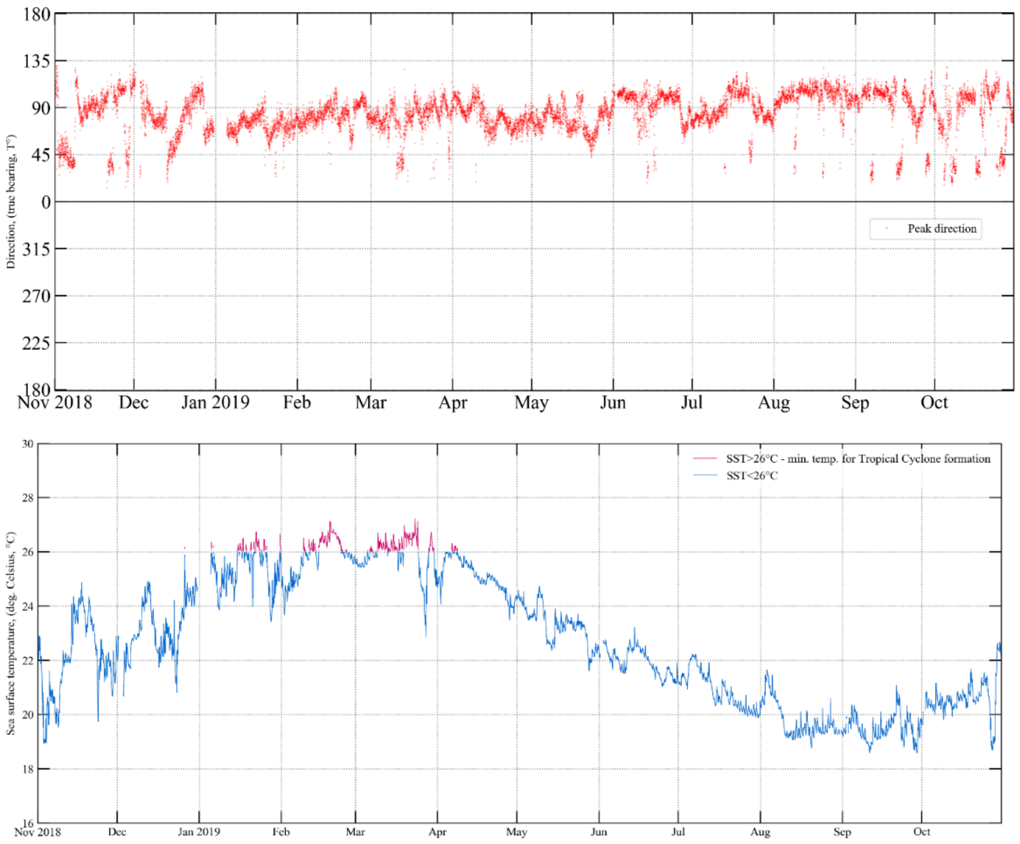


Figure 15 Palm Beach – Peak wave direction and sea surface temperature

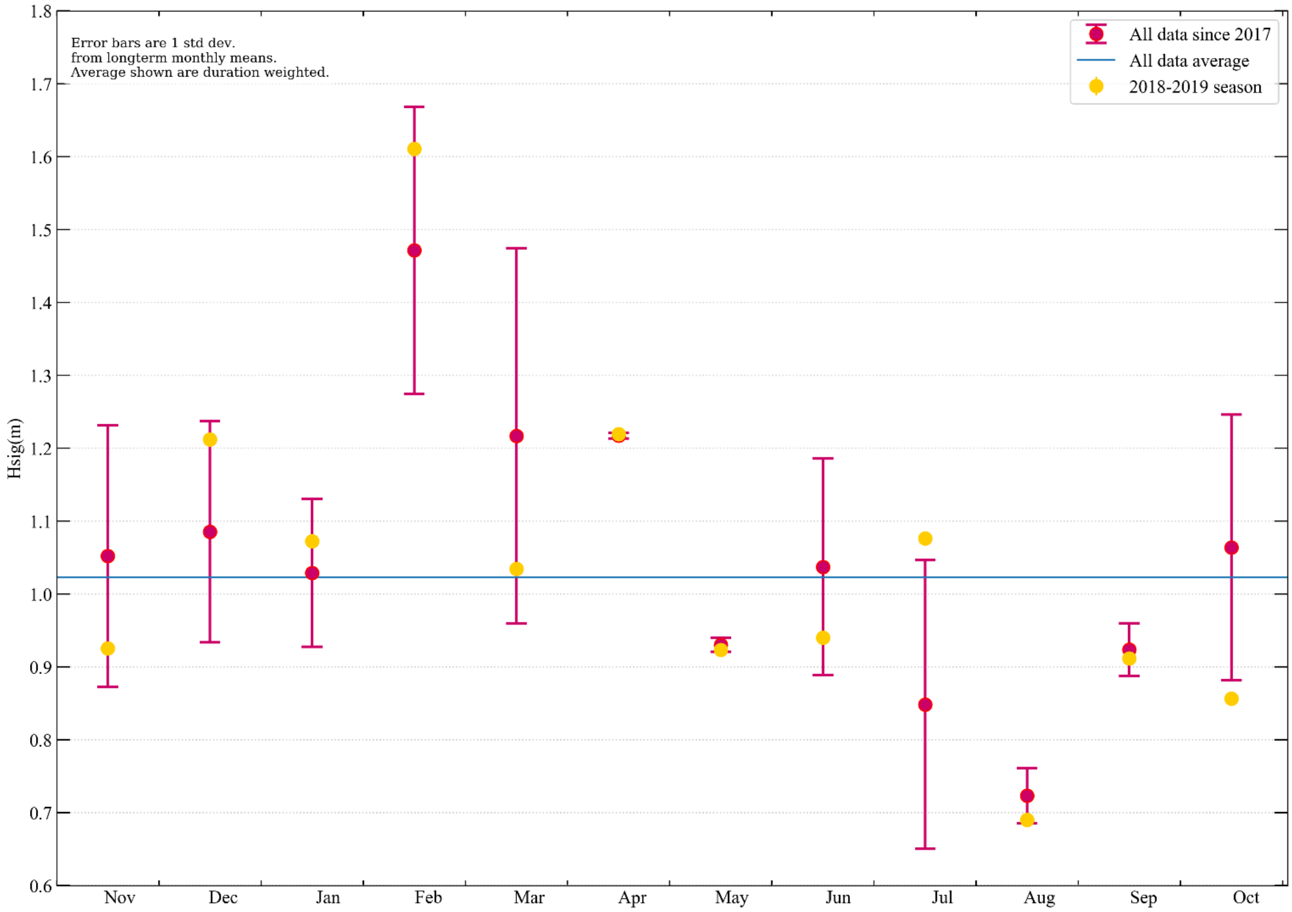


Figure 16 Palm Beach - Monthly average wave height (H_s) for seasonal year and for all data

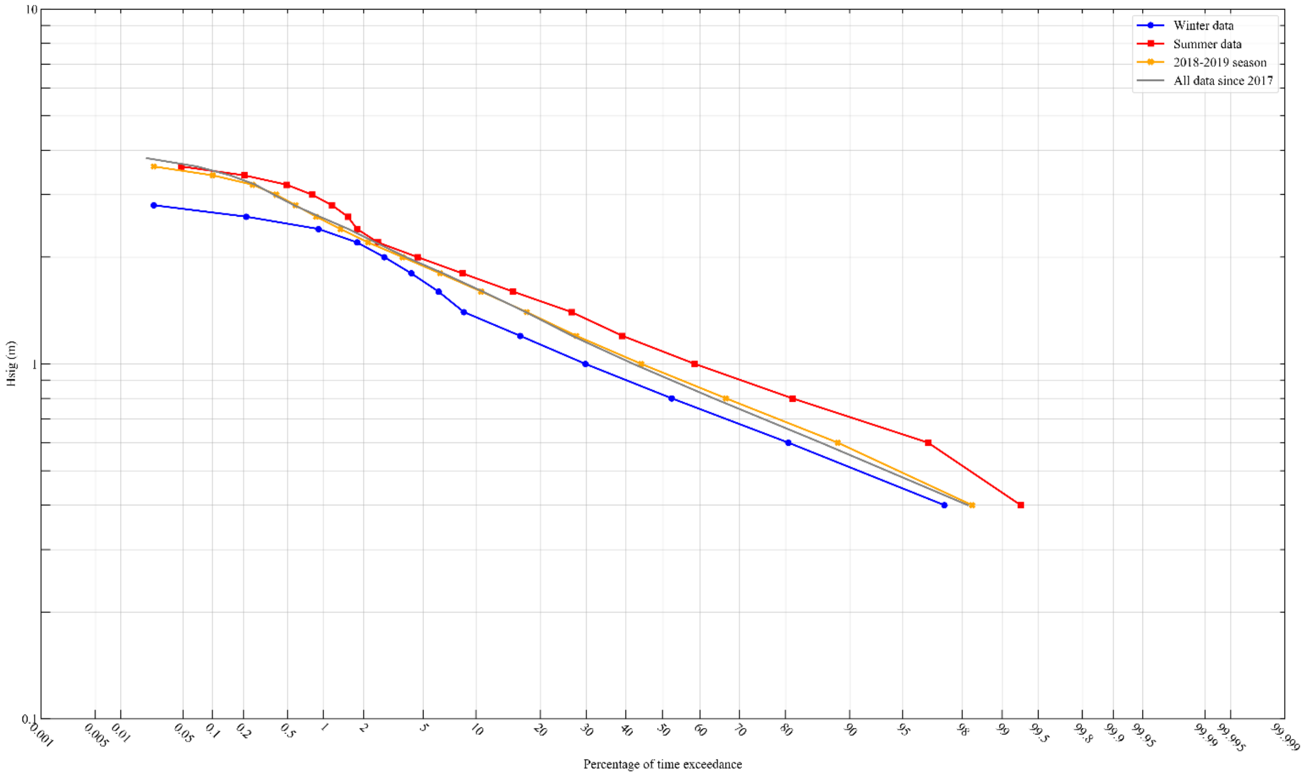


Figure 17 Palm Beach - Percentage exceedance of wave height (H_s) for all wave periods (T_p)

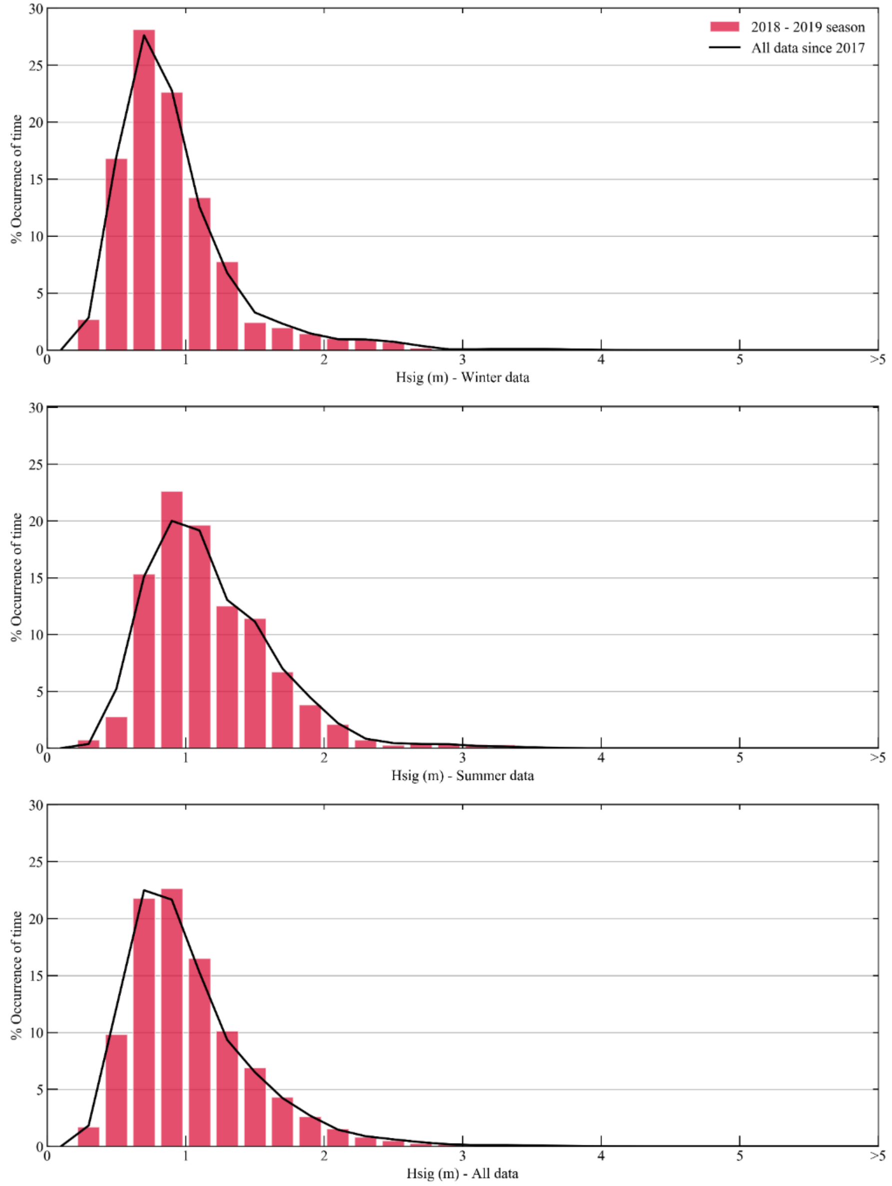


Figure 18 Palm Beach - Histogram percentage (of time) occurrence of wave height (H_s)

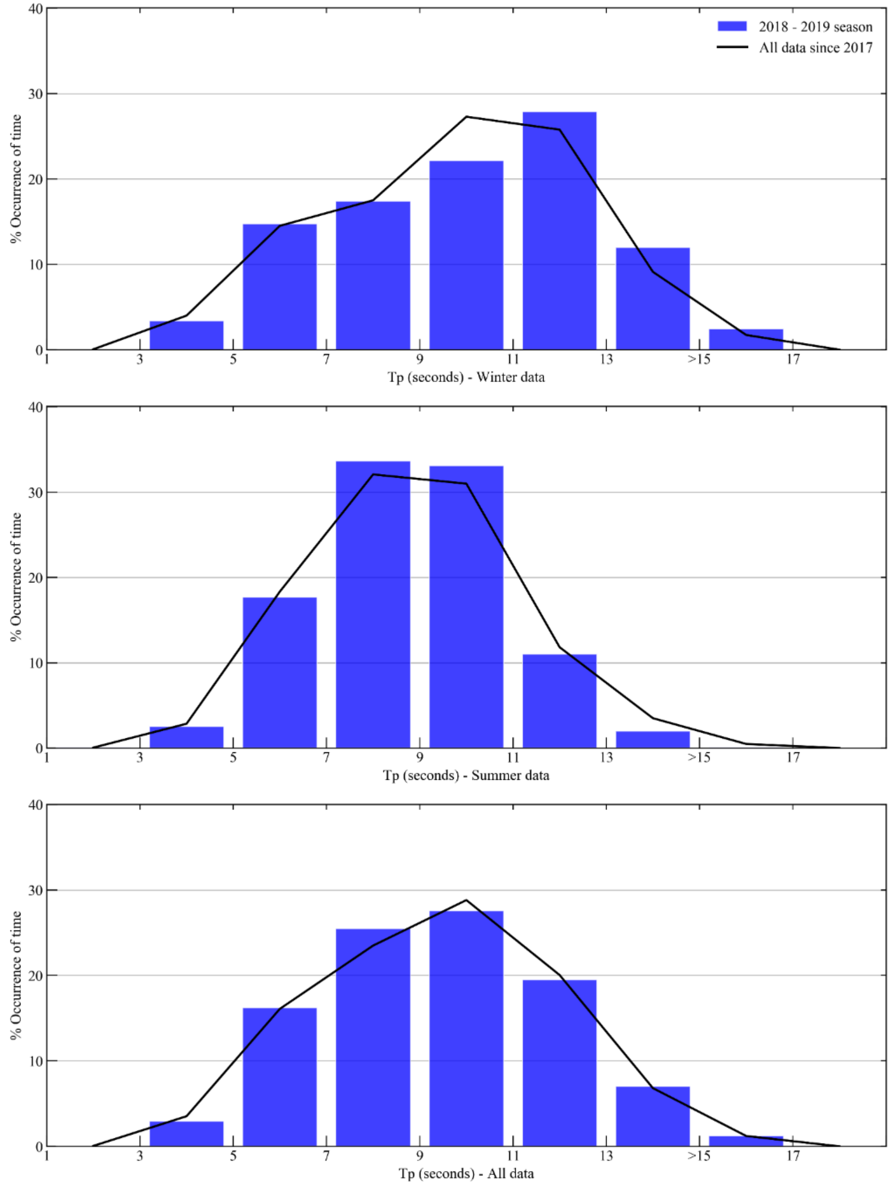


Figure 19 Palm Beach - Histogram percentage (of time) occurrence of wave periods (T_p)

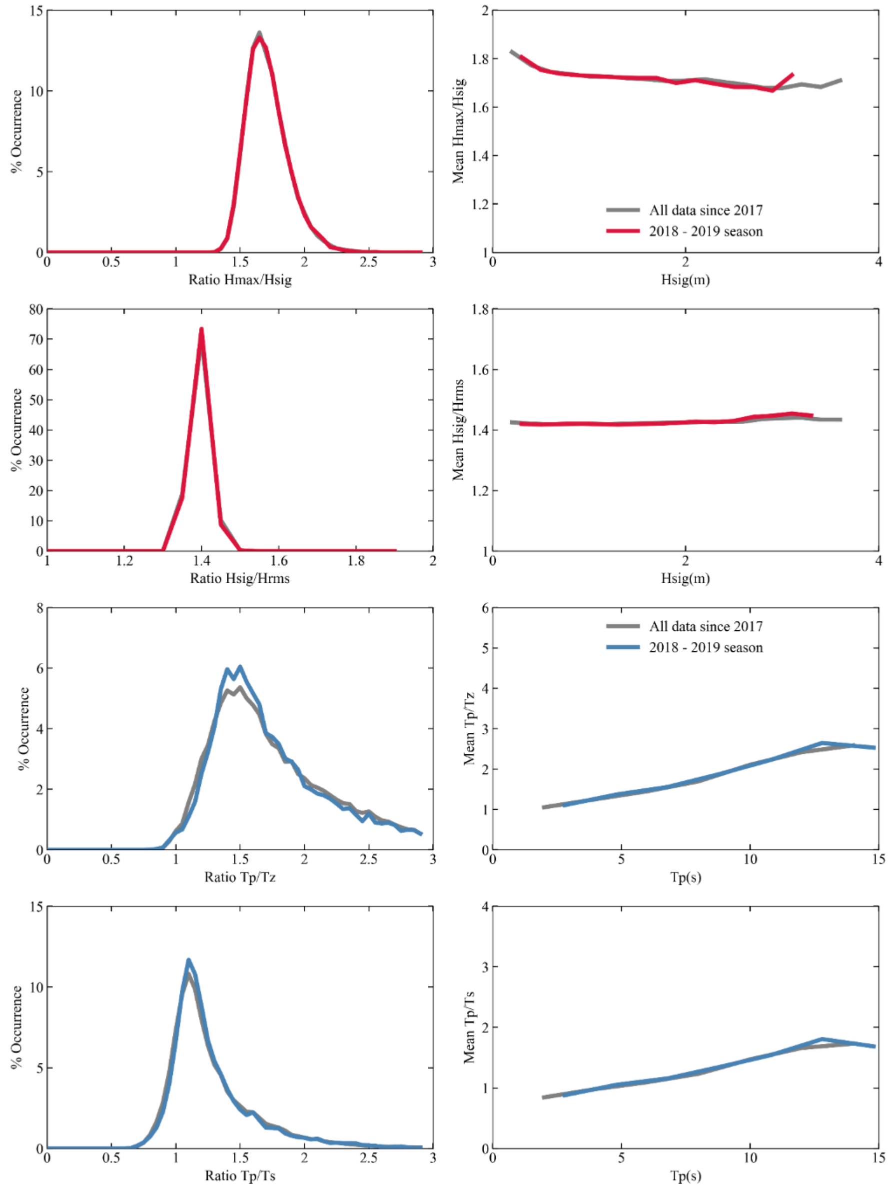


Figure 20 Palm Beach - Wave parameter relationships

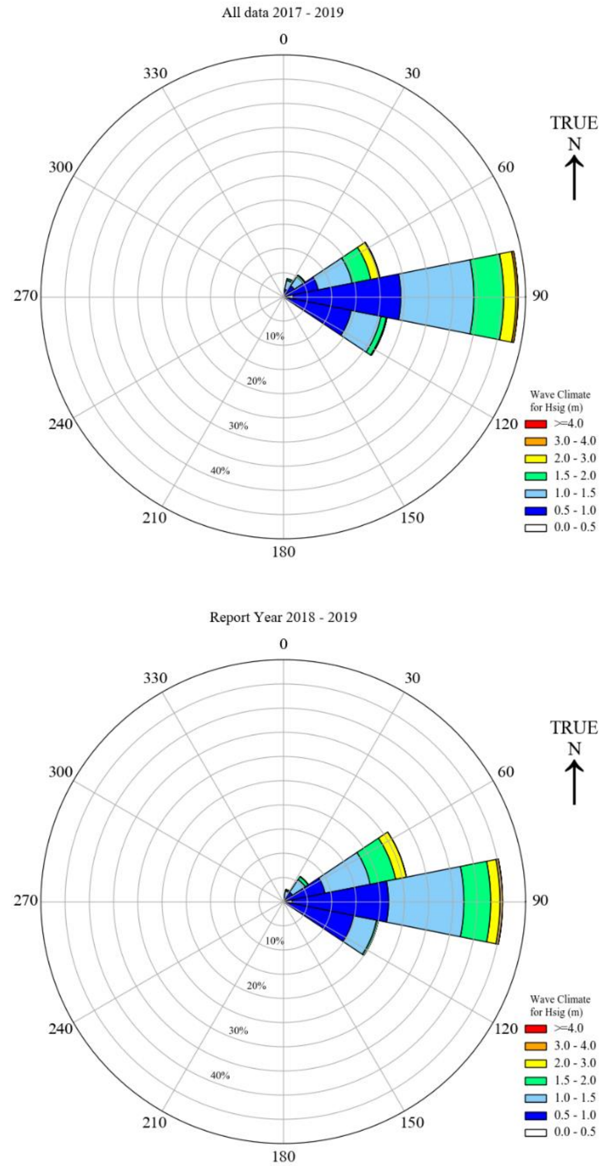


Figure 21 Palm Beach - Directional wave rose

Gold Coast

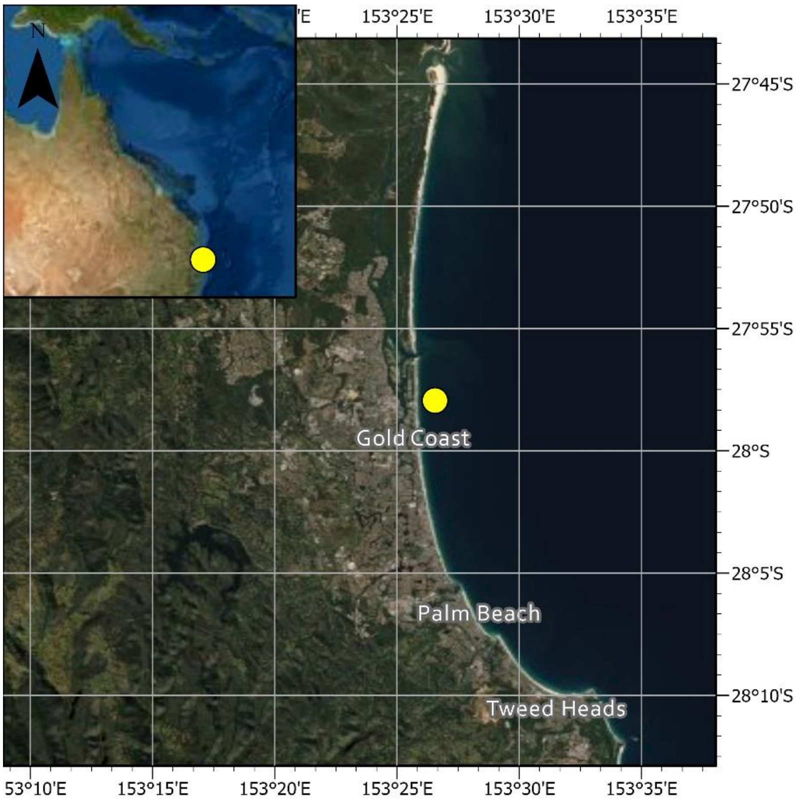


Figure 22 Gold Coast – Locality plan

Table 13 Gold Coast – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
2008–19*	04/07/2008*	0.16 years	195248	11.33
2018–19	01/11/2018	6.98 days	17185	1

*See

Table 2 for site commission date.

Table 14 Gold Coast – Buoy deployments during the 2017-18 season

Latitude	Longitude	Type Buoy	Depth (m)	Deployed date	Removal date
27° 57.948' S	153° 26.552' E	DWR-MkIII	16	19/10/2018	current

Gold Coast – seasonal overview

The Gold Coast wave buoy has been operational for almost 33 years with an excellent overall data return of 94.09 per cent. The data return for the current period of November 2018 to October 2019 was also excellent, with total gaps of only 6.98 days, equivalent to 98 percent data return (Table 13). The buoy was replaced shortly before the reporting period on 19 October 2018 (Table 14).

The Gold Coast wave buoy was subjected to three significant meteorological events during the reporting period (Table 16). The peak event was tropical cyclone Oma which produced waves at the site with H_s of 4.4 m and a H_{max} of 8.7 m, but no changes were made to the highest recorded waves table for this site (Table 15). This event is clearly seen in the daily wave recording time series (Figure 23).

The time series of wave heights and periods (Figure 23) show the significant meteorological event, the passage of TC Oma, clearly with some other events creating lower wave height spikes of around 4 m and up to 6 m H_{max}, throughout the reporting period. Peak wave periods (T_p) in the summer months are commonly in the 6 to 12 seconds range with some longer period spikes to 17 seconds. There is an increase in the winter months, most notably August where T_p are longer, from 10 to 16 seconds, for extended periods with spikes back to 5 seconds interspersed.

The SST measured in the buoy hull showed a range of 19 °C to 27 °C (Figure 24). The SST from mid-January to early-April was sporadically warm enough for tropical cyclone development. Warm swings are noted November to the start of January.

For the most part, the monthly average H_s (Figure 25) for the 2018–2019 period fell within 1 sd of the historic record except for February which was above 1 sd and March which was below 1 standard deviation.

The wave climate during the 2018–2019 period was generally consistent with the wave climate of the whole record except for a slight deviation for winter waves nearing 2 m which occurred less frequently as seen in the percentage exceedance plot (Figure 26). Wave heights in summer were generally higher than winter. Histograms for occurrence of H_s (Figure 27) show in summer that there was a greater occurrence of the modal 0.4–0.6 m and 0.8 –1.0 m waves and lower occurrence of waves exceeding 1.4 m. During winter 0.4–0.6 m waves and 0.8–1.0 m waves and waves exceeding 2.4 m occurred less often. Data for the whole period generally lines up with the whole data record, if not slightly lower occurrences.

The histograms of occurrence of T_p show (Figure 28) that in winter there was a higher than the historical average occurrence of wave periods longer than 11 seconds, with the most common wave period of between 11 and 13 seconds. A decrease from the average occurrence of wave periods between 7 and 11 seconds is also noted. In summer, waves with periods between 7 and 9 seconds occurred most frequently and more than the average compared to data. A decreased occurrence of wave periods longer than 11 seconds can be seen for the summer data. The all-data histogram shows similar distribution between the reporting period and the entire record with a slight shift away from waves in the 7 to 11 second range.

The ratios between different wave parameters such as H_{max}/ H_s were generally consistent between this reporting period and all of the historic data, these are plotted in (Figure 29). The ratio T_p/T_s was skewed slightly towards a larger ratio in line with the decrease in occurrence of H_s over 1.2 m and increase in T_p longer than 11 seconds in winter.

The time series for wave direction (Figure 24) shows a dominant east to east-southeast wave direction with occasional swings throughout the year to the northeast. This is also reflected in the directional wave rose plots (Figure 30) which shows 1.0 to 1.5 m waves as most common. The wave directions for the reporting period are very similar to the entire record.

Table 15 Gold Coast – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	03/05/1996 06:30	7.1	03/05/1996 06:30	12.0
2	28/01/2013 10:30	6.3	17/03/1993 04:30	11.0
3	23/05/2009 03:30	6.1	05/03/2006 05:00	10.7
4	05/03/2004 23:00	5.9	22/05/2009 12:30	10.6
5	17/03/1993 12:30	5.7	05/03/2004 22:00	10.6
6	25/04/1989 21:00	5.6	12/06/2012 07:00	10.5
7	12/06/2012 07:00	5.5	28/01/2013 09:30	10.5
8	05/03/2006 08:00	5.3	25/04/1989 09:30	10.0
9	04/06/2016 20:00	5.1	15/02/1995 10:30	9.2
10	15/02/1995 07:00	5.0	04/06/2016 20:00	9.1

Table 16 Gold Coast – Significant meteorological events with threshold H_s of 2.5 metres.

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
23/02/2019 08:30 Peak Event	4.4	8.7	13.4	TC Oma was nearest the east coast of Qld on 22 February before returning to a low-pressure system and heading northeast.
30/06/2019 23:30	2.9	5.7	12.8	Low pressure system moving east from central Australia.
05/07/2019 16:00	3	5.8	9.6	Upper-level trough developed near central Qld around the 4th and interacted with surface troughs over several days.

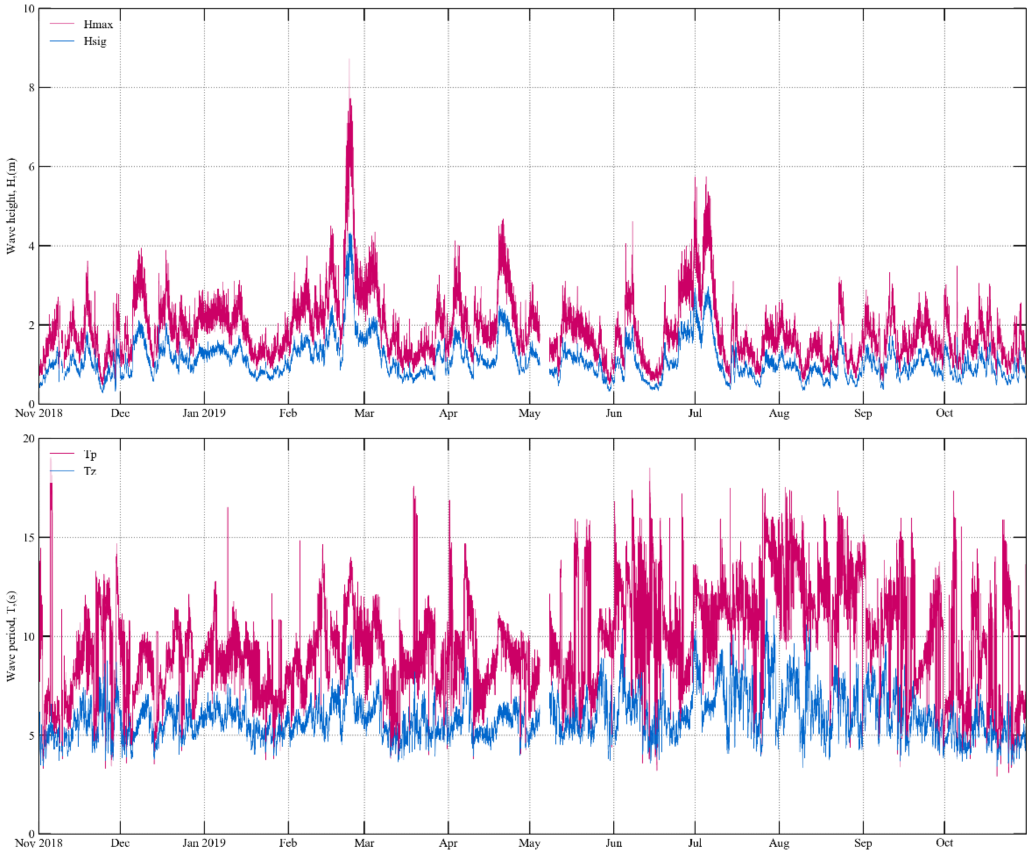


Figure 23 Gold Coast – Daily wave recordings

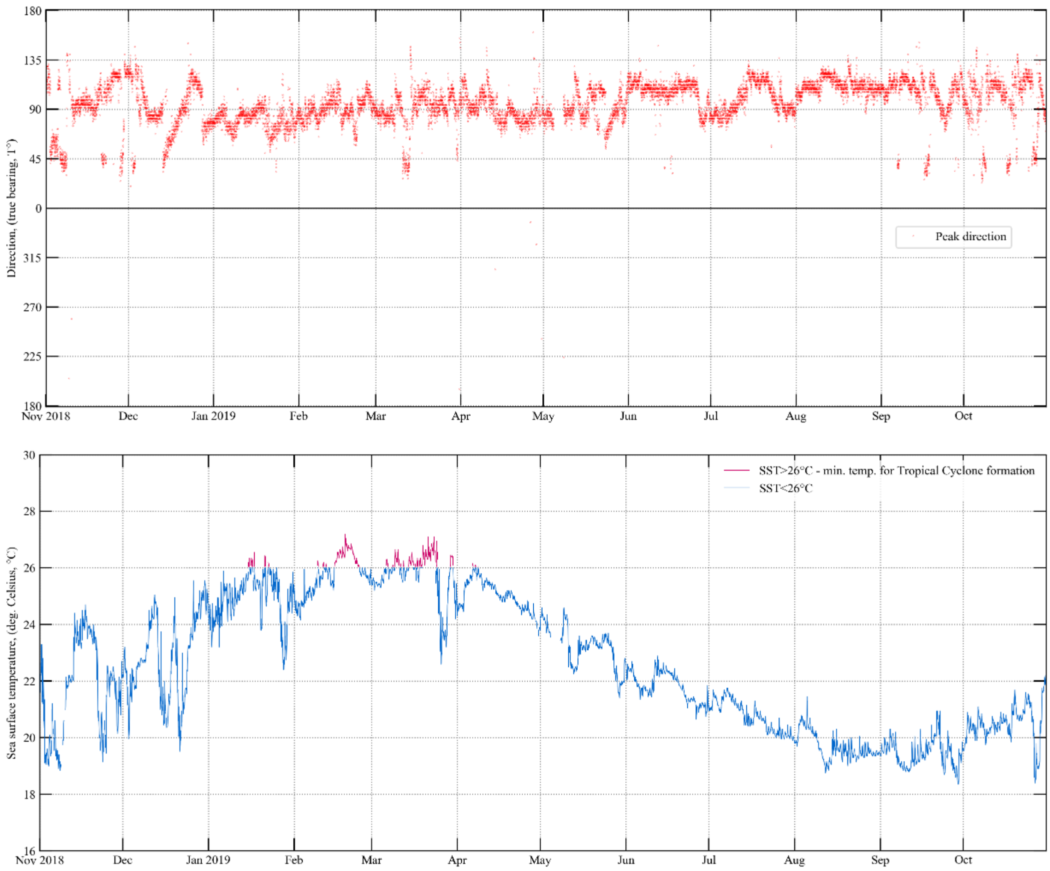


Figure 24 Gold Coast – peak wave direction and sea surface temperature

Figure 25 Gold Coast – Monthly average wave height (H_s) for seasonal year and for all data

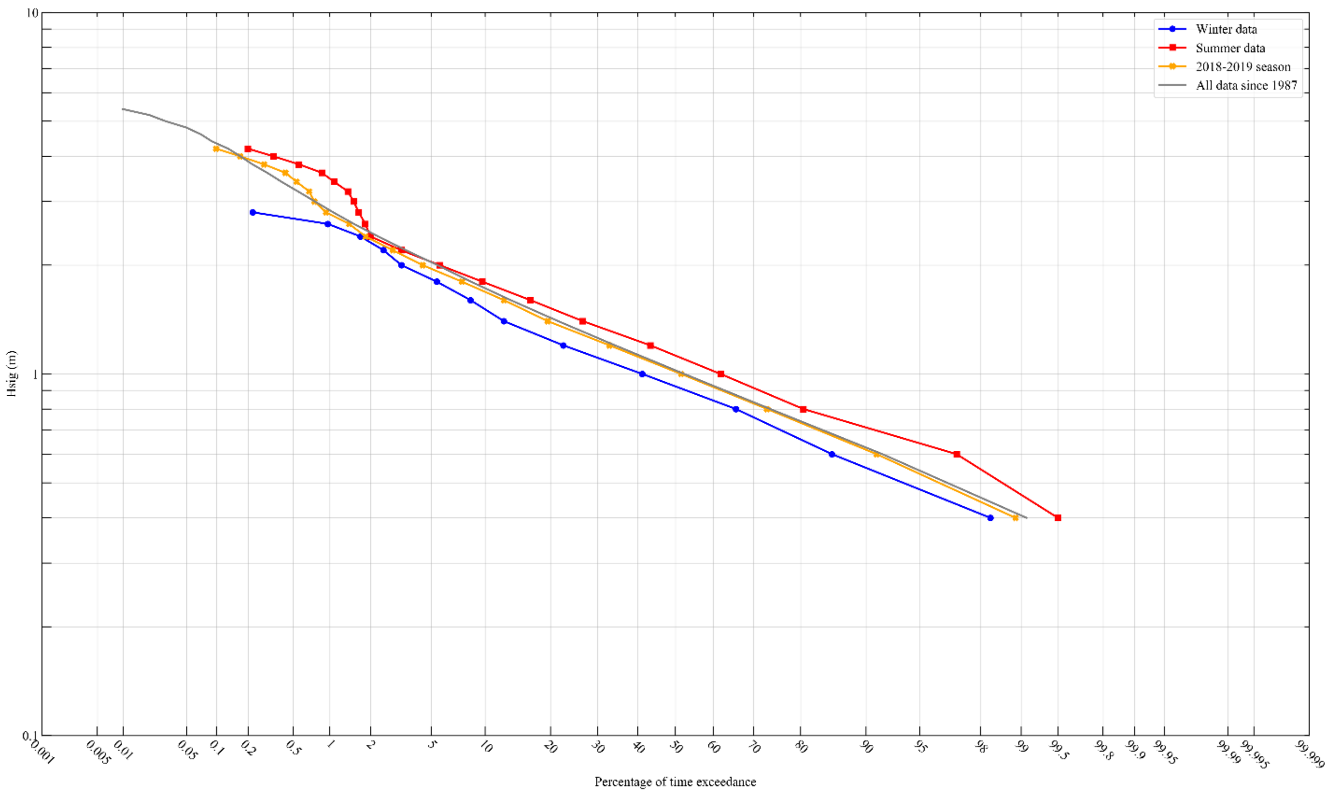


Figure 26 Gold Coast – Percentage exceedance of wave height (H_s) for all wave periods (T_p)

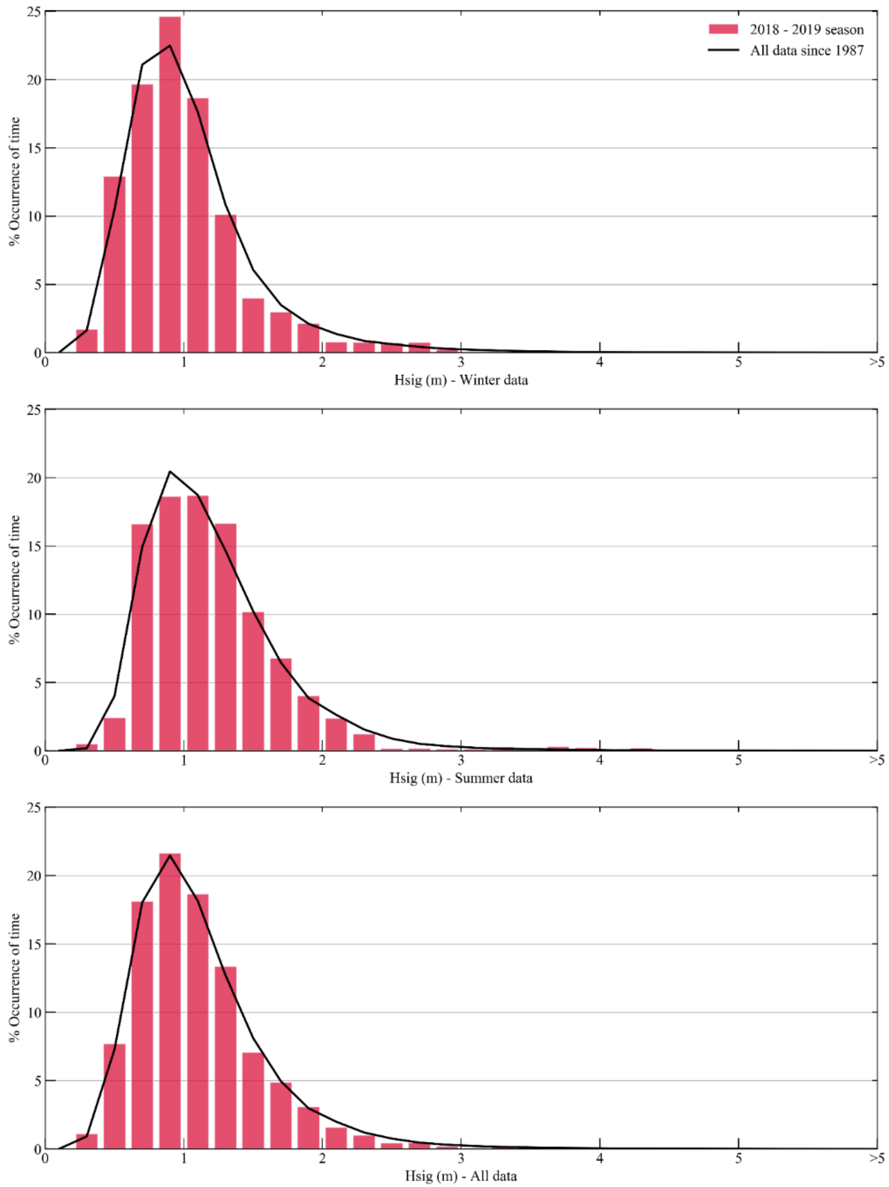


Figure 27 Gold Coast – Histogram percentage (of time) occurrence of wave heights (H_s)

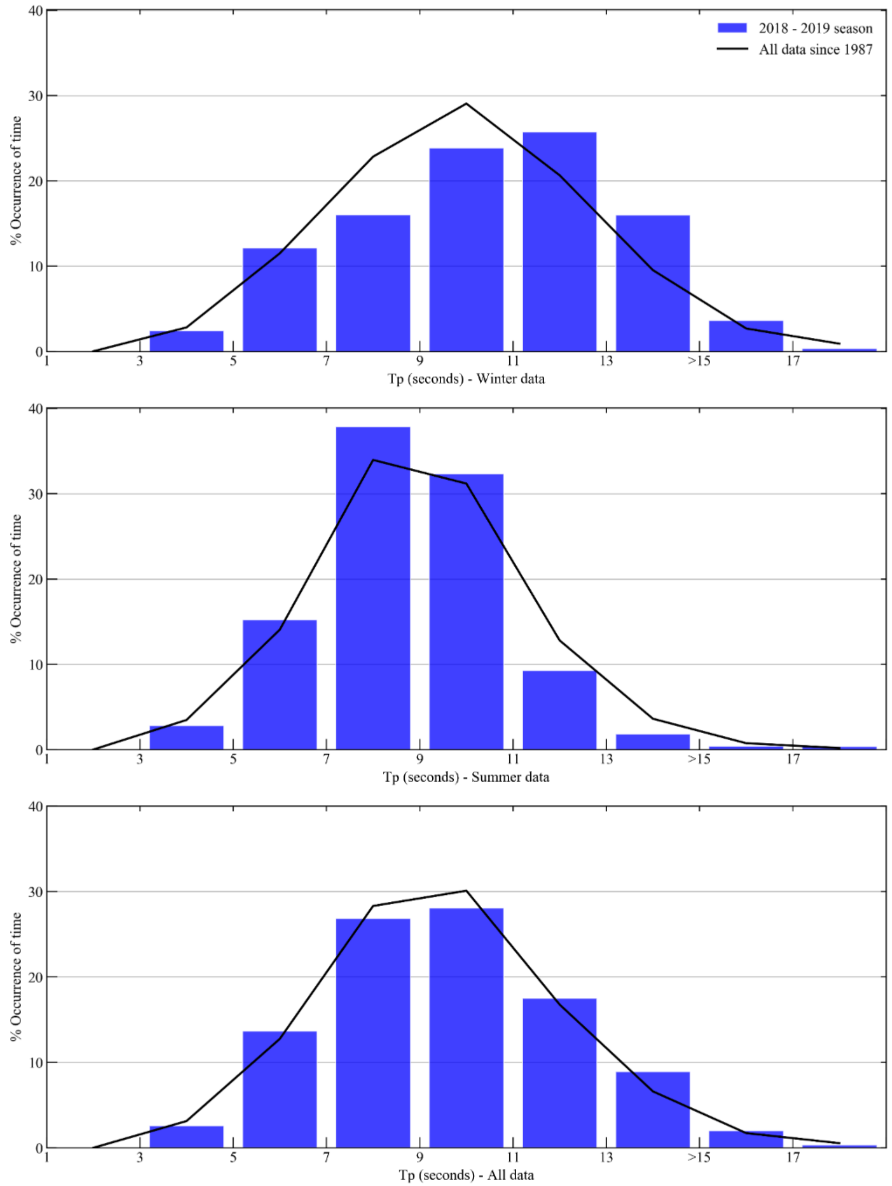


Figure 28 Gold Coast – Histogram percentage (of time) occurrence of wave periods (T_p)

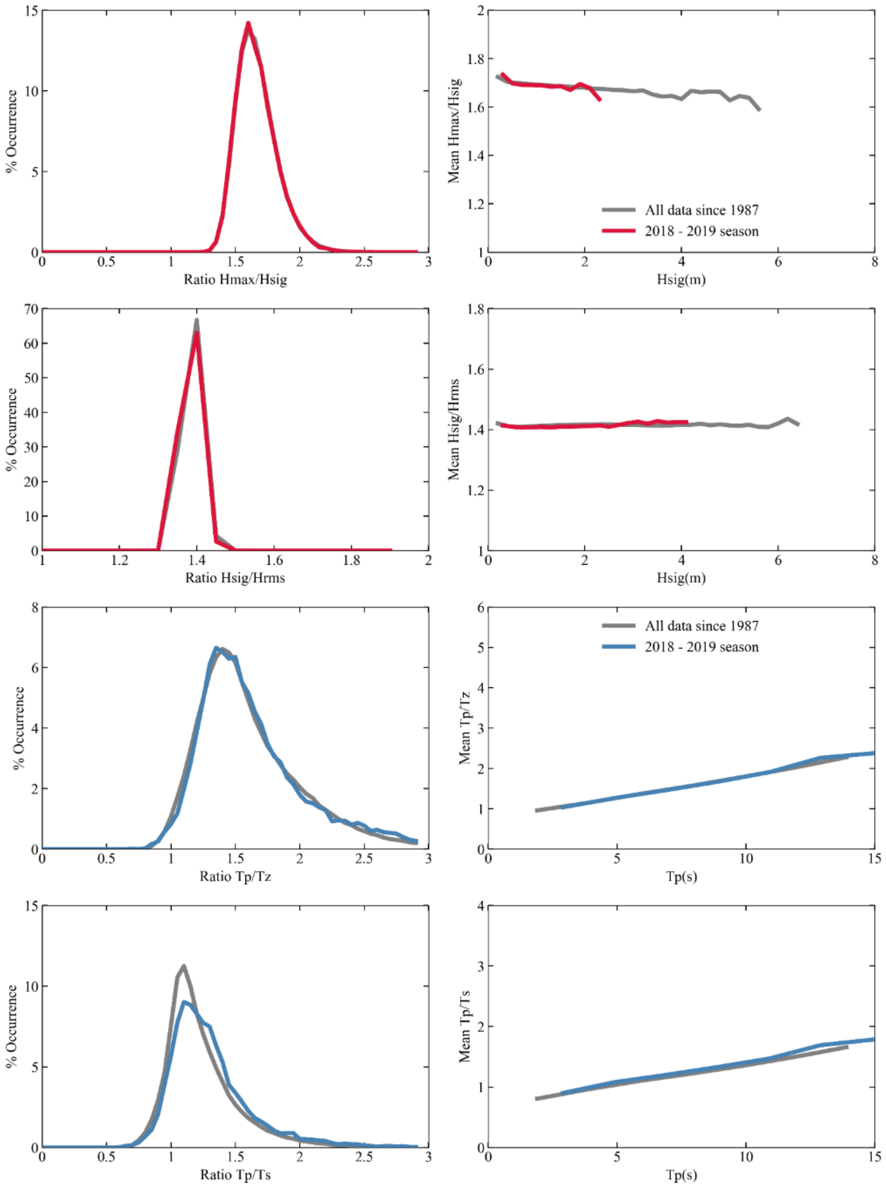


Figure 29 Gold Coast – Wave parameter relationships

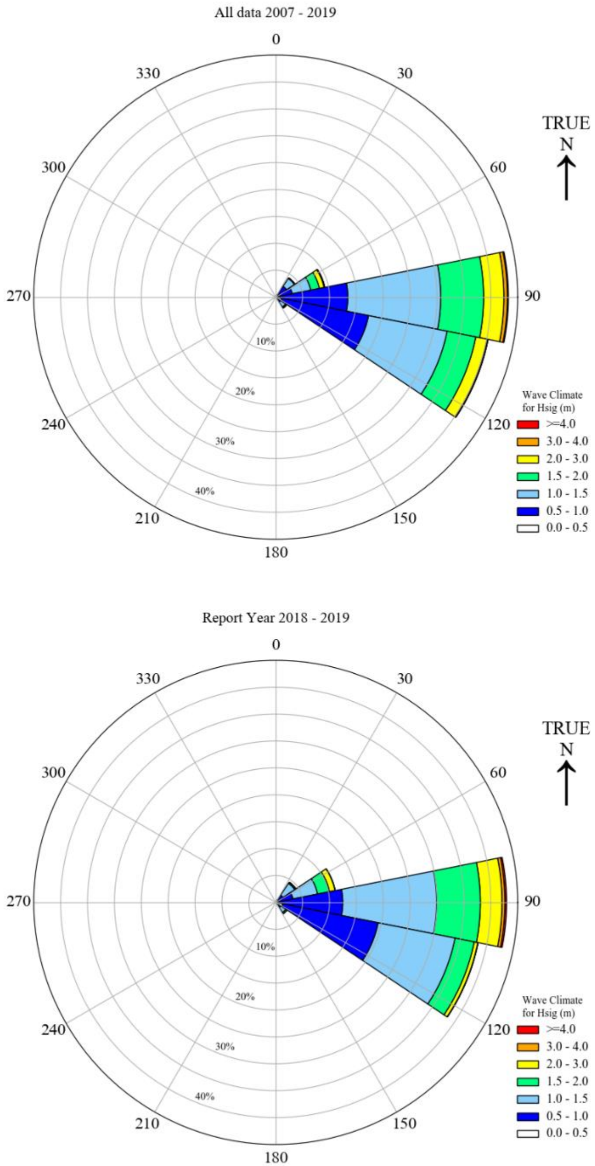


Figure 30 Gold Coast – Directional wave rose

Brisbane

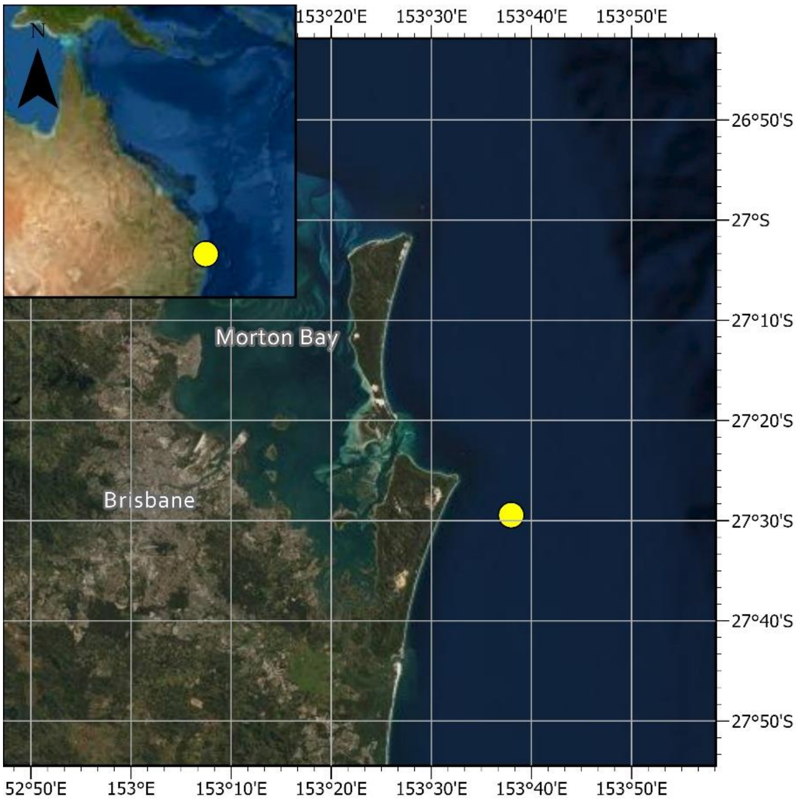


Figure 31 Brisbane – Locality plan

Table 17 Brisbane – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	31/10/1976	12.16 years	400,878	43
2018–2019	01/11/2018	64.4 days	17,321	1

Table 18 Brisbane – Buoy deployments during the 2018-19 season

Latitude	Longitude	Type buoy	Depth (m)	Deployed date	Removal date
27° 29.420’ S	153° 38.044’ E	DWR4	80	22/12/2017	15/07/2019
27° 29.451’ S	153° 37.980’ E	DWR4	80	15/07/2019	current

Brisbane – seasonal overview

The Brisbane wave buoy has been operational for 43 years. The data recorded for the period November 2018 to October 2019 has a significant gap from the start of March to the end of April, equivalent to an 82.36 per cent data return (Table 17). This appears to be a heave sensor malfunction as directional and temperature data is consistent with previous data captured for this time of year. These gaps will unfortunately affect several plots and analysis in both summer and winter periods which require wave height and period data. The buoy was changed once during the period on the 15 July 2019 (Table 18)

The site was exposed to five significant weather events (Table 20) the most notable of which is TC Oma on 22 February with H_s of 6.9 m and H_{max} of 13.1 m recorded at the site. This event added a new wave to the top 10 highest waves for Brisbane (Table 19) and was the largest H_s and H_{max} recorded in the state this monitoring period.

Daily wave recordings (Figure 32) show several spikes of high wave occurrence including the largest wave recorded in the state in late February. Variations in T_p can be seen throughout the monitoring period. There is a two month gap in the data from the start of March to the end of April.

The sea surface temperature (SST) measured in the buoy hull showed a range of 19 °C to 28 °C (Figure 33). The SST from January to mid-April was predominantly warm enough for tropical cyclone development. Temperature swings can be seen throughout the period with more significant changes detected during November and from August to the end of the record.

The monthly average H_s for the 2018–2019 recording period was within one standard deviation of the entire data record except for January, which was below 1 sd, and February above 1 standard deviation. Due to gaps in data March and April data points are missing (Figure 34).

The wave climate during the reporting period was very similar to the wave climate of the entire record, as seen in the percentage exceedance plot (Figure 35). Waves exceeding 3 m show some variation with an increased presence in summer. Histograms for occurrence of H_s (Figure 36) show a lower occurrence of wave heights 1.0 to 1.2 m and higher occurrence of 1.4 to 2.0 m waves for all graphs compared to the historical data. 1.2 to 1.4 m waves where most frequent during the reporting period. A decreased occurrence of waves exceeding 2m is noted during summer though some waves over 4.8 metres. Histograms of the occurrence of peak wave periods (T_p) (Figure 37) show a similar distribution to other sites in Southeast Queensland. Winter T_p shows longer wave periods occurred more frequently than in previous years on record, with a period between 11 and 13 seconds being more frequent. Summer periods were mostly consistent with the record with a slight increase in waves of 5 to 7 second peak periods.

The ratios between different wave parameters such as H_{max}/ H_s and T_p/T_s were consistent between this reporting period and all of the historic data (Figure 38).

Time series for wave direction (Figure 33) indicates dominant wave directions east and south-southeast with occasional swings to the north in summer. The directional wave rose plots (Figure 39) clearly show incident waves with directions more frequently from the east than compared to the entire dataset, but with a spread from east to south. Most common waves for this period are 2.0–3.0 m waves from the south-southeast.

Table 19 Brisbane – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	17/03/1993 10:30	7.4	04/03/2006 21:00	16.8
2	04/03/2006 09:00	7.2	05/03/2004 17:30	14.3
3	28/01/2013 07:30	7.1	17/03/1993 03:30	13.1
4	05/03/2004 17:30	7	22/02/2019 13:30	13.1
5	22/02/2019 16:30	6.9	02/05/1996 14:00	12.8
6	02/05/1996 20:30	6.9	16/01/2018 21:30	12.3
7	15/02/19950 6:00	6.4	15/02/1995 06:30	12.2
8	23/08/2008 23:00	6.4	28/01/2013 07:30	12.1
9	12/06/2012 09:30	6.4	15/02/1996 19:00	12.1
10	06/06/2012 19:30	6.3	15/10/2018 22:30	12.1

Table 20 Brisbane – Significant meteorological events with threshold H_s of 4.0 metres

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
30/11/2018 01:30	5	8.9	12.9	A trough moving east through Vic and NSW collected a low-pressure system and moved offshore by 29 November
14/02/2019 18:00	4.2	7.8	10	TC Oma had just formed out near Vanuatu on the 12th
22/02/2019 04:30 Peak Event	6.9	13.1	11.7	TC Oma was nearest the east coast of Qld on 22 February before returning to a low-pressure system and heading northeast.
05/07/2019 17:00	4.3	9	9.5	Upper-level trough developed near central Qld around the 4th and interacted with surface troughs over several days.
23/08/2019 05:00	4.7	8.5	11.4	High pressure system over NSW moving NE into the Coral Sea

Figure 32 Brisbane – Daily wave recordings

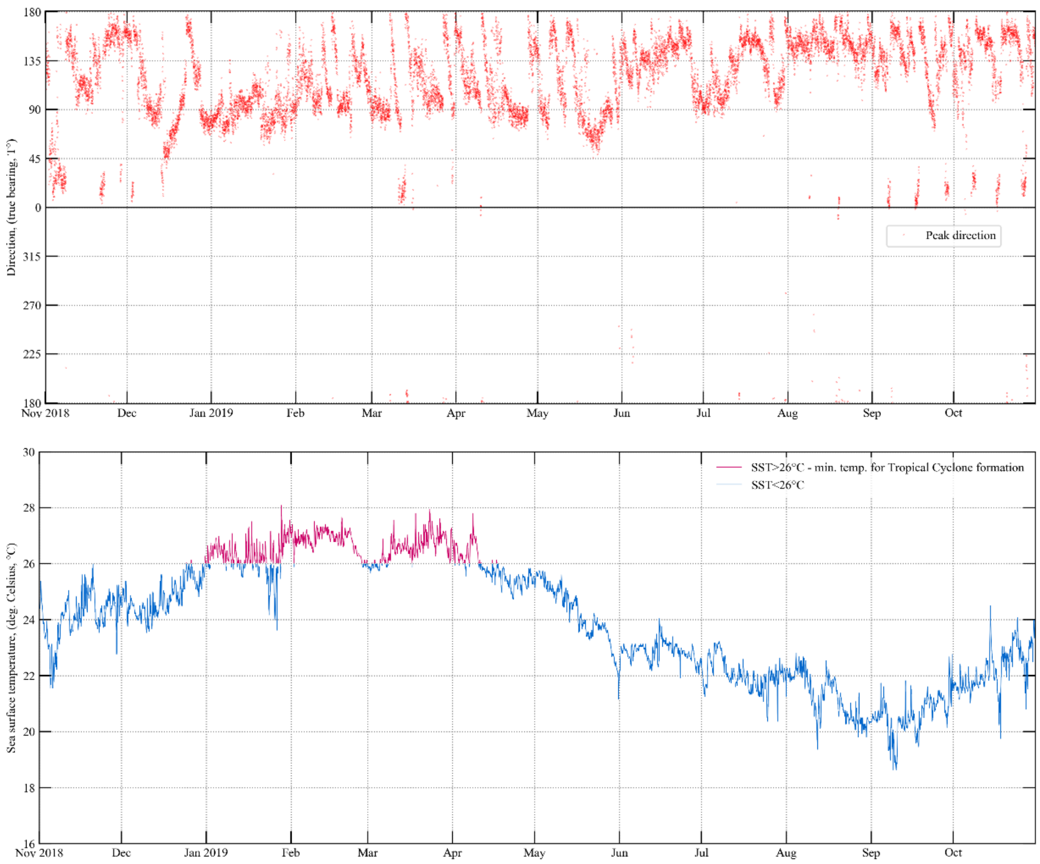


Figure 33 Sea surface temperature and peak wave directions

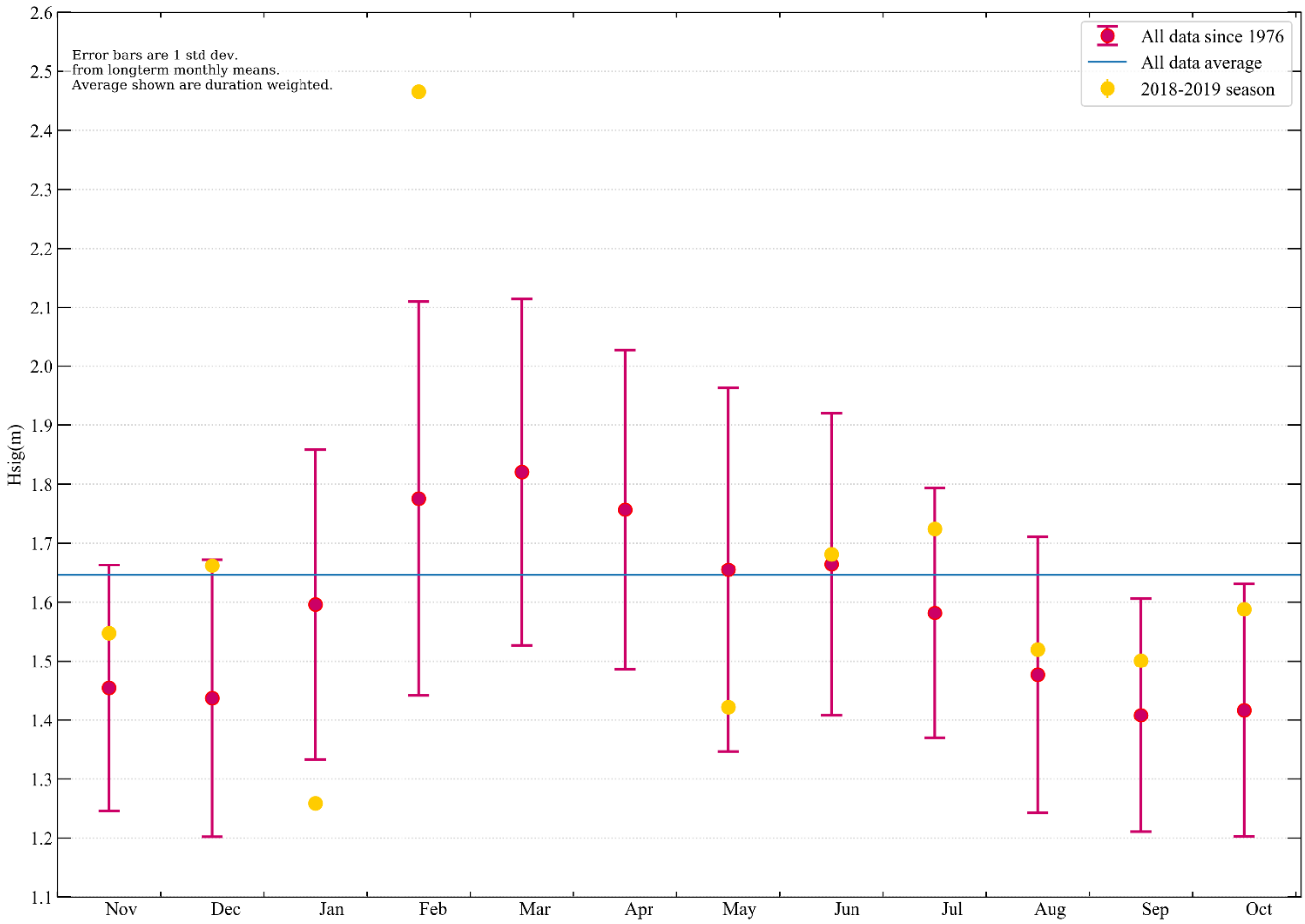


Figure 34 Brisbane – Monthly average wave height (H_s) for seasonal year and for all data

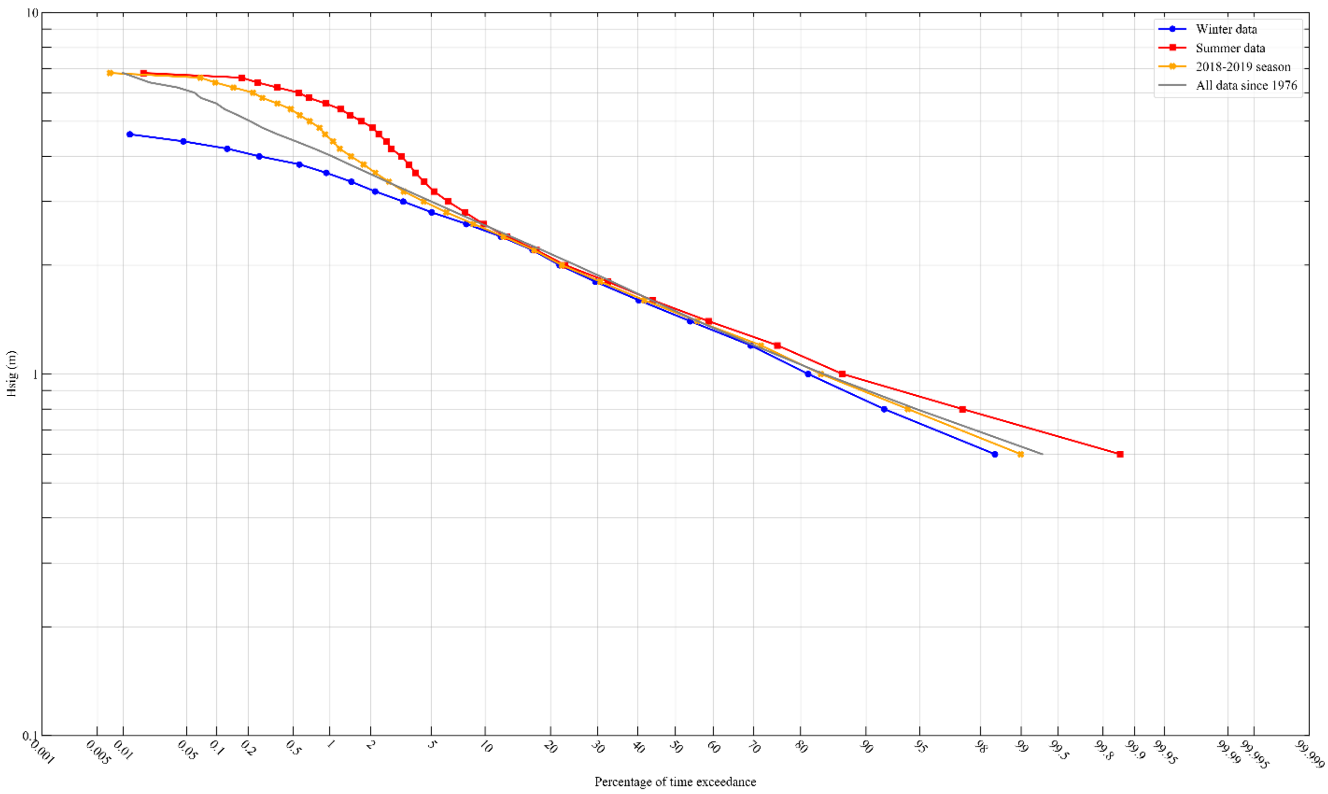


Figure 35 Brisbane – Percentage exceedance of wave height (H_s) for all wave periods (T_p)

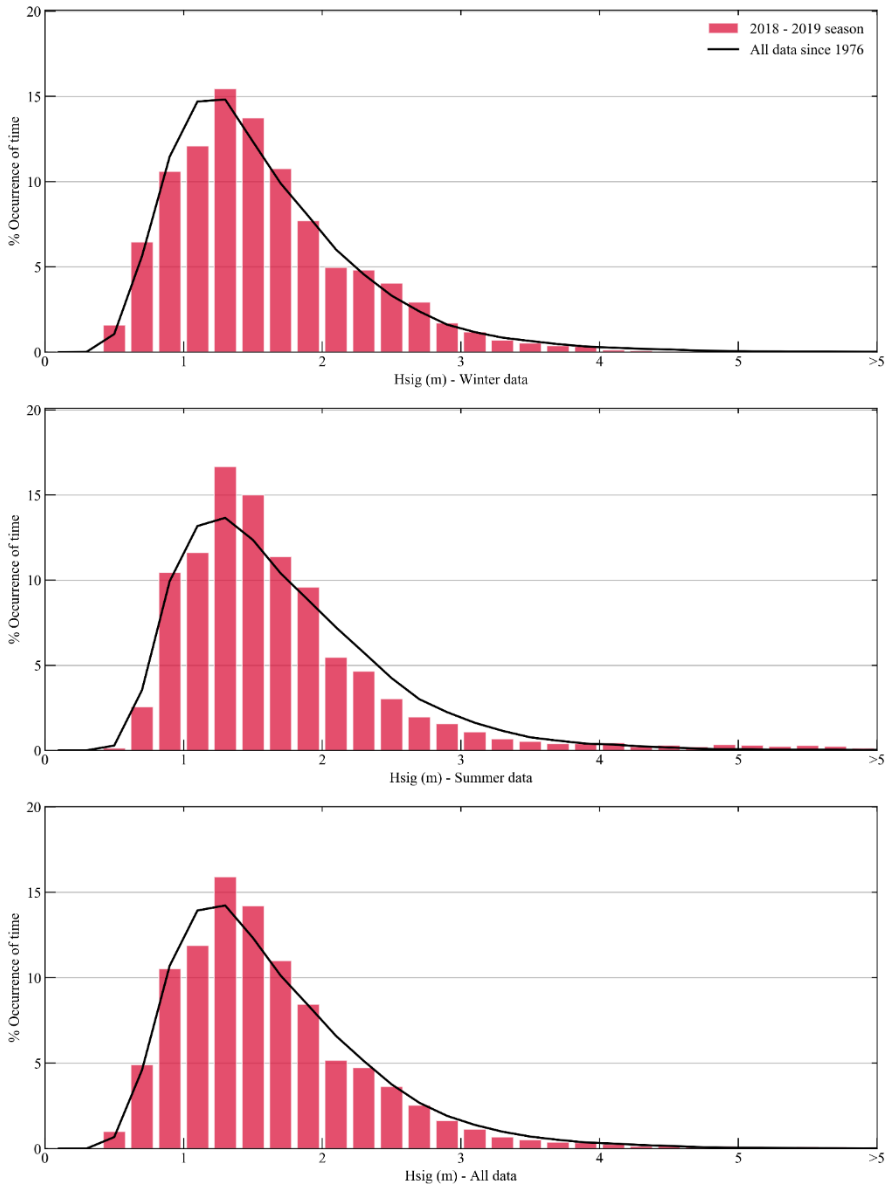


Figure 36 Brisbane – Histogram percentage (of time) occurrence of wave heights (H_s)

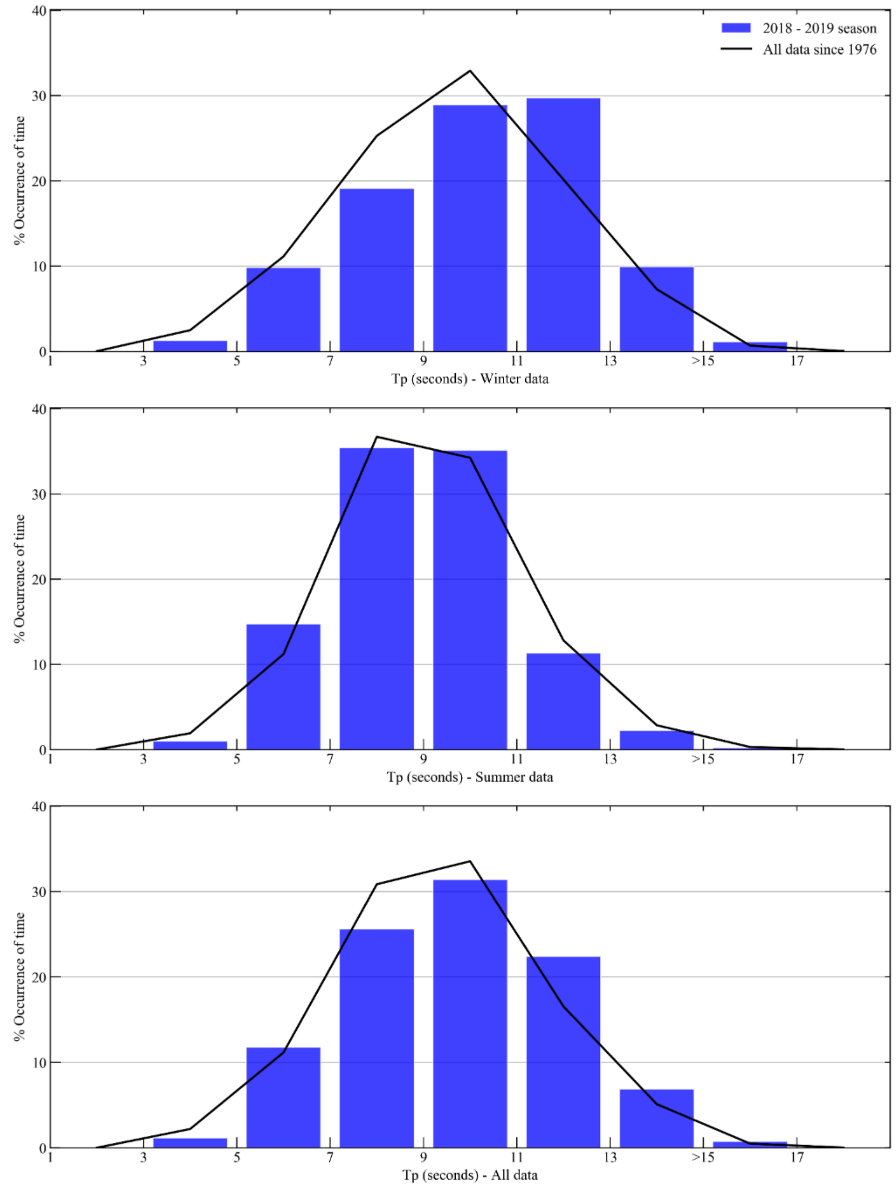


Figure 37 Brisbane – Histogram percentage (of time) occurrence of wave periods (T_p)

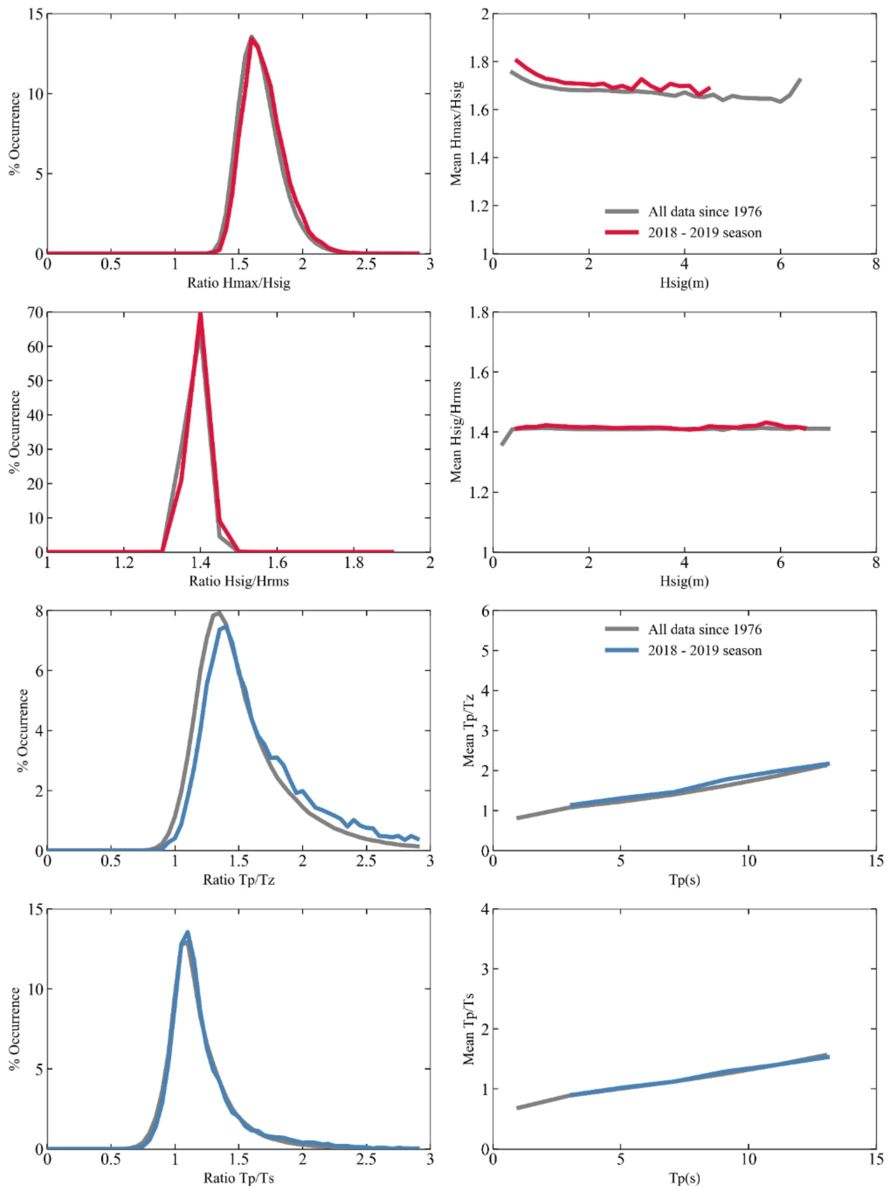


Figure 38 Brisbane – Wave parameter relationships

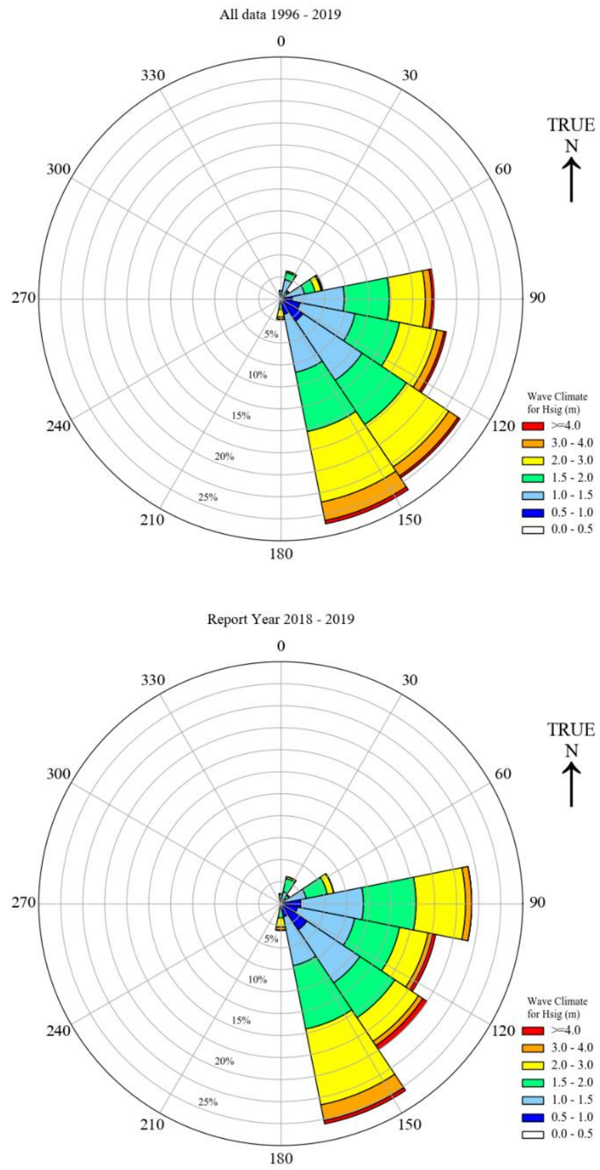


Figure 39 Brisbane – Directional wave rose

North Moreton

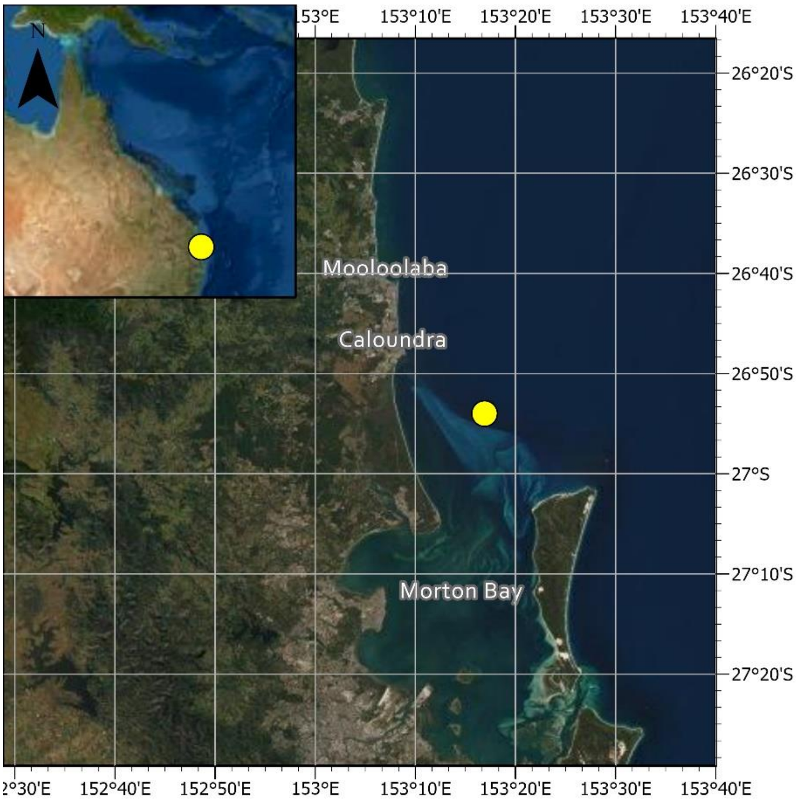


Figure 40 North Moreton – Locality plan

Table 21 North Moreton – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	31/10/2010	0.08 years	158,522	9.24
2018–19	01/11/2018	3.4 days	17,357	1

Table 22 North Moreton – Buoy deployments during the 2018–19 season

Latitude	Longitude	Type buoy	Depth (m)	Deployed date	Removal date
26° 54.000’ S	153° 16.900’ E	DWR-GPS	35	28/06/2017	04/12/2018
26° 54.025’ S	153° 16.933’ E	DWR-GPS	35	04/12/2018	21/05/2019
26° 53.993’ S	153° 16.903’ E	DWR-GPS	35	21/05/2019	current

North Moreton – seasonal overview

The North Moreton wave buoy has been operational for over 9 years with an overall data return of 98.95 per cent. The data recorded for the period November 2018 to October 2019 was excellent, with total gaps of 3.44 days, equivalent to a 99.07 percent data return. The buoy was changed twice during the reporting period (Table 21 and Table 22).

During the reporting period the North Moreton site was subject to four storm events (Table 24), however none of these events had waves large enough to make the top 10 highest waves (Table 23).

The time series of wave height and period (Figure 41) shows the four significant meteorological events clearly with events in December and October creating lower wave height spikes of around 4 m H_{max}, throughout the reporting period. Peak wave periods (T_p) in the summer months are commonly in the 5 to 11 seconds range with some longer period spikes to 14 seconds. There is a change in the winter months, where T_P are longer and there are greater variations, from 3 to 16 seconds.

The SST (Figure 42) measured in the buoy hull ranged from 19 °C up to 29 °C, with SST from January to early April being predominantly warm enough for tropical cyclone development. Some warm spikes noted in November and December with significant variations from June to the end of the reporting period.

The monthly average significant wave height for the recording period fell above one standard deviation of the monthly average for December, February and April, with March falling below one sd (Figure 43).

Summer waves were higher than winter waves and in general very similar to the whole record, however a decrease in waves exceeding 2 m across both seasons is shown (Figure 44).

The winter histogram (Figure 45) shows waves between 0.4 to 0.8 m occurred more often than typical winter periods on record, with 0.6 and 0.8 m waves occurring most frequently with a decrease in waves between 1.0 and 1.6 m to the total data record. The histogram for summer months resulted in less frequent waves below 1.0 m, with the most significant decrease being in waves 0.6 to 0.8 m, and an increase in waves between 1.4 and 2.2 m compared to the data record. The most common waves for the summer period were 0.8 to 1.0 metres.
The reporting period in general was similarly distributed when compared to the entire data set with only minor deviations. Histograms of the occurrence of peak wave periods (T_p) (Figure 46) for the recording period show a small increase in wave periods of 5 to 7 seconds and decrease in 9 to 11 second wave periods in the winter months where 7 to 9 second periods were most frequent. During the summer months, T_p is distributed similarly to the entire dataset with noted increase 7 to 9 second peak wave periods and a decrease in those of 3 to 5 seconds and 11 to 13 seconds. The whole period data has similar distribution to the complete data record.

The ratios between different wave parameters such as H_{max}/ H_s were consistent between this reporting period and the whole data record, with slight variations seen in T_p/T_z, these are plotted in (Figure 47).

The time series for wave direction (Figure 42) shows a peak wave direction generally from the east, with swings to the north throughout spring and early summer as well as some minor swings southeast which can also be seen reflected in the directional wave rose plots (Figure 48). The wave directions for the reporting period are very similar to the entire record.

Table 23 North Moreton – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	27/01/2013 22:00	5.9	27/01/2013 23:30	10.3
2	01/05/2015 15:30	4.9	01/05/2015 13:30	9.6
3	04/06/2016 09:00	4.1	30/03/2017 19:30	7.5
4	25/12/2011 07:00	3.9	25/12/2011 07:00	7.3
5	30/03/2017 19:00	3.8	04/06/2016 09:30	6.5
6	19/02/2013 11:30	3.5	19/02/2013 15:30	6.3
7	28/06/2012 02:30	3.2	19/02/2015 11:00	6.2
8	17/01/2012 06:30	3	28/06/2012 05:30	5.7
9	12/10/2010 13:30	3	22/08/2011 08:30	5.7
10	19/02/2015 12:30	3	27/03/2014 22:30	5.7

Table 24 North Moreton – Significant meteorological events with threshold H_s of 2.2 metres

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
16/02/2019 18:30	2.2	3.8	10.6	TC Oma had just formed out near Vanuatu on 12 February
22/02/2019 11:00	3	5.8	11.4	TC Oma was nearest the east coast of Qld on the 22 February before returning to a low-pressure system and heading northeast.
21/04/2019 02:00	2.5	5.2	9.6	A low-pressure system developing near Solomon Islands and New Caledonia.
05/07/2019 11:30 Peak Event	2.6	5.2	8.1	Upper-level trough developed near central Qld around the 4th and interacted with surface troughs over several days.

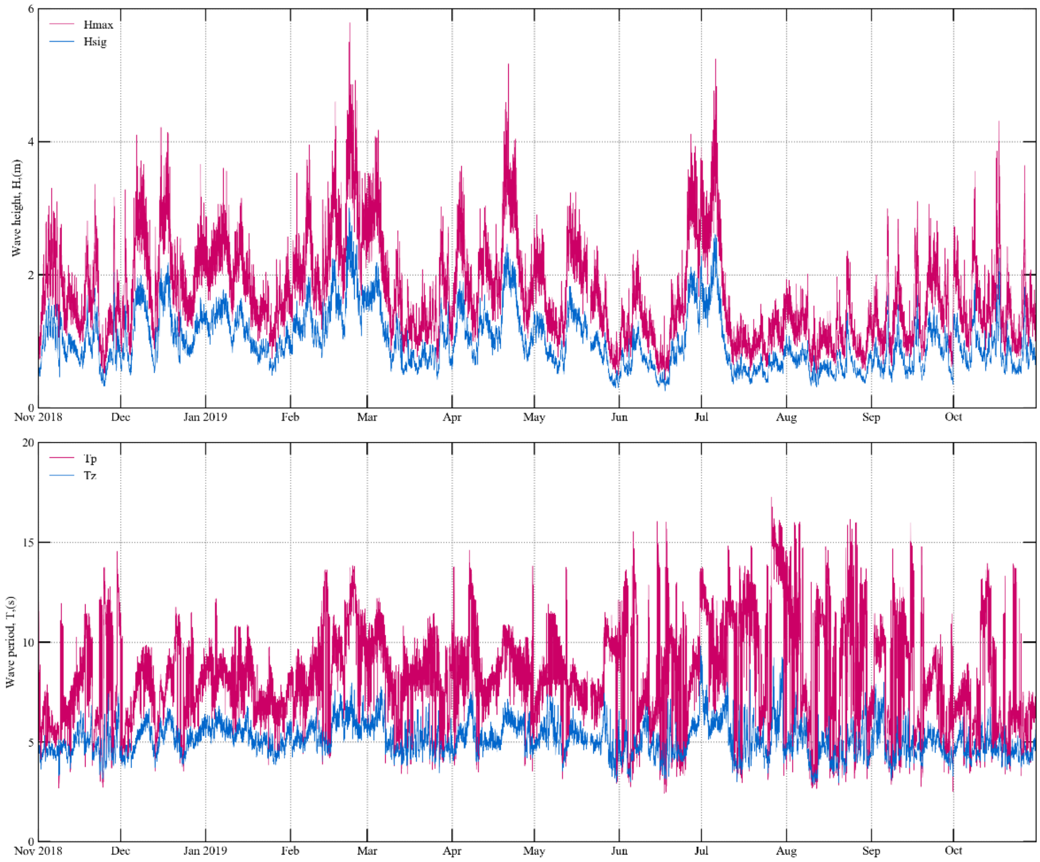


Figure 41 North Moreton – Daily wave recordings

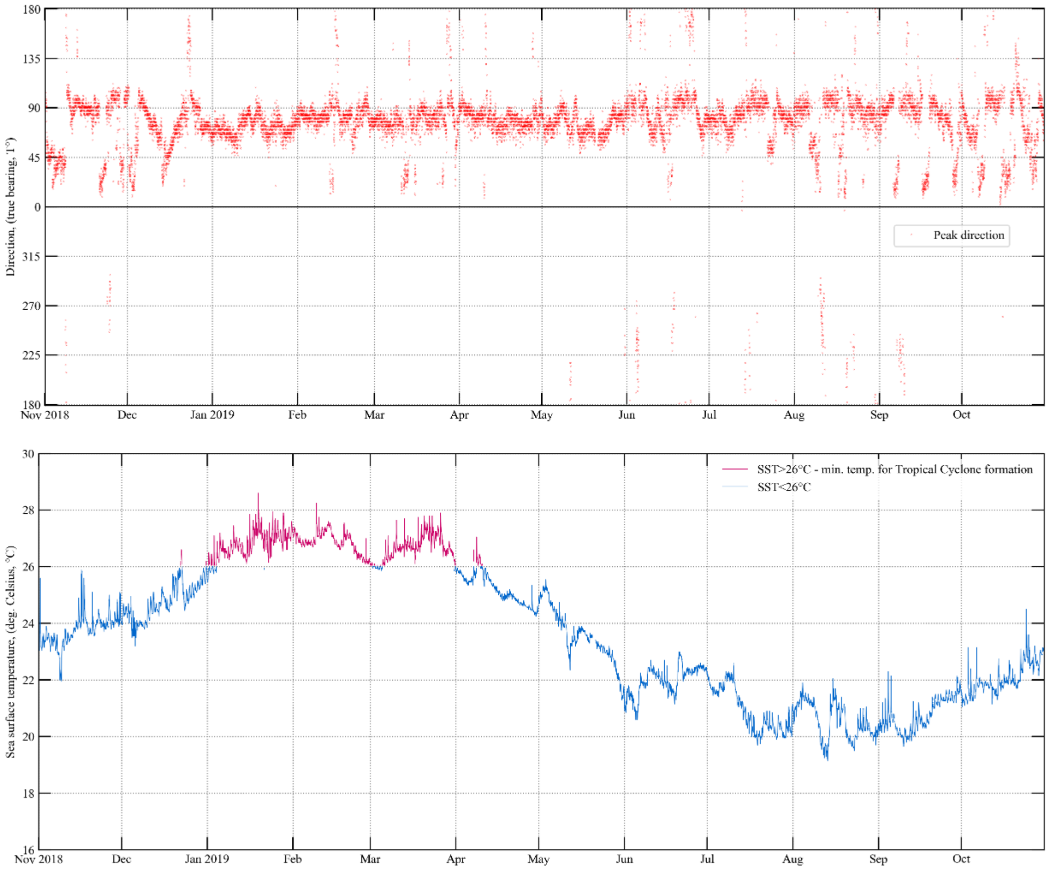


Figure 42 North Moreton – Peak wave direction and sea surface temperature

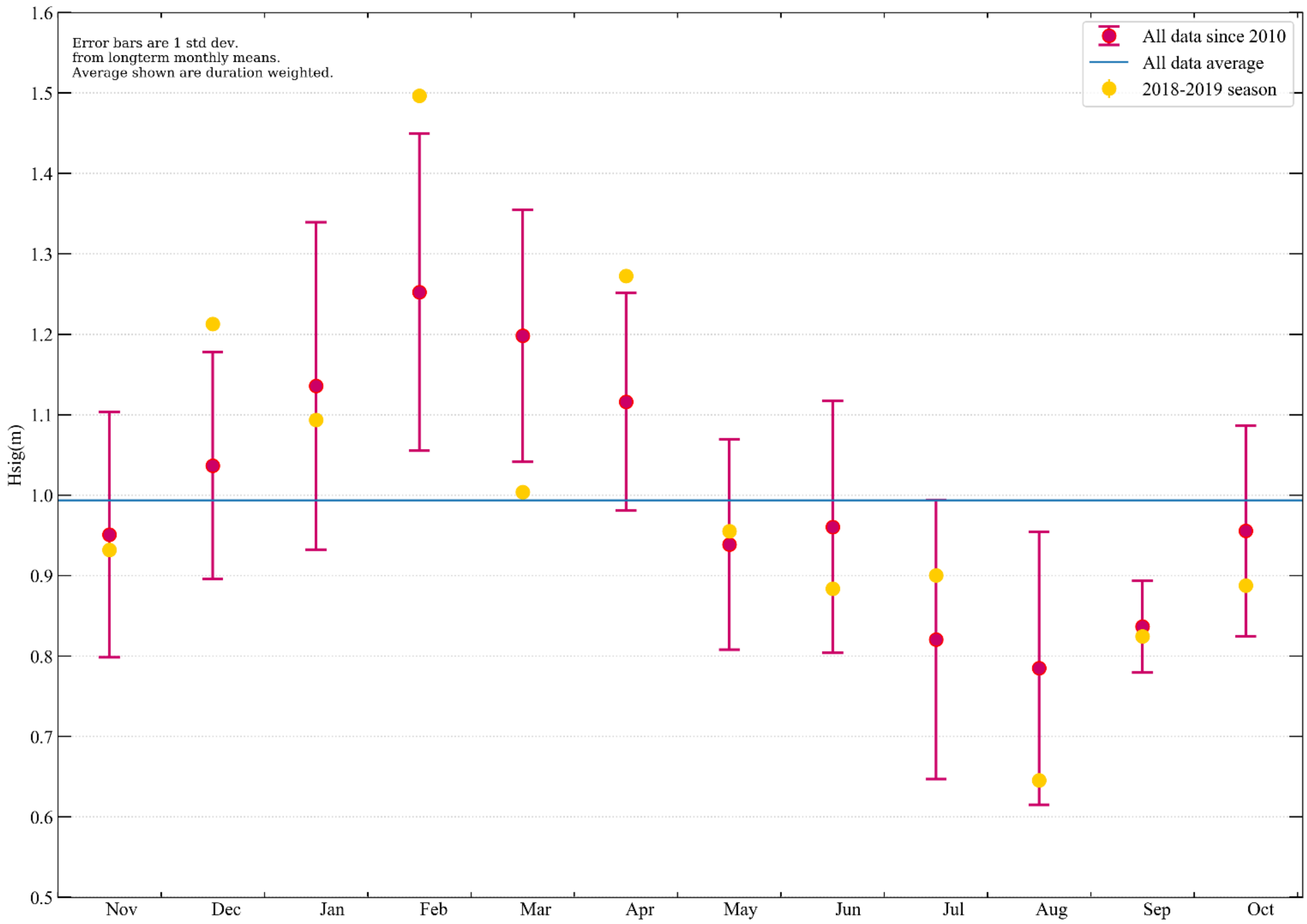


Figure 43 North Moreton – Monthly average wave height (H_s) for seasonal year and for all data

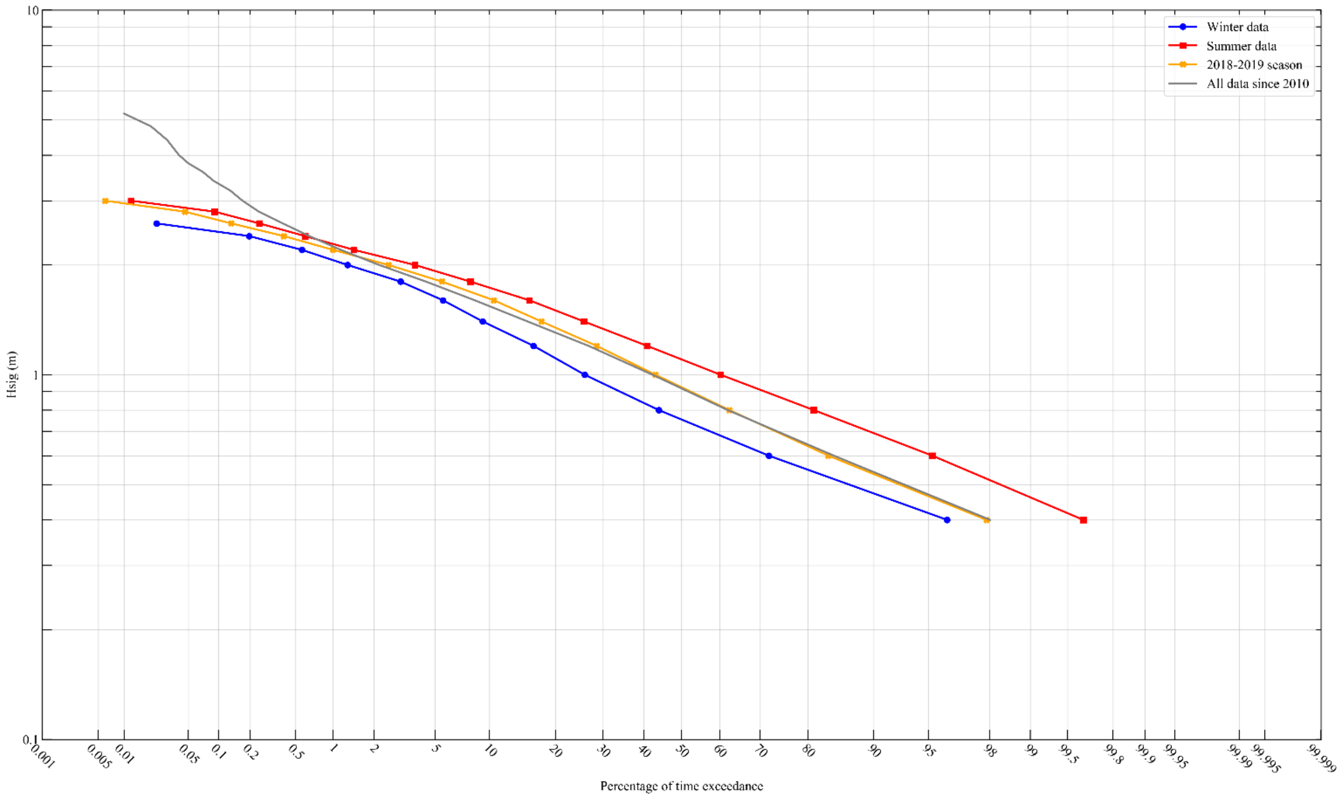


Figure 44 North Moreton – Percentage exceedance of wave height (H_s) for all wave periods (T_p)

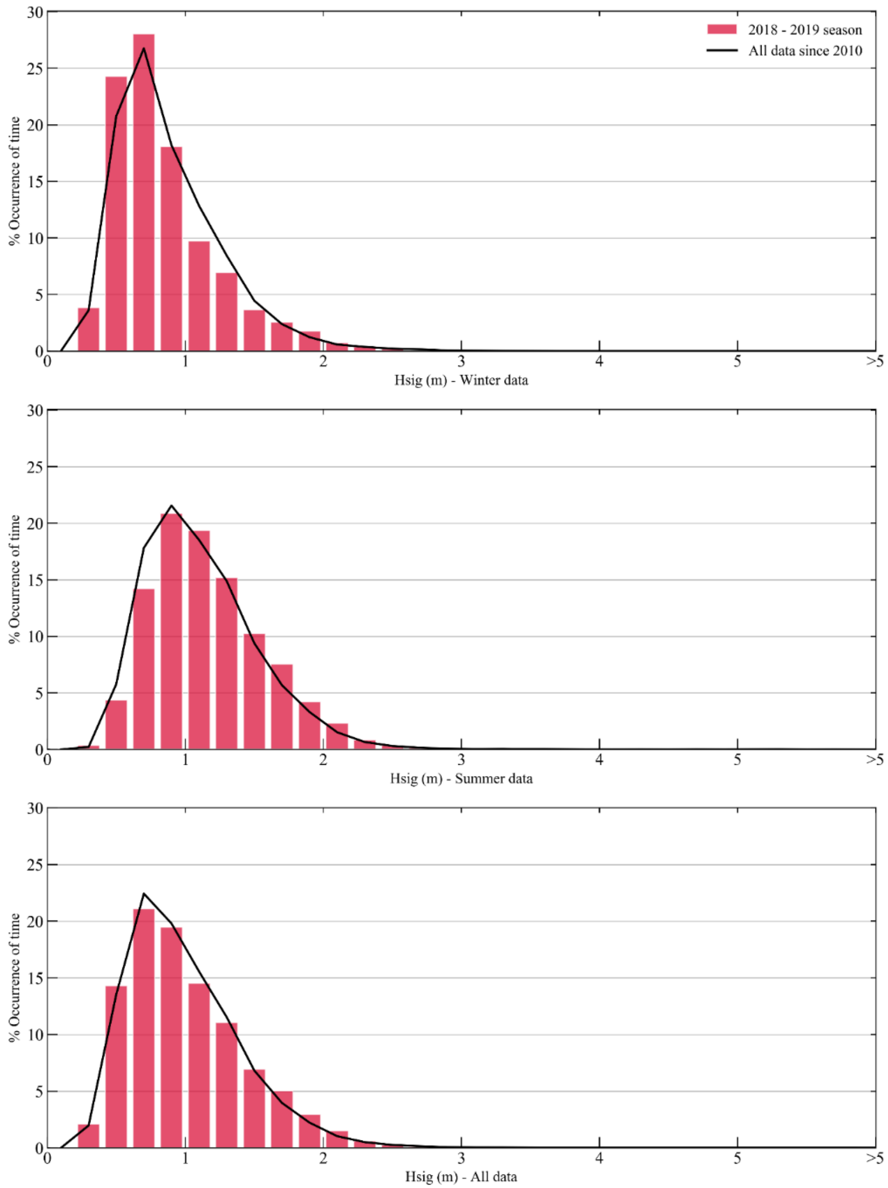


Figure 45 North Moreton – Histogram percentage (of time) occurrence of wave heights (H_s)

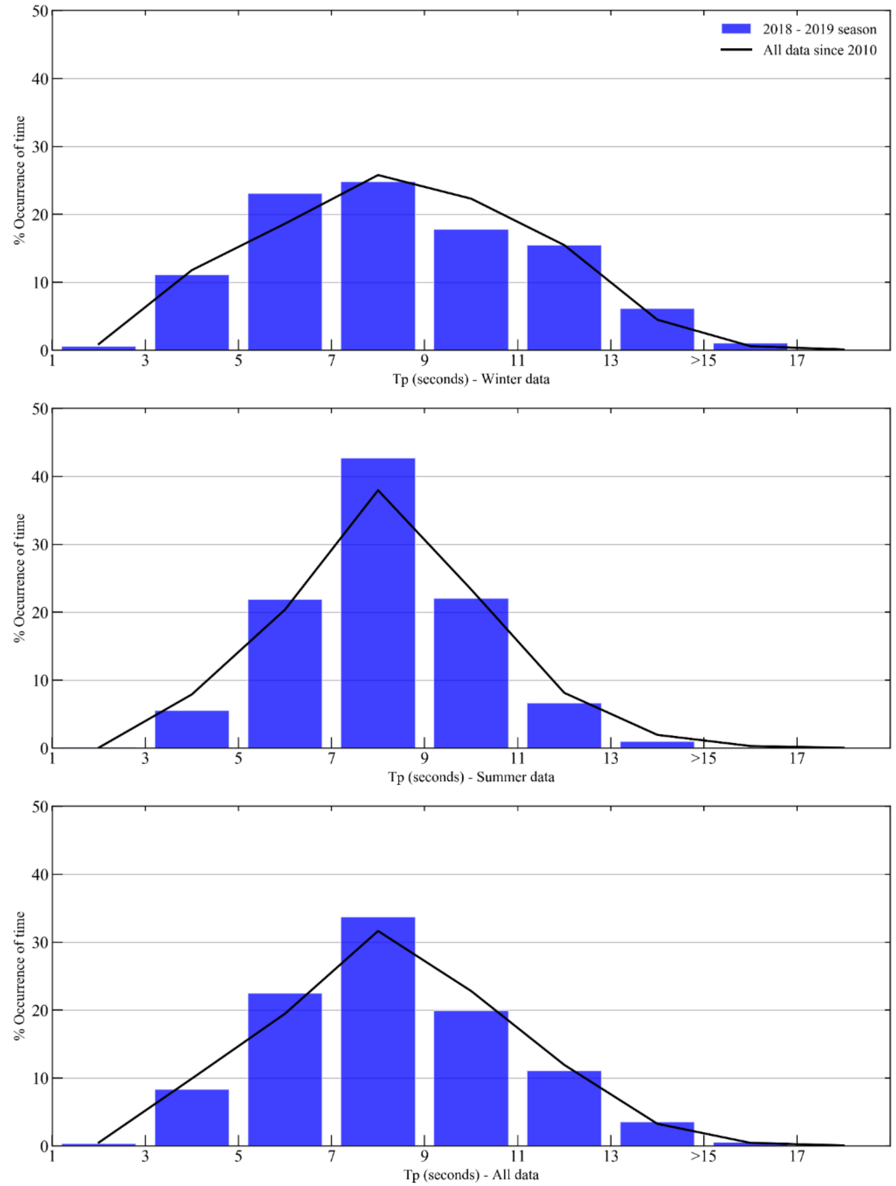


Figure 46 North Moreton – Histogram percentage (of time) occurrence of wave periods (T_p)

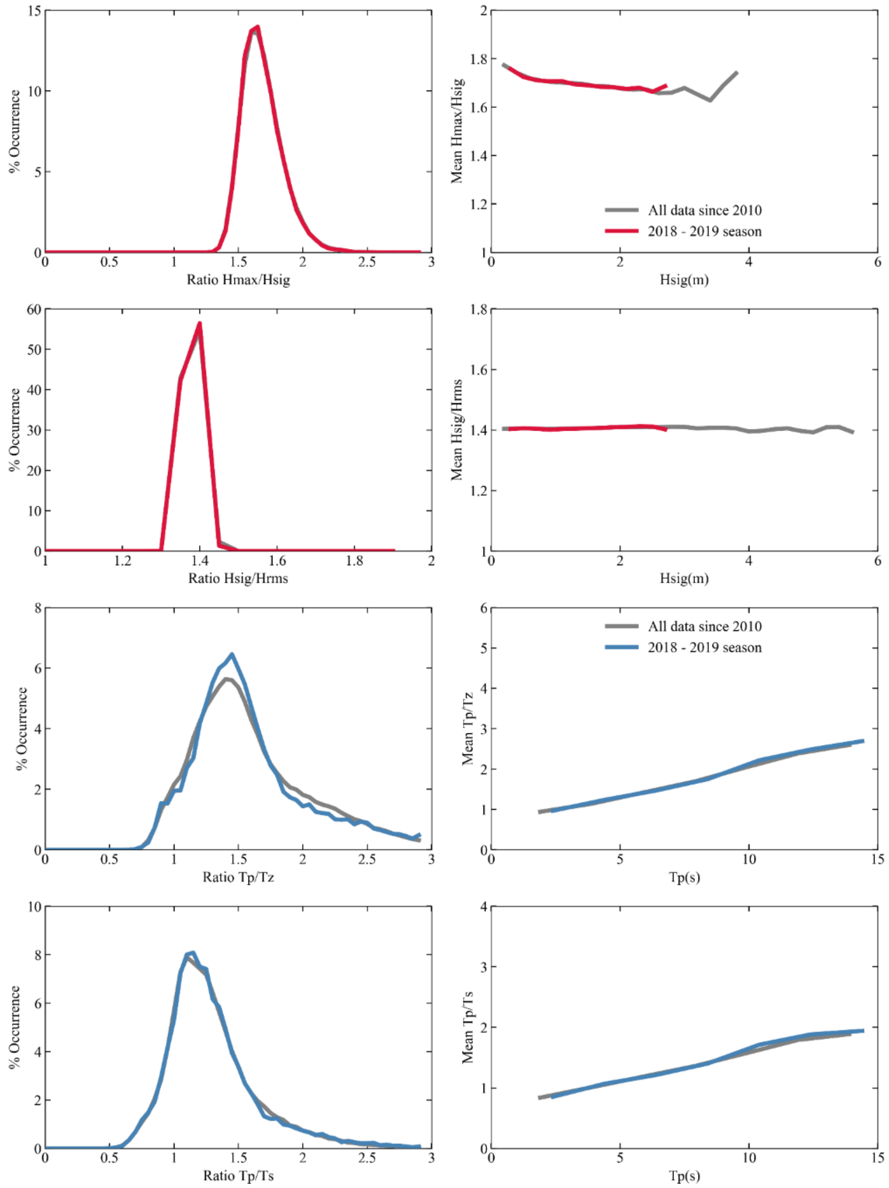


Figure 47 North Moreton – Wave parameter relationships

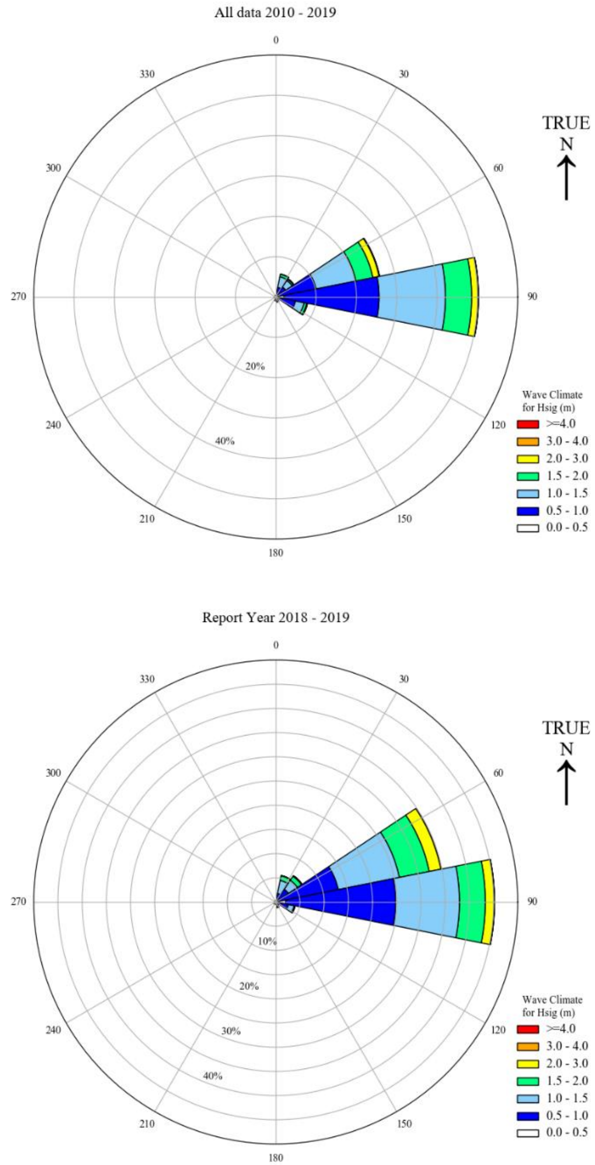


Figure 48 North Moreton – Directional wave rose

Caloundra

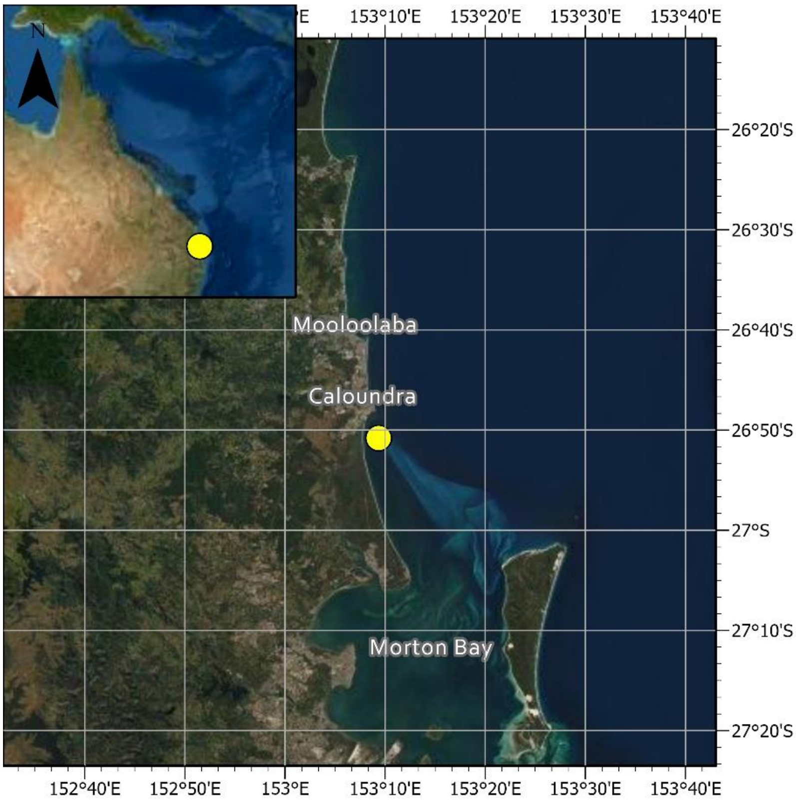


Figure 49 Caloundra – Locality plan

Table 25 Caloundra – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	01/05/2013	0.17 years	110,363	6.51
2018–19	01/11/2018	1.52 days	17,447	1

Table 26 Caloundra – Buoy deployments for 2018-19 season

Latitude	Longitude	Type Buoy	Depth (m)	Deployed date	Removal date
26° 50.798’ S	153° 09.348’ E	DWR-MkIII	17	14/04/2018	19/11/2019
26° 50.811’ S	153° 09.291’ E	DWR-MkIII	17	19/11/2019	current

Caloundra – seasonal overview

The Caloundra wave buoy has been operational since 01 May 2013 with an overall data return of 97 per cent. The data record for the period November 2018 to October 2018 was good (Table 25), with total gaps of 1.52 days, equivalent to 99.67 per cent data return. The buoy was replaced once during the reporting period, see (Table 26).

The Caloundra site was subject to three significant events during the reporting period (Table 28) which resulted in an update of the highest waves (Table 27) for both H_s and H_{max}. TC Oma during February generated the highest wave for this site for the reporting period with H_s of 3.1 m and 5.5 m H_{max}.

The daily wave recordings of wave height and period (Figure 50) show the three significant meteorological events clearly standing out over other events with lower wave height spikes of almost 4 m H_{max}. Peak wave periods (T_p) in the summer months are commonly in the 5 to 9 seconds range with some longer period spikes exceeding 15 seconds. There is a change in the winter months, where T_p are longer and there are greater variations, from 5 to 15 seconds, with spikes up to 17 and as low as 3 seconds.

The sea surface temperature (SST) measured in the buoy hull showed a range of 18° C to 28 °C (Figure 51). The SST from mid-December to the end of April was warm enough for tropical cyclone development. Throughout the entire reporting period there are significant variations in SST.

December, February and April all fell above one standard deviation of the monthly average H_s (Figure 52). The remainder of the recording period fell within one standard deviation.

The wave climate during the reporting period was for the most part similar to the wave climate of the whole record with only minor deviations on the percentage exceedance plot (Figure 53). Histograms for occurrence of H_s (Figure 54) show a distribution for the period that is in line with the historic dataset. The most common significant wave height for the current record 0.6–0.8 m was more frequent during winter. Summer shows a decrease in waves lower than 1 m with a slight increase in those in the 1.4 to 2.2 m range. The histogram of peak wave period (T_p) for all data is comparable to the historical recorded data, (Figure 55) with a period of 7 to 11 seconds most common throughout the year and higher than average in summer.

The ratios between different wave parameters such as H_{max}/ H_s were consistent between this reporting period and the whole data record, with slight variations seen in T_p/T_z due to deviations from the trends in T_p this recording period. These are plotted in (Figure 56).

The time series for wave direction (Figure 51) show waves predominantly from the east, swinging at times to northeast. Directional wave rose plots (Figure 57) show the dominant wave directions were east to east south-easterly and this period is consistent with the entire data record for this site.

Table 27 Caloundra – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	01/05/2015 17:00	4.5	01/05/2015 15:00	7.5
2	04/06/2016 16:30	3.9	30/03/2017 18:30	7
3	15/10/2018 22:30	3.7	04/06/2016 10:00	6.7
4	30/03/2017 18:30	3.7	19/02/2015 07:30	6.2
5	19/02/2015 07:30	3.2	16/10/2018 00:00	5.5
6	22/02/2019 10:00	3.1	22/02/2019 10:00	5.5
7	17/10/2017 13:00	2.8	16/10/2017 14:30	5.4
8	15/03/2018 00:00	2.7	27/03/2014 22:00	4.8
9	29/03/2018 23:00	2.7	14/03/2018 23:30	4.8
10	18/02/2018 22:30	2.7	19/06/2016 19:30	4.7

Table 28 Caloundra – Significant meteorological events with threshold H_s of 2.2 metres

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
22/02/2019 10:00 Peak Event	3.1	5.5	11.2	TC Oma was nearest the east coast of Qld on 22 February before returning to a low-pressure system and heading northeast.
21/04/2019 05:30	2.3	4.4	10.1	A low-pressure system developing Solomon Islands and New Caledonia.
06/07/2019 01:30	2.6	4.5	9	Upper-level trough developed near central Qld around the 4th and interacted with surface troughs over several days.

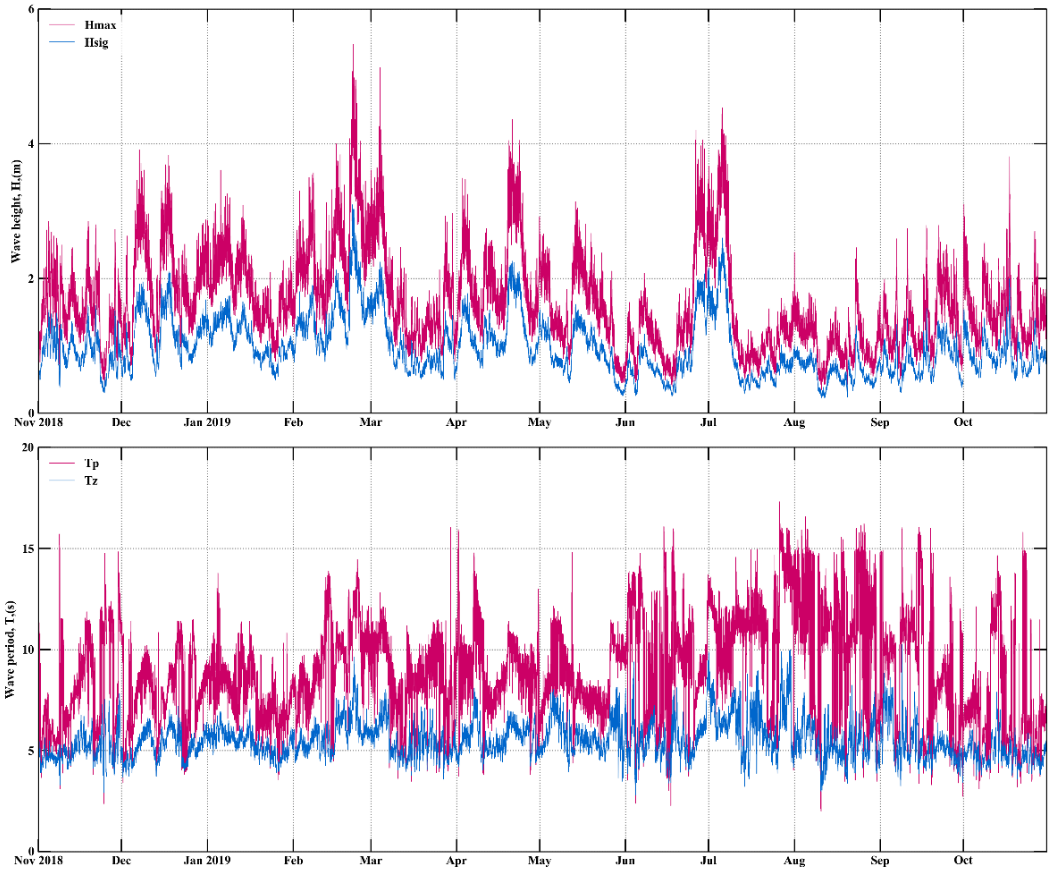


Figure 50 Caloundra – Daily wave recordings

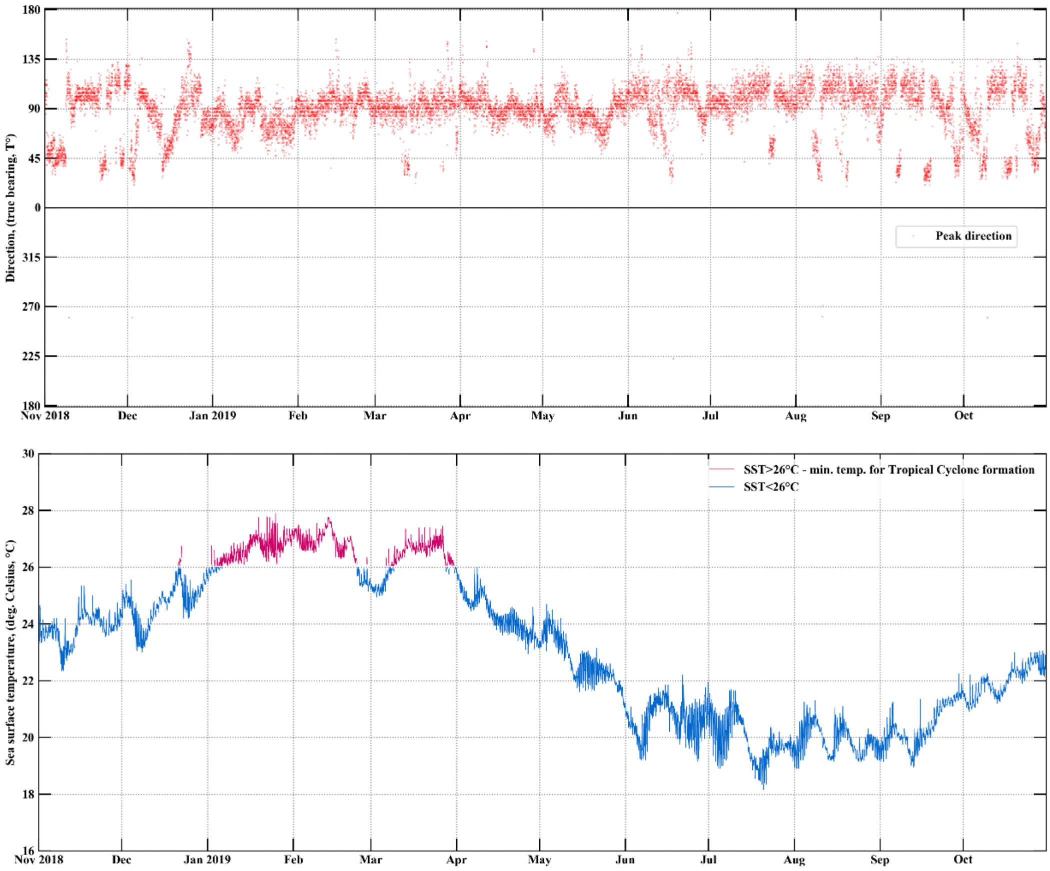


Figure 51 Caloundra – Sea surface temperature and peak wave directions

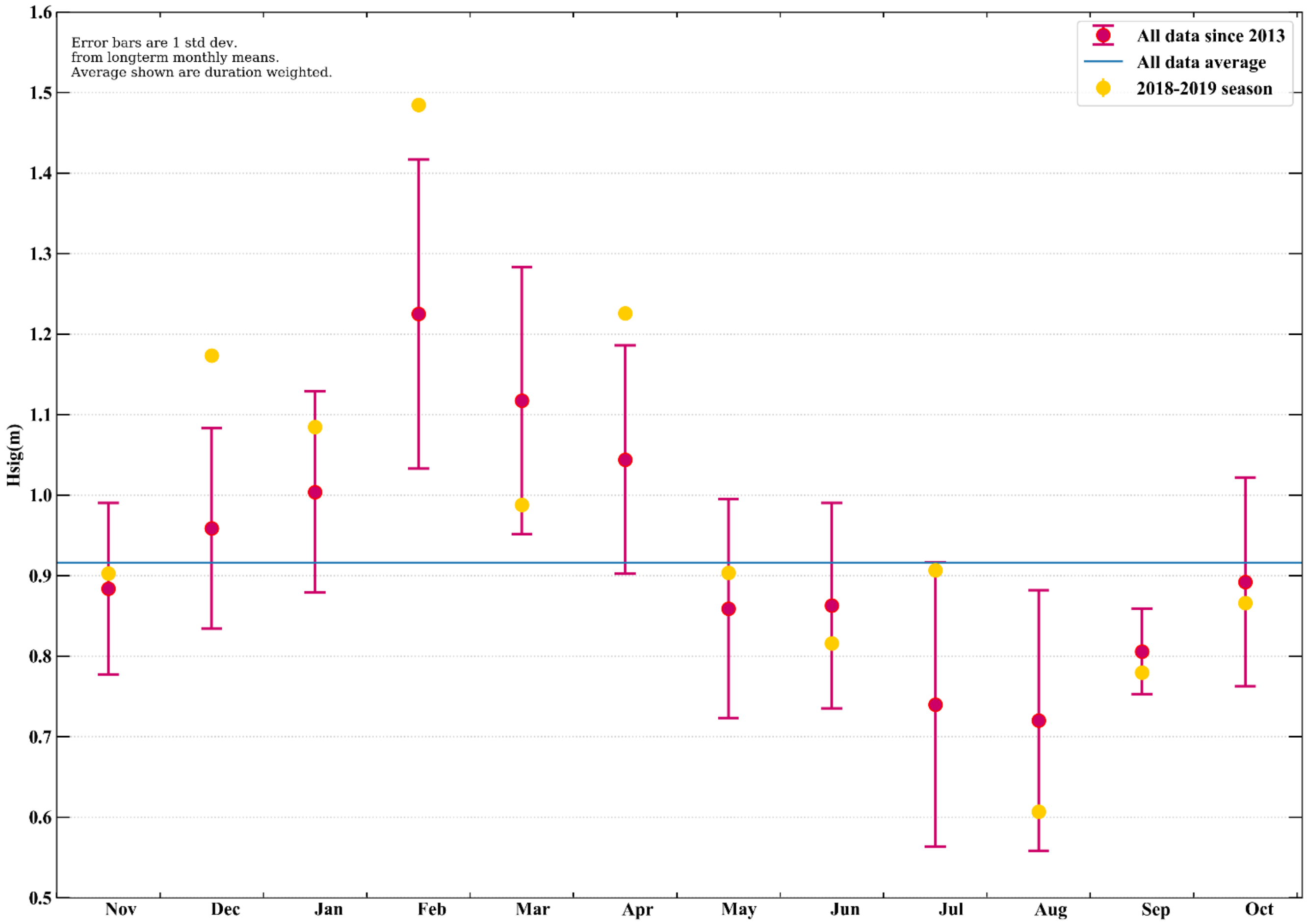


Figure 52 Caloundra – Monthly average wave height (H_s) for seasonal year and for all data

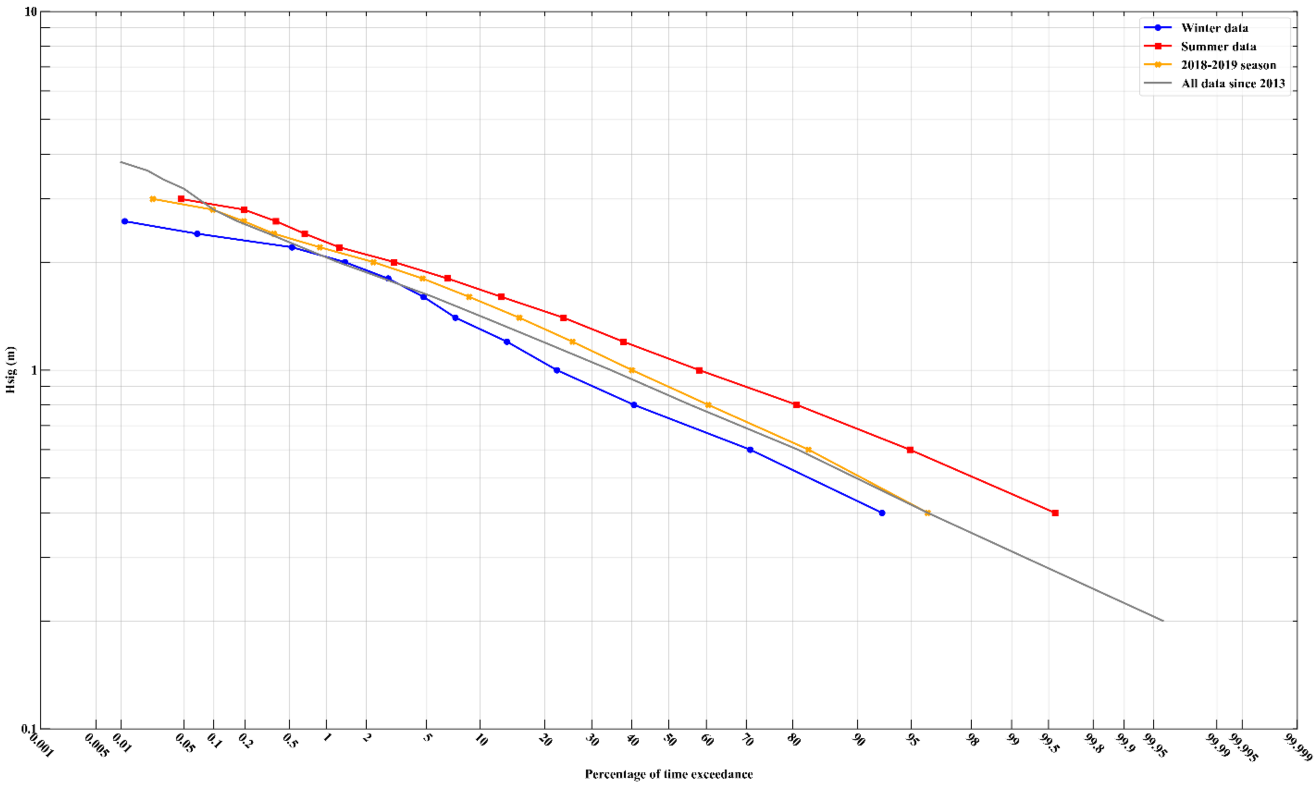


Figure 53 Caloundra – Percentage exceedance of wave height (H_s) for all wave periods (T_p)

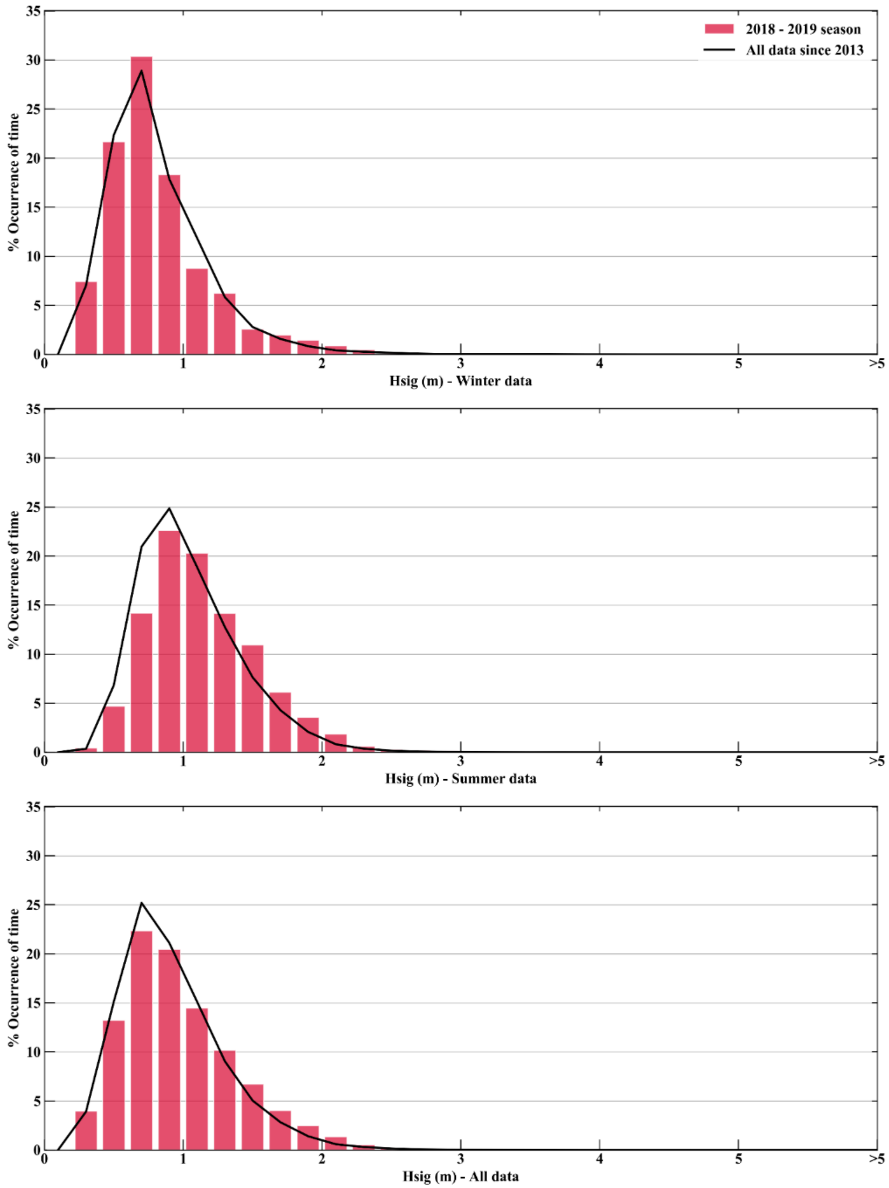


Figure 54 Caloundra – Histogram percentage (of time) occurrence of wave heights (H_s)

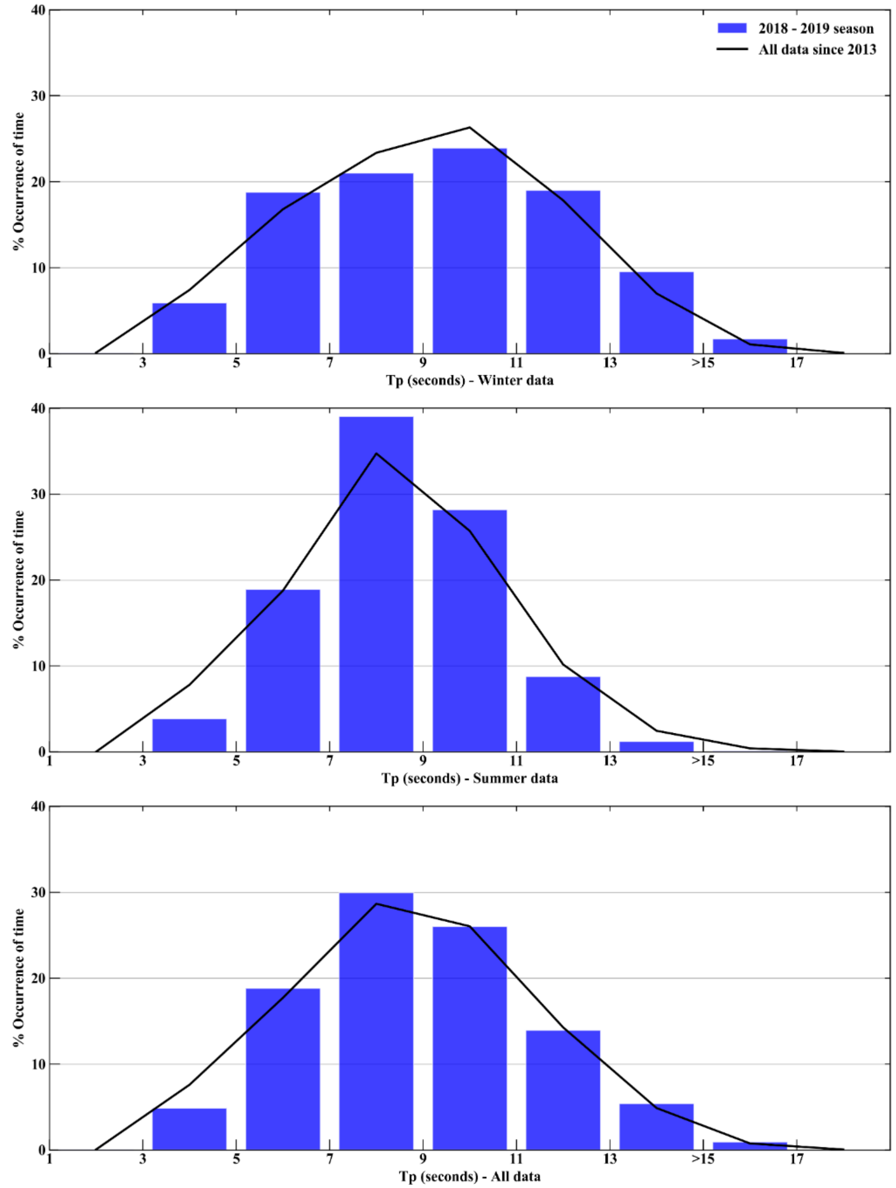


Figure 55 Caloundra – Histogram percentage (of time) occurrence of wave periods (T_p)

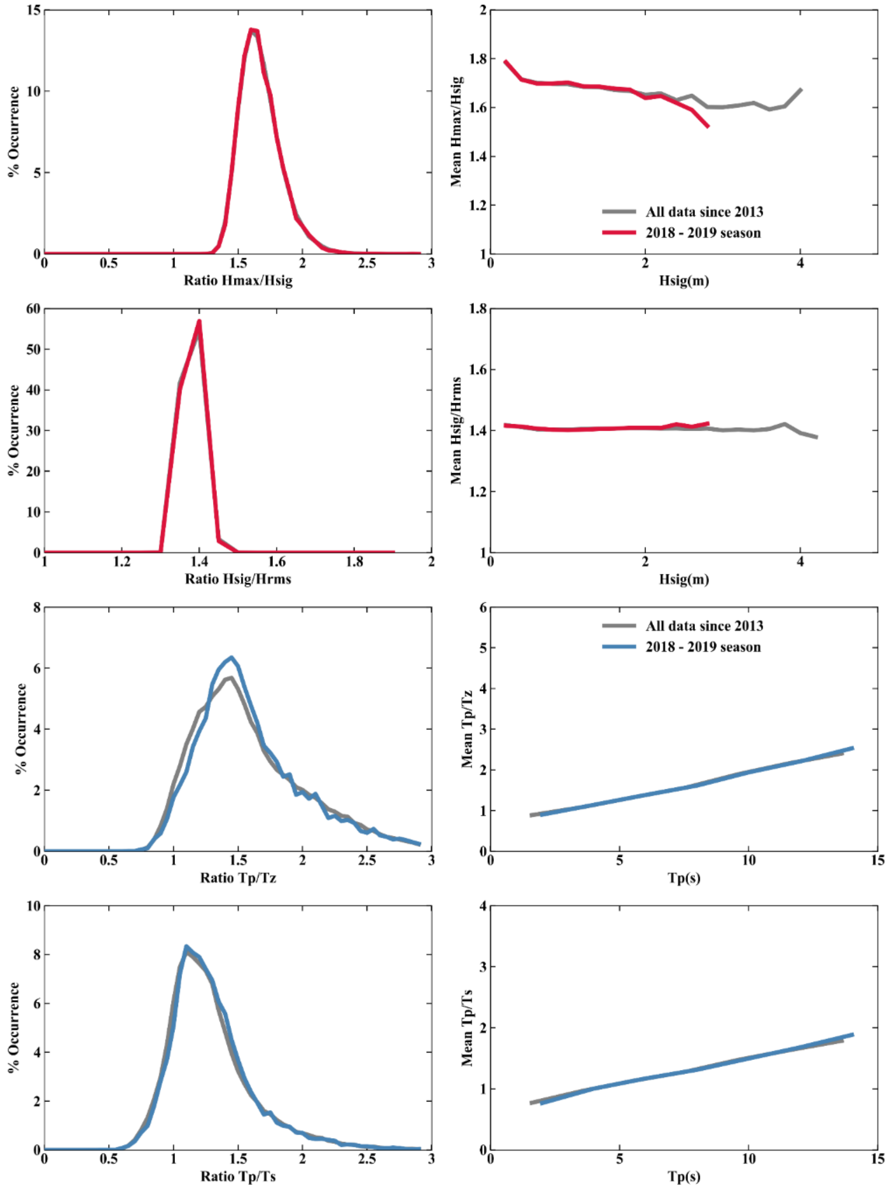


Figure 56 Caloundra – Wave parameter relationships

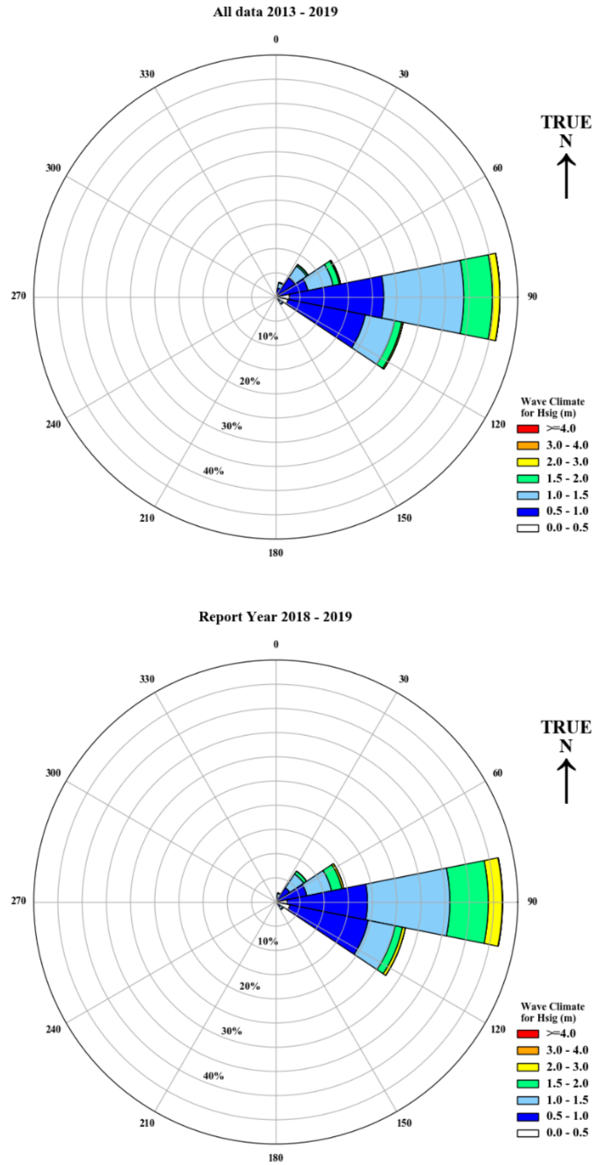


Figure 57 Caloundra – Wave rose

Mooloolaba

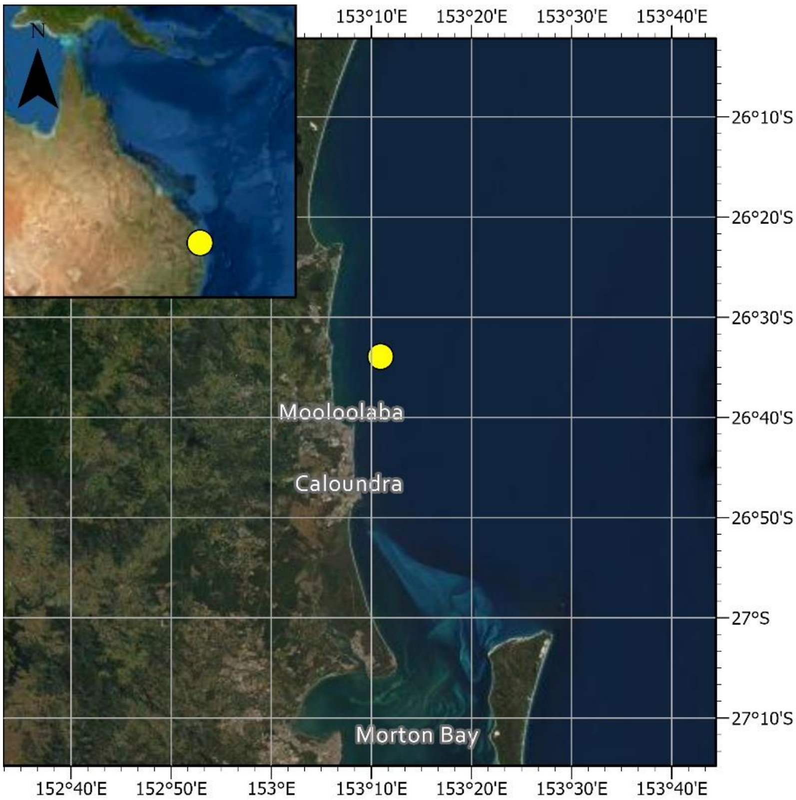


Figure 58 Mooloolaba – Locality plan

Table 29 Mooloolaba – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
2006–19*	22/10/2006*	0.77 years	321,850	13.11
2018–19	01/11/2019	1.31 days	17,457	1

*See

Table 2 for site commission date.

Table 30 Mooloolaba – Buoy deployments for 2018–19 season

Latitude	Longitude	Type buoy	Depth (m)	Deployed date	Removal date
26° 33.941’ S	153° 10.931’ E	DWR-GPS	33	13/04/2018	current

Mooloolaba – seasonal overview

The Mooloolaba wave buoy has been operational for over 19 years with an overall data return of 95.7 per cent. The data record for the period November 2018 to October 2019 was excellent, with total gaps of 1.31 days (Table 29), equivalent to 99.6 per cent data return. The buoy was replaced once during the reporting period (Table 30).

During the reporting period the buoy recorded 5 events resulting in significant wave heights H_s were greater than 2.5 m (

Table 32). The highest recorded was due to TC Oma on 22 February with a H_s of 4.2 m and H_{max} of 7.9 m. This highest wave was not high enough to rank in the top 10 wave record for this monitoring site (Table 31). Peaks in wave heights can be seen from these events in the time series of daily wave recordings (Figure 59). Some other events created lower wave height spikes exceeding 4 m H_{max}, as well as several smaller events with H_{max} below 4 m, throughout the monitoring period. Peak wave periods (T_p) show variations from 5 to 10 seconds are common with spikes to and exceeding 15 seconds interspersed. From July to the end of the record, variations in T_p are more rapid and frequent with a tendency for more waves in the 10 to 15 second range.

The sea surface temperature (SST) measured in the buoy hull showed a range of 20 °C to 28 °C (Figure 60), with the SST from the beginning of January to the end of April being predominantly warm enough for the formation of tropical cyclones.

Except for exceeding one standard deviation (sd) for December and February, the monthly average H_s for the recording period fell within one sd of the entire record (Figure 61).

The wave climate for the reporting period was very similar to the wave climate for the entire record, as seen in the percentage exceedance plot for H_s (Figure 62). There is a slight deviation from the record with waves exceeding 2.5 m H_s less frequent than average. Histograms of occurrence of H_s (Figure 63) show that during winter months, waves of 0.8 to 1.0 m were the most common, with lower occurrences of waves 0.6 to 0.8 m and 1.0 to 1.2 metres. Summer months show a significant shift in distribution to the historic record with 0.8 to 1.0 m waves being in line with the record but a lower occurrence of waves up to 0.8 m and from 1.0 to 1.4 m. Waves from 2.0 to 2.4 m also occurred more than the historic record. All data histogram shows a similar distribution of wave heights compared to the record with some variations. Waves 0.8 to 1.0 m were the most common and occurred more than the record, with lower occurrences of waves 0.6 to 0.8 m and 1.0 to 1.2 metres. Histograms of the occurrence of peak wave periods (T_p) (Figure 64) show a higher occurrence of the modal 11–13 seconds T_p range and lower occurrence of 7 –11 second waves during winter. The overall data of the period shows similar occurrences compared to all data with most common peak wave periods of 7–9 seconds.

The ratios between different wave parameters such as H_{max}/ H_s were generally consistent between this reporting period and all of the historic data with the exception of T_p/T_s which were slightly skewed towards a smaller ratio, these are plotted in (Figure 65).

Time series for wave direction (Figure 60) shows waves predominantly from the east to east-south-east with occasional swings to NNE. The directional wave rose plots (Figure 66) show that wave direction for the reporting period is very similar to the entire record with the most common waves being east south-easterly 1.0 to 1.5 m H_s.

Table 31 Mooloolaba – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	05/03/2004 16:00	5.9	05/03/2004 15:30	12.1
2	28/01/2013 05:30	5.6	28/01/2013 05:00	10.5
3	03/03/2006 06:30	5.3	01/05/2000 18:30	10
4	01/05/2015 15:30	5.2	01/05/2015 17:30	9.2
5	01/05/2000 19:30	5.1	03/03/2006 06:30	9.2
6	24/08/2007 01:00	5.1	31/12/2007 08:00	8.9
7	30/05/2008 20:30	4.5	24/08/2007 01:30	8.5
8	30/12/2007 22:00	4.4	25/12/2011 07:30	8.4
9	25/12/2011 08:30	4.3	04/06/2016 21:00	8.2
10	28/06/2012 07:00	4.3	28/06/2012 04:30	7.9

Table 32 Mooloolaba – Significant meteorological events with threshold H_s of 2.5 metres

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
16/02/2019 06:00	2.7	5.1	9.3	TC Oma had just formed out near Vanuatu on 12 February
22/02/2019 01:30 Peak Event	4.2	7.9	12	TC Oma was nearest the east coast of Qld on 22 February before returning to a low-pressure system and heading northeast.
04/03/2019 06:30	2.7	4.9	11	Low Pressure systems along the east coast
21/04/2019 05:30	2.9	5.3	10.1	Storm activity due to Upper-level lows moving east through Qld
05/07/2019 23:30	3.5	6.6	9.5	Upper-level trough developed near central Qld around the 4th and interacted with surface troughs over several days.

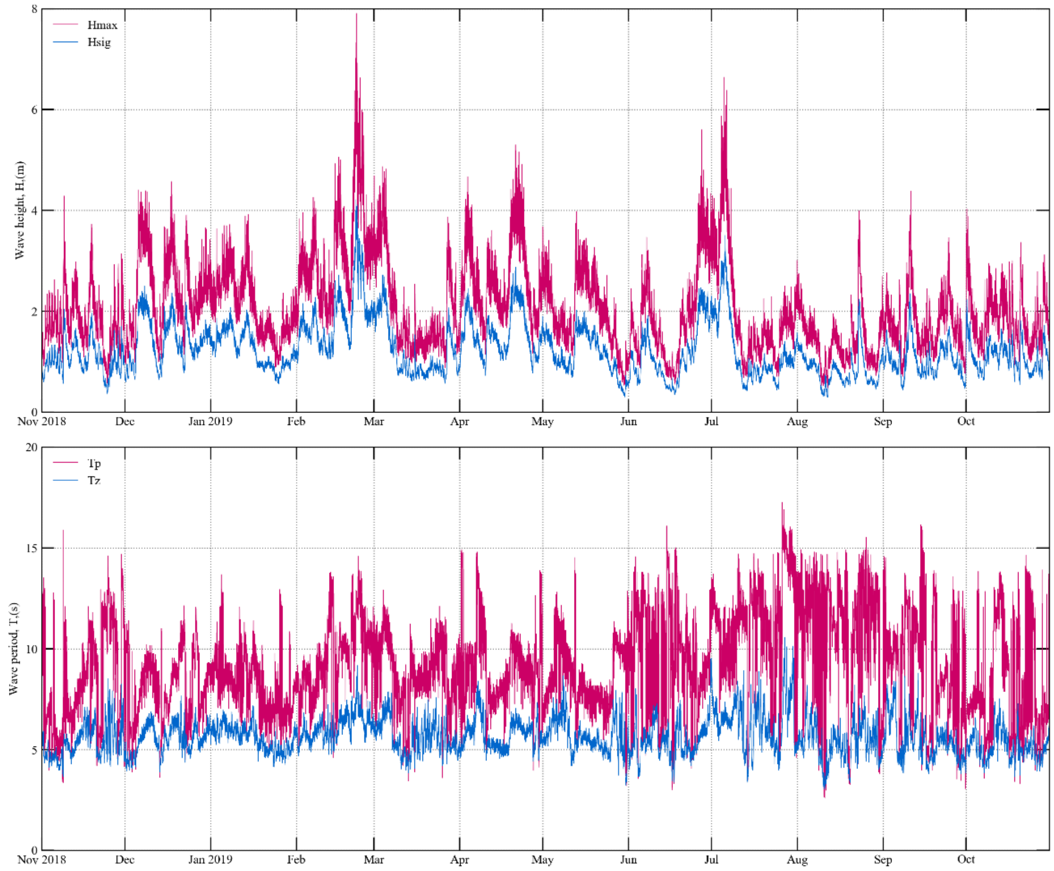


Figure 59 Mooloolaba – Daily wave recordings

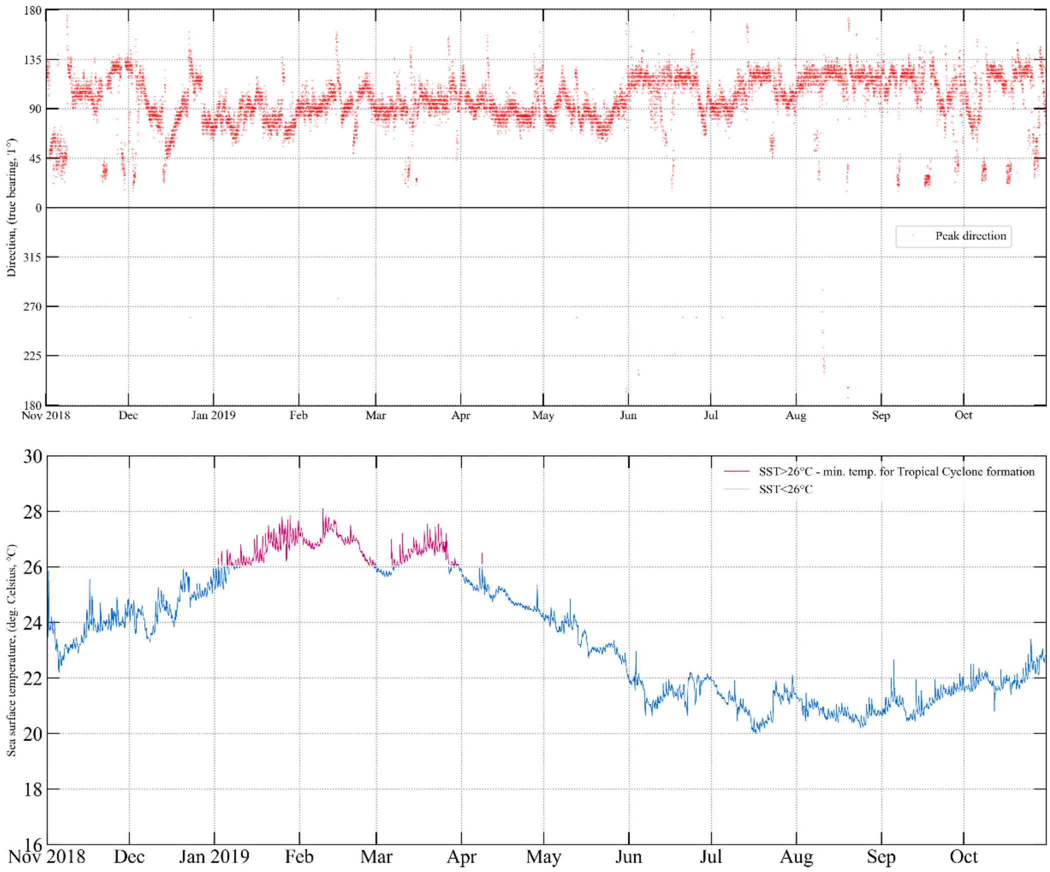


Figure 60 Mooloolaba – Peak wave directions and sea surface temperature

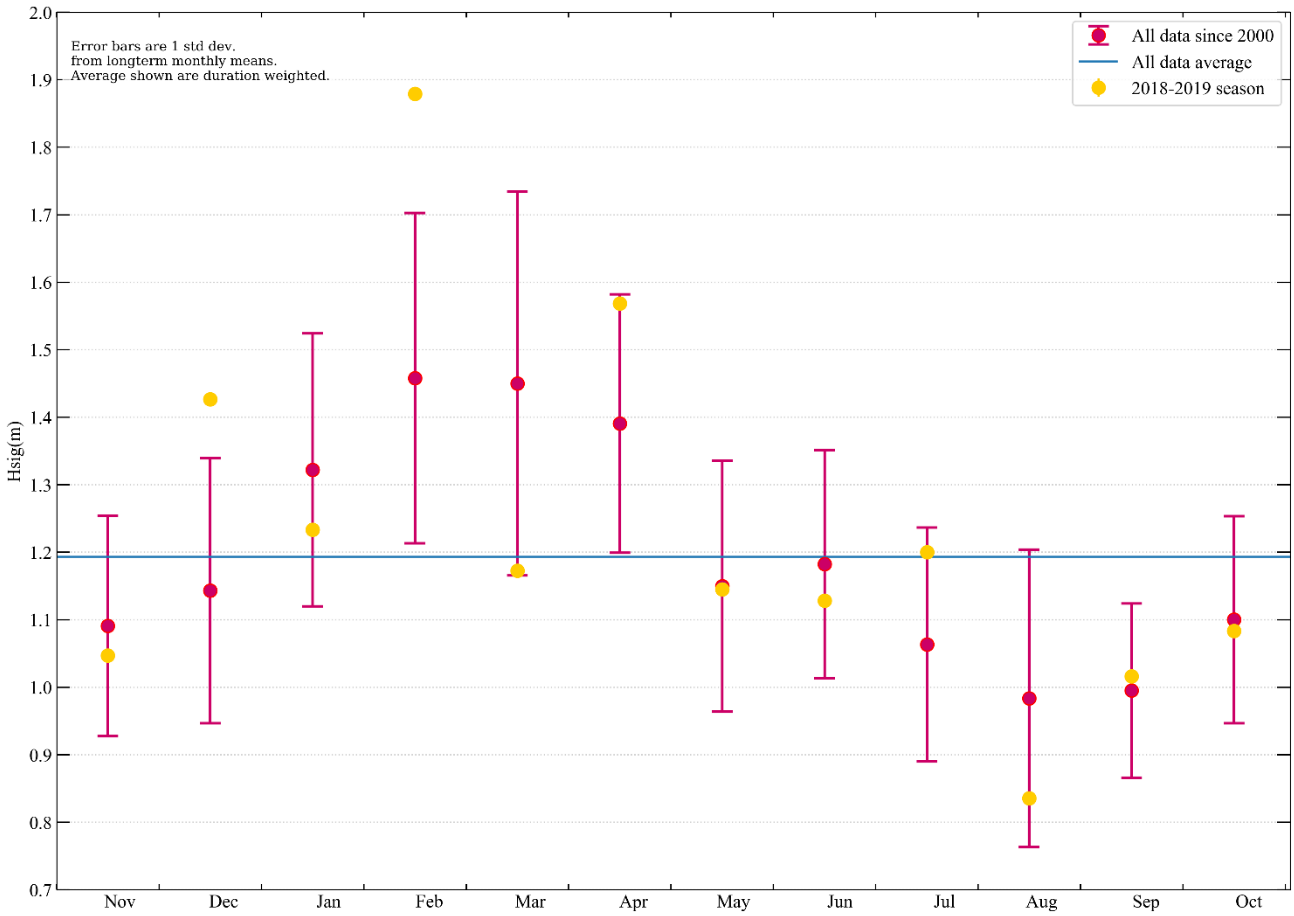


Figure 61 Mooloolaba – Monthly average wave height (H_s) for seasonal year and for all data

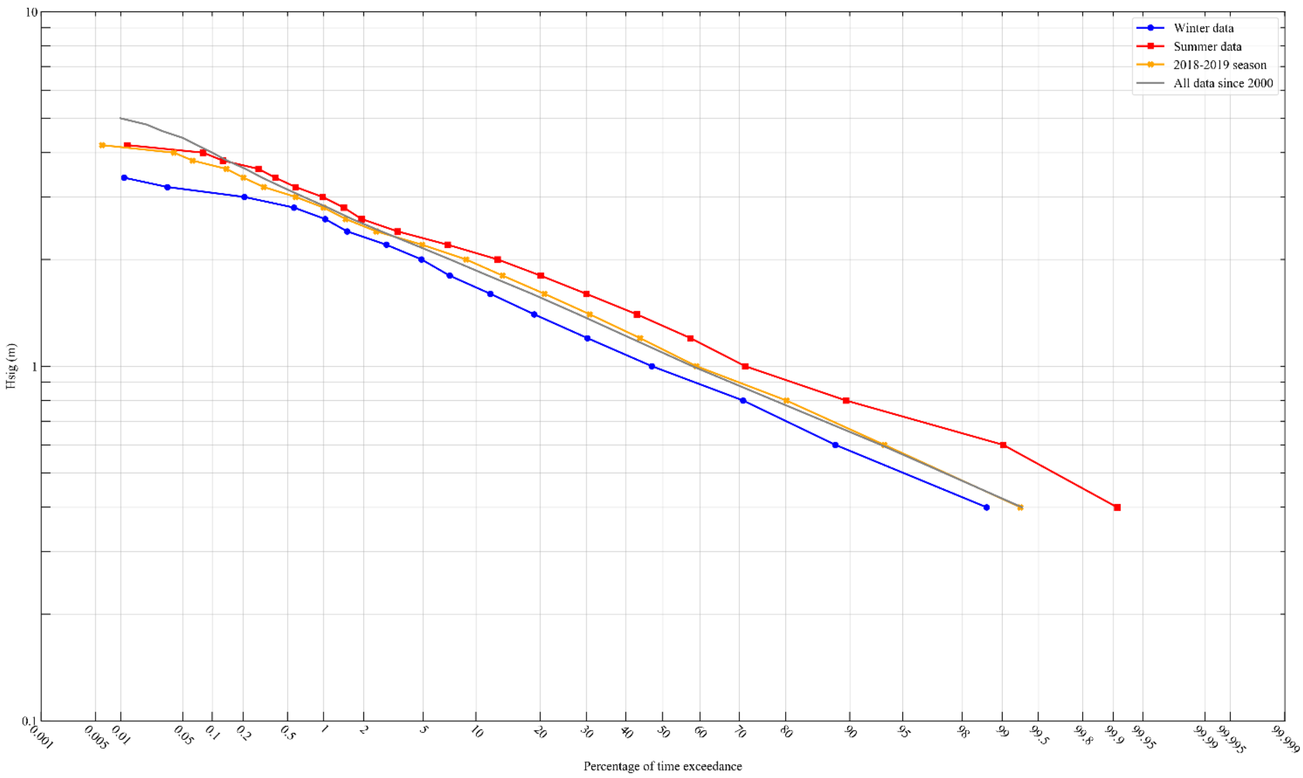


Figure 62 Mooloolaba – Percentage exceedance of wave height (H_s) for all wave periods (T_p)

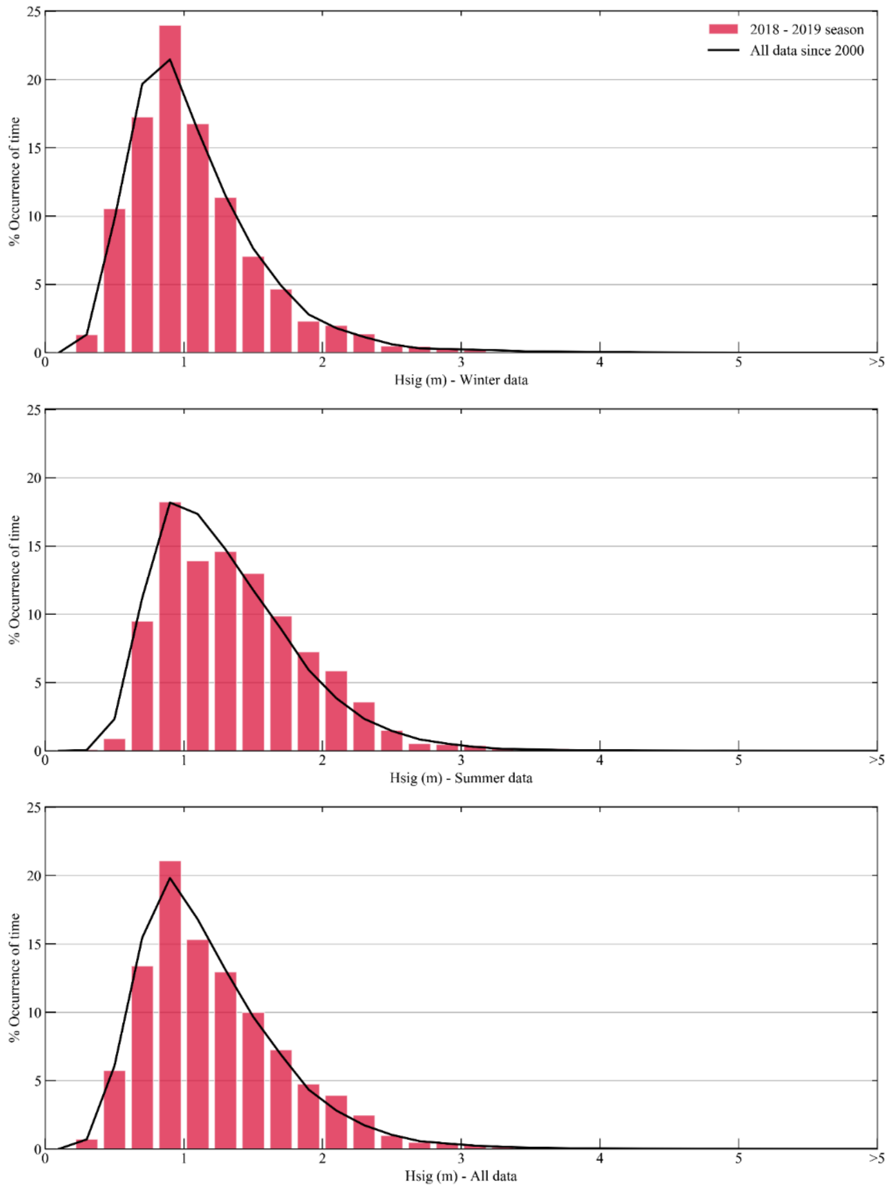


Figure 63 Mooloolaba – Histogram percentage (of time) occurrence of wave heights (H_s)

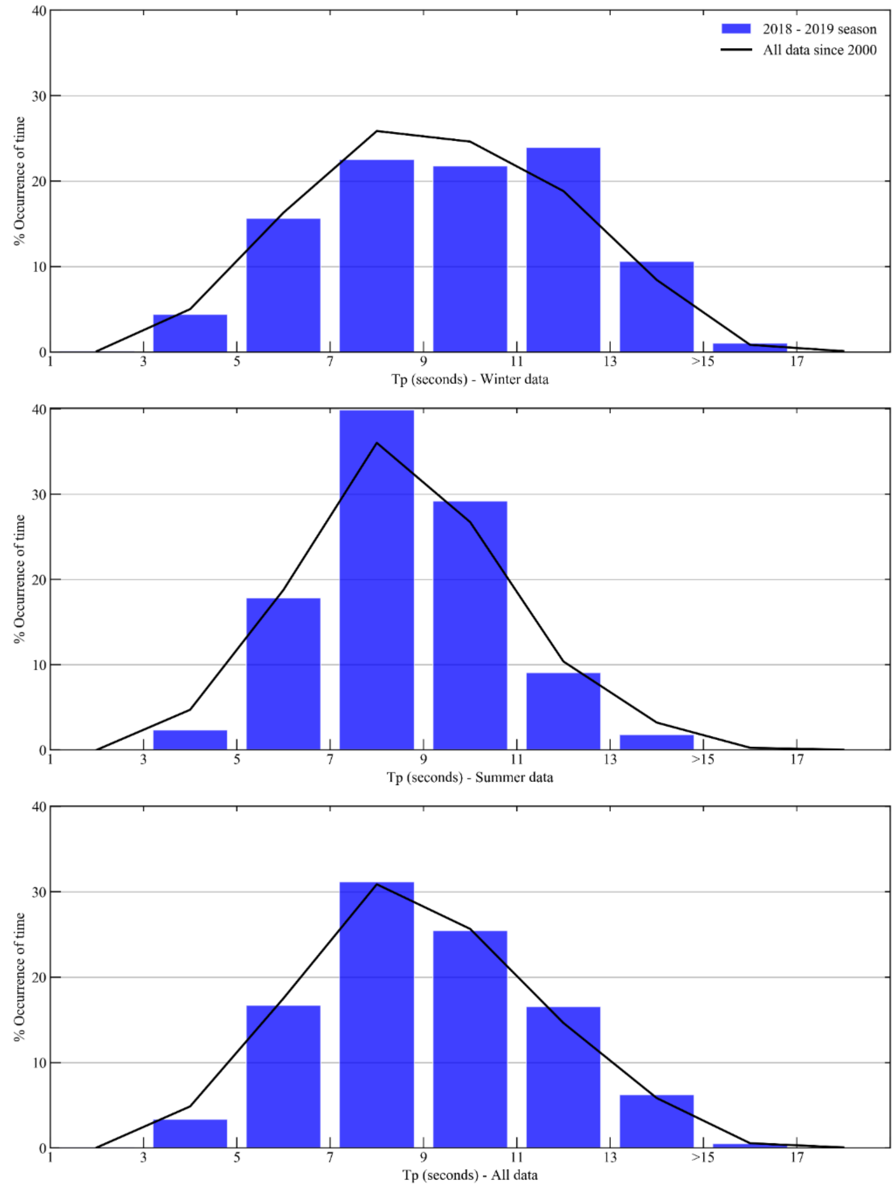


Figure 64 Mooloolaba – Histogram percentage (of time) occurrence of wave periods (T_p)

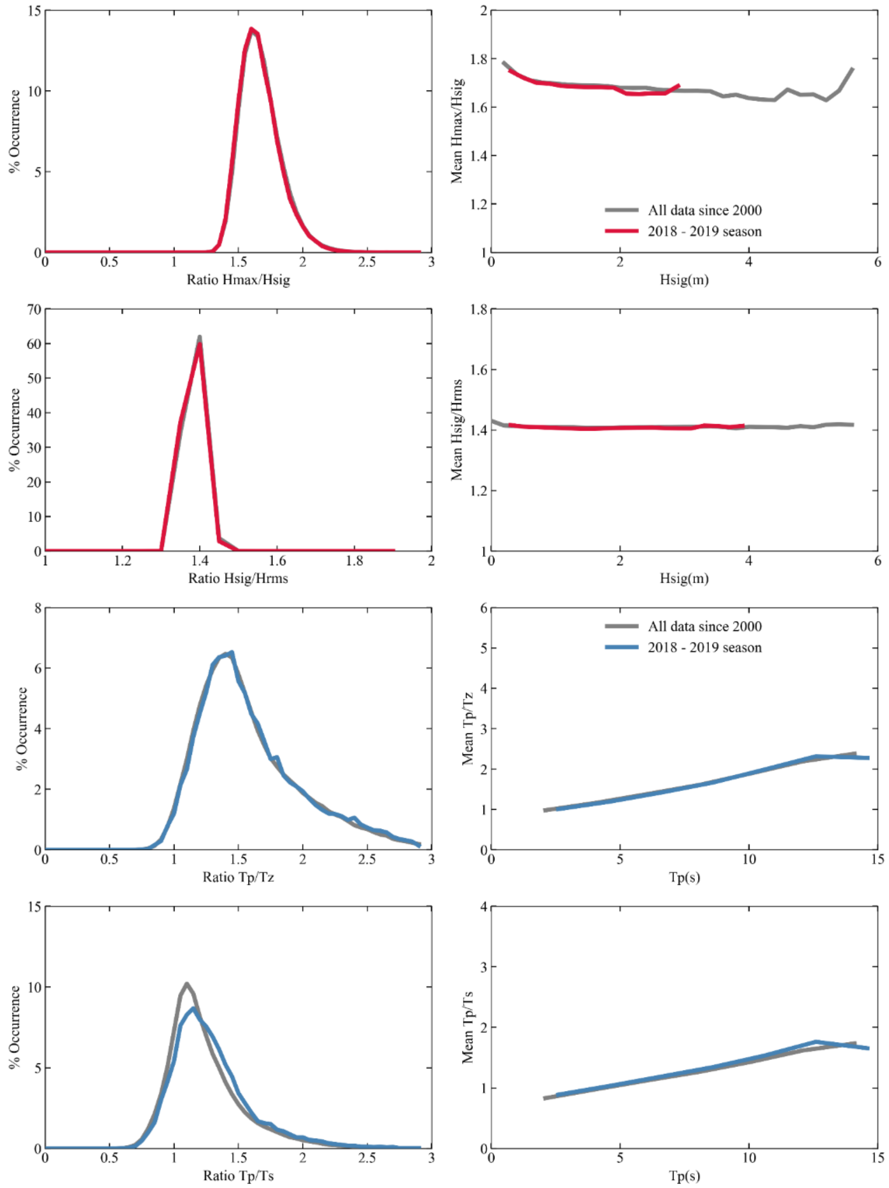


Figure 65 Mooloolaba – Wave parameter relationships

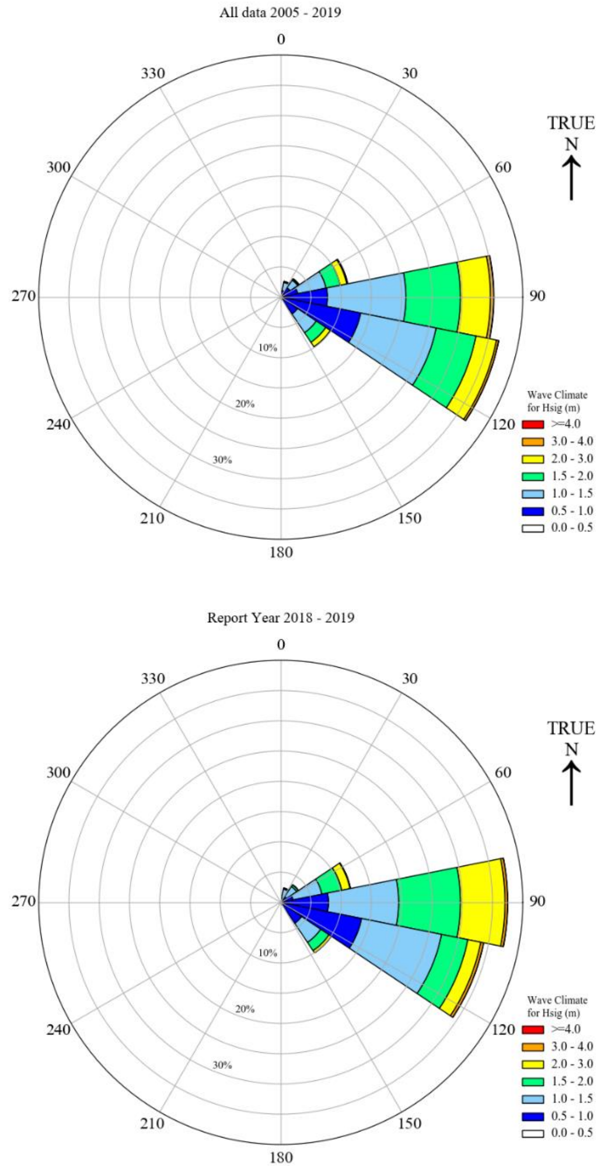


Figure 66 Mooloolaba – Directional wave rose

Bundaberg

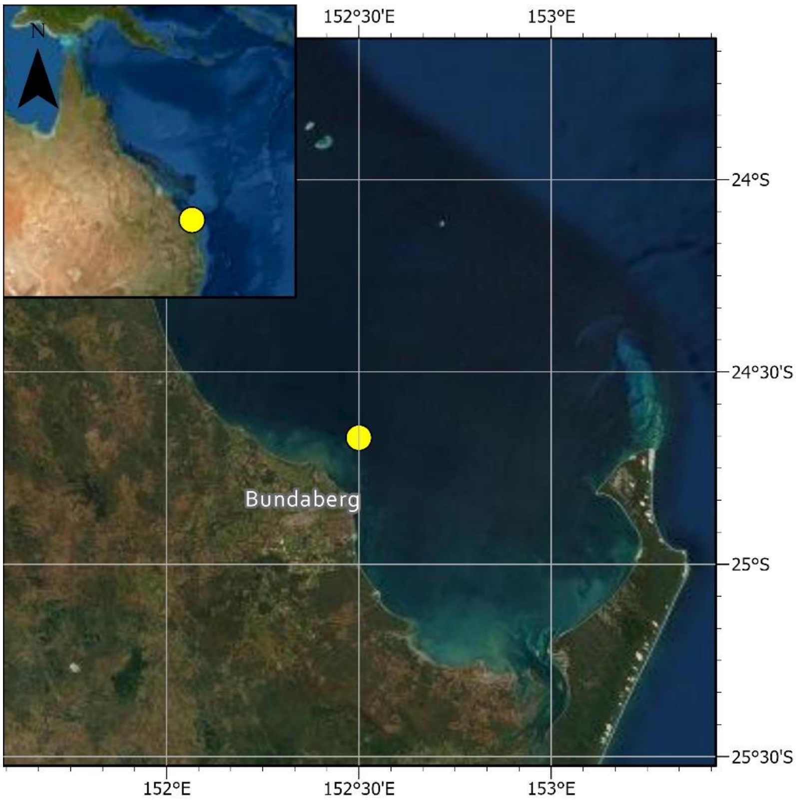


Figure 67 Bundaberg – Locality plan

Table 33 Bundaberg – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	08/09/2015	0.35 years	87,718	4.14
2018-19	01/11/2018	3.65 days	17,296	1

Table 34 Bundaberg – Buoy deployments for 2018-19 season

Latitude	Longitude	Type buoy	Depth (m)	Deployed date	Removal date
24° 40.085' S	152° 29.993' E	SG	18	17/04/2018	12/06/2019
24° 40.252' S	152° 30.022' E	SG	18	12/06/2019	Current

Bundaberg – seasonal overview

The Bundaberg monitoring site has a SG buoy which doesn't record wave direction or sea surface temperature.

The Bundaberg wave buoy has been operational for just over 4 years with an overall data return of 91.55 per cent. The data recorded for the period November 2018 to October 2019 was excellent, with total gaps of 3.65 days, equivalent to a 99 per cent data return (Table 33). The buoy was replaced during the reporting period on 12 June (Table 34).

There were six significant events Hs during the reporting period, two of which, due to the short dataset of the Bundaberg monitoring site, had waves that made it into the top 10 (Table 35 and Table 36). Tropical Cyclones Owen and Oma both produced waves with a Hs of 2.2 m and Hmax above 4.3 metres.

The daily wave recordings of wave heights and periods (Figure 68) shows the six significant meteorological events with several other events creating lower wave height spikes of around 2.5 m H_{max}, throughout the reporting period. Peak wave periods (T_p) in the summer months are commonly in the 4 to 7 seconds range with some longer period spikes from 10 up to 15 seconds.

The monthly average H_s for the recording period fell within one standard deviation (sd) of the entire record, except for December, February and April which were above one sd and March which was below one sd (Figure 69).

The wave climate for the 2018–2019 period was very similar to the wave climate for the entire record, as seen in the percentage exceedance plot for H_s (Figure 70). Overall, the winter period has a lower wave height frequency and for summer it has an overall higher frequency of moderate wave heights compared to the full season.

Histograms of occurrence of H_s (Figure 71) show a variation in distribution of wave heights, with waves from the average 0.8 to 1.0 m trending higher than the record throughout the period. Most common significant wave height (H_s) was 0.6 to 0.8 m for the period, with 0.4 to 0.6 m waves in winter and 0.8 to 1.0 m waves in summer occurring most frequently. Histograms of the occurrence of peak wave periods (T_p) (Figure 72) show a similar occurrence distribution with the overall data record with minor variations.

The ratios between different wave parameters such as H_{max}/ H_s were generally consistent between this reporting period and all of the historic data, these are plotted in Figure 73.

Table 35 Bundaberg – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	30/03/2017 13:30	3.1	30/03/2017 12:00	5.6
2	16/10/2017 19:30	2.3	17/10/2017 02:30	4.8
3	08/03/2018 01:30	2.3	24/02/2019 00:00	4.5
4	16/07/2016 06:00	2.3	16/12/2018 23:00	4.3
5	24/02/2019 00:00	2.2	08/03/2018 01:30	4.2
6	04/01/2016 23:30	2.2	03/02/2018 21:30	4.2
7	16/12/2018 23:00	2.2	28/11/2018 20:30	4.2
8	03/12/2015 16:00	2.1	16/07/2016 16:00	4.1
9	03/02/2018 23:30	2.1	29/03/2018 21:00	4.1
10	14/03/2018 17:00	2.1	14/03/2018 11:30	4.1

Table 36 Bundaberg– Significant meteorological events with threshold H_s of 1.8 metres

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
06/12/2018 07:00	2	3.9	5.9	TC Owen weakened to a tropical low on 04 December that would later move west across the Qld coast and reform before entering NT
16/12/2018 23:00	2.2	4.3	6.4	TC Owen had reformed on 12 December in the Gulf of Carpentaria and moved east to the Coral Sea
23/12/2018 08:30	2	3.6	6.1	Series of lows moving east past the coast to the sea
16/02/2019 04:30	1.9	3.5	5.8	TC Oma had just formed out near Vanuatu on 12 February
24/02/2019 12:00 Peak Event	2.2	4.5	6.2	TC Oma was nearest the east coast of Qld on 22 February before returning to a low-pressure system and heading northeast.
06/07/2019 04:00	2.1	3.7	5.4	Upper-level trough developed near central Qld around the 4th and interacted with surface troughs over several days.

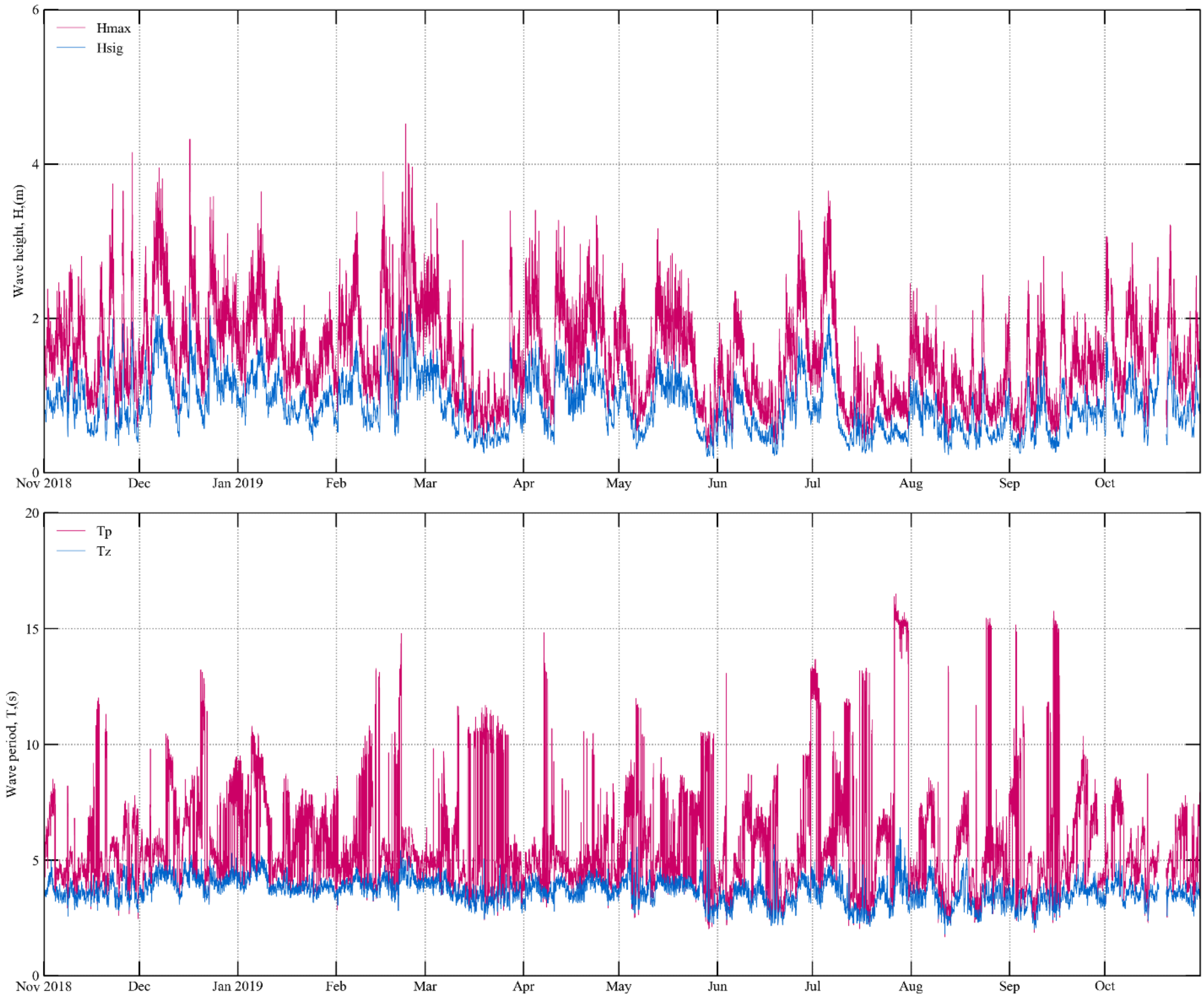


Figure 68 Bundaberg – Daily wave recordings

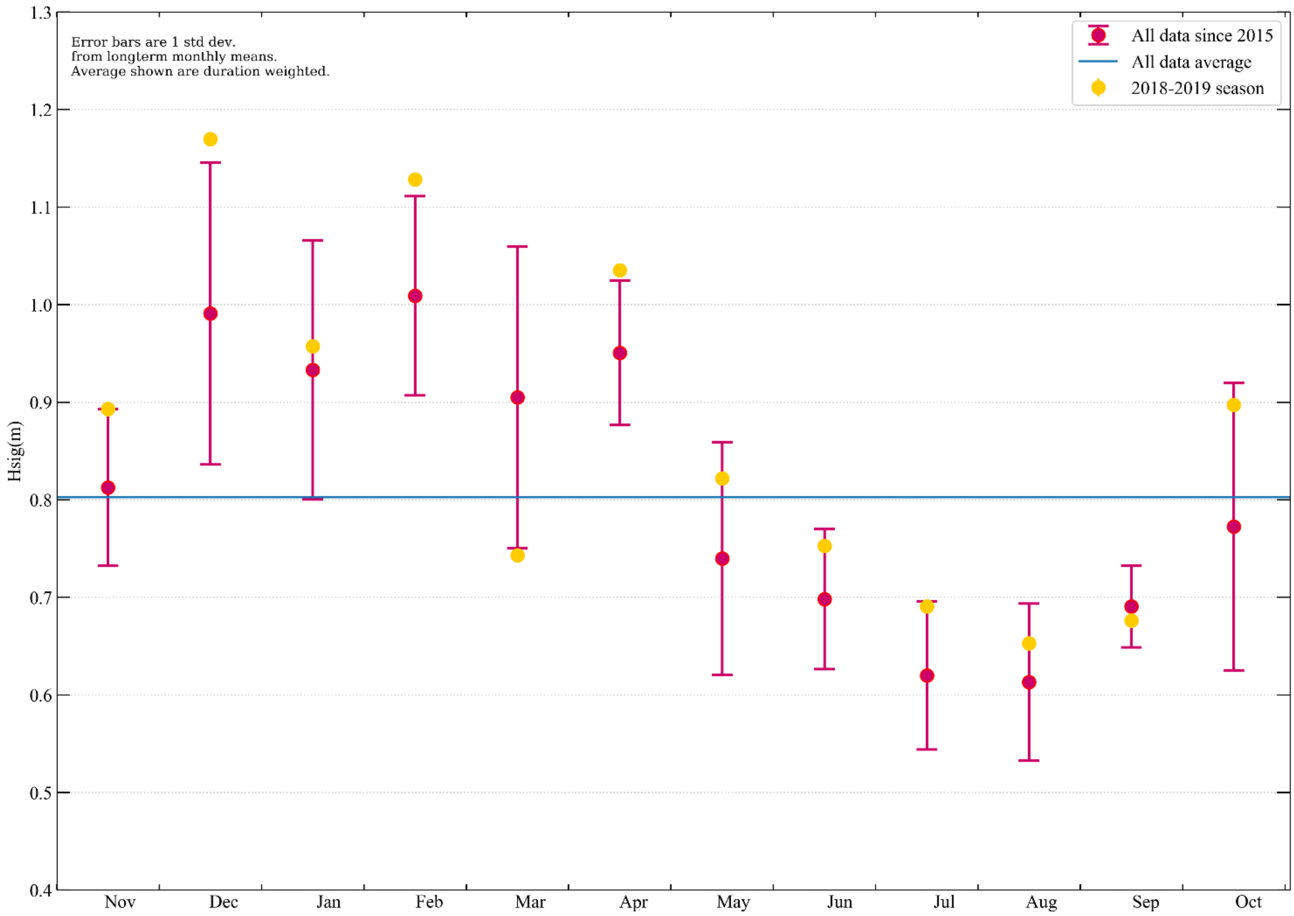


Figure 69 Bundaberg - Monthly average wave height (H_s) for seasonal year and for all data

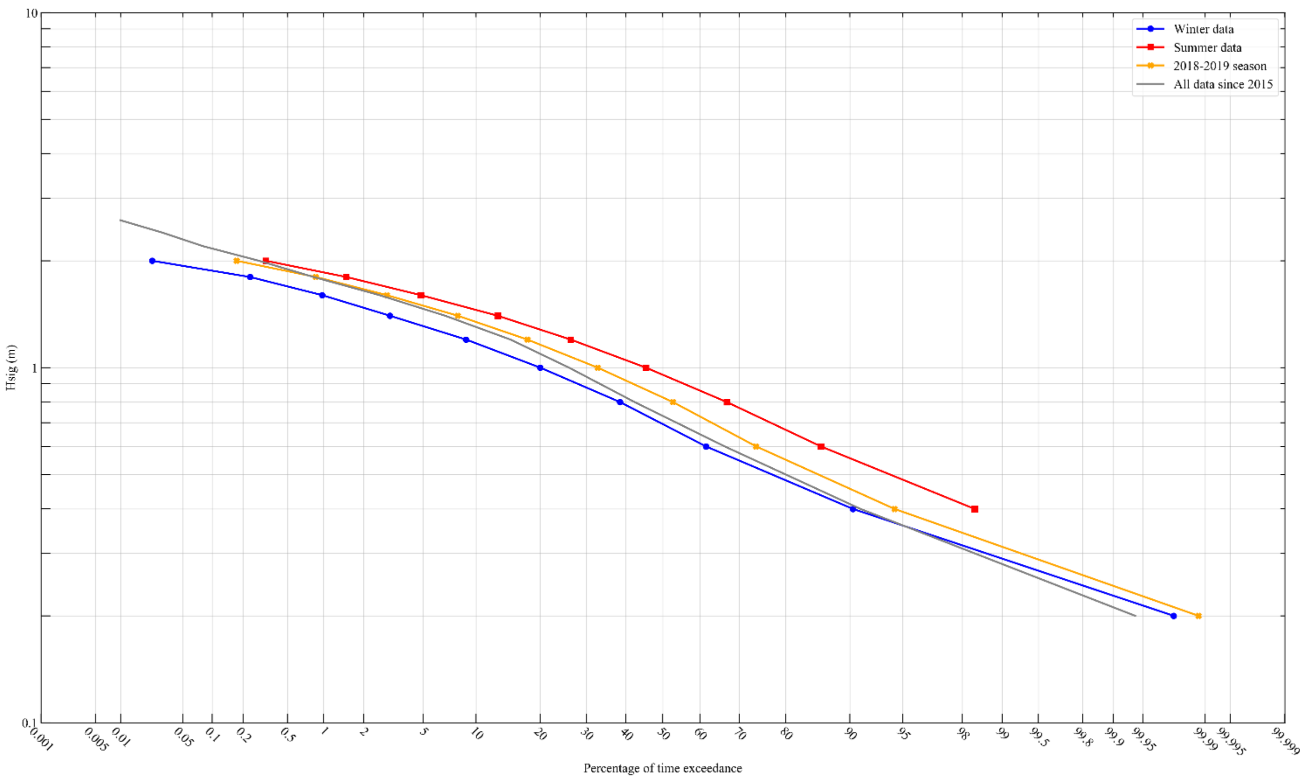


Figure 70 Bundaberg – Percentage exceedance of wave height (H_s) for all wave periods (T_p)

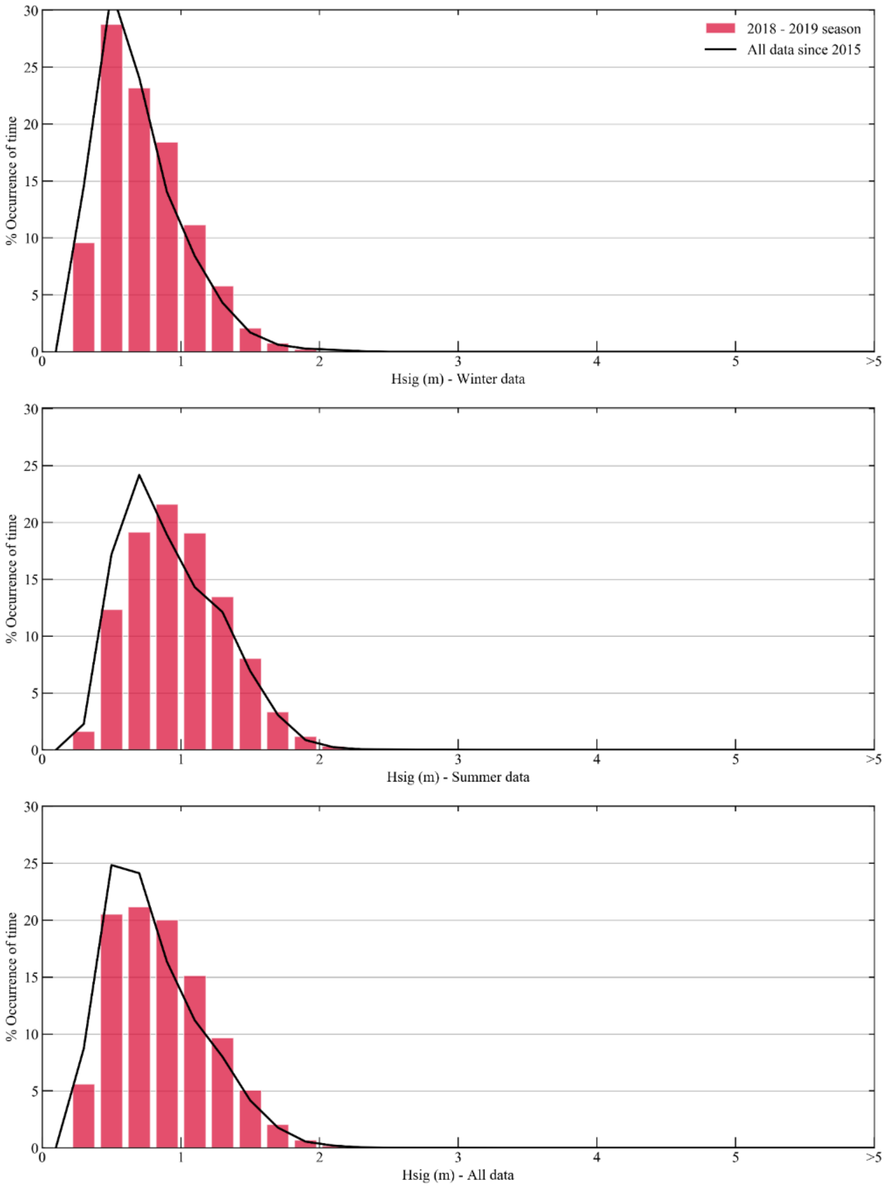


Figure 71 Bundaberg – Histogram percentage (of time) occurrence of wave heights (H_s)

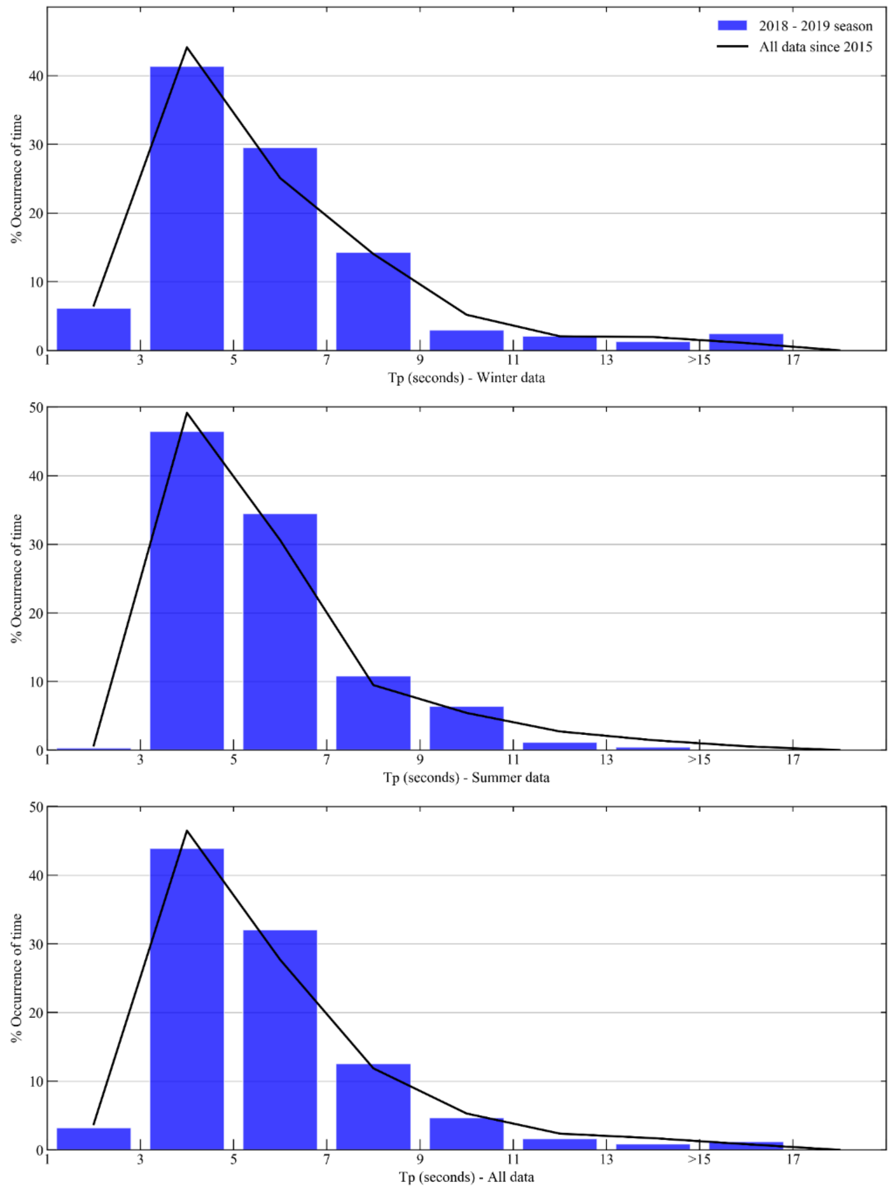


Figure 72 Bundaberg – Histogram percentage (of time) occurrence of wave periods (T_p)

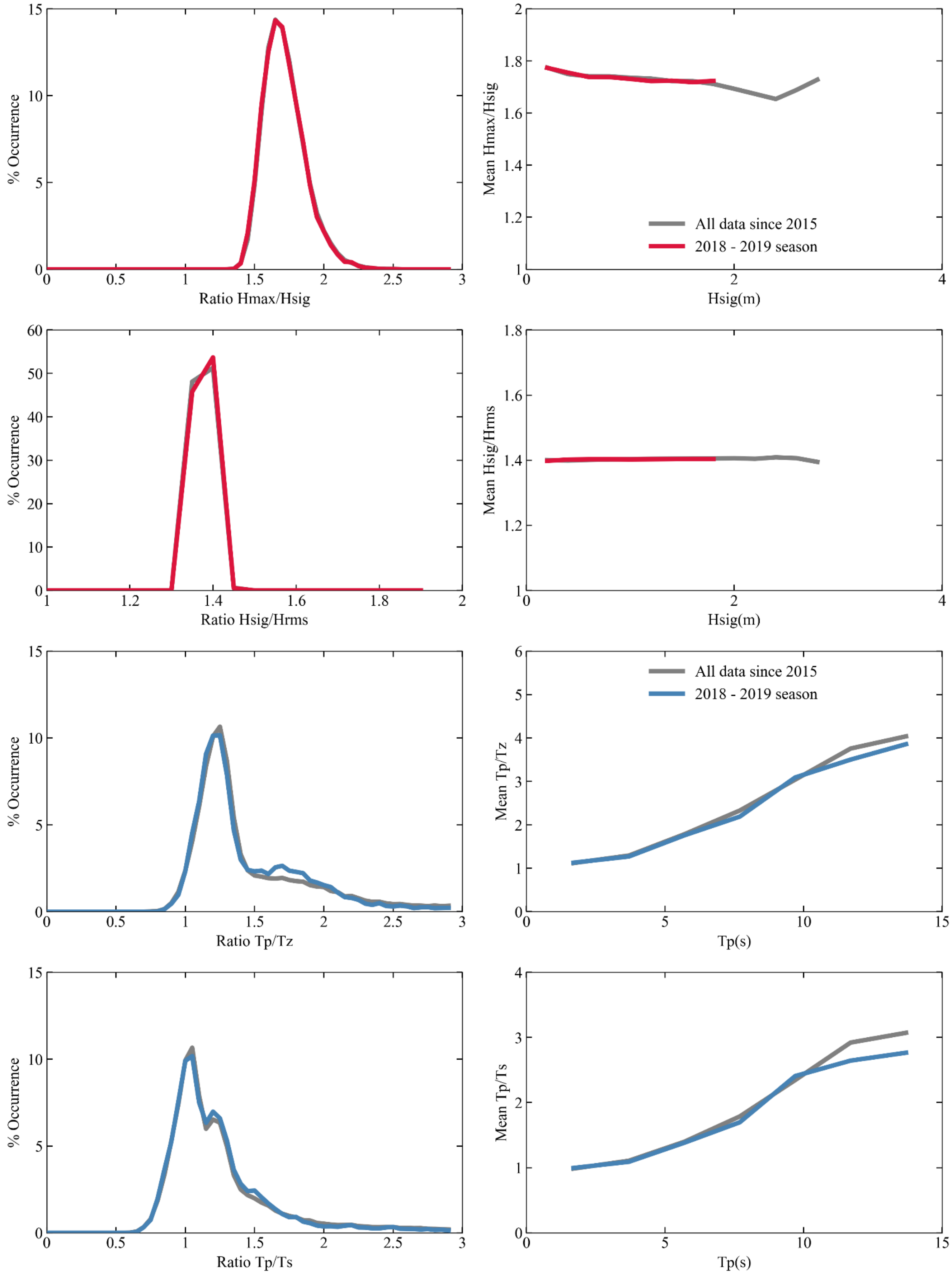


Figure 73 Bundaberg – Wave parameter relationships

Gladstone

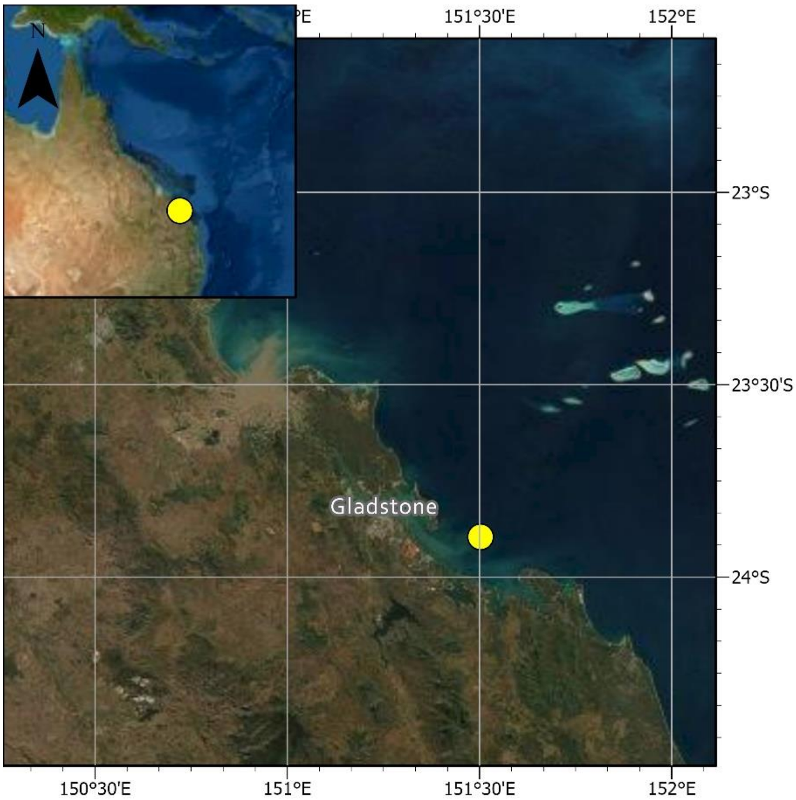


Figure 74 Gladstone – Locality plan

Table 37 Gladstone wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	23/09/2009	0.21 (years)	171,434	10.1
2018-19	01/11/2018	23.02 (days)	16,415	1

Table 38 Gladstone – Buoy deployments during the 2018-19 season

Latitude	Longitude	Type buoy	Depth (m)	Deployed date	Removal date
23° 53.753' S	151° 30.183' E	DWR-MkIII	15.5	3/11/2017	13/09/2019
23° 53.753' S	151° 30.182' E	DWR-MkIII	16	13/09/2019	current

Gladstone – seasonal overview

The Gladstone wave buoy has been operational for over nine years with an overall data return of 97.79 per cent. The data recorded for the period November 2018 to October 2019 was ok, with total gaps of 23.02 days, equivalent to a 93.4 per cent data return (Table 37). The buoy was replaced once during the reporting period on 13 September (Table 38).

There were two significant storm events throughout the reporting period (Table 40). Significant wave height (H_s) of 2.3 m, and H_{max} of 4.3 m has been added to the bottom of the top 10 highest waves (Table 39).

Daily wave recordings (Figure 75) show several events throughout the monitoring period which produced high waves with H_{max} above 2 m. Variations in peak wave periods T_p are also noted with several days where T_p stayed around 14 seconds at the end of July.

The SST was over the threshold for cyclone development (26 °C) from November to the end of early April (Figure 76). Temperatures at the site range from 19 to 29 degrees Celsius. The anomaly from September to the end of the record is likely due to sensor or signal malfunction or due to an error in signal processing. Due to this anomaly the low temperature of 19 °C is an assumption based on SST data from the nearest adjacent site of Emu Park showing lowest temperatures in mid-July.

The monthly average H_s for the recording period fell within one standard deviation (sd) of the entire record (Figure 77), except for December, February and April, which were above and March which was below the monthly average for all data.

The wave climate for the 2018–19 period was very similar to the wave climate for the entire record, though a decrease in waves exceeding 1.8 m can be seen in the percentage exceedance plot for H_s (Figure 78). Overall, the winter period has a lower frequency of wave heights and summer has an overall higher frequency compared to the 2018–19 season. Histograms of occurrence of H_s (Figure 79) show a distribution approximately similar to the historic data for the winter period, with a lower occurrence for H_s 0.4–0.6 m than the historic data. The summer period trended towards higher waves with a noted decrease from the historic data for waves below 0.8 m and an increased occurrence of waves between 1.0 and 1.8 metres. Histograms of the occurrence of T_p (Figure 80) show a similar distribution of occurrence with the overall data with nominal variation.

The ratios between different wave parameters such as H_{max}/ H_s were generally consistent between this reporting period and all of the historic data per Figure 81.

The plot of wave direction over the 2018–19 season (Figure 76) showed a dominant east north-easterly direction with an occasional swing to the North during summer and an occasional swing to the South in winter. The incident wave direction is reflected in the directional wave rose plot (Figure 82) which is for the most part identical to the historical data, with the most common wave height (H_s) of 0.5 m to 1.0 metres.

Table 39 Gladstone – Highest waves

Rank	Date	H_s (m)	Date	H_{max} (m)
1	01/02/2010 20:00	3.2	30/03/2017 11:00	6.8
2	25/01/2013 02:00	3.2	01/02/2010 20:00	6.1
3	30/03/2017 11:00	3.2	01/02/2014 01:00	6
4	20/02/2015 15:00	3	25/01/2013 14:00	5.8
5	16/07/2016 09:00	2.9	20/02/2015 16:30	5.5
6	01/02/2014 01:00	2.8	16/07/2016 09:00	5.5
7	20/03/2010 10:30	2.3	20/03/2010 21:00	4.7
8	16/01/2012 22:00	2.3	12/04/2013 03:00	4.5
9	12/04/2013 04:00	2.3	16/01/2012 23:00	4.5
10	06/07/2019 04:00	2.3	06/07/2019 04:00	4.3

Table 40 Gladstone – Significant meteorological events with threshold H_s of 2.0 metres

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
08/12/2018 14:30	2.1	3.8	8.2	TC Owen weakened to a tropical low on 04 December that would later move west across the Qld coast and reform before entering NT
06/07/2019 04:00 Peak Event	2.3	4.3	9.3	Upper-level trough developed near central Qld around the 4th and interacted with surface troughs over several days.

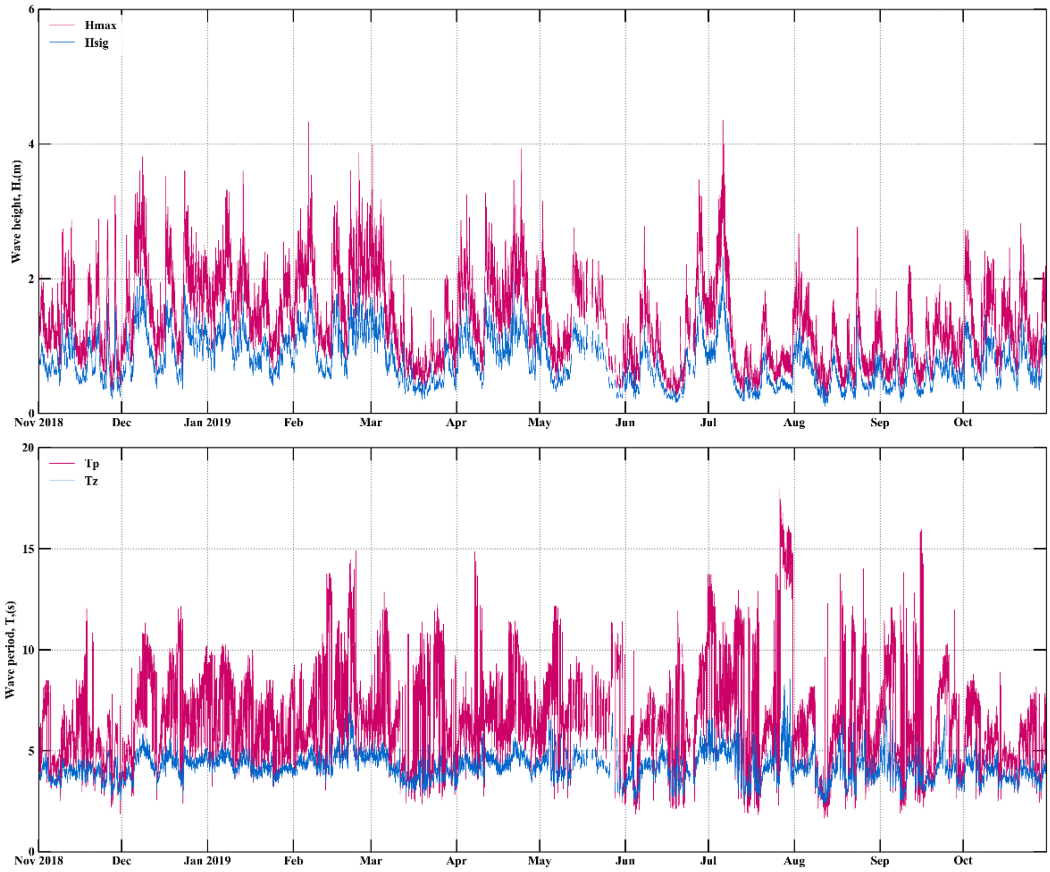


Figure 75 Gladstone – Daily wave recordings

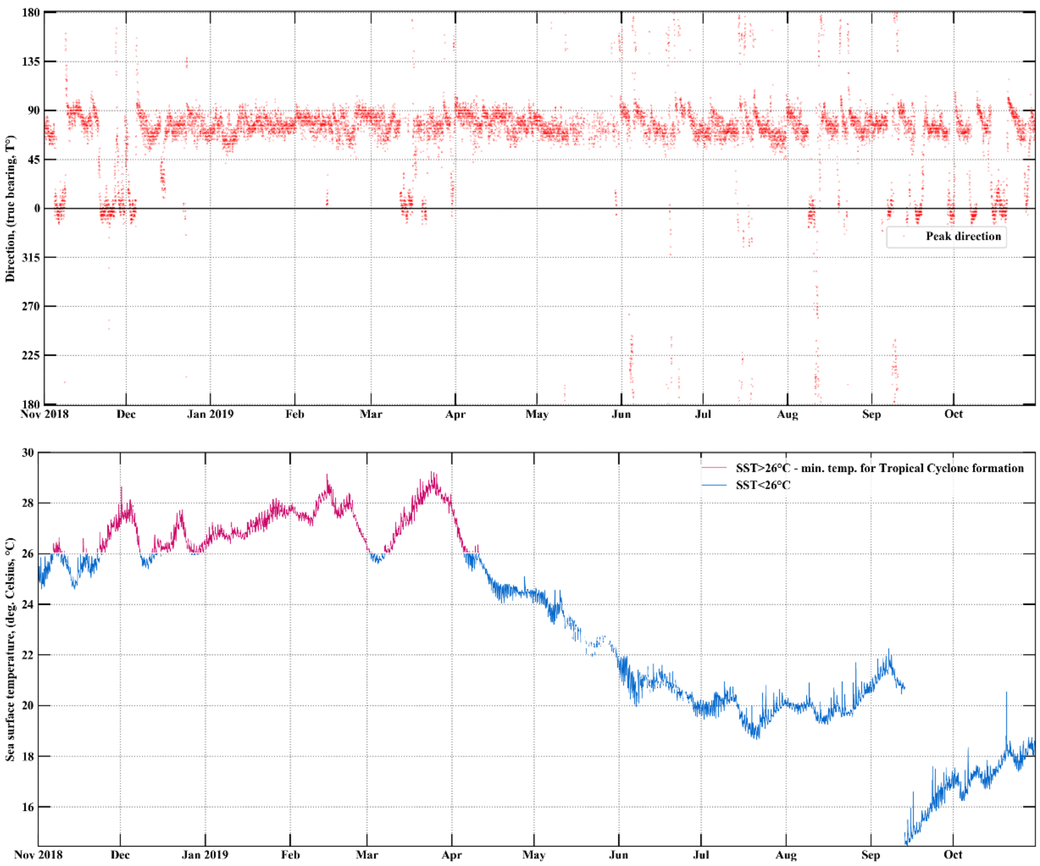


Figure 76 Gladstone – Peak wave directions and sea surface temperature

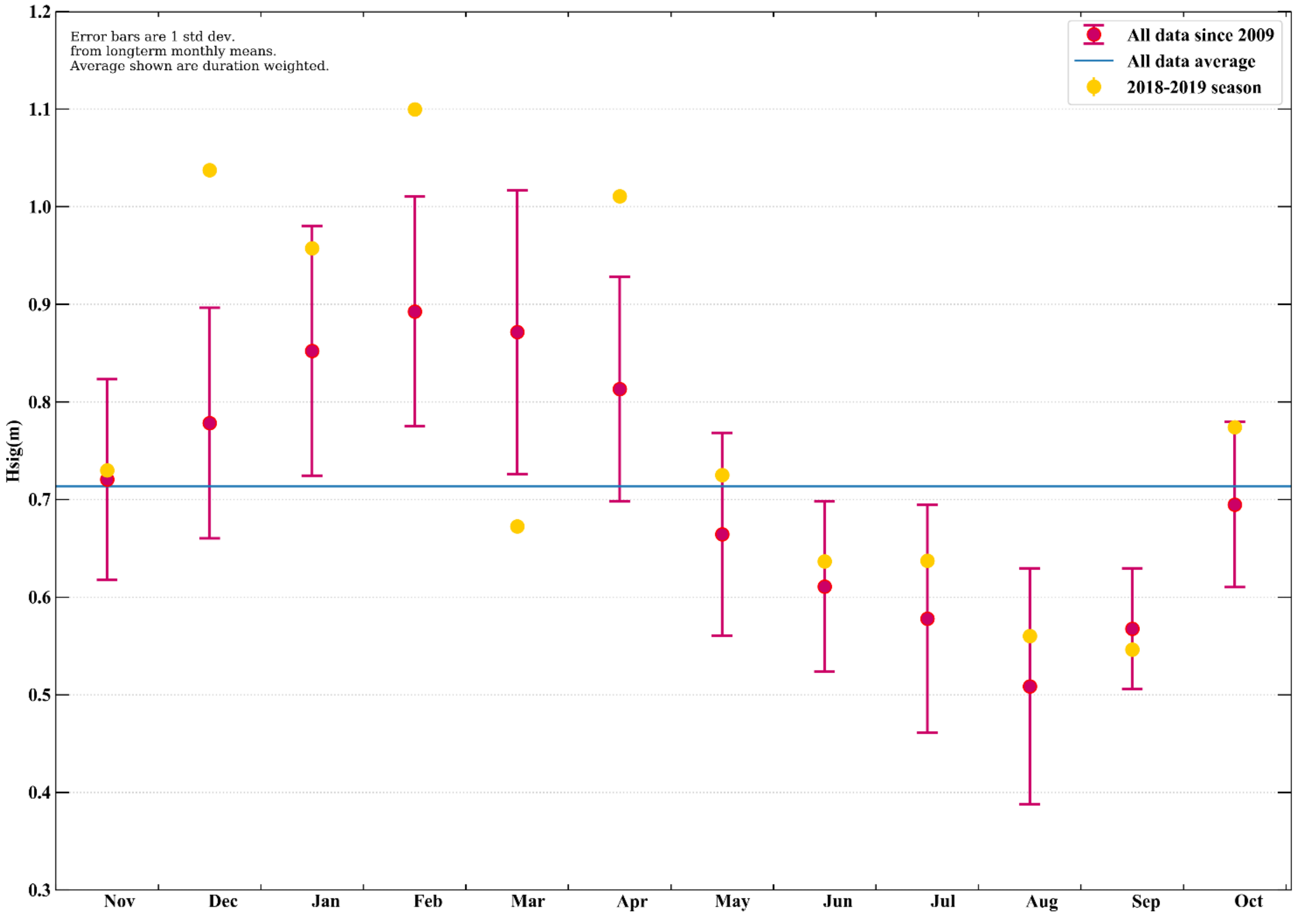


Figure 77 Gladstone – Monthly average wave height (H_s) for seasonal year and for all data

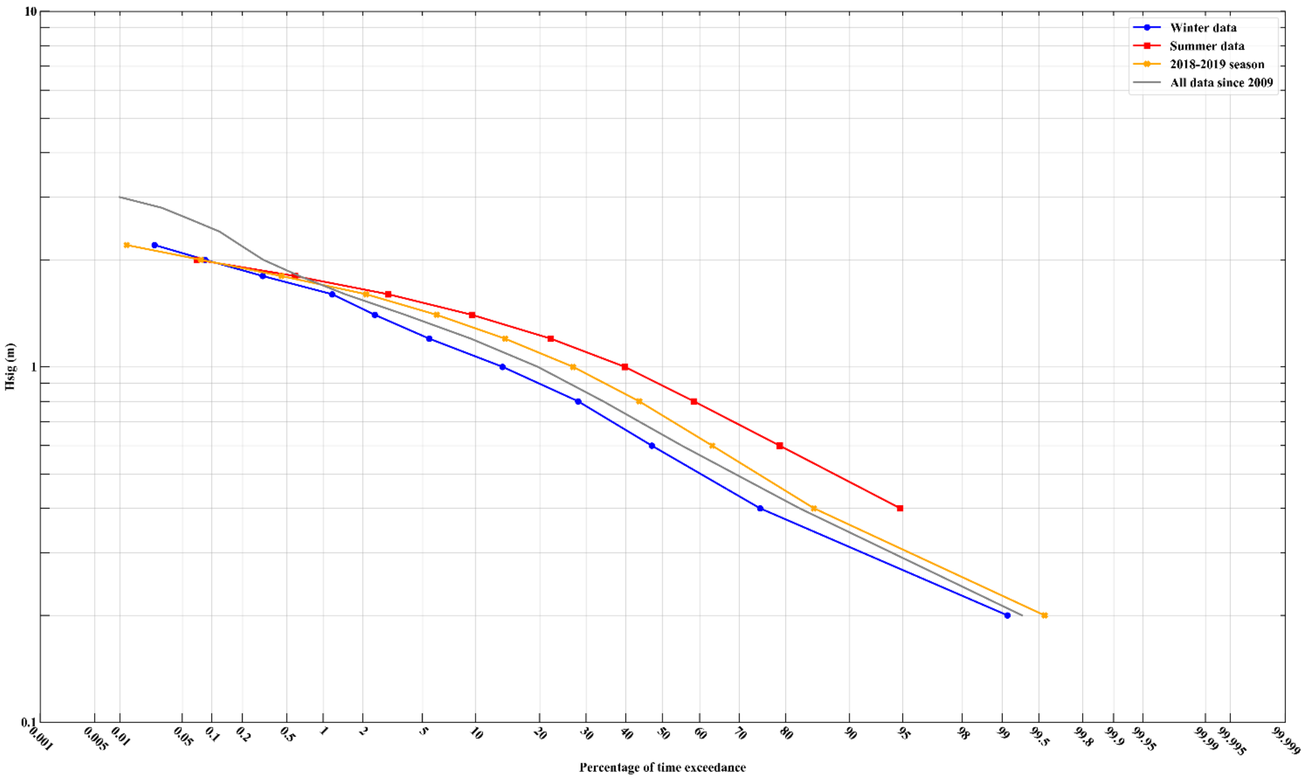


Figure 78 Gladstone – Percentage exceedance of wave height (H_s) for all wave periods (T_p)

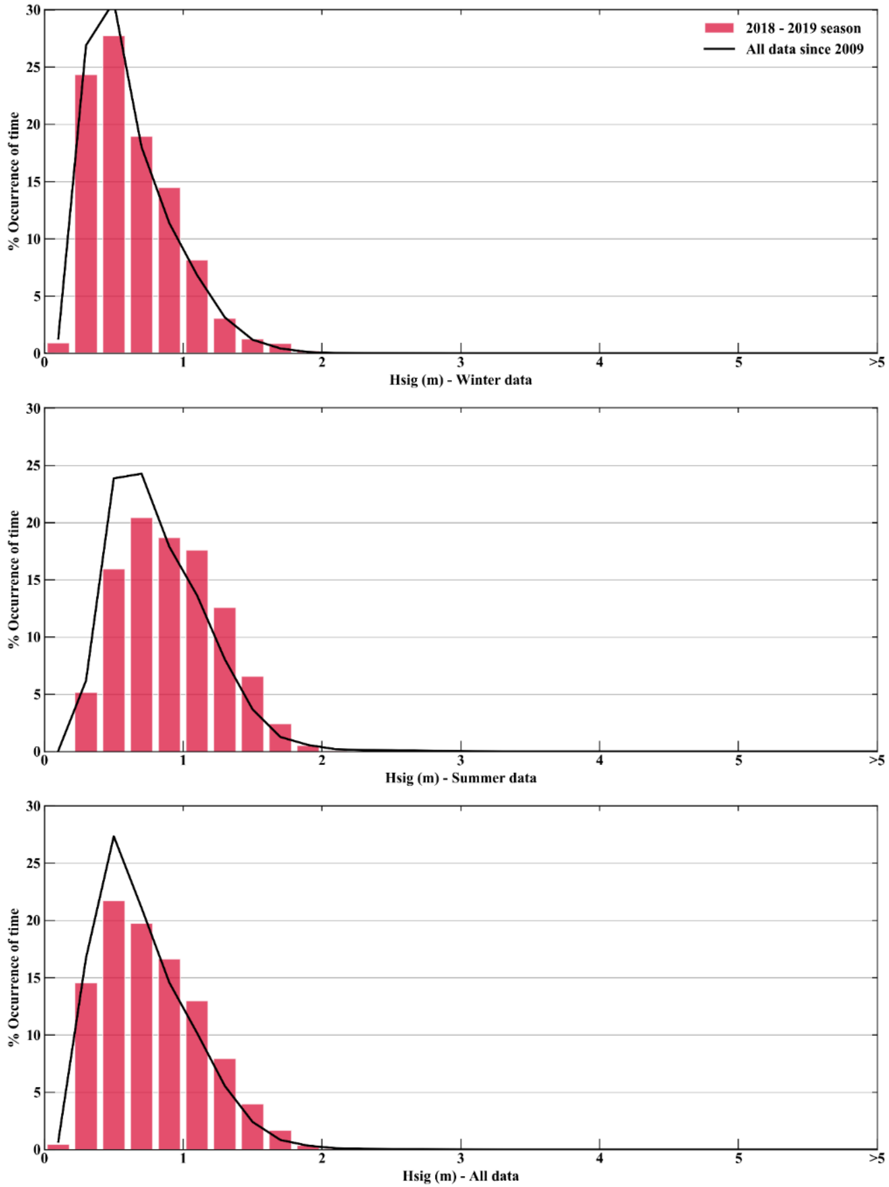


Figure 79 Gladstone – Histogram percentage (of time) occurrence of wave heights (H_s)

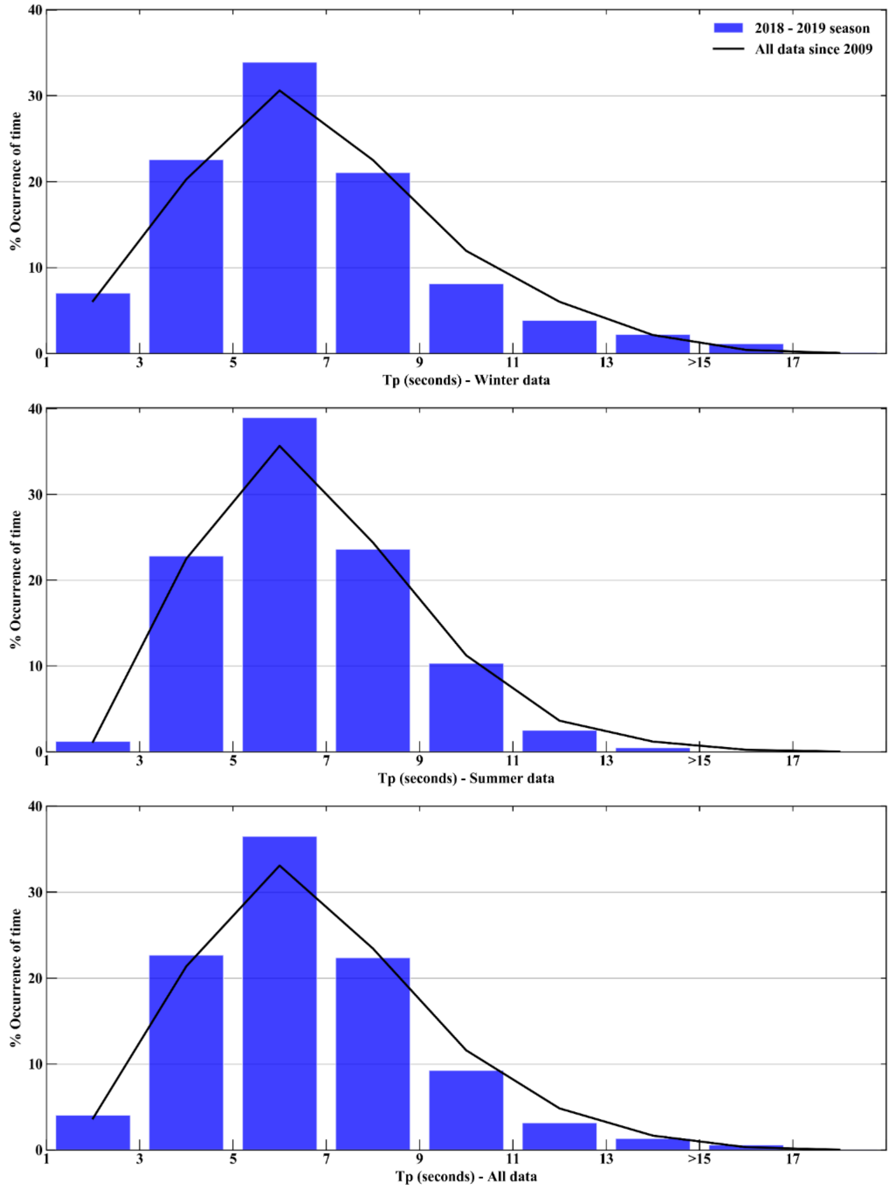


Figure 80 Gladstone – Histogram percentage (of time) occurrence of wave periods (T_p)

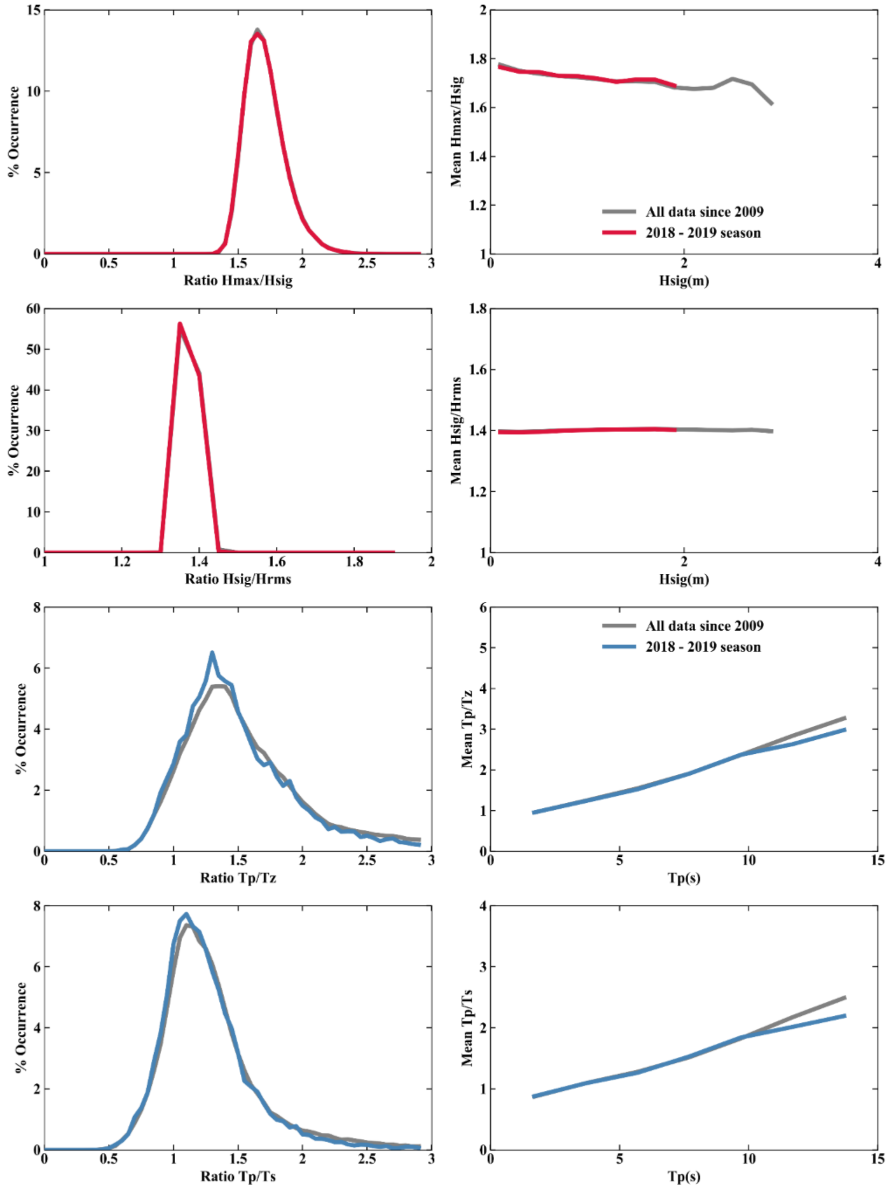


Figure 81 Gladstone – Wave parameter relationships

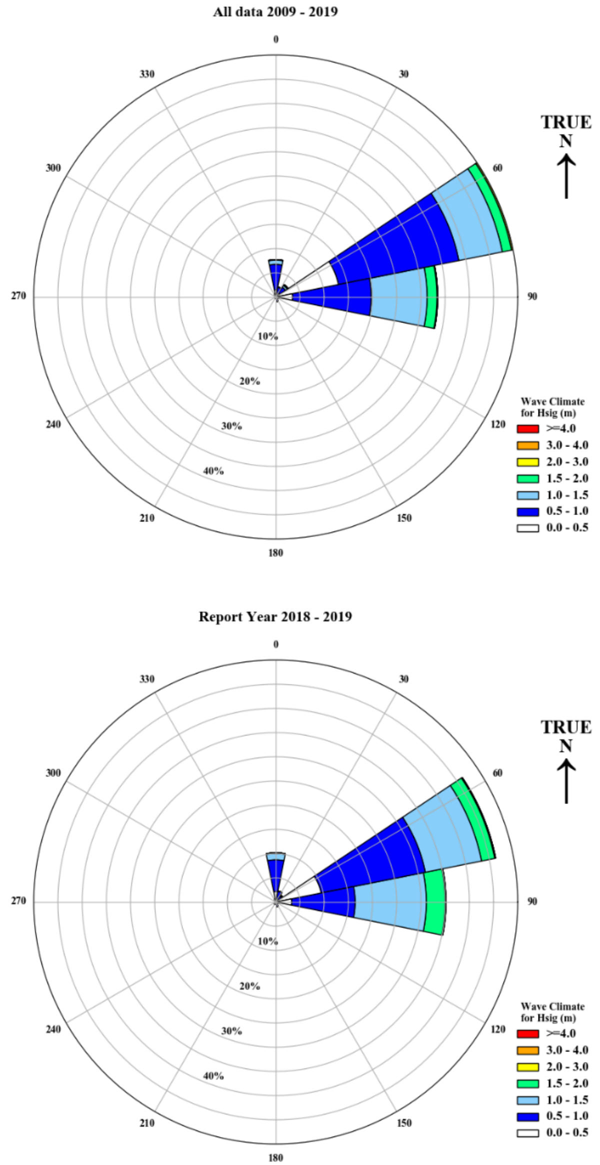


Figure 82 Gladstone – Directional wave rose

Emu Park

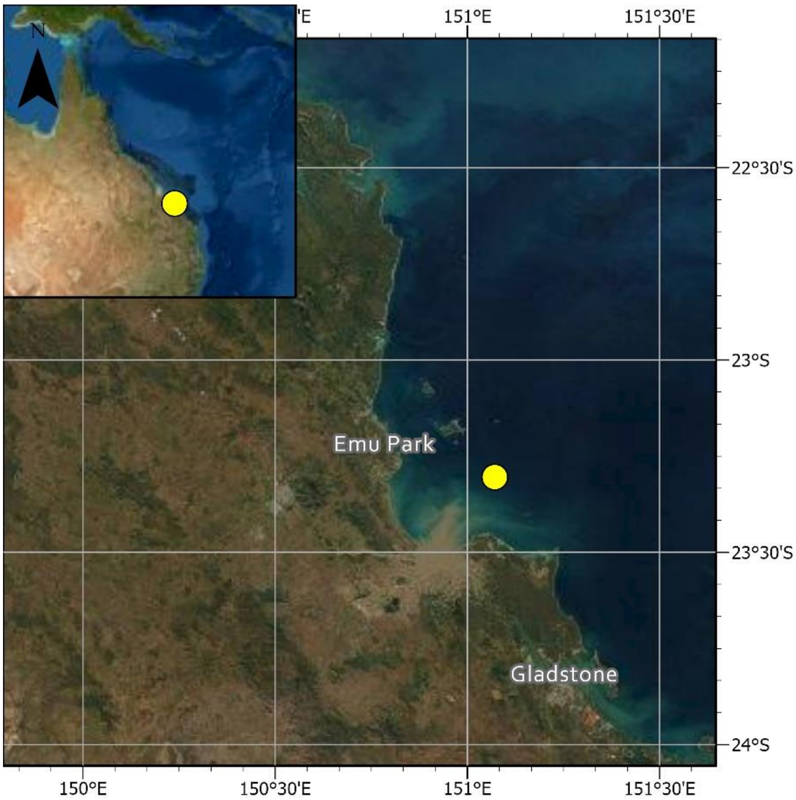


Figure 83 Emu Park – Locality plan

Table 41 Emu Park – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	24/07/1996	1.27 years	335,425	23.27
2018–19	01/11/2018	1.31 days	17,457	1

Table 42 Emu Park – Buoy deployments during the 2018–19 season

Latitude	Longitude	Type buoy	Depth (m)	Deployed date	Removal date
23° 18.244' S	151° 04.273' E	DWR-MkIII	18	19/04/2018	current

Emu Park – seasonal overview

The Emu Park wave buoy has been operational for just over 23 years with an overall data return of 94.5 per cent. The data recorded for the period November 2017 to October 2018 was good, with total gaps of 1.31 days, equivalent to 99.6 per cent data return (Table 41). The buoy was not replaced during this reporting period, but was replaced in the previous period on 19 of April, (see Table 42).

During the reporting year there was two significant weather events which impacted Emu Park wave buoy (Table 44), however neither of these events had waves that made it into the top 10 highest waves (Table 43).

Daily wave recordings (Figure 84) shows this site experienced numerous occurrences of maximum wave heights H_{max} exceeding 4 metres. There are notable variations in peak wave periods T_p throughout the monitoring period with some events producing significantly longer T_p for several days at the end of July.

Sea surface temperature (SST), measured in the buoy hull showed a range of 19.5 °C to 29 °C (Figure 85), with the SST from mid-December to early-April warm enough for tropical cyclone formation. The plot shows significant rapid temperature spiking throughout the period.

The monthly average H_s was outside of one standard deviation (sd) of the long-term mean during December, February and April which were above one sd and March, which was below one sd (Figure 86).

Percentage exceedance of H_s (Figure 87) shows wave heights followed the trends of the overall dataset and were lower during the winter months and higher during the summer months compared to the reporting period and historic data. Histograms of occurrence of H_s show a significant variation from the trend in the reporting period's summer months, with a notable decrease in waves below 1.0 m H_s and an increase in waves between 1.0 and 2.0 m H_s (Figure 88). A lower occurrence than the trend of winter waves of 0.4 to 0.6 m H_s can also be seen. The histograms for T_p show similarity to the historic data (Figure 89) with 5 to 7 second peak energy wave periods occurring more frequently than the dataset trend.

The ratios between different wave parameters such as H_{max} / H_s and T_p/T_z is in general consistent between this reporting period and all the historic data (Figure 90). The ratio H_s / H_{rms} is slightly increased compared to the historical data. The ratios between the T_p/T_s slightly decreased compared to the historic data.

The peak wave direction time series plot (Figure 85) shows predominantly east north-easterly to east south-easterly waves with nominal swings to the north and minor swings south-west. The dominant incident waves from the east-north-east to east-south-east, show a very similar distribution for the reporting period and the entire record (Figure 91).

Table 43 Emu Park – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	20/02/2015 13:30	4.0	01/02/2010 03:30	8.2
2	25/01/2013 11:00	3.9	25/01/2013 11:30	7.4
3	30/03/2017 08:30	3.8	30/03/2017 08:30	7.0
4	01/02/2010 02:00	3.7	20/02/2015 14:00	7.0
5	16/07/2016 12:00	3.7	09/03/1997 11:30	6.9
6	31/01/2014 06:30	3.5	31/01/2014 04:00	6.7
7	28/08/1998 06:30	3.2	16/07/2016 12:00	6.6
8	04/06/2002 13:00	3.2	28/08/1998 08:00	6.4
9	09/03/1997 19:30	3.1	04/06/2002 17:30	6.4
10	20/03/2010 16:00	3	20/03/2010 12:30	5.9

Table 44 Emu Park – Significant meteorological events with threshold H_s of 2.5 metres

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
24/02/2019 20:30	2.6	5.1	6.8	TC Oma was nearest the east coast of Qld on 22 February before returning to a low-pressure system and heading northeast.
06/07/2019 04:30 Peak Event	2.6	5.3	7.3	Upper-level trough developed near central Qld around the 4th and interacted with surface troughs over several days.

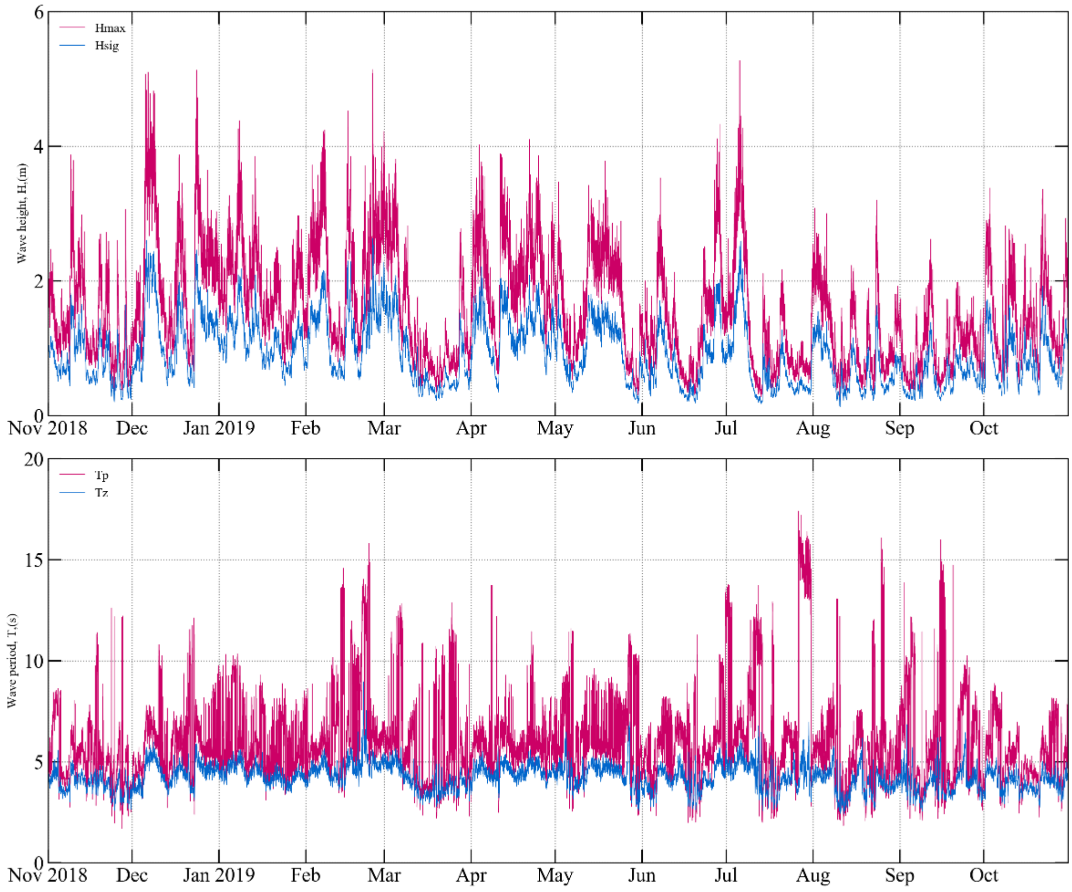


Figure 84 Emu Park – Daily wave recordings

Figure 85 Emu Park – Peak wave directions and sea surface temperature

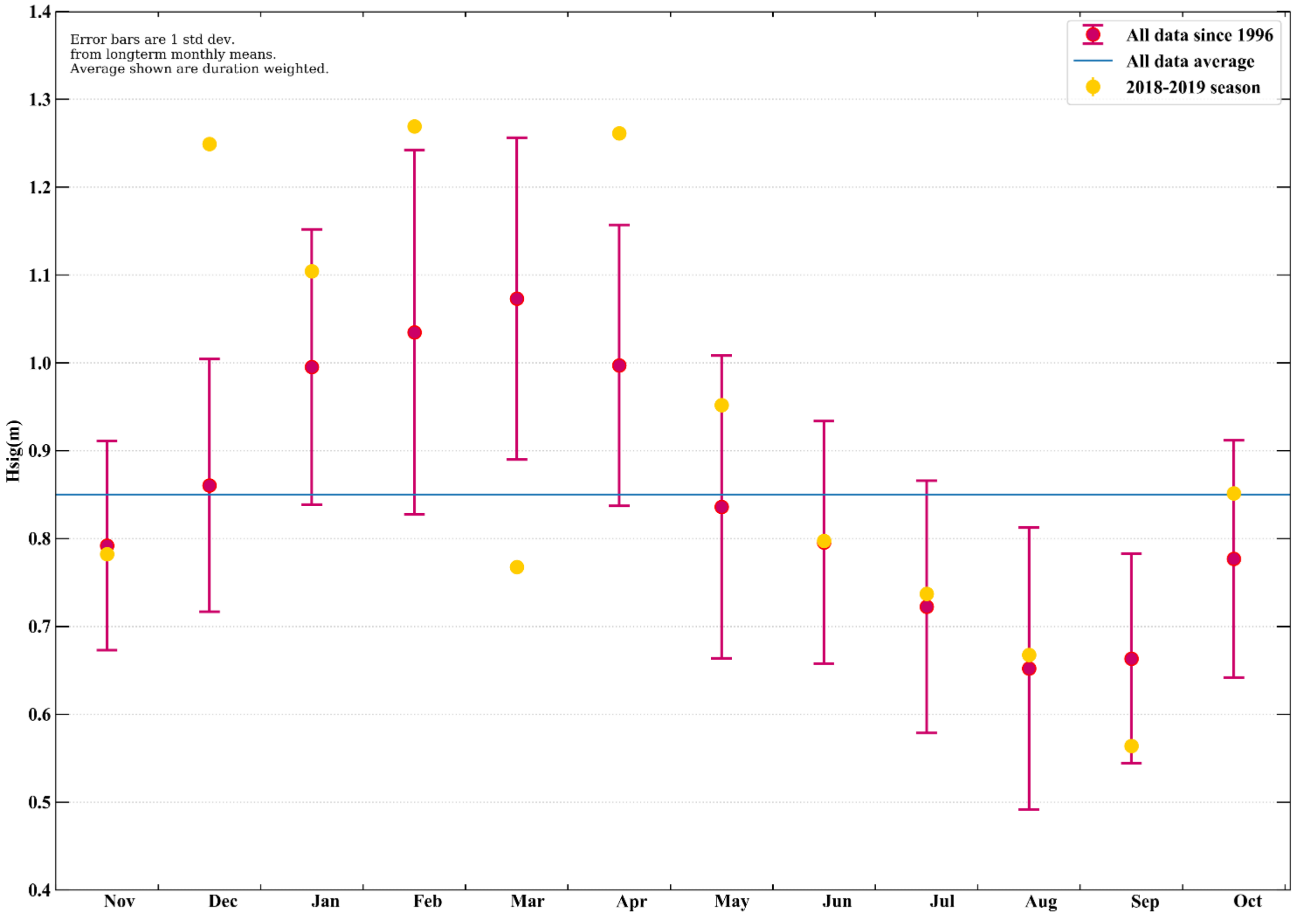


Figure 86 Emu Park – Monthly average wave height (H_s) for seasonal year and for all data

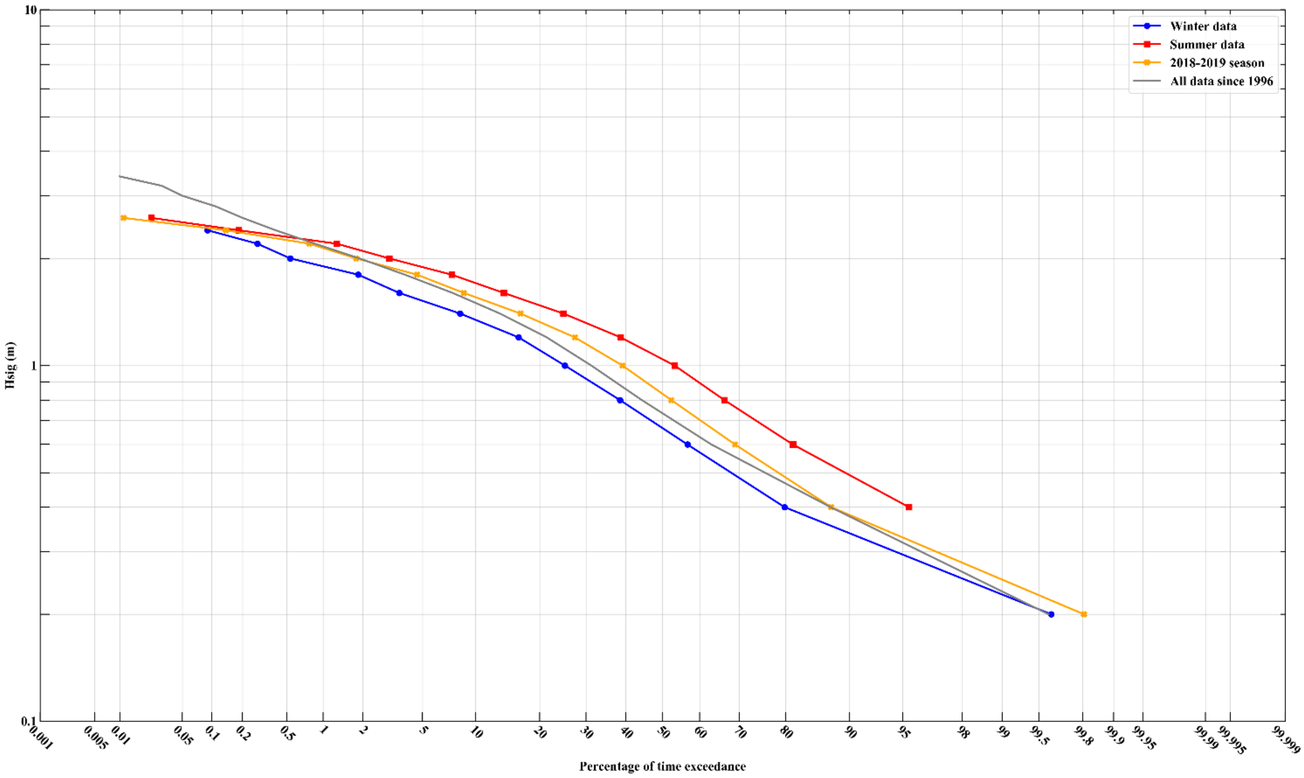


Figure 87 Emu Park – Percentage exceedance of wave height (H_s) for all wave periods (T_p)

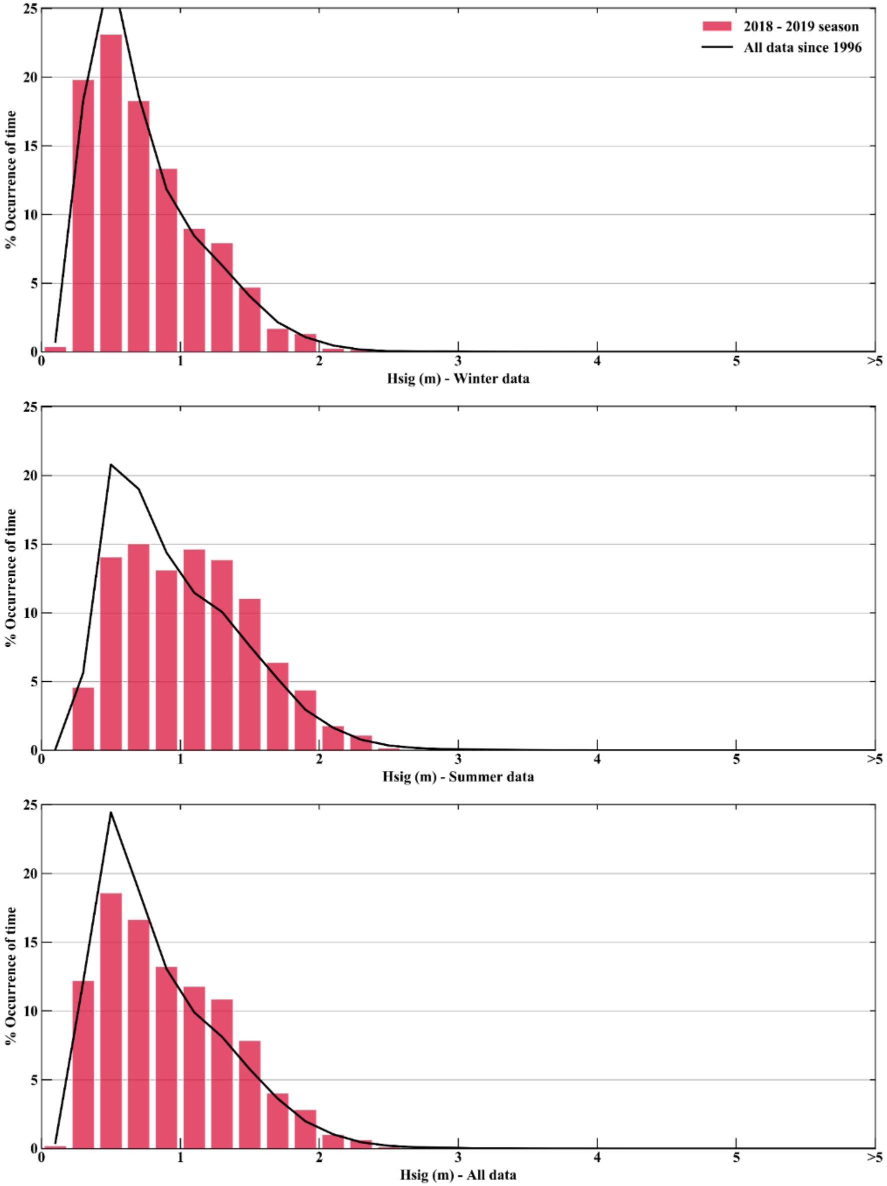


Figure 88 Emu Park – Histogram percentage (of time) occurrence of wave heights (H_s)

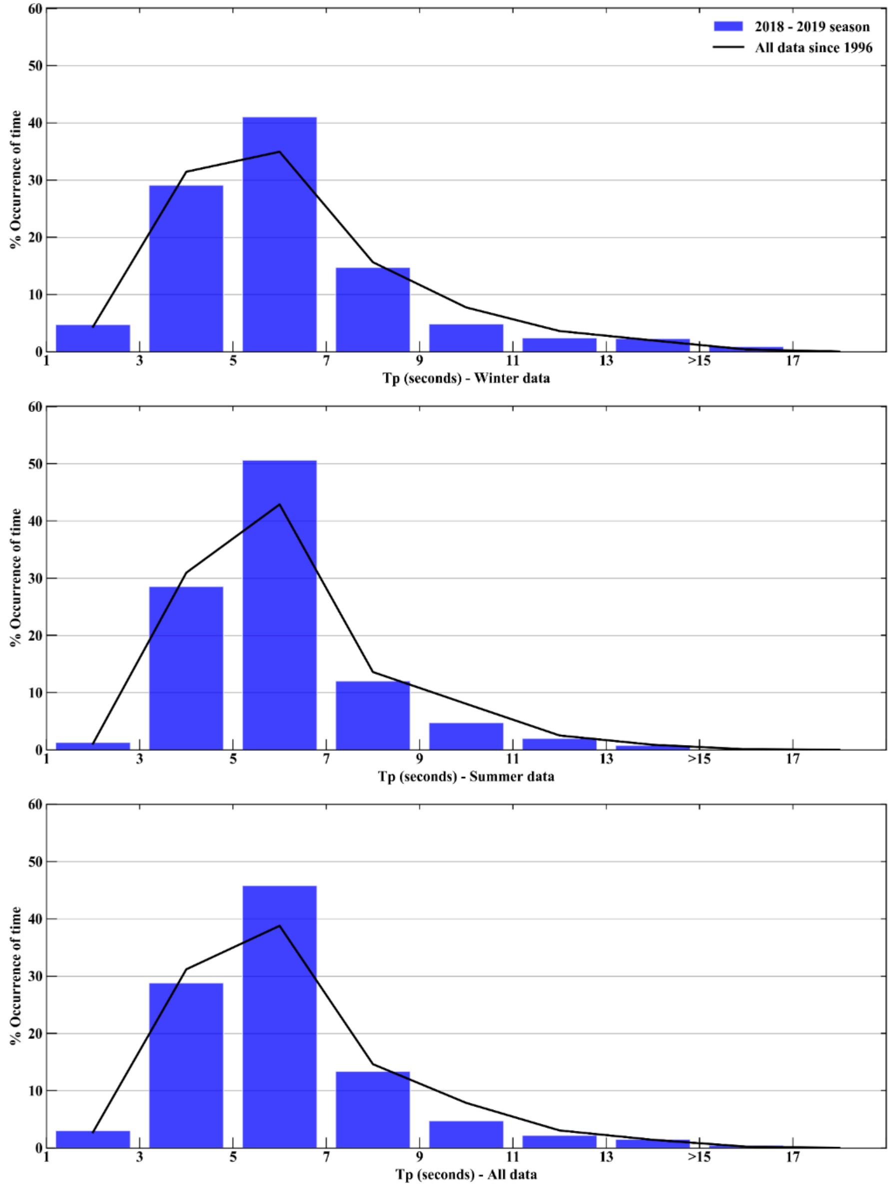


Figure 89 Emu Park – Histogram percentage (of time) occurrence of wave periods (T_p)

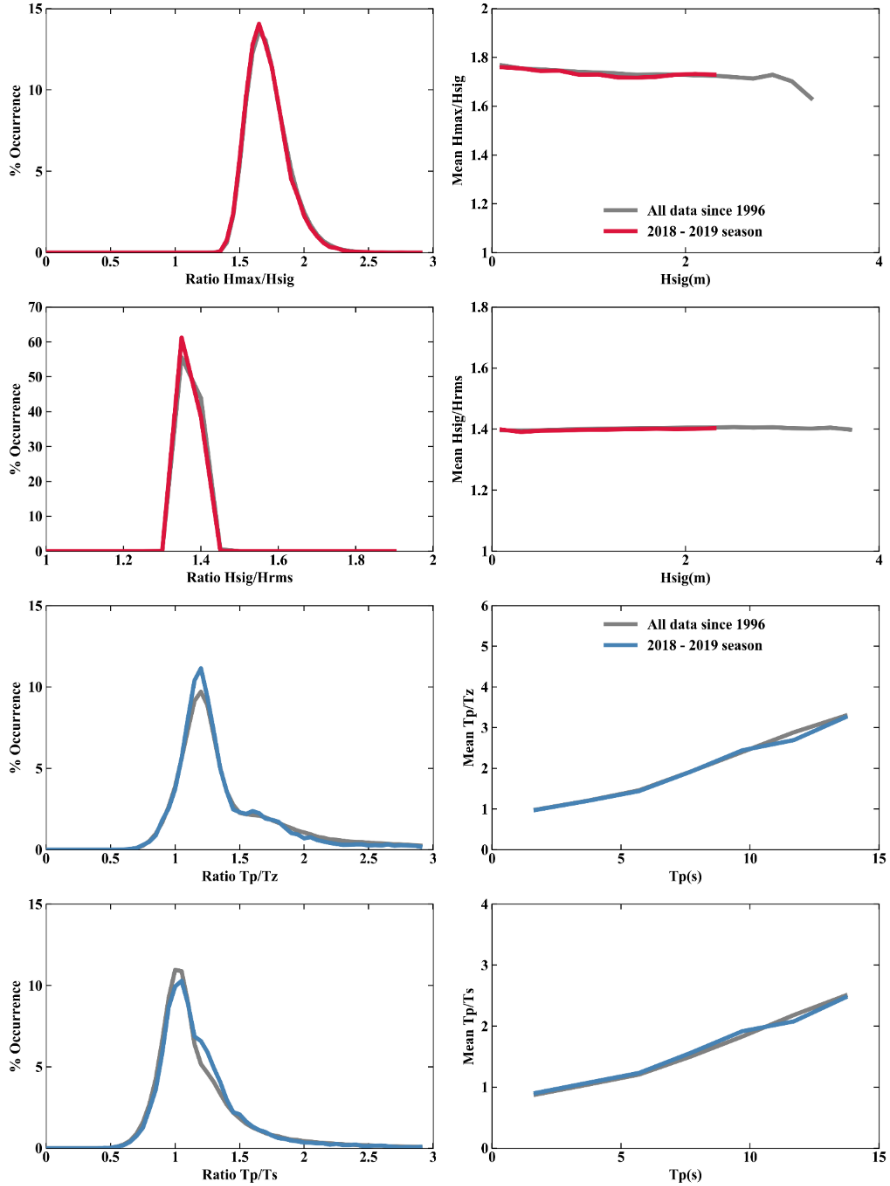


Figure 90 Emu Park – Wave parameter relationships

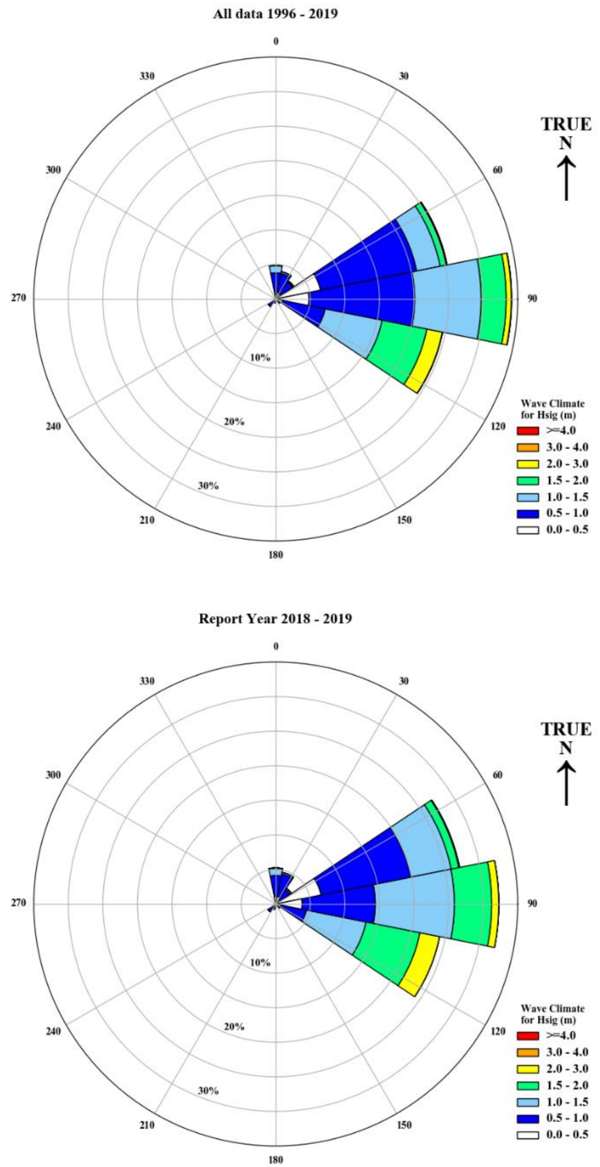


Figure 91 Emu Park – Directional wave rose

Hay Point

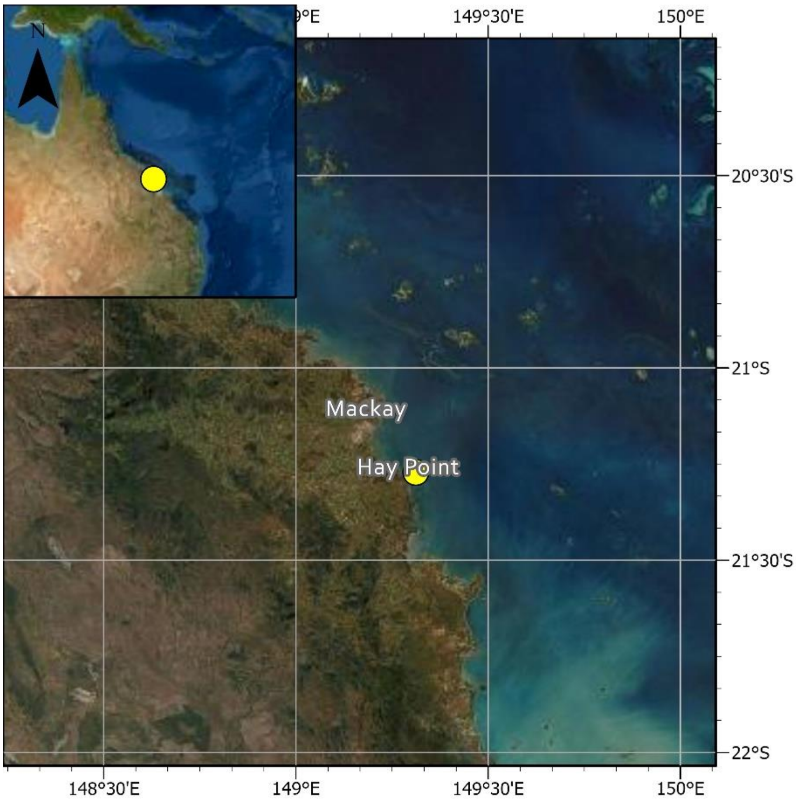


Figure 92 Hay Point – Locality plan

Table 45 Hay Point – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
2008–19*	28/08/2008*	0.9 years	443,483	42.6
2018–19	01/11/2018	5.5 days	17,256	1

*See

Table 2 for site commission date.

Table 46 Hay Point – Buoy deployments for the 2018–19 season

Latitude	Longitude	Type buoy	Depth (m)	Deployed date	Removal date
21° 16.332’ S	149° 18.696’ E	DWR-GPS	8.8	30/1/2018	14/11/2018
21° 16.317’ S	149° 18.689’ E	DWR-GPS	9	14/11/2018	current

Hay Point – seasonal overview

The Hay Point wave buoy has been operational for almost 43 years. The data record for the period of November 2018 to October 2019 was good, with total gaps of 5.5 days, equivalent to 98.4 per cent data return (Table 45). The buoy was replaced once during the reporting period on 14 November 14 (*See

Table 2 for site commission date.

Table 46 for current period).

During the reporting period there were three significant weather events that impacted the Hay Point buoy. Only one of these events, TC Owen, had sufficient significant wave height H_s to appear in the highest waves (Table 47), with a 2.5 m H_s.

The Daily wave recordings for hay Point (Figure 93) shows this site experienced numerous H_{max} events exceeding 3 metres. Brief events producing longer peak wave periods are also visible throughout the monitoring period.

SST ranged from 19 °C to 31.5 °C (Figure 94) and was considered to exceed the threshold temperature of 26 °C and therefore be high enough for tropical cyclone development from the start of the record, 01 November through to mid-April, and again mid-October to the end of the record. A spike to below −5 °C at the end of September can be seen and is due to a sensor malfunction.

The monthly average H_s predominantly fell within one standard deviation (sd) of the long-term mean, with two months above one sd, December and April, and two months below one sd March and September (Figure 95).

Percentage of time exceedance of H_s (Figure 96) shows larger waves occurring throughout summer in comparison to winter. The overall wave climate during the reporting period was comparable to the wave climate of the whole record; however, summer appears to be slightly below average for waves >2 metres. The histogram of the occurrence of H_s (Figure 97) shows waves between 0.2–0.8 m occurring lower than average during summer, and 0.2 to 0.4 m H_s waves having the most frequent occurrence overall. Histograms for peak wave period for 2018–19 follows the data trends closely with 3 to 5 second wave periods T_p occurring most frequently (Figure 98).

The ratios between different wave parameters such as H_{max}/ H_s and H_s /H_{rms} were consistent between this reporting period and all of the historic data (Figure 99). The ratio T_p/T_z has increased slightly T_p/T_s has slightly decreased compared to the historic data.

Peak wave direction (Figure 94) for the 2018–19 period was predominately from the east to east-south-east, with occasional swings to the north and south-west. Directional wave rose plots (Figure 100) show a dominant incident wave from the east to east-south-east. Wave directions for the reporting period are very similar to the entire record.

Table 47 Hay Point – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	21/03/2010 01:30	4	30/01/2014 22:00	7
2	30/01/2014 22:00	3.7	10/03/1997 10:00	6.8
3	28/03/2017 11:00	3.6	28/03/2017 09:00	6.6
4	09/03/1997 20:00	3.1	21/03/2010 04:30	6.3
5	31/01/2010 07:30	2.8	24/02/1996 02:00	5.6
6	16/02/2008 17:30	2.8	03/04/2018 23:00	5.6
7	03/04/2018 23:30	2.7	17/02/2008 21:00	5.4
8	01/02/1978 03:00	2.6	10/02/1999 18:00	5.3
9	08/12/2018 23:00	2.5	07/01/2017 05:30	5.3
10	29/08/1998 18:00	2.5	19/01/2004 18:00	5

Table 48 Hay Point – Significant meteorological events with threshold H_s of 2.0 metres

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
08/12/2018 11:00 Peak Event	2.5	4.3	6.9	TC Owen weakened to a tropical low on the 4th that would later move west across the Qld coast and reform before entering NT
24/12/2018 09:30	2	3.6	6.2	Series of lows moving east past the coast to the sea
06/02/2019 21:00	2.4	4.1	6.8	Low pressure systems near Vanuatu that would later form TC Oma

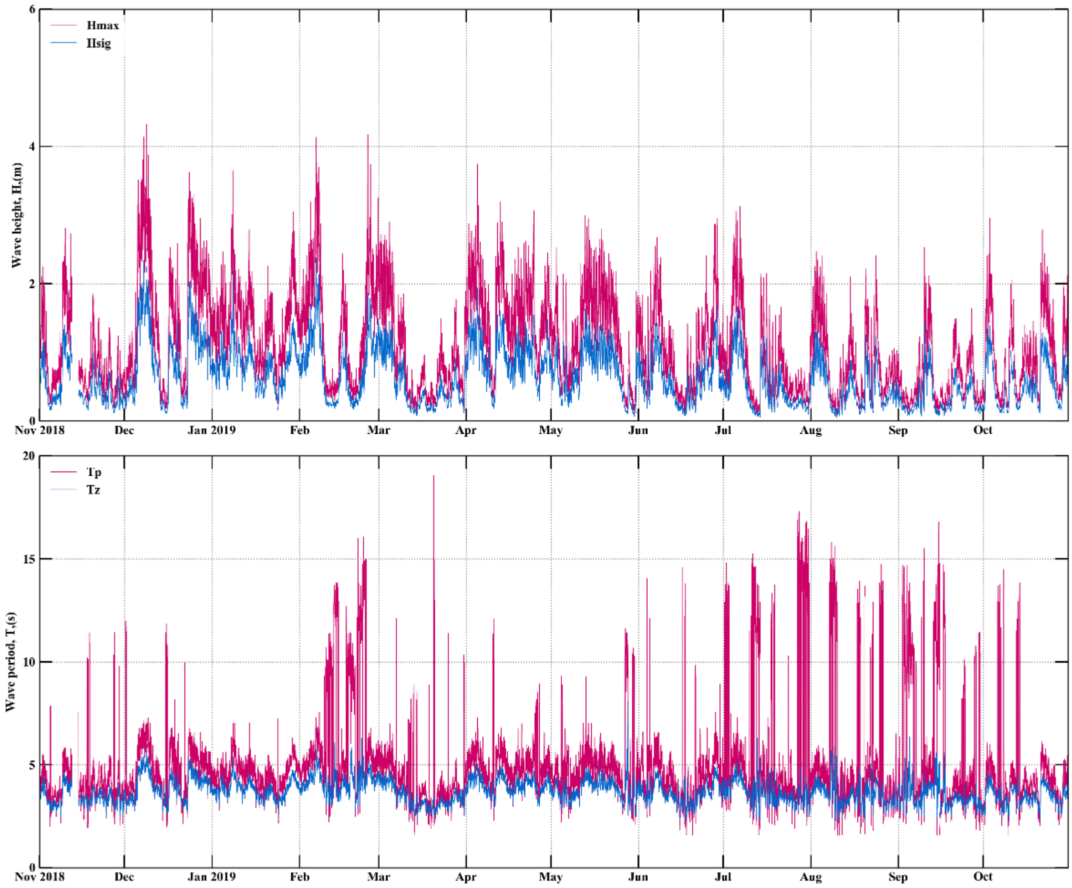


Figure 93 Hay Point – Daily wave recordings

Figure 94 Hay Point – Peak wave directions and sea surface temperature

Figure 95 Hay Point – Monthly average wave height (H_s) for seasonal year and for all data

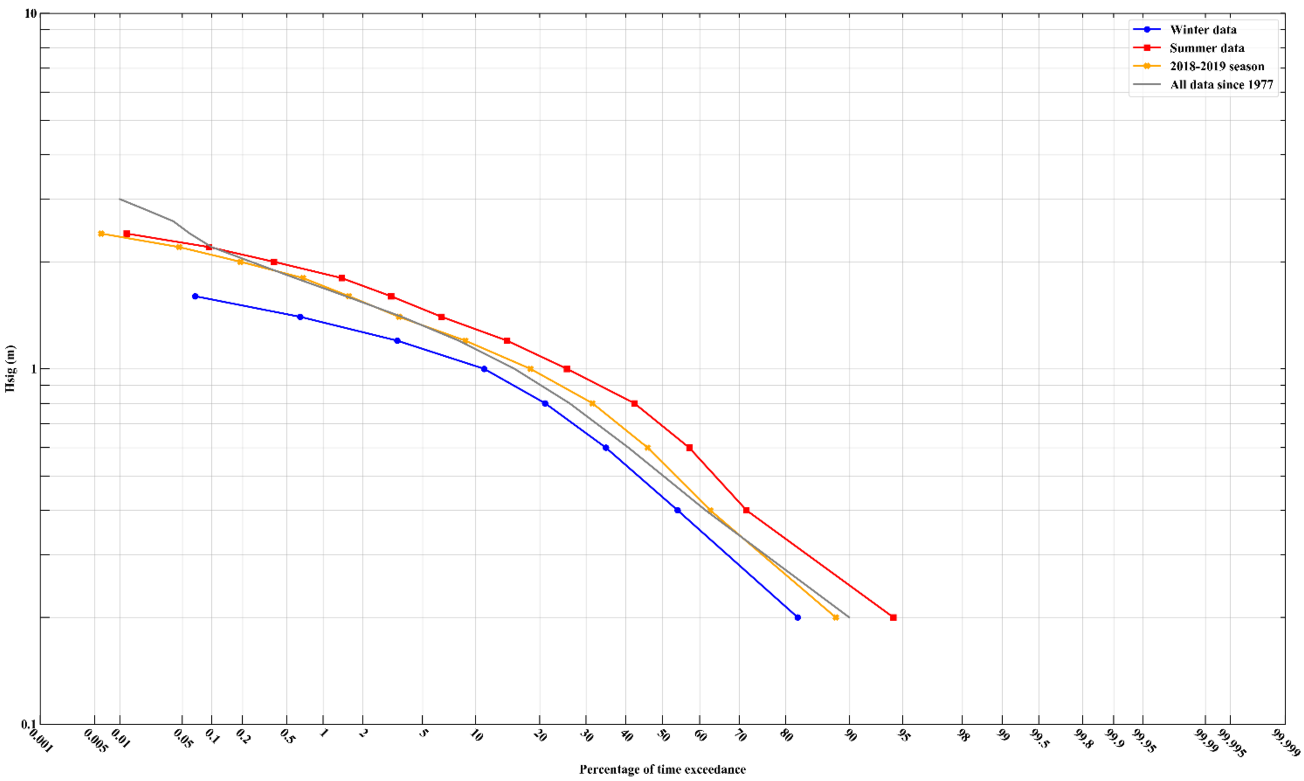


Figure 96 Hay Point – Percentage exceedance of wave height (H_s) for all wave periods (T_p)

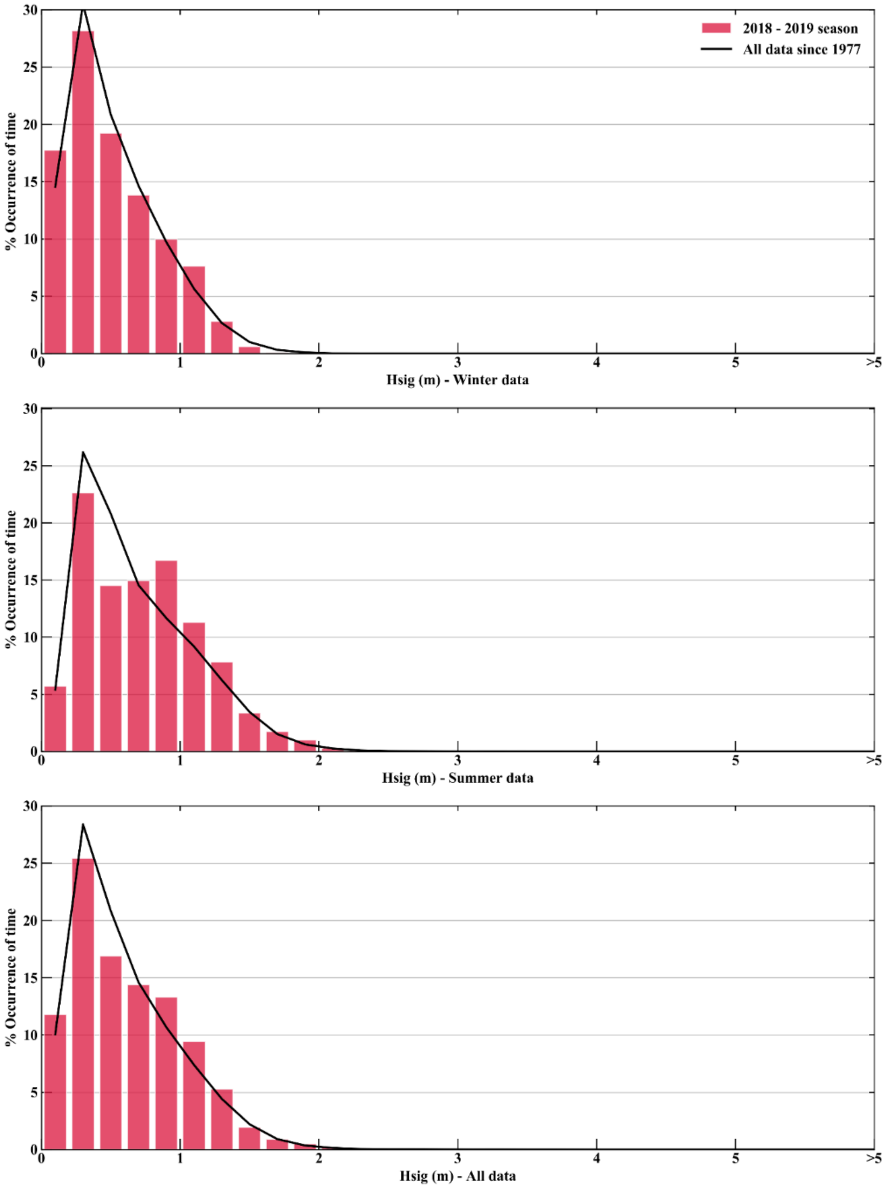


Figure 97 Hay Point – Histogram percentage (of time) occurrence of wave heights (H_s)

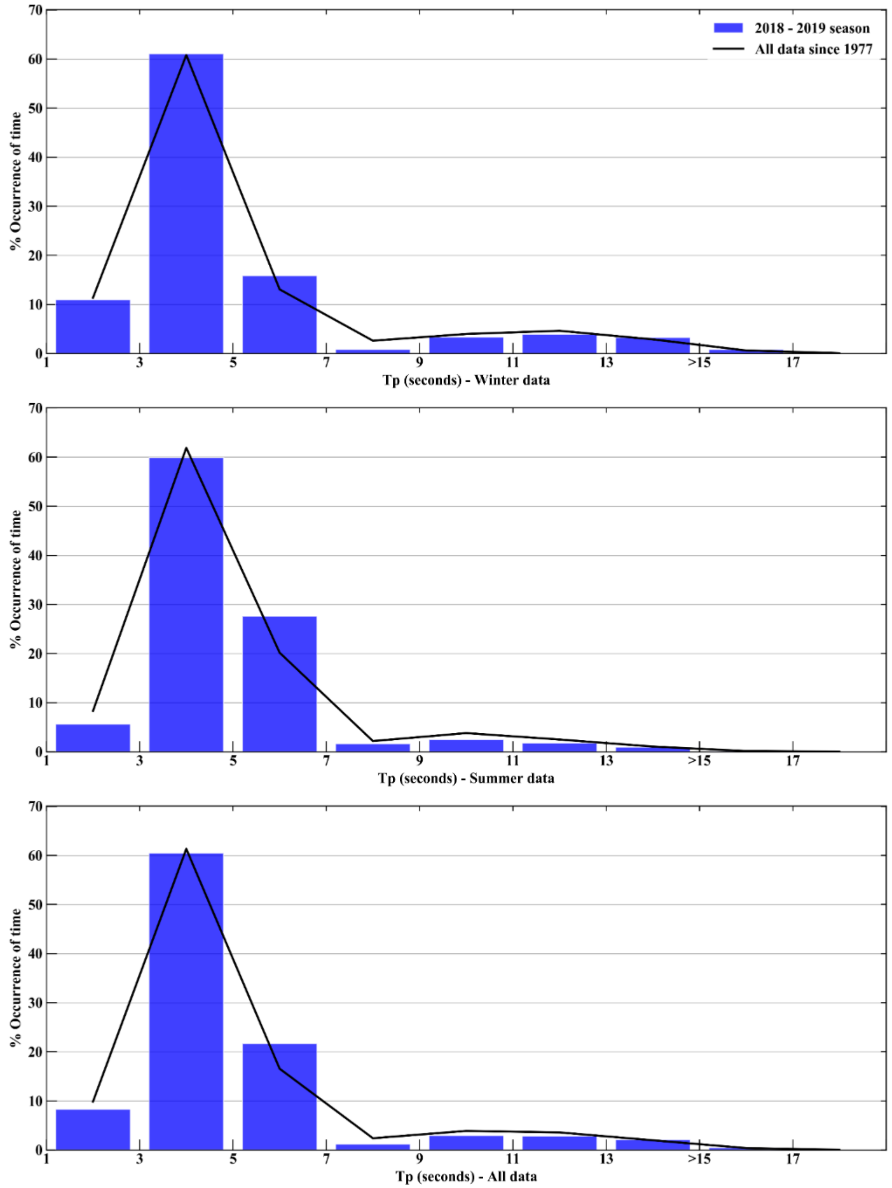


Figure 98 Hay Point – Histogram percentage (of time) occurrence of wave periods (T_p)

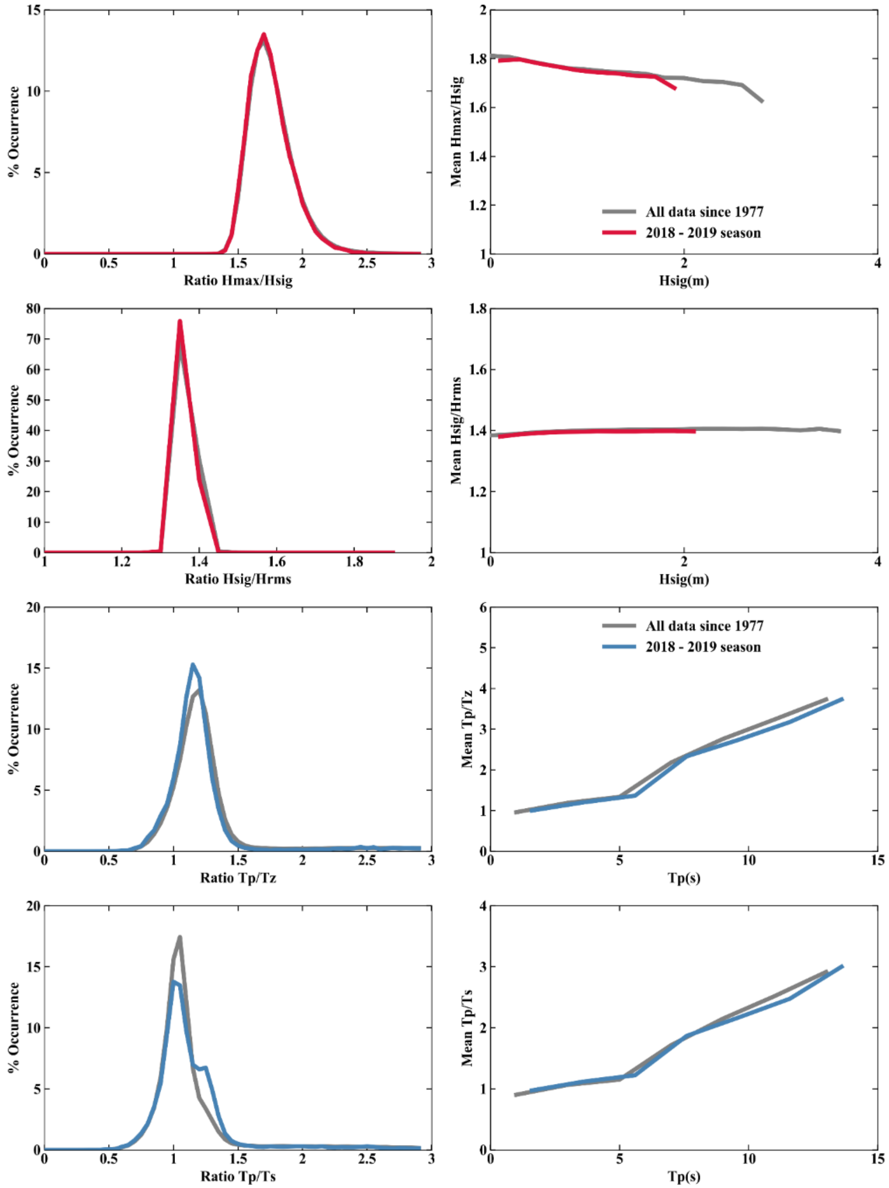


Figure 99 Hay Point – Wave parameter relationships

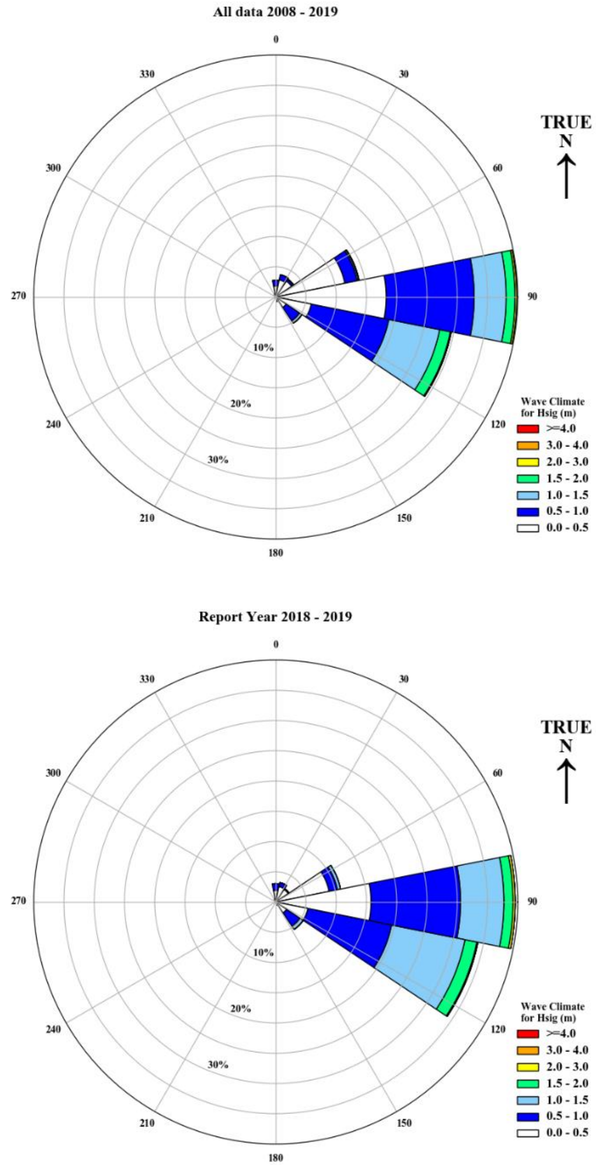


Figure 100 Hay Point – Directional wave rose

Mackay

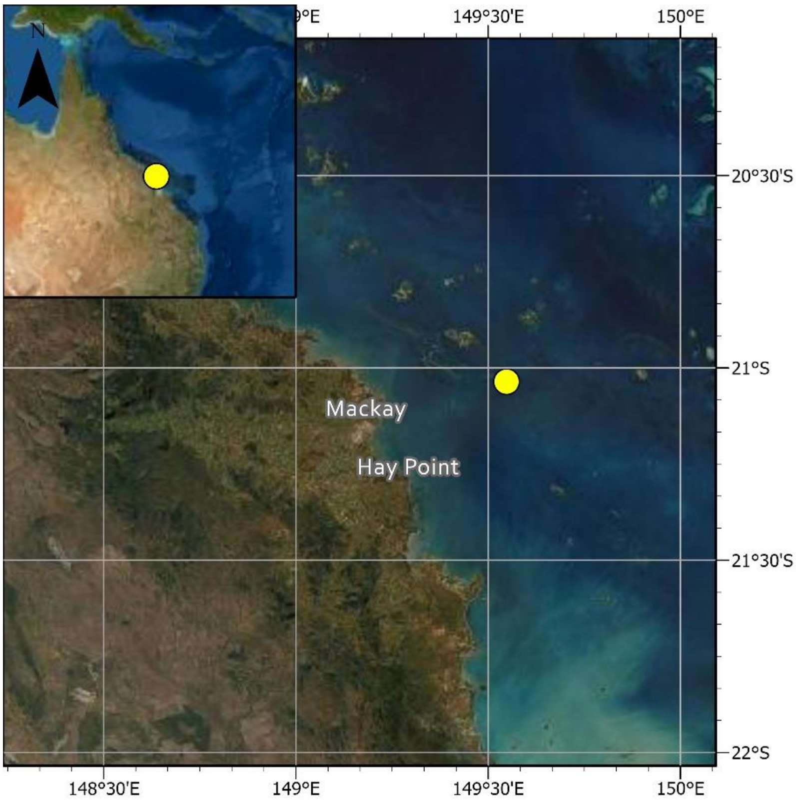


Figure 101 Mackay – Locality plan

Table 49 Mackay – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	19/09/1975	13.81 years	362,023	44.12
2018–19	01/11/2018	9.67 (days)	17,056	1

Table 50 Mackay – Buoy deployments during the 2018-19 season

Latitude	Longitude	Type buoy	Depth (m)	Deployed date	Removal date
21° 02.240’ S	149° 32.802’ E	Mk4	34	26/04/2017	18/11/2018
21° 02.168’ S	149° 32.853’ E	Mk4	32.8	18/11/2018	current

Mackay – seasonal overview

The Mackay wave buoy has been operational for just over 44 years. The data record for the period from November 2018 to October 2019 was excellent, with total gaps of 9.67 days, equivalent to 97.35 per cent data return (Table 49). The wave buoy was replaced during the reporting on 18 November Table 50).

In total five significant events happened during the reporting period (Table 52), the largest of which was related to TC Oma. Two of these events were significant enough to take positions on the top 10 highest waves (Table 51) for this monitoring site. These events ranked as the seventh and ninth highest waves for $H_{s,}$ 4.0 m and 3.9 m respectively.

Daily wave recordings for the Mackay monitoring site (Figure 102) shows there were numerous meteorological events throughout the monitoring period with H_S over 2 m and H_{max} over 4 metres.

The SST ranged from 21 °C to 30 °C (Figure 103). The SST was high enough for tropical cyclone formation from November to May. There are spikes which indicate rapid heating and cooling events occurred from September to the end of the record with an anomaly in October indicated by a spike to 27.5 degrees Celsius.

Monthly average H_s (Figure 104) was higher than one standard deviation (sd) for five months: December, January, February, April and May. And below for March of the recording period.

Percentage exceedance of H_s (Figure 105) shows a slightly higher wave climate between the reporting period and historic data. Overall wave heights were consistently lower in winter than in summer for the 2018–19 period. Histograms for percentage occurrence of H_s (Figure 106) show a shift away from the trend during summer months with a significant increase in occurrence of higher waves with the most frequent 0.4 to 0.6 m followed closely by 1.2 to 1.4 m H_s. This is also seen in the all-data histogram with the most frequently occurring wave being from 0.4 to 0.6 m H_s. Peak weave period (T_p) histograms (Figure 107) show similar distributions between the reporting period and the entire record though with higher occurrence of 5 to 7 second T_p to the trend.

The ratios between different wave parameters were consistent between this reporting period and all of the historic data (Figure 108) with some skewing due to the shift towards higher waves and more frequent occurrence of T_p.

Peak wave direction was predominately from the east south-east (Figure 103) with some swings to the north and south. Directional wave rose plots (Figure 109) also show the dominant east-south-east wave direction for the reporting period observed in the time series and very similar to the entire record.

Table 51 Mackay – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	20/03/2010 22:30	5.7	30/01/2014 19:30	10
2	30/01/2014 19:30	5	21/03/2010 00:00	9.4
3	28/03/2017 05:00	5	28/03/2017 04:30	8.7
4	10/03/1997 00:00	4.8	09/03/1997 11:00	8.5
5	04/04/2018 02:00	4.1	04/04/2018 14:30	8.2
6	01/03/1979 03:00	4	06/02/2019 22:00	8
7	6/02/2019 22:00	4	08/03/2009 17:00	7.7
8	27/12/1990 03:41	3.9	19/01/2004 19:30	7.5
9	09/12/2018 01:00	3.9	04/03/2002 15:00	7.3
10	05/06/2002 00:00	3.8	06/02/2015 21:00	7.3

Table 52 Mackay – Significant meteorological events with threshold H_s of 2.8 metres

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
09/12/2018 01:00	3.9	7.1	9.4	EX-TC Owen was sitting in the Coral Sea
24/12/2018 08:30	3.1	6.2	7.9	Low Pressure system EX-TC Penny was in the coral sea
08/01/2019 09:30	3.4	6.4	8.2	A broad surface trough extended across Australia from the west coast to southeast QLD connecting to a low in the Tasman Sea. A high pressure located in the Bight
06/02/2019 10:00 Peak Event	4	8	8.2	Low pressure systems near Vanuatu that would later form TC Oma
05/07/2019 13:00	3.2	6.2	7.2	Upper-level trough developed over central Qld from the 4th which interacted with a surface trough

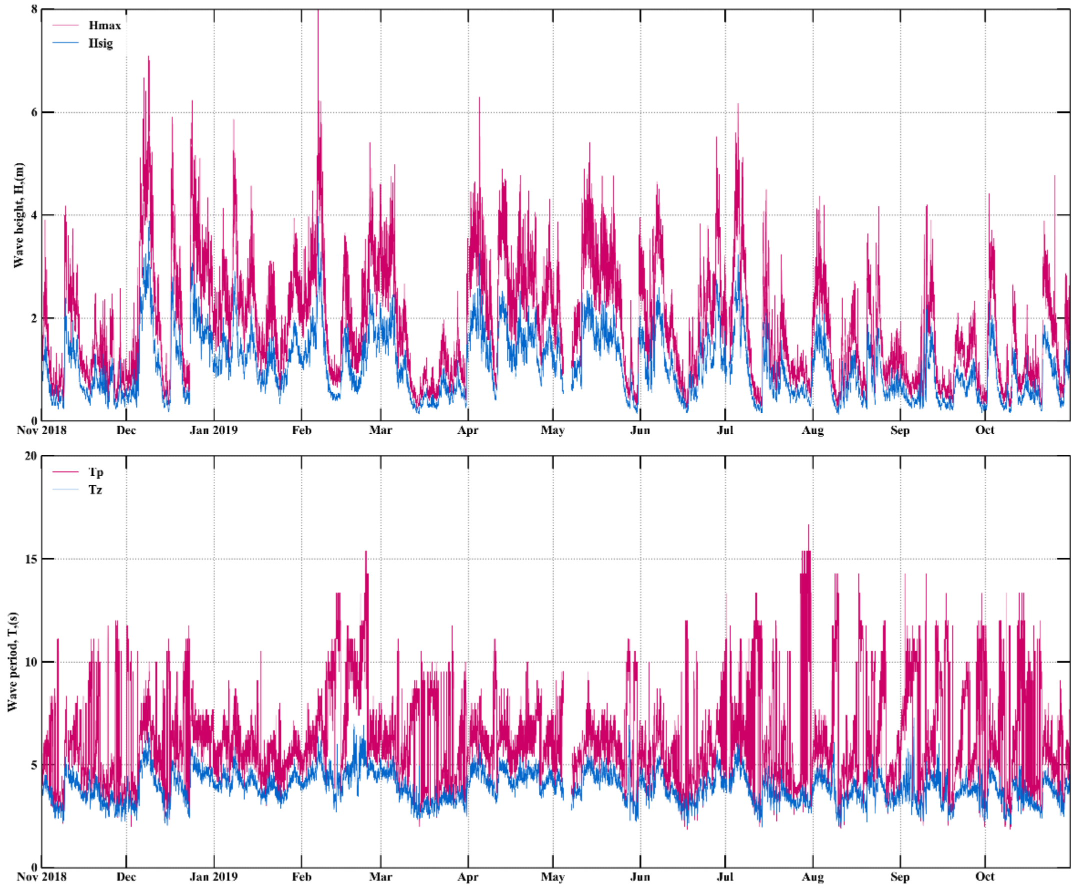


Figure 102 Mackay – Daily wave recordings

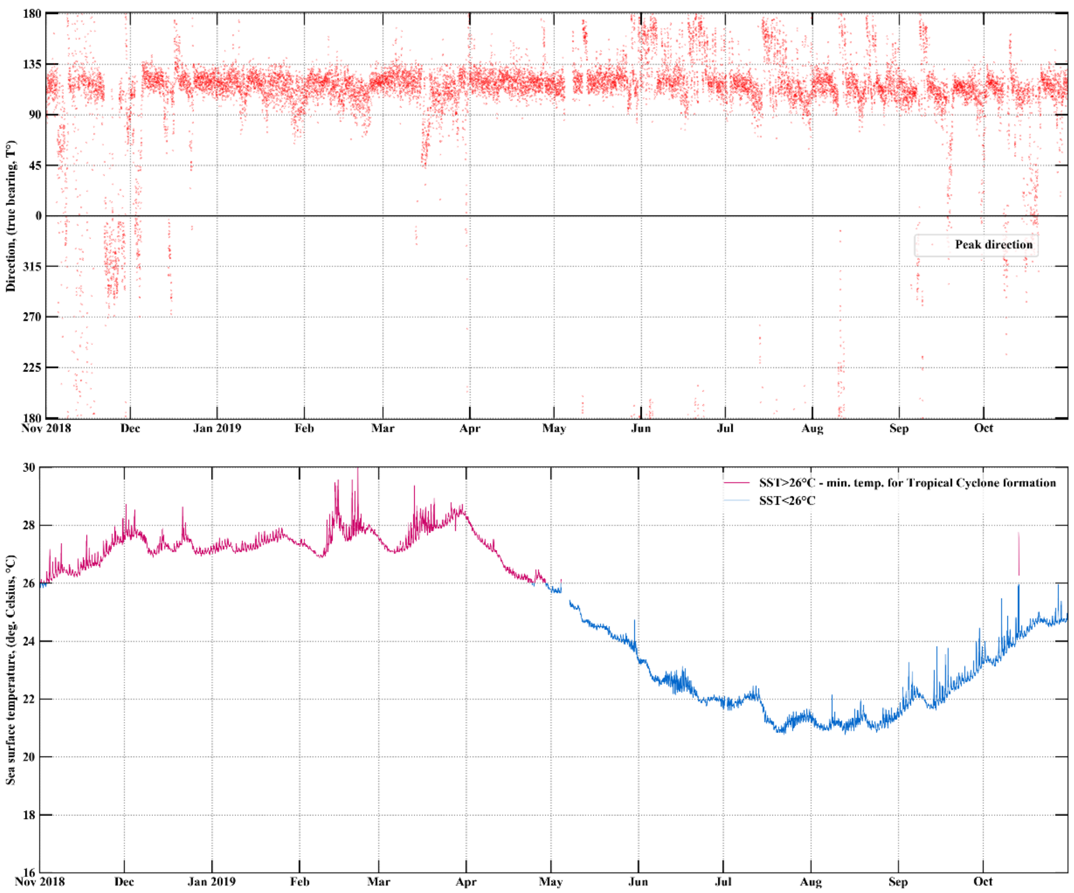


Figure 103 Mackay – Peak wave directions and sea surface temperature

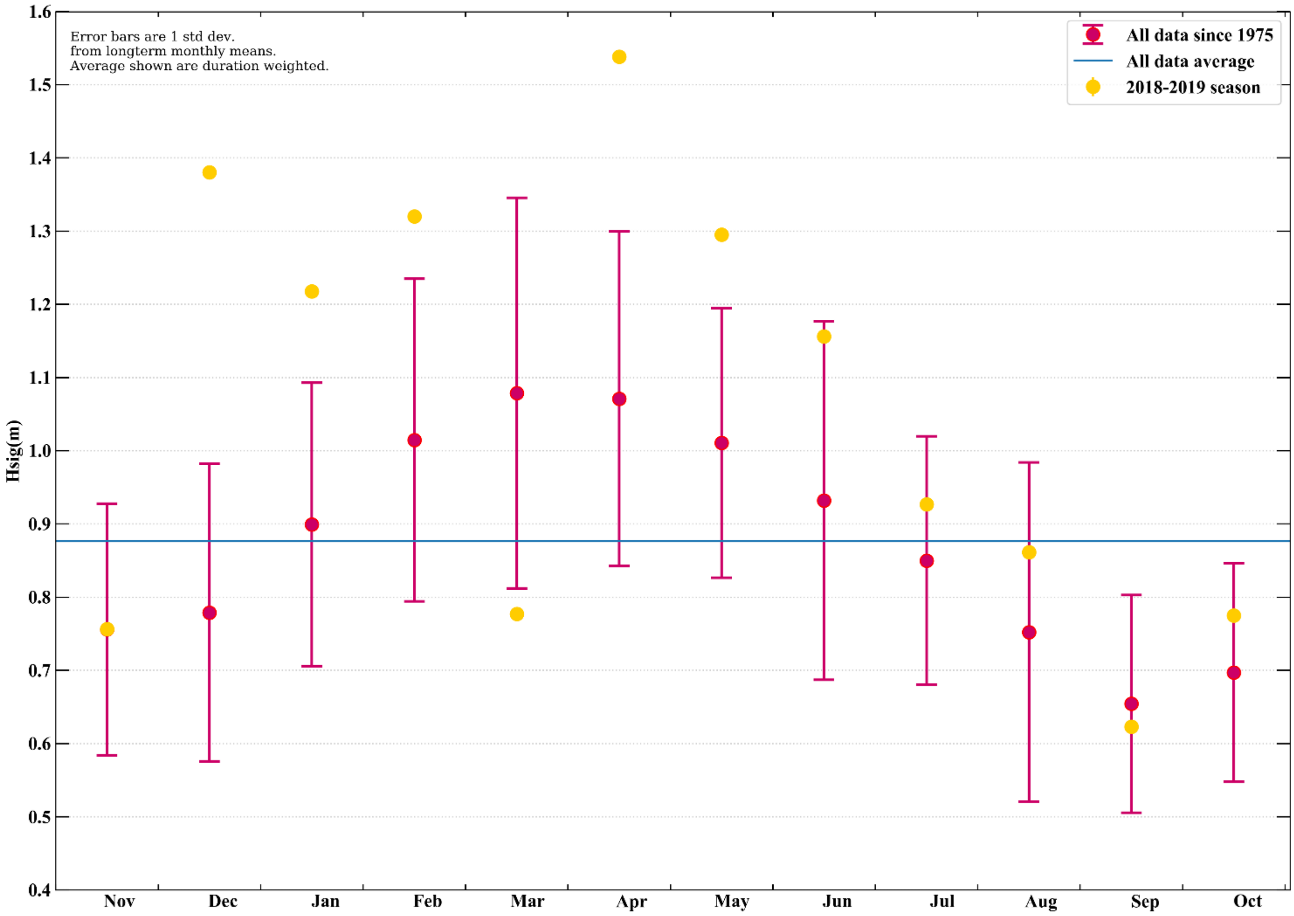


Figure 104 Mackay – Monthly average wave height (H_s) for seasonal year and for all data

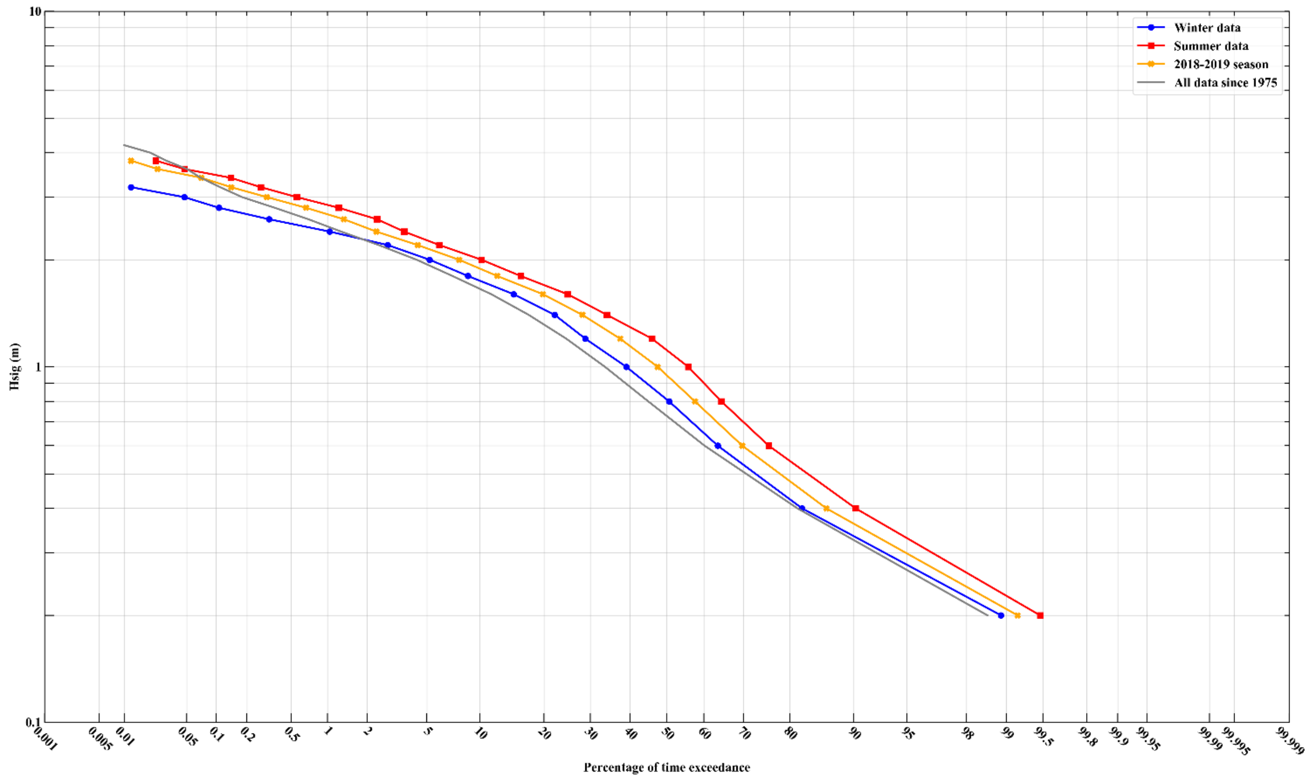


Figure 105 Mackay – Percentage exceedance of wave height (H_s) for all wave periods (T_p)

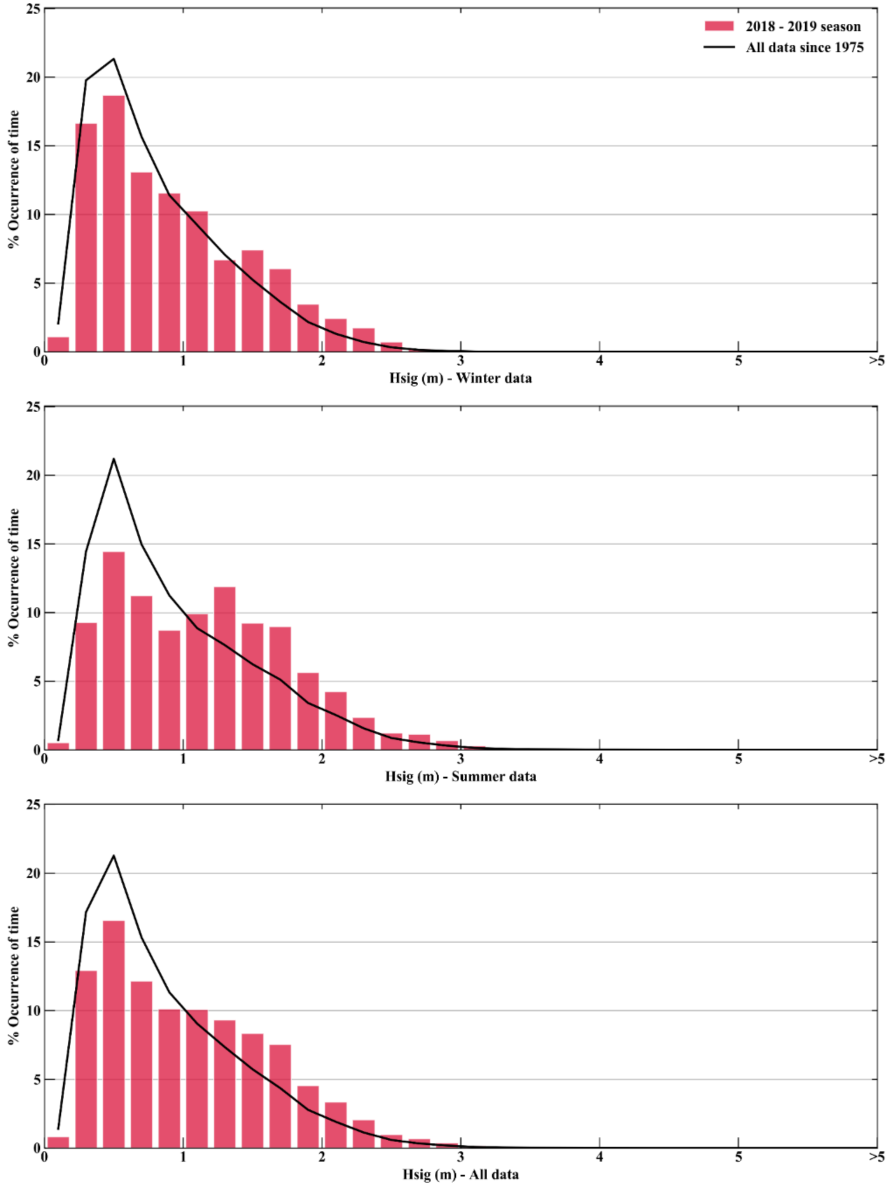


Figure 106 Mackay – Histogram percentage (of time) occurrence of wave heights (H_s)

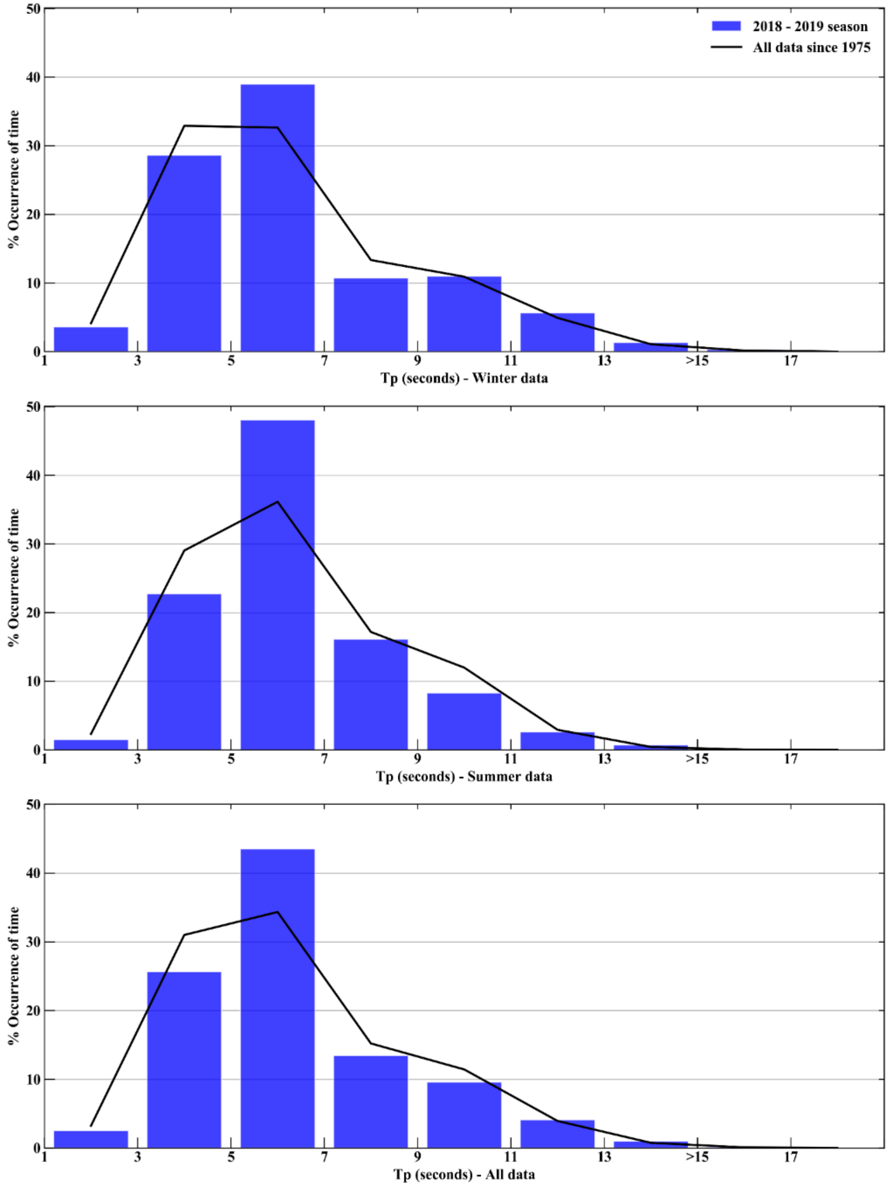


Figure 107 Mackay – Histogram percentage (of time) occurrence of wave periods (T_p)

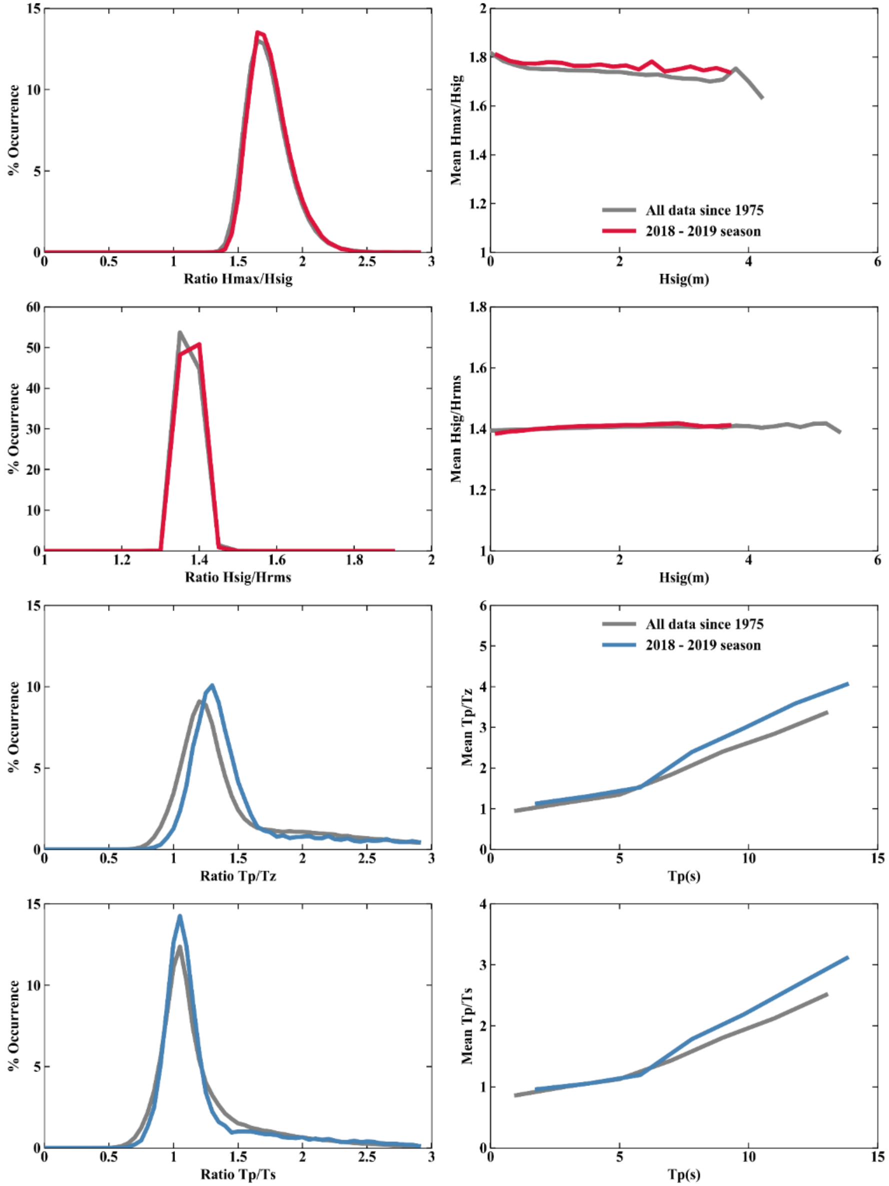


Figure 108 Mackay – Wave parameter relationships

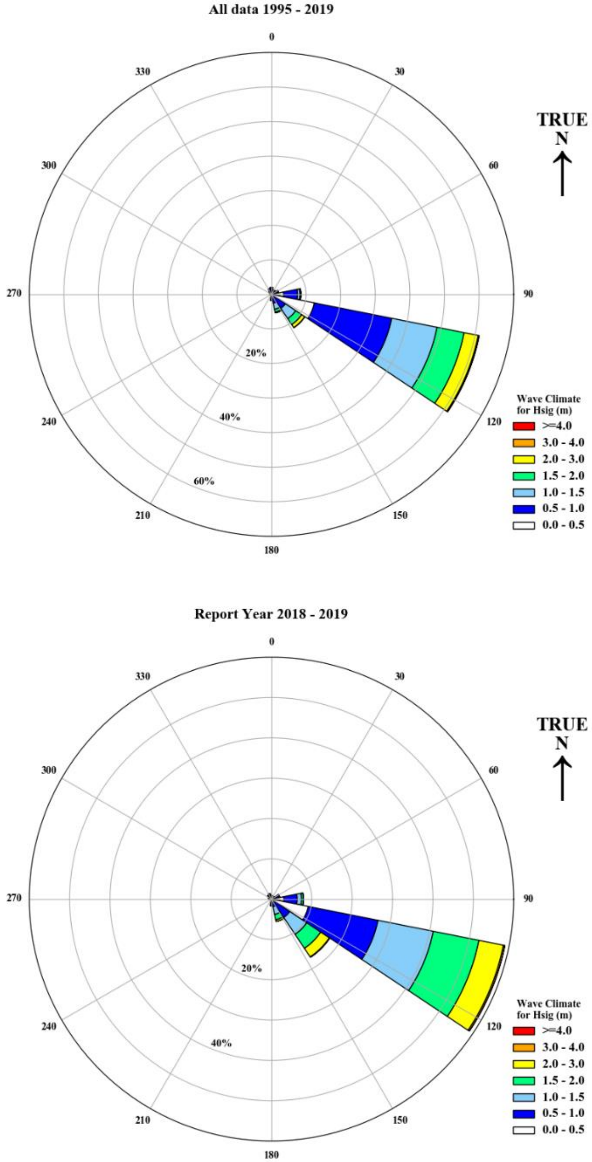


Figure 109 Mackay – Directional wave rose

Abbot Point

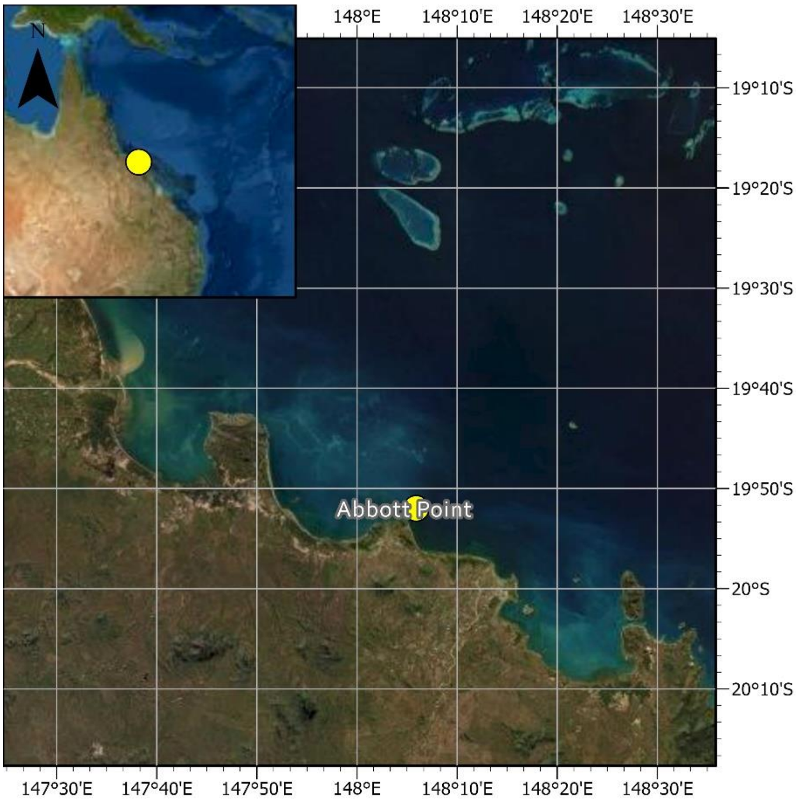


Figure 110 Abbot Point – Locality plan

Table 53 Abbot Point – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	17/01/2012	0.07 years	134,982	7.79
2018–19	01/11/2018	4.06 days	17,325	1

Table 54 Abbot Point – Buoy deployment for the 2018-19 season

Latitude	Longitude	Type buoy	Depth (m)	Deployed date	Removal date
19° 51.988' S	148° 05.916' E	DWR4	15	27/07/2018	current

Abbot Point – seasonal overview

The Abbot Point wave buoy has now been operational for over seven years. The data recorded for the period from November 2018 to October 2019 was excellent, with total gaps of 4.06 days, equivalent to 98.9 per cent data return (Table 53). The overall data return at the Abbot Point monitoring site is 95.25 per cent. The wave buoy was replaced during the previous reporting period on 27 July 2018 (Table 54).

There were six significant events reported at Abbot Point during the 2018–2019 period, 2 of which made it into the top 10 highest waves (Table 55 and Table 56). The most significant event on 01 February was due to an active monsoon seasonal trough which produced 1.9 m H_s and 3.8 m $H_{max.}$

The time series of H_s and T_p show the wave activity at Abbot point, with peaks and spikes throughout the monitoring period (Figure 111).

Sea surface temperatures SST (Figure 112) ranged from 21 °C to 31 °C and exceeded the threshold minimum temperature for tropical cyclone formation from 01 November to the first week of May, and again for a period in mid-October. There are some spikes and dips which indicate rapid temperature variations.

The monthly average H_s only fell within one standard deviation (sd) of the long term mean for four months during this reporting period. The monthly mean was higher than 1 sd of the long-term mean (Figure 113) for December, January, February, April, May, June and August. March was the only month which saw a monthly mean lower than 1 sd of the long-term data.

Percentage exceedance of H_s (Figure 114) indicate lower wave heights during winter and higher during summer with waves in 2018–19 trending higher than the average. The Histograms for H_s for the recorded period (Figure 115) show a deviation from the historical data with a lower frequency for H_s below 0.4 m compared to the entire record and a higher frequency of H_s from 0.4 to 1.4 metres. Histograms of peak wave period T_p show (Figure 116) a slight shift towards longer wave periods with a decrease in 1 to 3 second T_p and increase in 5 to 7 second $T_{p.}$ The most common wave this period was between 0.4 to 0.6 m H_s with a 3 to 5 second T_p.

The wave parameters for the recorded period are similar to the historical data with skews in T_p/T_z and T_p/T_s ratios indicating the changes mentioned above (Figure 117).

Peak wave direction (Figure 112) was predominately from the east throughout the period with some short swings to the north. Directional wave rose plots (Figure 118) corroborate the peak wave direction plot, showing a dominant easterly incident wave direction with deviations though minimal to the north for this reporting period. This is consistent with the data set over the 7+ years of operation.

Table 55 Abbot Point – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	13/04/2014 14:30	3.8	13/04/2014 14:30	6.5
2	24/01/2013 16:00	3	24/01/2013 18:30	5.5
3	28/03/2017 20:30	2.9	29/03/2017 00:00	5.4
4	1/02/2019 23:00	1.9	03/02/2019 07:30	3.8
5	21/03/2012 03:00	1.9	12/04/2013 00:00	3.6
6	12/04/2013 00:00	1.8	13/06/2016 10:30	3.6
7	24/12/2018 12:00	1.7	20/03/2012 23:00	3.4
8	08/03/2018 01:00	1.7	09/12/2018 11:30	3.3
9	02/02/2012 07:00	1.7	11/07/2012 03:30	3.3
10	12/04/2012 15:00	1.6	12/04/2012 15:00	3.3

Table 56 Abbot Point – Significant meteorological events with threshold H_s of 2.5 metres

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
09/12/2018 10:30	1.6	3.3	6.4	Low pressure systems in the Coral Sea
24/12/2018 12:00	1.7	3	6	Low Pressure troughs moving east with high pressure systems in the southeast
28/12/2018 16:00	1.4	3	5.7	Low Pressure troughs moving east with high pressure systems in the southeast
10/01/2019 07:30	1.6	2.9	5.3	Low pressure system crossing the coast
01/02/2019 11:00 Peak Event	1.9	3.8	5.6	Active Monsoon trough
3/04/2019 22:00	1.4	2.7	6	Low pressure system moving west towards the coast in the Coral Sea

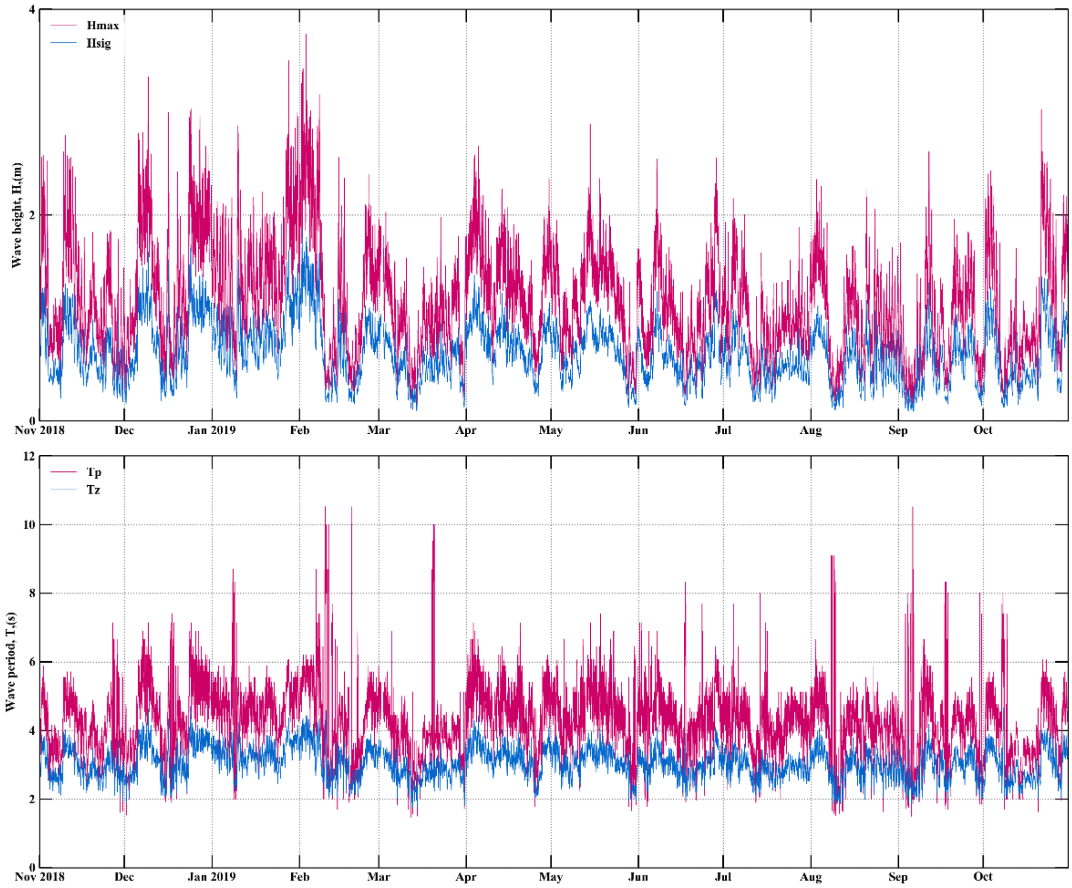


Figure 111 Abbot Point – Daily wave recordings

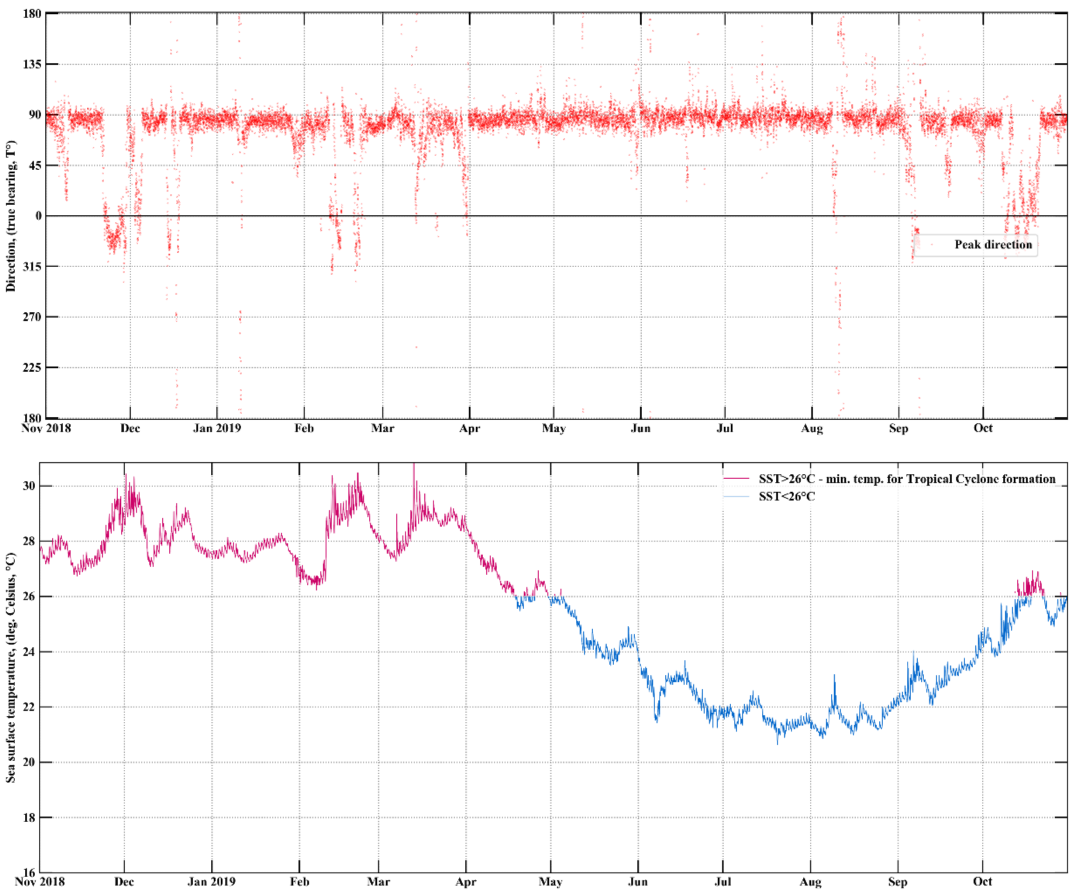


Figure 112 Abbot Point – Peak wave directions and sea surface temperature

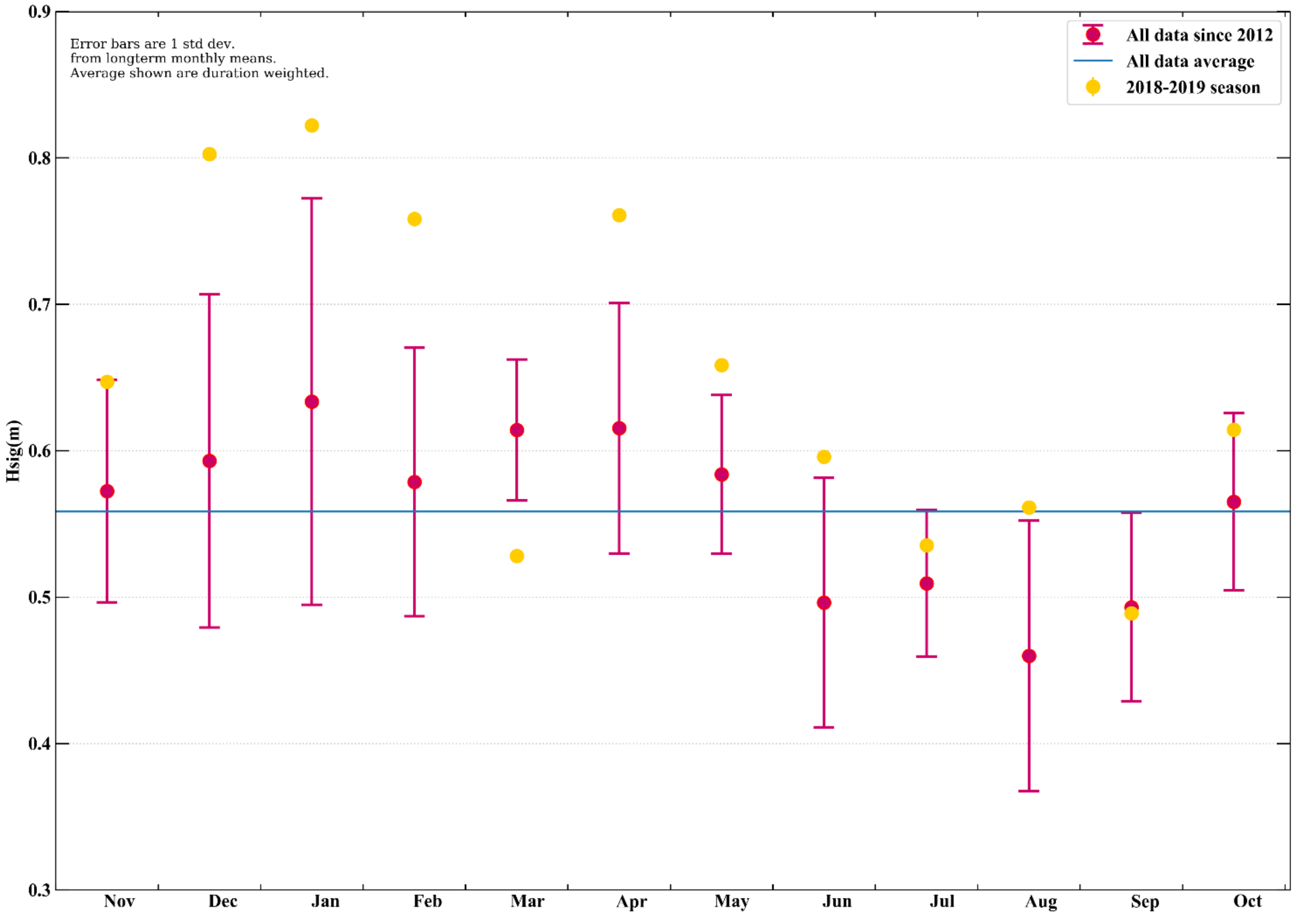


Figure 113 Abbot Point – Monthly average wave height (H_s) for seasonal year and for all data

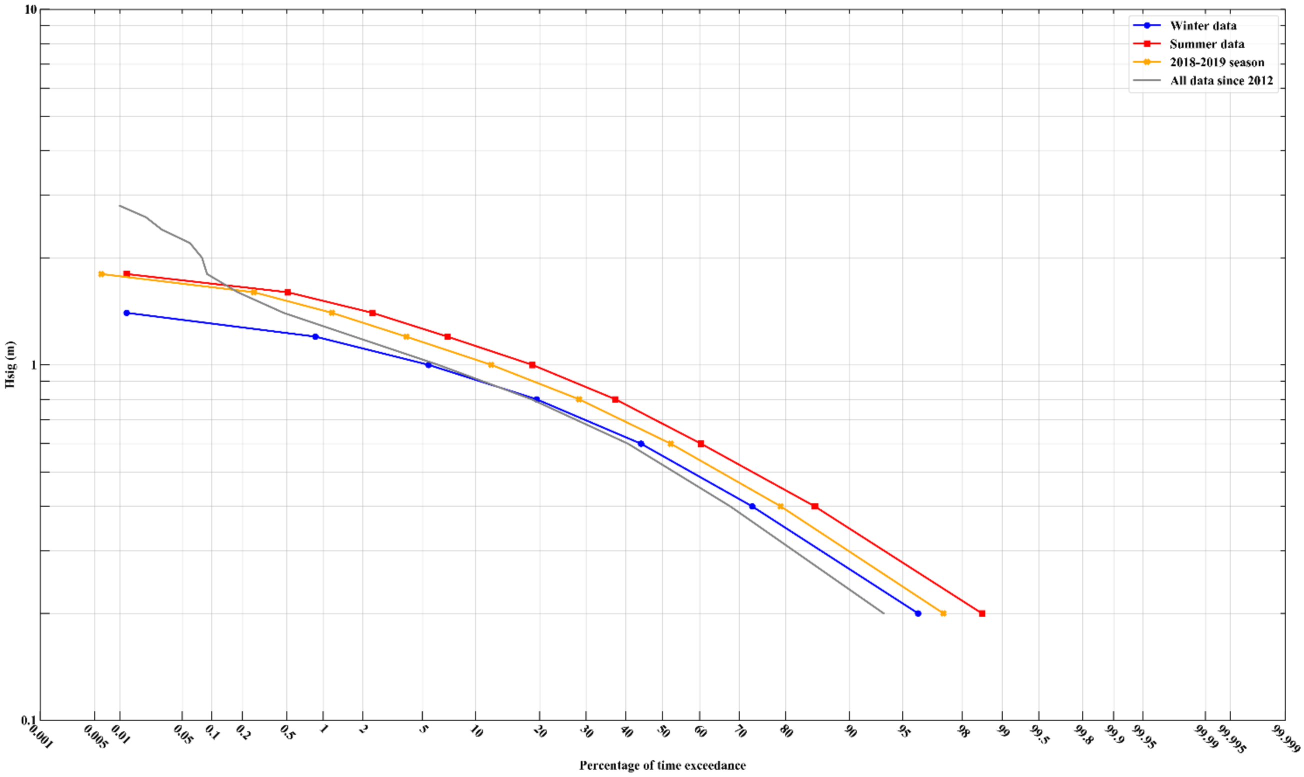


Figure 114 Abbot Point – Percentage exceedance of wave height (H_s) for all wave periods (T_p)

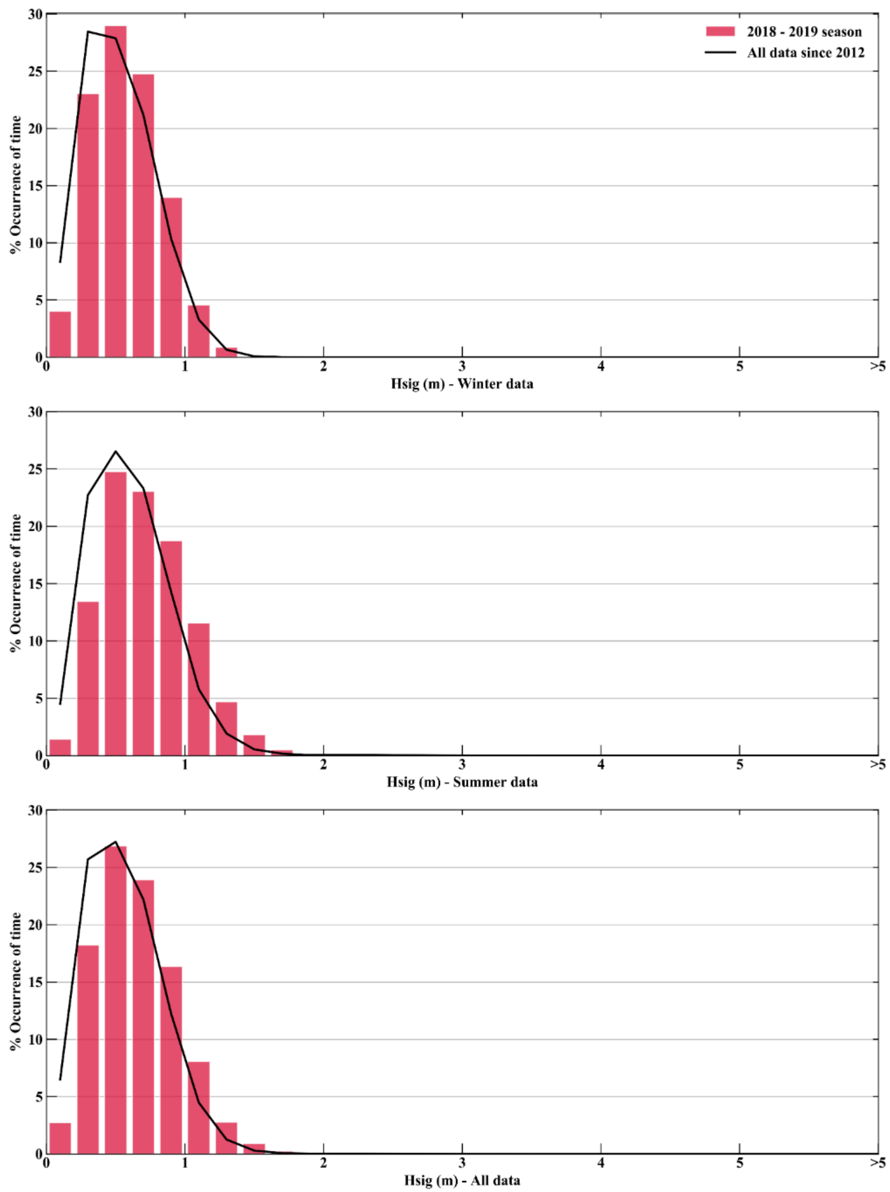


Figure 115 Abbot Point – Histogram percentage (of time) occurrence of wave heights (H_s)

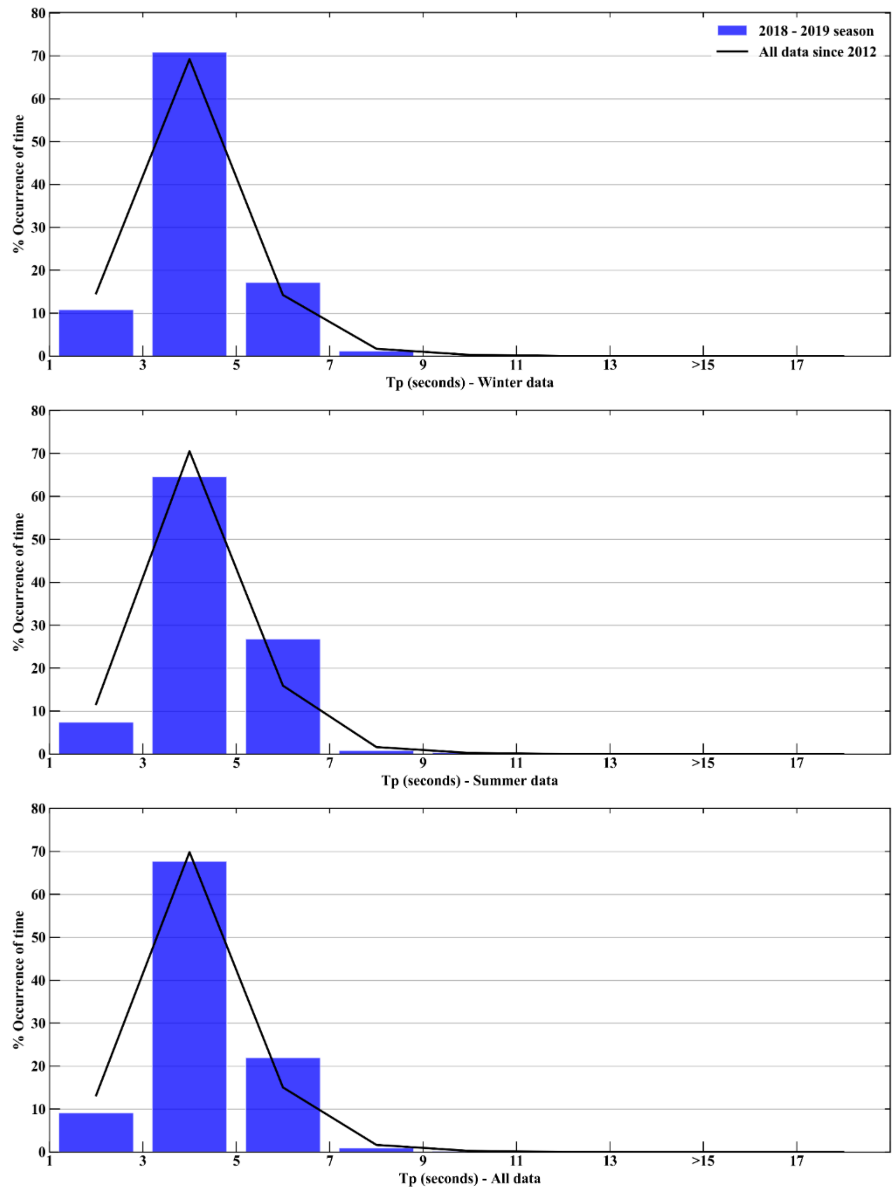
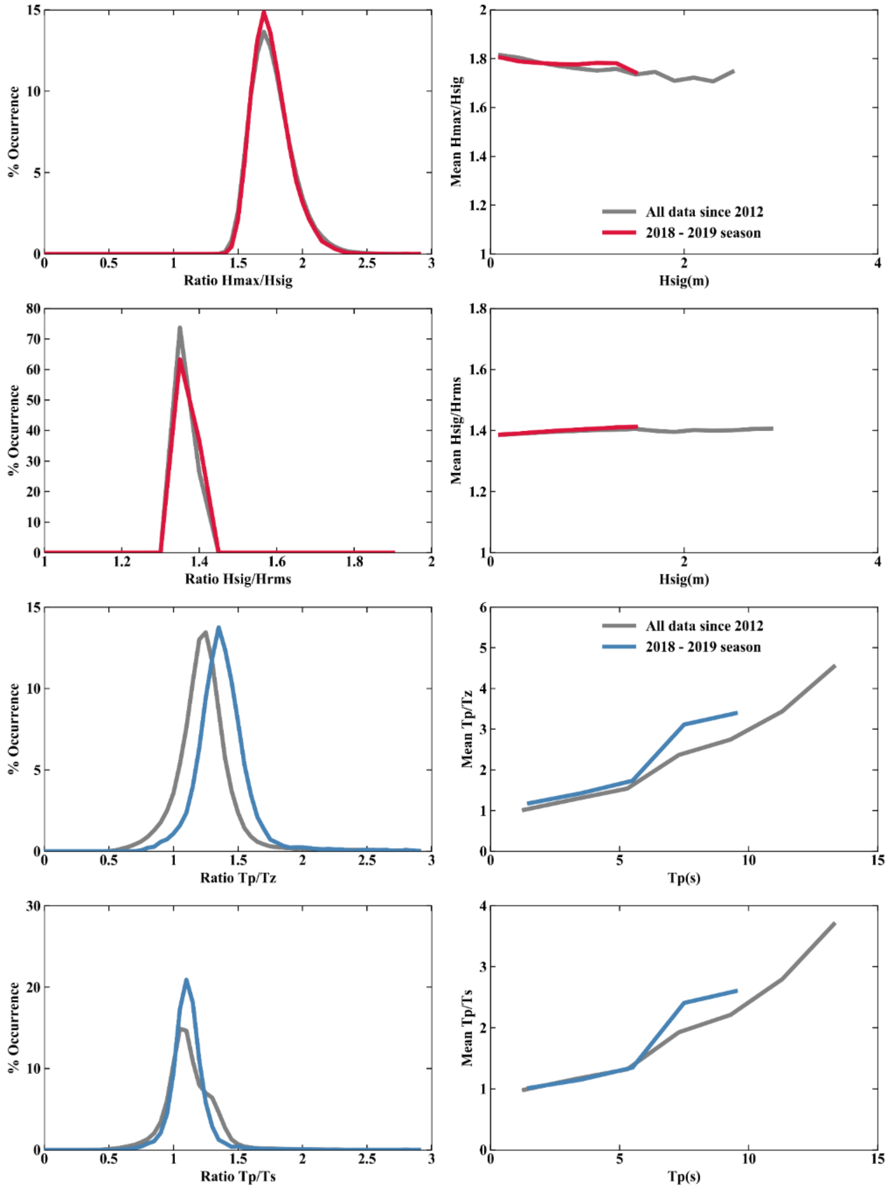


Figure 116 Abbot Point – Histogram percentage (of time) occurrence of wave periods (T_p)



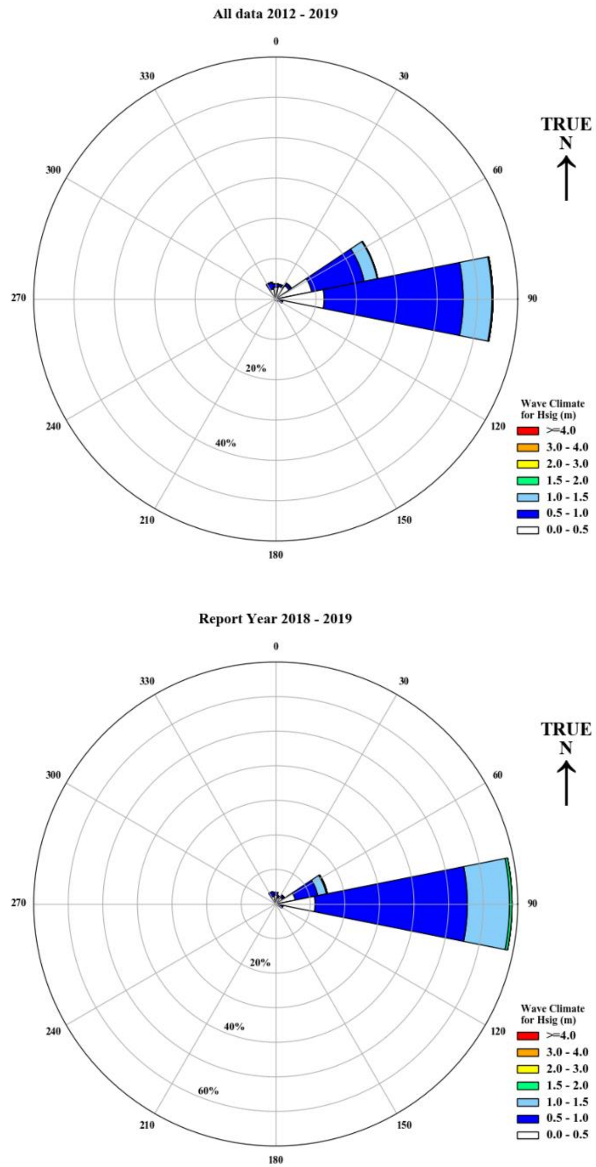


Figure 117 Abbot Point – Wave parameter relationships

Figure 118 Abbot Point – Directional wave rose

Townsville

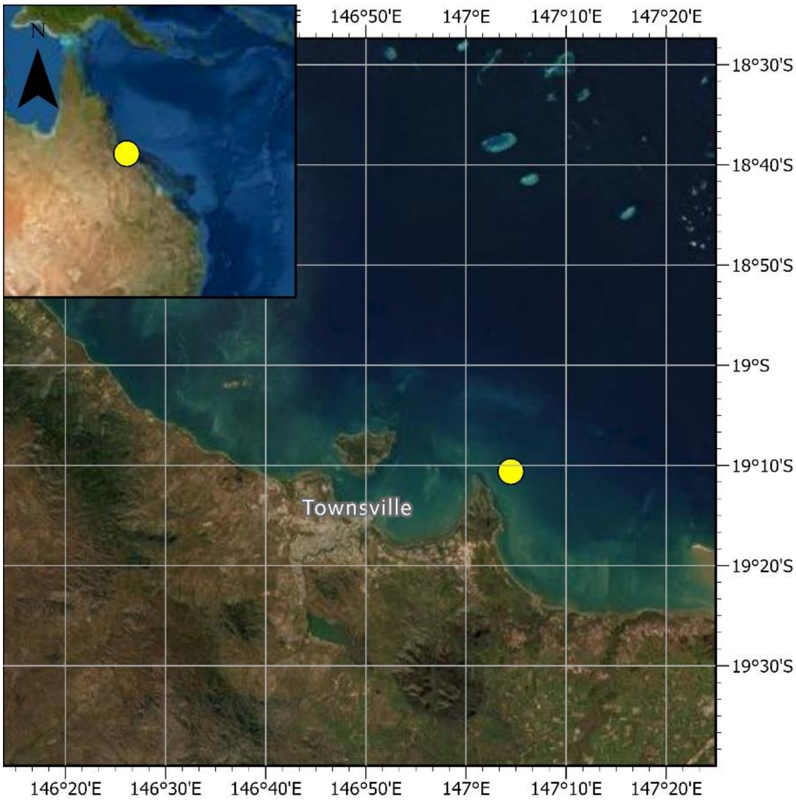


Figure 119 Townsville – Locality plan

Table 57 Townsville – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
2000–19*	14/10/2000*	5 years	238,831	19.05
2018–19	01/11/2017	0.17 (days)	17,512	1

*See

Table 2 for site commission date.

Table 58 Townsville – Buoy deployments during the 2018-19 season

Latitude	Longitude	Type buoy	Depth (m)	Deployed date	Removal date
19° 10.606’ S	147° 04.482’ E	DWR-MkIII	16	24/07/2018	current

Townsville – seasonal overview

The Townsville wave buoy has been operational for nearly 44 years. During the period from November 2018 to October 2019 there was a total gap of 0.17 days, just over 4 hours, equivalent to 99.95 per cent data return (Table 57). The buoy was not replaced during the reporting period but was replaced the previous reporting period on 24 July 2018 (Table 58).

There were four significant storm events throughout the 2018–2019 period (Table 60). The Tropical Low that formed into TC Oma generated a H_{max} of 5.1 m which made it into the top 10 highest waves (Table 59).

Time series of daily wave recordings (Figure 120) shows the four significant weather events in December, January, and February clearly with peaks in H_{max} and H_s visible. Typical variations in H_{max} and H_s are seen throughout the period, but not above 3.8 m for H_{max} or 2 m for H_s. There is some variation in peak wave periods T_p with spikes of longer periods seen throughout the record and significant spikes in January and February between 13 and 14 seconds.

Sea surface temperature (SST) values ranged from 21 °C to 32 °C (Figure 121). The SST was high enough for tropical cyclone development from the start of the record period in November till the first week of May and then again from mid-October to the end of the period. There is a rapid temperature change spike in August, with some typical variations throughout the period.

Monthly average significant wave heights (H_s) (Figure 122) was within 1 sd for 9 months of the reporting period. December and January were above 1 sd and March was below 1 sd. January and August show the highest variation over the entire record.

Wave climate for the 2018–2019 reporting period followed the trend of the wave climate of the entire record with some variations of the higher waves with lower exceedance above 2 m H_s. The summer wave heights were consistently higher than winter waves as well as the historic data up to around 2.3 m H_s. Winter wave height exceedance was lower than the entire record for waves 0.8 m H_s (Figure 123). Histograms for percentage occurrence of H_s (Figure 124) show a decrease in occurrence of waves below 0.4 m Hs and an increase in waves from 0.8 to 1.0 m Hs throughout the period; however, distribution matches the trend closely. Additionally, the winter plot shows a slight increase in occurrence of 0.4 to 0.6 m Hs waves, which are shown to have occurred less in summer. The Histograms for T_p show little variation from the trend with distribution following the historic data closely except for less than five percent variations (Figure 125).

The ratios between different wave parameters such as H_{max}/H_s and H_s/H_{rms} were consistent between this reporting period and all the historic data (Figure 126). While the ratio T_p/T_s slightly decreased and T_p/T_z slightly increased compared to the historic data.

Peak wave direction (Figure 121) was predominately from the east with an irregular swing to the north-east and north and minor swings north and south. Some instances of wave from the west are seen mid-December also. Directional wave rose plots (Figure 127) highlight the dominant easterly direction for the reporting period which was very similar to the entire record. The most common waves were easterly waves of 0.5 to 1.0 m H_s.

Table 59 Townsville – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	03/02/2011 01:30	5.5	03/02/2011 01:00	10.1
2	13/01/2009 08:00	3.7	13/01/2009 07:30	6.6
3	13/04/2014 09:00	3.6	13/04/2014 09:30	6.4
4	24/03/1997 02:00	3.6	24/03/1997 03:00	6.0
5	30/01/2010 22:30	3.0	24/01/2013 07:30	5.4
6	23/12/1990 09:27	3.0	10/01/1998 15:00	5.4
7	10/01/1998 15:00	2.9	20/03/2006 08:00	5.3
8	20/03/2006 08:00	2.9	30/01/2010 20:30	5.2
9	03/03/1979 03:00	2.8	03/02/2019 21:30	5.1
10	24/01/2013 06:30	2.7	11/02/1999 18:30	5.1

Table 60 Townsville – Significant meteorological events with threshold H_s of 1.8 metres.

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
09/12/2018 12:00	2.2	4.6	6.8	Tropical low-pressure system that developed into TC Owen
24/12/2018 12:30	2.1	4.1	7.3	Low pressure troughs moving east with high pressure systems in the southeast
28/01/2019 07:30	2.1	3.7	6.3	Low pressure monsoon trough extending east to west across Australia to TC riley off Western Australia
03/02/2019 09:30 Peak Event	2.5	5.1	7.1	Active Monsoon trough and low-pressure systems that would form TC Oma

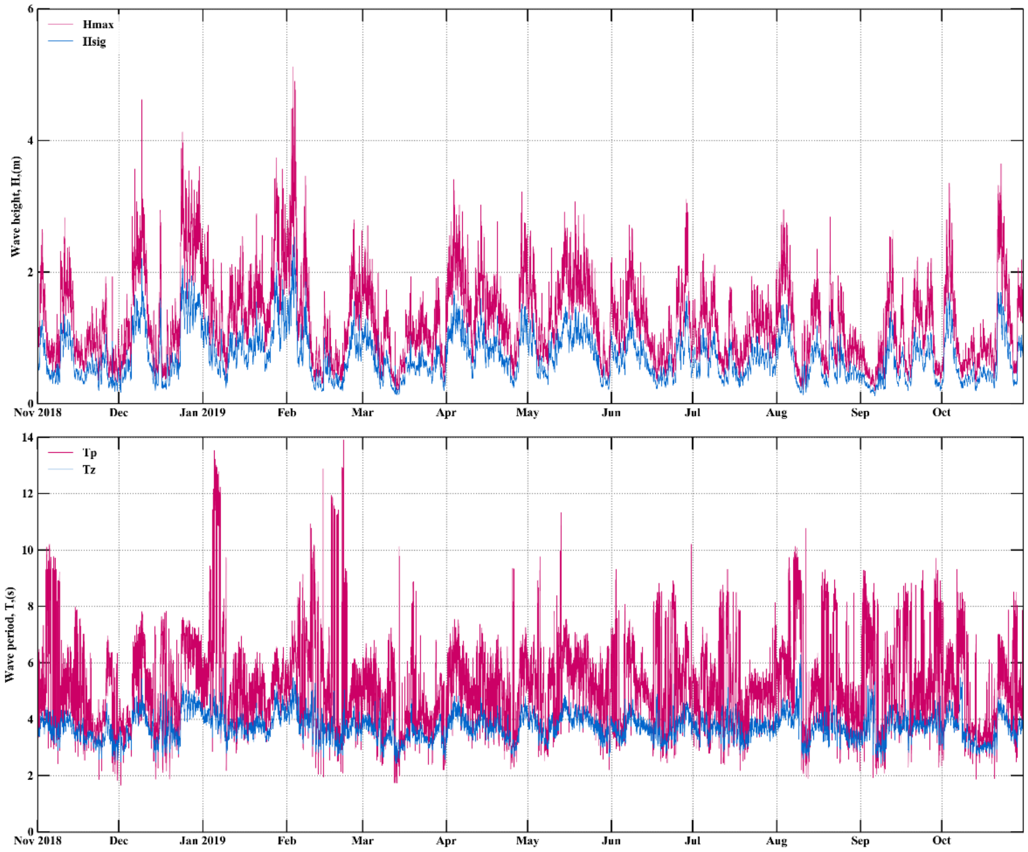


Figure 120 Townsville – Daily wave recordings

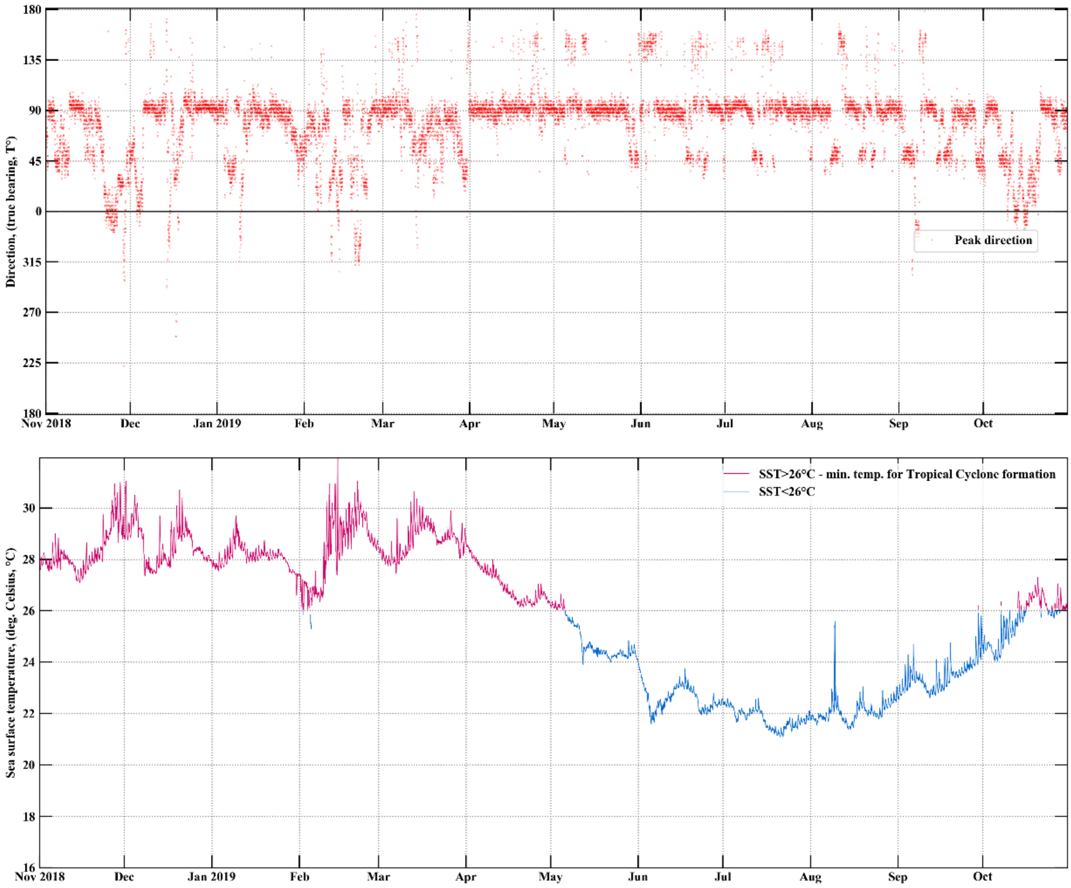


Figure 121 Townsville – Peak wave directions and sea surface temperature

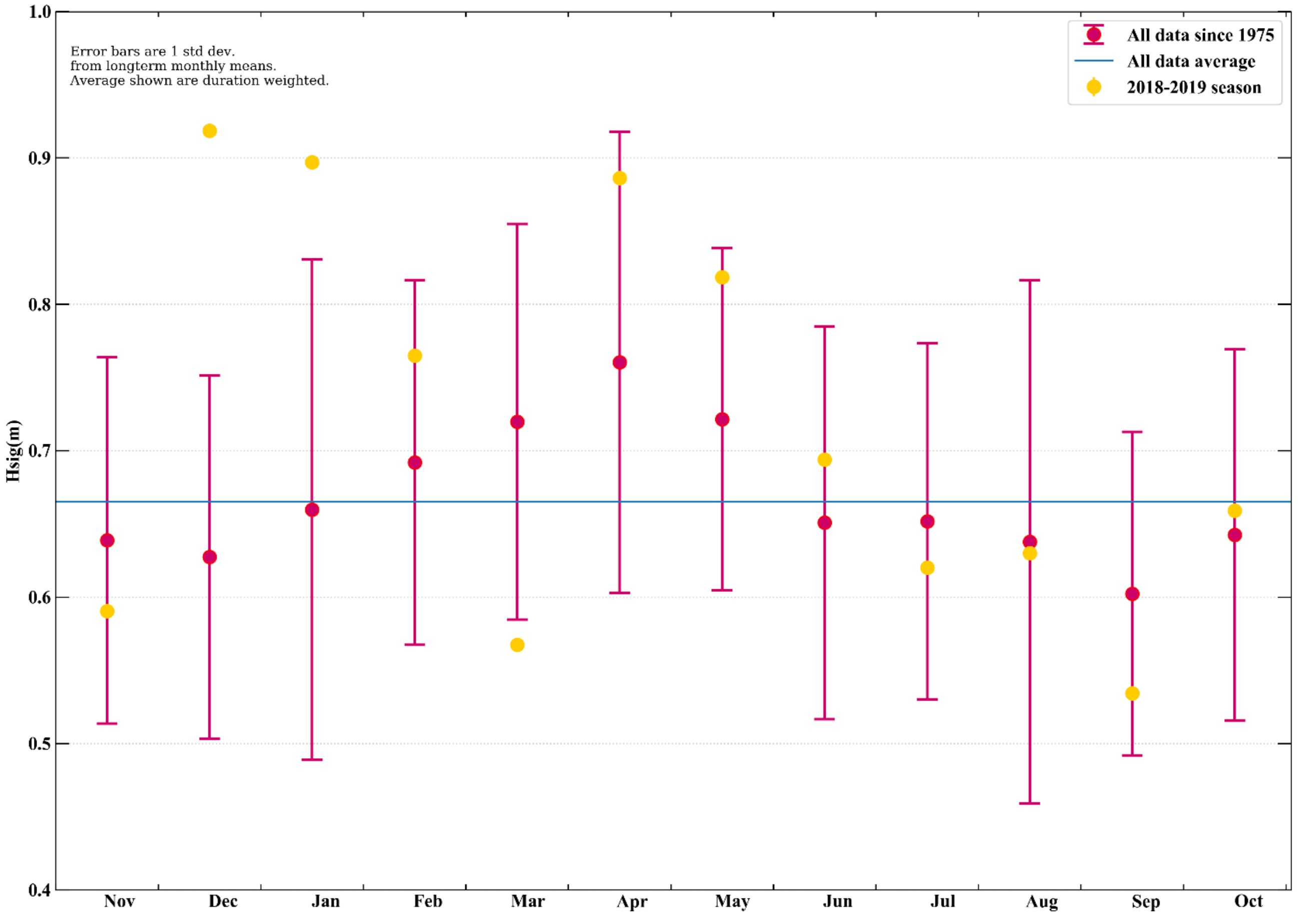


Figure 122 Townsville – Monthly average wave height (H_s) for seasonal year and for all data

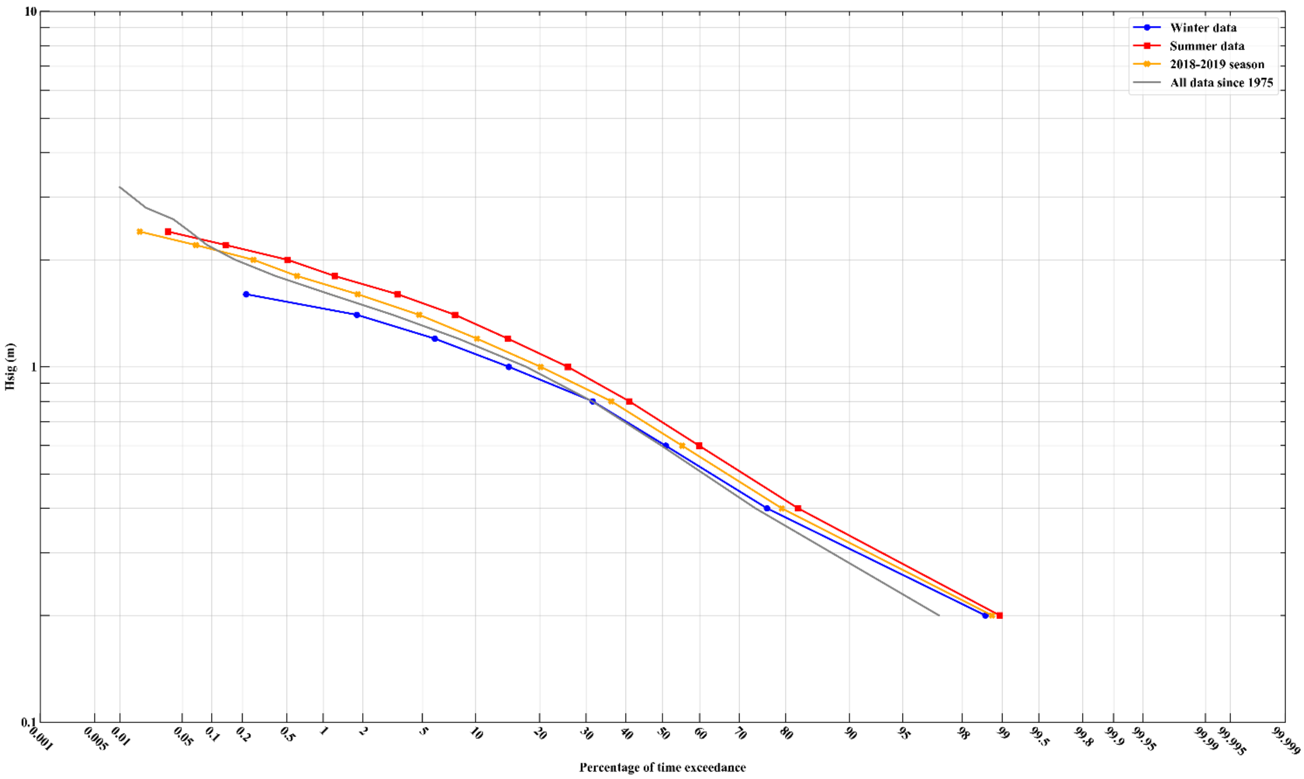


Figure 123 Townsville – Percentage exceedance of wave height (H_s) for all wave periods (T_p)

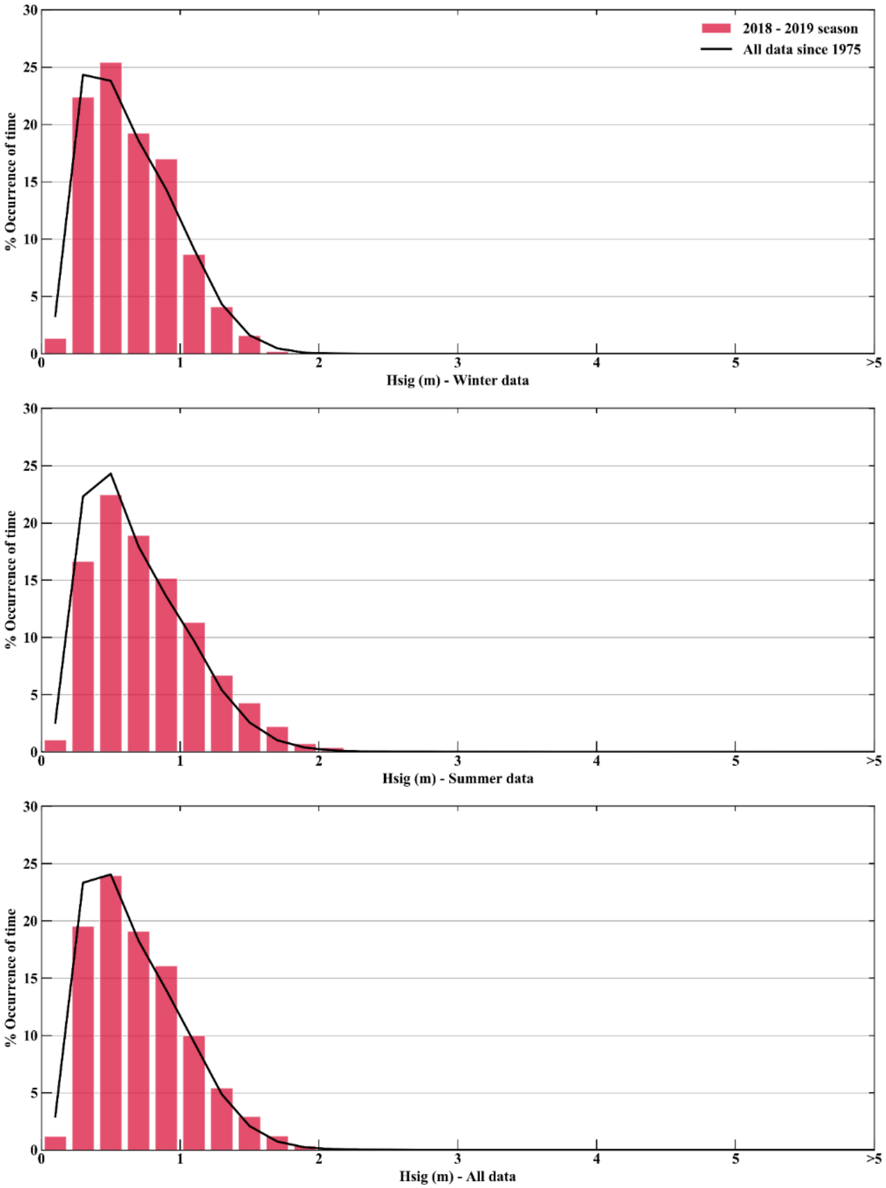


Figure 124 Townsville – Histogram percentage (of time) occurrence of wave heights (H_s)

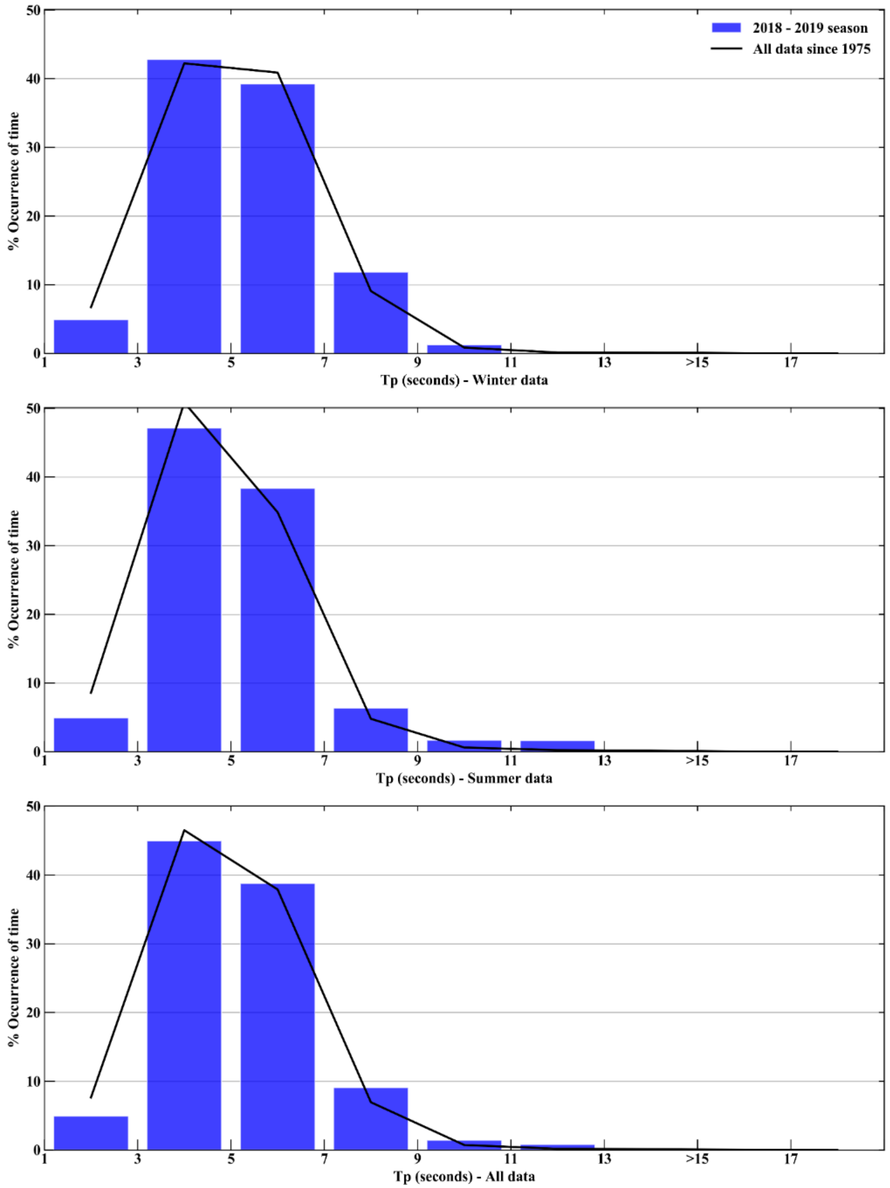


Figure 125 Townsville – Histogram percentage (of time) occurrence of wave periods (T_p)

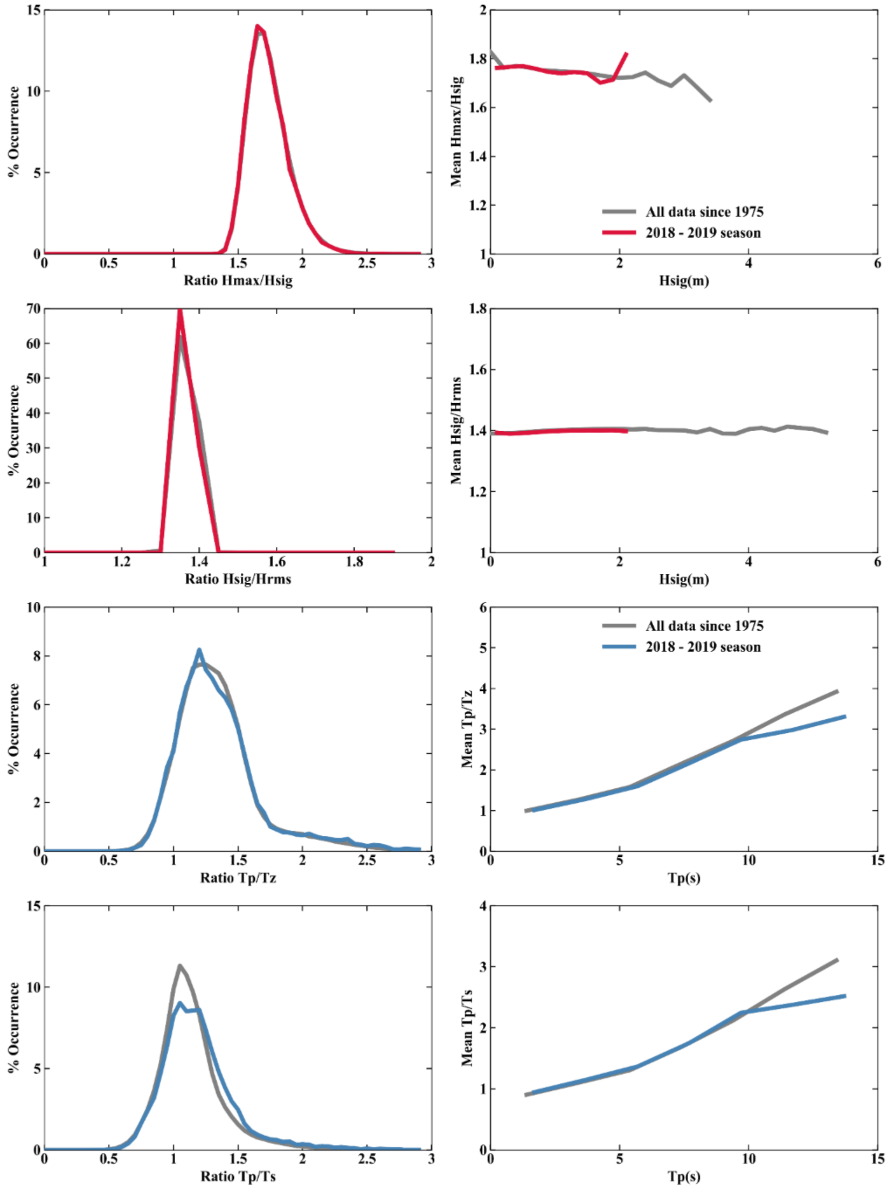


Figure 126 Townsville – Wave parameter relationships

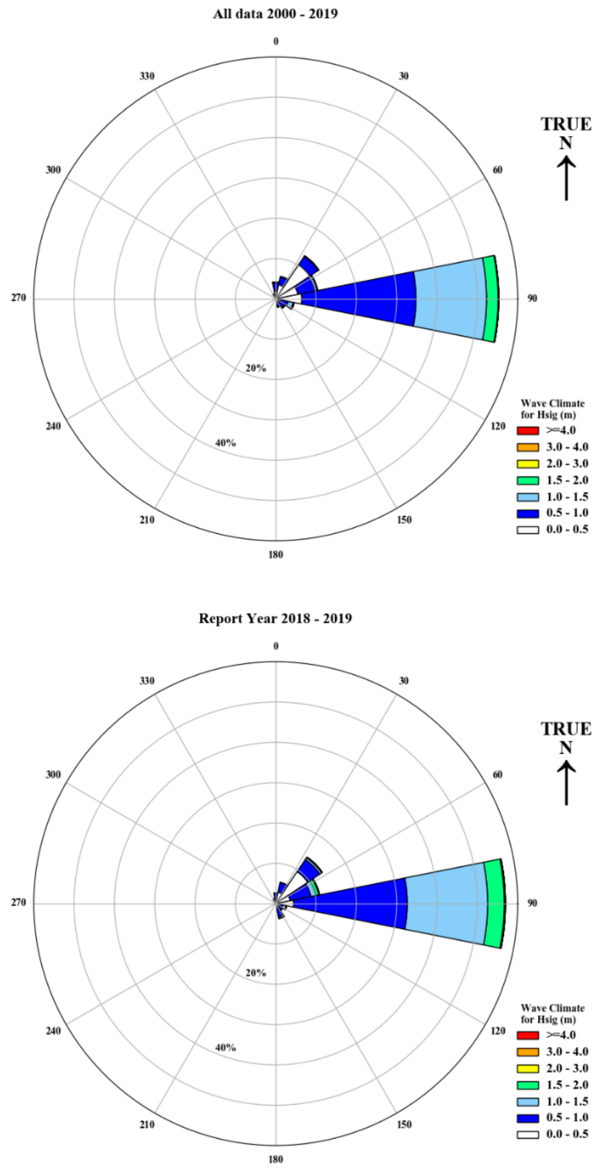


Figure 127 Townsville – Directional wave rose

Cairns

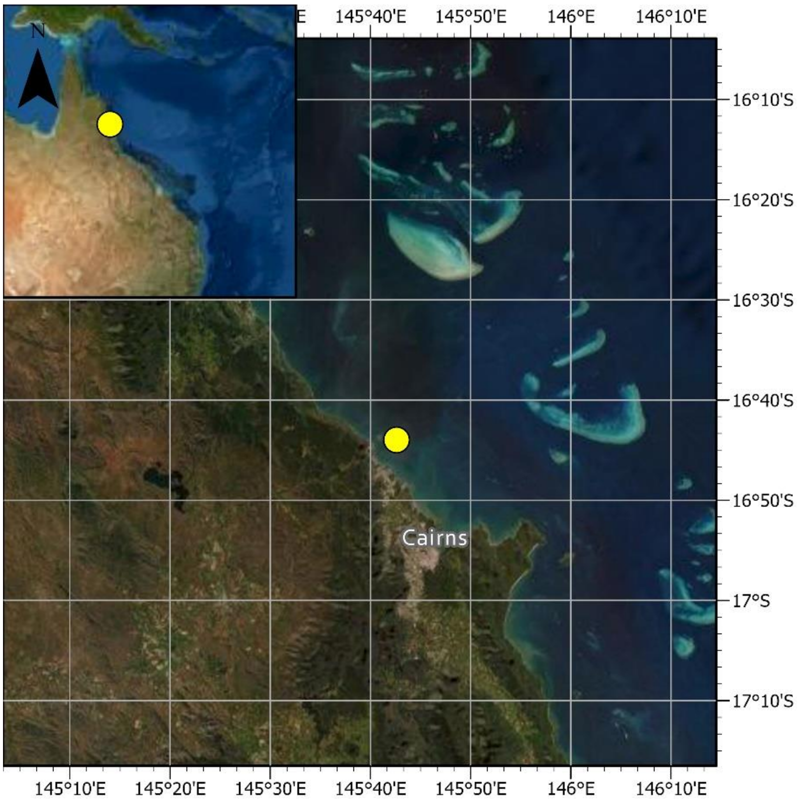


Figure 128 Cairns – Locality plan

Table 61 Cairns – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
1997–2019*	20/11/1997*	12.08 years	149,351	21.95
2018-19	01/11/2018	28.21 (days)	16.166	1

*See

Table 2 for site commission date.

Table 62 Cairns – Buoy deployments for the 2018-19 season

Latitude	Longitude	Type buoy	Depth (m)	Deployed date	Removal date
16° 44.030' S	145° 42.642' E	DWR-MkIII	13	20/02/2018	03/07/2019
16° 43.993' S	145° 42.597' E	DWR-MkIII	14	03/07/2019	current

Cairns – seasonal overview

The Cairns wave buoy has been operational for 44.5 years. The data for the period November 2018 to October 2019 had gaps of 8.87 days, equivalent to 97.57 per cent data return (Table 61). The buoy was replaced once during the reporting period on 03 July 2019 for the annual buoy change. (Table 62).

Note: The Cairns buoy was changed from a non-directional site to a directional site on 26 February 2016.

There were 3 significant meteorological events during the reporting period, one of which was due to the development of TC Owen in December 2018 (Table 64). This event made it to the top 10 table (Table 63) with a significant wave heigh (H_s) of 2.0 m and a maximum wave height (H_{max}) of 3.4 metres.

The time series of H_s and T_p (Figure 129) shows the daily wave heights and period with the significant weather event visible in early December. There is a gap in data from the last week of June and first week of July, with a significant data gap in August for both H_s and T_p.

Recording of Sea Surface Temperatures (SST) was high enough for the development of cyclones from the beginning of the period at the start of November until the first week of April. Temperatures ranged from 19.5 °C to 29.5 °C. There is a gap in data from the last week of June into the first week of July, and a data gap in August as discussed above (Figure 130).

The monthly average H_s (Figure 131) was within 1 standard deviation (sd) of the historic monthly mean, apart from December and January which were above 1 sd of historic data.

The percentage exceedance of Hs for 2018–19 (Figure 132) show there was a higher exceedance of waves below 0.8 m H_s in winter. Exceedance converged from 0.8 m to 1.2 m H_s. Beyond to 2 m H_s, summer wave show more exceedance. Histograms of percentage occurrence of time for Hs (Figure 133) show a minimal decreased occurrence of waves below 0.4 m H_s and a minimal increase in waves from 0.6 to 0.8 m H_s for the period. Waves of 0.4 to 0.6 m H_s occurred less frequently in winter than on record, as did 0.2 to 0.4 m H_s waves in summer. Histograms for peak wave period (T_p) (Figure 134) vary slightly from trends and follow the distribution established by all data collected since 1975.

The ratios between different wave parameters such as H_{max}/H_s were consistent between this reporting period and all of the historic data, these are plotted in Figure 135. The ratio of H_s/H_{rms} is slightly higher and shows a deviation The ratio T_p/T_z is slightly increased and T_p/T_s is slightly decreased when compared to the historic data.

The general wave directions were from east through to northeast occasional swings to the north and south (Figure 130). There is a gap in data from the last week of June and first week of July, with a significant data anomaly in August. The incidental wave direction for the period (Figure 136) presented as wave rose shows very little departure from the trend.

Table 63 Cairns – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	12/04/2014 15:30	3.4	12/04/2014 14:00	5.6
2	27/02/2000 21:30	2.8	28/02/2000 01:00	5
3	11/02/1999 21:00	2.5	23/01/2013 23:00	4.7
4	03/02/2011 04:30	2.4	11/02/1999 22:00	4.6
5	23/01/2013 23:30	2.3	23/12/1990 20:54	4.5
6	23/12/1990 20:54	2.2	03/02/2011 04:00	4.1
7	10/12/2018 02:00	2	12/01/2009 07:00	3.4
8	19/03/1990 08:42	1.9	10/12/2018 02:30	3.4
9	31/01/1977 09:00	1.9	03/01/1979 03:00	3.3
10	12/01/2009 07:00	1.9	31/01/1977 09:00	3.2

Table 64 Cairns – Significant meteorological events with threshold H_s of 1.3 metres

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
10/12/2018 02:00 Peak Event	2	3.4	5.4	Tropical low-pressure system that developed into TC Owen
30/12/2018 17:30	1.4	3.1	4.7	Low pressure troughs moving east with high pressure systems in the southeast
26/01/2019 23:00	1.4	2.7	4.8	Low pressure monsoon trough extending east to west across Australia to TC Riley off Western Australia

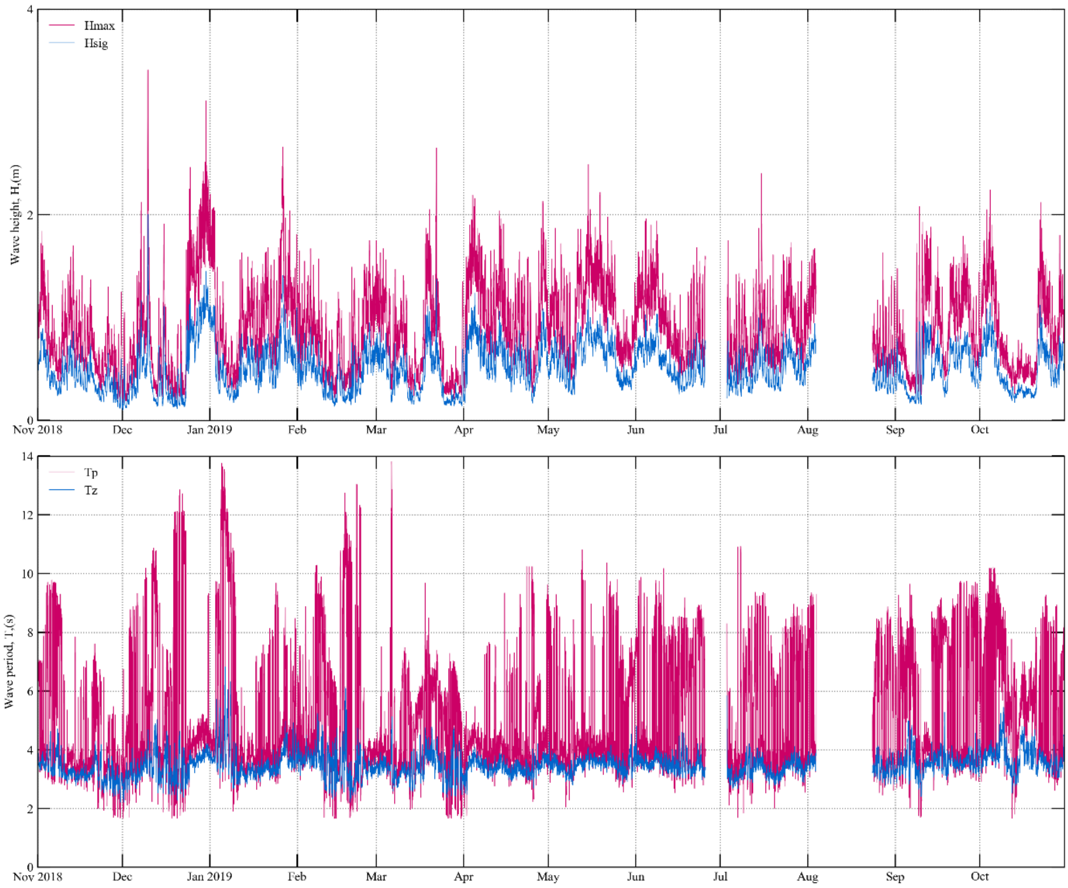


Figure 129 Cairns – Daily wave recordings

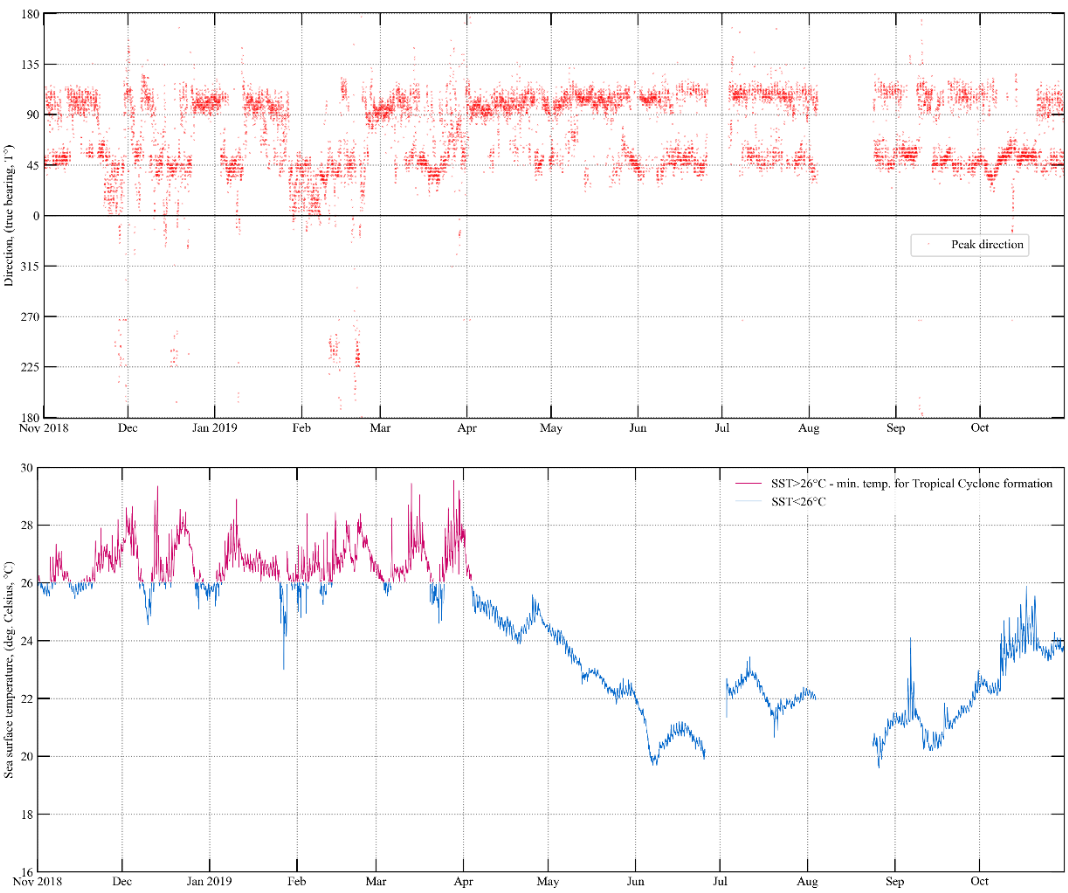


Figure 130 Cairns – Peak wave directions and sea surface temperature

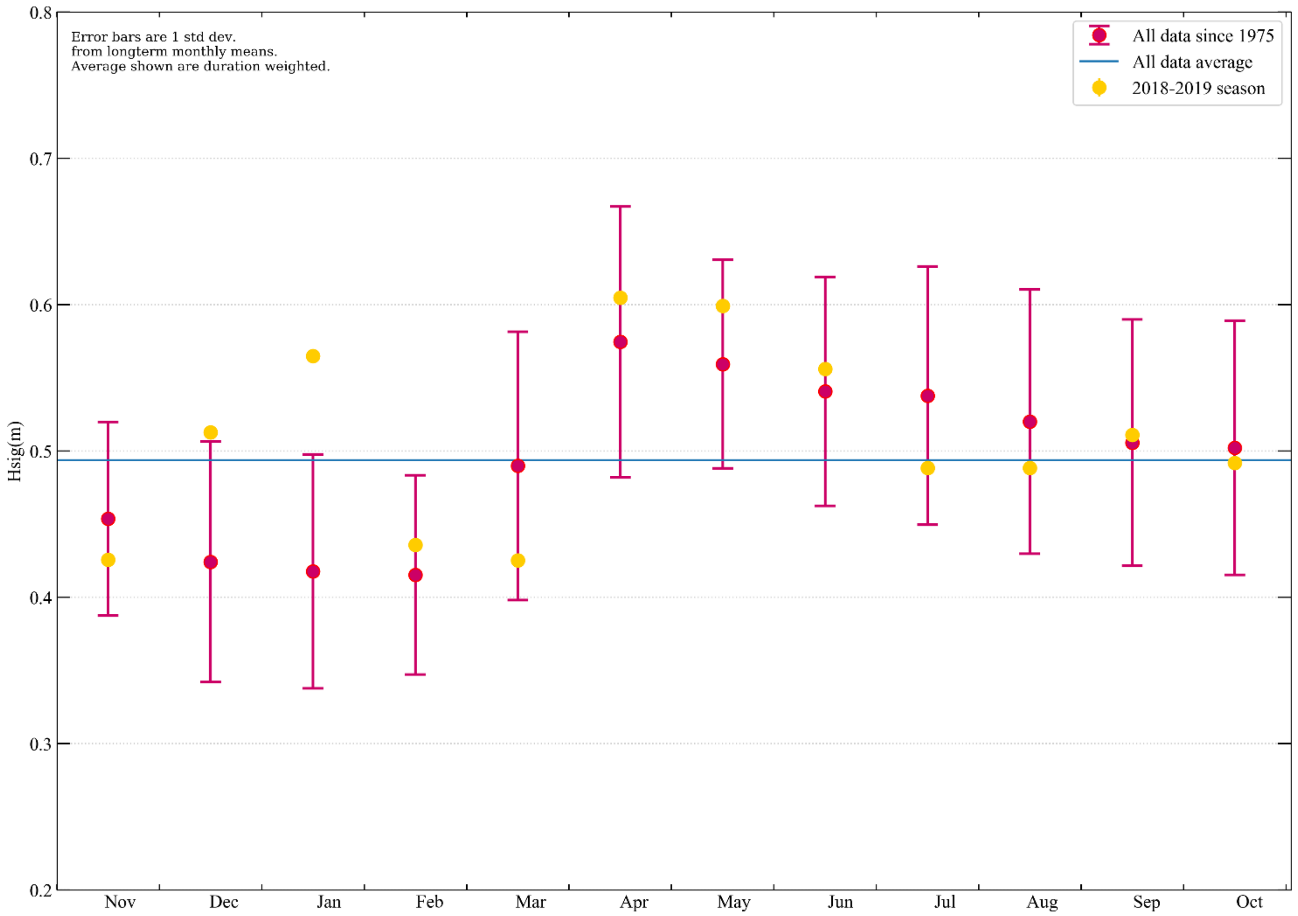


Figure 131 Cairns – Monthly average wave height (H_s) for seasonal year and for all data

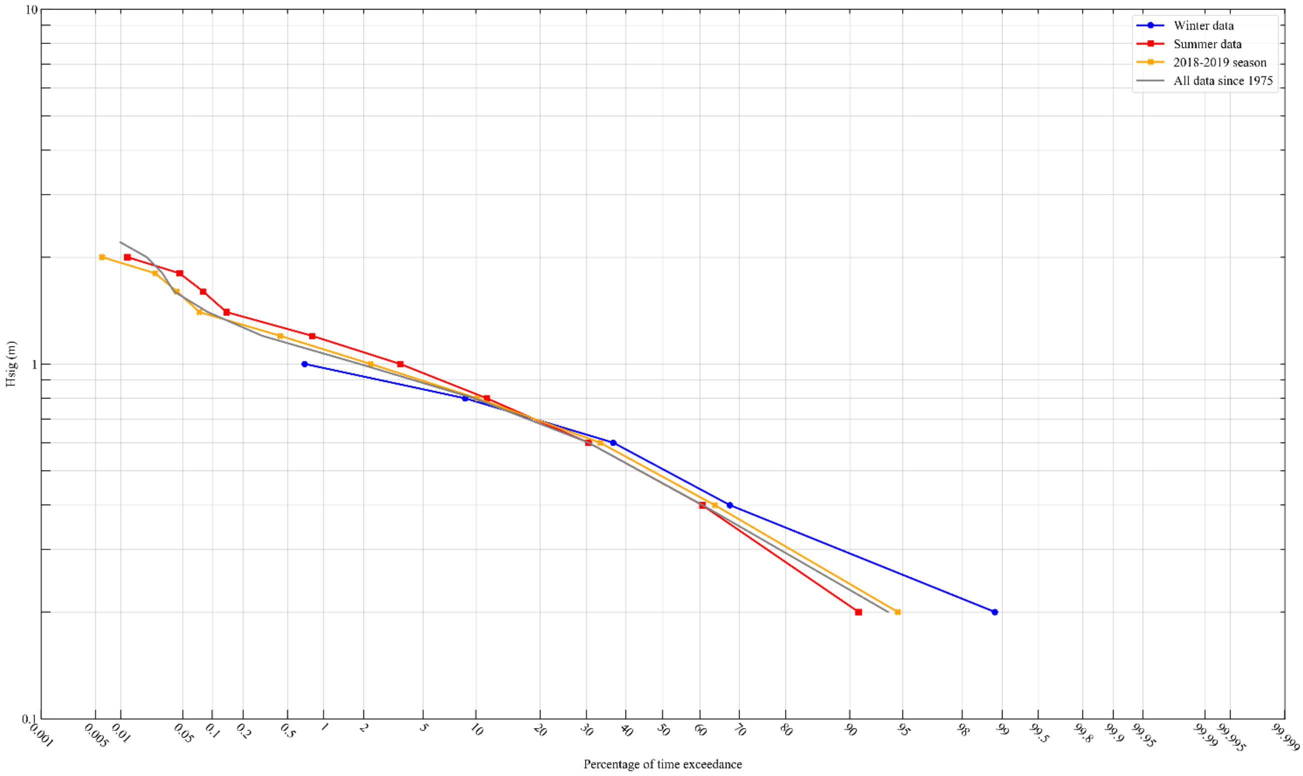


Figure 132 Cairns – Percentage exceedance of wave height (H_s) for all wave periods (T_p)

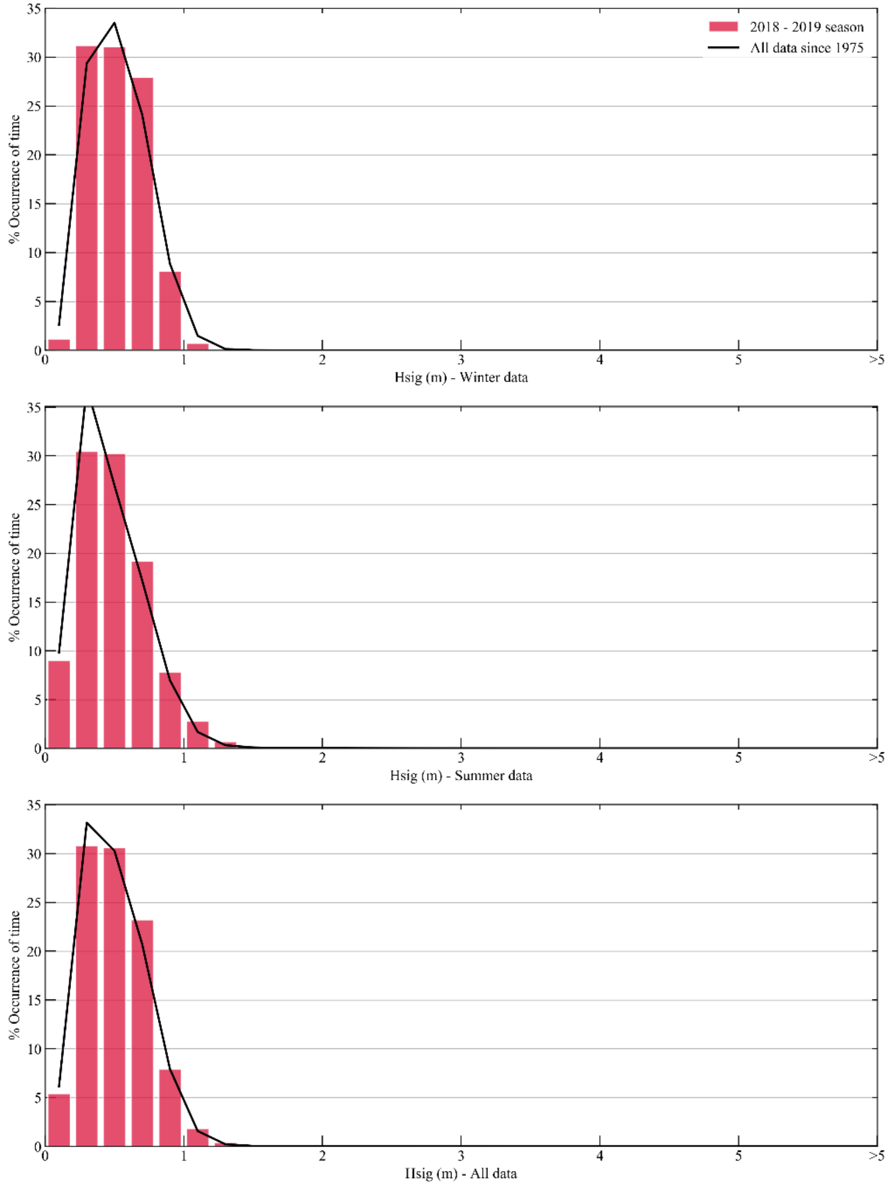


Figure 133 Cairns – Histogram percentage (of time) occurrence of wave heights (H_s)

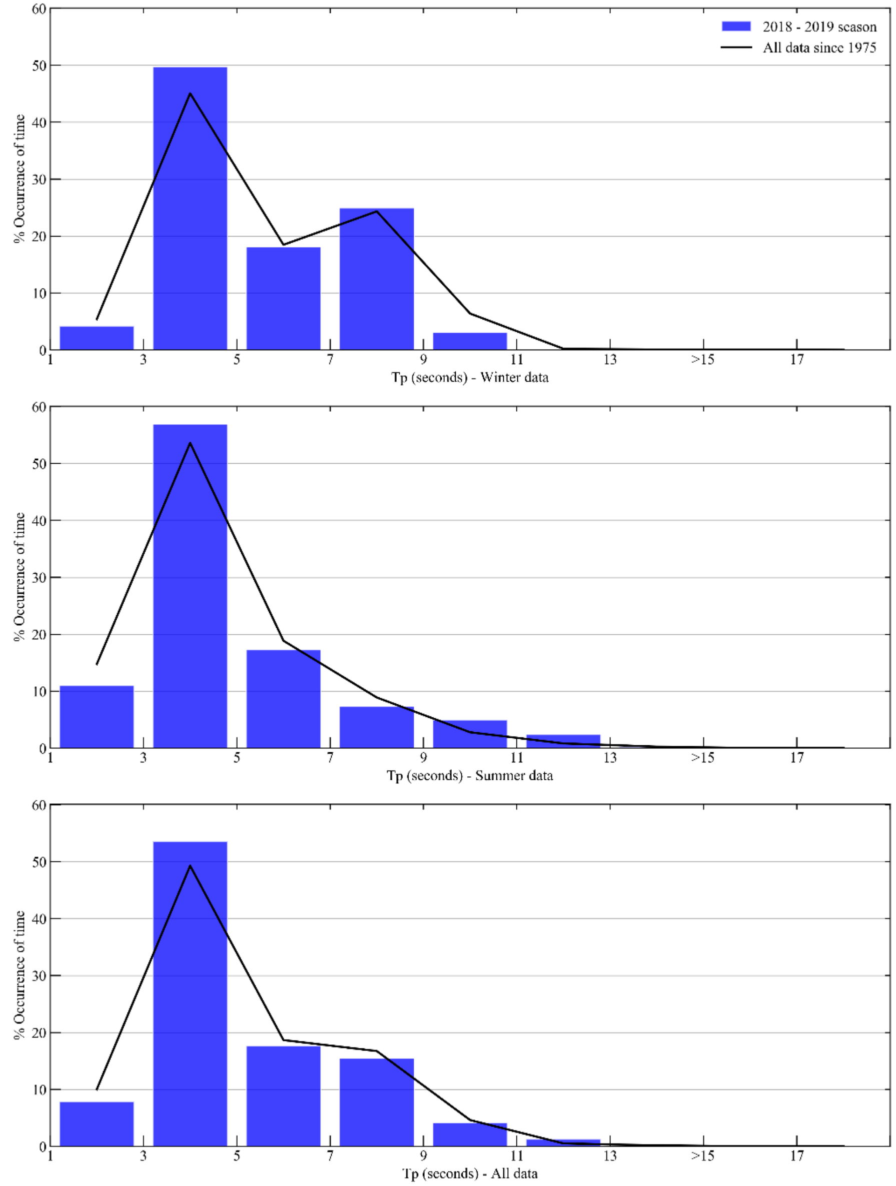


Figure 134 Cairns – Histogram percentage (of time) occurrence of wave periods (T_p)

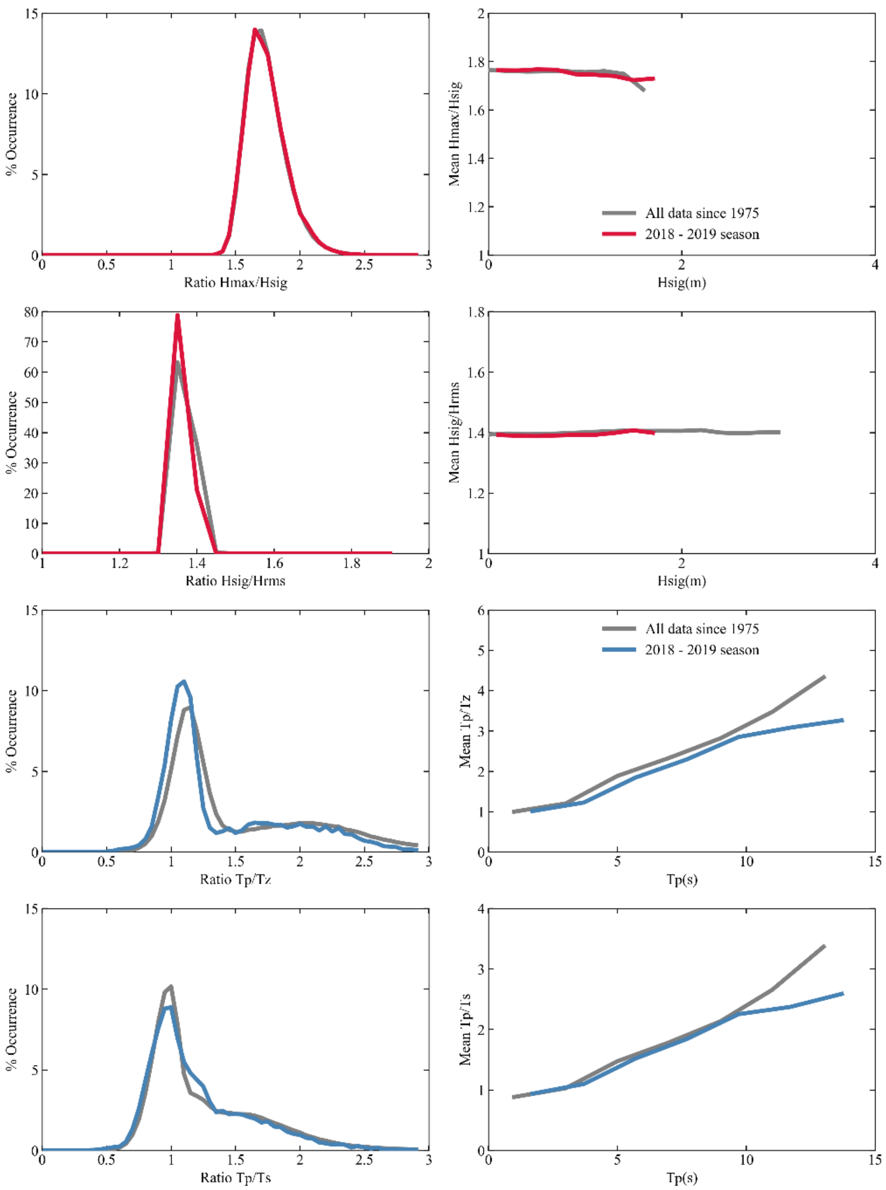


Figure 135 Cairns – Wave parameter relationships

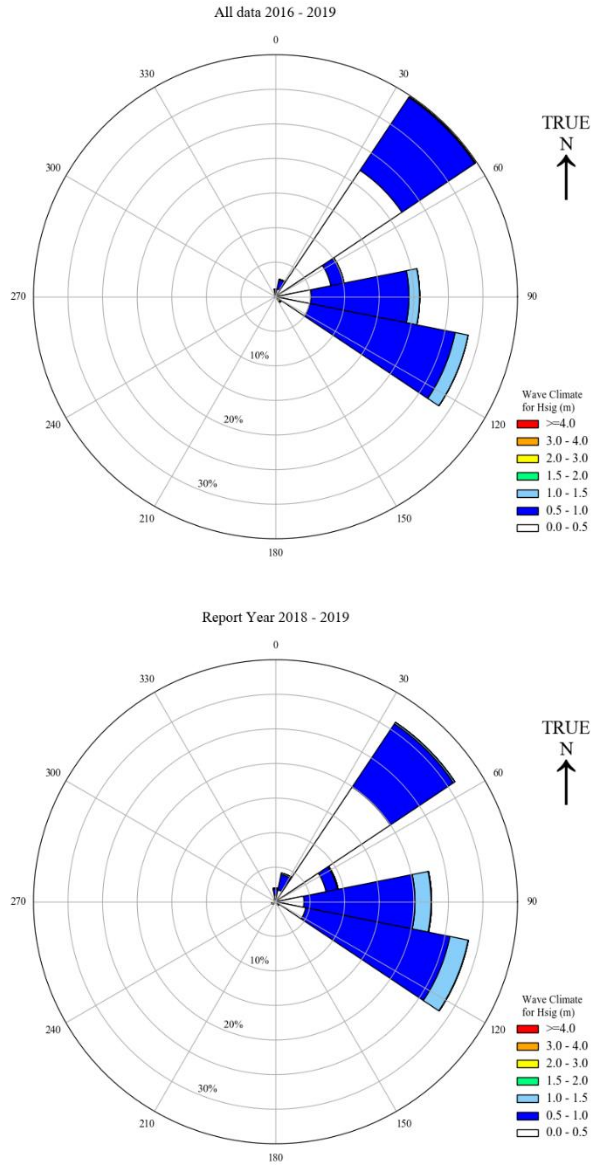


Figure 136 Cairns – Directional wave rose

Skardon River Inner

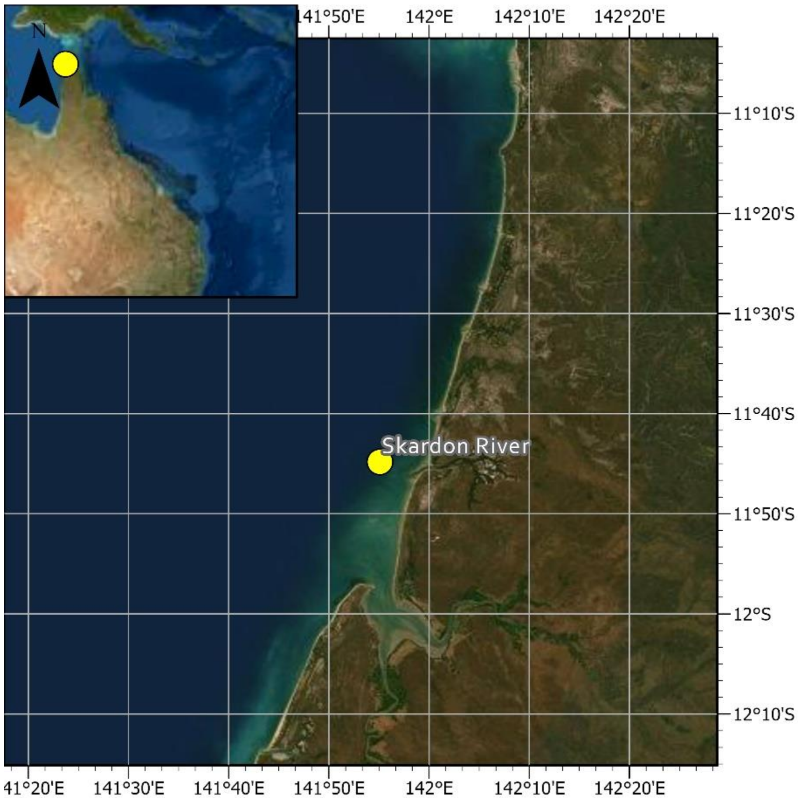


Figure 137 Skardon River Inner – Locality plan

Table 65 Skardon River Inner – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	06/01/2019	0.092 years	12,969	0.82
2018–19	06/01/2019	33.65 days	12,969	0.82

Table 66 Skardon River Inner – Buoy deployments for the 2018-19 season

Latitude	Longitude	Type buoy	Depth (m)	Deployed date	Removal date
11° 44.832’ S	141° 55.104’ E	DWR-MK4	14	06/01/2019	current

Skardon River Inner – seasonal overview

The Skardon River Inner wave buoy was deployed and became operational 06 January 2019 and therefore a complete dataset for the monitoring period is not available. These is also no historical data for this site and as such no comparisons can be made to historic trends. The data recorded from January 2019 to October 2019 was ok, with total gaps of 27.48 days, equivalent to 90.78 per cent data return (Table 65). The buoy was not replaced during the 2018–19 reporting period (Table 66).

Three significant events were recorded throughout the 2018–19 recording period, with the peak event being TC Trevor (Table 68). All Three of the weather events have been added to the top 10 highest waves table (Table 67), with the remaining entries being the next seven highest events in this recording period.

Time series for H_s at the Skardon River Inner site (Figure 138) shows the three significant weather events from January to April stand out from the wave climate of around 0.5 m H_s for the remainder of the period. Variations in peak wave period T_p can be seen throughout the monitoring period.

The Sea Surface Temperature (SST) measured in the buoy hull shows the recorded values ranged from 24 °C to 32.5 °C during the year. The SST was high enough for tropical cyclone development from the beginning of the record in January to early June with some infrequent spikes above 26 ^{O}C through to mid-July. Temperatures begin to climb above 26 °C again the last week of September and exceeded 26 °C to the end of the reporting period (Figure 139).

The histograms for percentage occurrence of H_s (Figure 140) show the most frequently occurring waves throughout the recorded period are 0.2 m to 0.4 m H_s. Histograms for peak wave period T_p (Figure 141) show waves with periods between the 1 to 3 seconds being the most predominant, with 5 to 7 second waves having a high occurrence also in summer due to the significant weather events discussed above.

The wave directions during summer were from west-northwest and in winter southwest with swings east throughout the period (Figure 139). The incident wave direction is reflected in the directional wave rose plot (Figure 142) with the most common wave height H_s of less than 0.5 m from the east, with all incident waves exceeding 1.0m H_s being west-north-westerly.

Table 67 Skardon River Inner – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	21/03/2019 14:30	2.9	21/03/2019 14:30	5.5
2	26/01/2019 18:30	2.8	26/01/2019 18:30	5.2
3	08/02/2019 20:00	1.9	08/02/2019 20:00	2.9
4	21/02/2019 16:30	1.2	21/02/2019 16:30	2.1
5	28/03/2019 23:30	1.1	28/03/2019 23:30	2.1
6	06/01/2019 09:00	0.9	06/01/2019 09:00	2
7	11/05/2019 10:00	0.9	15/02/2019 10:30	1.6
8	15/02/2019 10:30	0.8	11/05/2019 10:00	1.6
9	29/08/2019 18:00	0.8	05/06/2019 15:00	1.6
10	05/06/2019 15:00	0.7	29/08/2019 18:00	1.4

Table 68 Skardon River Inner – Significant meteorological events with threshold H_s of 1.3 metres

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
26/01/2019 18:30	2.8	5.2	7.5	Low pressure monsoon trough extending east to west across Australia to TC Riley off Western Australia
08/02/2019 20:00	1.9	2.9	8.3	Active Monsoon trough and low-pressure systems that would form TC Oma
21/03/2019 02:30 Peak Event	2.9	5.5	7.8	Passage of TC Trevor from Gulf of Carpentaria to Cape York

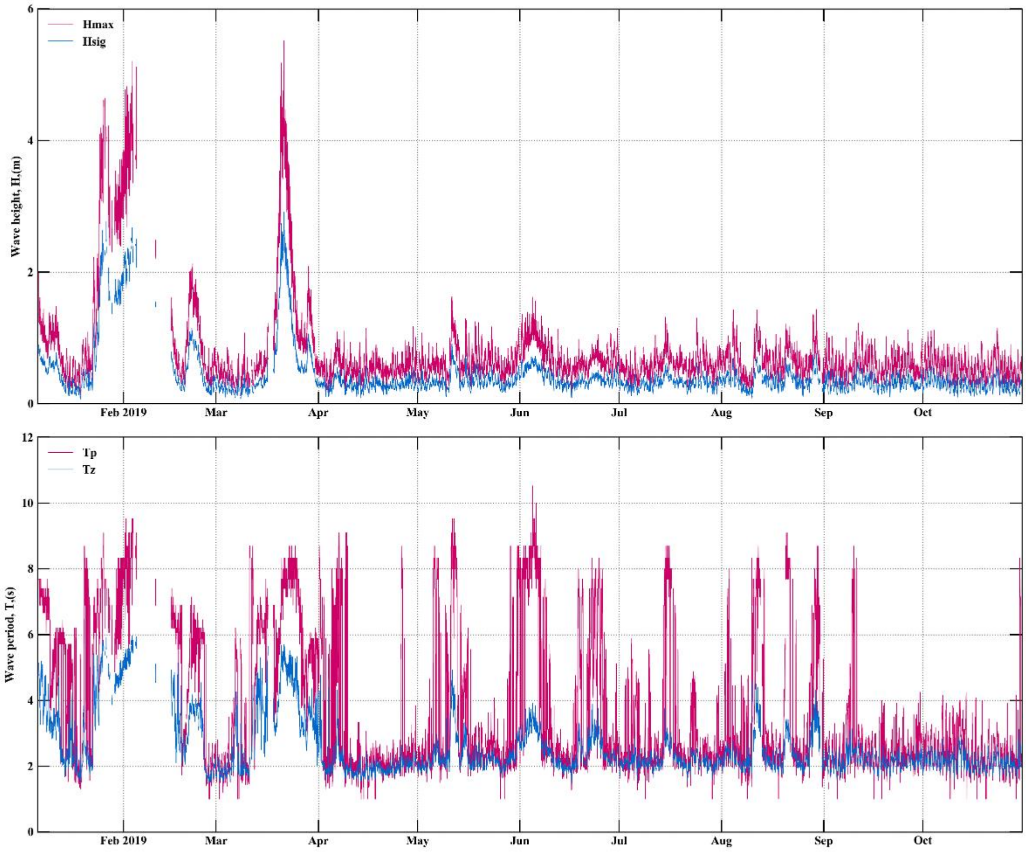


Figure 138 Skardon River Inner – Daily wave recordings

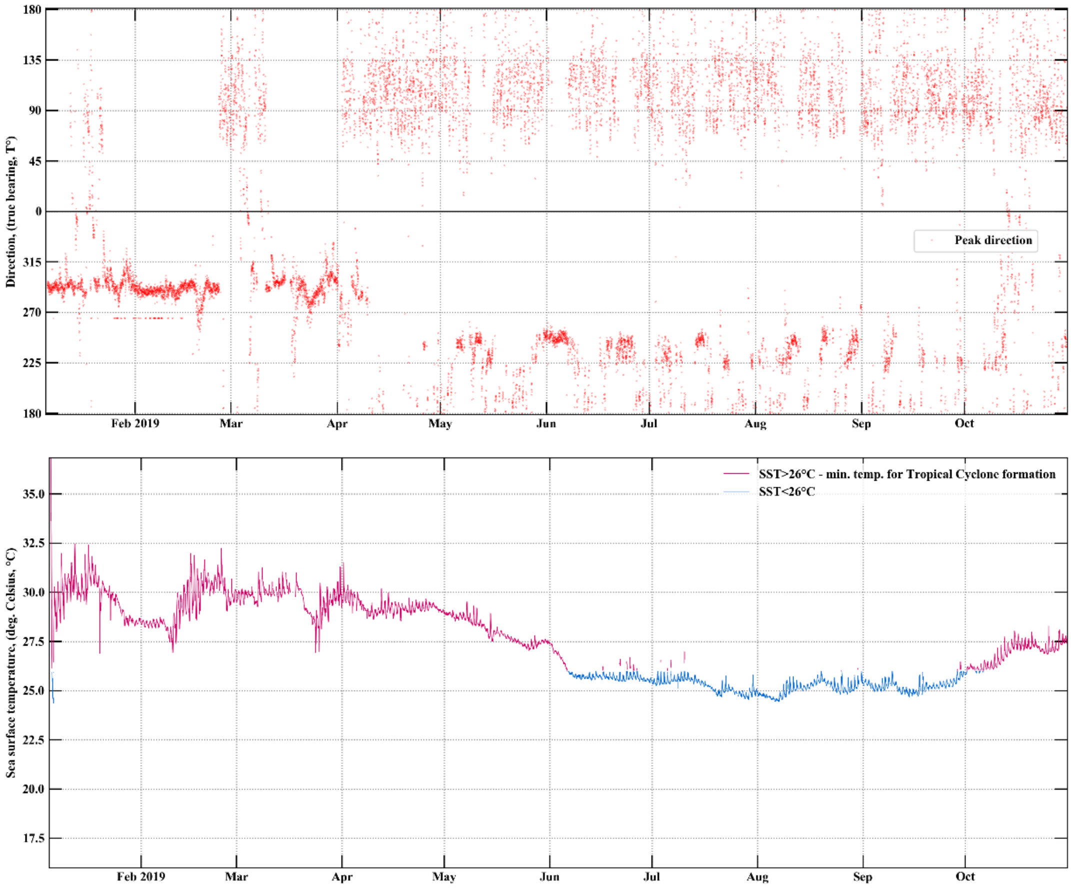


Figure 139 Skardon River Inner – Peak wave directions and sea surface temperature

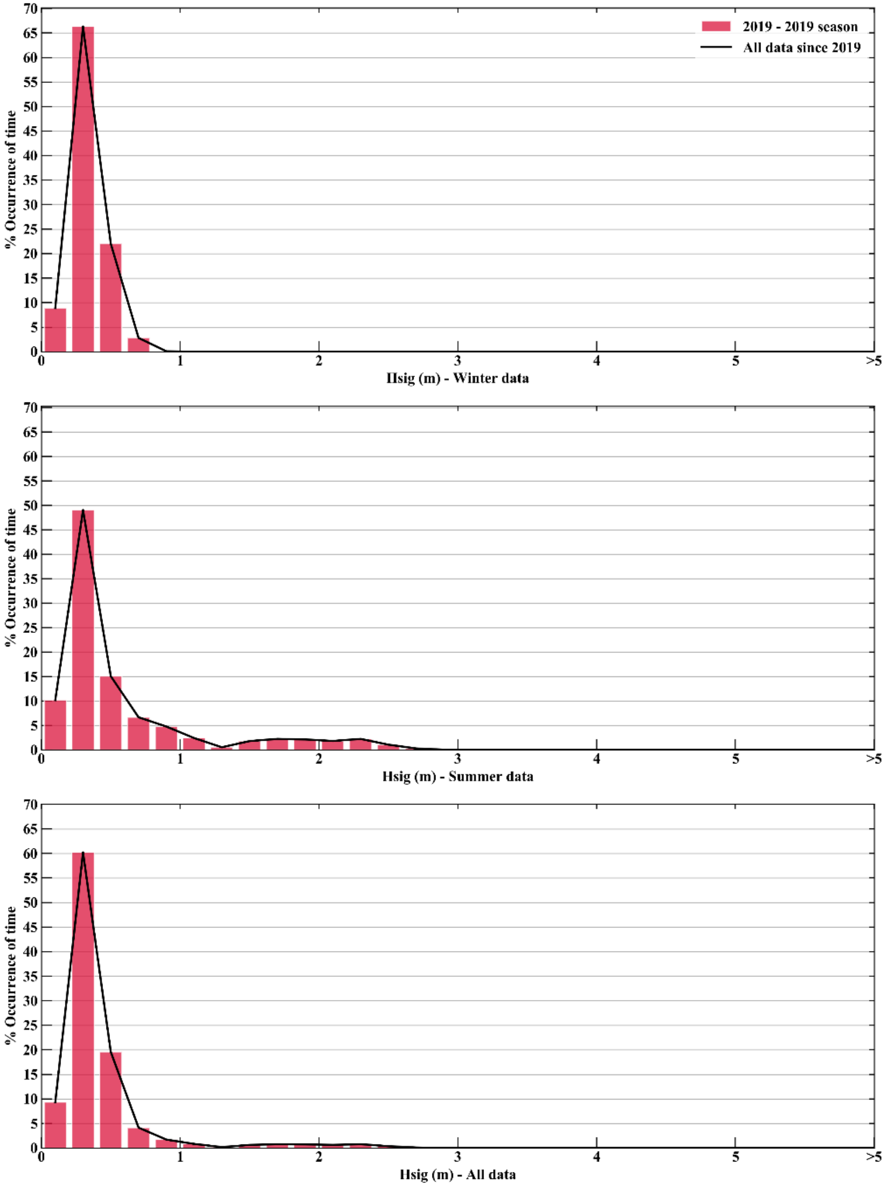


Figure 140 Skardon River in – Histogram percentage (of time) occurrence of wave heights (H_s)

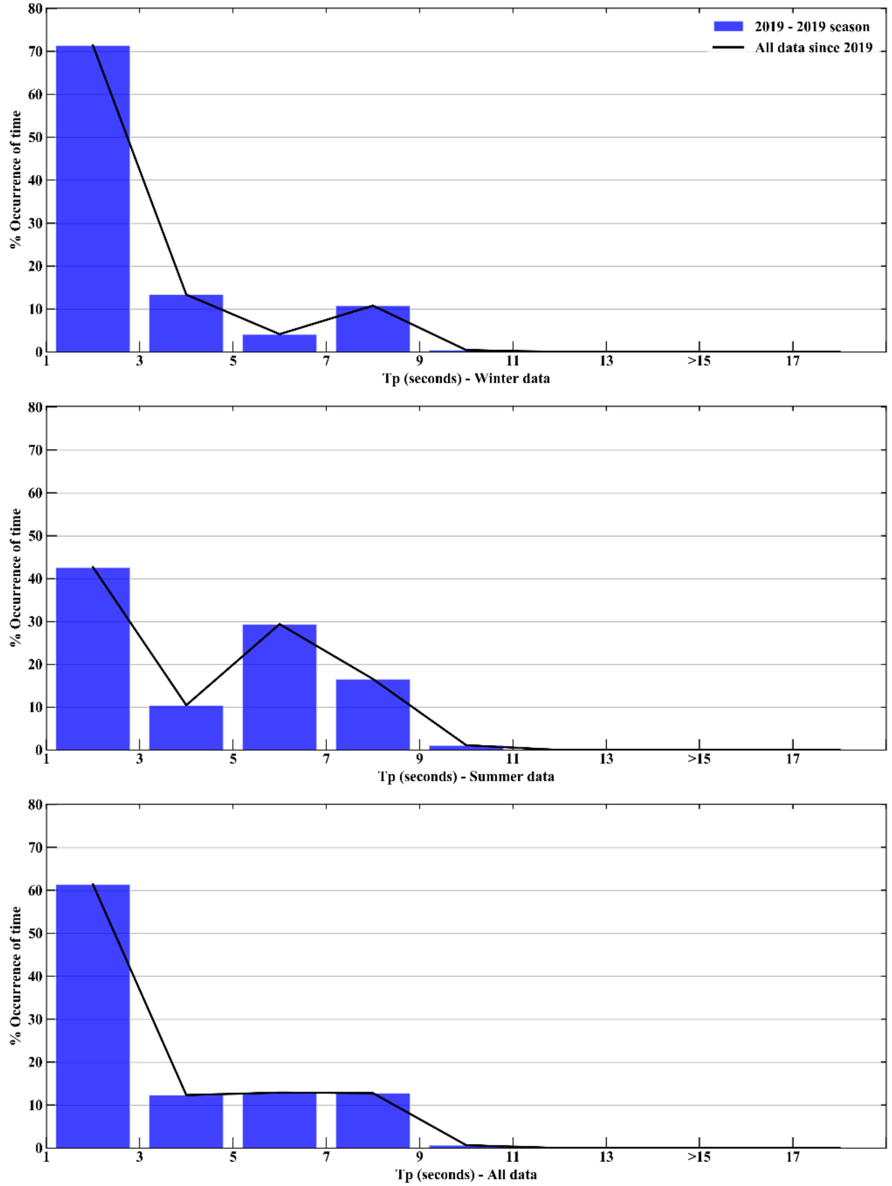
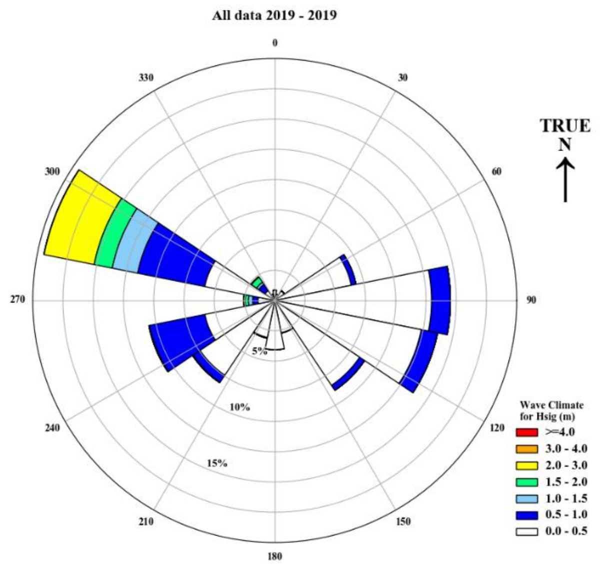


Figure 141 Skardon River in – Histogram percentage (of time) occurrence of wave periods (T_p)



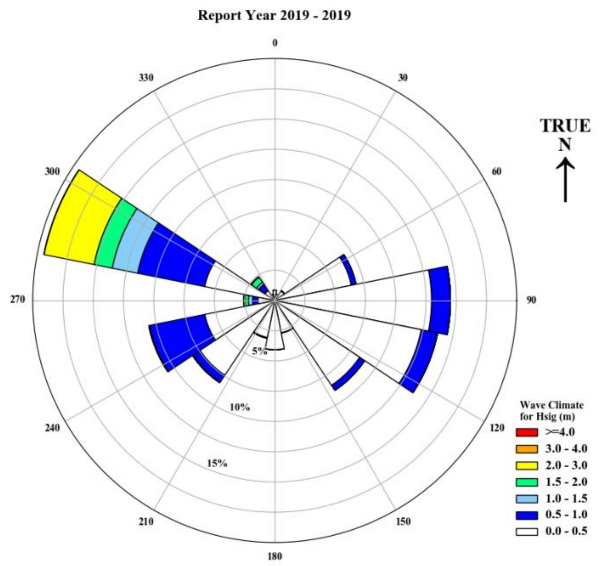


Figure 142 Skardon River Inner – Directional wave rose

Skardon River Outer

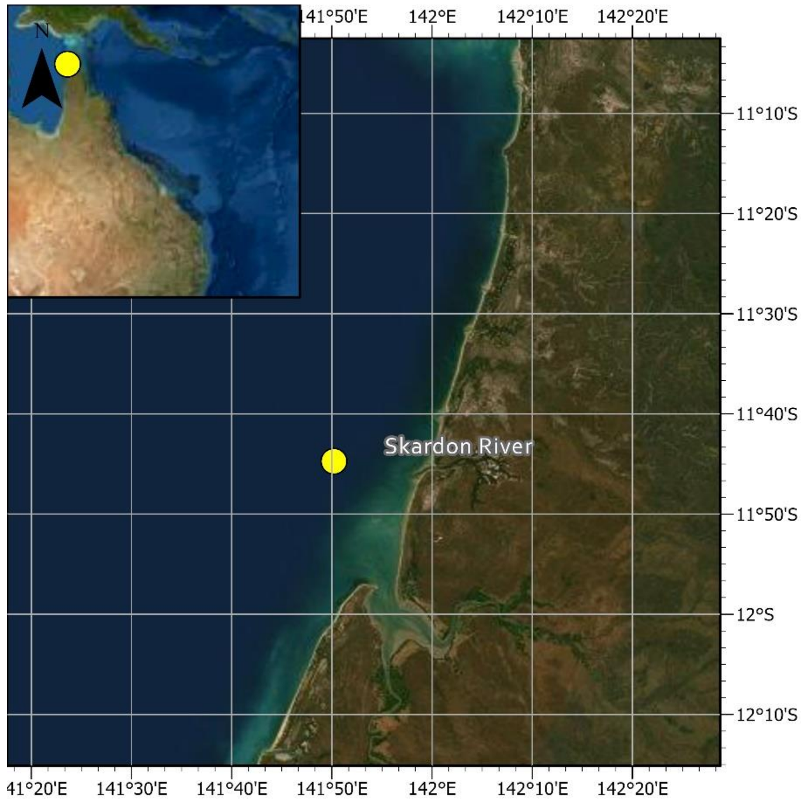


Figure 143 Skardon River Outer – Locality plan

Table 69 Skardon River Outer – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	06/01/2019	N/A	N/A	0.82
2018–19	06/01/2019	N/A	N/A	0.82

Table 70 Skardon River Outer – Buoy deployments for the 2018-19 season

Latitude	Longitude	Type buoy	Depth (m)	Deployed date	Removal date
11° 44.757’ S	142° 50.1918’ E	DWR-MK4	22	06/01/2019	current

Skardon River outer – seasonal overview

The Skardon River Outer wave buoy has been operational for just under 1 year and has had some data communication setbacks during this reporting period. As such, the data presented for the Skardon River Outer monitoring site is limited (Table 69). The buoy was deployed the 2018–19 reporting period on 06 January 2019 (Table 70).

Three significant events were recorded throughout the 2018–19 recording period, with the peak event being an active monsoon trough and low-pressure systems that would later form TC Oma (Table 72). All 3 of the weather events have been added to the top 10 highest waves table (Table 71), with the remaining entries being the next seven highest events in this recording period.

The time series for plot for Skardon River Outer (Figure 144) shows H_{srms}, not H_s. The plot shows clearly defined significant weather events during January and April.

The Sea Surface Temperature (SST) measured in the buoy hull shows the recorded values ranged from 25 °C to 32.5 °C during the reported year. The SST was high enough for tropical cyclone development from the beginning of the record in January to early June with some spikes above 26 °C through to mid-July and infrequent spikes until temperatures begin to climb above 26 °C again at the beginning of October to the end of the reporting period (Figure 145).

The wave directions at the Skardon River outer Site swing from east-north-east to west-south-west throughout the period with swings north-west during significant weather events (Figure 145). The dominance of the incident wave direction is reflected in the directional wave rose plot (Figure 146) with the most common wave height H_s of less than 0.5 m from the south-eastern direction.

Table 71 Skardon River Outer – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	05/02/2019 02:30	3.7	25/01/2019 18:30	6.8
2	25/01/2019 18:30	3.5	05/02/2019 02:30	6.7
3	21/03/2019 02:30	3.5	21/03/2019 02:30	5.5
4	11/05/2019 12.00	1.3	04/06/2019 12.00	2.55
5	21/02/2019 12.00	1.25	21/02/2019 12.00	2.48
6	04/06/2019 12.00	1.14	11/08/2019 12.00	2.28
7	28/03/2019 12.00	1.11	11/05/2019 12.00	2.2
8	11/08/2019 12.00	1.08	28/03/2019 12.00	2.0
9	20/08/2019 12.00	1.01	20/08/2019 12.00	1.79
10	10/09/2019 12.00	1.0	10/09/2019 12.00	1.7

Table 72 Skardon River Outer – Significant meteorological events with threshold Hs of 1.3 metres

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
25/01/2019 18:30	3.5	6.8	9.1	Low pressure monsoon trough extending east to west across Australia to TC Riley off Western Australia
05/02/2019 02:30 Peak Event	3.7	6.7	10	Active Monsoon trough and low-pressure systems that would form TC Oma
21/03/2019 02:30	3.5	5.5	7.4	Passage of TC Trevor from Gulf of Carpentaria to Cape York

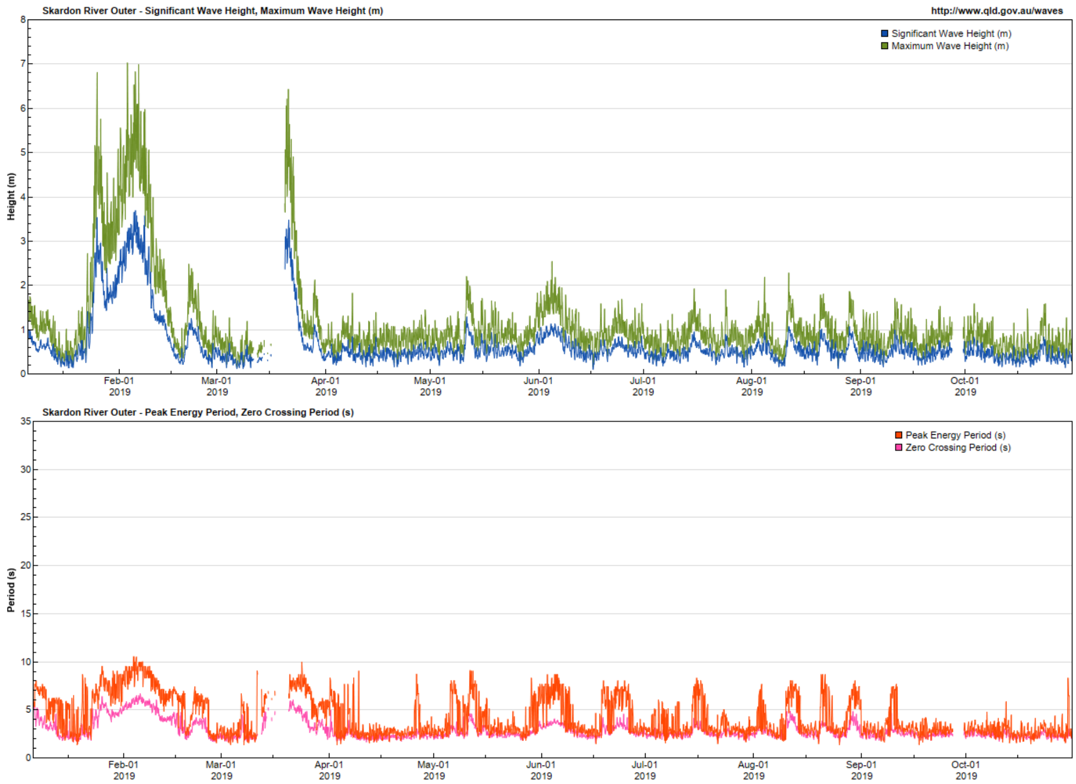


Figure 144 Skardon River Outer – Daily wave recordings

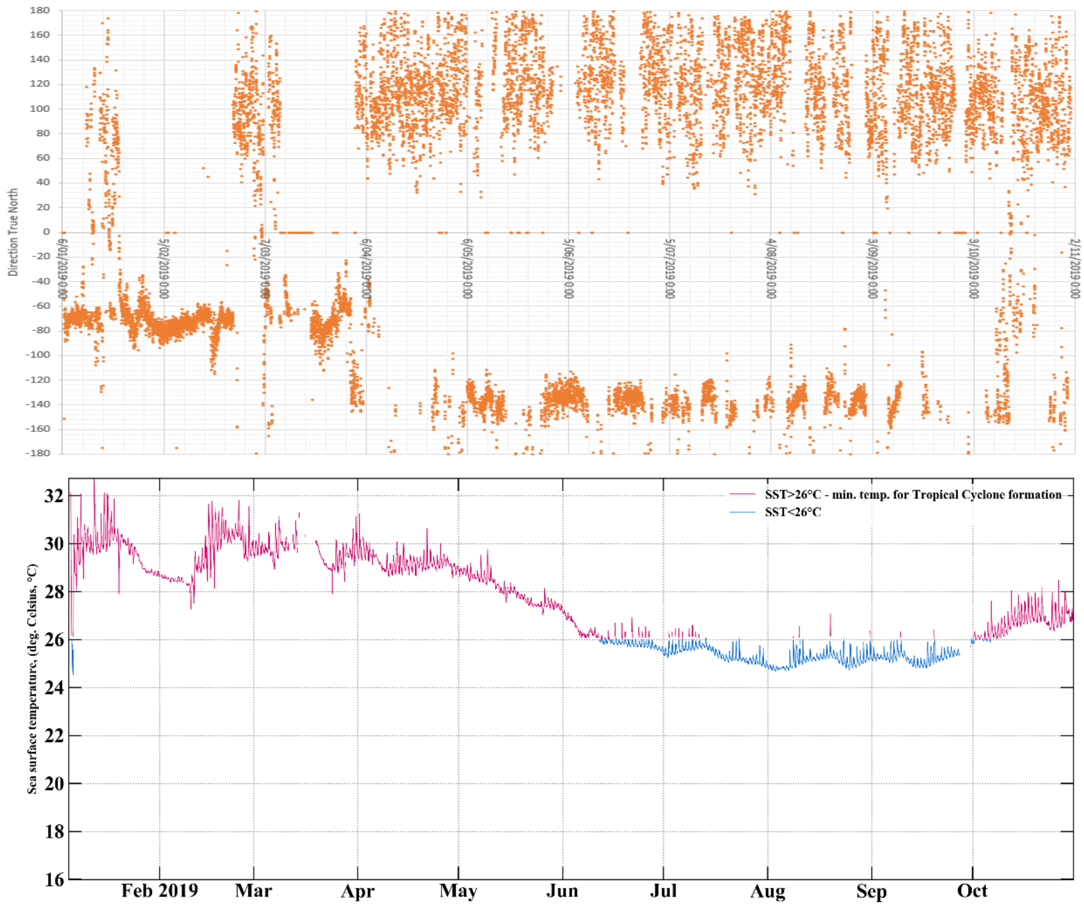


Figure 145 Skardon River Outer – Peak wave directions and sea surface temperature

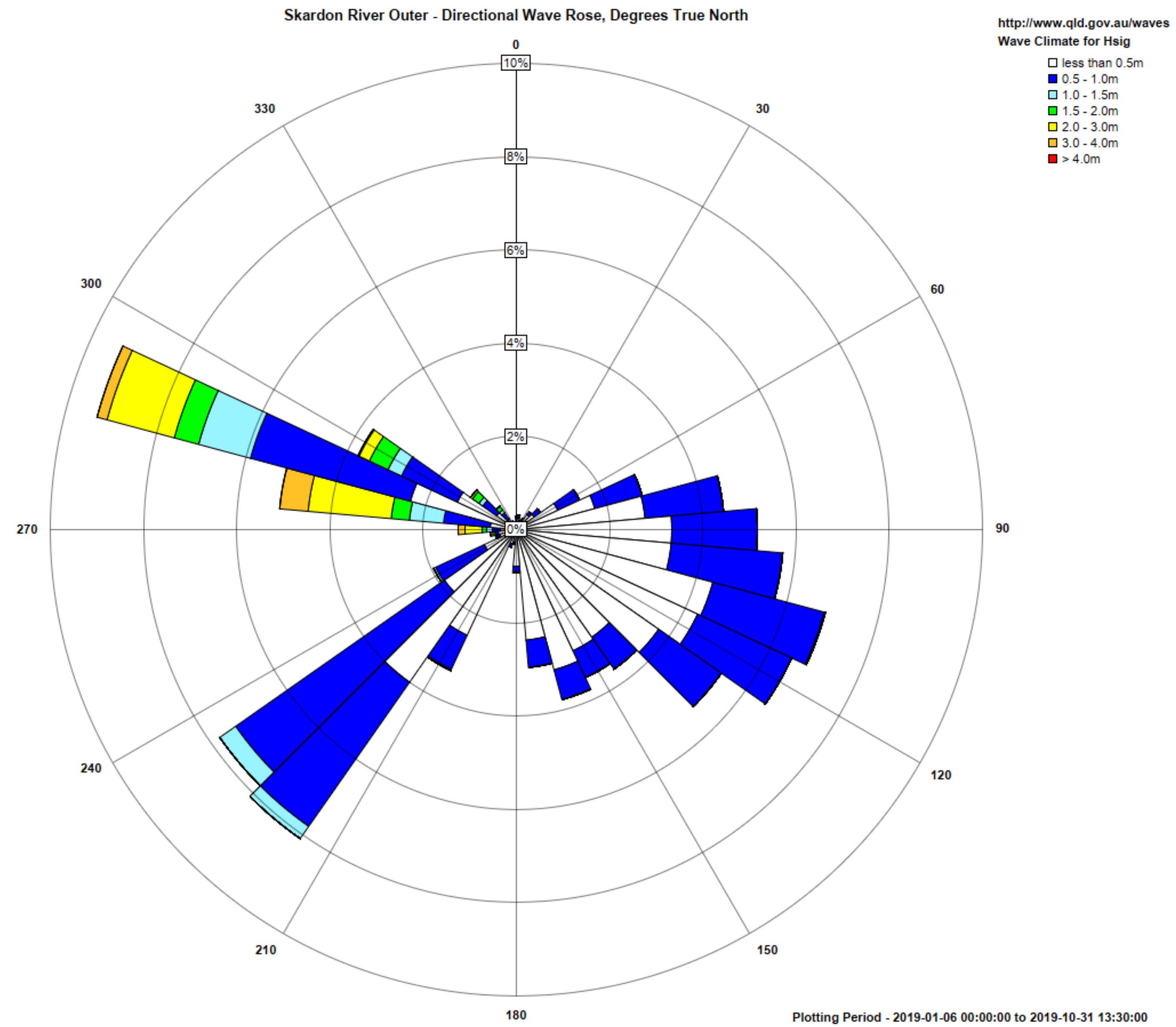


Figure 146 Skardon River Outer – Directional wave rose

Albatross Bay

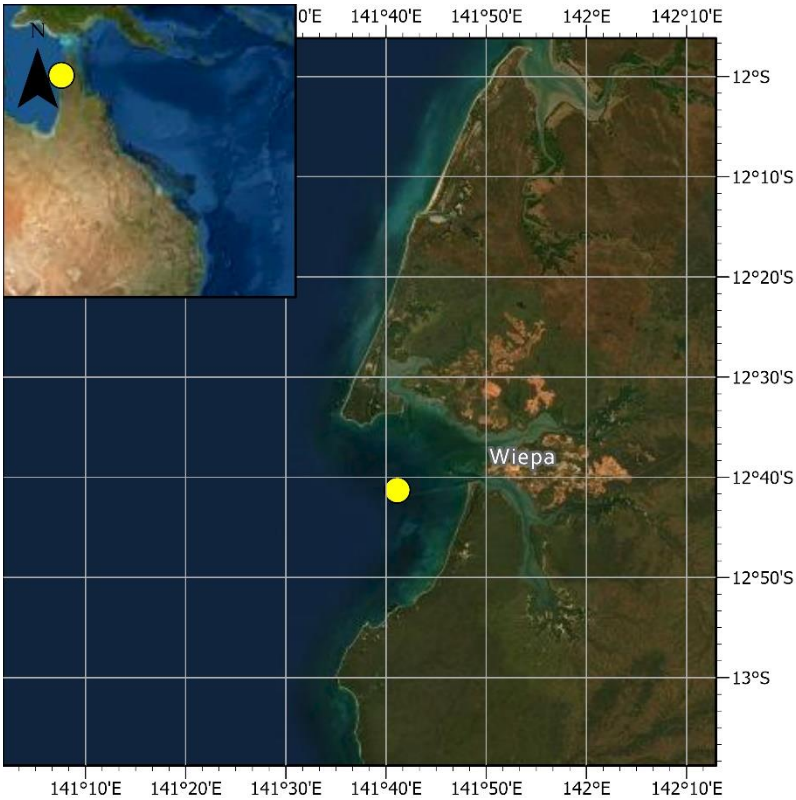


Figure 147 Albatross Bay – Locality plan

Table 73 Albatross Bay – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
2009–19*	16/06/2009*	0.32 years	173727	10.93
2018–19	01/11/2018	8.4 days	17,117	1

*See

Table 2 for site commission date.

Table 74 Albatross Bay – Buoy deployments for the 2018-19 season

Latitude	Longitude	Type buoy	Depth (m)	Deployed date	Removal date
12° 41.276’ S	141° 41.095’ E	DWR-GPS	11.8	10/08/2017	03/08/2019
12° 41.279’ S	141° 41.123’ E	DWR-GPS	12	03/08/2019	current

Albatross Bay – seasonal overview

The Albatross Bay wave buoy has been operational for just under 11 years with an overall data return of 98.26 per cent. The data record for the period November 2018 to October 2019 was good, with total gaps of 8.4 days, equivalent to 97.7 per cent data return (Table 73). The buoy was replaced during the 2018-2019 reporting period on 03 August 2019 (Table 74).

Four significant events were recorded throughout the 2018–2019 recording period, three of which were Tropical Cyclones Owen, Penny and Trevor (Table 76). Three of the weather events produced wave heights that made the top 10 highest waves table (Table 75). Passage of TC Penny from Gulf of Carpentaria to Cape York resulted in the highest Hs event and second highest H_{max} wave at Albatross Bay this period.

Time series for H_s at Albatross Bay (Figure 148) shows clearly defined peaks for the 4 significant weather events from December through to April. A number of events occurred throughout the period which also produced spikes in wave heights with lower H_S and H_{max}.

The Sea Surface Temperature (SST) measured in the buoy hull shows the recorded values ranged from 24.5 °C to 34 °C during the reported year. The SST was high enough for tropical cyclone development from the beginning of November to early June where night-time temperatures begin to drop below 26 °C until the end of July. Day time temperatures begin to climb above 26 °C again through August and September and then exceed 26 °C for the remainder of the record (Figure 149).

Monthly average H_s showed 5 months varied by more than 1 standard deviation to the long-term mean. November, December and February were all higher than 1 sd and July and October were below 1 sd outside range established since 2008 (Figure 150).

Wave climate for the reporting period shows a departure from the trend with higher H_s waves in summer due to tropical cyclone activity, this has resulted in significant departure from the all-time data in the plot (Figure 151). Winter waves had substantially lower exceedance this period than all winter data. The histograms for percentage occurrence of H_s (Figure 152) show a similar distribution to the trend with a decrease in waves up to 0.2 m H_s throughout the period. Small variations in occurrence are noted in winter waves from 0.4 to 1.0 m H_s. Summer waves exceeding 1.6 m and up to 3.0 m H_s are visible also. Histograms for peak wave period T_p (Figure 153) were very similar this reporting period compared to the whole record, with the T_p values between the 1 to 3 second period being the most predominant. A small percentage decrease in occurrence of 3 to 5 second T_p waves and small increase in 7 to 9 second T_p waves can be noted.

The ratios between different wave parameters show very little deviation between this reporting period and the trends established by the historic data, these are plotted in Figure 154.

The wave directions during summer were from west-northwest and in winter southwest with swings north throughout the period (Figure 149). The dominance of the incident wave direction is reflected in the directional wave rose plot (Figure 155) with the most common wave height H_s of less than 0.5 metres from the southwestern direction.

Table 75 Albatross Bay – Highest waves

Rank	Date (H_s)	H_s (m)	Date (H_{max})	H_{max} (m)
1	24/03/2018 15:00	4.3	22/01/2013 13:00	6.7
2	22/01/2013 13:00	4.1	24/03/2018 15:00	6.6
3	01/01/2019 11:00	3.6	21/03/2019 14:30	6
4	12/01/2009 00:00	3.5	11/01/2009 23:30	5.7
5	30/01/2010 03:00	3.3	03/02/2019 21:30	5.6
6	20/03/2019 16:00	3.2	30/01/2010 05:30	5.5
7	05/02/2019 10:30	3.1	31/12/2018 22:00	5.5
8	02/02/2012 08:30	2.7	09/01/2015 08:30	5.4
9	19/03/2012 02:30	2.6	03/02/2012 09:00	5.1
10	31/01/2018 08:00	2.6	19/02/2014 08:00	5

Table 76 Albatross Bay – Significant meteorological events with threshold Hs of 1.3 metres

Date	H_s(m)	H_{max}(m)	T_p(s)	Event
15/12/2018 10:30	2.3	3.9	7.7	Passage of TC Owen from Gulf of Carpentaria to Cape York
01/01/2019 11:00 Peak Event	3.6	5.5	10.4	Passage of TC Penny from Gulf of Carpentaria to Cape York
05/02/2019 10:30	3.1	5.6	9.6	Low pressure systems near Vanuatu that would later form TC Oma
20/03/2019 16:00	3.2	6	8.2	Passage of TC Trevor

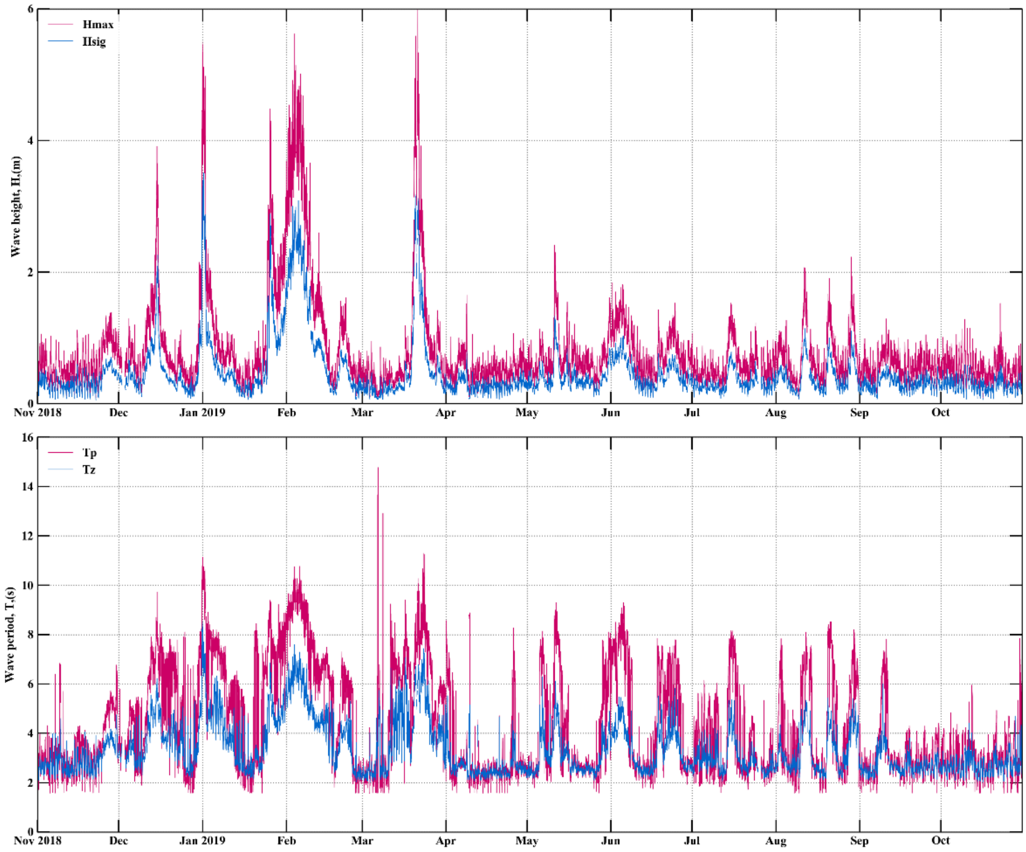


Figure 148 Albatross Bay – Daily wave recordings

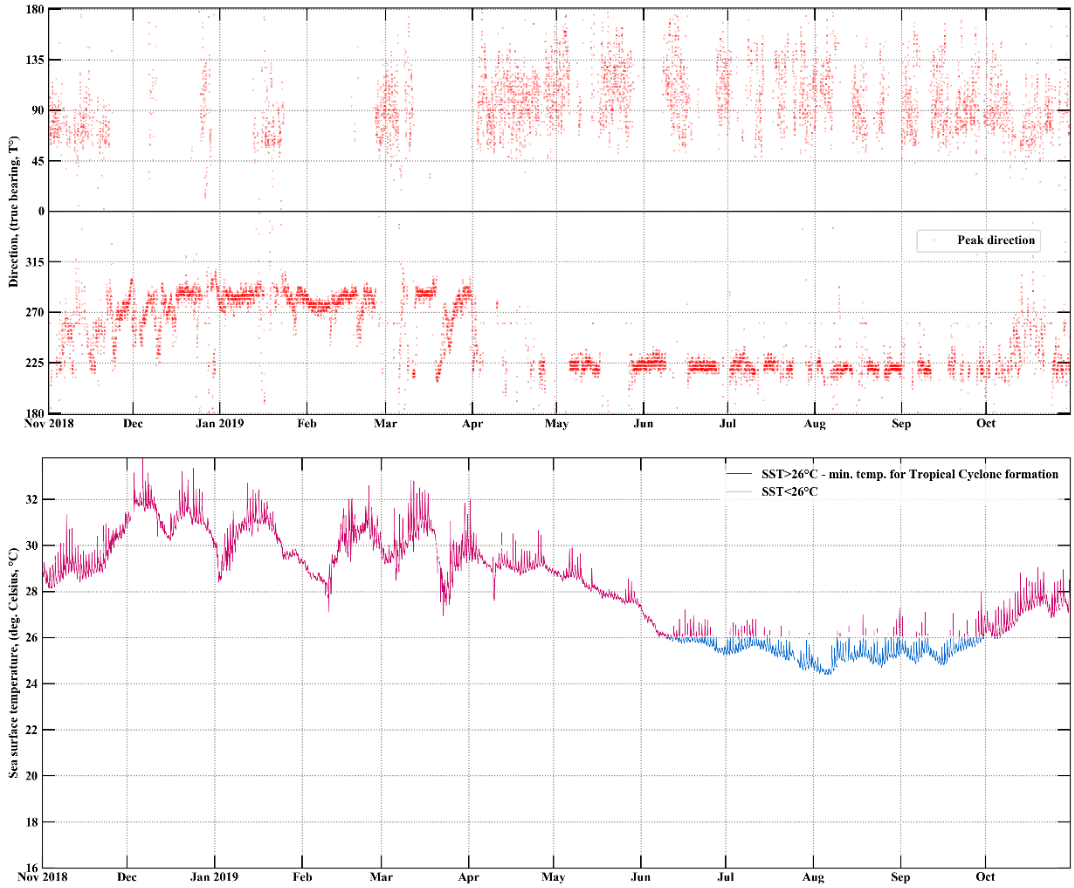


Figure 149 Albatross Bay – Peak wave directions and sea surface temperature

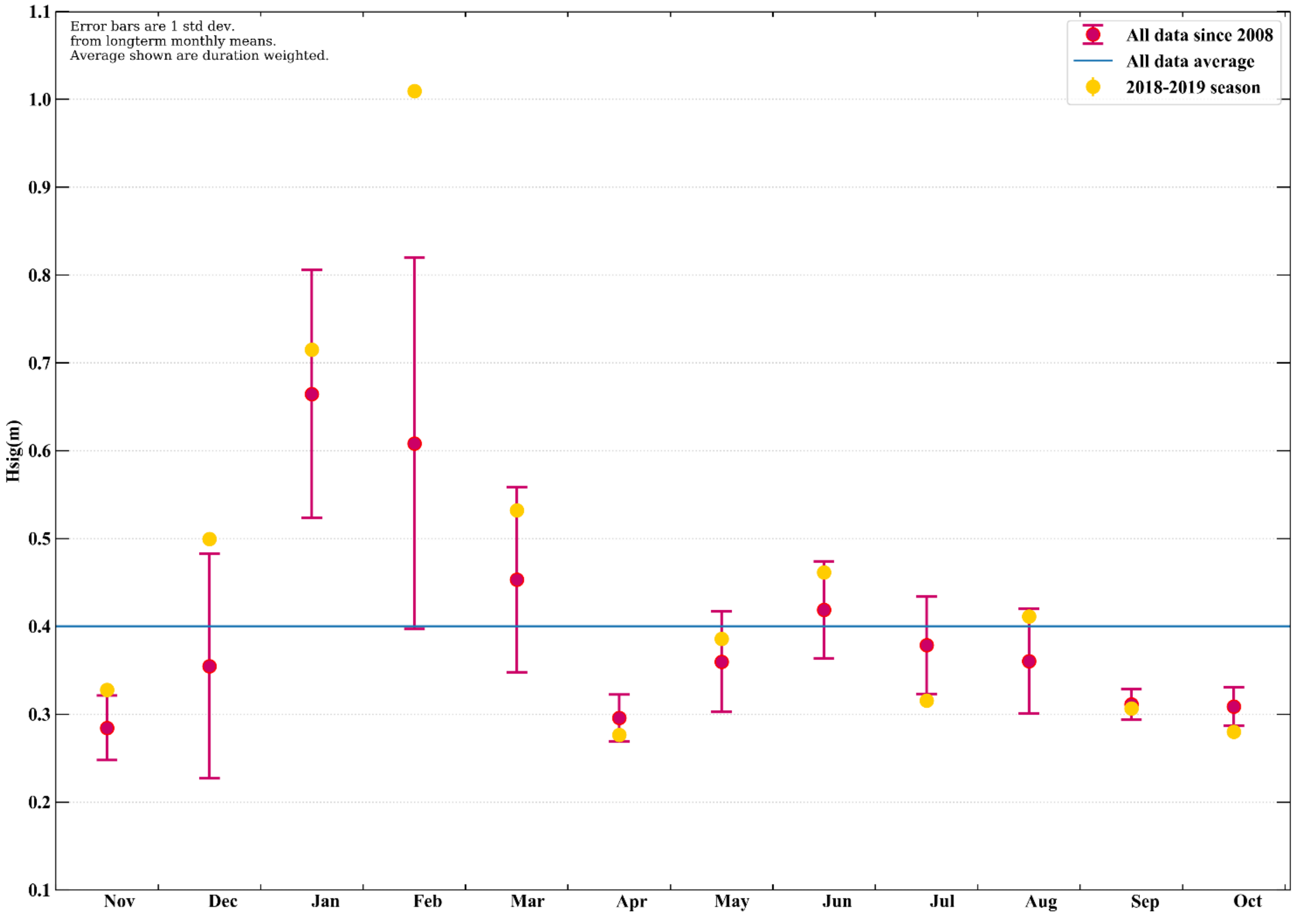


Figure 150 Albatross Bay – Monthly average wave height (H_s) for seasonal year and for all data

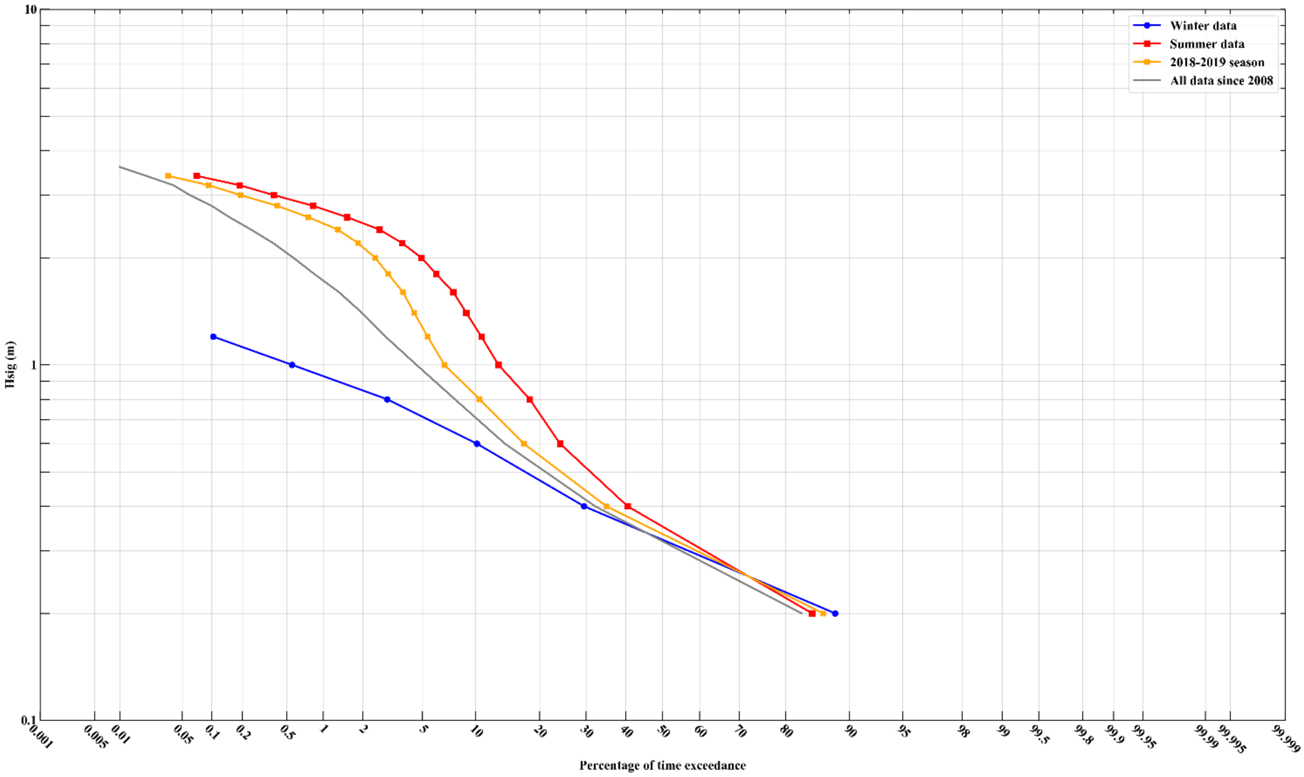


Figure 151 Albatross Bay - Percentage exceedance of wave height (H_s)

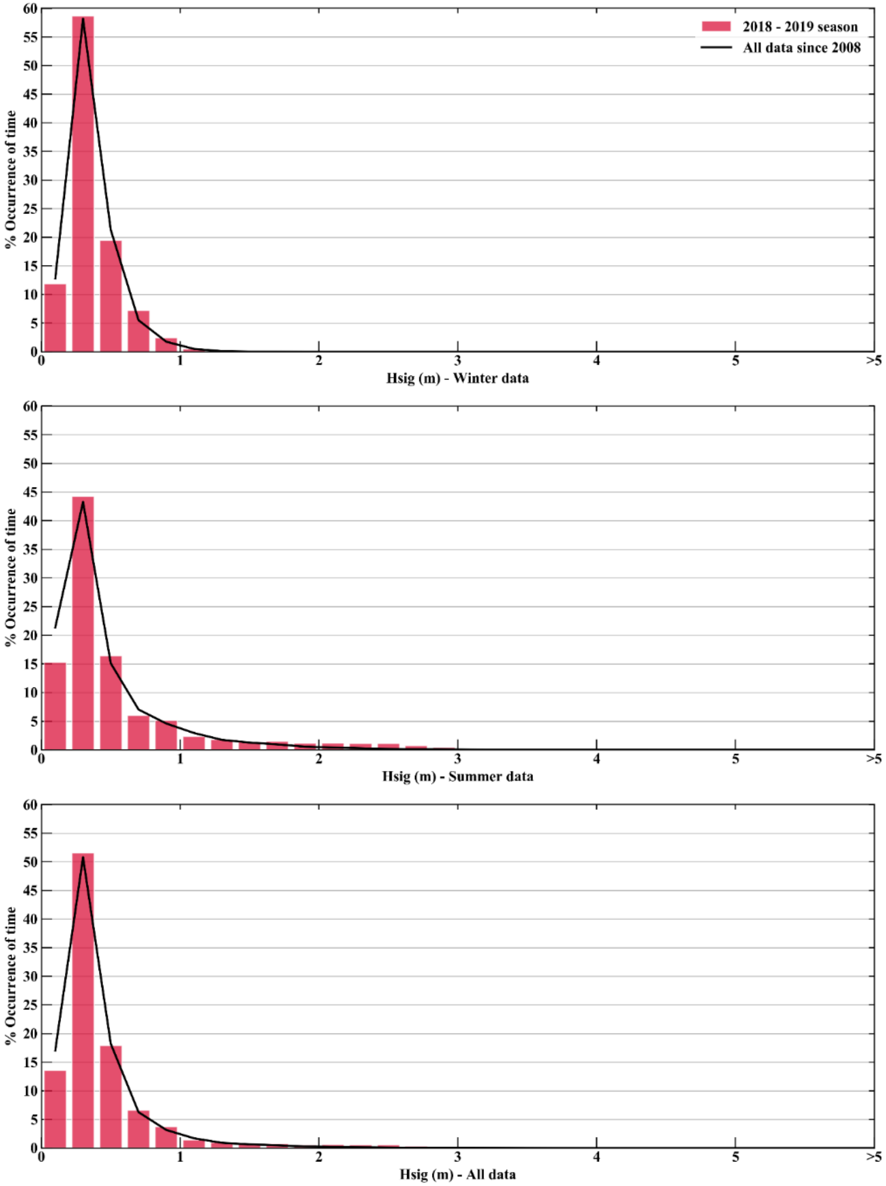


Figure 152 Albatross Bay – Histogram percentage (of time) occurrence of wave heights (H_s)

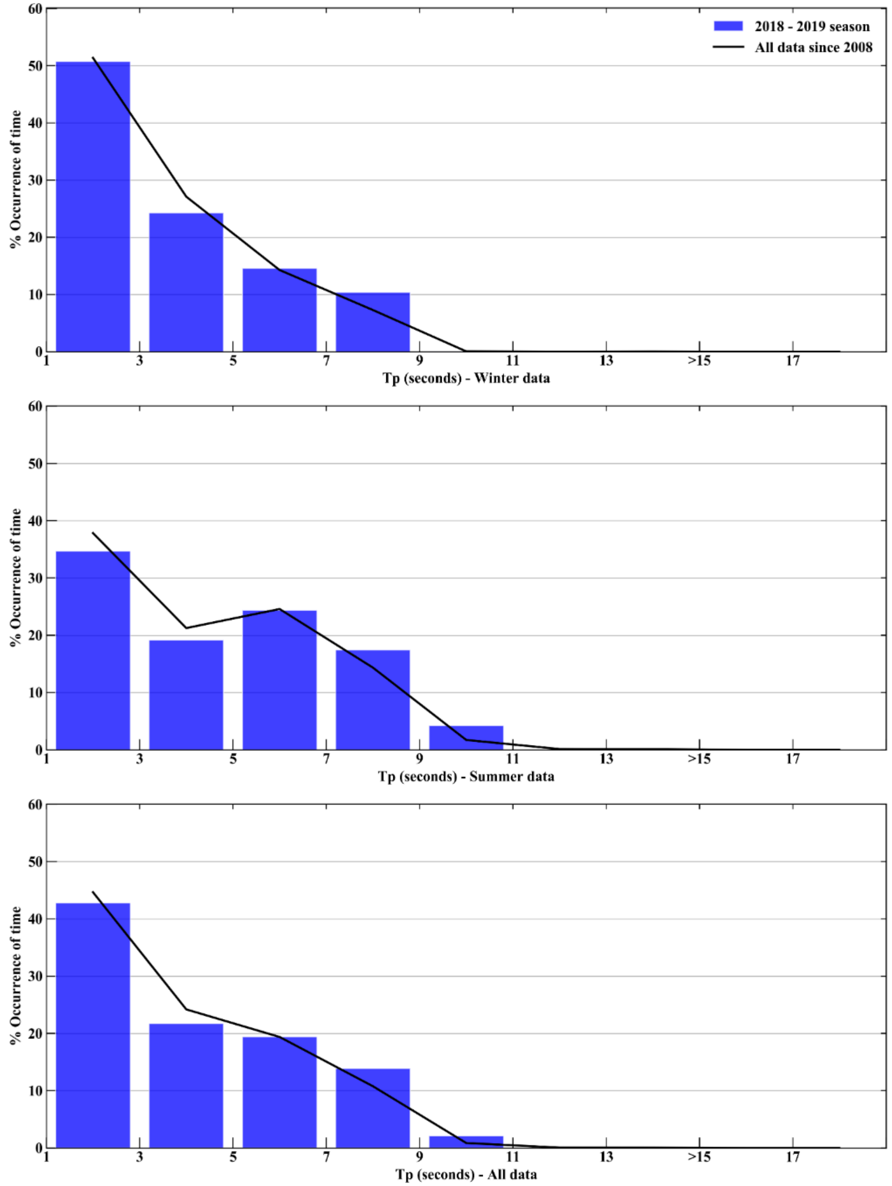


Figure 153 Albatross Bay – Histogram percentage (of time) occurrence of wave periods (T_p)

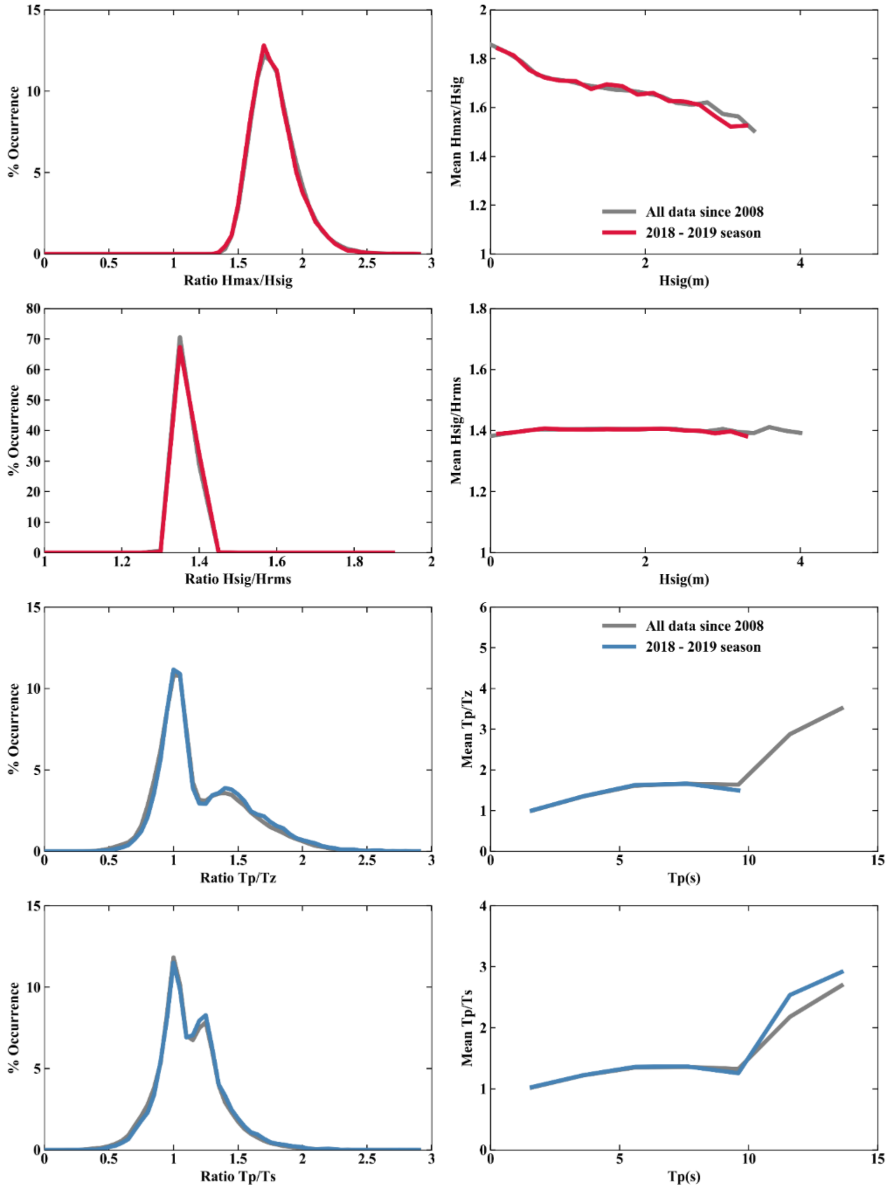


Figure 154 Albatross Bay – Wave parameter relationships

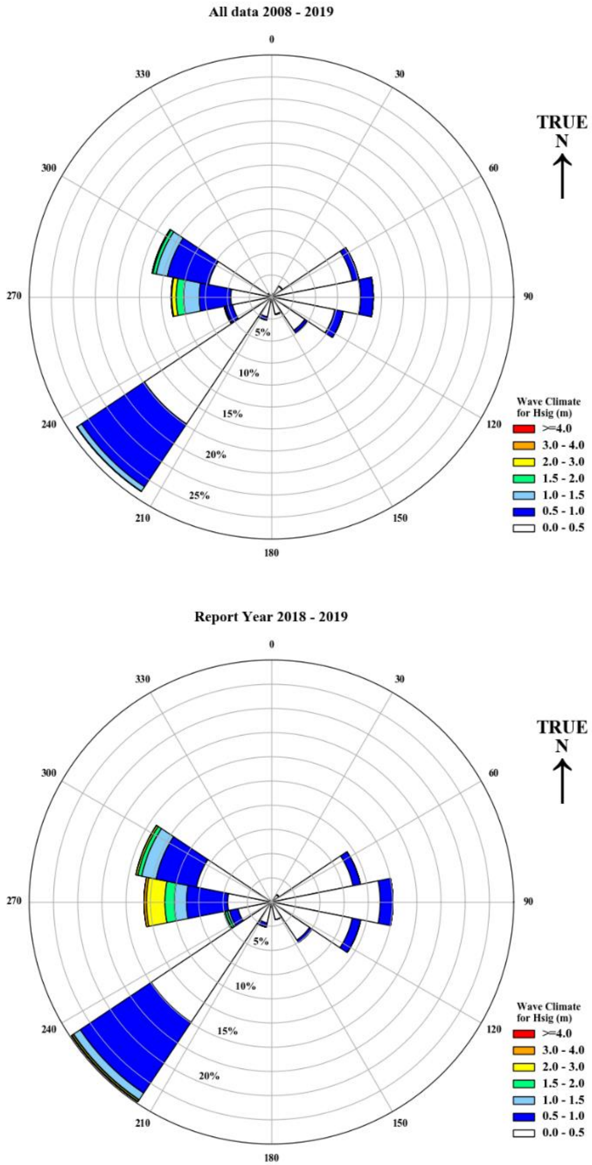


Figure 155 Albatross Bay – Directional wave rose

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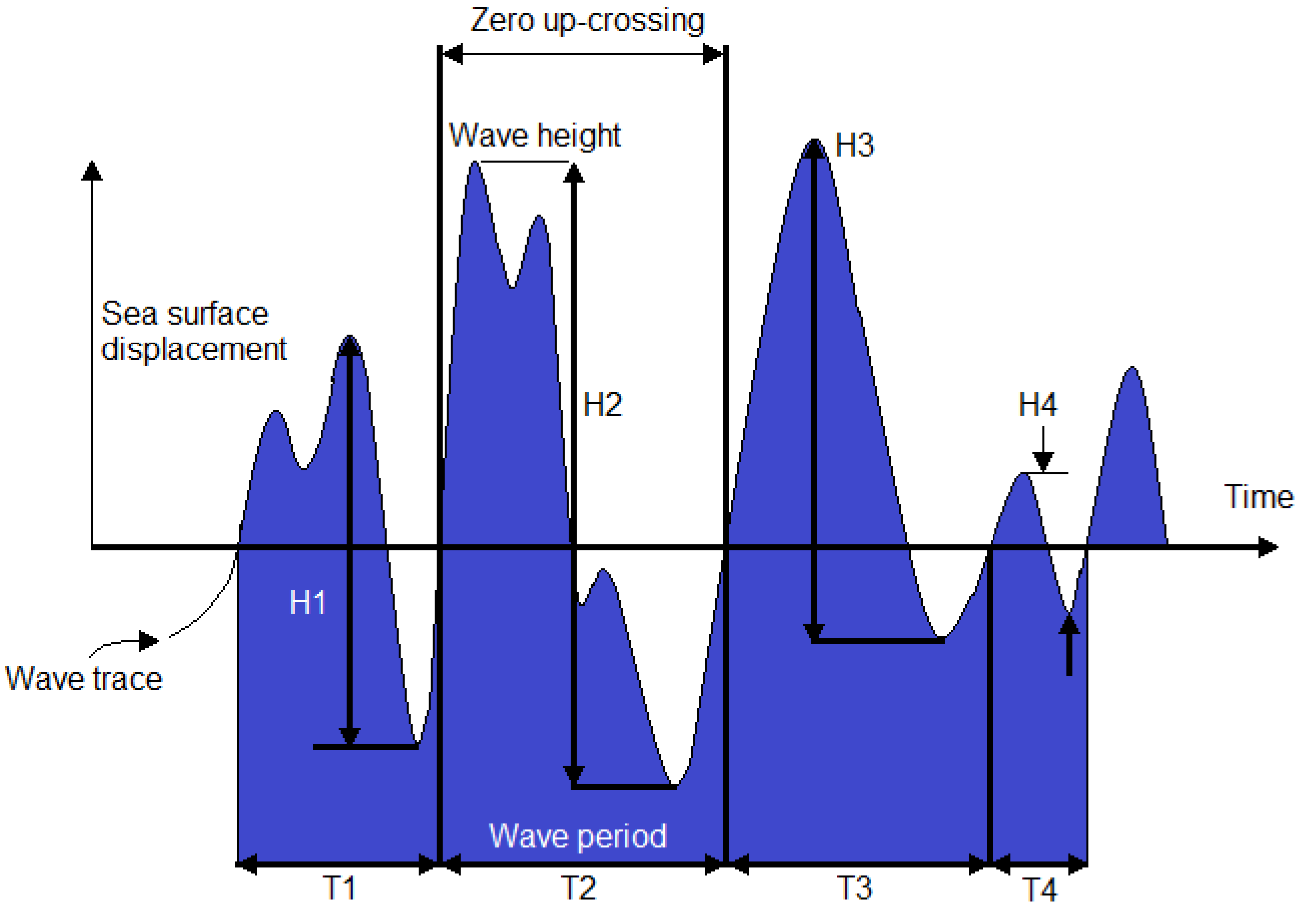
Appendix A Zero up-crossing analysis

Zero up-crossing analysis is a direct, repeatable and widely accepted method to extract representative statistics from wave traces recorded by a wave measuring buoy. A wave is defined as the portion of the record between 2 successive zero up-crossings of the mean water line. Waves are ranked, with their corresponding periods, and statistical wave parameters are computed in the time domain.



Appendix B Comparison between GPS and Mk4 at Tweed Heads

DES strives for continual improvement regarding the scientific instrumentation utilised as part of Queensland's wave monitoring network. The next generation of waverider buoy is the DWR-Mk4, which are poised to replace older buoy models that are currently used throughout the wave monitoring network. As such a dual deployment of a DWR-G and Mk4 waverider buoy has been arranged at Tweed Heads. The buoys are moored approximately 250 m apart as seen in Figure B.1. There are 2 major differences between the two units: 1) an increase in sampling frequency for the Mk4 and; 2) a change in the calculating method utilised for spectral data. An in-depth report outlining the differences between the two buoy models has been undertaken by DISITI (2017) and can be found as an addendum. A comparison of the data collected from both the DWR-G and Mk4 is provided below (Figure B.2 and Figure B.3). It is important to note that due to the nature of the comparison simultaneous records for both devices were necessary, as such corresponding data points to any data outages from one buoy were removed from the record for the other. Comparison is for the period 10/06/2017 – 30/04/2018.

Figure B.1: Locality plan for the Tweed Heads DWR-G and MK4 buoys

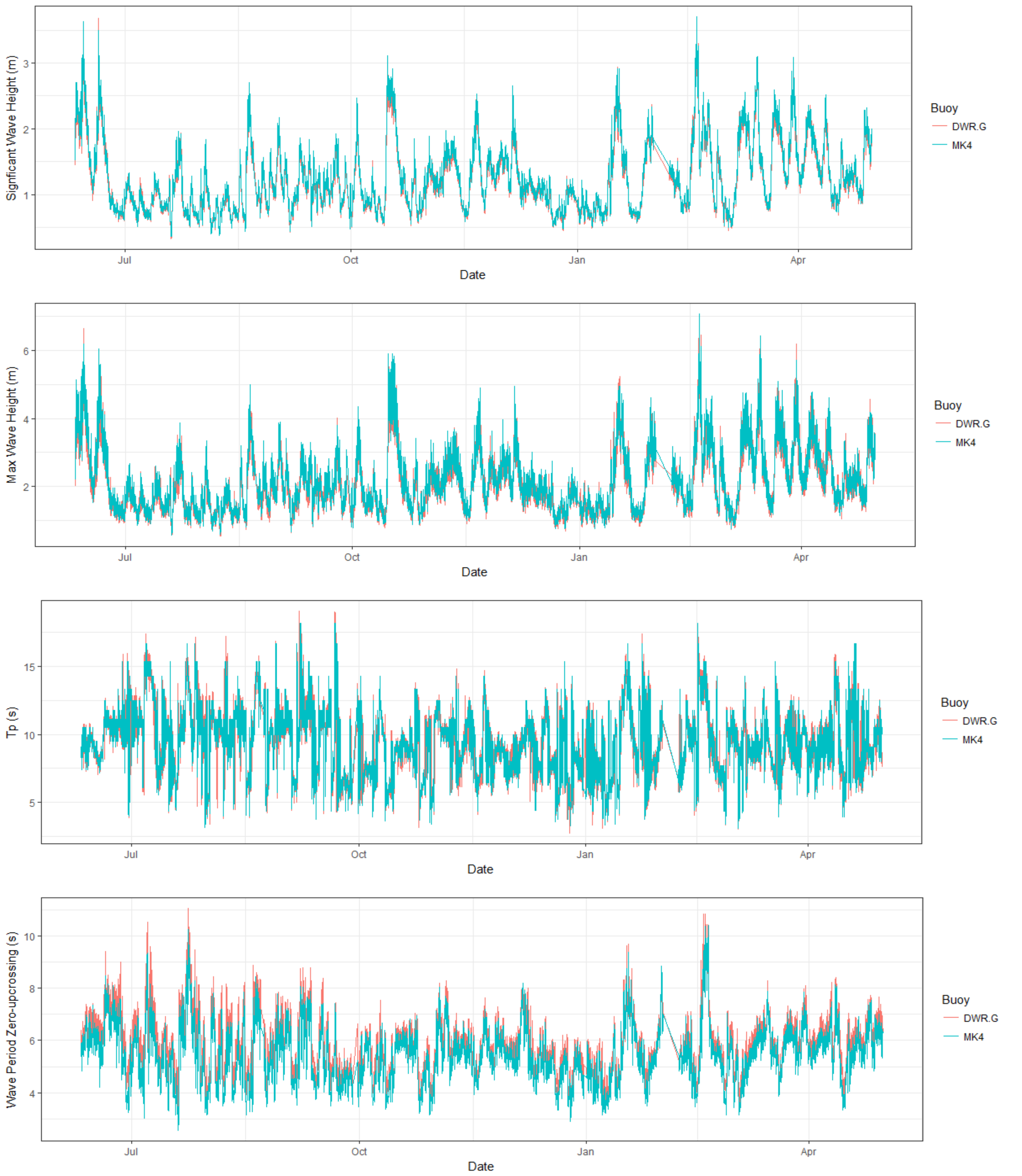


Figure B.2: Comparison between the Tweed Heads DWR-G and MK4 parameters; H_s, H_{max}, Tp, Tz

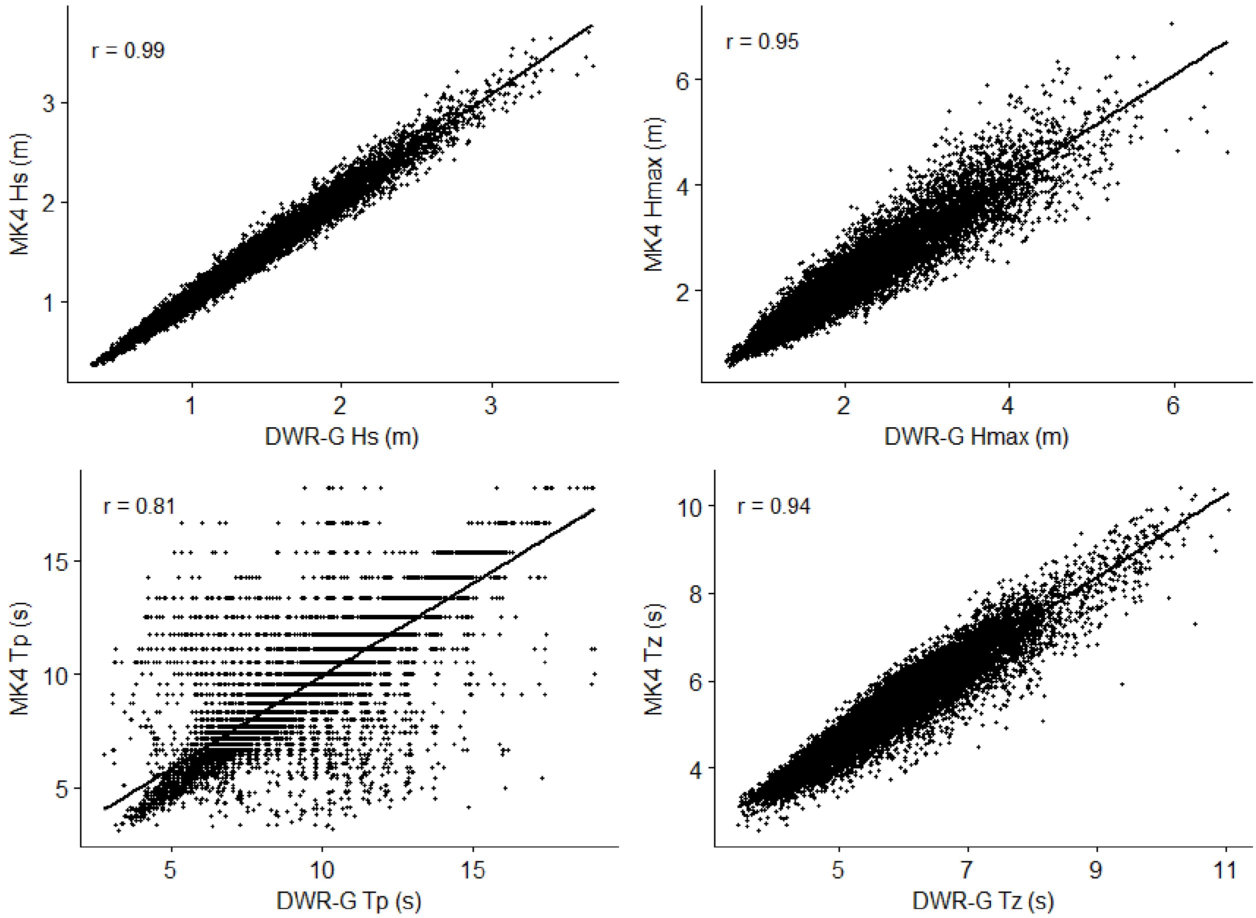


Figure B.3: Spearmans correlation coefficient between the DWR-G and Mk4 parameters; H_s, H_{max}, Tp, and Tz

As seen in Figure 5.3 H_s, H_{max} and Tz between the MK4 and DWR-G have a high correlation (r 0.99, 0.95, 0.94 respectively), Tp on the other hand has a weaker correlation (r 0.81). Whilst both devices calculate Tp in a similar manner, there are differences in both sampling frequency and the amount of spectral bins utilised. As such, differences in Tp between the two devices are to be expected. Bimodal sea states also have the potential to effect Tp, due to the potential for each device to pick up alternate peak periods from differing wave fields. For a more in-depth comparison of the Mk4 to the MKIII refer to DSITI (2017).

This part has been copied from the Tweed Heads/ Brisbane wave climate annual summary May 2017 – April 2018, prepared by CIU, (DSITI, 2017).

Appendix C Glossary

Parameter	Description
H_s	The significant wave height (in metres), defined as the average of the highest one-third of the zero up-crossing wave heights in a 26.6-minute wave record. This wave height closely approximates the value a person would observe by eye. Significant wave heights are the values reported by the Bureau of Meteorology in their forecasts.
T_{Hs}	The average period of the highest one-third of zero up-crossing wave heights
H_{rms}	Root mean square wave height from the time domain
H_{max}	The maximum zero up-crossing wave height (in metres) in a 26.6-minute record.
Kurtosis	The sharpness of the peak of a frequency-distribution curve.
T_c	The average crest period (in seconds) in a 26.6-minute record.
T_z	The average of the zero up-crossing wave periods (in seconds) in a 26.6-minute record.
H_{10}	Average of the highest 10 percent of all waves in a record
T_{H10}	The period of the H10 waves
T_{Hmax}	Period of maximum height, zero up-crossing
T_{zmax}	The maximum zero crossing in a record
H_{m0}	Estimate of the significant wave height from frequency domain $4\sqrt{m_0}$
$T_{0,2}$	Average period from spectral moments zero and two, defined by $\sqrt{m_0/m_2}$
T_p	Wave period at the peak spectral energy (in seconds). This is an indication of the wave period of those waves that are producing the most energy in a wave record. Depending on the value of Tp, waves could either be caused by local wind fields (sea) or have come from distant storms and have moved away from their source of generation (swell).
Dir_p	Direction the Peak Period waves are coming from (in °TRUE)
Wave setup	The increase in mean water level above the SWL towards the shoreline caused by wave action in the surf zone. The amount of rise of the mean water level depends on wave height and beach slope such that setup increases with increasing wave height and increasing beach steepness. It can be very important during storm events as it results in a further increase in water level above the tide and surge levels.