Department of Environment and Science

Queensland Wave Climate

Wave Monitoring Annual Summary

November 2015 – October 2016

Queensland Government

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Citation

DES. 2018. Queensland wave climate; wave monitoring annual summary, November 2015 to October 2016. Brisbane: Department of Environment and Science, Queensland Government.

Acknowledgements

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Contents

List of Tables

List of Figures

Executive Summary

This summary of wave climate in Queensland is prepared annually by the Coastal Impacts Unit (CIU) of the Department of Environment and Science (DES) (known formerly as the Department of Science, Information Technology and Innovation (DSITI)). Annual wave reports supplement the reporting ability of the CIU 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 2015 to 31 October 2016.

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 for the new Bundaberg site, where a non-directional Waverider buoy is deployed. The Cairns buoy was changed to a directional buoy on 27 February 2016. 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 have 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 2015–16 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.

Figure 3 graphically illustrates the tracks and intensities of the cyclones during the 2015–2016 season. The information presented in this figure was obtained from the Bureau of Meteorology database of cyclone tracks. Each cyclone track is represented by points of cyclone intensity at daily intervals, depicting the geographic location of the cyclone at midnight each night.

The Queensland coast did not encounter a cyclone during the reporting year but was subjected to a several east coast lows, with one as a results of ex tropical cyclone (TC) Tatiana.

The largest weather event seen along the Queensland coast was an east coast low during June. This upper level trough moved off the mainland and developed into an east coast low. The results from this low was seen along the entire Queensland coast with the maximum wave height of 11.2 m observed at the Gold Coast wave station.

The low pressure system created by ex TC Tatiana was the second largest event during the year. TC Tatiana started north of Noumea on 12 February 2016 and lost intensity as it moved west towards Australia through the Pacific Ocean. By the time it had an effect on the Queensland coastline it was an east coast low which travelled north along the coast before moving further out to sea.

During February 2016 the wave height along the coast were elevated with the largest waves experienced in the southern region of the QLD coast, with the largest waves seen from Mooloolaba south.

Introduction

This summary of wave climate in Queensland is one of a series of technical wave reports prepared annually by the Coastal Impacts Unit of the Department of Environment and Science (DES). Annual wave reports supplement the reporting ability of DES's Coastal Impacts Unit 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 2015 to 31 October 2016.

The data covers all of the seasonal variations for one year, and includes the 2015–16 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'. 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 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 2015 to October 2016

Long-term	Project partnership	Project partner agencies
Brisbane		
Bundaberg		
Emu Park		
Mackay		
Townsville		
Cairns		
	Tweed Heads	TRESBP*
	Gold Coast	Gold Coast City Council
	Caloundra	Port of Brisbane Corporation
	North Moreton Bay	Port of Brisbane Corporation
	Mooloolaba	Department of Transport and Main Roads
	Gladstone	Gladstone Ports Corporation
	Hay Point	North Queensland Bulk Ports Corporation Ltd

	Abbot Point	North Queensland Bulk Ports Corporation Ltd
	Albatross Bay (Weipa)	North Queensland Bulk Ports Corporation Ltd

* Tweed River Entrance Sand Bypassing Project, a joint project of Queensland and New South Wales Governments with support from the Council of the City of Gold Coast.

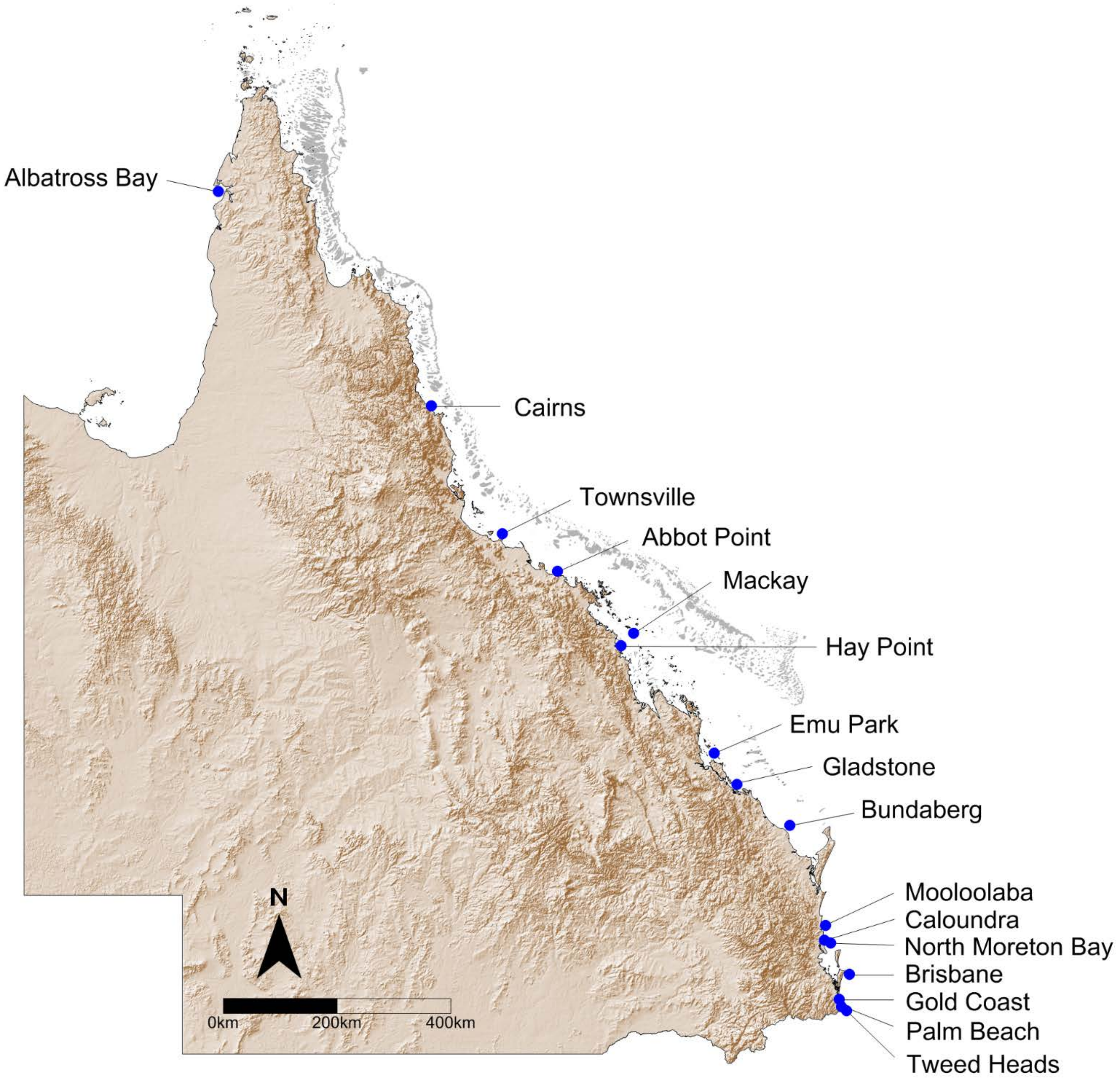


Figure 1 DES wave monitoring sites in Queensland

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

Site	Start date	End date	Restart	Directional start date	Total years	Directional years
Tweed Heads	13/01/1995	-	-	13/01/1995	21.8	21.8
Gold Coast	21/03/1987	-	-	17/07/2007	29.6	9.3
Brisbane	31/10/1976	-	-	20/01/1997	40.0	19.8
Caloundra	01/05/2013	-	-	01/05/2013	3.5	3.5
North Moreton Bay	08/03/2010	-	-	08/03/2010	6.7	6.7
Mooloolaba	20/04/2000	-	-	11/05/2005	16.5	11.5
Bundaberg	08/09/2015	-	-	-	1.1	-
Gladstone	23/09/2009	-	-	23/09/2009	7.1	7.1
Emu Park	24/07/1996	-	-	24/07/1996	20.3	20.3
Hay Point	24/04/1977	25/05/1987	3/04/1993	31/10/2009	33.7	7.0
Mackay	19/09/1975	-	-	13/03/2002	41.1	14.6
Abbot Point	17/01/2012	-	-	17/01/2012	4.8	4.8
Townsville	20/11/1975	-	-	29/10/2008	41.1	8.0
Cairns	04/05/1975	-	-	26/02/2016	41.5	0.7
Albatross Bay (Weipa)	22/12/1978	-	-	25/11/2008	38.9	8.9

Wave monitoring equipment

For the monitoring period documented in this summary report DES's Coastal Impacts Unit wave monitoring program utilised the Waverider buoy system manufactured by Datawell of the Netherlands to measure the sea surface fluctuations at coastal locations. Directional Waverider buoys were in operation at all sites except Cairns during the period of this report. A non-directional Waverider buoy is deployed at Bundaberg.

Accelerometer Buoys

The directional Waverider buoys at the Brisbane, Cairns, Gold Coast, Gladstone, Emu Park, Abbot Point, Mackay, and Townsville sites measure 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 x and y 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 displacement values for recording.

Only waves with 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 (Datawell, 2010).

GPS Buoys

The directional Waverider buoys at the Tweed Heads, Caloundra, North Moreton Bay, Mooloolaba, Emu Park, 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.

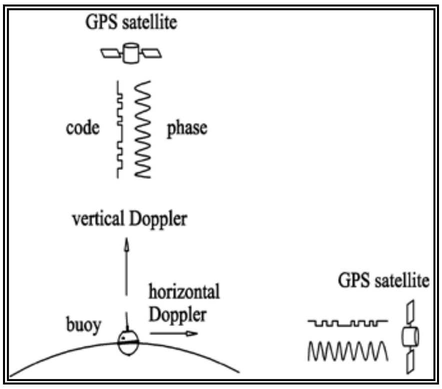


Figure 2 The GPS wave measurement principle (Datawell, 2010)

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 directional Waverider receiver stations on shore are each comprised of a computer system connected to a Datawell receiver/digitiser. The water level data at each site is digitised at 0.78 second intervals (1.28 Hz) and stored in bursts of 2,048 points (approximately 26 minutes) on the hard disk of the computer.

The software running on the computer 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 downloaded every hour to a central computer system in Brisbane for checking, further processing, and archiving. Data are also stored on-board each buoy as a data backup should communication of data to the receiver station fail.

Quality checks

Waverider buoys used by DES are calibrated before deployment and after recovery. Generally a buoy is calibrated every 12 months. Accelerometer buoys are calibrated at DES's Deagon site using a 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 the GPS buoys involves placing it in a fixed location on land for a period of several days while it records data. This location should be such that there are no obstructions between the buoy and the orbiting GPS satellites. A GPS buoy 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 averages are calculated based on available data and wave data records are rejected based on 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: losses due to equipment failure; and 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 analysis

The computer-based, wave-recording systems at all sites record data at half-hourly intervals. Raw 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 Fast Fourier Transform (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 data sub-sets and each sub-set is analysed using FFT techniques. 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 systems. Wave parameters resulting from the time and frequency domain analysis included the following:

Table 3 Parameters involved in the analysis

Parameter	Description
S(f)	Energy density spectrum (frequency domain)
Hsig	Significant wave height (time domain), the average of the highest third of the waves in the record
Hmax	The highest individual wave in the record (time domain)
Hrms	The root mean square of the wave heights in the record (time domain)
Tsig	Significant wave period (time domain), the average period of the highest third of waves in the record
Tz	The average period of all zero up-crossing waves in the record (time domain)
Tp	The wave period corresponding to the peak of the energy density spectrum (frequency domain)
Tc	The average period of all the waves in the record based on successive crests (time domain)
Dir	The direction (frequency domain) from which the peak period waves (Tp) are coming (in ° True)

SST	Sea surface temperature (in ° Celsius) sensor mounted inside the buoy.

These parameters form the basis for the summary plots and tables included in this report and provide the basic parameters used for coastal 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

Table 4 Tropical Cyclones in the Queensland region during the 2015–2016 season

Name	Start Time (AEDT)	End Time (AEDT)	Category	Central Pressure (hPa)
Tatiana	10/02/2016 10:00	15/02/2016 20:00	2	983
Winston	10/02/2016 10:00	27/02/2016 06:00	5	907

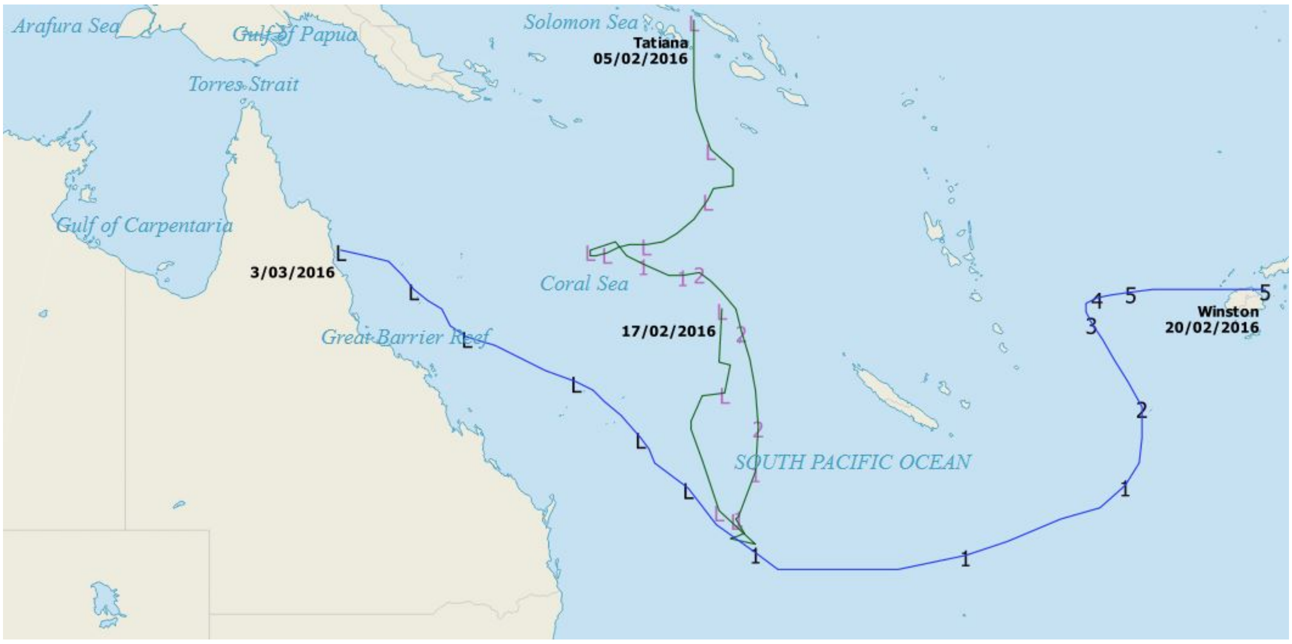


Figure 3 Tropical cyclones affecting Queensland coastline during the 2015–2016 season

There were two tropical cyclones that entered the Queensland region during the 2015 – 16 season. Tropical cyclone Winston travelled towards the east coast after devastating Fiji as a category 5 severe tropical cyclone. Winston then decayed into a tropical low pressure system and turned towards the North West travelling parallel with the coast. Tropical cyclone Tatiana developed in the Solomon Sea and generally travelled south through the Coral Sea. Tatiana developed into a category 2 system before weakening to a tropical low pressure system and turning around to travel back toward the north.

Queensland wave climate

Tweed Heads

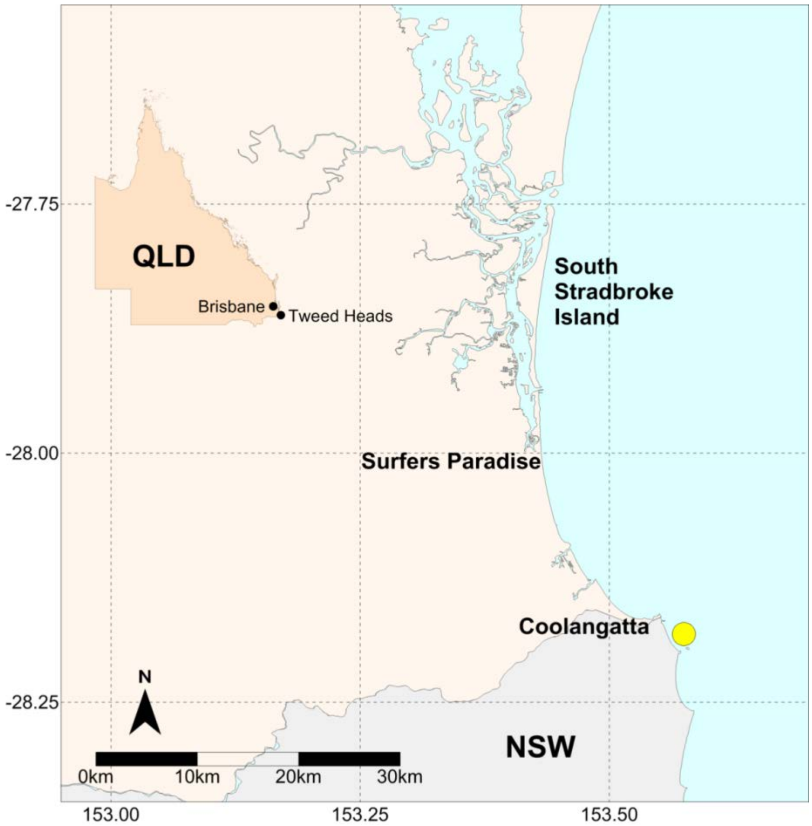


Figure 4 Tweed Heads – Locality plan

Table 5 Tweed Heads – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	13/01/1995	0.31 years	325,791	21.8
2015–16	01/11/2015	2.08 days	17,467	1

Table 6 Tweed Heads – Buoy deployments during the 2015–16 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
28°10.664' S	153°34.590' E	24	24/02/2016	current

Tweed Heads – seasonal overview

The Tweed Heads wave buoy has been operational for nearly 22 years with an overall data return of 98.5 per cent. The data recorded for the period November 2015 to October 2016 was excellent, with total gaps of only 2.08 days, equivalent to 99.4 per cent data return. The buoy was replaced once during the reporting period on 24 February 2016 (Table 6).

The Tweed Heads wave buoy was exposed to five significant events during the reporting period. The event that generated the largest wave conditions occurred on the 04 June (Table 8), with a significant wave height (Hsig) of 5.6 m and a maximum wave height (Hmax) of 9.8 metres. The largest waves generated during this event ranked fifth for the highest wave recordings at Tweed Heads (Table 7).

The temperature (sea surface temperature, SST) measured in the buoy hull showed a range of 18 °C to 28 °C (Figure 6). The SST from mid-February through to the mid-April was warm enough for tropical cyclone development.

The monthly average Hsig (Figure 7) generally fell within one standard deviation (sd) of the long term mean. Exceptions were during November, May, July and October where the mean was below −1 sd, and June which was greater than +1 sd due to the extended influence of ex-TC Tatiana.

In general the wave heights during the reporting period were predominately less frequent than the wave height of the whole record, during the summer period wave heights greater than 1.5 m were less frequent and below 1.5 m were more frequent. As for the winter, wave height greater than 3 m were more frequent (see Figure 8). Histograms of the occurrence of Hsig (Figure 9) indicate a lower occurrence of waves greater than 1.2 m and an increased occurrence of wave heights less than 0.8 m in winter. During summer there was a lower occurrence of wave heights greater than 1.8 metres. Histograms of the occurrence of peak wave periods (Tp) (Figure 10) show a very similar distribution between the reporting period and entire record with the most frequently occurring Tp ranging from 7 to 11 seconds.

The ratios between different wave parameters such as Hmax/Hsig were consistent between this reporting period and all of the historic data, these are plotted in Figure 11. The ratio of Tp/Ts shows a 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 during summer months. The dominance of east to east-southeast incident wave direction is reflected in the directional wave rose plot (Figure 12) with the most common Hsig of 1.0 to 1.5 metres.

Table 7 Tweed Heads – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (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 Hsig of 2.5 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
26/02/2016 13:30	3.2 (3.7)	5.2 (6.5)	14.9	Tropical low (990) from ex – TC Tatiana approaching the Qld coast
25/04/2016 6:30	3.1 (3.2)	5.2 (5.6)	12	Two high pressure systems combining along the south NSW coast and a high pressure system south of Noumea causing strong winds and unsettled conditions
04/06/2016 19:30	5.2 (5.6)	8.1 (9.8)	11.1	An upper level trough over Queensland intensified as it tracked across the state's southeast, drawing moist air into its eastern flank as it moved off the coast of northeast New South Wales, developing into an east coast low early on the 5th
19/06/2016 15:30	2.5 (2.7)	4.4 (5.4)	7.1	Low pressure area (1006) crossed the coast near the NSW-VIC boarder coupled with a high north of New Zealand produce strong Northerly winds
04/08/2016 09:30	2.9 (3.3)	4.5 (5.9)	11.9	Two lows (1004 & 1006) located off the coast caused strong easterly winds

Denotes peak Hsig event

Notes: 1. Barometric pressure measured in hectopascals (hPa). The Hsig and Hmax values are the maximums recorded for each event and are not necessarily coincident in time. The Tp and Hsig values are coincident as a single event on the date shown. Due to possible statistical errors arising from finite length records used in calculating wave climate, the above storm peak Hsig and Hmax values are derived from the time series smoothed by a simple three hourly moving average following the recommendation of the literature (Forristall, Heideman, Leggett, Roskam, & Vanderschuren, 1996).

2. Hsig and Hmax values shown in brackets are unsmoothed values as recorded at the site.

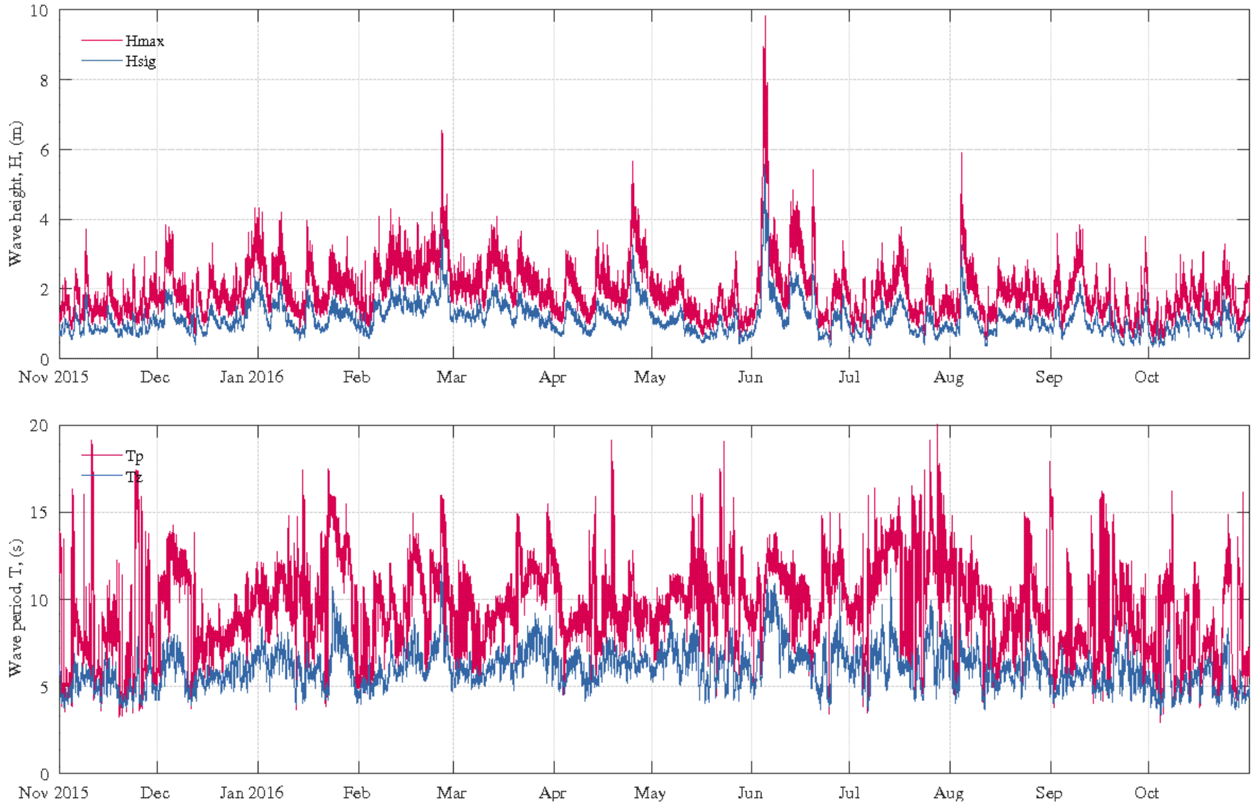


Figure 5 Tweed Heads – Daily wave recordings

Figure 6 Tweed Heads – Sea surface temperature and peak wave directions

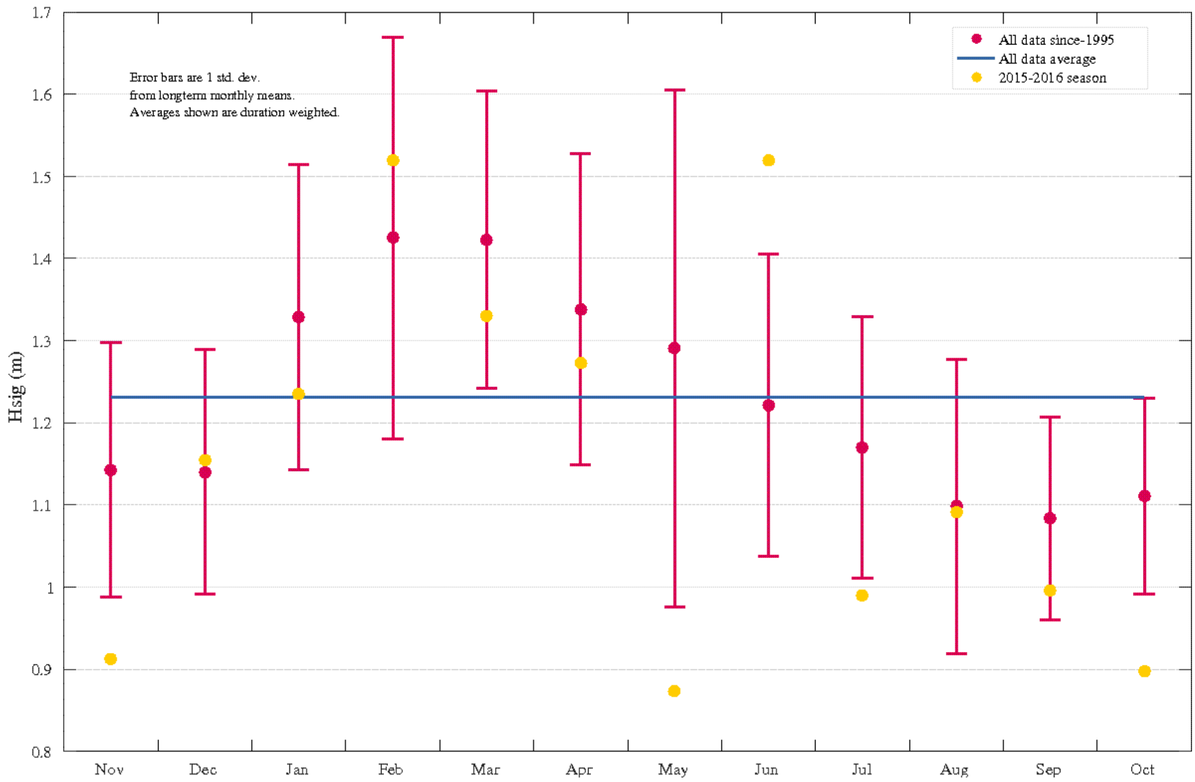


Figure 7 Tweed Heads – Monthly average wave height (Hsig) for seasonal year and for all data

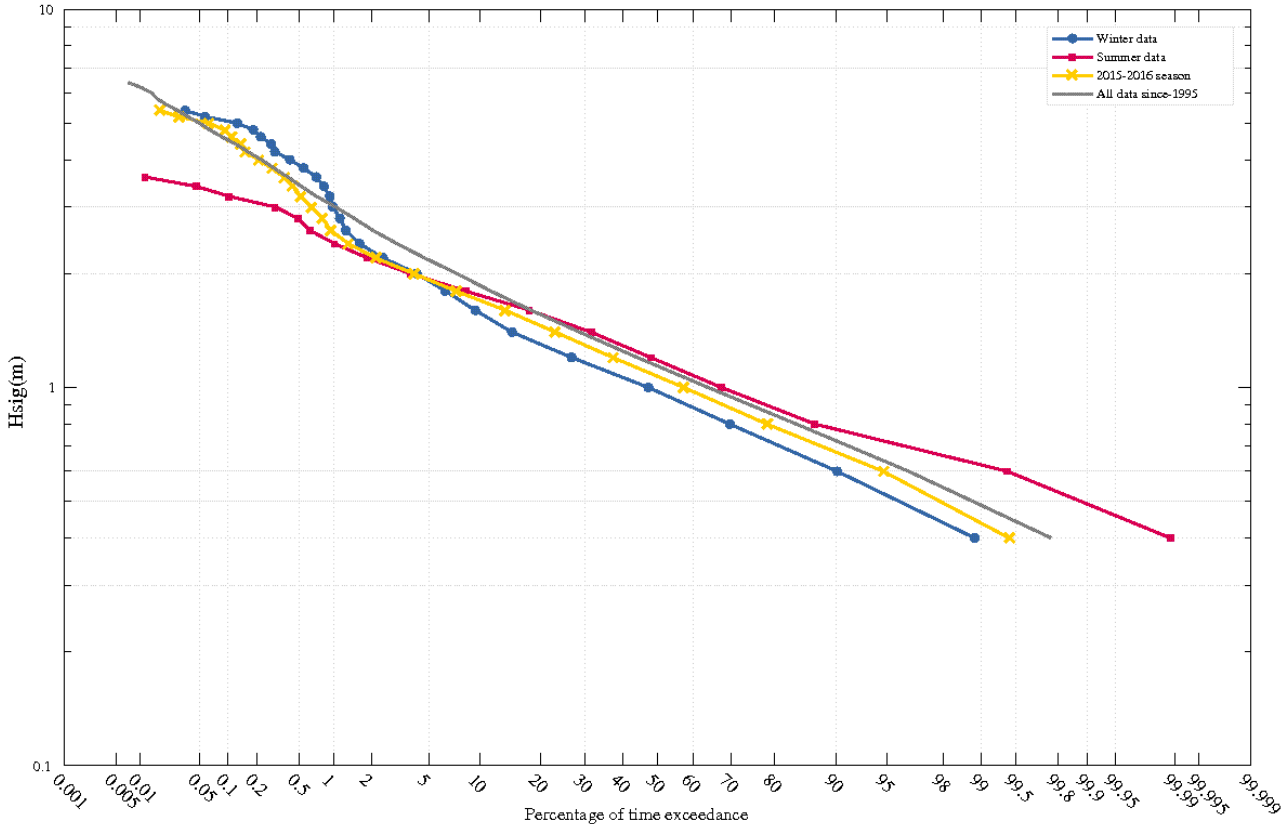


Figure 8 Tweed Heads – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

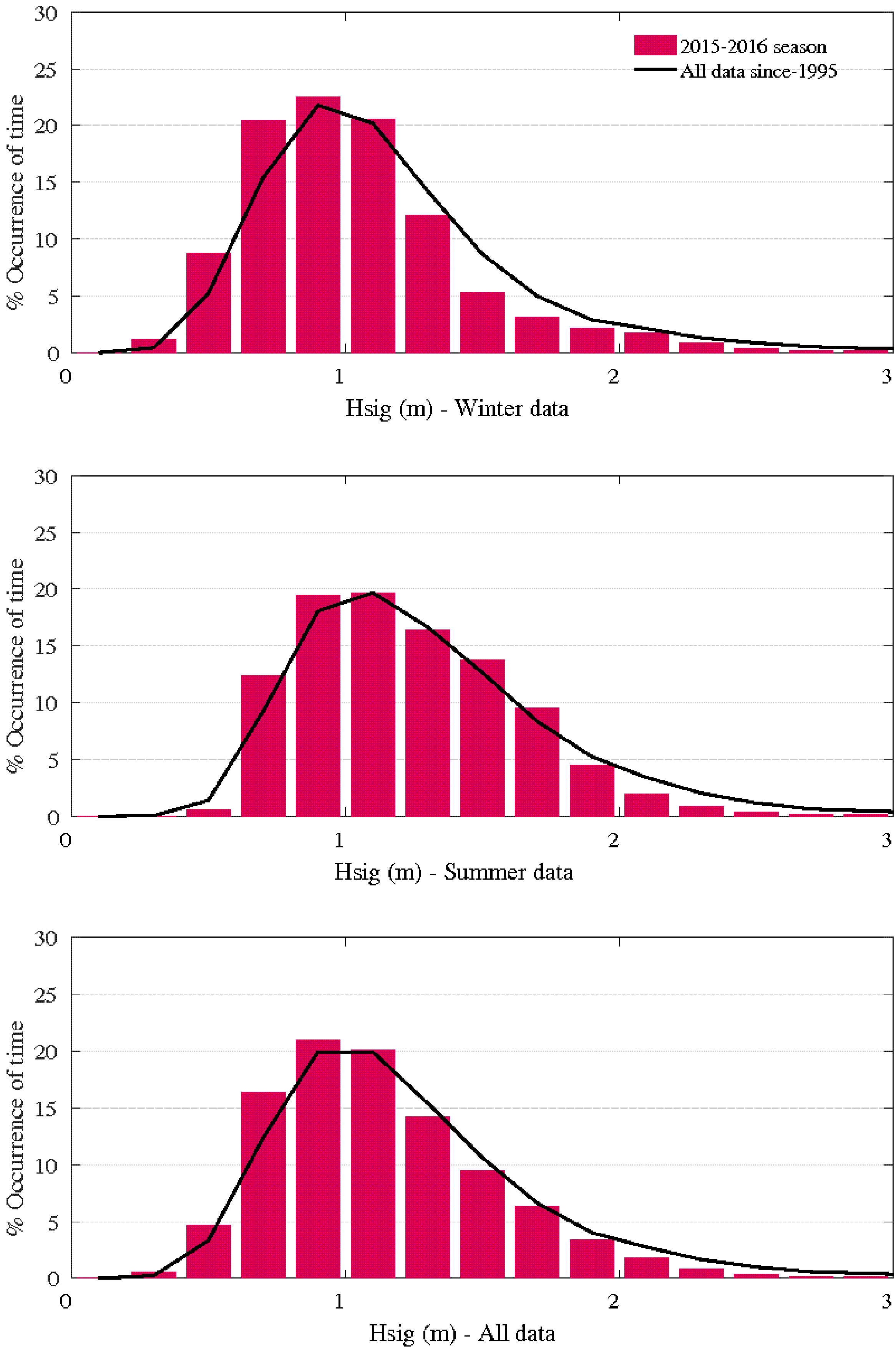


Figure 9 Tweed Heads – Histogram percentage (of time) occurrence of wave heights (Hsig)

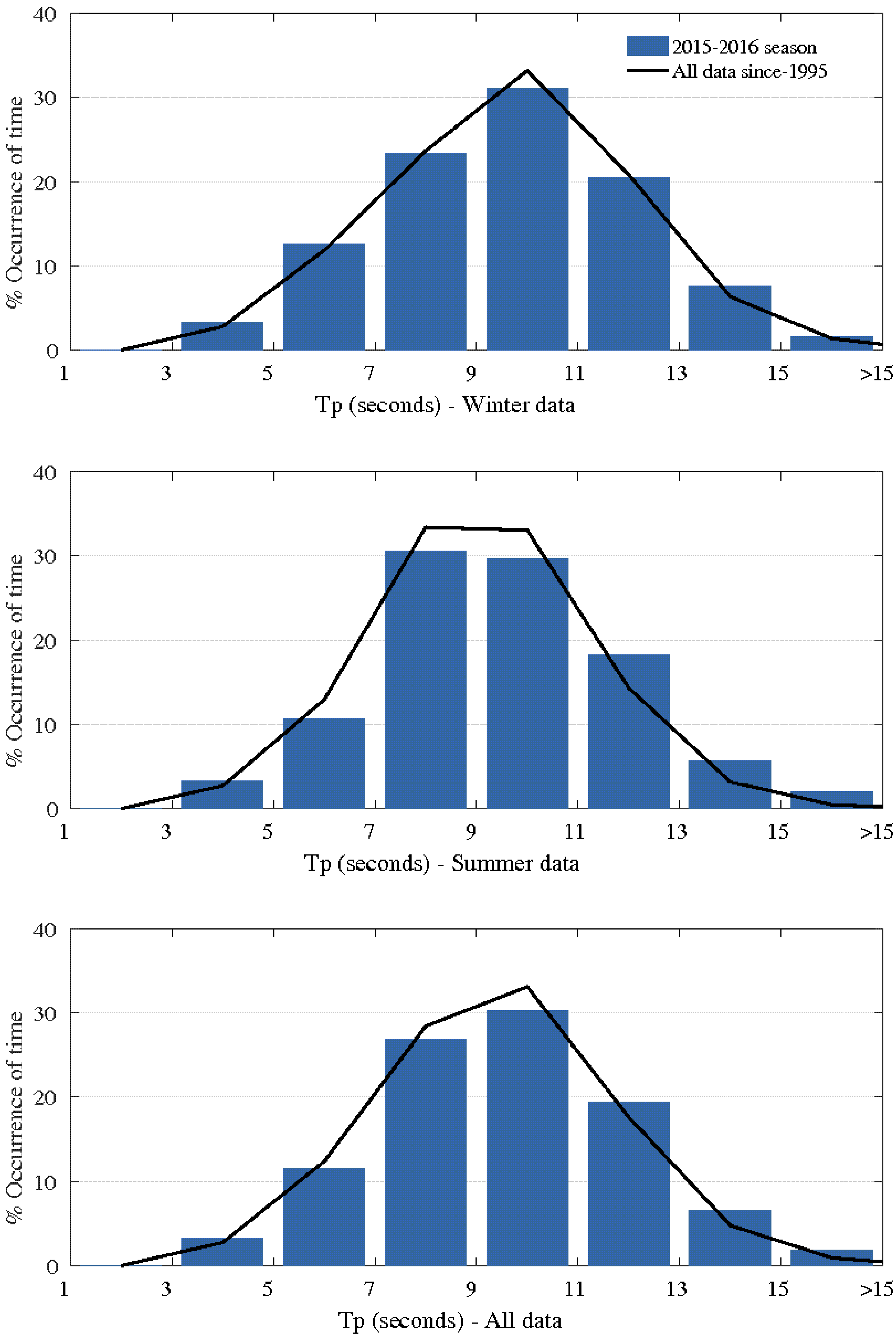


Figure 10 Tweed Heads – Histogram percentage (of time) occurrence of wave periods (Tp)

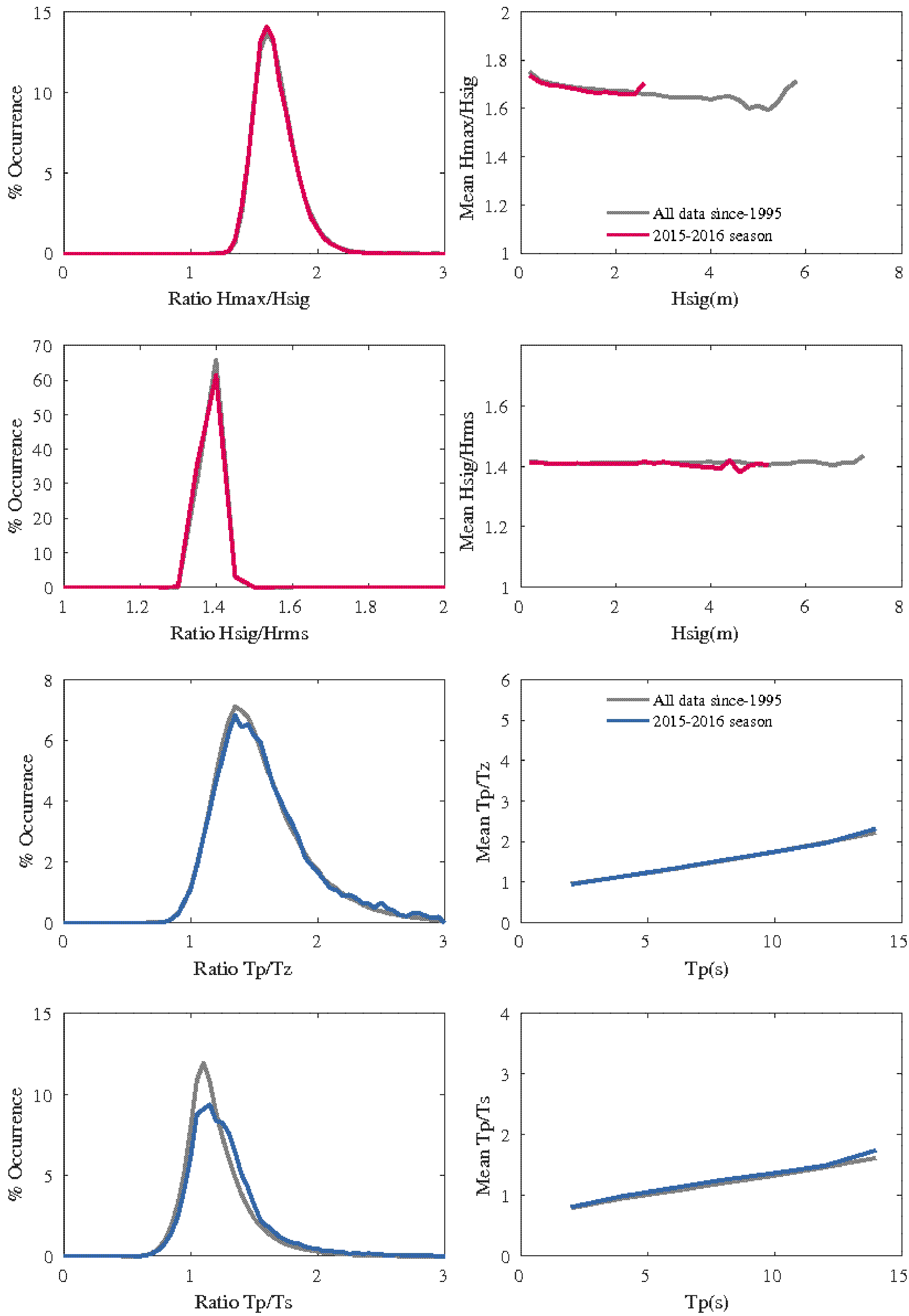
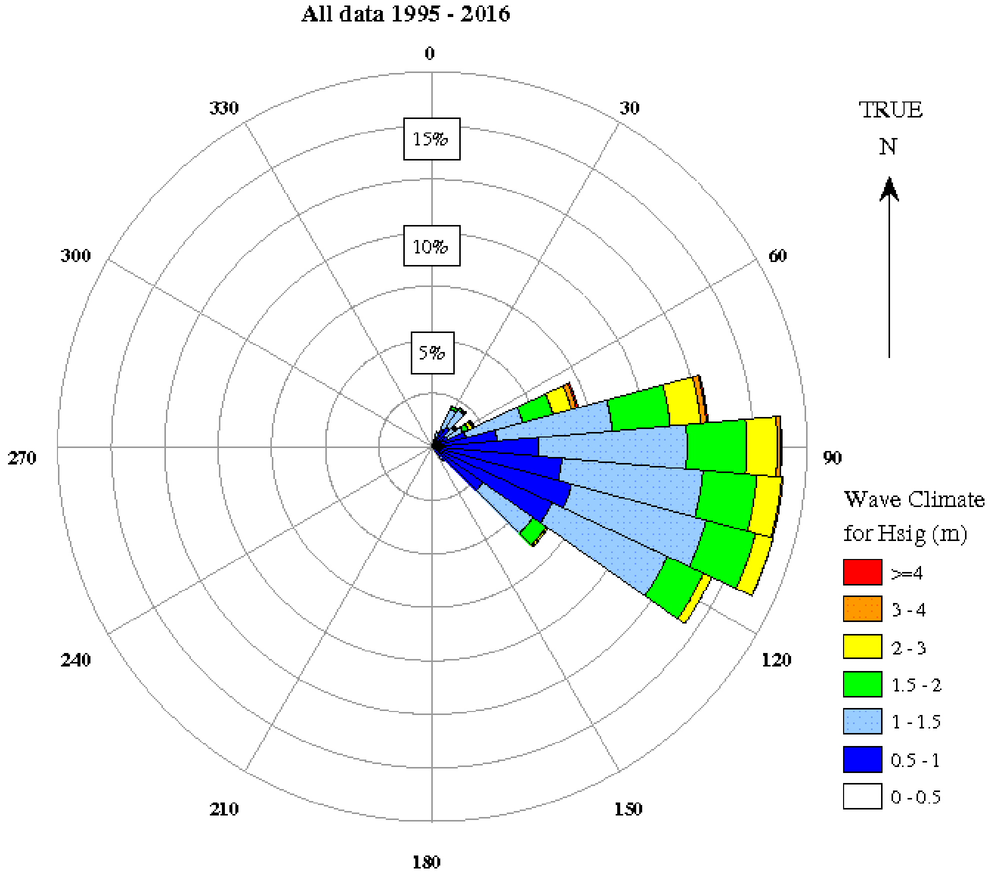


Figure 11 Tweed Heads – Wave parameter relationships



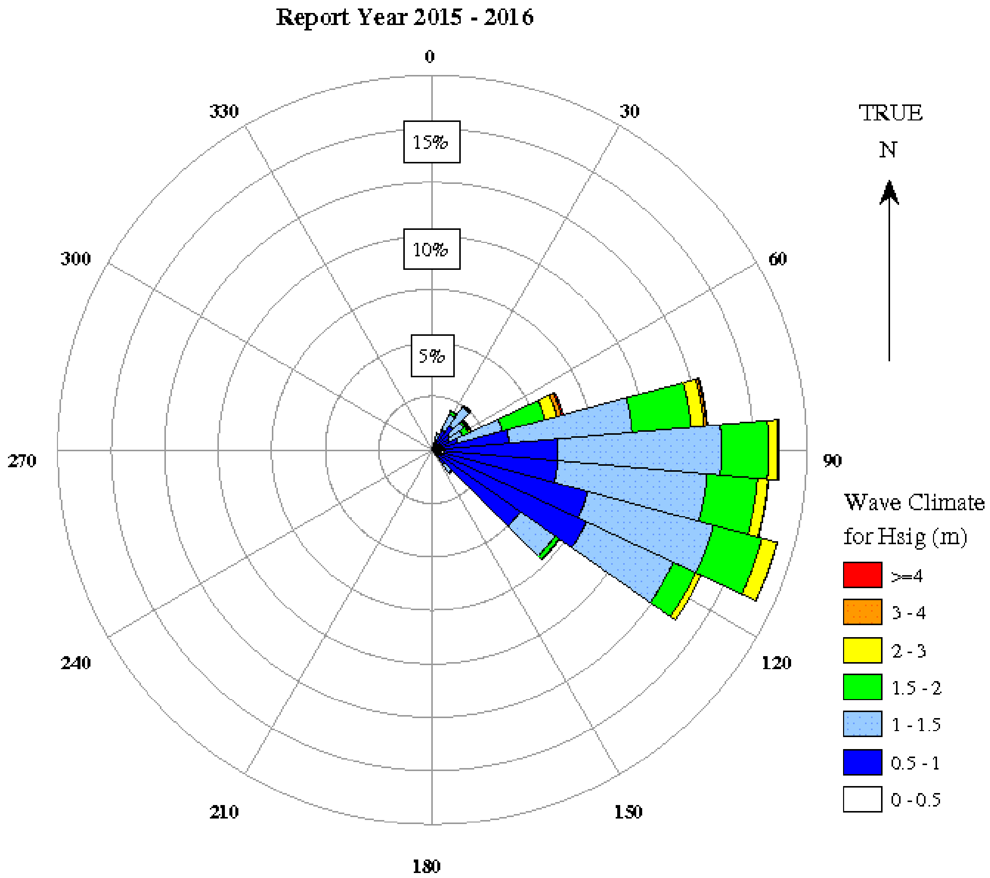


Figure 12 Tweed Heads – Directional wave rose

Gold Coast

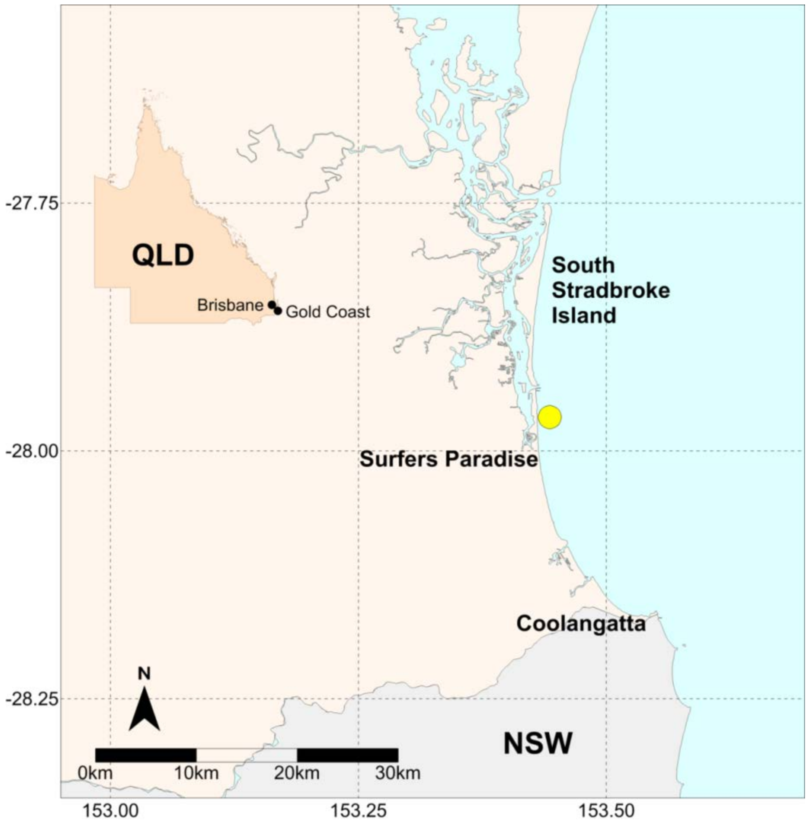


Figure 13 Gold Coast – Locality plan

Table 9 Gold Coast – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	21/03/1987	3.40 years	355,337	29.7
2015–16	01/11/2015	7.7 days	17,199	1

Table 10 Gold Coast – Buoy deployments during the 2015–16 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
27°57.838' S	153°26.488' E	17	24/02/2016	current

Gold Coast – seasonal overview

The Gold Coast wave buoy has been operational for almost 30 years with an overall data return of 88.5 per cent. The data return for the period November 2015 to October 2016 was exceptional, with total gaps of only 7.7 days, equivalent to 97.8 percent data return. The buoy was replaced once during the reporting period on the 24 February (Table 10).

The Gold Coast wave buoy was subjected to two significant events during the reporting periods (Table 12). The largest waves occurred during the east coast low on 04 June with a (Hsig) of 5.1 m and maximum wave height (Hmax) of 9.1 metres. This ranked ninth for significant wave height and tenth for the highest wave recordings at the Gold Coast (Table 11). Peaks in wave heights from the two significant meteorological events (Table 12) are clearly seen in the daily wave recording time series (Figure 14).

The temperature (sea surface temperature, SST) measured in the buoy hull showed a range of 19 °C to 27 °C (Figure 15). The SST from mid-February to mid-April was consistently warm enough for tropical cyclone development.

The monthly average Hsig (Figure 16) for the recording period fell within one standard deviation (sd) of the entire record with the exception of November, May, June, July and October. The high outlier in June is due to the extended increase in wave heights generated by ex-TC Tatiana.

The wave climate during the reporting period was equivalent to the wave climate of the whole record, with the exception of summer when Hsig over 2 m was less frequent, as seen in the percentage exceedance plot (Figure 17). Wave heights in summer were generally higher than winter except for higher, less frequently occurring waves. Histograms for occurrence of Hsig (Figure 18) show a greater occurrence of the modal 0.8–1.2 m waves during summer and the 0.8–1.0 m waves during winter for the reporting period compared to the whole record. Histograms of the occurrence of peak wave periods (Tp) (Figure 19) show a similar distribution between the reporting period and entire record. Tp during winter are more broadly spread than during summer, which is concentrated between 7 to 11 seconds.

The ratios between different wave parameters such as Hmax/Hsig were generally consistent between this reporting period and all of the historic data, these are plotted in Figure 20. The ratio Tp/Tz and Tp/Ts was skewed towards a larger ratio, reflecting the lower occurrence of Hsig over 1 m in winter.

The time series for wave direction (Figure 15) 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 21). The wave directions for the reporting period are very similar to the entire record.

Table 11 Gold Coast – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (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 12 Gold Coast – Significant meteorological events with threshold Hsig of 3 metres.

Date	Hs (m)	Hmax (m)	Tp (s)	Event
25/04/2016 9:00	3.0 (3.3)	5.2 (6.9)	11.9	Two high pressure systems combining along the South NSW coast and a high pressure system south of Noumea causing strong winds and unsettled conditions
04/06/2016 20:00	4.6 (5.1)	7.6 (9.1)	11.3	An upper level trough over Queensland intensified as it tracked across the State's southeast, drawing moist air into its eastern flank as it moved off the coast of northeast New South Wales, developing into an East Coast Low early on the 5th

Denotes peak Hsig event

Notes: 1. Barometric pressure measured in hectopascals (hPa). The Hsig and Hmax values are the maximums recorded for each event and are not necessarily coincident in time. The Tp and Hsig values are coincident as a single event on the date shown. Due to possible statistical errors arising from finite length records used in calculating wave climate, the above storm peak Hsig and Hmax values are derived from the time series smoothed by a simple three hourly moving average following the recommendation of the literature (Forristall, Heideman, Leggett, Roskam, & Vanderschuren, 1996).

2. Hsig and Hmax values shown in brackets are unsmoothed values as recorded at the site.

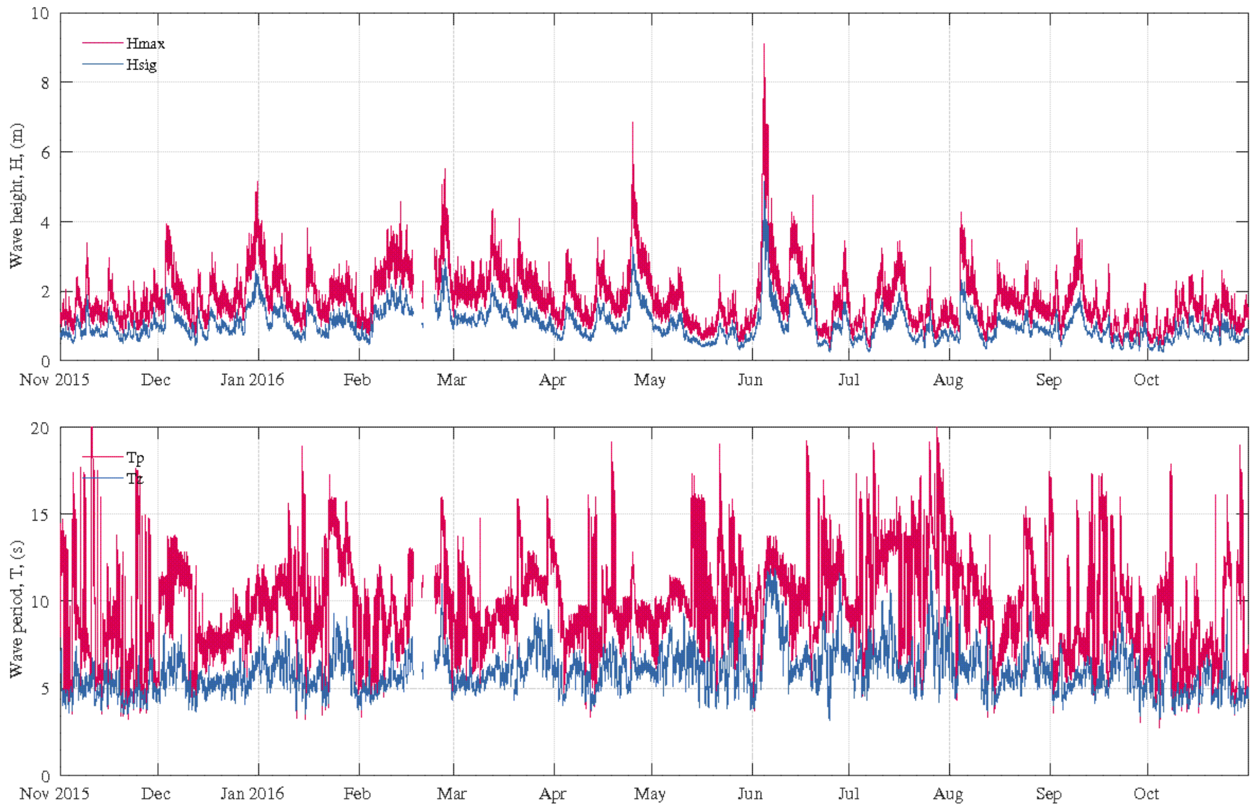


Figure 14 Gold Coast – Daily wave recordings

Figure 15 Gold Coast – Sea surface temperature and peak wave directions

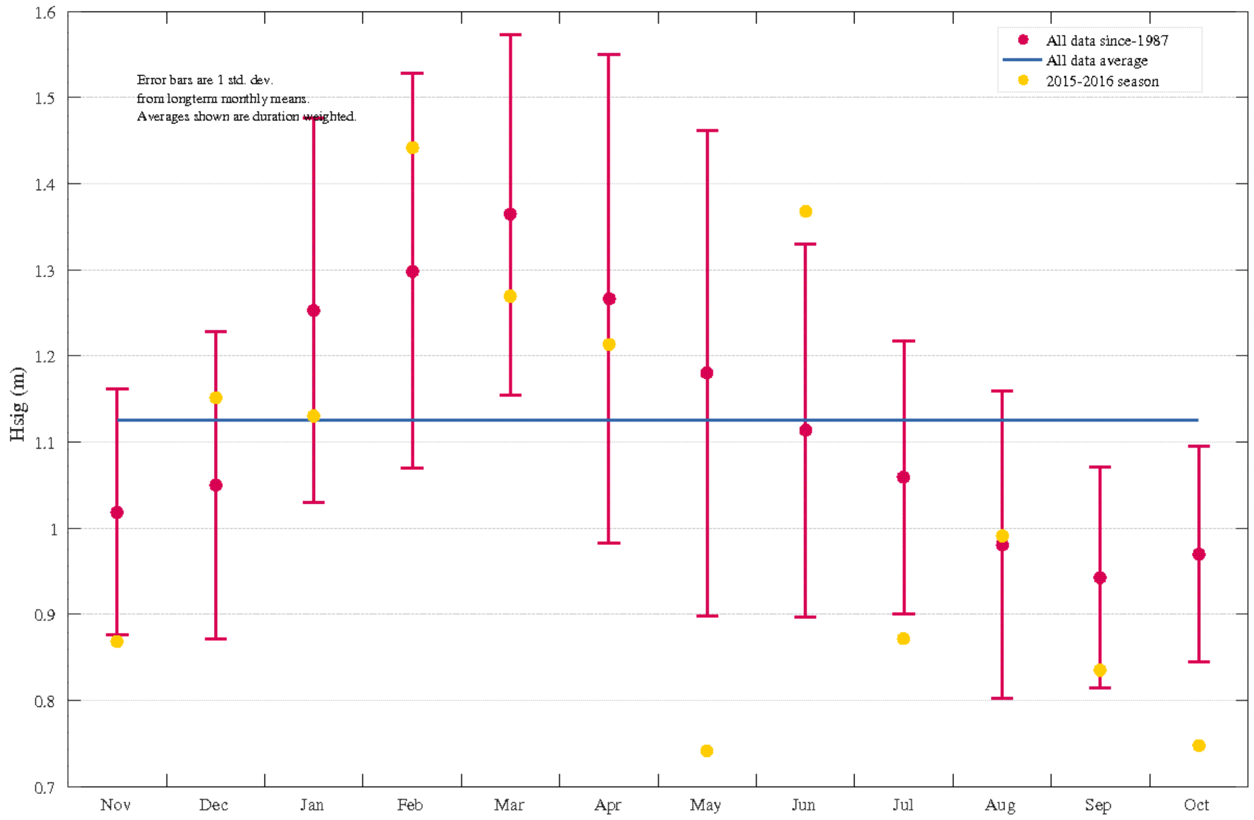


Figure 16 Gold Coast – Monthly average wave height (Hsig) for seasonal year and for all data

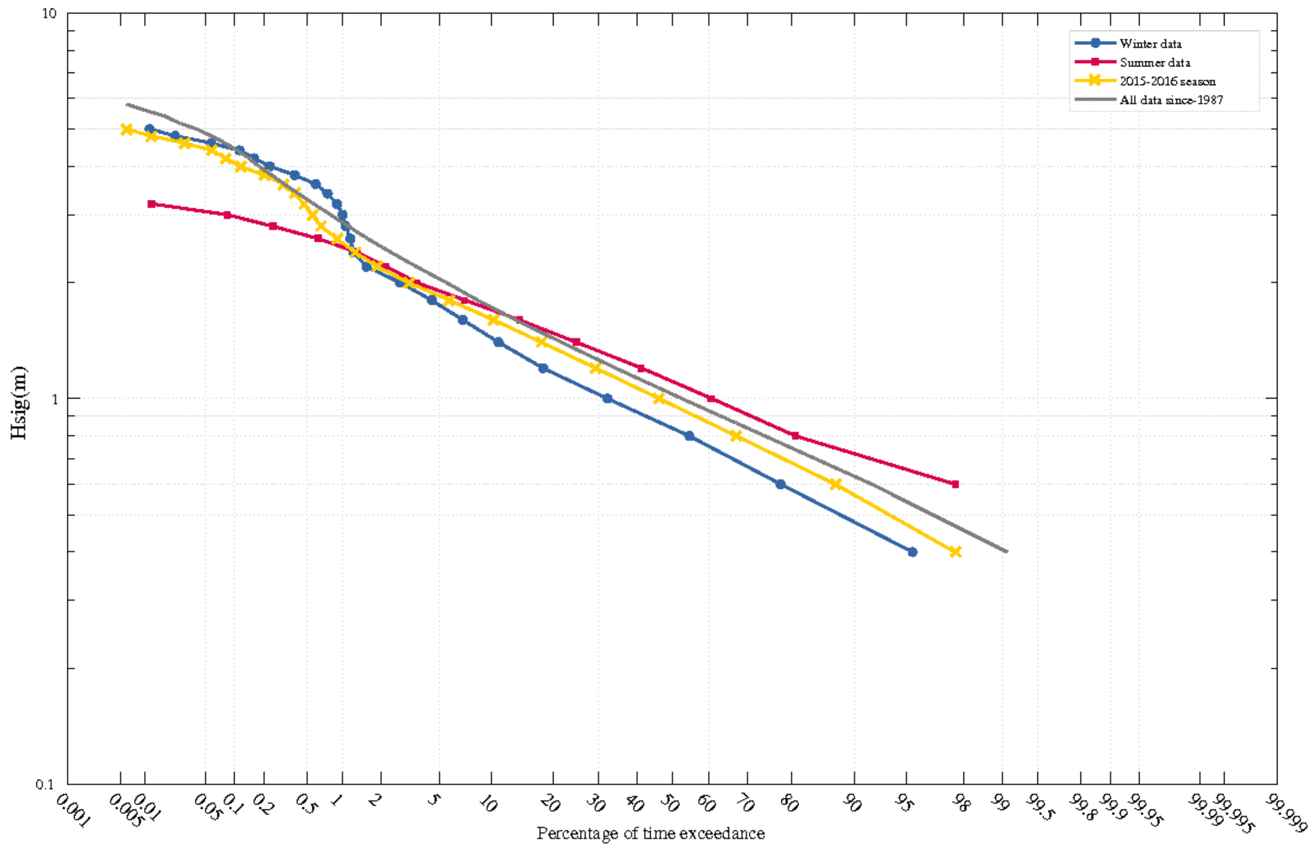


Figure 17 Gold Coast – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

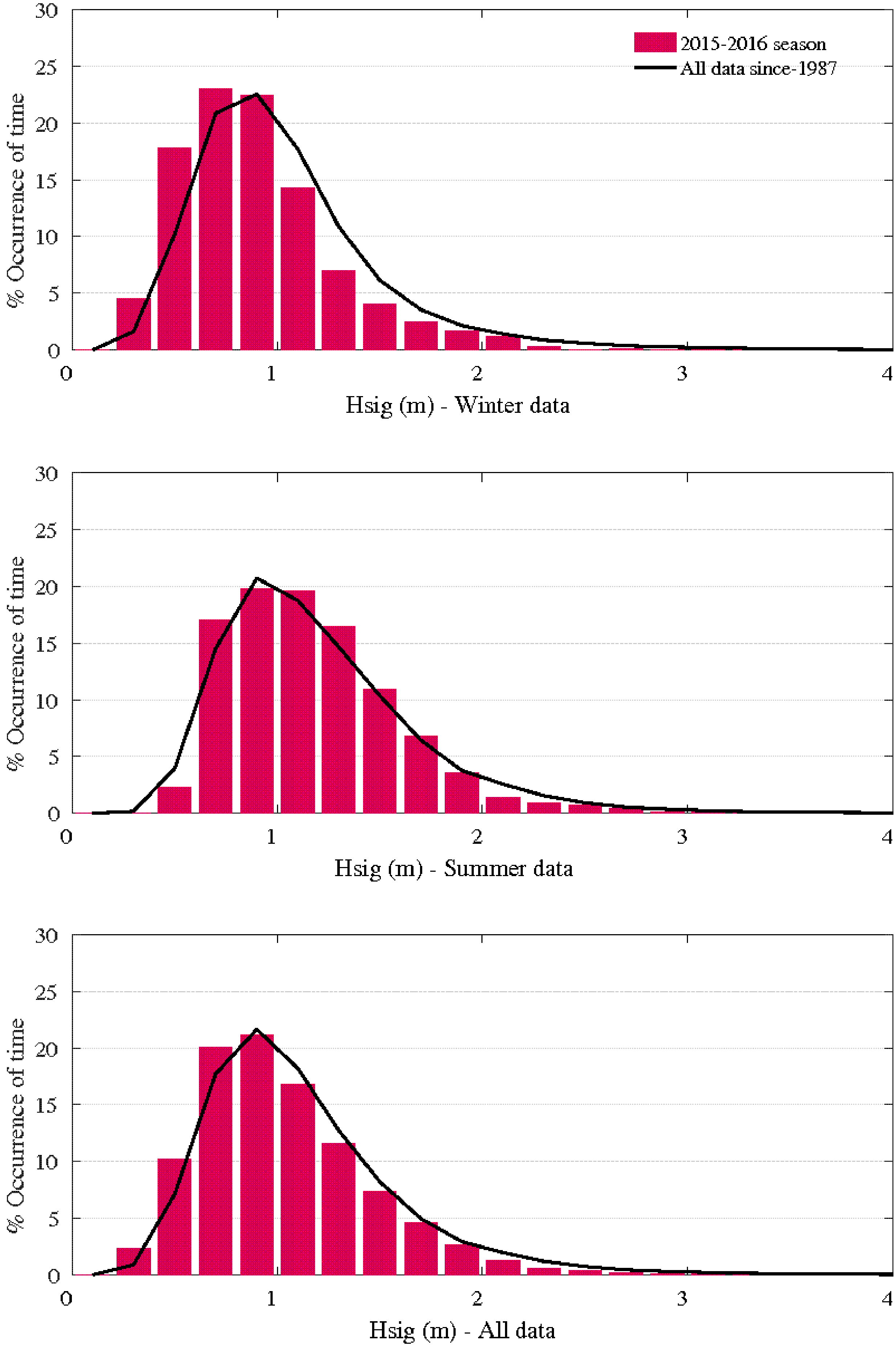


Figure 18 Gold Coast – Histogram percentage (of time) occurrence of wave heights (Hsig)

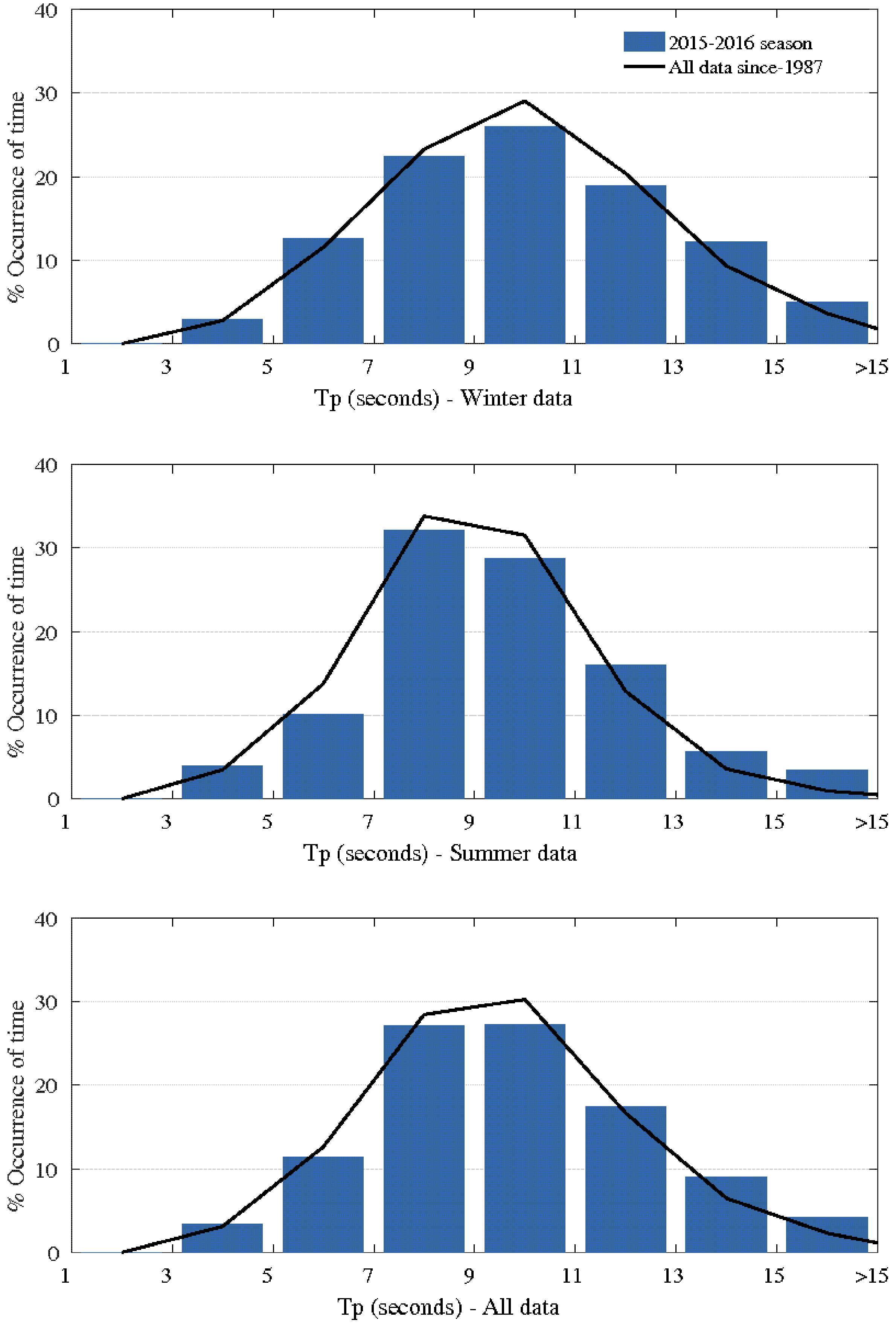


Figure 19 Gold Coast – Histogram percentage (of time) occurrence of wave periods (Tp)

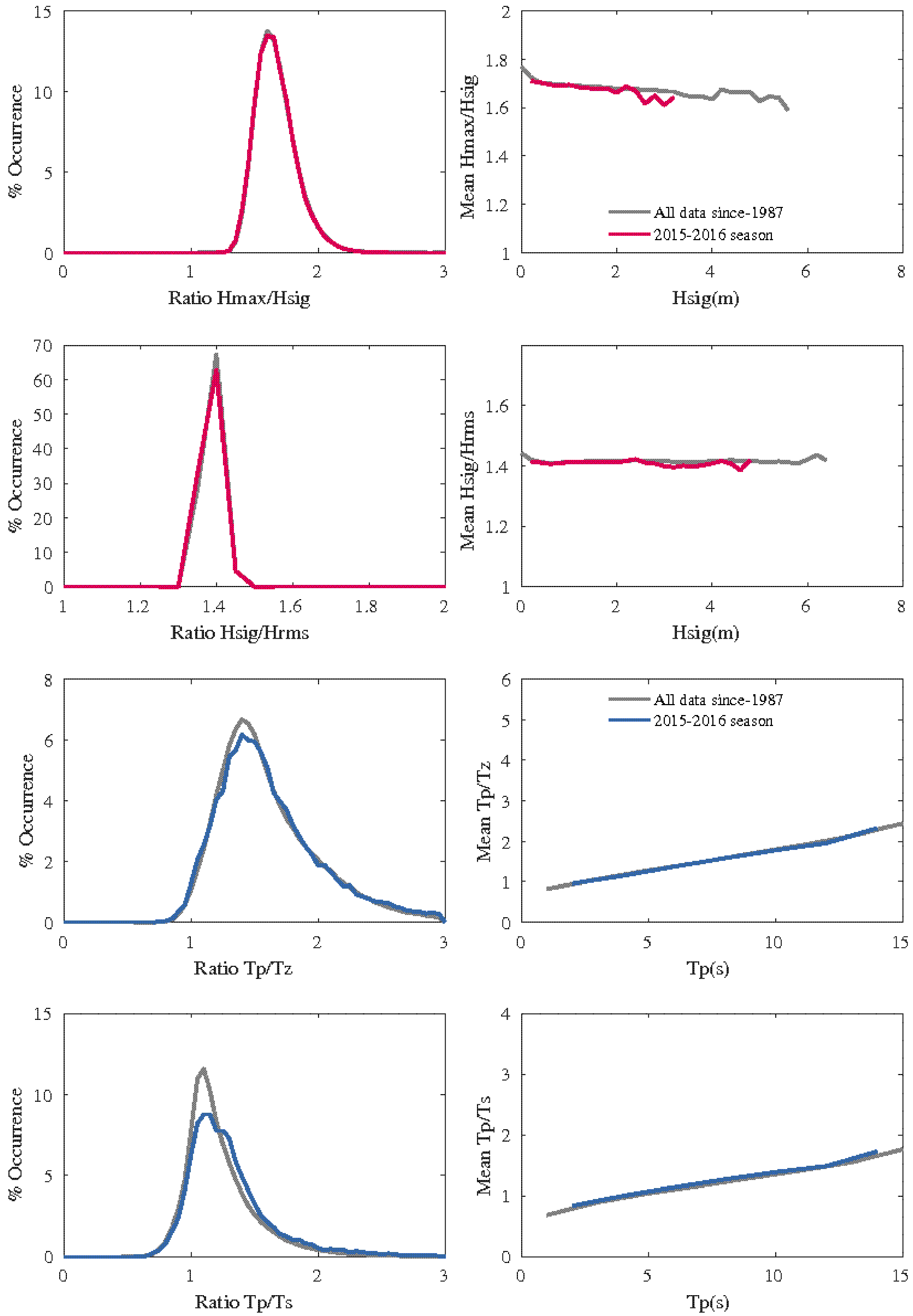
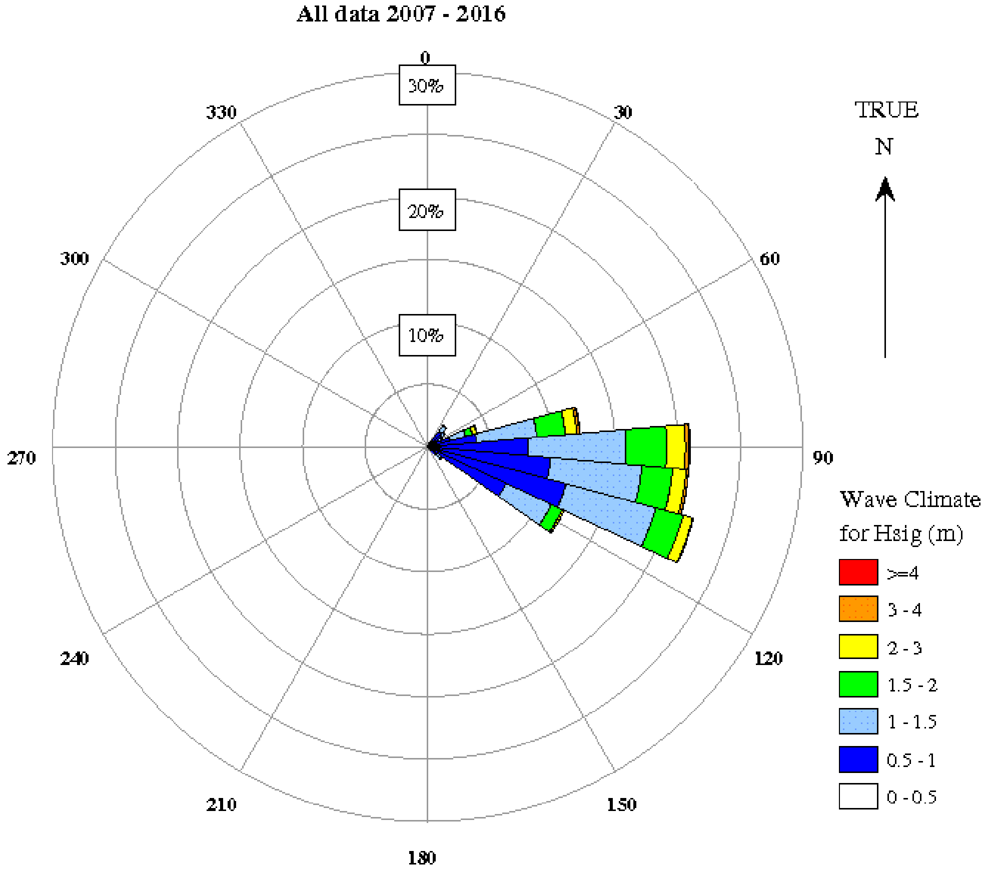


Figure 20 Gold Coast – Wave parameter relationships



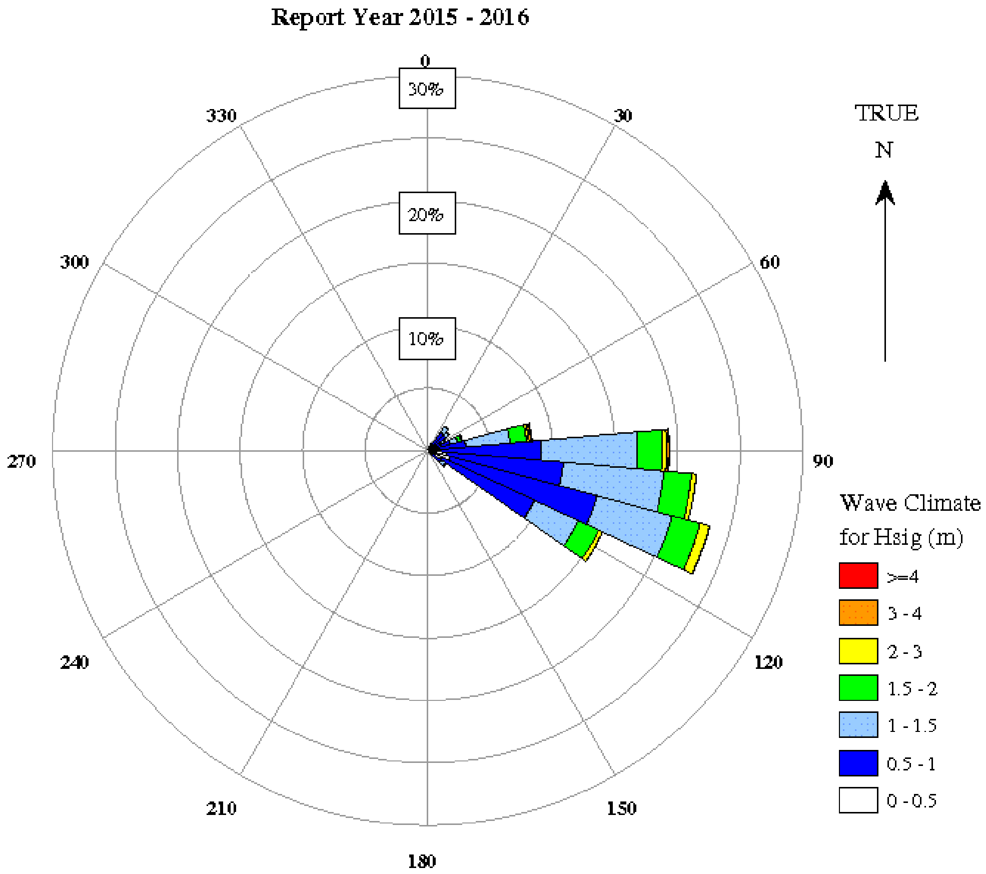


Figure 21 Gold Coast – Directional wave rose

Brisbane

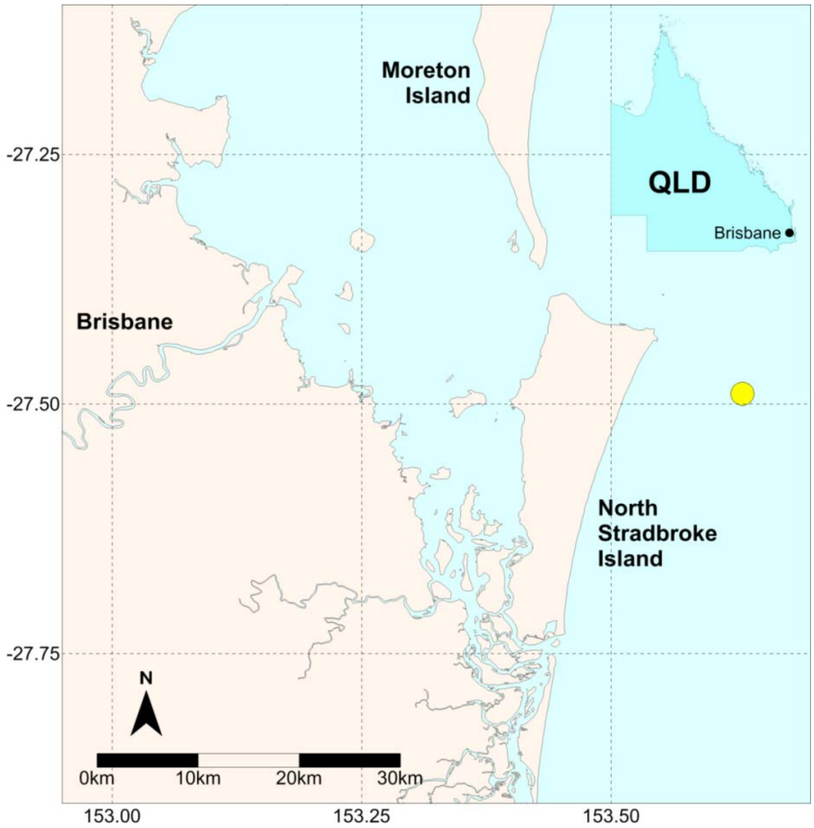


Figure 22 Brisbane – Locality plan

Table 13 Brisbane – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	31/10/1976	na	354,602	40
2014–15	01/11/2015	2.94 days	17,426	1

Table 14 Brisbane – Buoy deployments during the 2015–16 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
27°29.600' S	153°37.960' E	70	31/03/2015	current
27°29.624' S	153°37.923' E	75	31/03/2015	current

Brisbane – seasonal overview

The Brisbane wave buoy has been operational for 40 years. The data recorded for the period November 2015 to October 2016 was very good, with total gaps of 2.94 days, equivalent to a 99.2 percent data return. The buoy was not replaced during the reporting period, however there was a new Datawell mk4 wave buoy installed next to the existing buoy (Table14). The new mk4 has a higher sampling frequency giving higher accuracy and it also measures surface current around the buoy.

There were no recorded wave heights during the reporting period ranked in the highest waves for Brisbane (Table 15). Increases in wave height from the influence ex-TC Tatiana during July were captured by the wave buoy (Table 16). The largest waves for the recording period occurred on 01 May from an East Coast Low which developed north of Fraser Island. This generated a significant wave height (Hsig) of 5.8 m and a maximum wave height (Hmax) of 10.8 metres.

The temperature (sea surface temperature, SST) measured in the buoy hull showed a range of 19 °C to 29 °C (Figure 24). The SST from mid-December to mid – May was generally warm enough for tropical cyclone development.

The monthly average Hsig for the recording period was within one standard deviation (sd) of the entire record except for May where Hsig was well below the monthly mean and December, February and June which were just over the mean +1 sd (Figure 25). The high average wave heights in February is due to the passage of two cyclones during this month.

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 26). Histograms for occurrence of Hsig (Figure 27) show a higher occurrence of wave heights 1.4 to 1.6 m, for the summer and higher occurrence of Hsig below 1.4 m in winter and lower occurrence above 1.4 m compared to the long term record. Overall, the wave height distribution was similar between the reporting period and entire record. Histograms of the occurrence of peak wave periods (Tp) (Figure 28) show a similar distribution between the reporting period and the long term record, with a broader spread of Tp during winter. Tp most frequently ranged from 5 to 15 seconds.

The ratios between different wave parameters such as Hmax/Hsig were consistent between this reporting period and all of the historic data (Figure 29). The ratio of Tp/Ts shows a higher kurtosis for the recent period compared to the entire record.

Time series for wave direction (Figure 24) indicates a dominant wave direction between south and east with occasional swings to the north in summer. The directional wave rose plots (Figure 30) more clearly show incident wave directions more frequently from the south-east but a broad spread from east to south. The wave directions for the reporting period are very similar to the entire record.

Table 15 Brisbane – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (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	7.0	02/05/1996 14:00	12.8
5	02/05/1996 20:30	6.9	15/02/1995 06:30	12.2
6	15/02/1995 06:00	6.4	28/01/2013 07:30	12.1
7	23/08/2008 23:00	6.4	15/02/1996 19:00	12.1
8	12/06/2012 09:30	6.4	24/08/2008 02:00	11.5

9	06/06/2012 19:30	6.3	26/03/1998 07:00	11.5
10	31/12/2007 03:00	6.3	06/06/2012 19:30	11.1

Table 16 Brisbane – Significant meteorological events with threshold Hsig of 4.0 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
03/12/2015 14:00	4.5 (4.7)	7.4 (9.3)	10	A low pressure trough extending south east of the east coast
16/01/2016 04:00	4.7 (5.2)	7.3 (8.9)	11.5	A high south of Tasmania extends up the east coast and a low over New Zealand pushes up strong winds from the south
27/02/2016 15:00	4.5 (4.8)	7.4 (9.1)	8.3	Low pressure troughs extended across the tropics and tropical cyclone Tatiana
24/04/2016 00:30	4.2 (4.4)	7.3 (8.6)	9.5	Two high pressure systems combined along the South NSW coast and a high pressure system south of Noumea causing strong winds and unsettled conditions
04/06/2016 21:30	5.2 (5.6)	8.7 (10.3)	11.2	An upper level trough over Queensland intensified as it tracked across the State's southeast, drawing moist air into its eastern flank as it moved off the coast of northeast New South Wales, developing into an East Coast Low early on the 5th

Denotes peak Hsig event

Notes: 1. Barometric pressure measured in hectopascals (hPa). The Hsig and Hmax values are the maximums recorded for each event and are not necessarily coincident in time. The Tp and Hsig values are coincident as a single event on the date shown. Due to possible statistical errors arising from finite length records used in calculating wave climate, the above storm peak Hsig and Hmax values are derived from the time series smoothed by a simple three hourly moving average following the recommendation of the literature (Forristall, Heideman, Leggett, Roskam, & Vanderschuren, 1996).

2. Hsig and Hmax values shown in brackets are unsmoothed values as recorded at the site.

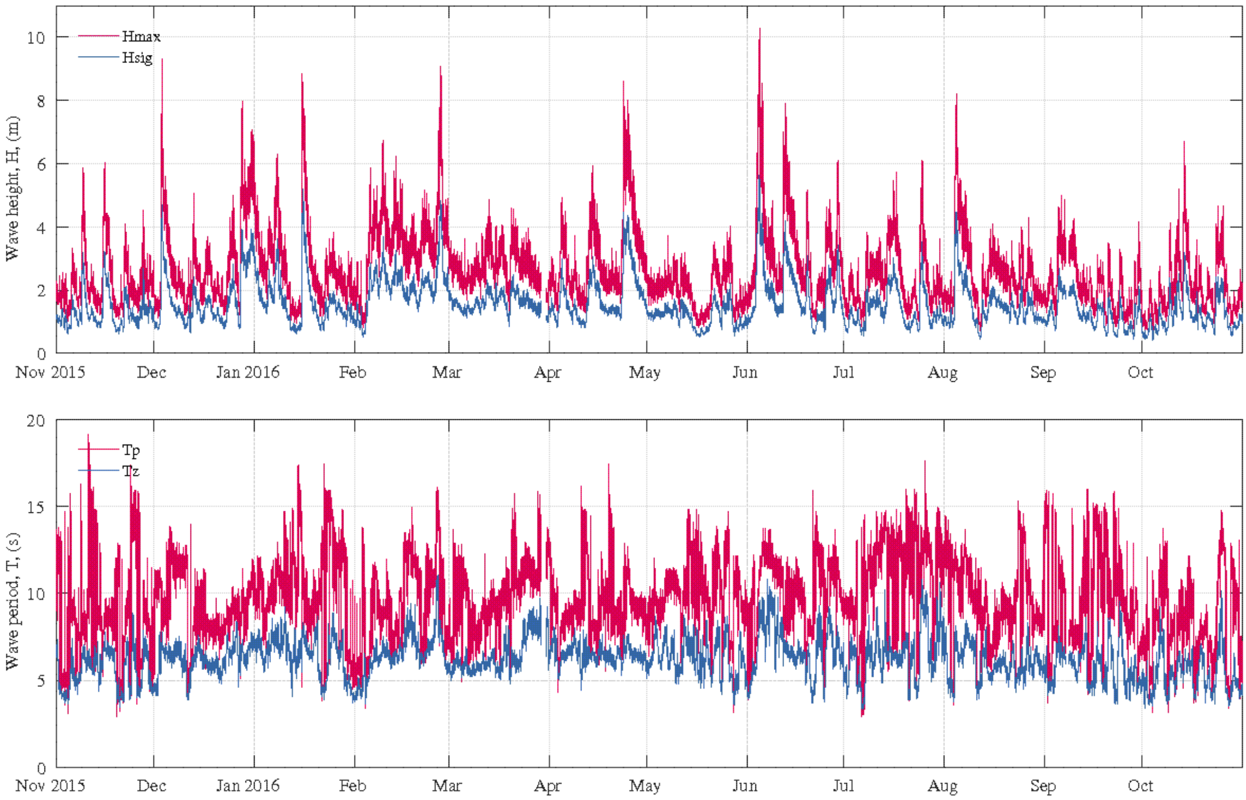


Figure 23 Brisbane – Daily wave recordings

Figure 24 Brisbane – Sea surface temperature and peak wave directions

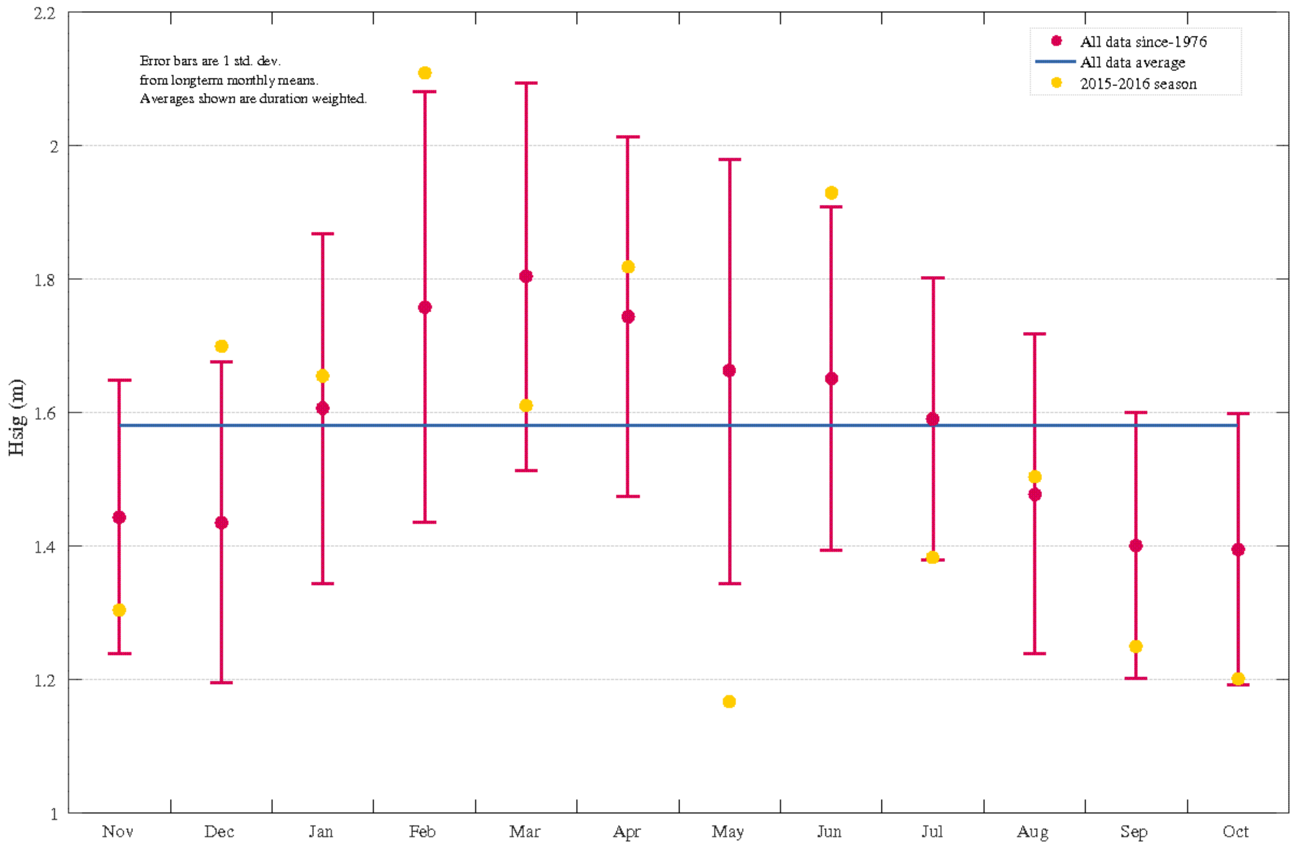


Figure 25 Brisbane – Monthly average wave height (Hsig) for seasonal year and for all data

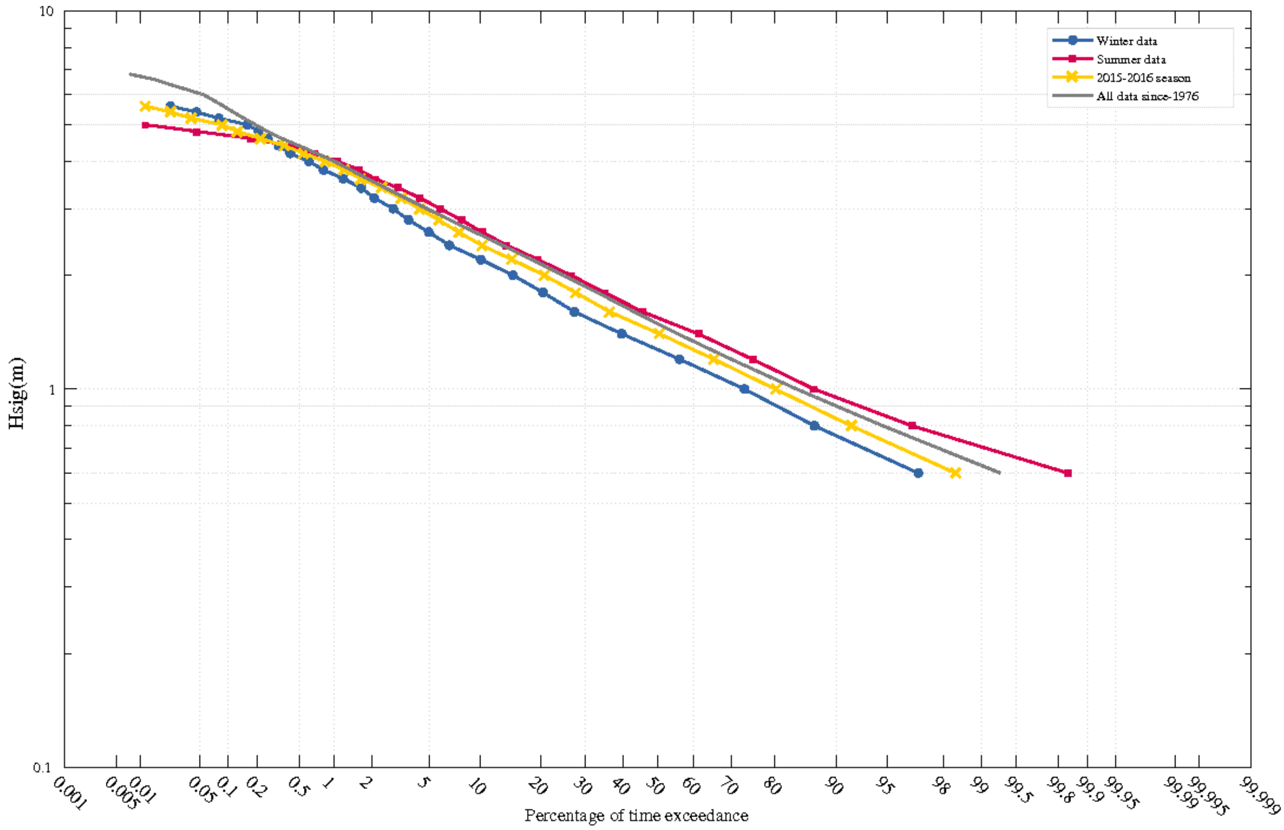


Figure 26 Brisbane – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

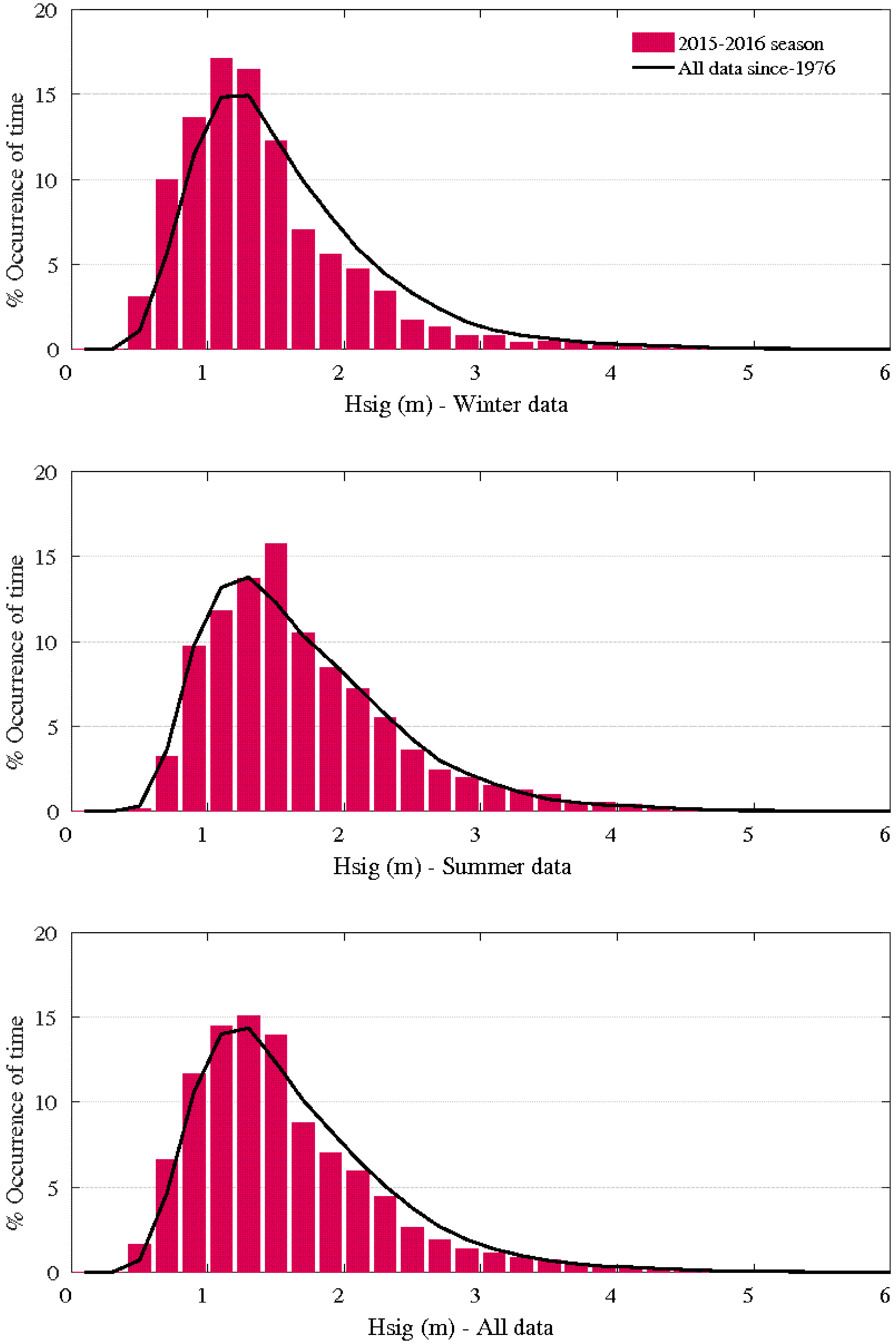


Figure 27 Brisbane – Histogram percentage (of time) occurrence of wave heights (Hsig)

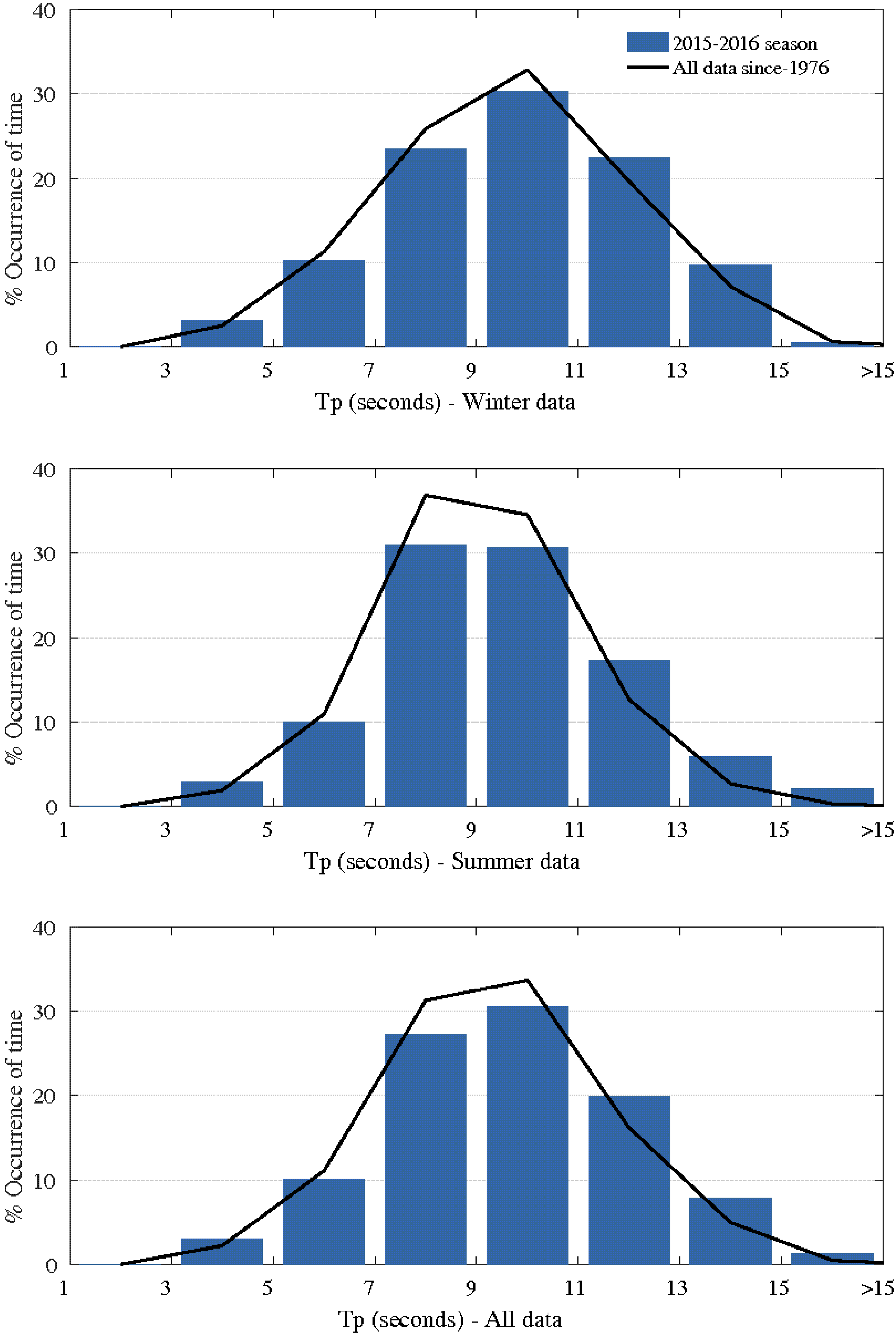


Figure 28 Brisbane – Histogram percentage (of time) occurrence of wave periods (Tp)

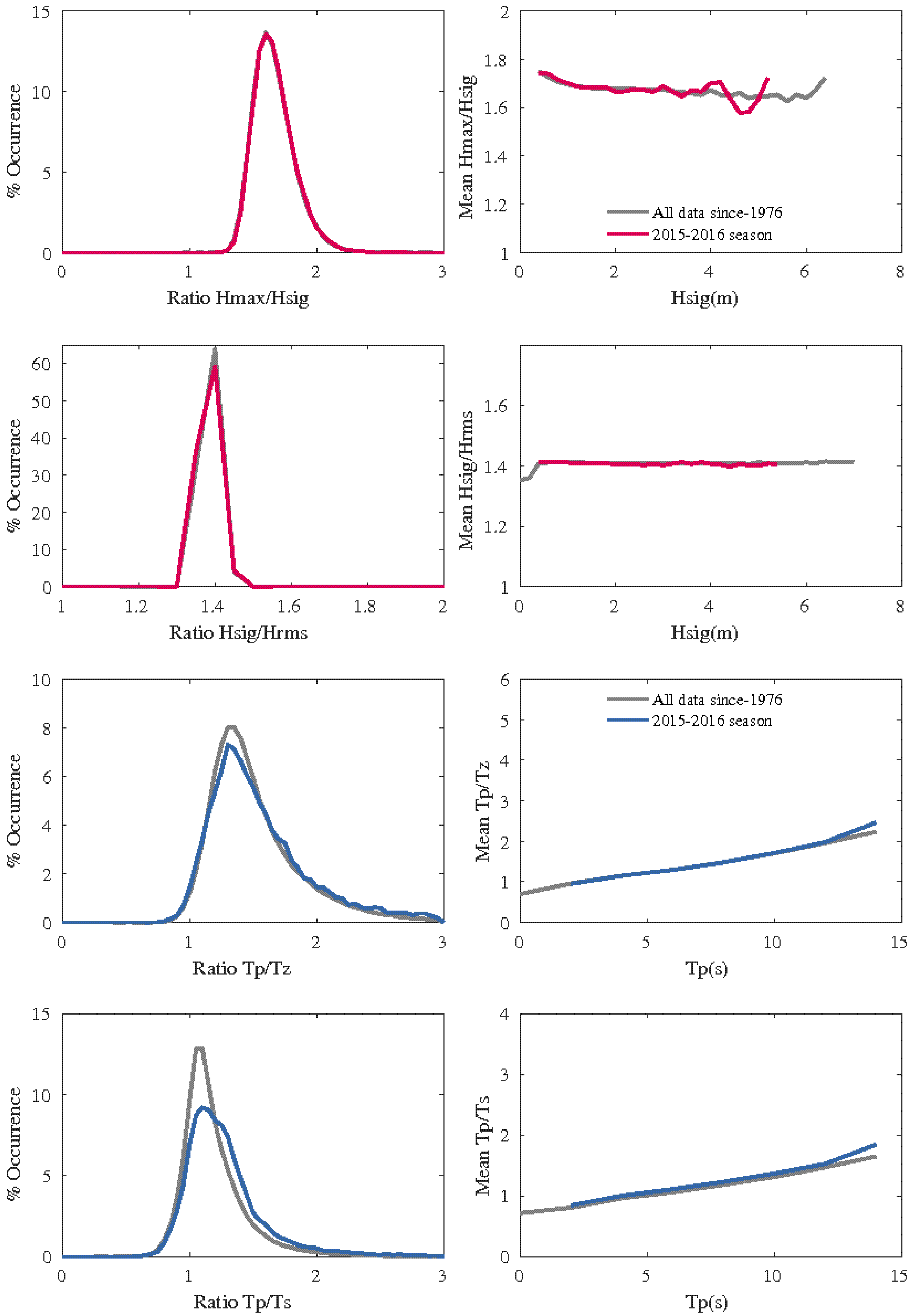
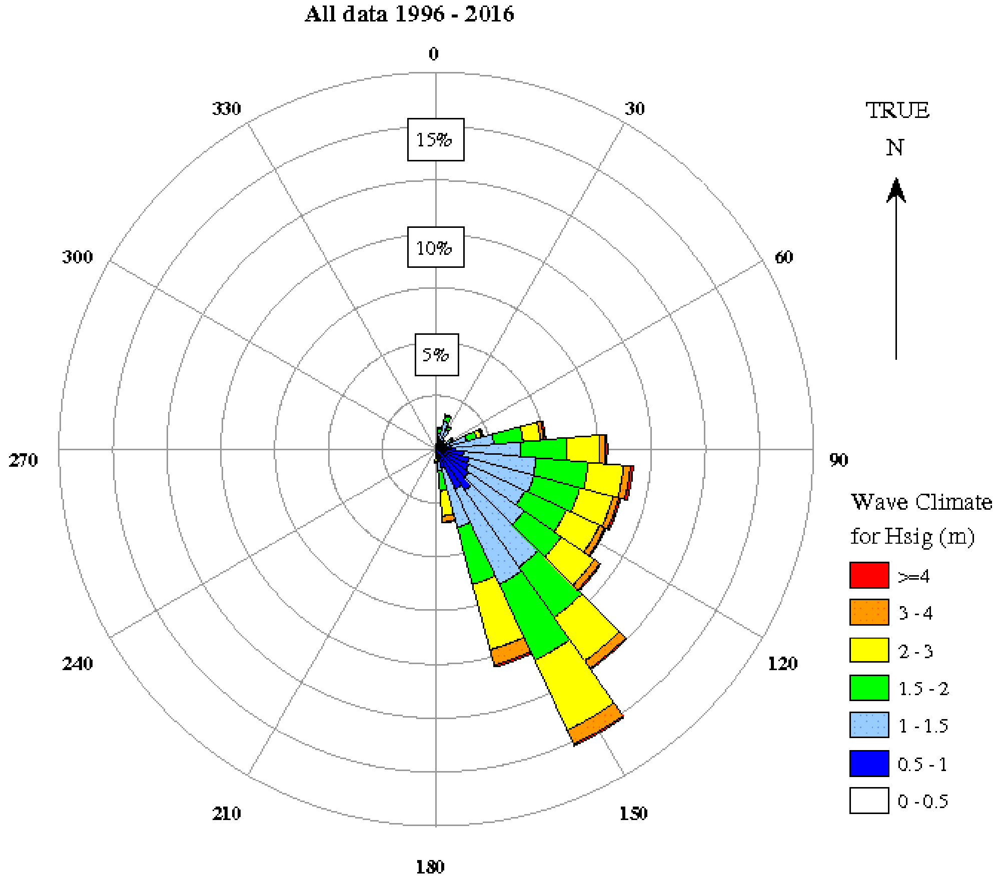


Figure 29 Brisbane – Wave parameter relationships



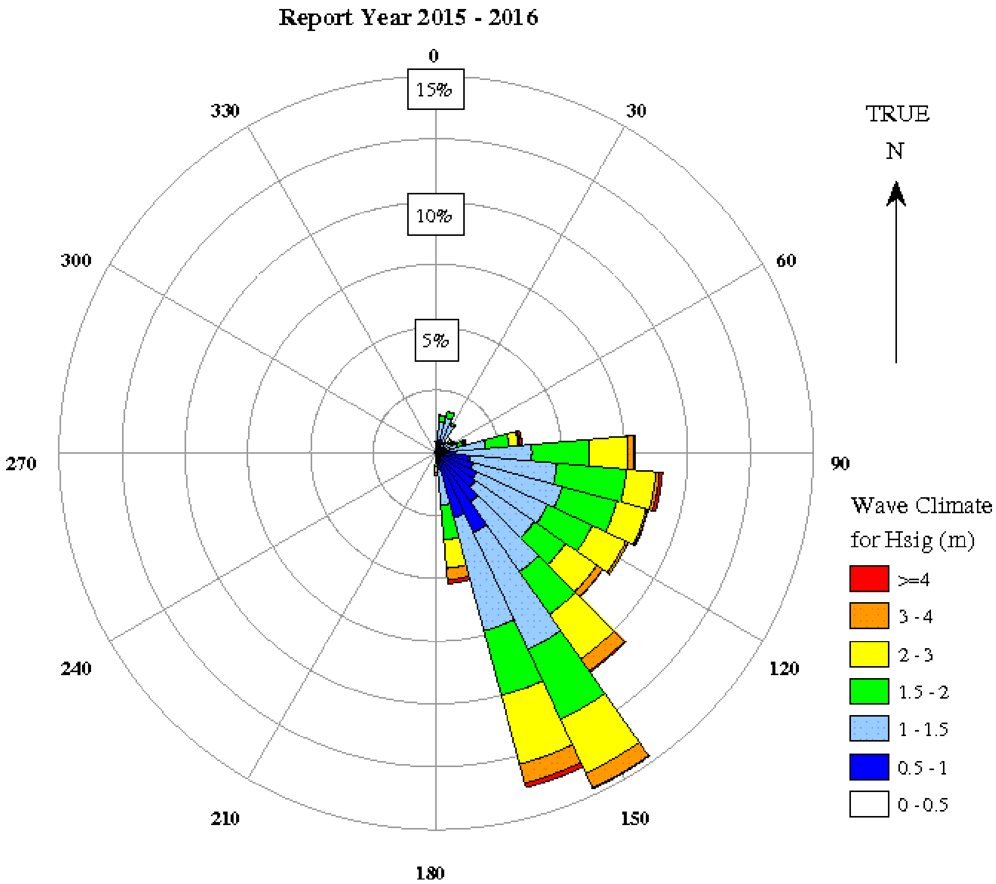


Figure 30 Brisbane – Directional wave rose

North Moreton

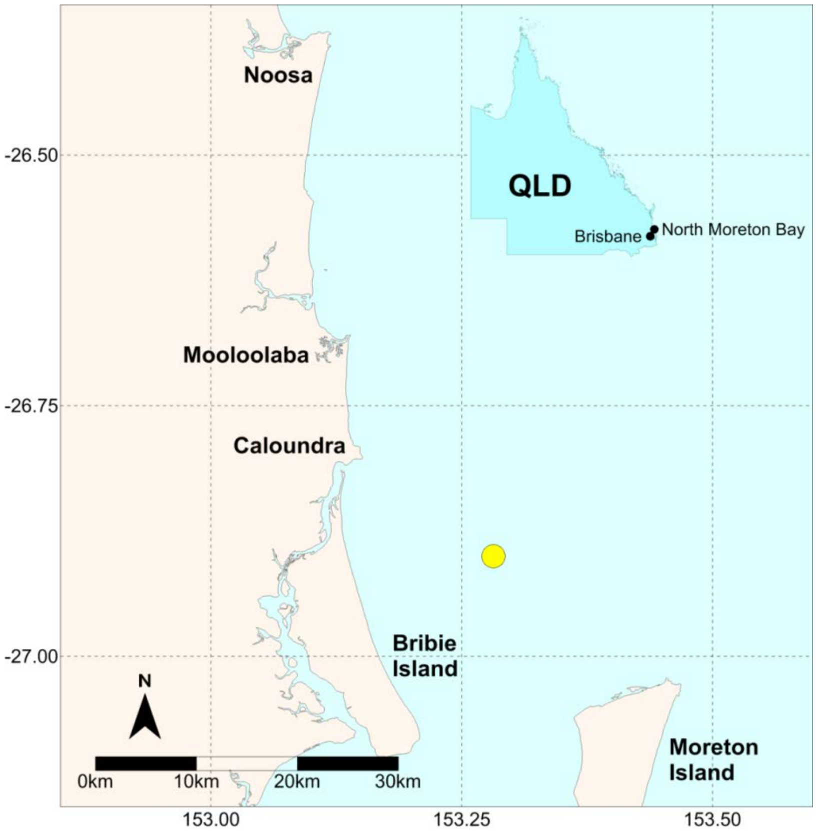


Figure 31 North Moreton – Locality plan

Table 17 North Moreton – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	31/10/2010	0.06 years	108,035	6.24
2015–16	01/11/2015	2.5 days	17,446	1

Table 18 North Moreton – Buoy deployments during the 2015–16 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
26°53.945' S	153°16.819' E	35	19/02/2016	current

North Moreton – seasonal overview

The North Moreton wave buoy has been operational for over six years with an overall data return of 99 per cent. The data record for the period November 2015 to October 2016 was good, with total gaps of two and a half days, equivalent to a 99.3 percent data return. The buoy was replaced once during the reporting period on 19 February 2016 (Table 18).

An east coast low that affected the whole Queensland coast during June also set the fourth highest wave recorded at the North Moreton site (Table 19), with Hsig of 4.1 m and Hmax of 6.5 metres.

The SST (Figure 33) measured in the buoy hull ranged from 19.5 °C to 28.5 °C. The SST from January to mid-April was consistently warm enough for tropical cyclone development.

Except for January, May and October, the monthly average Hsig (Figure 34) for the recording period fell within one standard deviation (sd) of the monthly average of the entire record.

The wave climate during the reporting period was similar to the wave climate of the whole record with the exception of wave heights over 2 metres which were less frequent, as seen in the percentage exceedance plot (Figure 35). Histograms for occurrence of Hsig (Figure 36) show a slightly higher occurrence of waves greater than 0.6 m for winter and a greater occurrence of the modal 0.6 to 0.8 Hsig waves in summer for the reporting period compared to the long term record. Histograms of the occurrence of peak wave periods (Tp) (Figure 37) show a lower occurrence of the modal 7 to 9 second Tp during summer for the reporting period compared to the long term record.

The ratios between different wave parameters such as Hmax/Hsig were consistent between this reporting period and all of the historic data with the exception of a higher kurtosis in the Tp/Tz ratio, these are plotted in Figure 38.

The time series for wave direction (Figure 33) shows a peak wave direction generally from the east, with swings to the north throughout spring and early summer. This is also reflected in the directional wave rose plots (Figure 39). The wave directions for the reporting period are very similar to the entire record.

Table 19 North Moreton – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (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	25/12/2011 07:00	7.3
4	25/12/2011 07:00	3.9	04/06/2016 09:30	6.5
5	19/02/2013 11:30	3.5	19/02/2013 15:30	6.3
6	28/06/2012 02:30	3.2	19/02/2015 11:00	6.2
7	17/01/2012 06:30	3	28/06/2012 05:30	5.7
8	12/10/2010 13:30	3	22/08/2011 08:30	5.7
9	19/02/2015 12:30	3	27/03/2014 22:30	5.7
10	12/06/2012 15:30	2.9	16/01/2011 22:00	5.7

Table 20 North Moreton – Significant meteorological events with threshold Hsig of 2.2 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
27/02/2016 12:30	2.2 (2.4)	3.8 (4.7)	12.3	Low pressure troughs extended across the tropics and tropical cyclone Tatiana

26/04/2016 02:30	2.1 (2.3)	3.6 (4.1)	9.7	Two high pressure systems combining along the South NSW coast and a high pressure system south of Noumea causing strong winds and unsettled conditions
04/06/2016 09:30	3.6 (4.1)	5.9 (6.5)	9.2	An upper level trough over Queensland intensified as it tracked across the State's southeast, drawing moist air into its eastern flank as it moved off the coast of northeast New South Wales, developing into an east coast low early on the 5th

Denotes peak Hsig event

Notes: 1. Barometric pressure measured in hectopascals (hPa). The Hsig and Hmax values are the maximums recorded for each event and are not necessarily coincident in time. The Tp and Hsig values are coincident as a single event on the date shown. Due to possible statistical errors arising from finite length records used in calculating wave climate, the above storm peak Hsig and Hmax values are derived from the time series smoothed by a simple three hourly moving average following the recommendation of the literature (Forristall, Heideman, Leggett, Roskam, & Vanderschuren, 1996).

2. Hsig and Hmax values shown in brackets are unsmoothed values as recorded at the site.

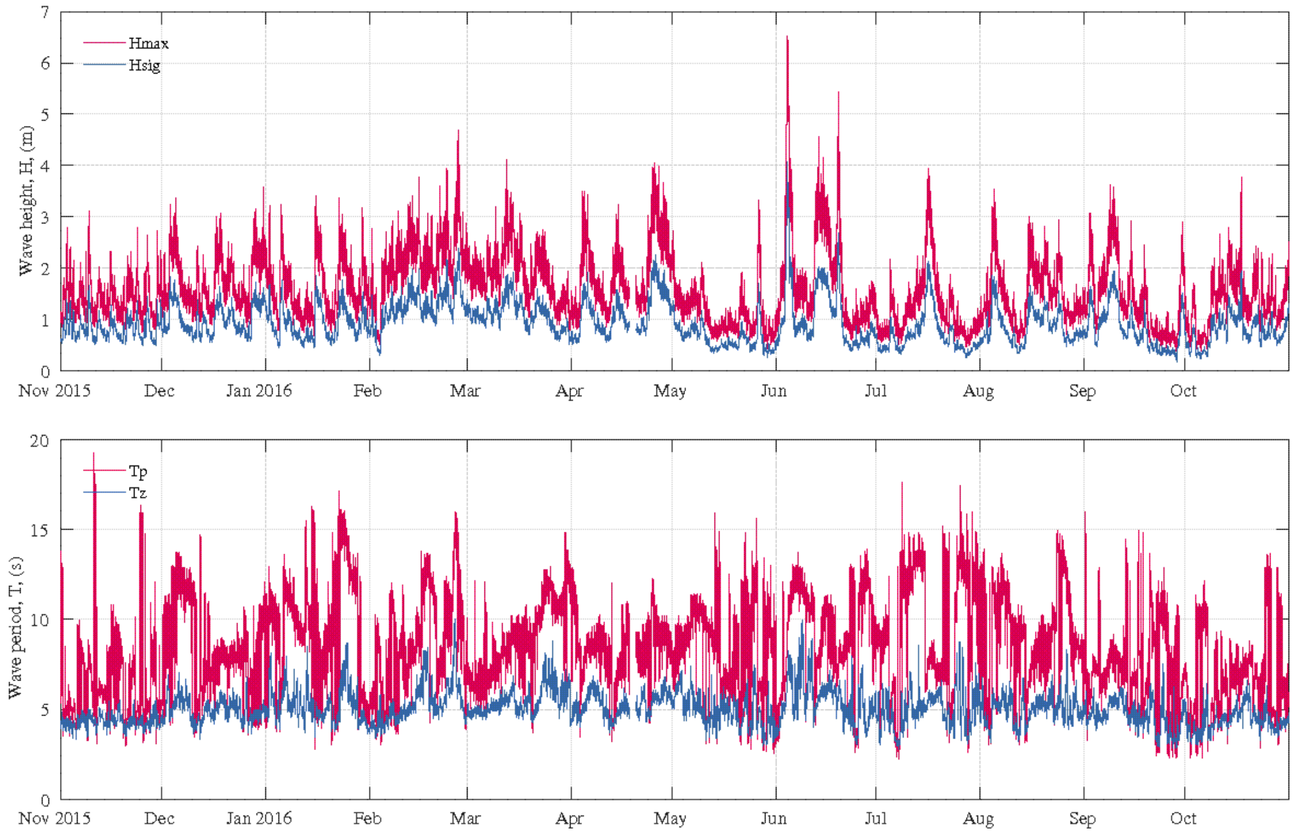


Figure 32 North Moreton – Daily wave recordings

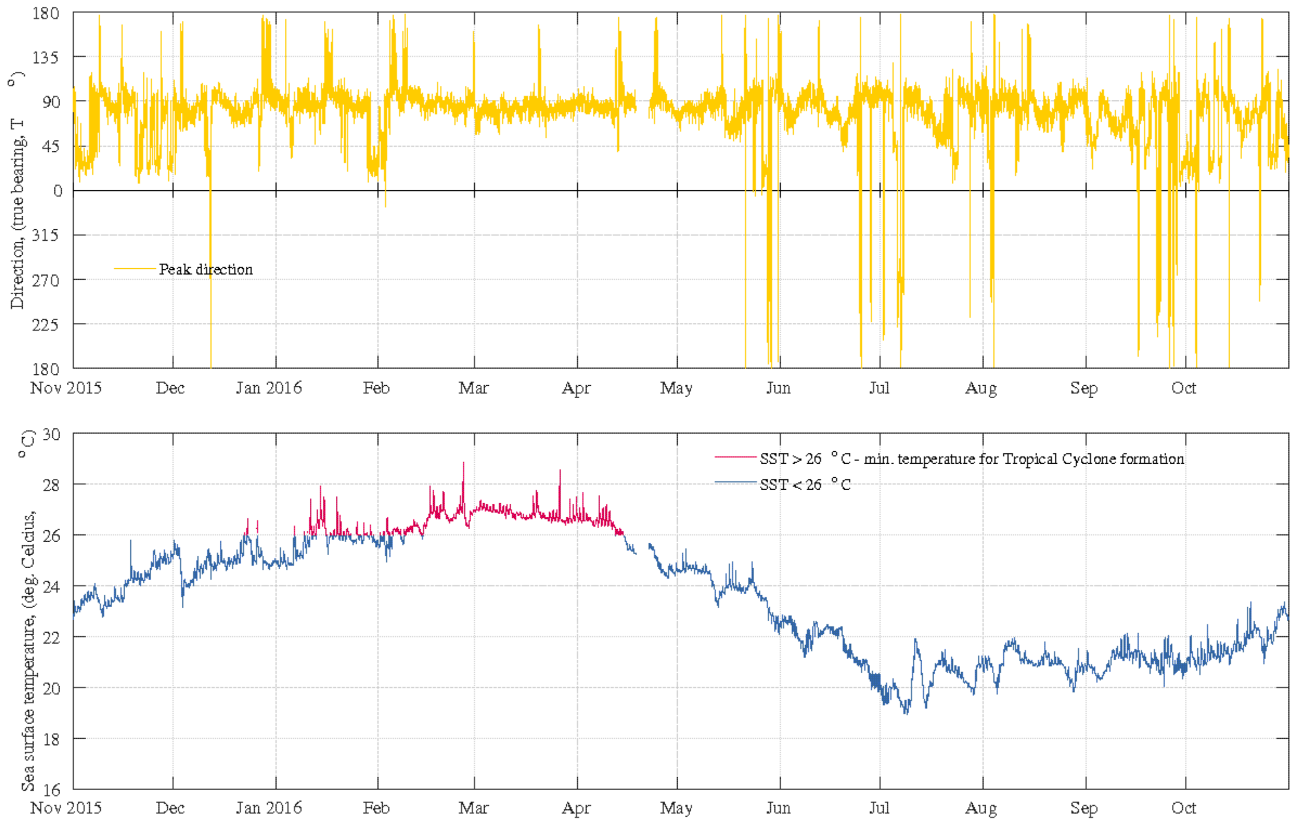


Figure 33 North Moreton – Sea surface temperature and peak wave direction

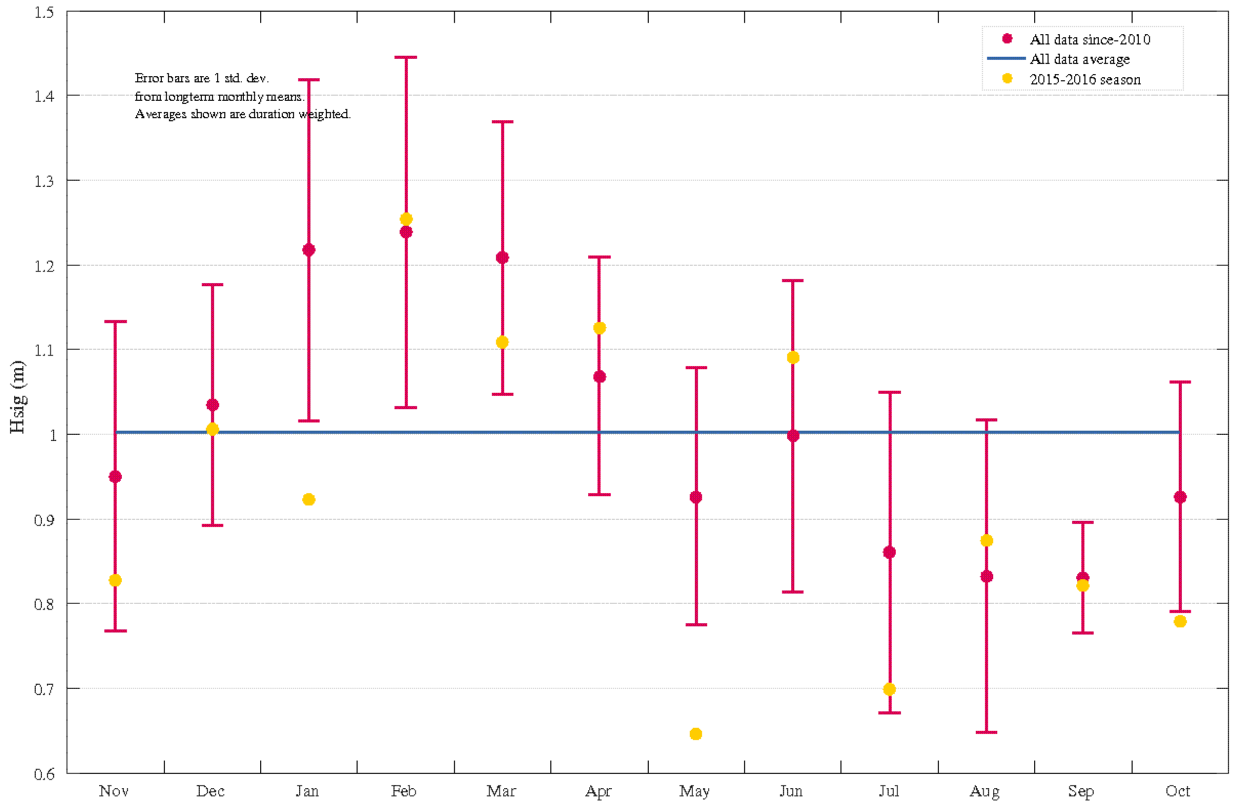


Figure 34 North Moreton – Monthly average wave height (Hsig) for seasonal year and for all data

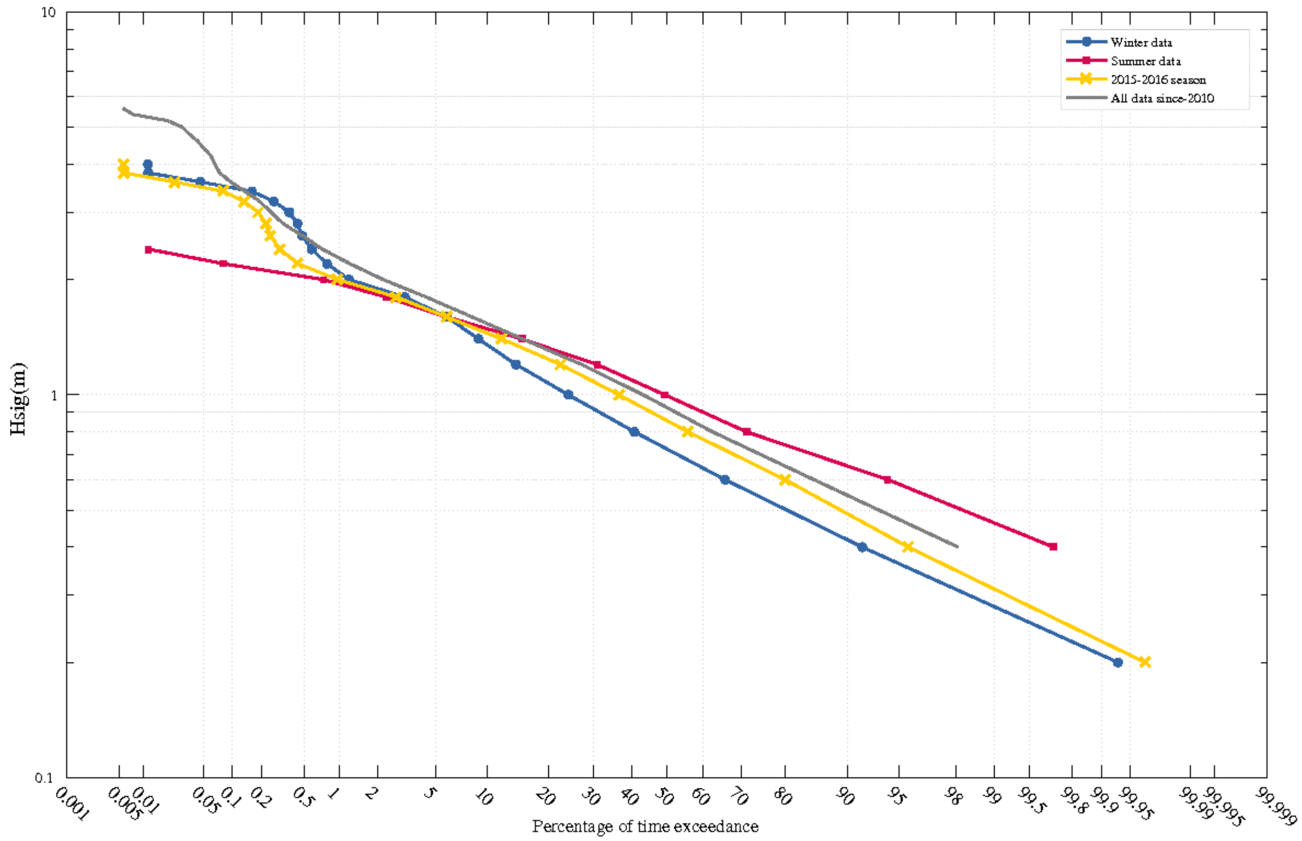


Figure 35 North Moreton – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

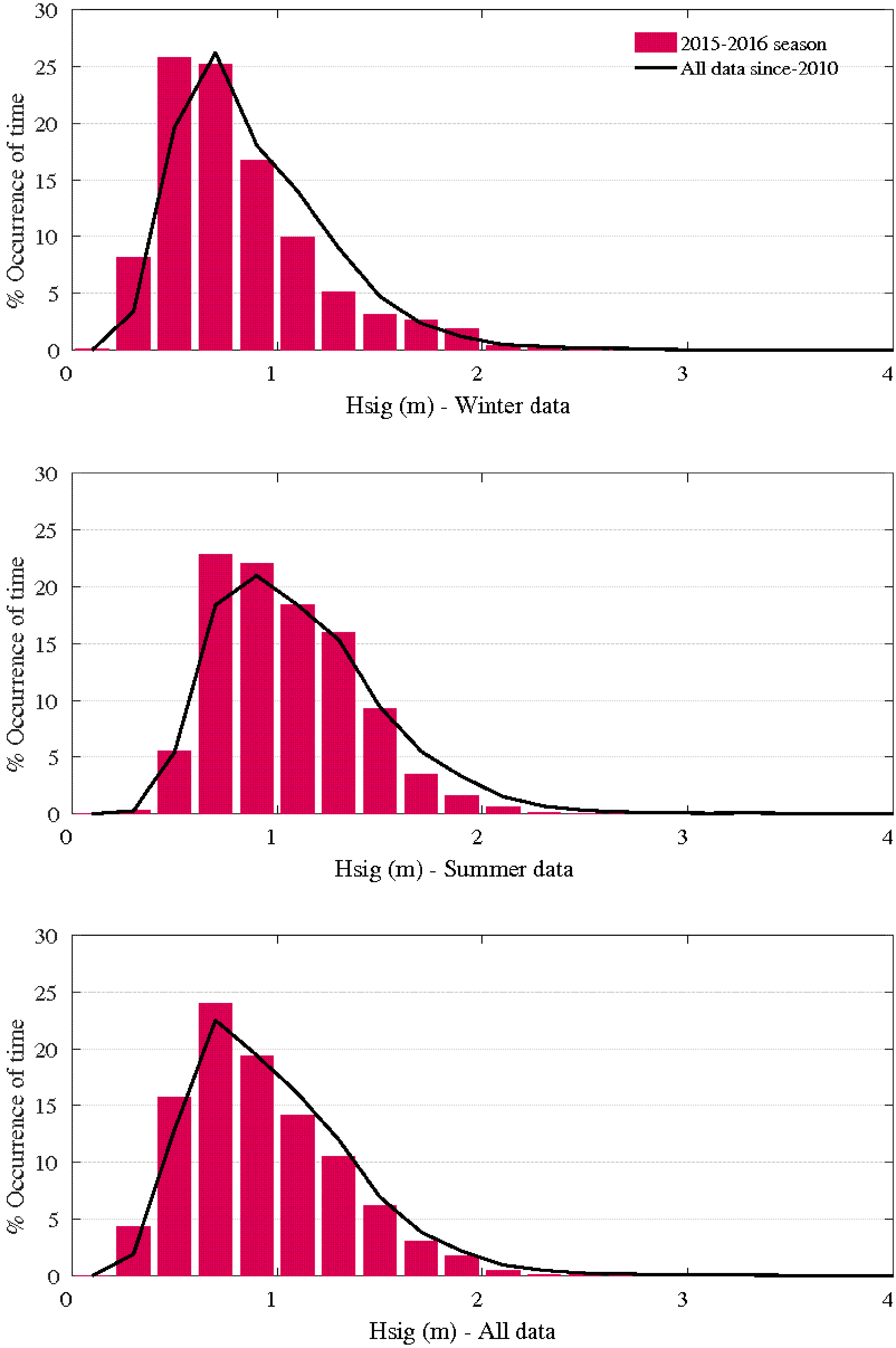


Figure 36 North Moreton – Histogram percentage (of time) occurrence of wave heights (Hsig)

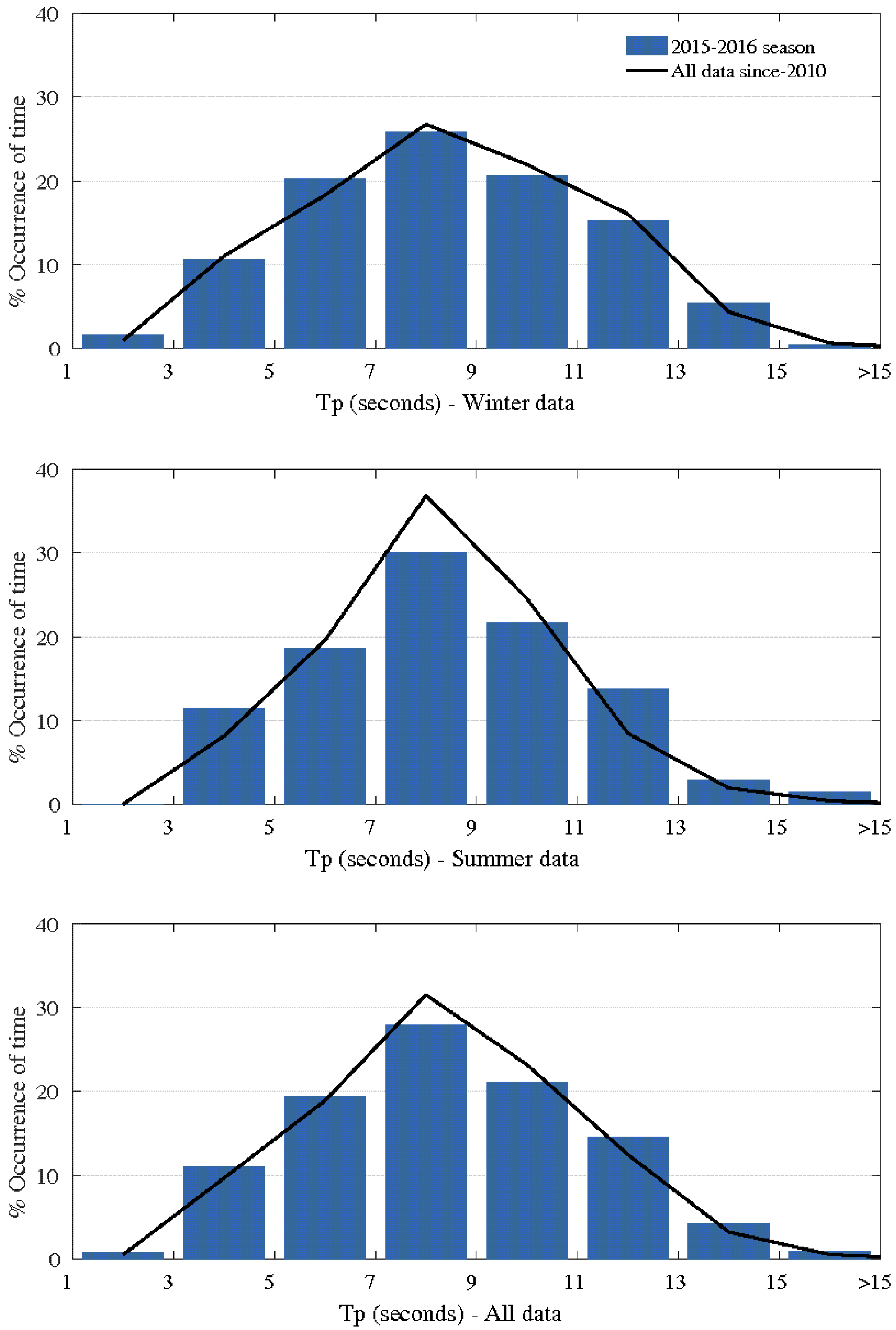


Figure 37 North Moreton – Histogram percentage (of time) occurrence of wave periods (Tp)

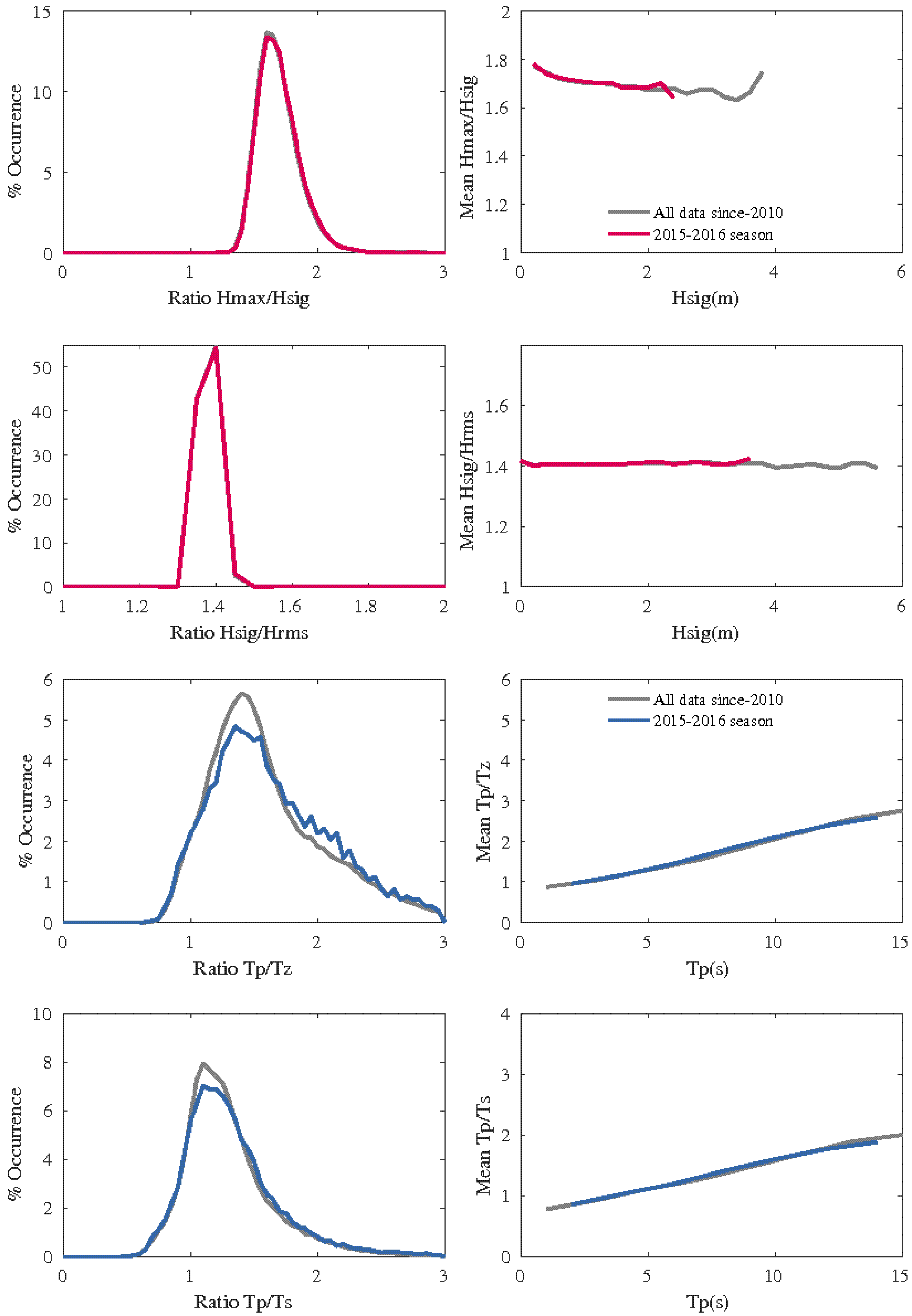
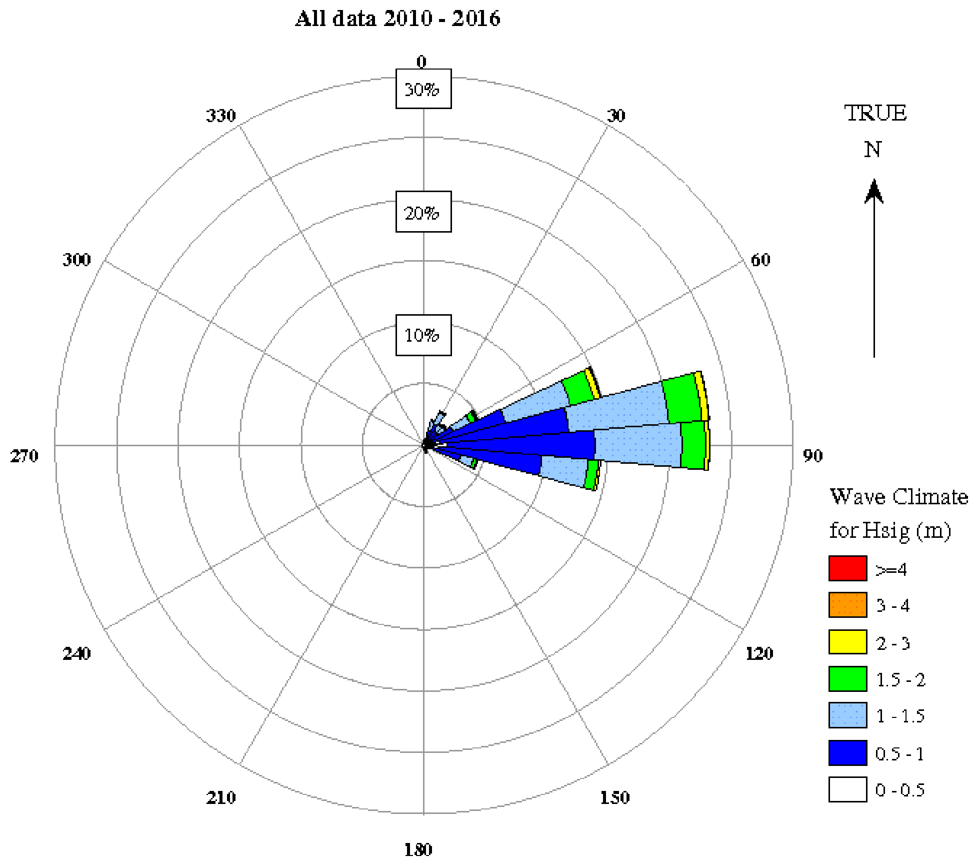


Figure 38 North Moreton – Wave parameter relationships



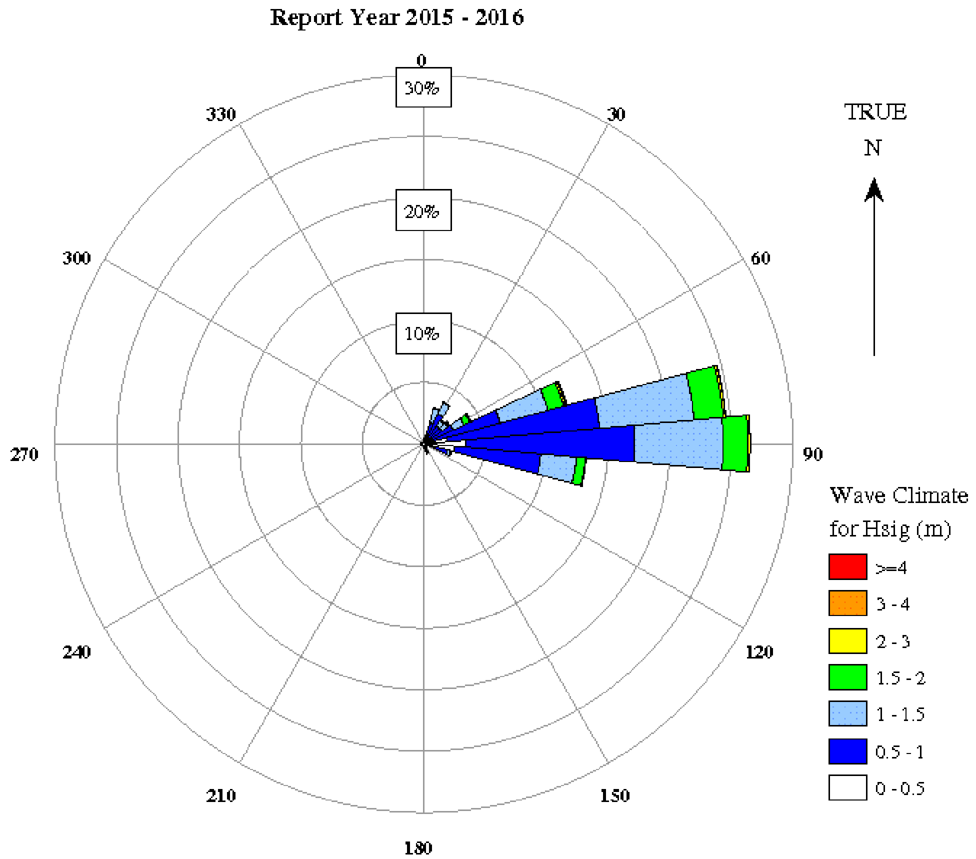


Figure 39 North Moreton – Directional wave rose

Caloundra

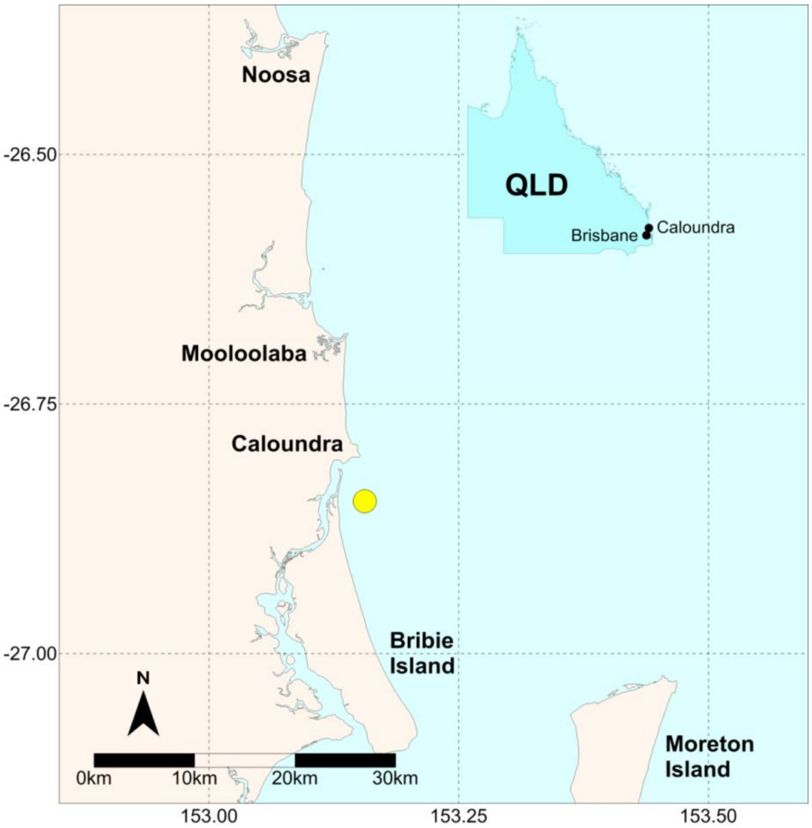


Figure 40 Caloundra – Locality plan

Table 21 Caloundra – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	01/05/2013	0.12 years	59,165	3.5
2015–16	01/11/2014	7.15 days	17,224	1

Table 22 Caloundra – Buoy deployments for 2015–16 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
26°50.833' S	153°09.382' E	18	28/05/2016	current

Caloundra – seasonal overview

The Caloundra wave buoy has only been operational since 01 May 2013 with an overall data return of 96.6 per cent. The data record for the period November 2015 to October 2016 was good, with total gaps of 7.15 days, equivalent to 98 per cent data return. The buoy was replaced once during the reporting period on 28 May 2016.

An east coast low off the south east coast in June generated large waves (Table 24) as seen in the time series of wave heights for Caloundra (Figure 41). The largest waves were on 04 June with a significant wave height (Hsig) of 3.9 m and a maximum wave height (Hmax) of 6.7 m, both ranked second for the Caloundra site.

The temperature (sea surface temperature, SST) measured in the buoy hull showed a range of 18° C to 27.5 °C (Figure 42). The SST from the early January to mid-April was warm enough for tropical cyclone development.

Except for January and May, the monthly average Hsig (Figure 44) for the recording period fell within one standard deviation (sd) of the monthly average of the entire record.

Histograms for occurrence of Hsig (Figure 45) show a modal Hsig height of 0.4–0.6 m during winter and a modal height of 0.6–0.8 m during summer, both lower than the long-term mean. Histograms for occurrence of peak wave period (Tp) (Figure 46) show a period of 7 to 11 seconds is most common throughout the year.

The time series for wave direction (Figure 42) show waves predominantly from the east, swinging at times to northeast. Directional wave rose plots (Figure 48) show the dominant east to east south-easterly wave directions.

Table 23 Caloundra – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (m)
1	01/05/2015 17:00	4.5	01/05/2015 15:00	7.5
2	04/06/2016 16:30	3.9	04/06/2016 10:00	6.7
3	19/02/2015 07:30	3.2	19/02/2015 07:30	6.2
4	27/03/2014 21:00	2.6	27/03/2014 22:00	4.8
5	19/06/2016 17:30	2.6	19/06/2016 19:30	4.7
6	27/02/2016 13:00	2.6	14/06/2016 21:30	4.4
7	16/03/2014 03:00	2.4	17/08/2014 06:00	4.4
8	17/08/2014 05:30	2.2	29/01/2014 22:30	4.2
9	14/06/2016 21:30	2.2	09/09/2016 10:30	4.2
10	03/02/2015 12:00	2.2	11/03/2014 12:30	4.2

Table 24 Caloundra – Significant meteorological events with threshold Hsig of 2.2 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
27/02/2016 13:00	2.4 (2.6)	3.6 (4.2)	13.2	Low pressure troughs extended across the tropics and tropical cyclone Tatiana
04/06/2016 16:30	3.4 (3.9)	5.9 (6.7)	10	An upper level trough over Queensland intensified as it tracked across the State's southeast, drawing moist air into its eastern flank as it moved off the coast of northeast New South Wales, developing into an East Coast Low early on the 5th
19/06/2016 17:30	2.4 (2.6)	3.7 (4.7)	7.5	Two low pressure systems formed on and off the northern Victorian coast.

Denotes peak Hsig event

Notes: 1. Barometric pressure measured in hectopascals (hPa). The Hsig and Hmax values are the maximums recorded for each event and are not necessarily coincident in time. The Tp and Hsig values are coincident as a single event on the date shown. Due to possible statistical errors arising from finite length records used in calculating wave climate, the above storm peak Hsig and Hmax values are derived from the time series smoothed by a simple three hourly moving average following the recommendation of the literature (Forristall, Heideman, Leggett, Roskam, & Vanderschuren, 1996).

2. Hsig and Hmax values shown in brackets are unsmoothed values as recorded at the site.

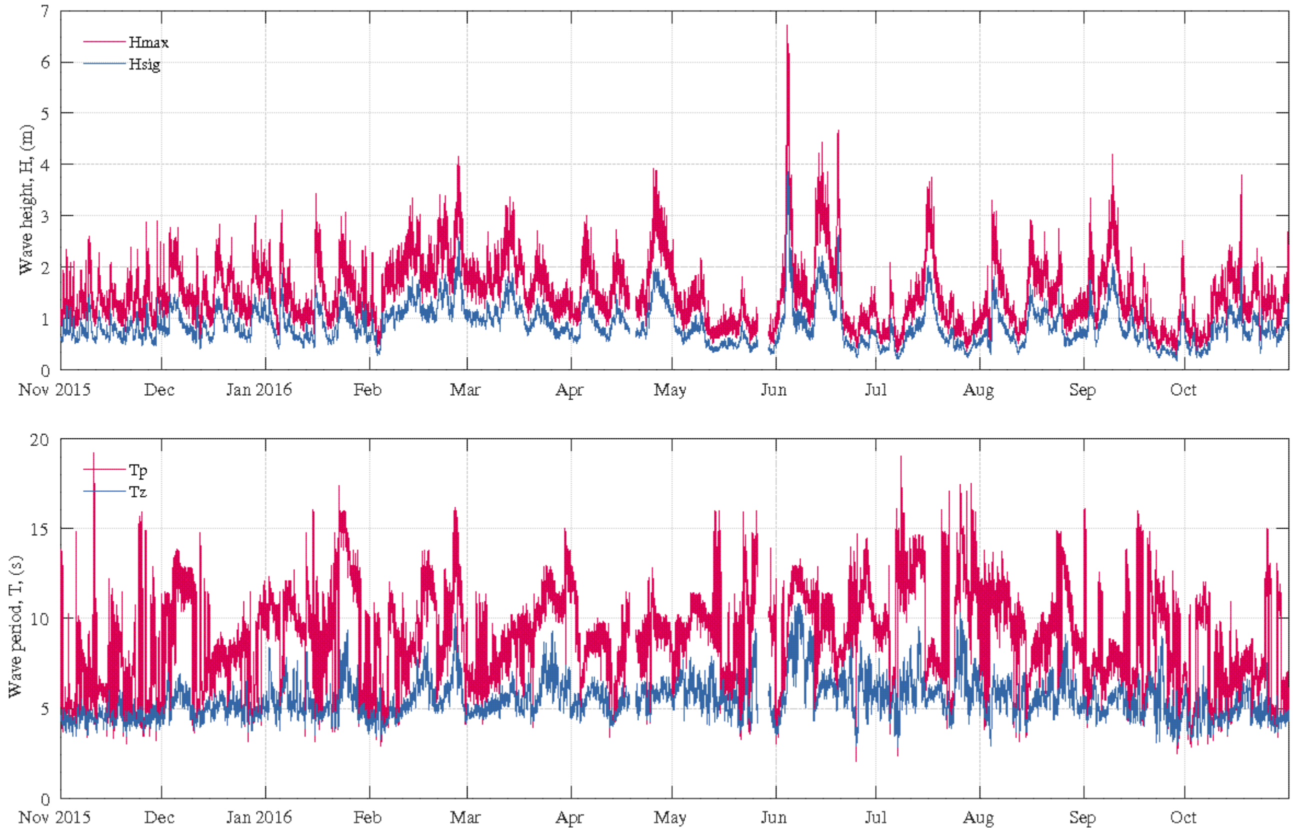


Figure 41 Caloundra – Daily wave recordings

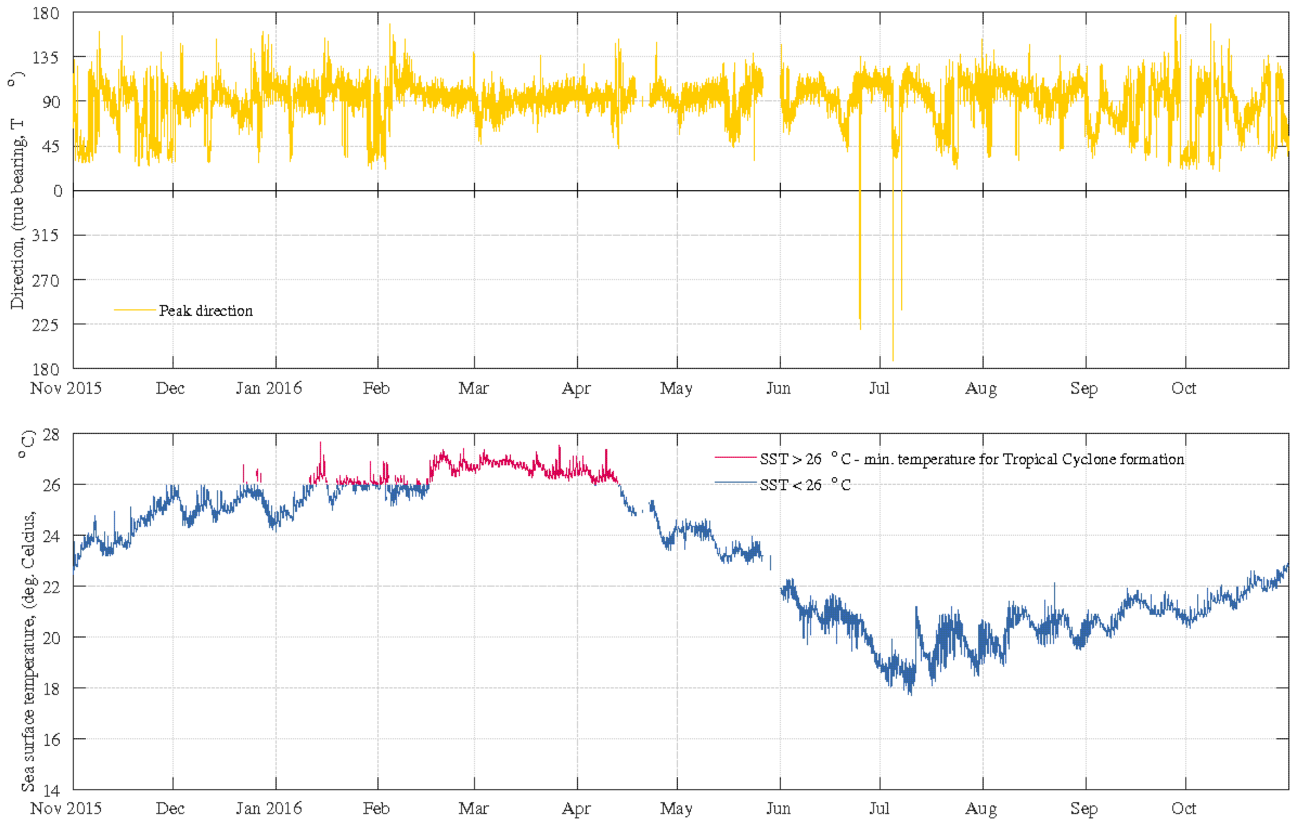


Figure 42 Caloundra – Sea surface temperature and peak wave directions

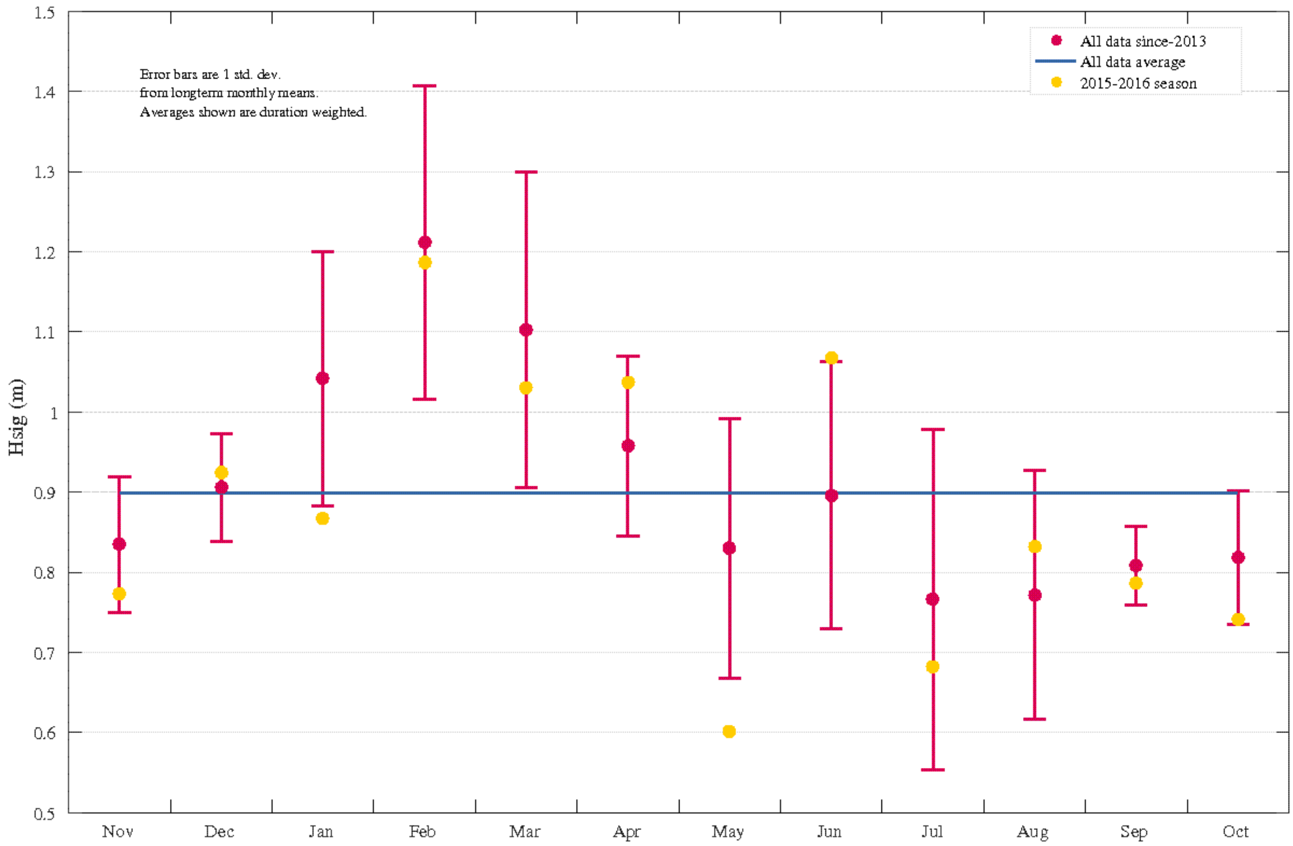


Figure 43 Caloundra – Monthly average wave height (Hsig) for seasonal year and for all data

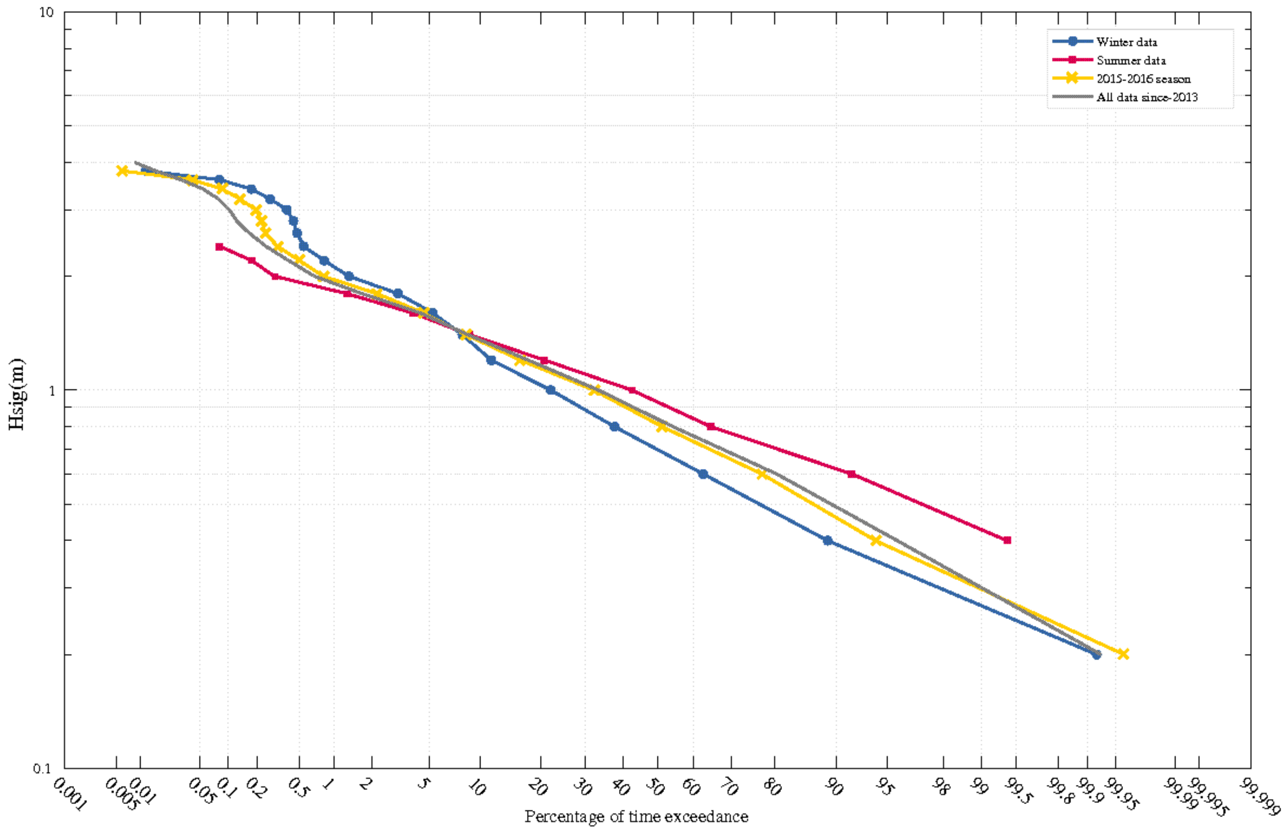


Figure 44 Caloundra – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

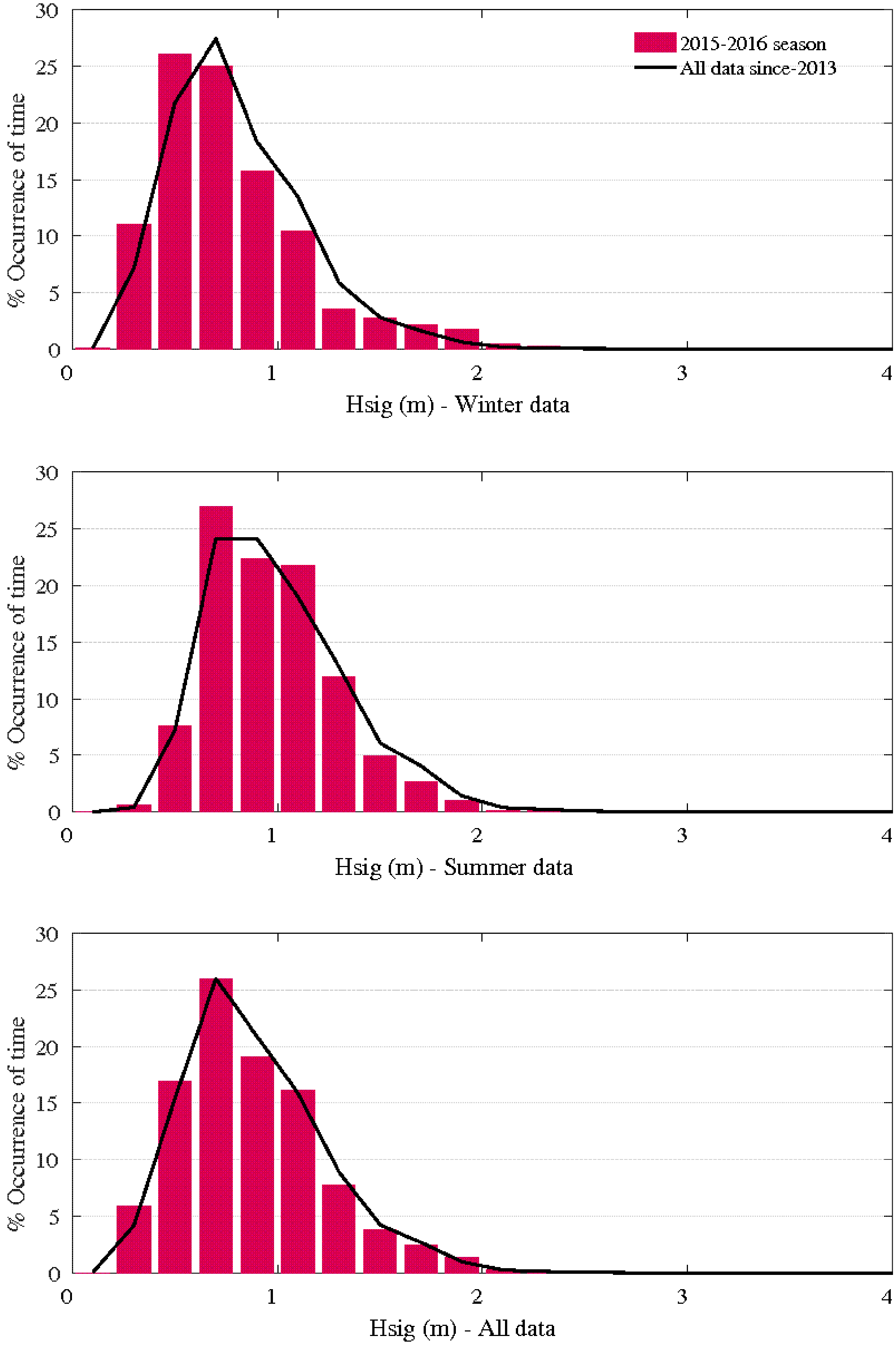


Figure 45 Caloundra – Histogram percentage (of time) occurrence of wave heights (Hsig)

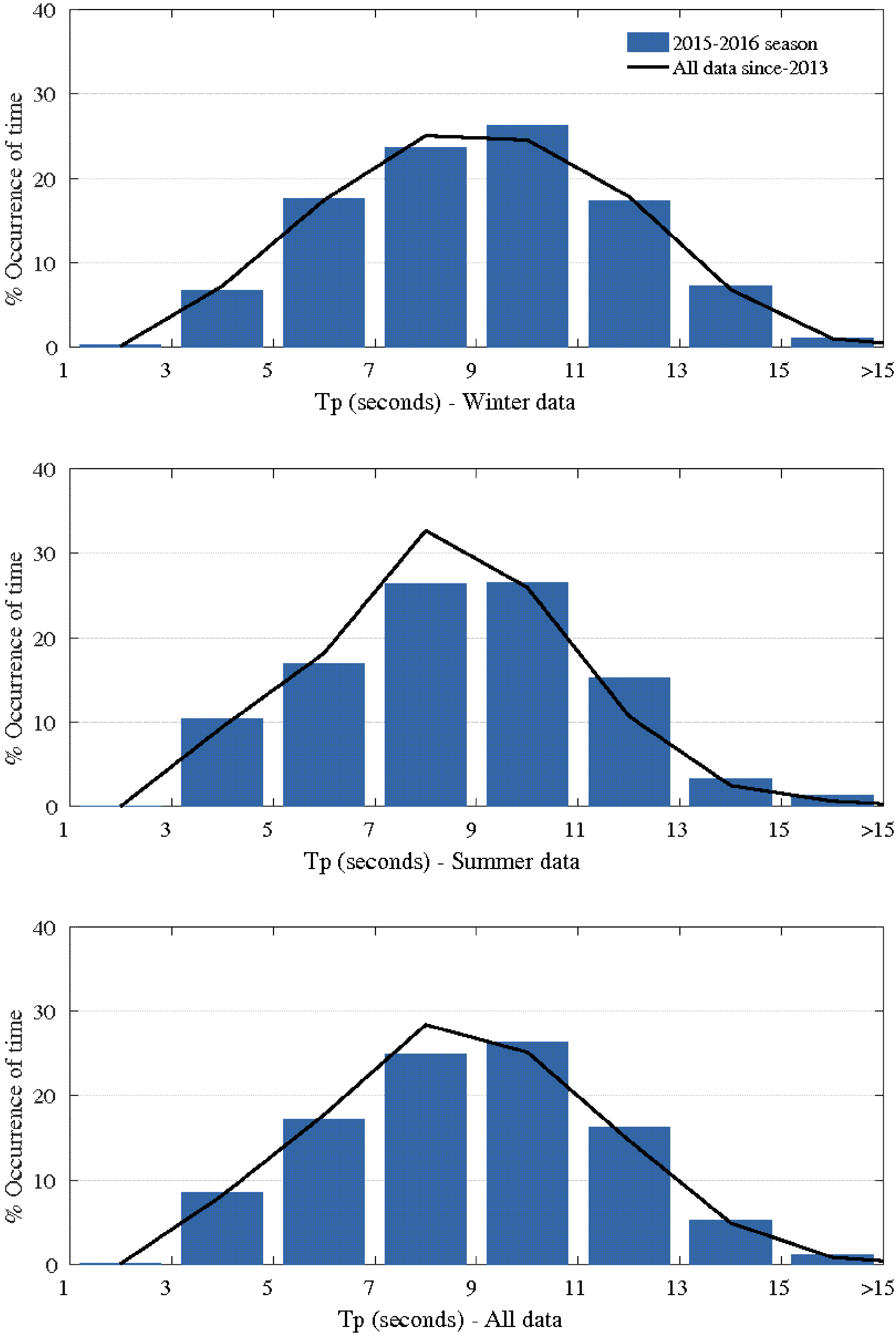


Figure 46 Caloundra – Histogram percentage (of time) occurrence of wave periods (Tp)

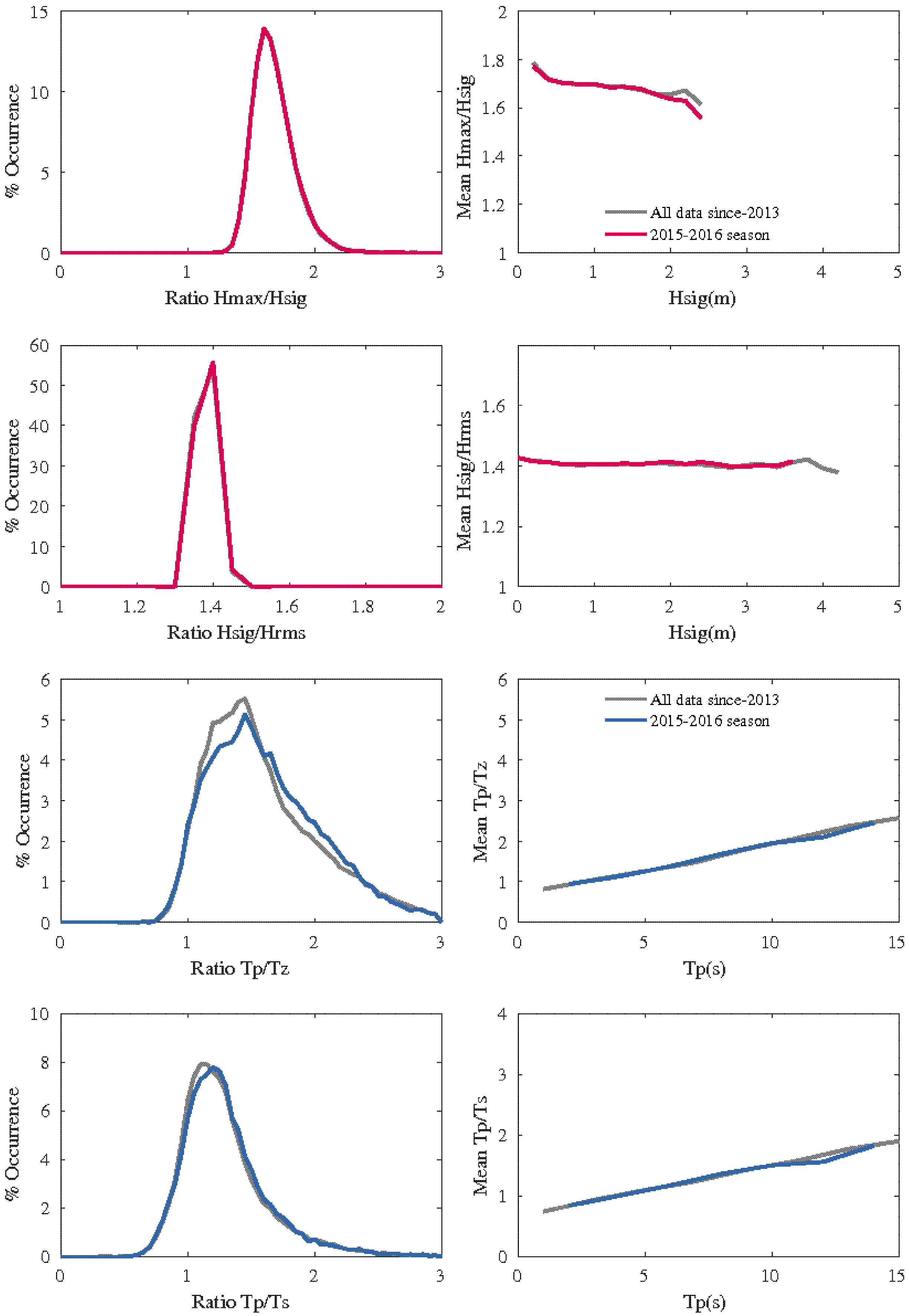
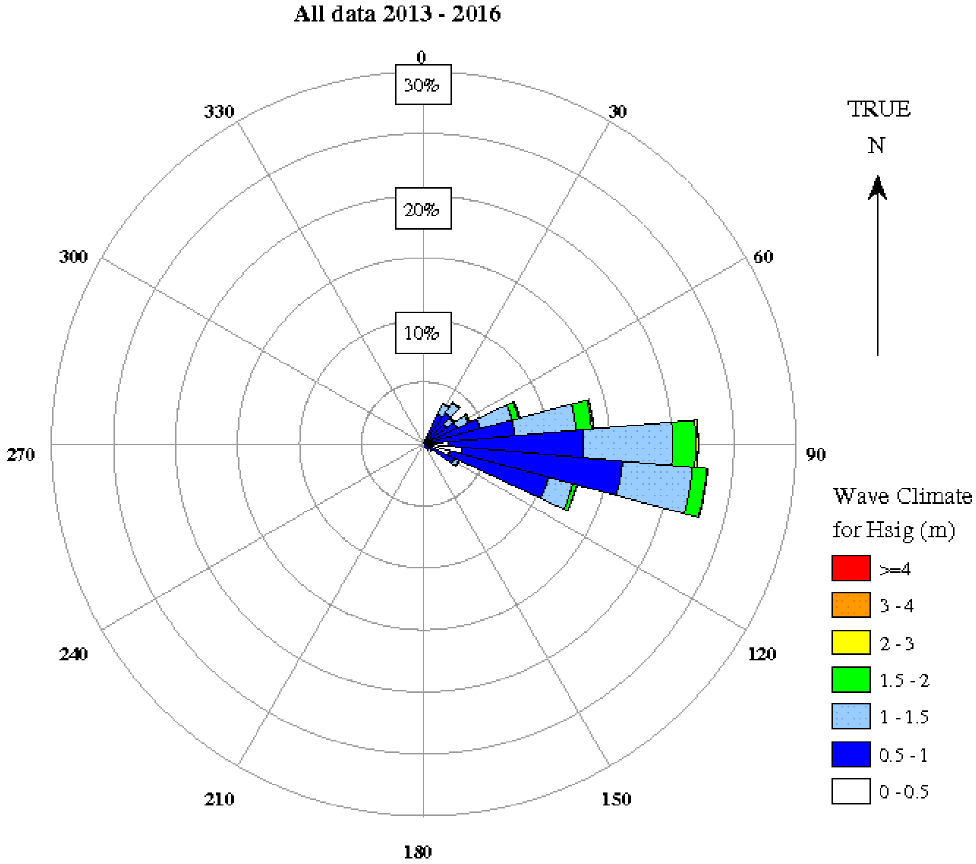


Figure 47 Caloundra – Wave parameter relationships



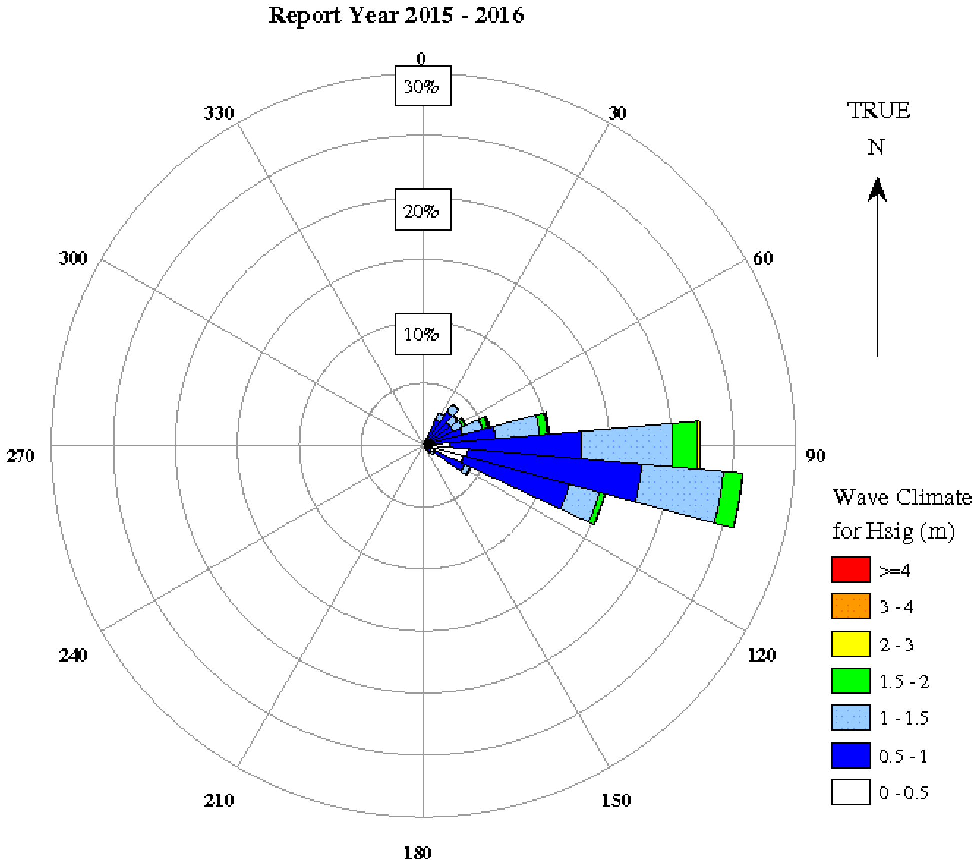


Figure 48 Caloundra – Wave rose

Mooloolaba

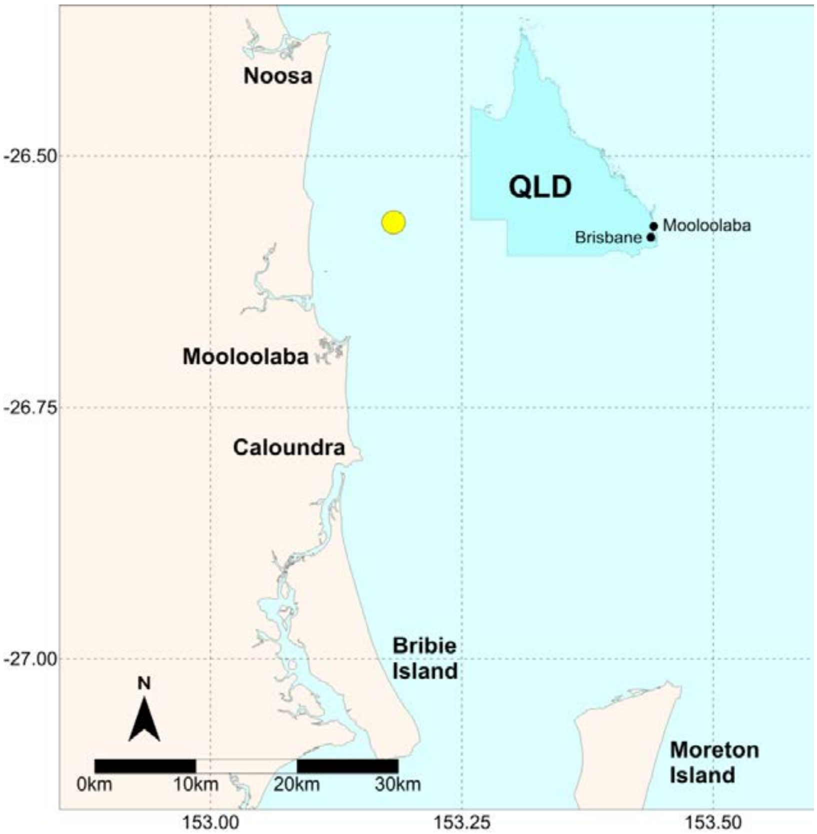


Figure 49 Mooloolaba – Locality plan

Table 25 Mooloolaba – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	01/05/2000	0.83 years	269,443	15.7
2015–16	01/11/2015	1.04 days	17,517	1

Table 26 Mooloolaba – Buoy deployments for 2015–16 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
26°33.987' S	153°10.918' E	33	13/09/2016	current

Mooloolaba – seasonal overview

The Mooloolaba wave buoy has been operational for over 15 years with an overall data return of 94.7 per cent. The data record for the period November 2015 to October 2016 was good, with total gaps of 1.04 days, equivalent to 99.7 per cent data return. The buoy was replaced once during the reporting period on 13 September 2016.

Increases in wave height occurred during February as a result of ex-TC Tatiana and an east coast low in June (Table 28). The highest waves recorded at Mooloolaba for the reporting period were on 27 February these did not rank in the top ten of the overall wave record (Table 27) with a significant wave height (Hsig) of 3.9 m and a maximum wave height (Hmax) of 6.6 metres. Peaks in wave height can be seen from these events in the time series for daily wave recordings (Figure 50).

The monthly average Hsig for the recording period fell within one standard deviation (sd) of the entire record except for May and October which were both below -1 sd (Figure 52).

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 Hsig (Figure 53). Histograms of occurrence of Hsig (Figure 54) show a similar distribution of wave heights, with slightly higher occurrence of wave heights from 0.2 – 0.8 m and lower occurrence of 1.0 – 1.2 m waves for the reporting period. Histograms of the occurrence of peak wave periods (Tp) (Figure 55) show a greater occurrence of the modal 13–15 seconds Tp range during winter and greater occurrence of the 11 to 15 seconds Tp and lower occurrence of 7–11 seconds during summer for the reporting period compared to the entire record.

The ratios between different wave parameters such as Hmax/Hsig were generally consistent between this reporting period and all of the historic data with the exception of Tp/Tz and Tp/Ts which were skewed towards a larger ratio, these are plotted in Figure 56.

Time series of wave direction (Figure 51) indicates wave direction is predominantly from the east to east south-east with occasional swings to NNE. The directional wave rose plots (Figure 57) support this too. The wave directions for the reporting period are very similar to the entire record.

The temperature (sea surface temperature, SST) measured in the buoy hull showed a range of 19.5 °C to 28 °C (Figure 51). The SST from the early January to mid-April was warm enough for tropical cyclone development.

Table 27 Mooloolaba – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (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 28 Mooloolaba – Significant meteorological events with threshold Hsig of 2.6 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
16/01/2016 01:30	2.8 (3.0)	4.5 (5.4)	9.4	A tropical low was positioned on the east coast of Australia with a trough extending along much of the east coast and into the Tasman Sea.
27/02/2016 12:30	3.6 (3.9)	5.9 (6.6)	13.3	Low pressure troughs extended across the tropics and the passage of tropical cyclone Tatiana
25/04/2016 11:00	2.9 (3.1)	4.9 (5.6)	11.8	Two high pressure systems south of the NSW border coupled with a low near Noumea pushed strong winds onto the south east coast.
04/06/2016 19:00	3.5 (3.8)	6.2 (8.2)	10.6	An upper level trough over Queensland intensified as it tracked across the State's southeast, drawing moist air into its eastern flank as it moved off the coast of north east New South Wales, developing into an east coast low early on the 5th
19/06/2016 17:30	2.6 (2.8)	4.2 (4.8)	7.6	Two low pressure systems formed on and off the northern Vic coast.
16/07/2016 17:00	2.6 (2.7)	4.4 (5.2)	7.9	A low pressure system to the north and a high positioned to the south driving strong easterly winds onto the southern Queensland coast
04/08/2016 19:00	2.9 (3.0)	4.3 (5.1)	11.7	Two low pressures systems (1004 & 1006) located off the south eastern coast

Denotes peak Hsig event

Notes: 1. Barometric pressure measured in hectopascals (hPa). The Hsig and Hmax values are the maximums recorded for each event and are not necessarily coincident in time. The Tp and Hsig values are coincident as a single event on the date shown. Due to possible statistical errors arising from finite length records used in calculating wave climate, the above storm peak Hsig and Hmax values are derived from the time series smoothed by a simple three hourly moving average following the recommendation of the literature (Forristall, Heideman, Leggett, Roskam, & Vanderschuren, 1996).

2. Hsig and Hmax values shown in brackets are unsmoothed values as recorded at the site.

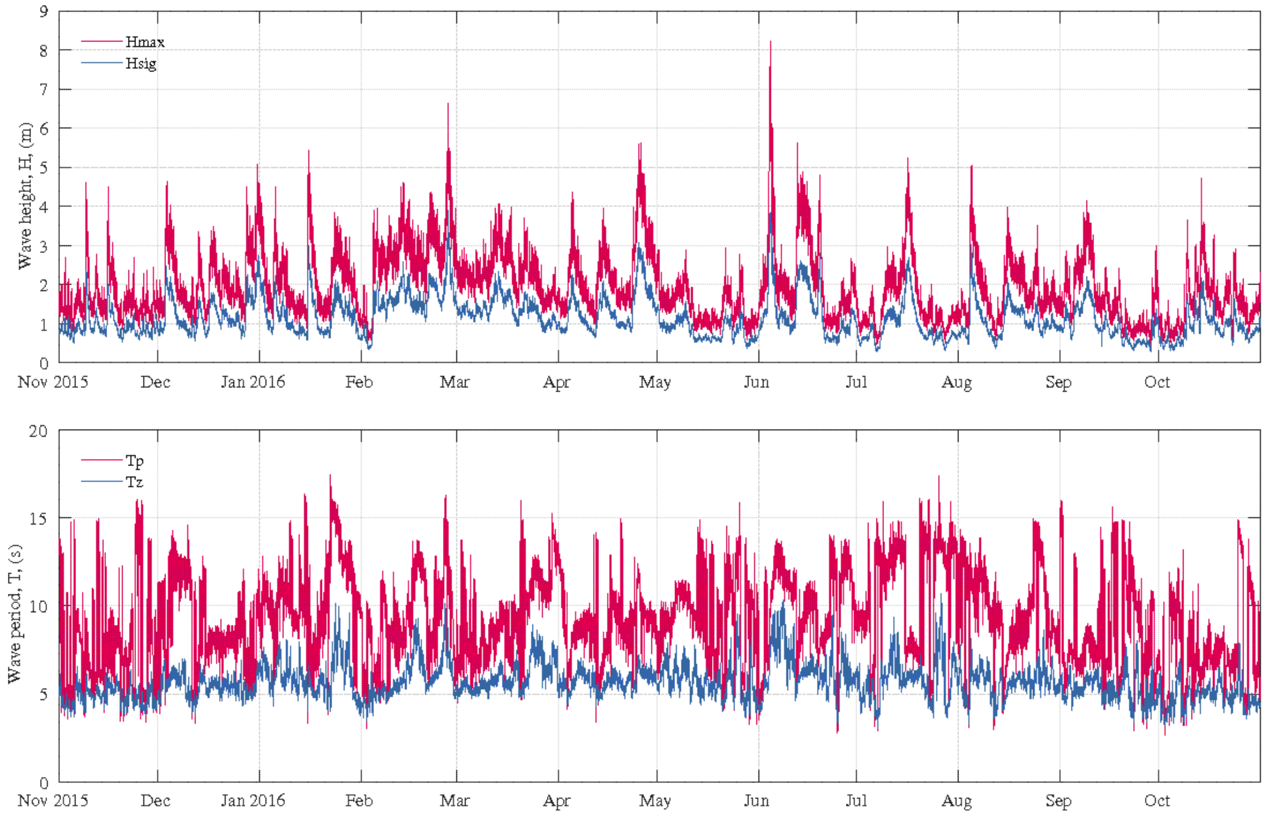


Figure 50 Mooloolaba – Daily wave recordings

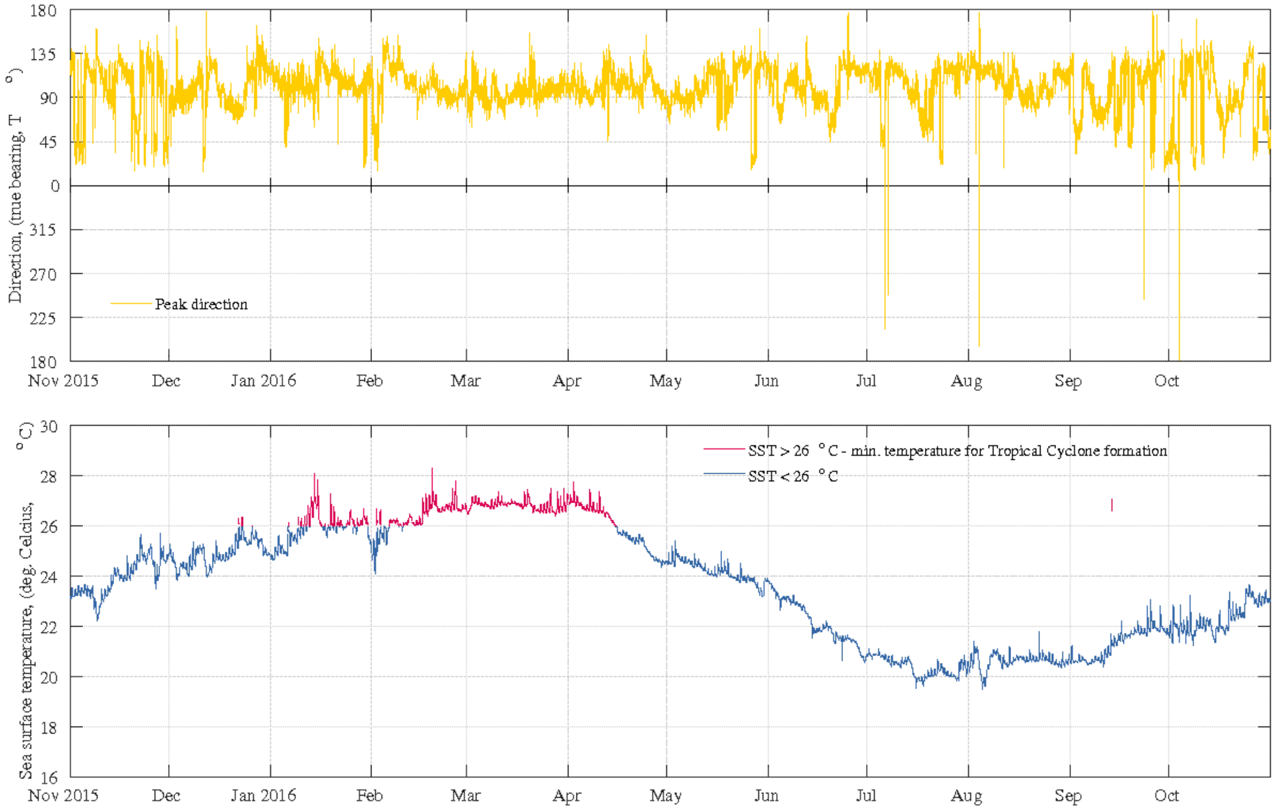


Figure 51 Mooloolaba – Sea surface temperature and peak wave directions

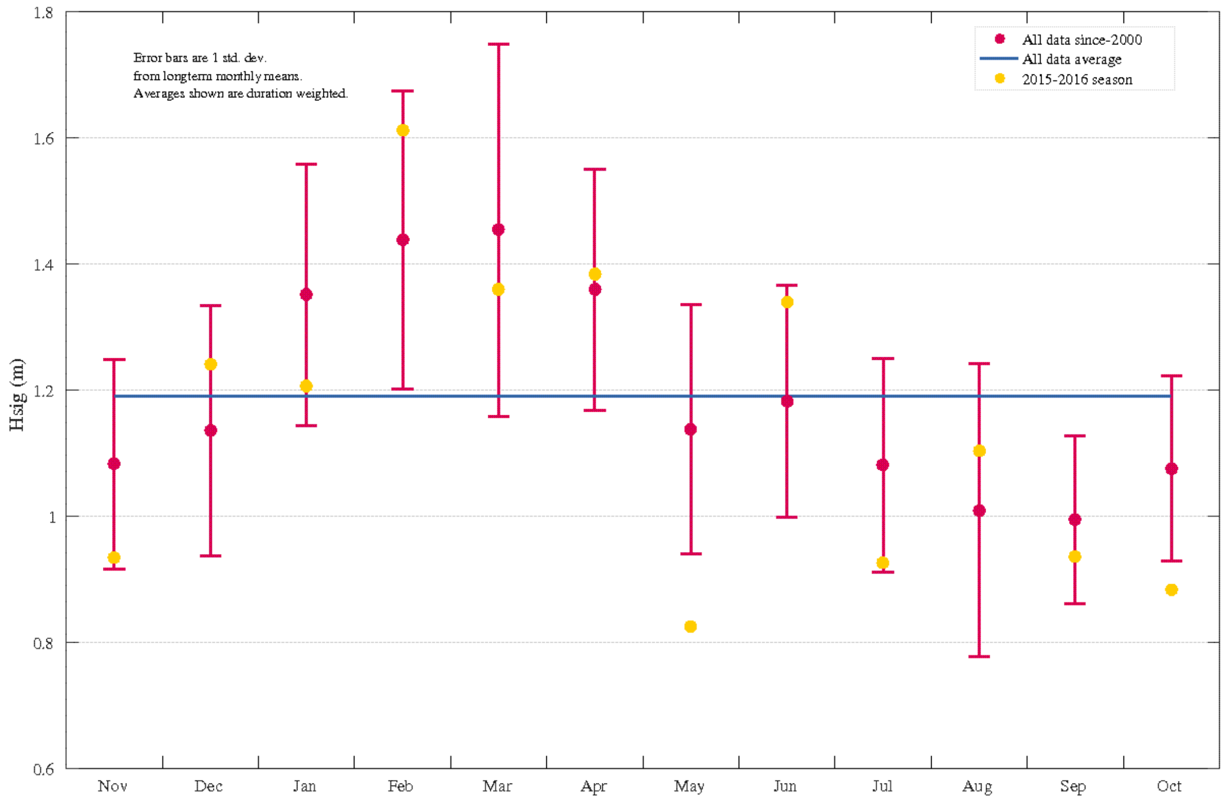


Figure 52 Mooloolaba – Monthly average wave height (Hsig) for seasonal year and for all data

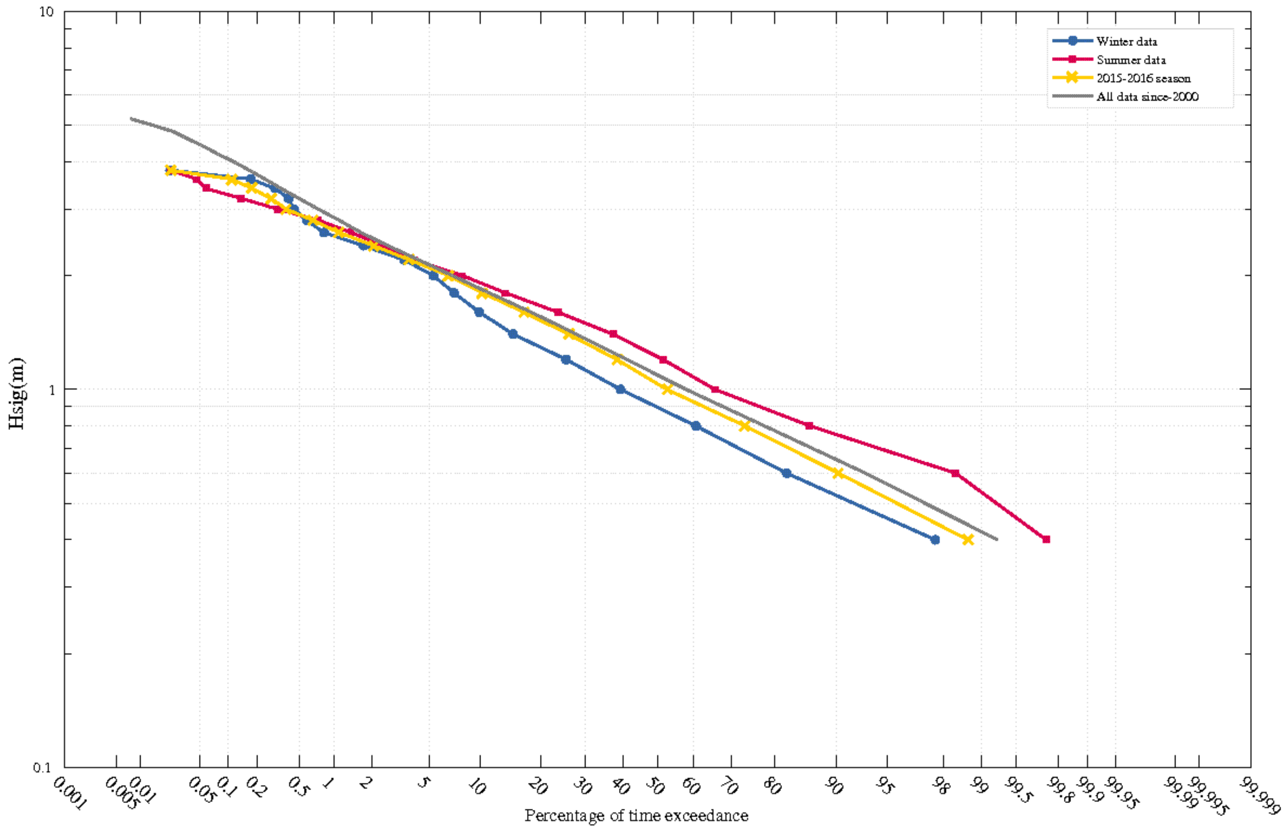


Figure 53 Mooloolaba – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

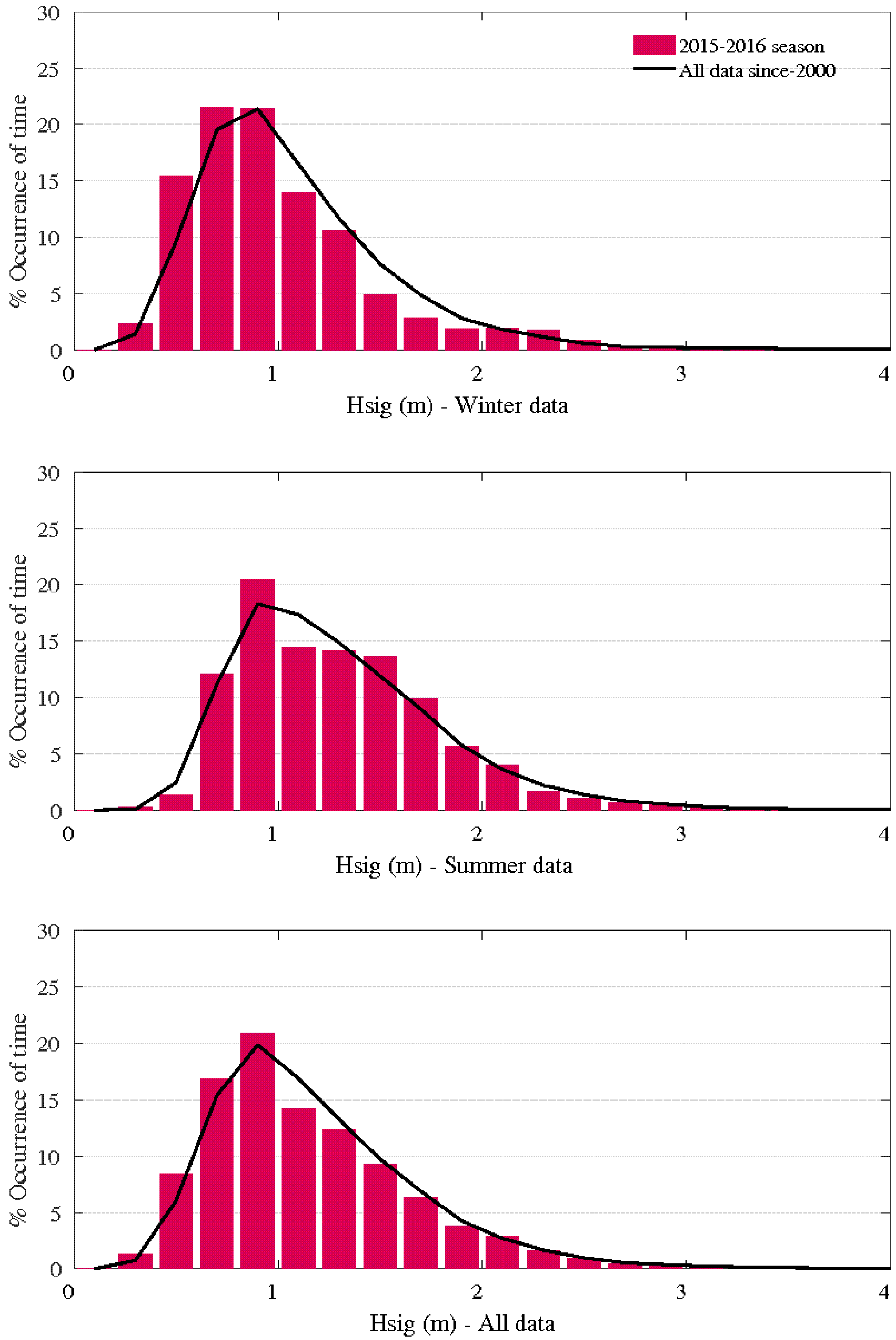


Figure 54 Mooloolaba – Histogram percentage (of time) occurrence of wave heights (Hsig)

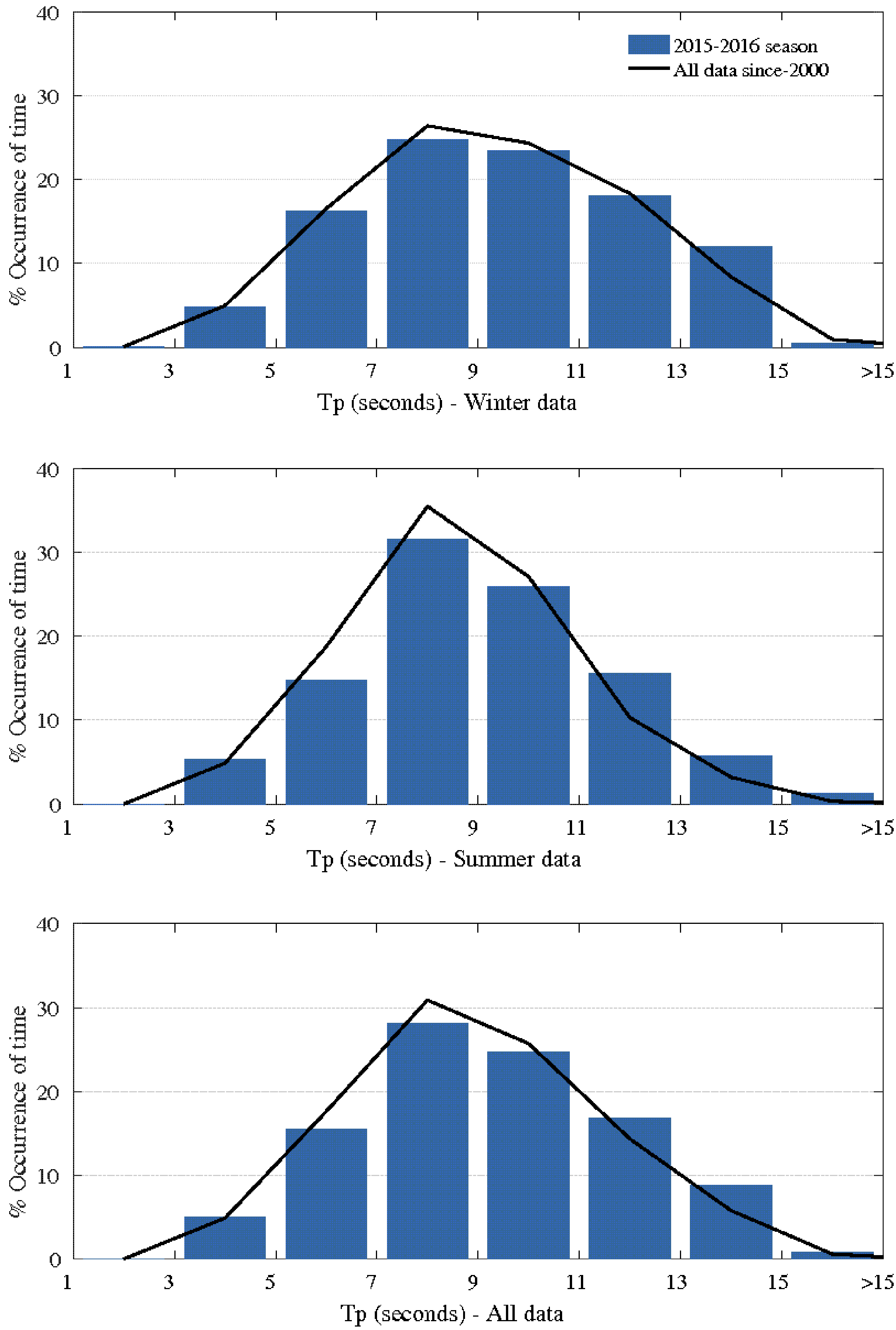


Figure 55 Mooloolaba – Histogram percentage (of time) occurrence of wave periods (Tp)

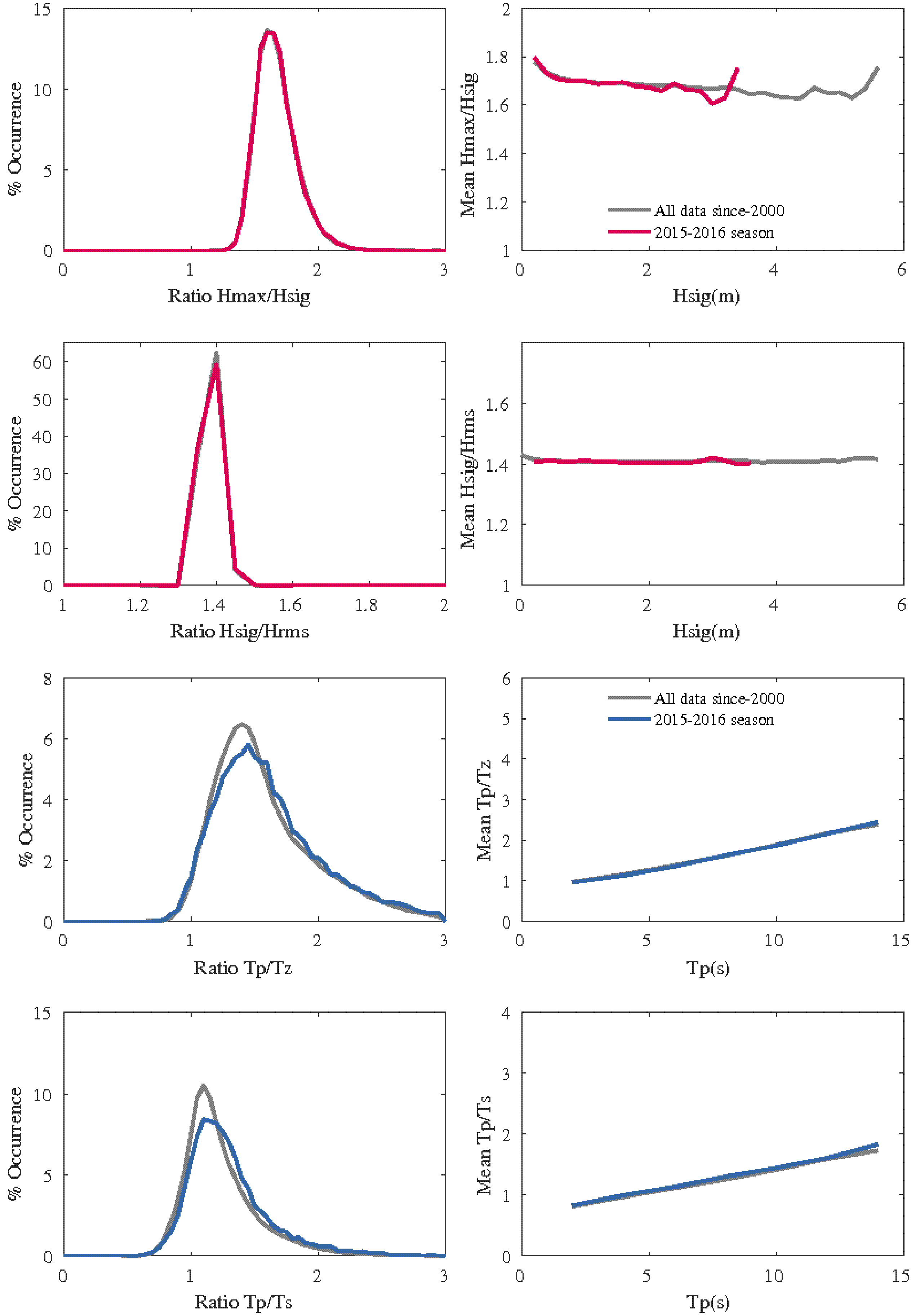
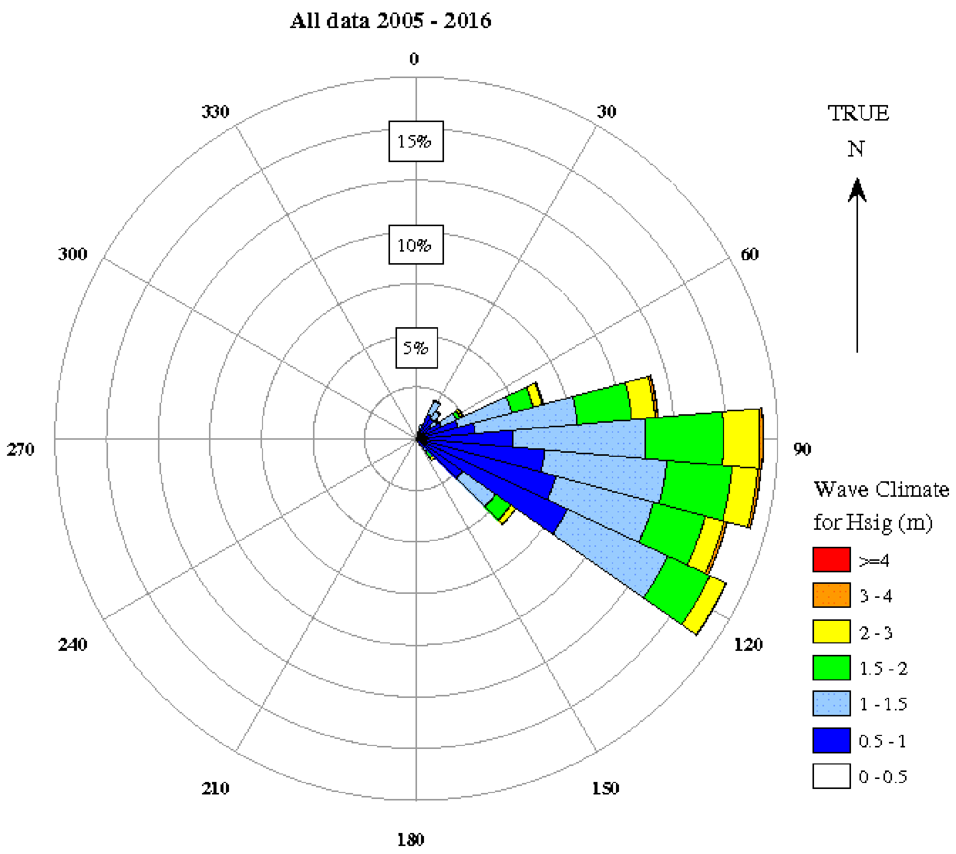


Figure 56 Mooloolaba – Wave parameter relationships



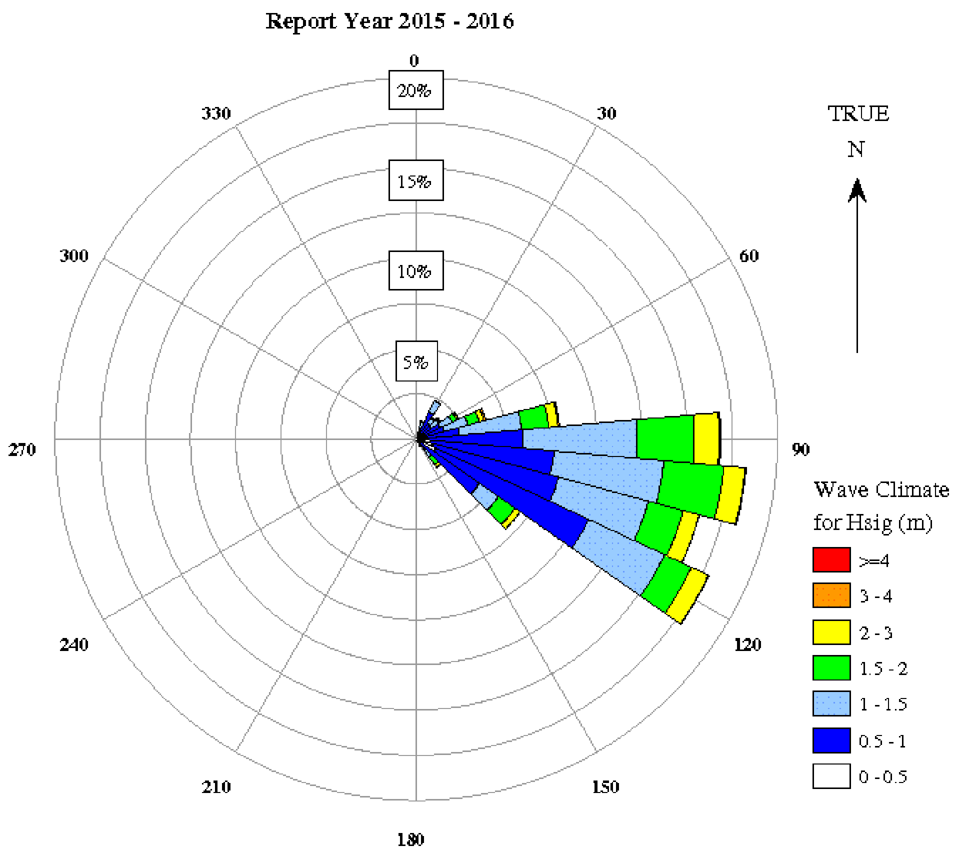


Figure 57 Mooloolaba – Directional wave rose

Gladstone

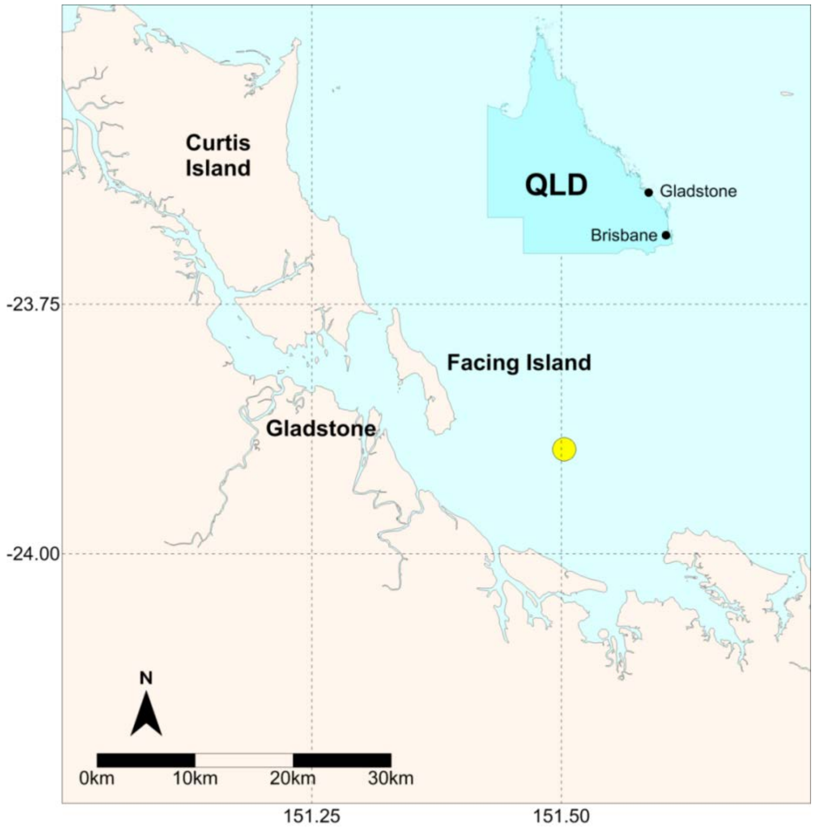


Figure 58 Gladstone – Locality plan

Table 29 Gladstone wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	23/09/2009	0.16 years	121,262	6.95
2015–16	01/11/2015	4.33 days	17,359	1

Table 30 Gladstone – Buoy deployments during the 2015–16 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
23°53.751' S	151°30.101' E	16.0	08/11/2015	27/10/2016
23°53.746' S	151°30.197' E	15.3	27/10/2016	current

Gladstone – seasonal overview

The Gladstone wave buoy has been operational for almost seven years with an overall data return of 97.7 per cent. The data recorded for the period November 2015 to October 2016 was good, with total gaps of 4.48 days, equivalent to a 98.8 per cent data return. The buoy was replaced twice during the reporting period on 8 November 2015 and 27 October 2016 (Table 30).

There was a significant wave height (Hsig) during the reporting period that made it into the top ten ranks (see table 5) and one maximum wave height (Hmax) that also made the top ten ranking. Notably, a Hsig of 2.9 m was reported when a low pressure trough extended over the north Queensland coast on 16 July and ranked forth, while a Hmax of 5.5 m was also reported on the same day and ranked fifth.

During the reporting year there was an absence of extreme weather events and particularly no tropical cyclones impacted on the Gladstone coast.

There are differences in the wave climate off Gladstone between summer and winter seasons. Over 20 per cent (30 per cent in the previous season) of the time Hsig exceeds 1.0 m during summer whereas during winter Hsig exceeds 1.0 m only 17 per cent of the time (Figure 62). The most common Tp is six seconds both in summer and winter (Figure 64).

The wave climate during the reporting period was very similar to the wave climate of the whole record, evidenced in the percentage time exceedance (Figure 62) and histograms of the occurrence of Hsig and Tp (Figures 63 and 64). It is worth noting that the ratios between different wave parameters such as Hmax/Hsig were consistent between this reporting period and all of the historic data, the exception being the ratio between Hsig/Hmax and Hsig/Hrms where the influence of TC Marcia pushed Hsig out to 3 m, these are plotted in Figure 59.

The monthly average Hsig generally fell within one standard deviation (sd) of the long term mean with the exception of three months: January, May and October. During these months the mean was lower than the mean +1 sd. (Figure 61).

The plot of wave direction over the 2015–16 season (Figure 60) showed a dominant Easterly (slightly North of East) direction with an occasional swing to the North during summer and an occasional swing to the South in winter. The dominance of incident wave direction is reflected in the directional wave rose plot (Figure 66) along with the most common wave height (Hsig) of 0.5 m to 1.0 metres.

The SST was over the threshold for cyclone development (26.5 °C) from November 2015 to May 2016 (Figure 60).

Table 31 Gladstone – Highest waves

Rank	Date	Hs (m)	Date	Hmax (m)
1	01/02/2010 20:00	3.2	01/02/2010 20:00	6.1
2	25/01/2013 02:00	3.2	01/02/2014 01:00	6.0
3	20/02/2015 15:00	3.0	25/01/2013 14:00	5.8
4	16/07/2016 09:00	2.9	20/02/2015 16:30	5.5
5	01/02/2014 01:00	2.8	16/07/2016 09:00	5.5
6	20/03/2010 10:30	2.3	20/03/2010 21:30	4.7
7	16/01/2012 22:00	2.3	16/01/2012 22:30	4.5
8	12/04/2013 04:00	2.3	12/04/2013 05:00	3.9
9	12/10/2010 12:00	2.2	12/10/2010 11:00	3.8
10	13/03/2010 13:30	2.1	13/03/2010 14:00	3.8

Table 32 Gladstone – Significant meteorological events with threshold Hsig of 2.0 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
16/07/2016 09:00	2.5 (2.9)	4.3 (5.5)	9.8	A low pressure system located over Gladstone region

Denotes peak Hsig event

Notes: 1. Barometric pressure measured in hectopascals (hPa). The Hsig and Hmax values are the maximums recorded for each event and are not necessarily coincident in time. The Tp and Hsig values are coincident as a single event on the date shown. Due to possible statistical errors arising from finite length records used in calculating wave climate, the above storm peak Hsig and Hmax values are derived from the time series smoothed by a simple three hourly moving average following the recommendation of the literature (Forristall, Heideman, Leggett, Roskam, & Vanderschuren, 1996).

2. Hsig and Hmax values shown in brackets are unsmoothed values as recorded at the site.

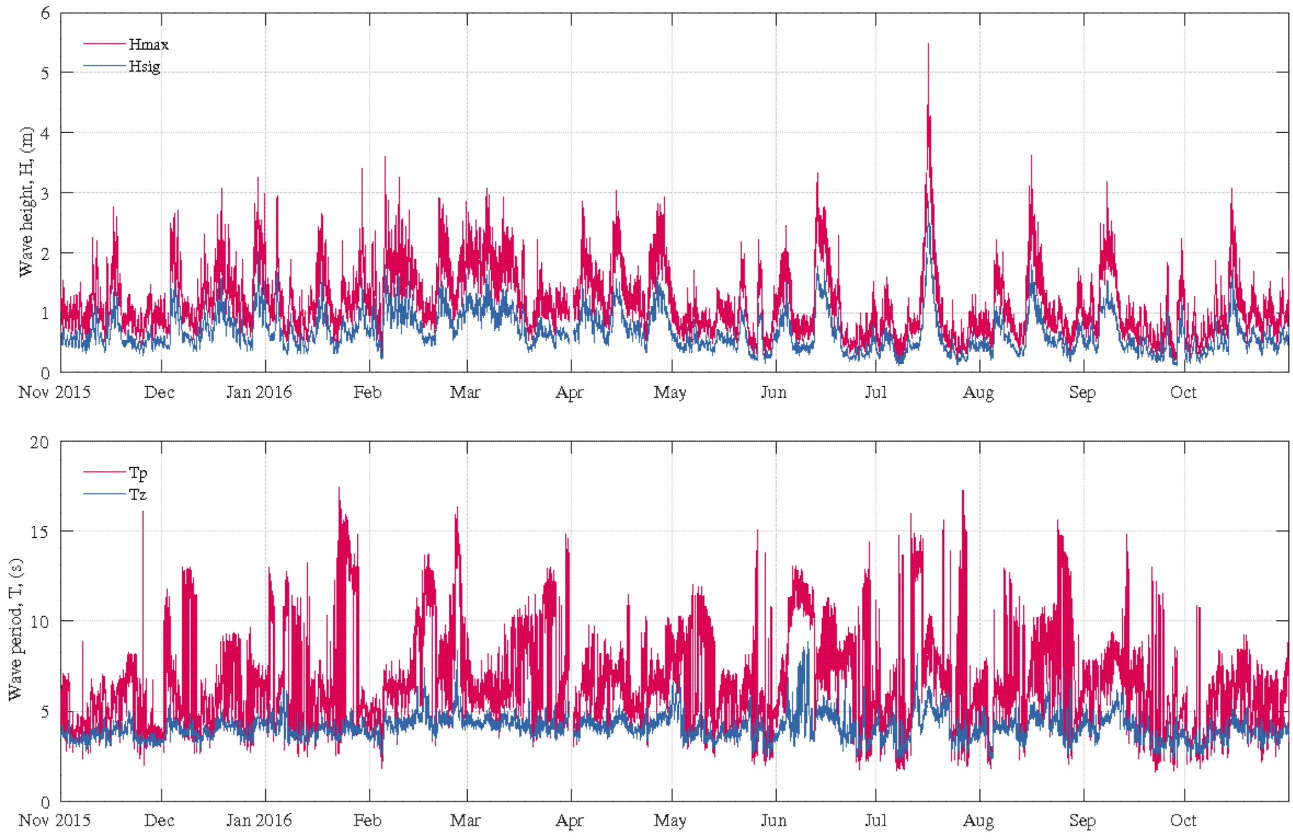


Figure 59 Gladstone – Daily wave recordings

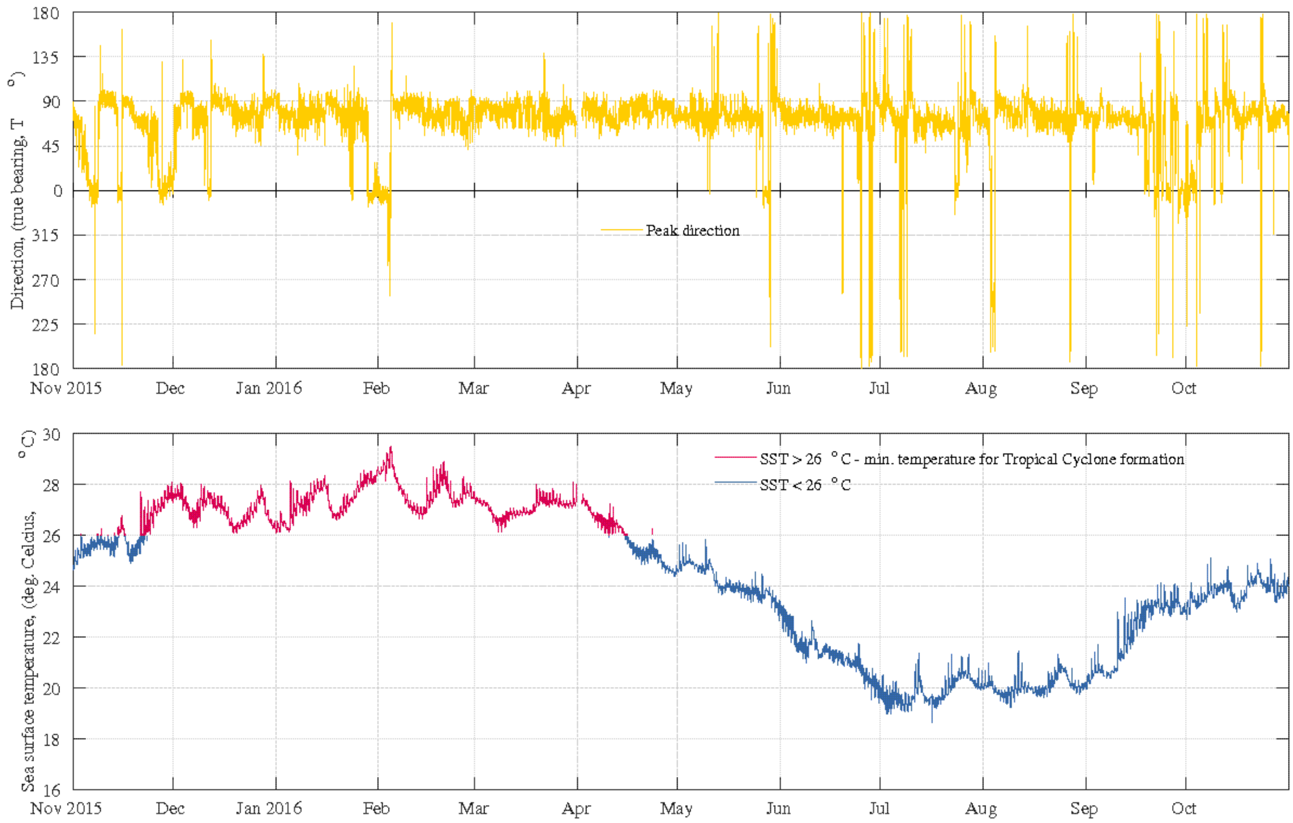


Figure 60 Gladstone – Sea surface temperature and peak wave directions

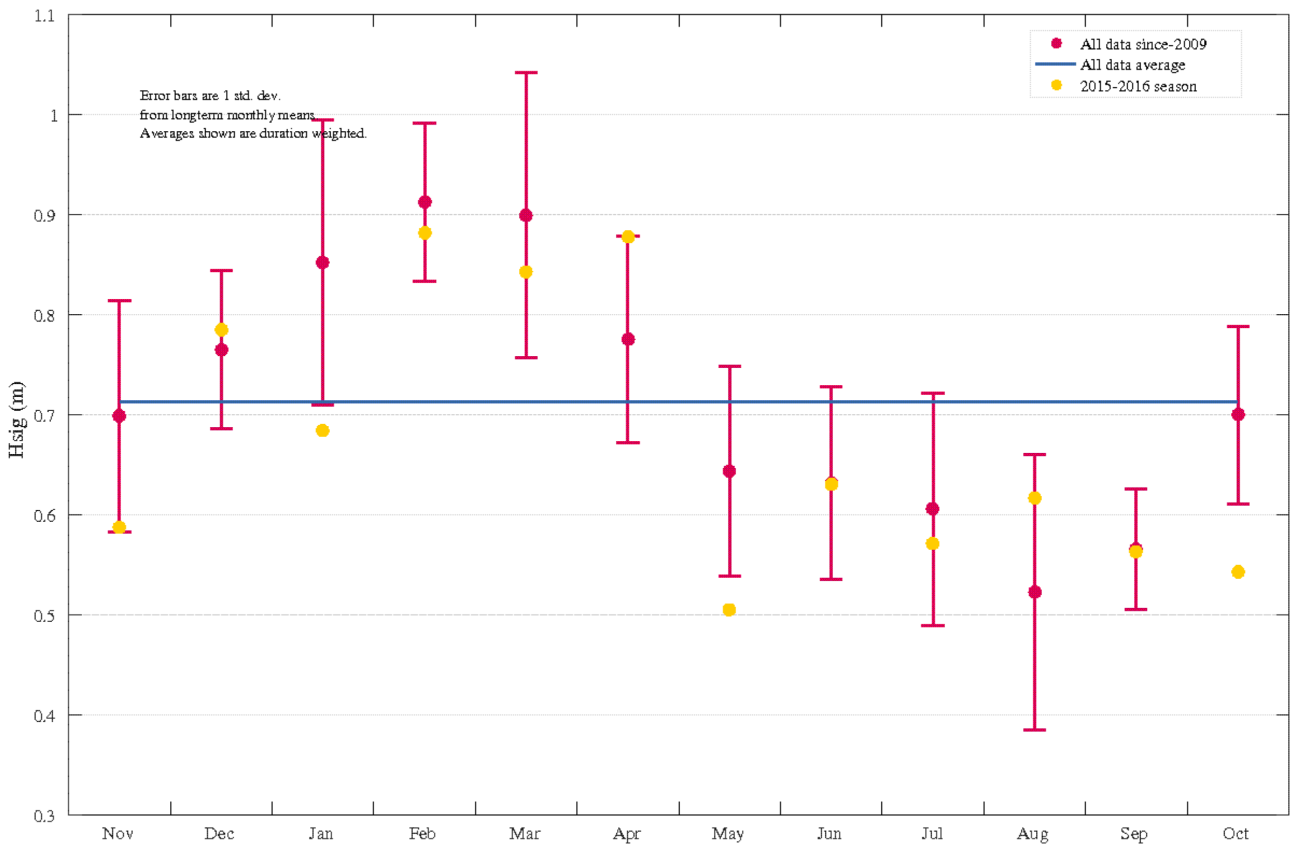


Figure 61 Gladstone – Monthly average wave height (Hsig) for seasonal year and for all data

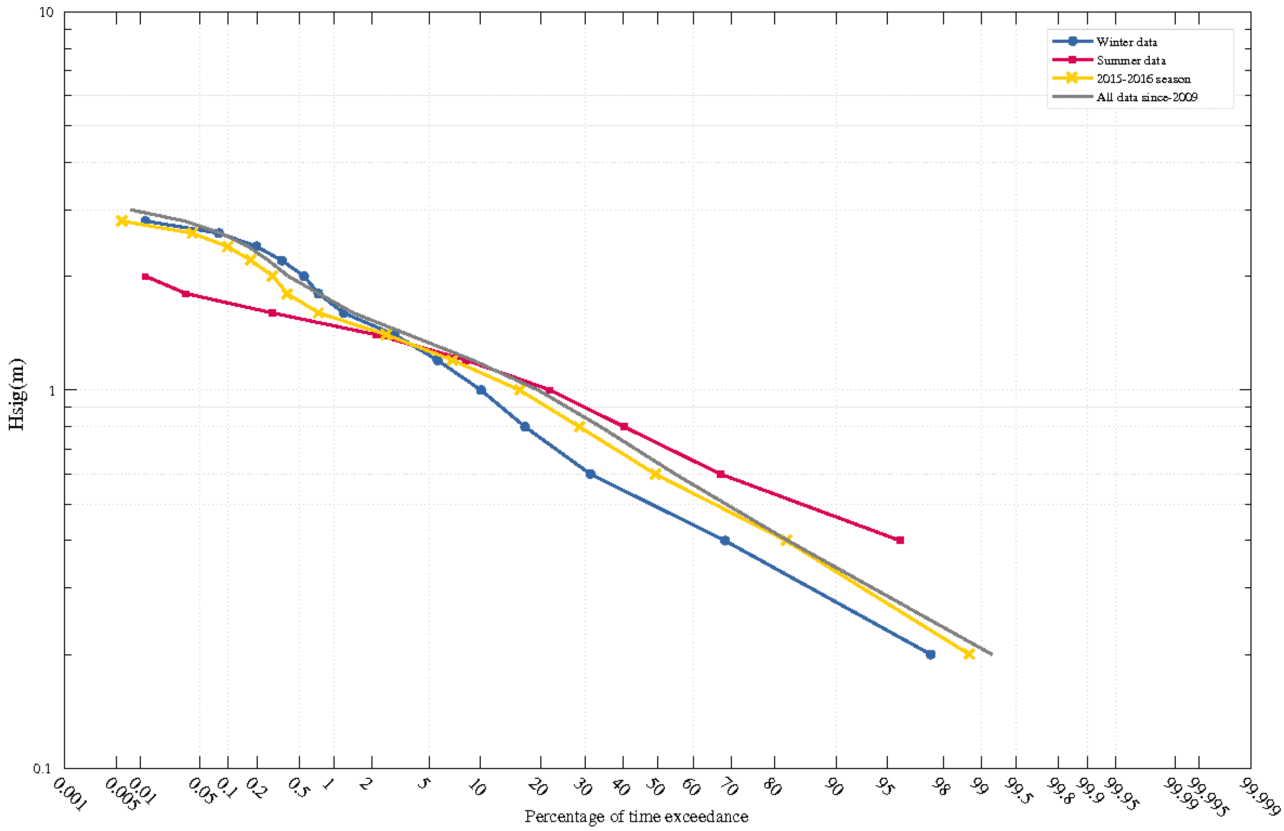


Figure 62 Gladstone – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

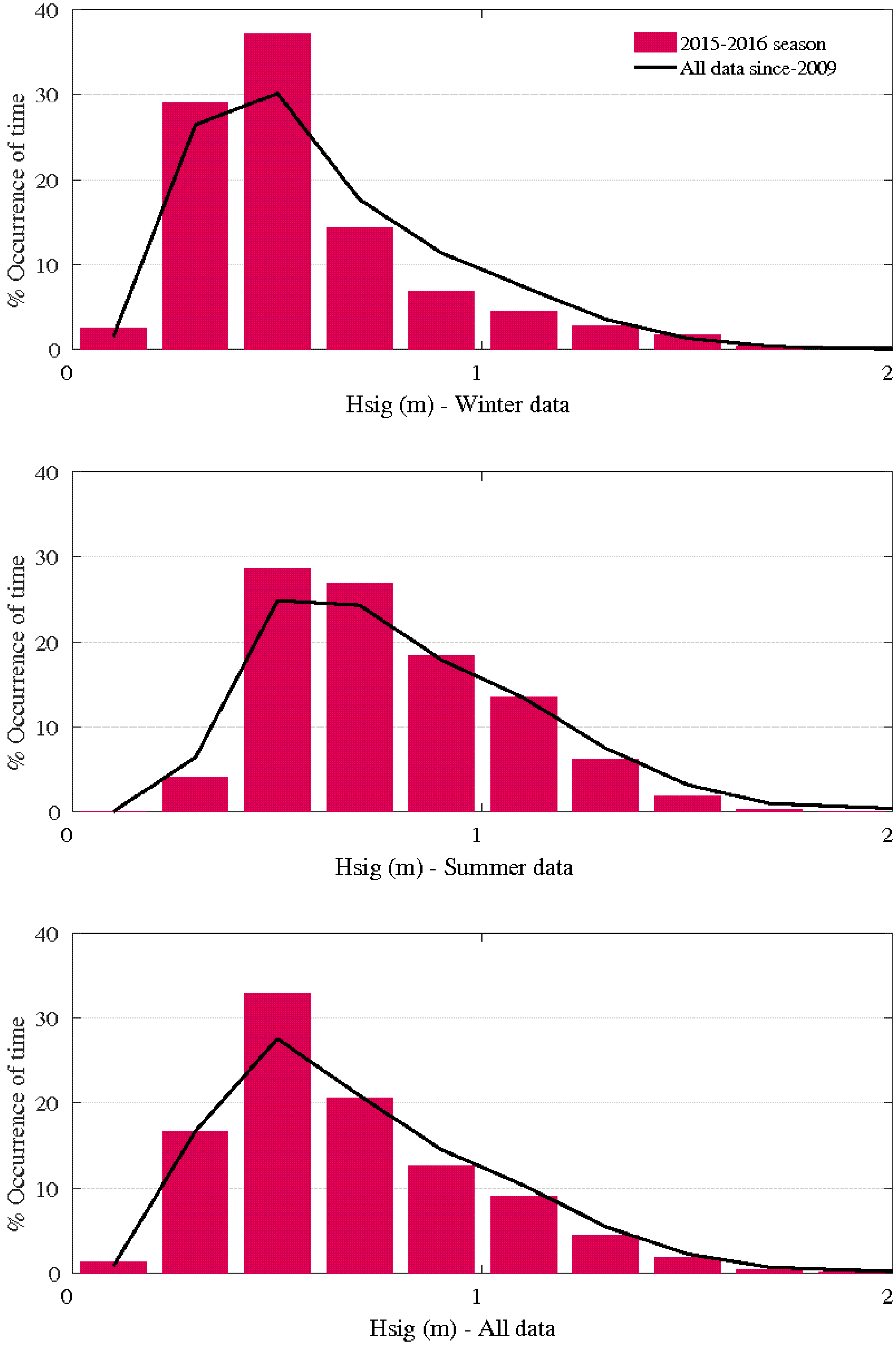


Figure 63 Gladstone – Histogram percentage (of time) occurrence of wave heights (Hsig)

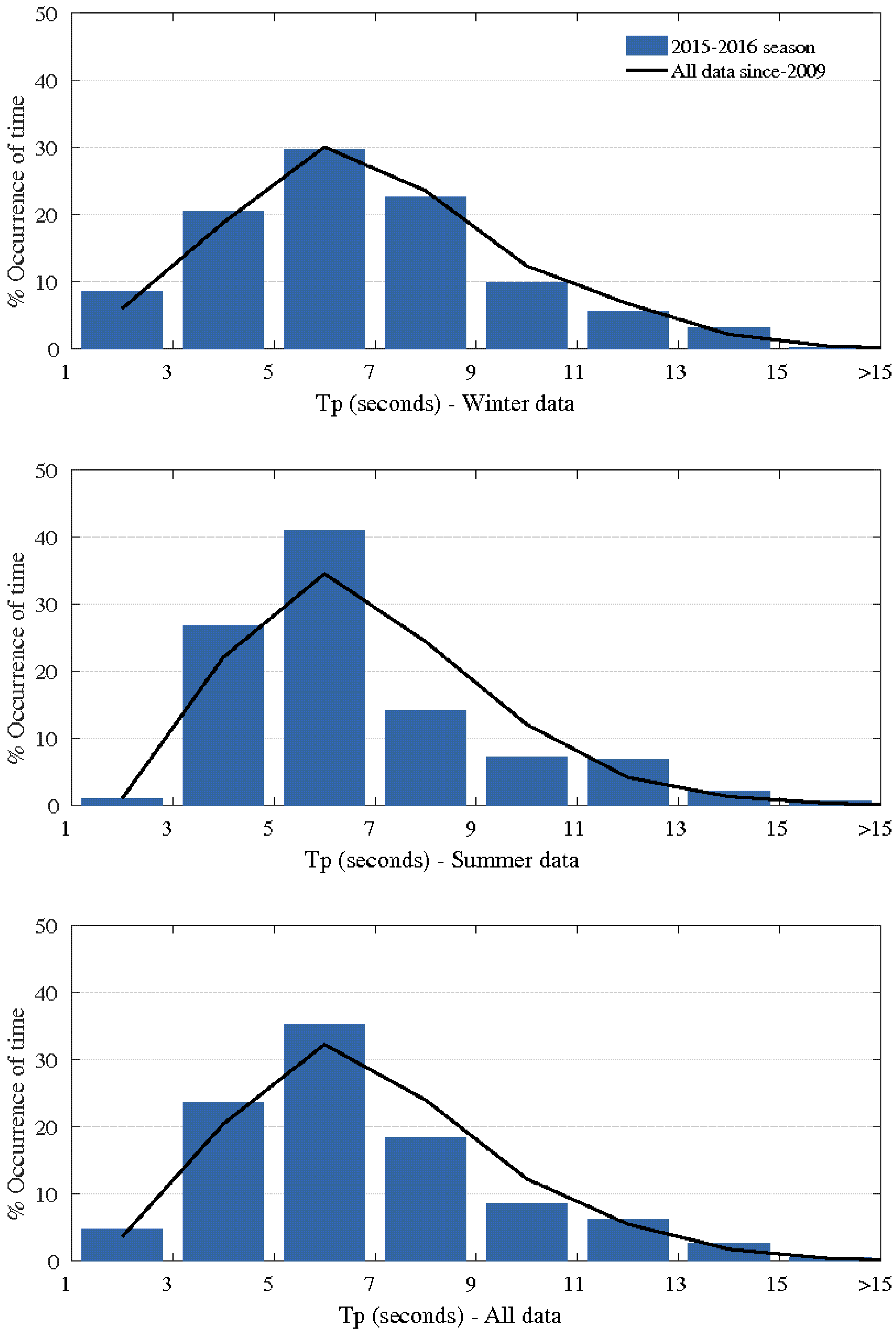


Figure 64 Gladstone – Histogram percentage (of time) occurrence of wave periods (Tp)

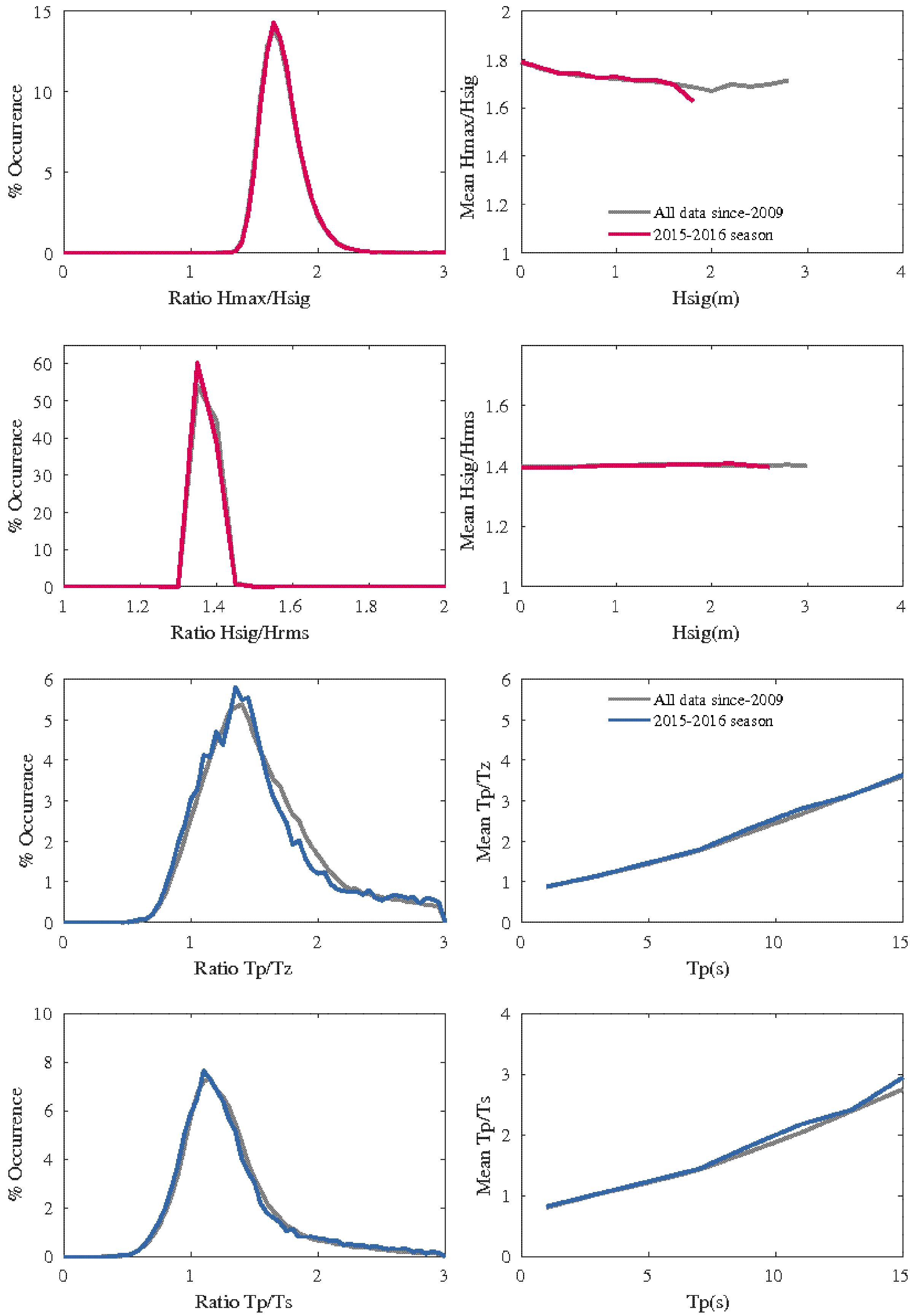


Figure 65 Gladstone – Wave parameter relationships

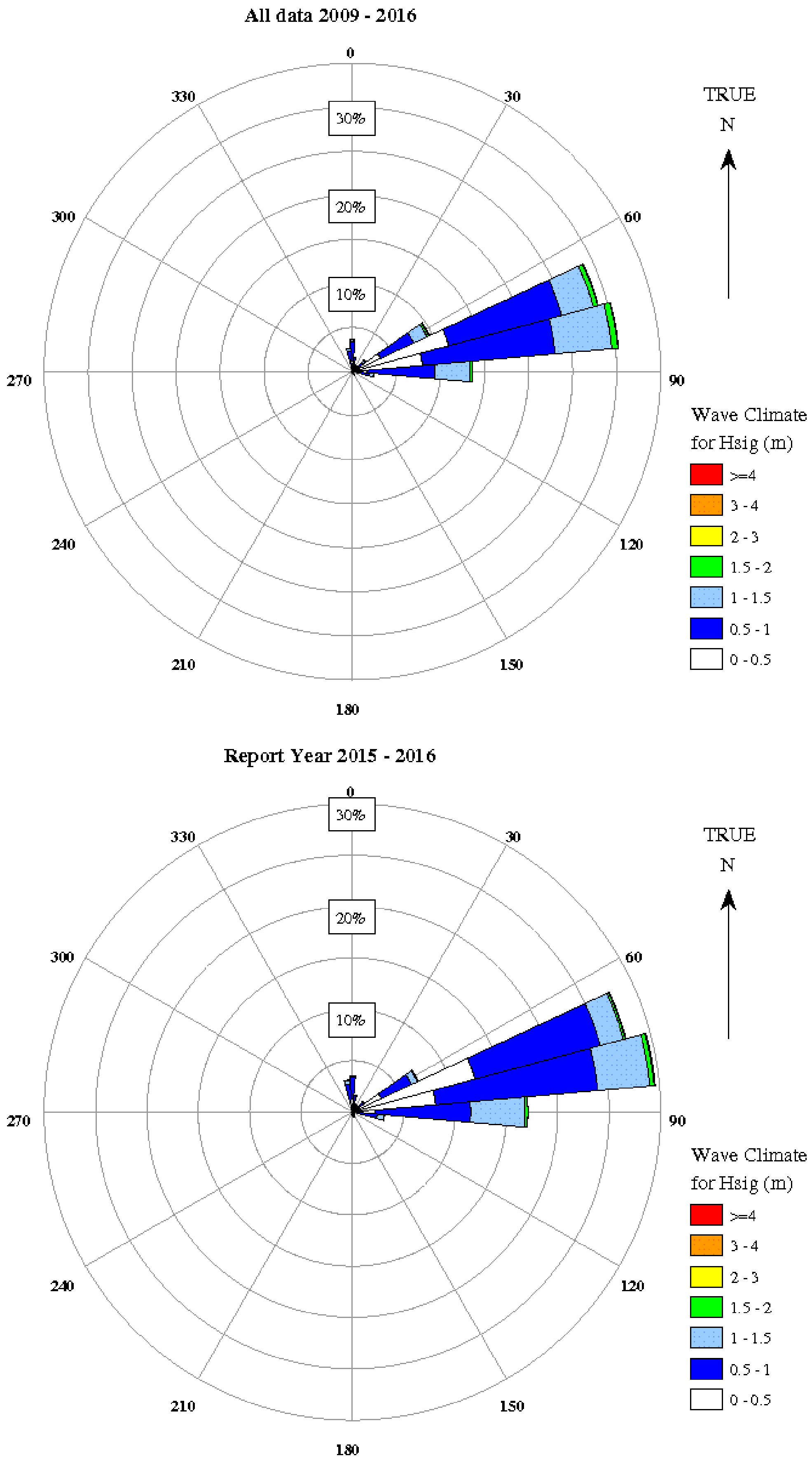


Figure 66 Gladstone – Directional wave rose

Emu Park

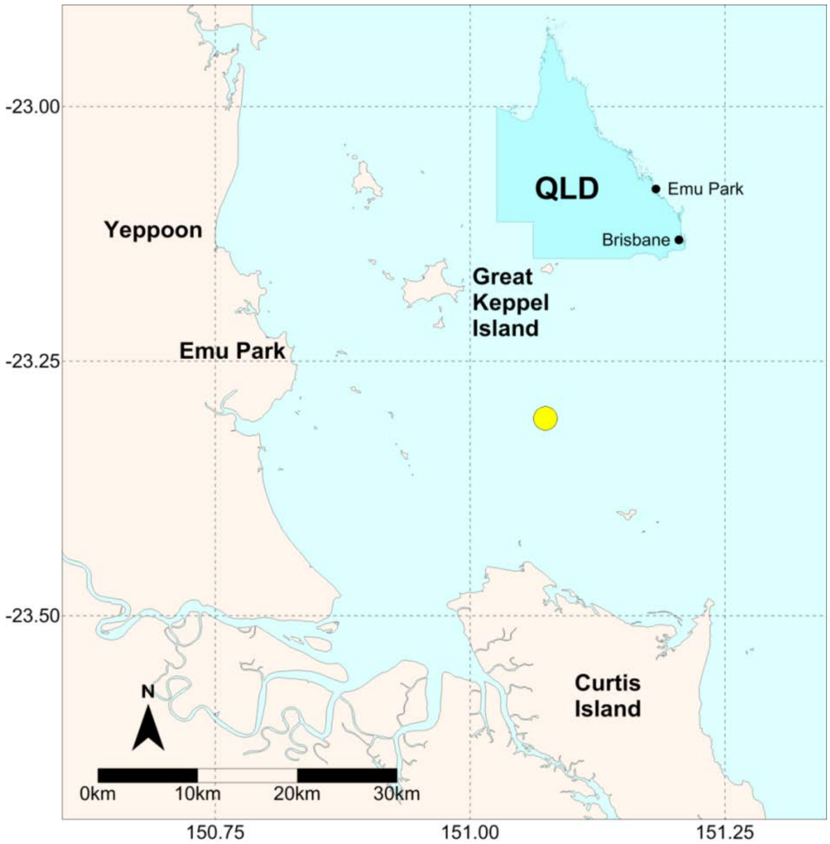


Figure 67 Emu Park – Locality plan

Table 33 Emu Park – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	24/07/1996	0.92 years	288,131	20.3
2015–16	01/11/2015	3.98 days	17,376	1

Table 34 Emu Park – Buoy deployments during the 2015–16 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
21°18.271' S	151°04.287' E	18	20/01/2016	current

Emu Park – seasonal overview

The Emu Park wave buoy has been operational for just over 20 years with an overall data return of 95.5 per cent. The data recorded for the period November 2015 to October 2016 was good, with total gaps of 3.98 days, equivalent to 98.9 per cent data return (Table 33). The buoy was replaced during the reporting period on 20 January 2016 (Table 34).

The fourth highest significant wave height (Hsig) and the sixth highest maximum wave height (Hmax) in the 20 years of operation were recorded on 16 July during an east coast low (Table 35). Hsig and Hmax reached 3.7 m and 6.6 m respectively during this event and is most distinguishable in the time series of wave heights for the reporting period (Figure 68).

Peak wave direction (Figure 69) was predominately from the east throughout the reporting period. During winter the wave direction occasionally turned to the north and swung more frequently toward a southern direction. During summer the direction swung to the north and remained consistently from the east between late February and early May. Sea surface temperature (SST) (Figure 69) ranged from 19.5 °C to 31 °C. SST was high enough for tropical cyclone development from late November to mid-April.

The monthly average Hsig was outside of one standard deviation (sd) of the long-term mean during November, January, April and May (Figure 70) during the reporting period. November, January and May were lower than one sd and April was higher than one sd of the mean Hsig.

Percentage exceedance of Hsig (Figure 71) shows wave heights lower than one metre were more frequent during summer and less frequent in winter. Wave heights over two metres were less frequent in summer and more frequent in winter than all previous data. The overall wave climate during the reporting period was mainly similar to the wave climate for the entire record. Histograms of occurrence of Hsig and peak wave period (Tp) (Figure 72 and Figure 73) also show similarity to the entire record. Although, there was a greater occurrence of 0.40.8 m waves Hsig during the recorded period, this range being the most common Hsig.

The ratios between different wave parameters such as Hmax/Hsig and Hsig/Hrms were consistent between this reporting period and all of the historic data (Figure 74). The ratios between the Tp/Tz and Tp/Ts slightly decreased compared to the historic data.

Directional wave rose plots (Figure 75) show dominant incident waves from the east-north-east to east-south-east, which is a very similar distribution for the reporting period and the entire record.

The temperature (sea surface temperature, SST) measured in the buoy hull showed a range of 19.5 °C to 31 °C (Figure 51). The SST from late November to mid–April was warm enough for tropical cyclone development.

Table 35 Emu Park – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (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	01/02/2010 02:00	3.7	20/02/2015 14:00	7.0
4	16/07/2016 12:00	3.7	09/03/1997 11:30	6.9
5	31/01/2014 06:30	3.5	31/01/2014 04:00	6.7
6	28/08/1998 06:30	3.2	16/07/2016 12:00	6.6
7	04/06/2002 13:00	3.2	28/08/1998 08:00	6.4
8	09/03/1997 19:30	3.1	04/06/2002 17:30	6.4
9	20/03/2010 16:00	3	20/03/2010 12:30	5.9
10	09/03/2009 01:30	3	04/03/2003 11:30	5.9

Table 36 Emu Park – Significant meteorological events with threshold Hsig of 2.5 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
16/07/2016 12:00	3.3 (3.7)	5.7 (6.6)	7.7	A low pressure system located over Gladstone region

Denotes peak Hsig event

Notes: 1. Barometric pressure measured in hectopascals (hPa). The Hsig and Hmax values are the maximums recorded for each event and are not necessarily coincident in time. The Tp and Hsig values are coincident as a single event on the date shown. Due to possible statistical errors arising from finite length records used in calculating wave climate, the above storm peak Hsig and Hmax values are derived from the time series smoothed by a simple three hourly moving average following the recommendation of the literature (Forristall, Heideman, Leggett, Roskam, & Vanderschuren, 1996).

2. Hsig and Hmax values shown in brackets are unsmoothed values as recorded at the site.

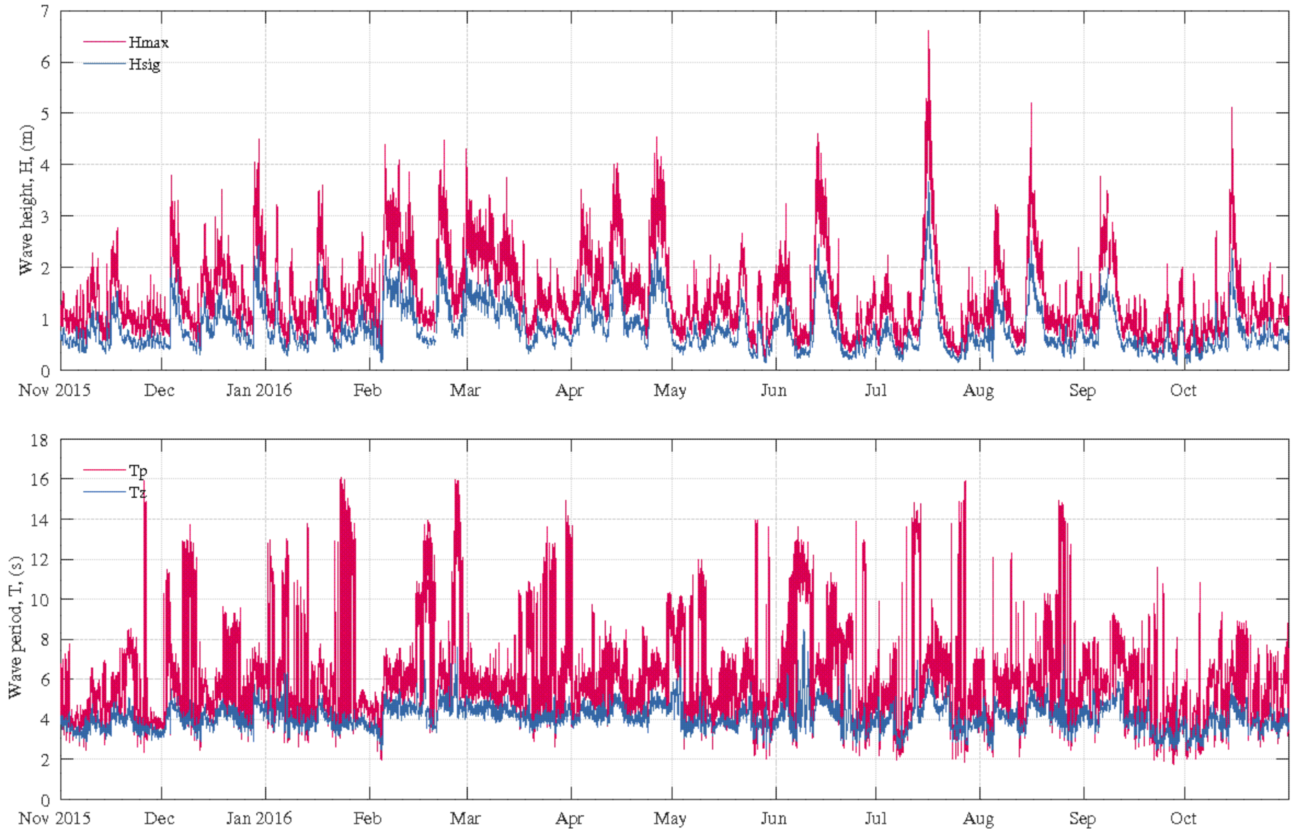


Figure 68 Emu Park – Daily wave recordings

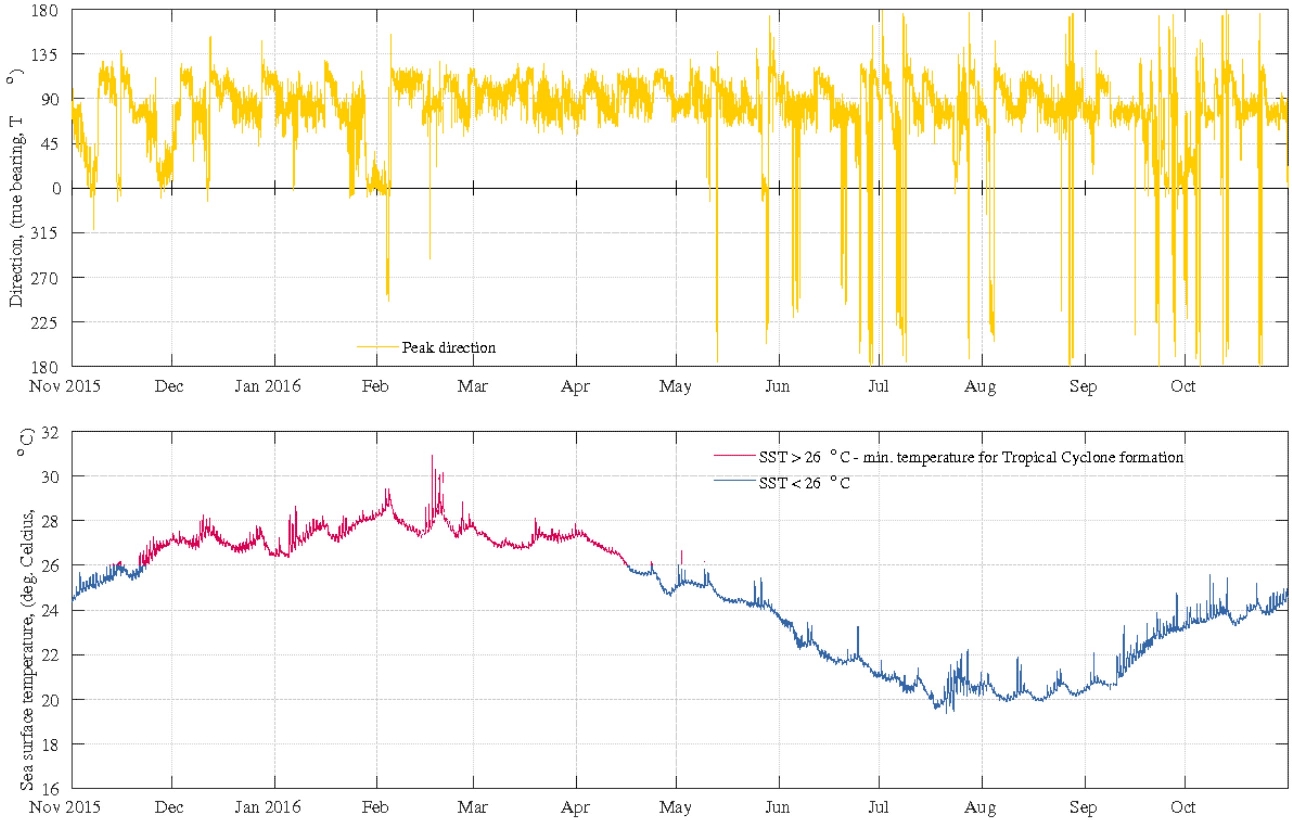


Figure 69 Emu Park – Sea surface temperature and peak wave directions

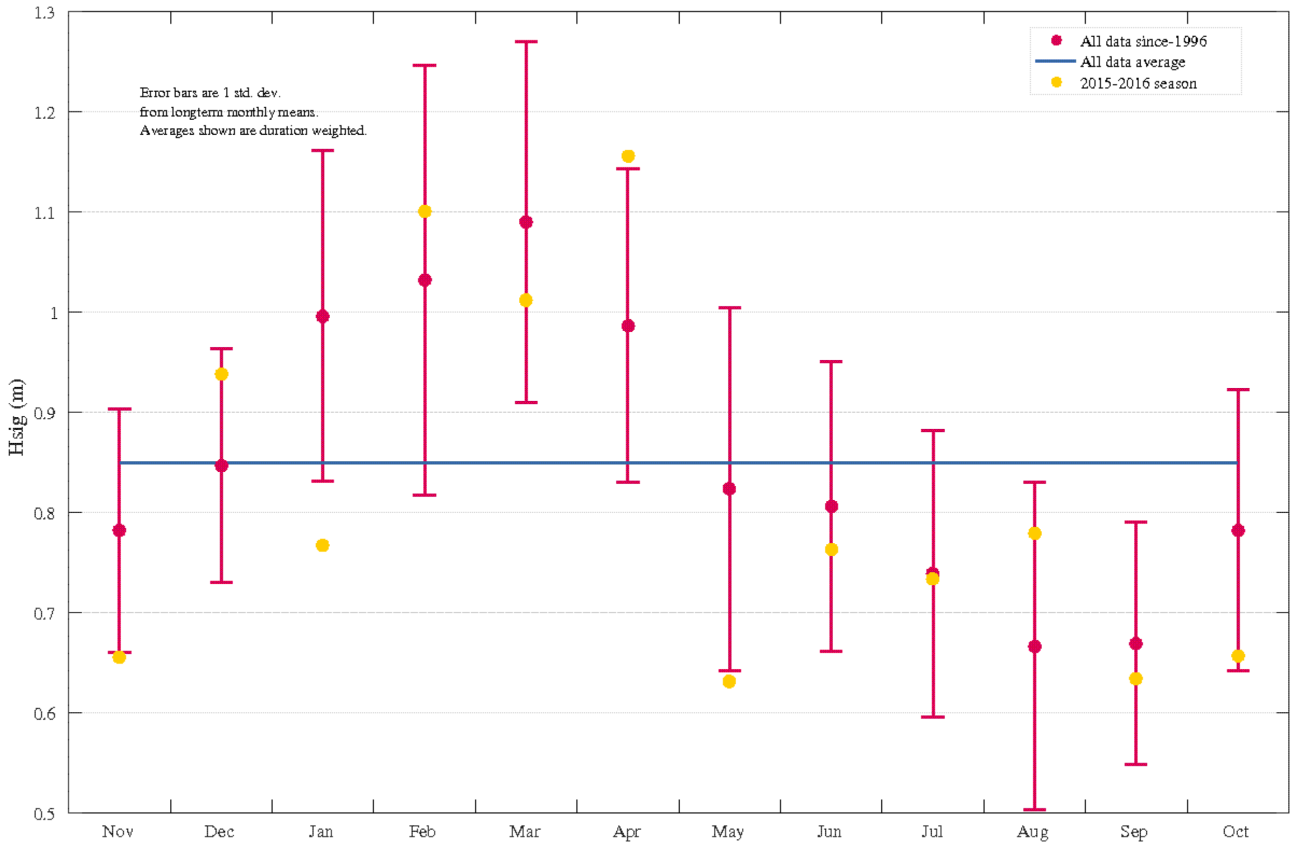


Figure 70 Emu Park – Monthly average wave height (Hsig) for seasonal year and for all data

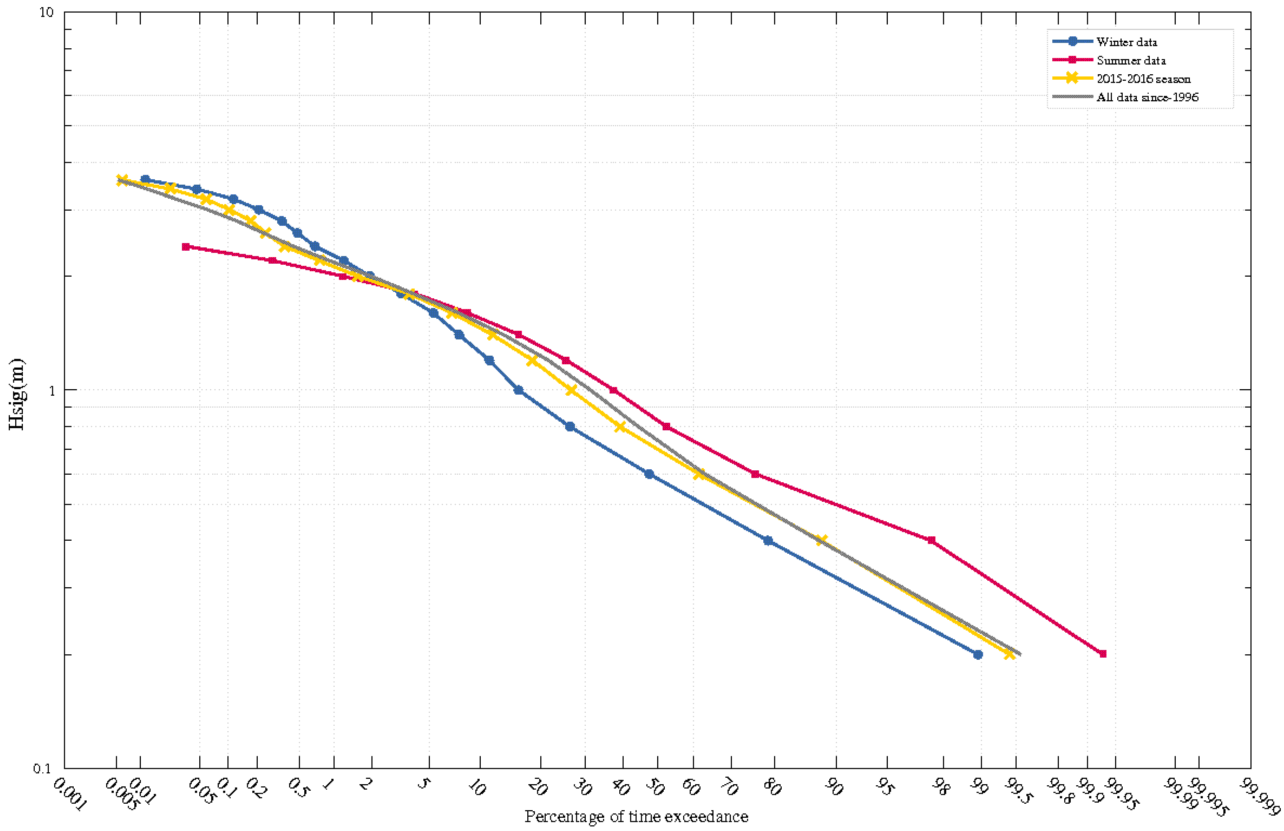


Figure 71 Emu Park – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

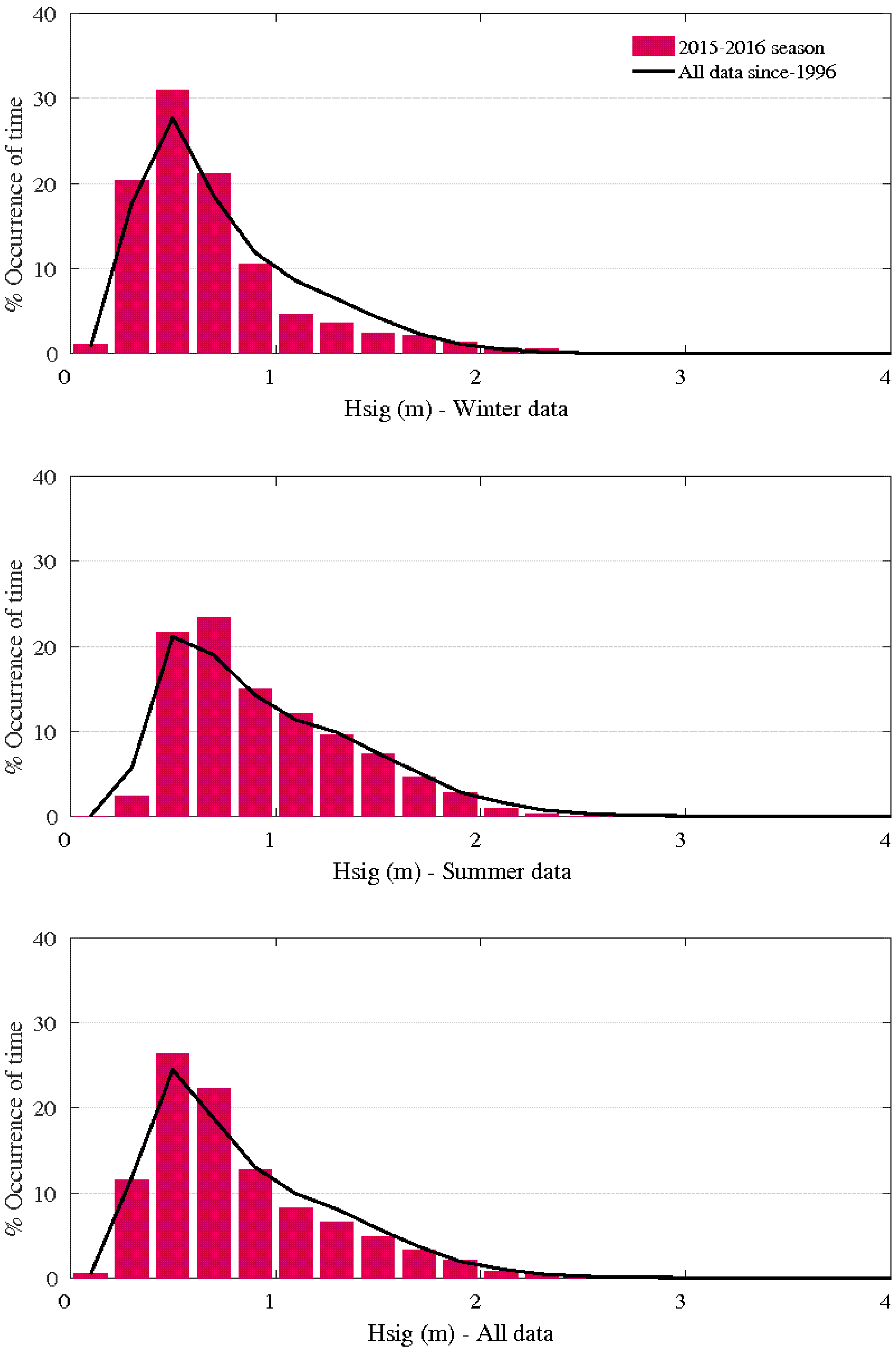


Figure 72 Emu Park – Histogram percentage (of time) occurrence of wave heights (Hsig)

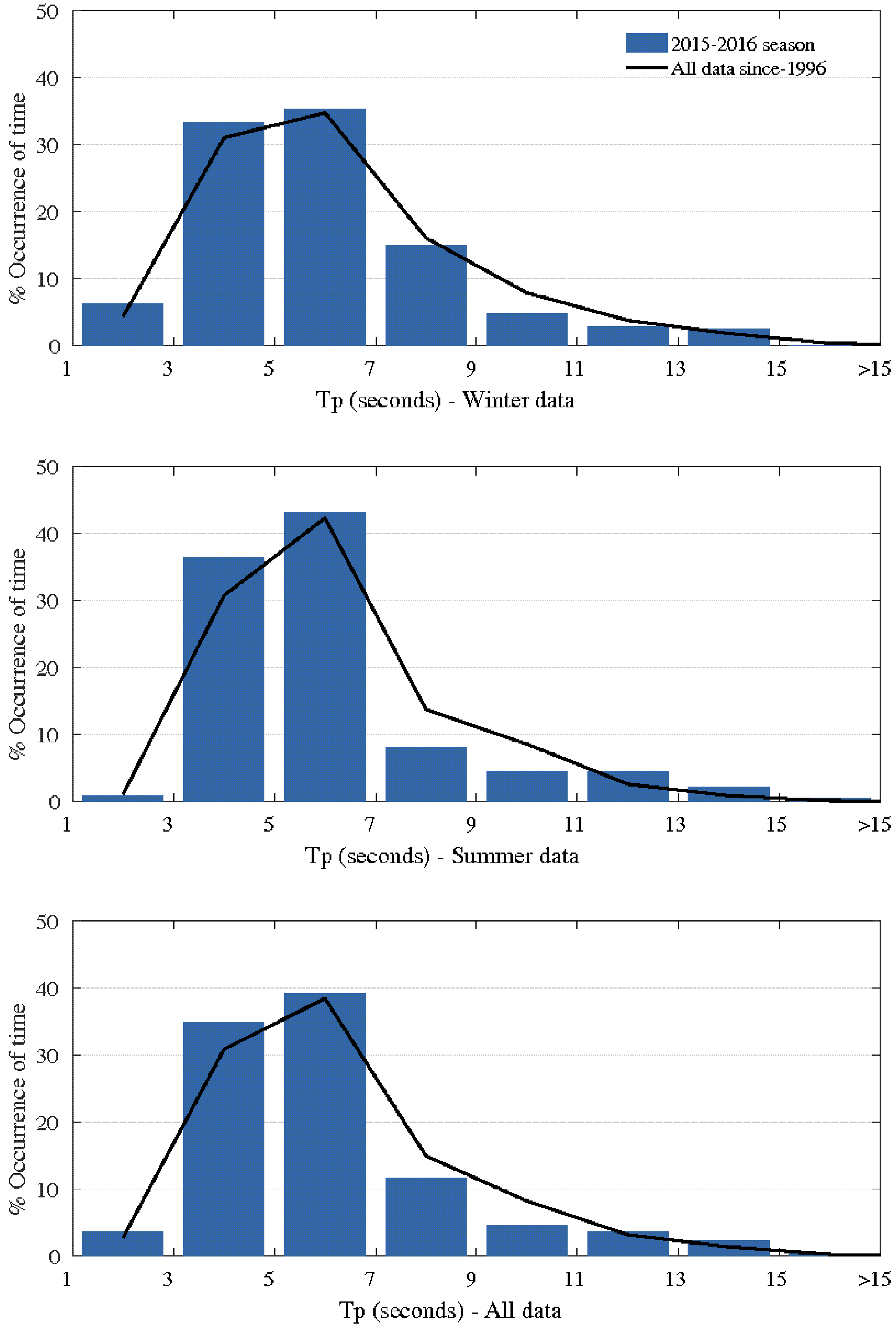


Figure 73 Emu Park – Histogram percentage (of time) occurrence of wave periods (Tp)

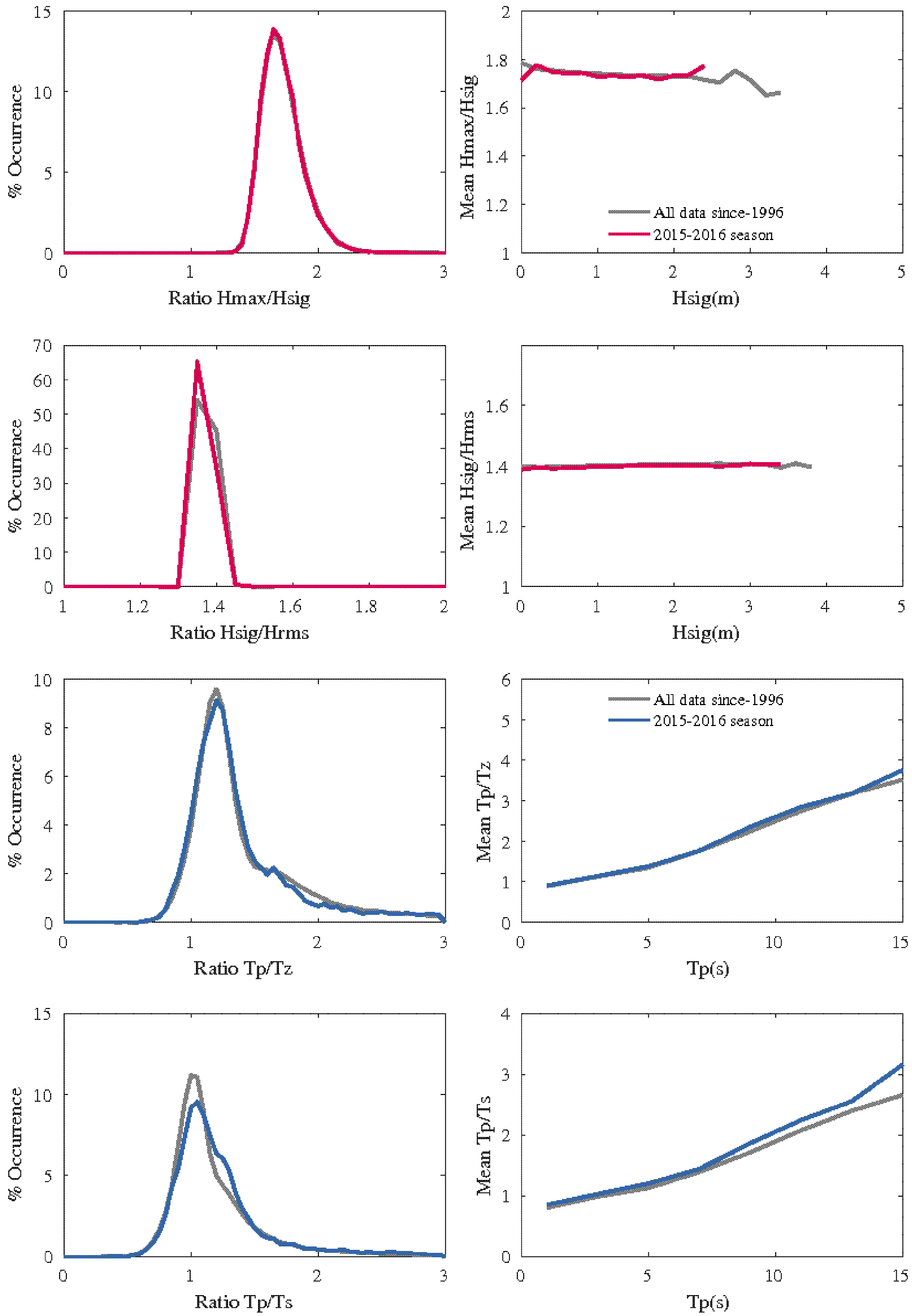


Figure 74 Emu Park – Wave parameter relationships

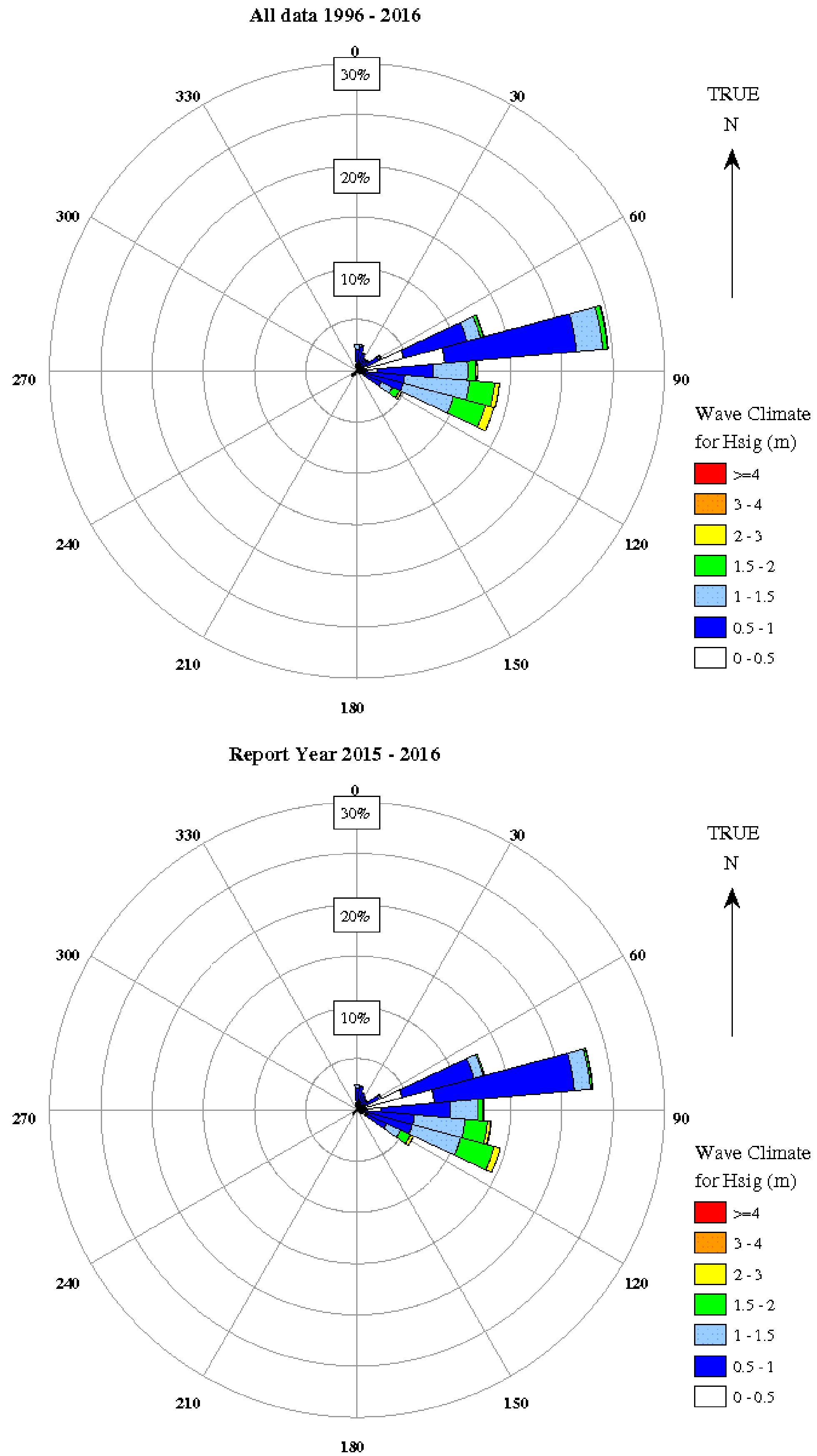


Figure 75 Emu Park – Directional wave rose

Hay Point

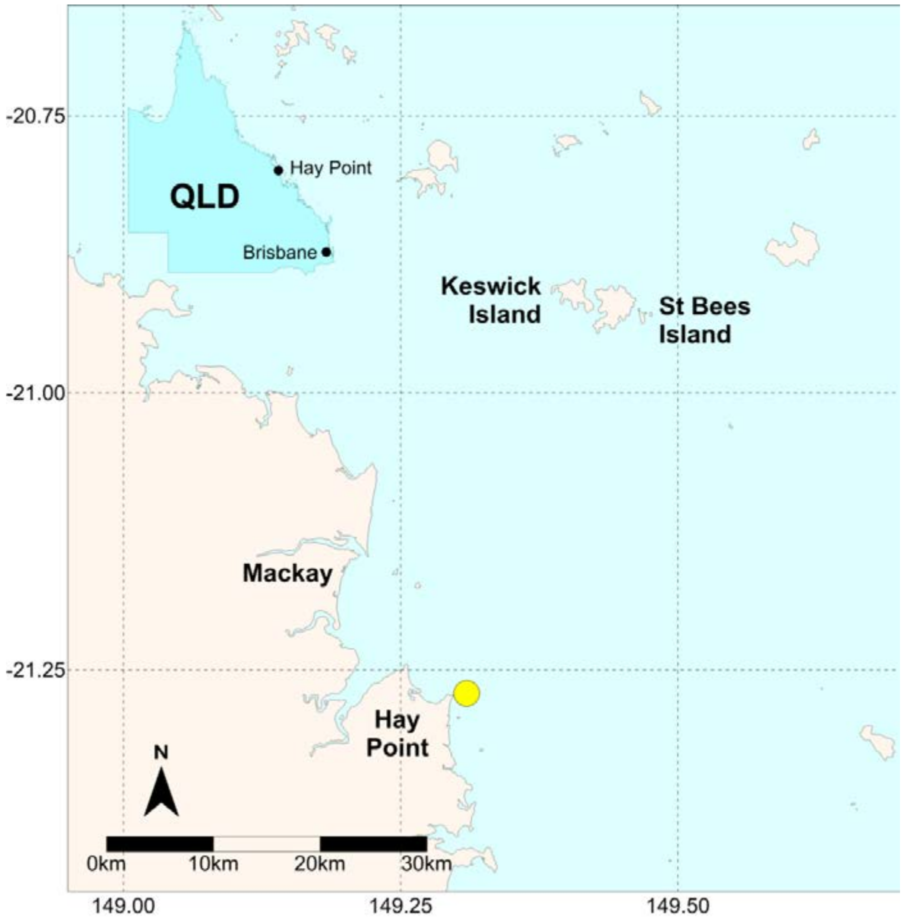


Figure 76 Hay Point – Locality plan

Table 37 Hay Point – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	24/04/1977	na	359,330	39.6
2015–16	01/11/2015	2.71 days	17,437	1

Table 38 Hay Point – Buoy deployments for the 2015–16 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
21°16.332' S	149°18.696' E	13	19/06/2016	current

Hay Point – seasonal overview

The Hay Point wave buoy has been operational for almost 40 years. The data record for the period of November 2015 to October 2016 was excellent, with total gaps of 2.71 days, equivalent to 99.2 per cent data return (Table 37). The buoy was replaced once during the reporting period on 19 June 2016 (Table 38).

The largest waves occurred in February (Figure 77) during the passage of Tropical Cyclone Tatiana and ex-Tropical Cyclone Winston however these events did not make it into the top ten waves (Table 39) for the site or exceed the 2.0 m storm threshold.

Peak wave direction (Figure 78) was predominately from the east, with occasional swings to the north and south. Sea surface temperature (SST) ranged from 20 °C to 31 °C (Figure 78) and was high enough for tropical cyclone development from October through to early-May.

The monthly average Hsig generally fell within one standard deviation (sd) of the long-term mean. November, January, May and October were well below one sd of the mean (Figure 79).

Percentage exceedance of Hsig (Figure 80) shows higher waves occurring through summer compared to winter. The overall wave climate during the reporting period was similar to the wave climate of the whole record with the exception of waves over one metre which were less frequent. This is also reflected in the histogram of the occurrence of Hsig and peak wave period (Tp) with wave heights in the 0.2 – 0.4 m range being more frequent and wave heights greater than0.6 m less frequent than the long-term record (Figure 81). The most common Tp was 3 – 5 seconds, with periods during winter and summer having similar distribution.

The ratios between different wave parameters such as Hmax/Hsigm, Hsig/Hrms and Tp/Tz were consistent between this reporting period and all of the historic data (Figure 74). The ratio Tp/Ts has slightly decreased compared to the historic data.

Directional wave rose plots (Figure 84) 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 39 Hay Point – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (m)
1	21/03/2010 01:30	4	30/01/2014 22:00	7.0
2	30/01/2014 22:00	3.7	10/03/1997 10:00	6.8
3	09/03/1997 20:00	3.1	21/03/2010 04:30	6.3
4	31/01/2010 07:30	2.8	24/02/1996 02:00	5.6
5	16/02/2008 17:30	2.8	17/02/2008 21:00	5.4
6	01/02/1978 03:00	2.6	10/02/1999 18:00	5.3
7	29/08/1998 18:00	2.5	19/01/2004 18:00	5
8	24/01/2005 23:30	2.5	26/12/2007 00:30	5
9	01/02/2007 22:30	2.4	22/03/1994 19:00	4.8
10	03/05/2000 05:30	2.4	03/03/2004 21:00	4.7

Table 40 Hay Point – Significant meteorological events with threshold Hsig of 2.0 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
No significant events to report				

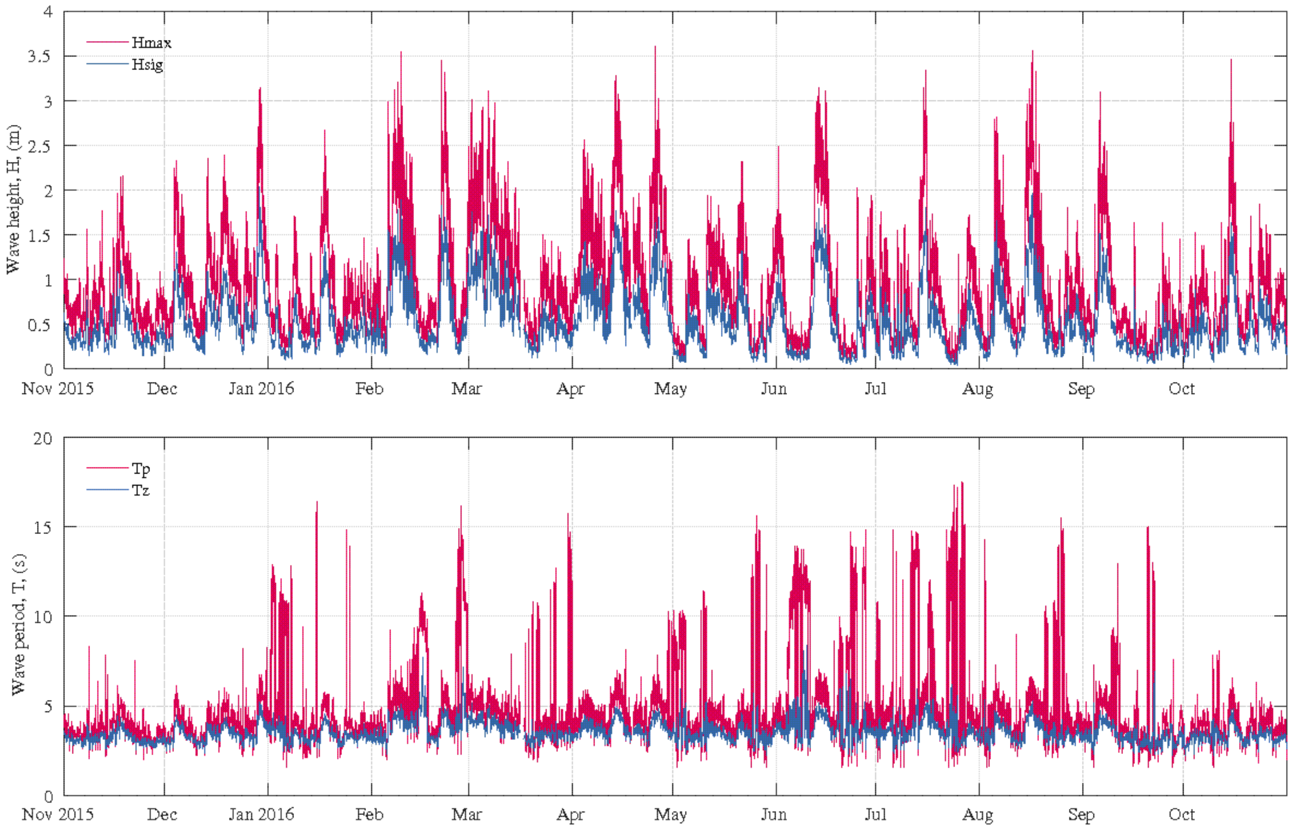


Figure 77 Hay Point – Daily wave recordings

Figure 78 Hay Point – Sea surface temperature and peak wave directions

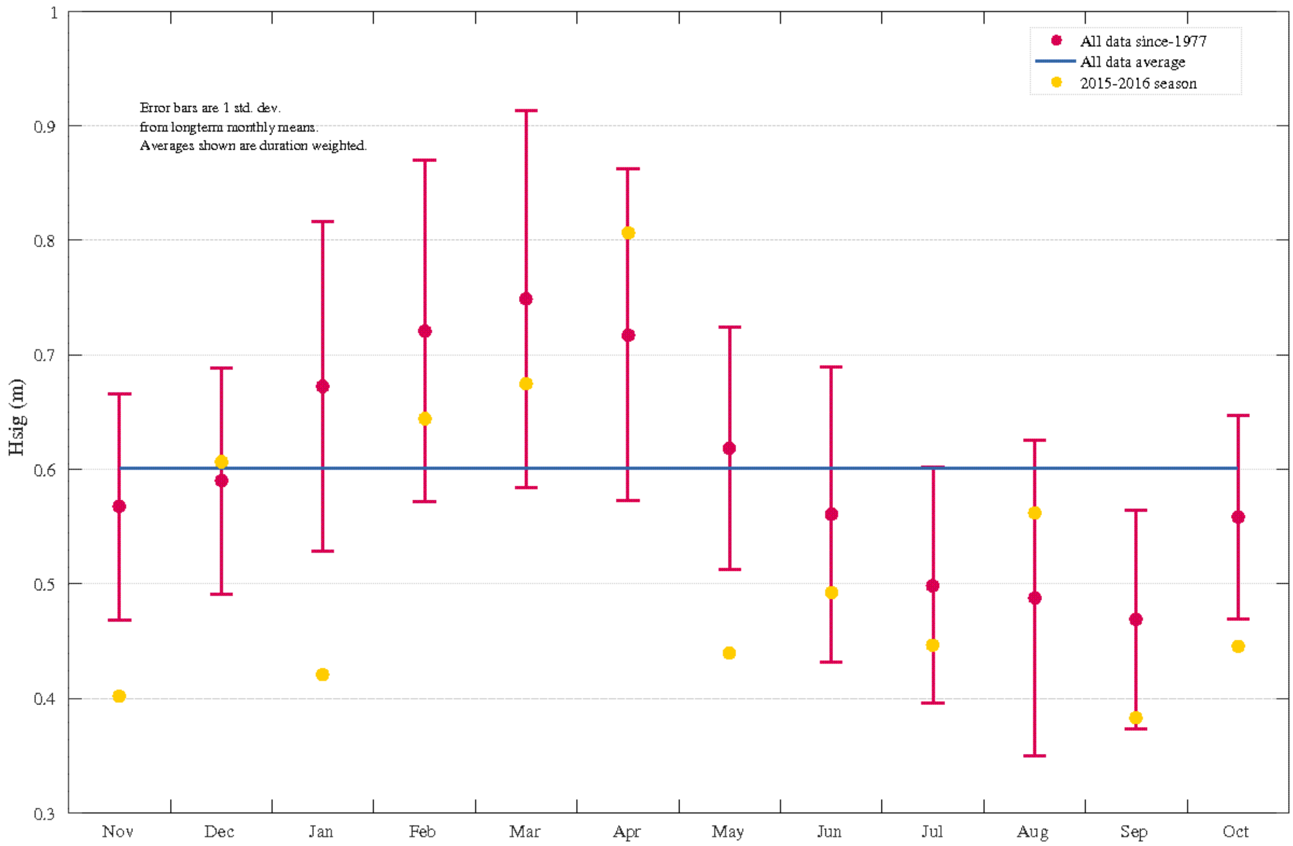


Figure 79 Hay Point – Monthly average wave height (Hsig) for seasonal year and for all data

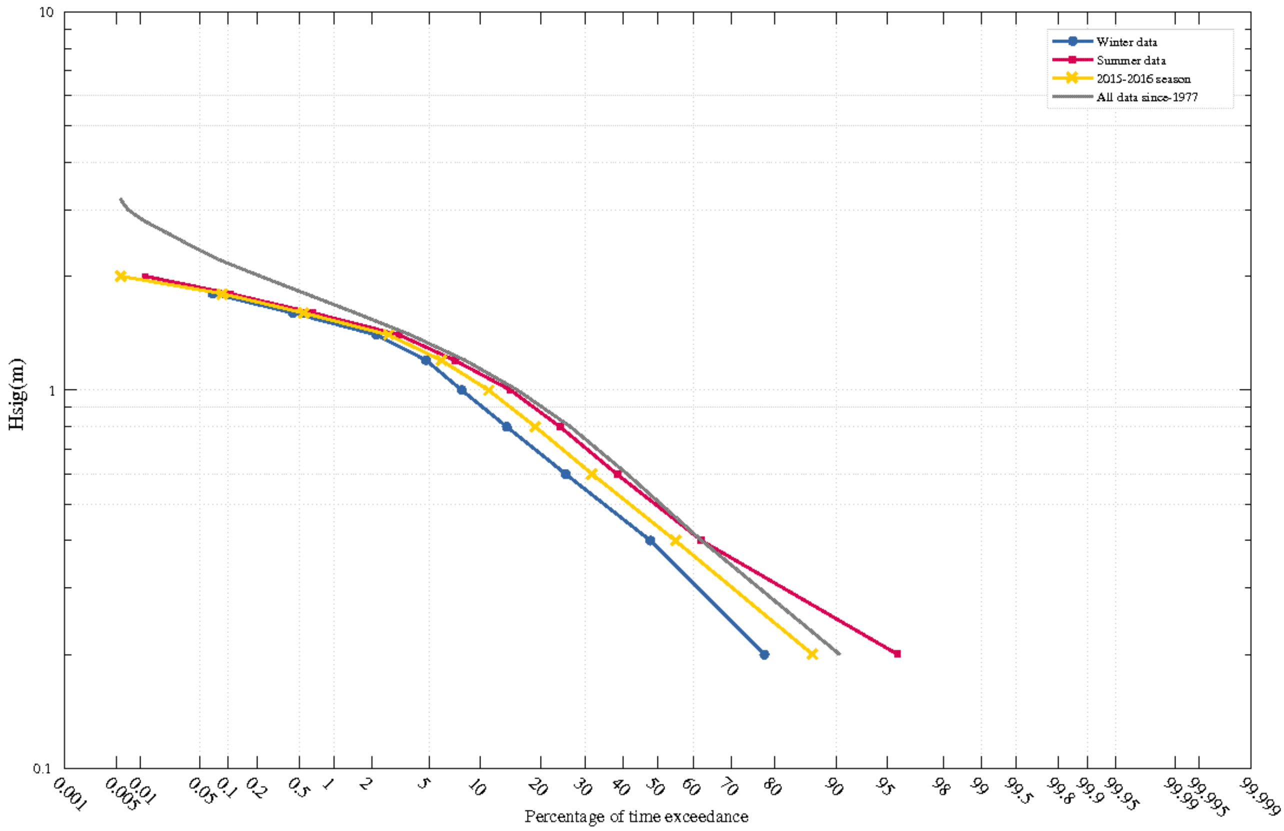


Figure 80 Hay Point – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

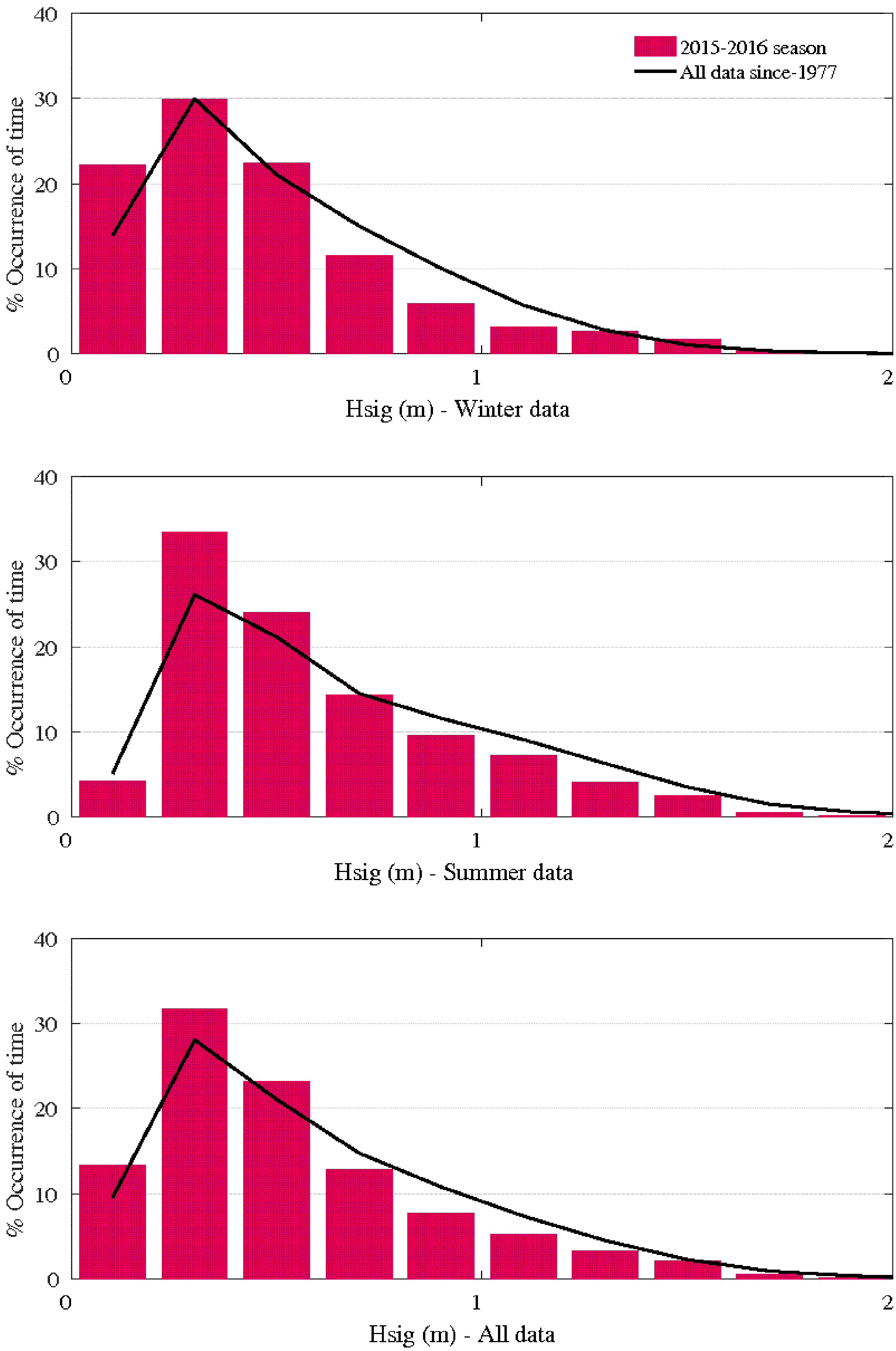


Figure 81 Hay Point – Histogram percentage (of time) occurrence of wave heights (Hsig)

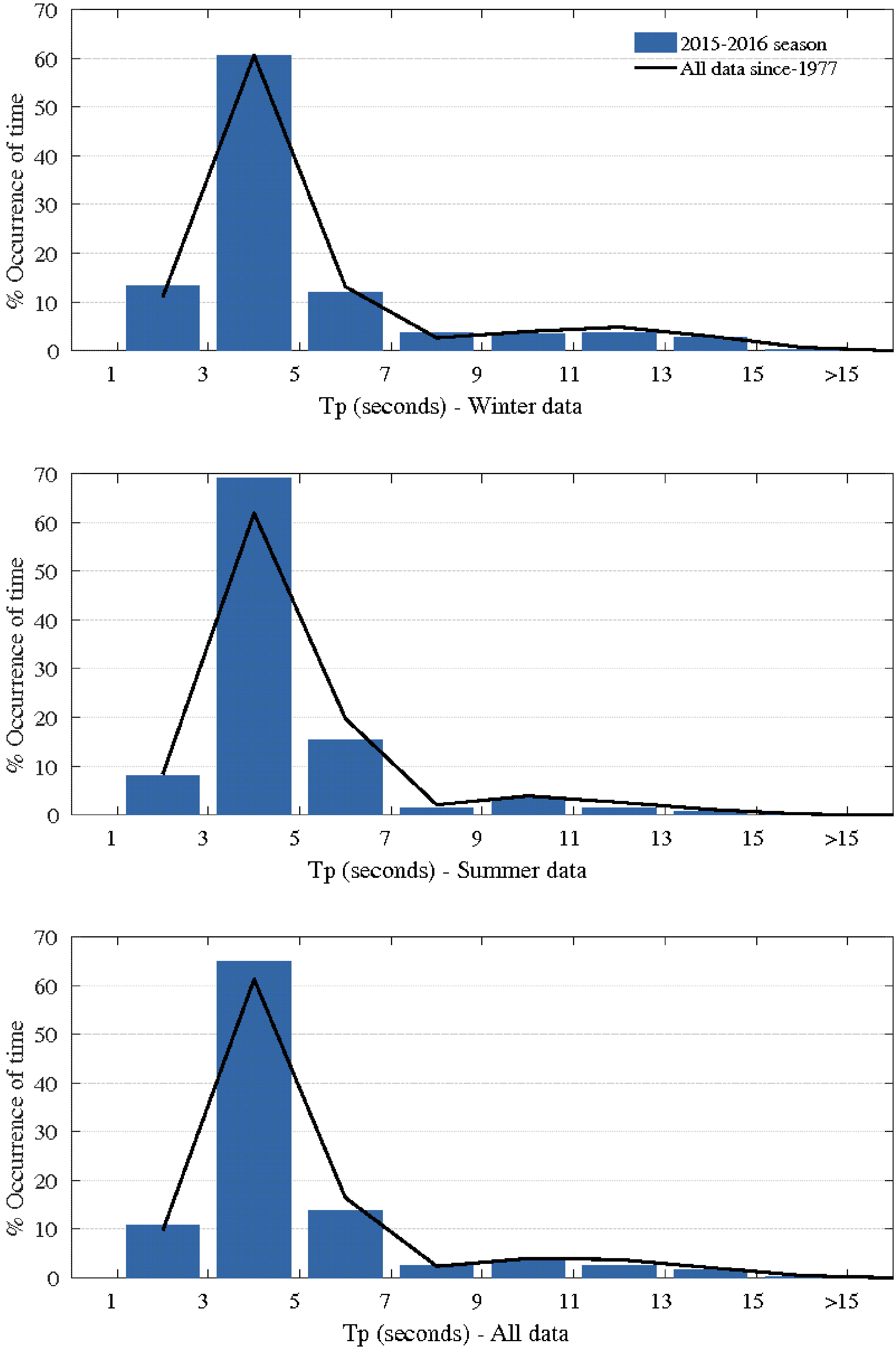


Figure 82 Hay Point – Histogram percentage (of time) occurrence of wave periods (Tp)

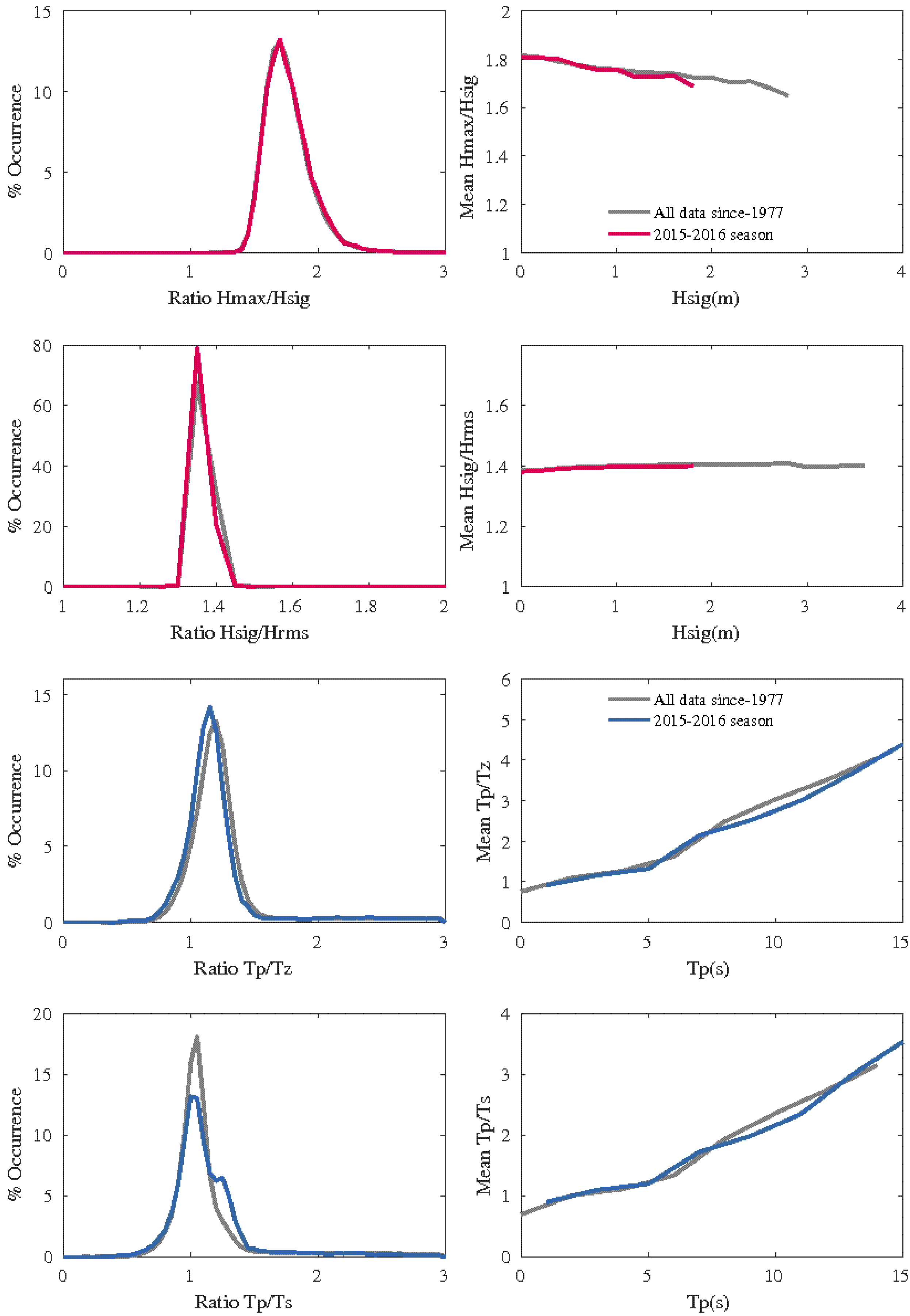
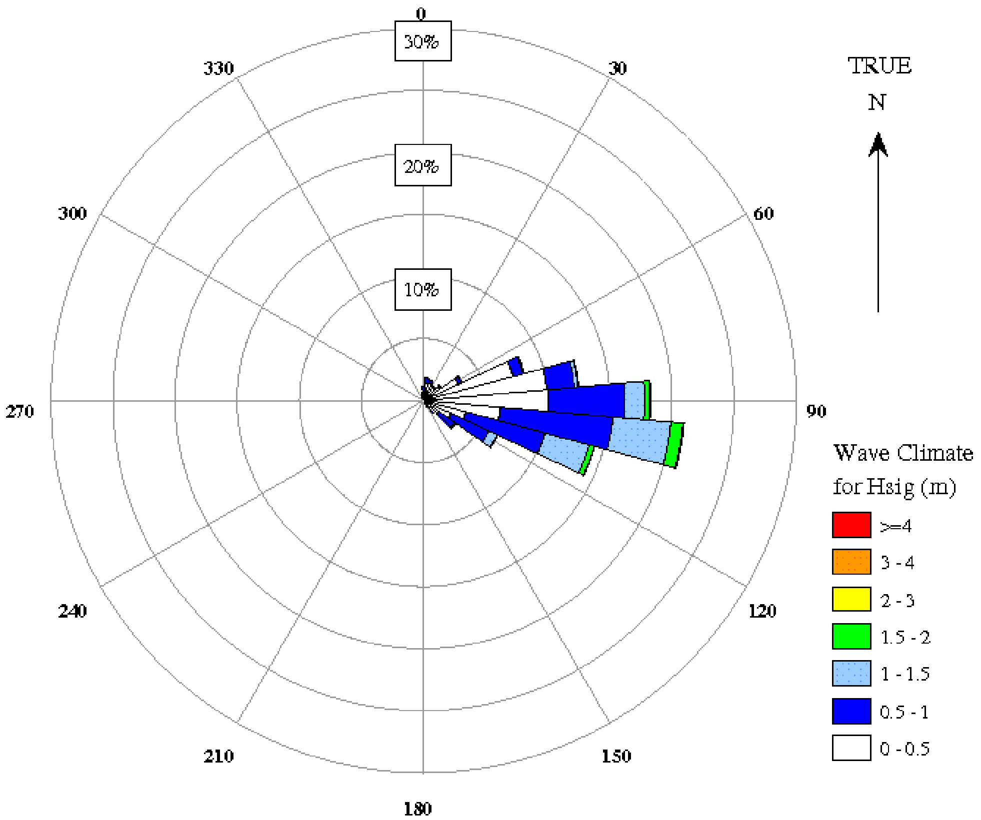


Figure 83 Hay Point – Wave parameter relationships

All data 2008 - 2016



Report Year 2015 - 2016

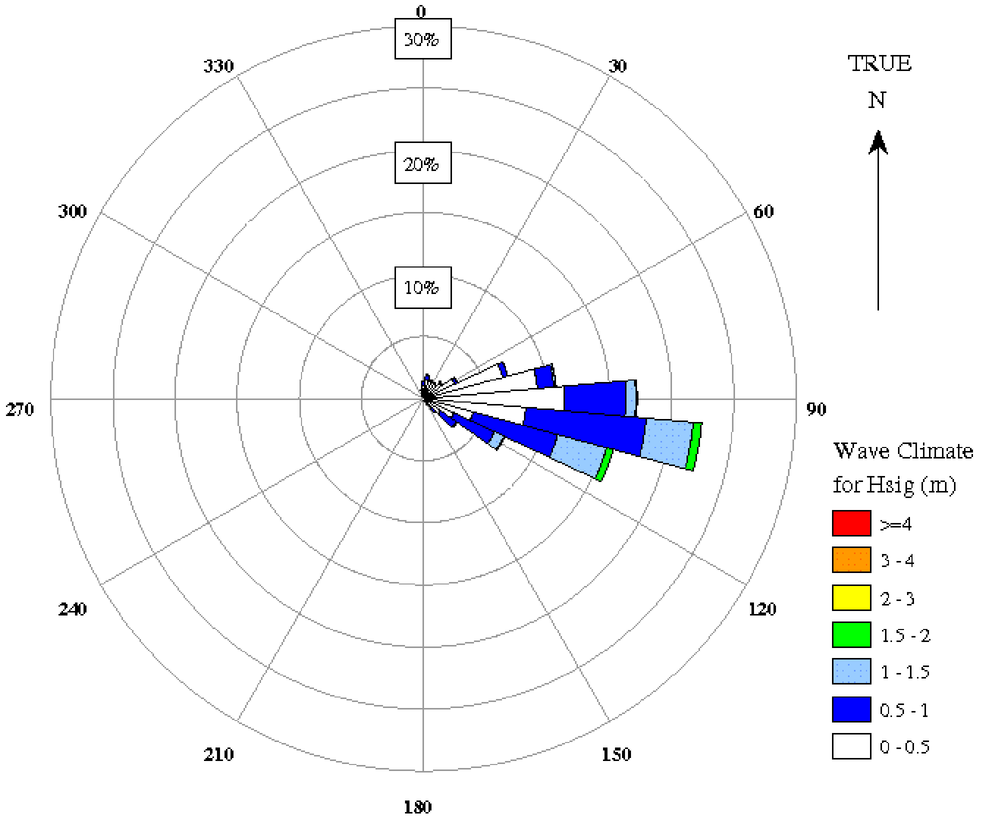


Figure 84 Hay Point – Directional wave rose

Mackay

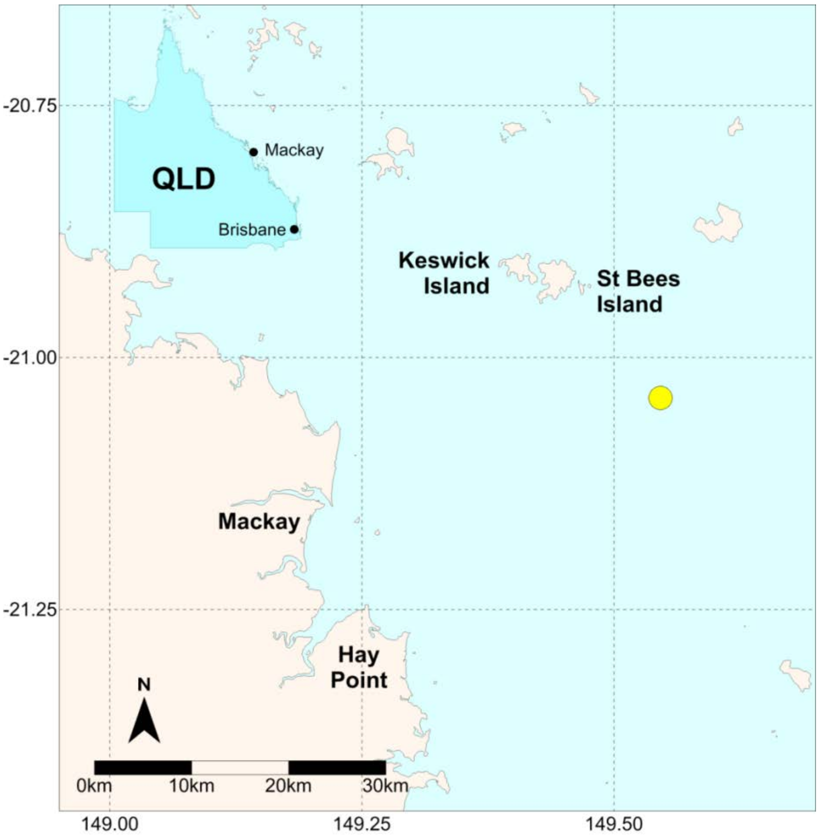


Figure 85 Mackay – Locality plan

Table 41 Mackay – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	19/09/1975	na	313,615	41.1
2015–16	1/11/2016	17.9 days	16,706	1

Table 42 Mackay – Buoy deployments during the 2015-16 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
21°02.197' S	149°32.885' E	36.1	28/10/2016	current

Mackay – seasonal overview

The Mackay wave buoy has been operational for just over 41 years. The data record for the period from November 2015 to October 2016 was reasonable, with total gaps of 17.9 days, equivalent to 95.1 per cent data return. The wave buoy was replaced on 28 October 2016 (Table 42).

In total four significant events happened during the reporting period. The events occurred in March, June, July and August (Table 44). The largest of the maximum wave heights during the reporting period occurred on 16 August as a result of strong winds from the south these did not make it into the highest 10 waves (Table 43). Time series of daily wave recordings (Figure 86) show clear increases in wave heights from the influence of the significant meteorological events (Table 44) over the duration of the reporting period.

Peak wave direction was predominately from the east south east (Figure 87) with swings to the south mostly in the summer months. The Sea surface temperature (SST) ranged from 21.5 °C to 32 °C (Figure 87). The SST was high enough for tropical cyclone development for the summer months and extended until mid-May.

Monthly average Hsig (Figure 88) was lower than the mean minus one standard deviation (sd) in November, January and May of the recording period.

Percentage exceedance of Hsig (Figure 89) shows a very similar wave climate between the reporting period than over the entire record. Overall wave heights over 2 m were less frequent in the reporting period than for the record. Histograms for percentage occurrence of Hsig (Figure 90) and peak weave period (Tp) (Figure 91) also show similar distributions between the reporting period and the entire record. The Hsig 0.4 – 0.6 m has a higher percentage of occurrence for both the summer and winter months.

The ratios between different wave parameters such as Hmax/Hsigm, Hsig/Hrms and Tp/Tz were consistent between this reporting period and all of the historic data (Figure 92). The ratio of Tp/Ts slightly decreased compared to the historic data.

Directional wave rose plots (Figure 93) 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 43 Mackay – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (m)
1	20/03/2010 22:30	5.7	30/01/2014 19:30	10.0
2	30/01/2014 19:30	5.0	21/03/2010 00:00	9.4
3	10/03/1997 00:00	4.8	09/03/1997 11:00	8.5
4	01/03/1979 03:00	4	08/03/2009 17:00	7.7
5	27/12/1990 03:41	3.9	19/01/2004 19:30	7.5
6	05/06/2002 00:00	3.8	04/03/2002 15:00	7.3
7	19/02/2015 22:30	3.6	06/02/2015 12:00	7.3
8	19/01/2004 19:30	3.6	17/02/2008 19:30	7.1
9	17/02/2008 19:30	3.6	05/06/2002 01:00	6.9
10	12/01/1979 03:00	3.6	26/12/2007 01:30	6.9

Table 44 Mackay – Significant meteorological events with threshold Hsig of 2.5 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
01/03/2016 23:00	2.7 (3.1)	4.2 (5.0)	6.9	Low pressure troughs dominated much of northern Australia over the first week of March, a low pressure system located in the Coral Sea directed a moist air flow along the Queensland coast
13/06/2016 20:00	2.8 (3.0)	4.9 (5.9)	7.2	A large high pressure system (1039) off the NSW coast affecting all of the Queensland coast.
15/07/2016 08:00	2.7 (2.9)	4.6 (5.2)	7.8	A trough located down the far north coast impacting with a large high (1035) located east of Adelaide
16/08/2016 07:00	2.8 (3.1)	4.9 (6.3)	8	Two high pressure systems extending from the south Queensland coast to New Zealand and a low pressure system north of New Zealand causing strong winds to push up the east coast of Queensland

Denotes peak Hsig event

Notes: 1. Barometric pressure measured in hectopascals (hPa). The Hsig and Hmax values are the maximums recorded for each event and are not necessarily coincident in time. The Tp and Hsig values are coincident as a single event on the date shown. Due to possible statistical errors arising from finite length records used in calculating wave climate, the above storm peak Hsig and Hmax values are derived from the time series smoothed by a simple three hourly moving average following the recommendation of the literature (Forristall, Heideman, Leggett, Roskam, & Vanderschuren, 1996).

2. Hsig and Hmax values shown in brackets are unsmoothed values as recorded at the site.

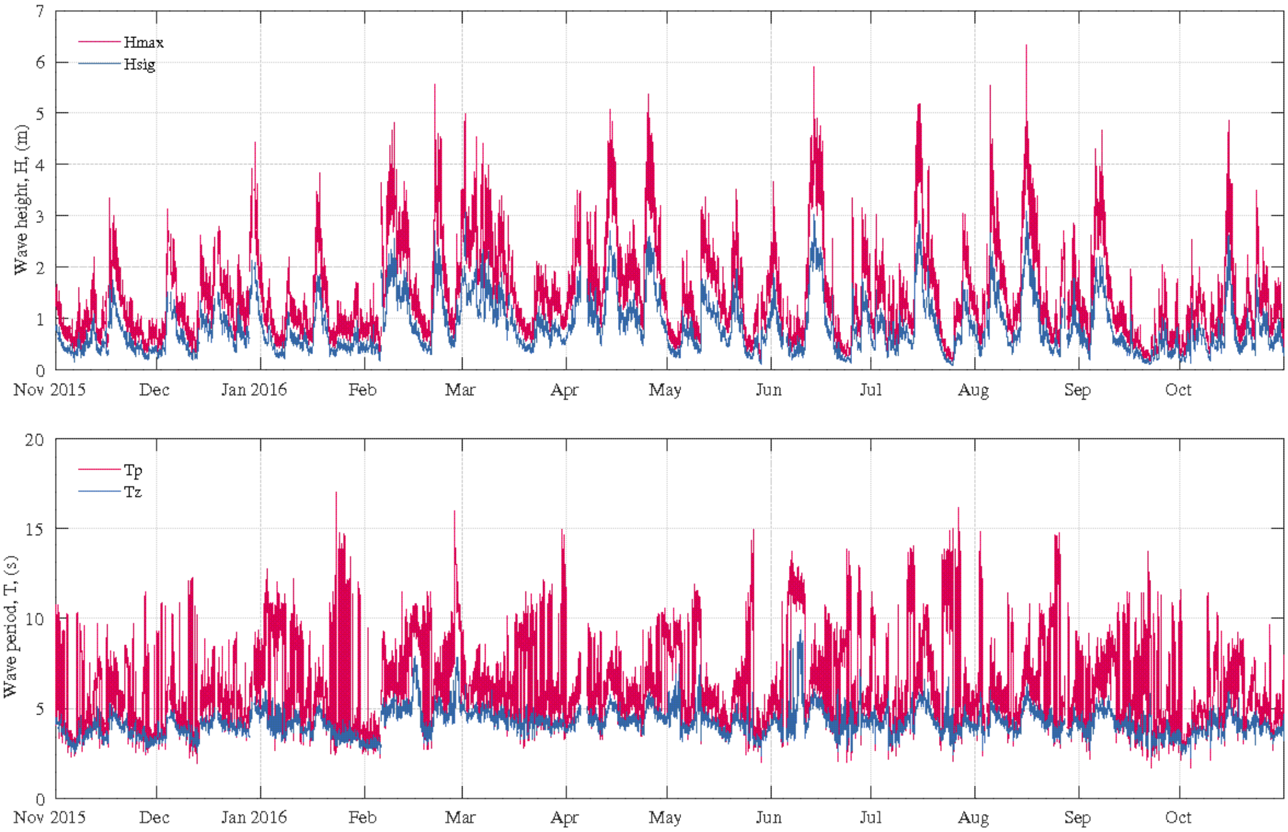


Figure 86 Mackay – Daily wave recordings

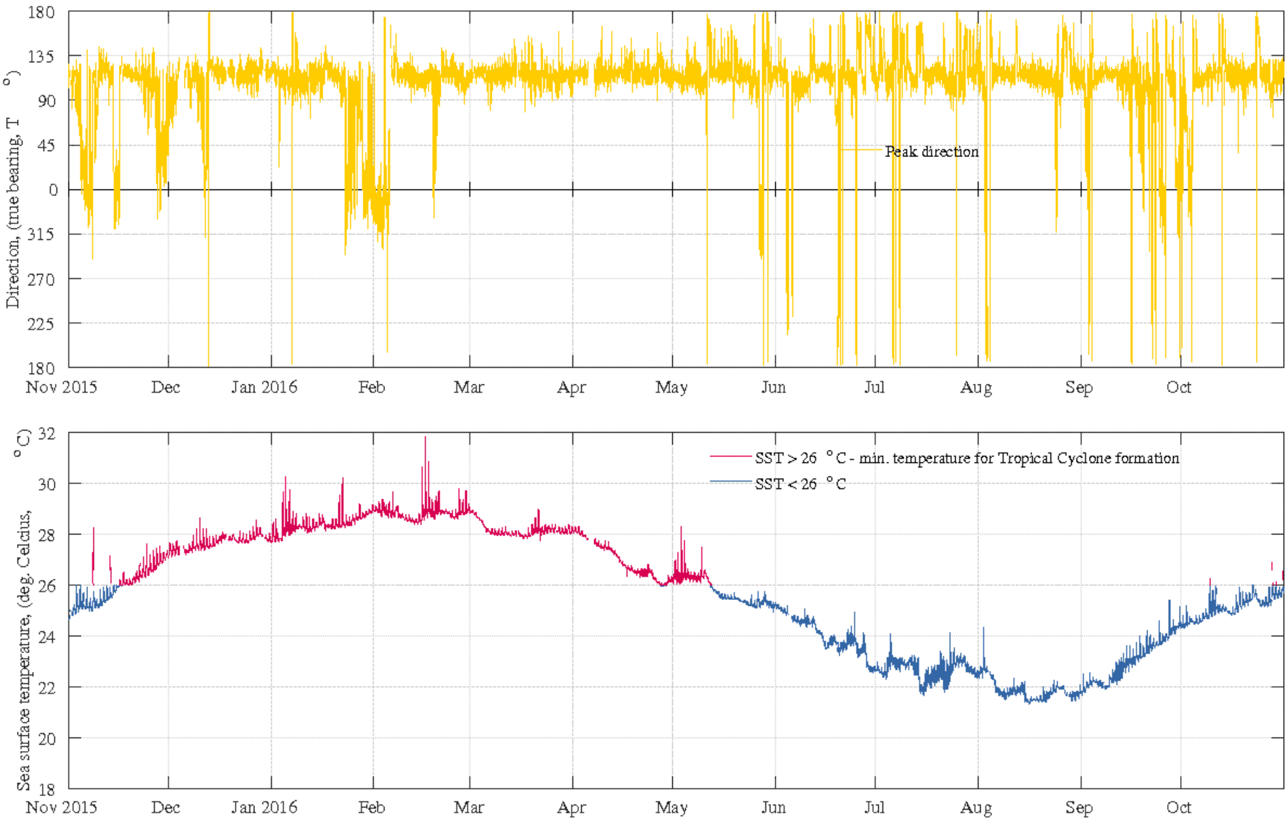


Figure 87 Mackay – Sea surface temperature and peak wave directions

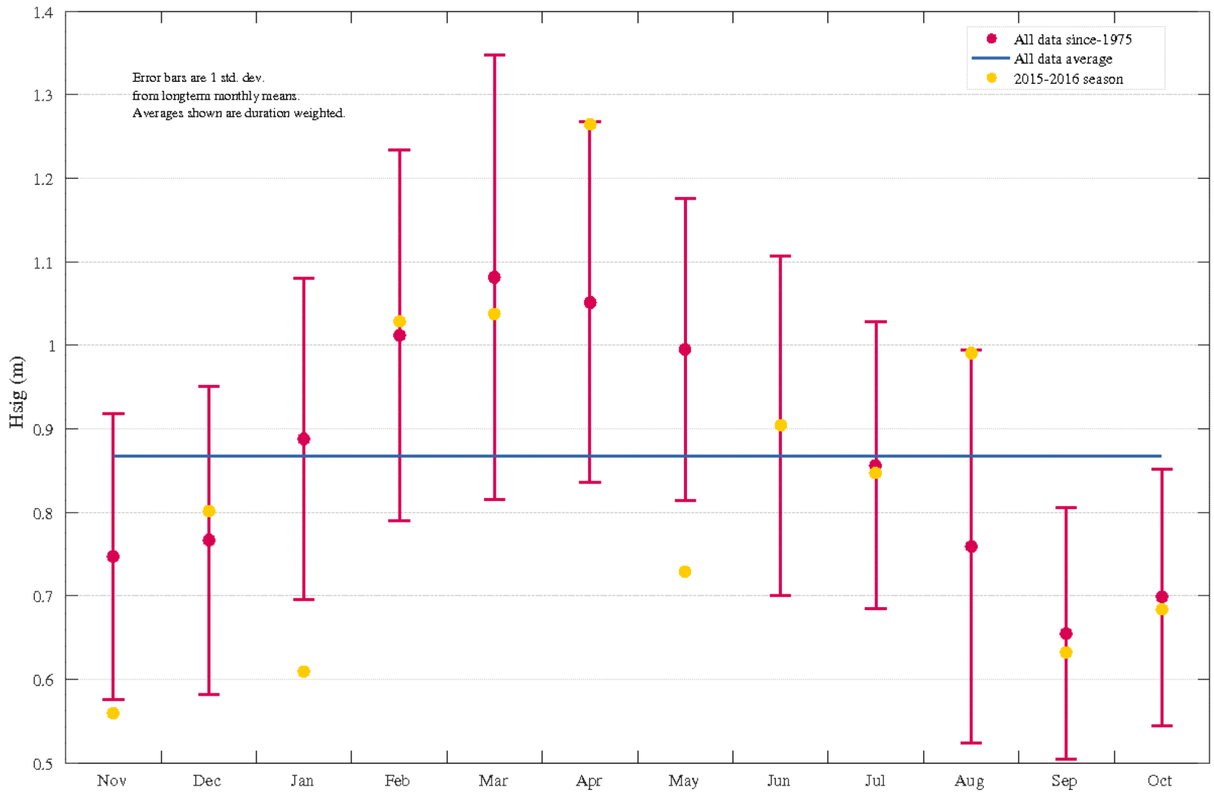


Figure 88 Mackay – Monthly average wave height (Hsig) for seasonal year and for all data

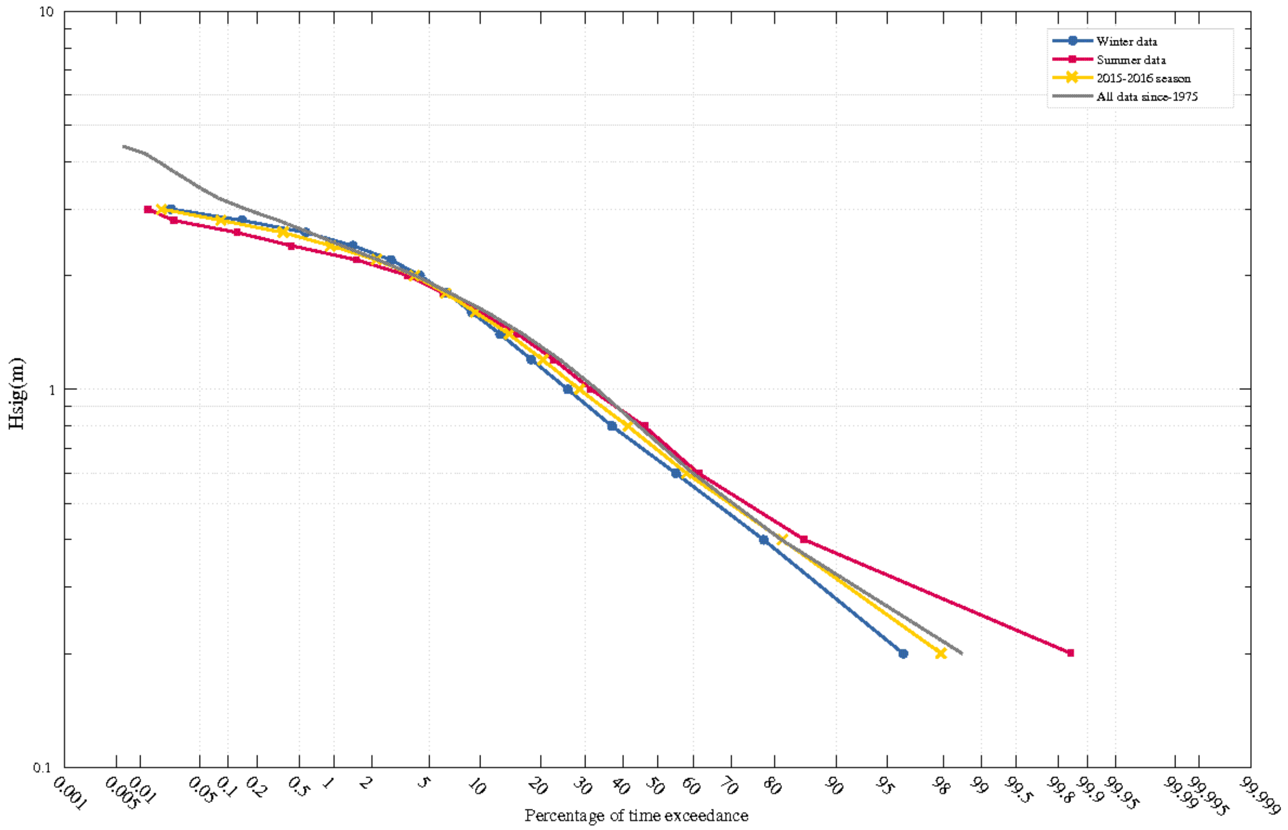


Figure 89 Mackay – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

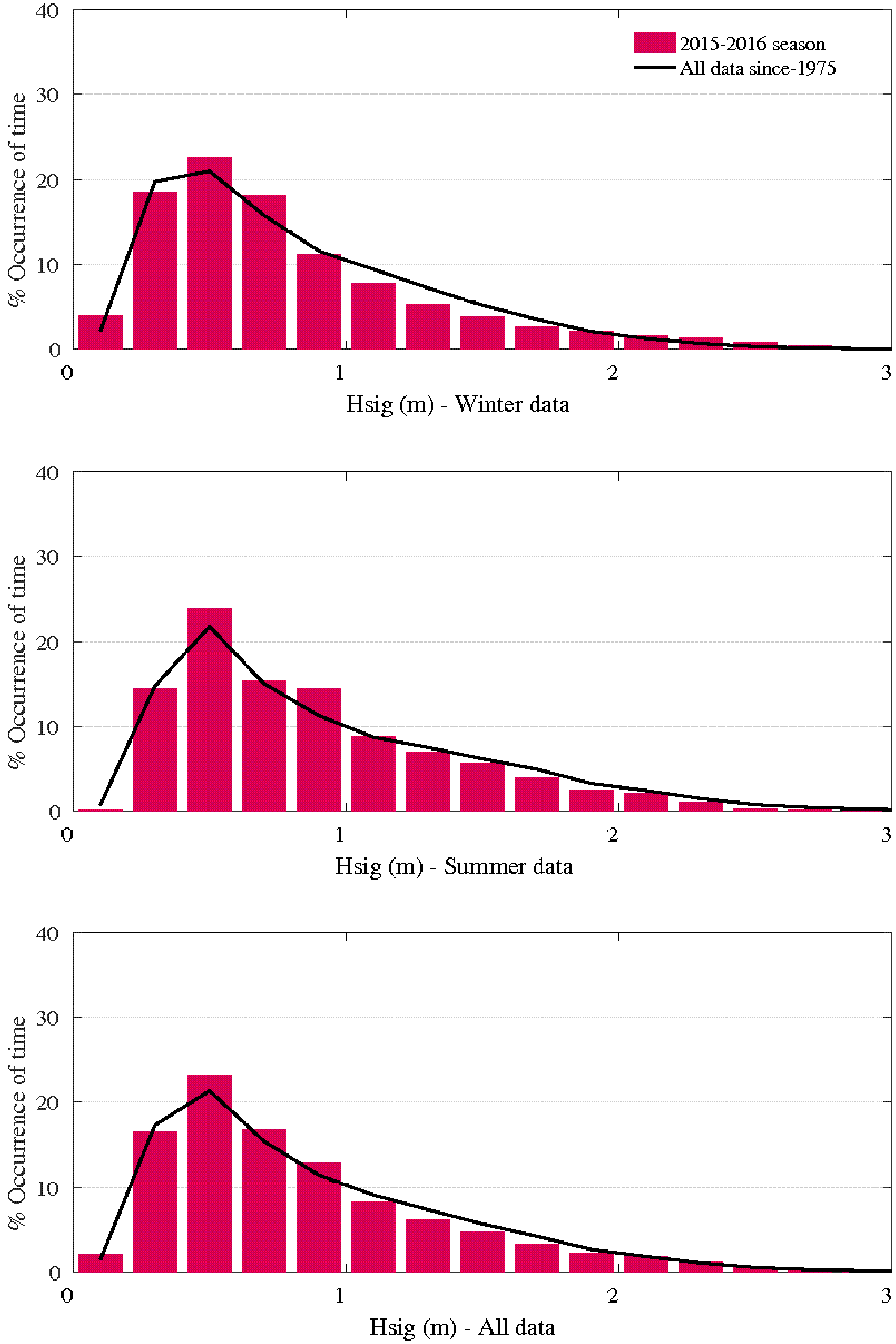


Figure 90 Mackay – Histogram percentage (of time) occurrence of wave heights (Hsig)

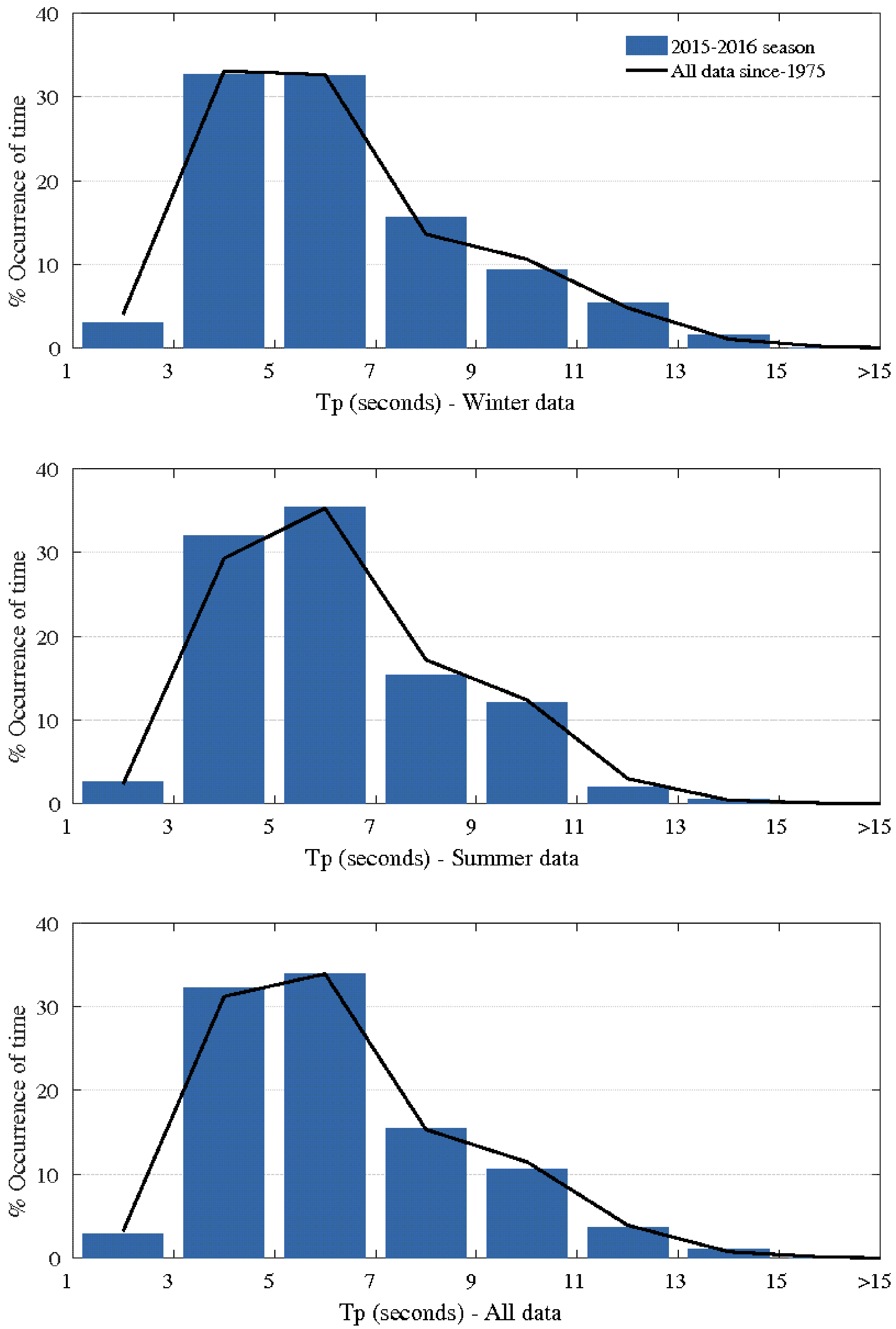


Figure 91 Mackay – Histogram percentage (of time) occurrence of wave periods (Tp)

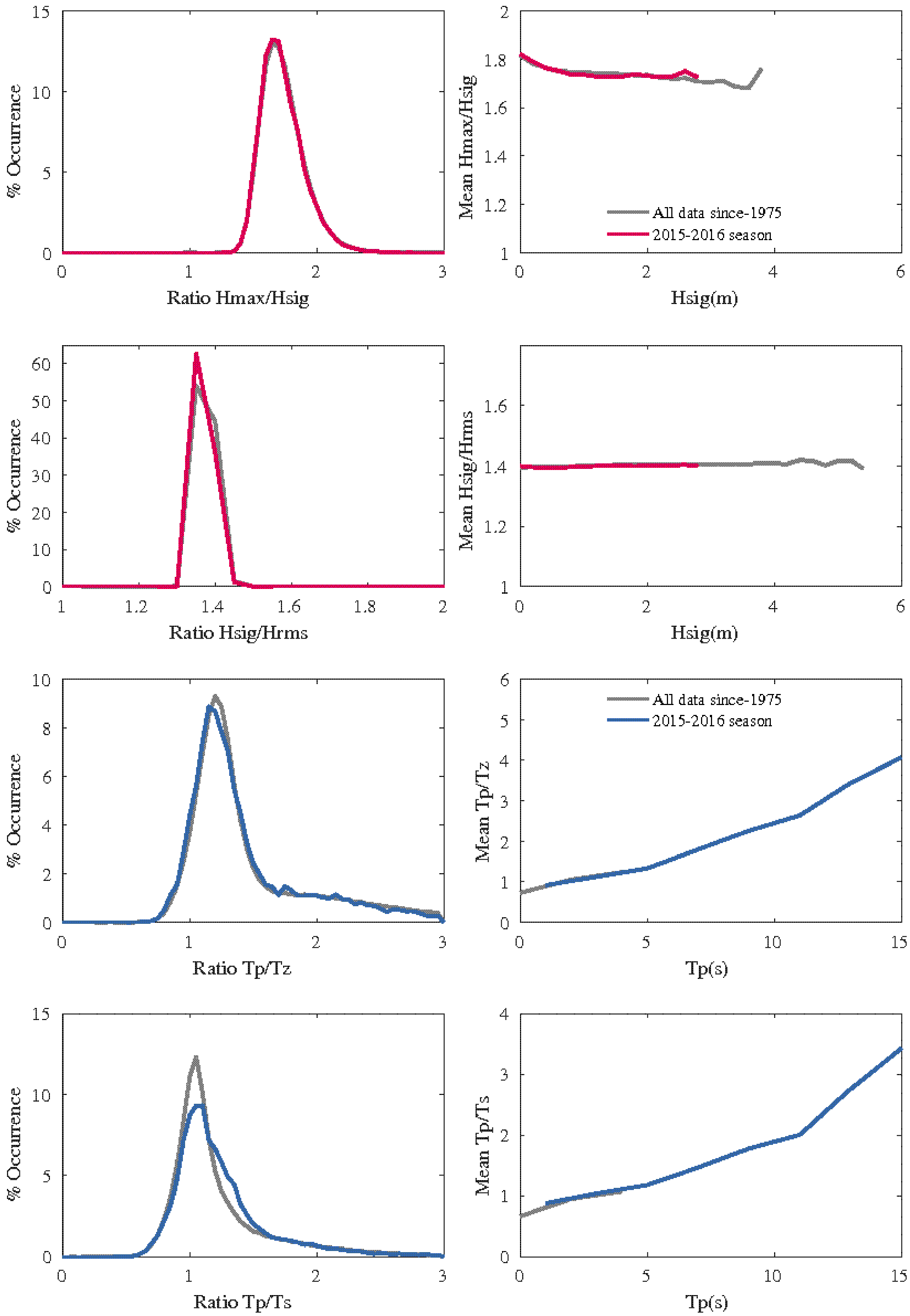
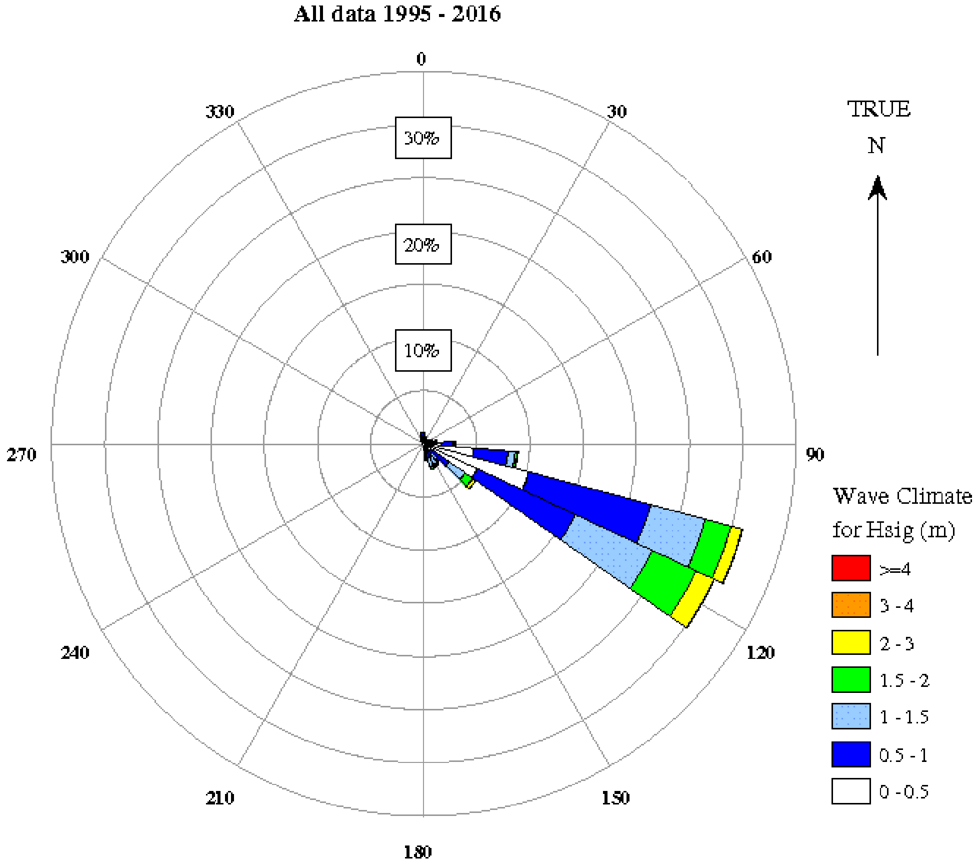


Figure 92 Mackay – Wave parameter relationships



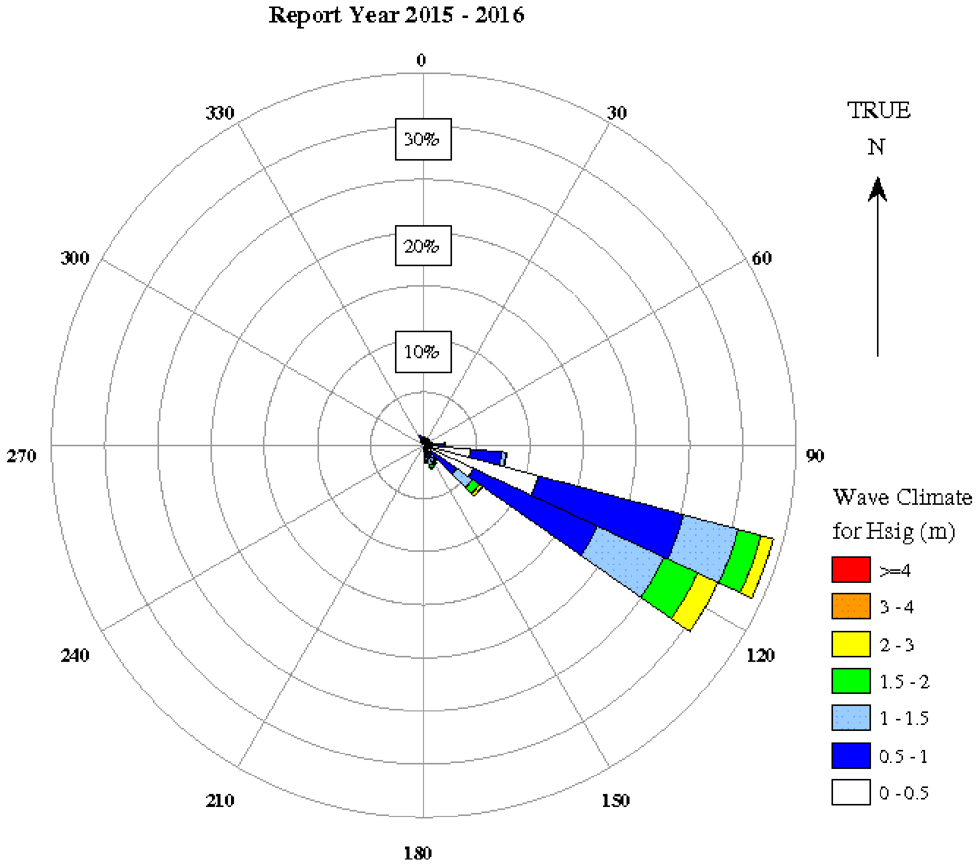


Figure 93 Mackay – Directional wave rose

Abbot Point

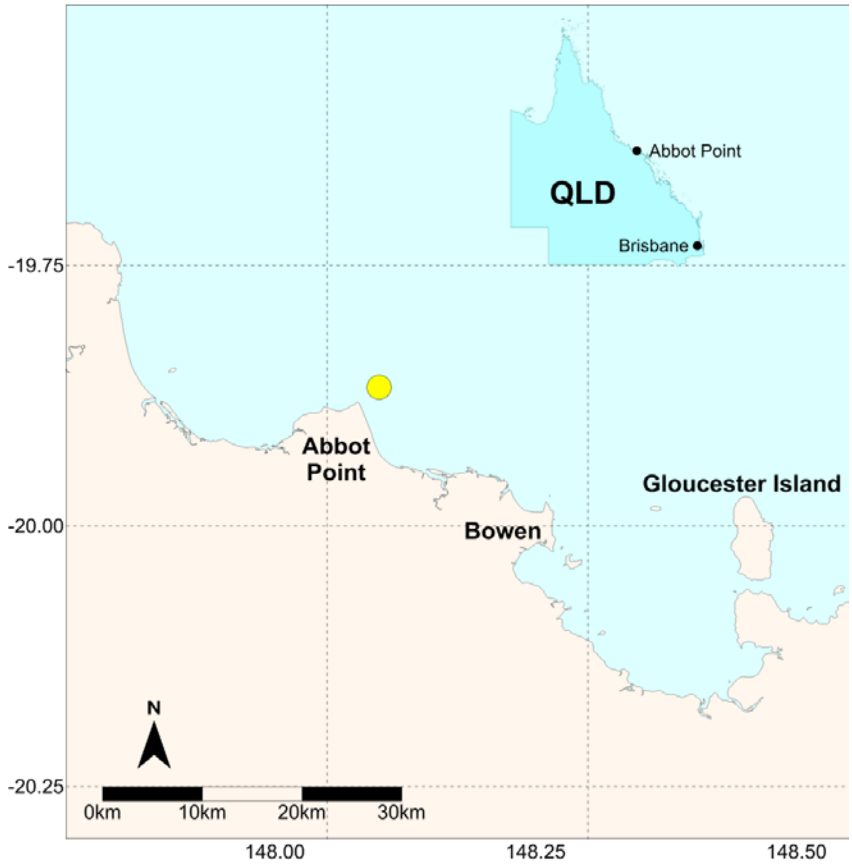


Figure 94 Abbot Point – Locality plan

Table 45 Abbot Point – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	17/01/2012	0.06 years	82,755	4.8
2015–16	01/11/2015	0.88 days	17,525	1

Table 46 Abbot Point – Buoy deployment for the 2015-16 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
19°51.956' S	148°05.883' E	15	28/01/2016	current

Abbot Point – seasonal overview

The Abbot Point wave buoy has now been operational for just under five years. The data recorded for the period from November 2015 to October 2016 was excellent, with total gaps of 0.88 days, equivalent to 99.8 per cent data return (Table 45). The overall data return is 98.8 per cent. The wave buoy was replaced on 28 January (Table 46).

The largest waves recorded by the Abbot Point wave rider buoy during the reporting period occurred during June. This generated a maximum wave height (Hmax) of 3.6 m, ranked 4 (Table 47), on 13 June. On 30 December a record maximum Hsig of 1.5 m ranked tenth largest.

Peak wave direction (Figure 96) was predominately from the east with swings to the south in late winter and to the north in summer. Sea Surface Temperature (SST) values ranged from 22 °C to 31.5 °C (Figure 96) were the SST was high enough for tropical cyclone development from November till Mid-April and then again from late September.

The monthly average Hsig generally fell within one standard deviation (sd) of the long term mean with the exception of April and August where the monthly mean was greater than the long term mean and November and May which were below the mean −1 s and wave heights over 1 m less frequent, (Figure 97).

Percentage exceedance of Hsig (Figure 98) indicate similar wave heights during summer and winter. The percent occurrence of Hsig (Figure 99) indicates a higher occurrence of waves in the 0.4 – 0.6 m range and a lower occurrence of waves less than 0.2 m in summer.

The most common Tp was between 3 to 5 seconds in both summer and winter (Figure 100).

Directional wave rose plots (Figure 102) highlight the dominant east-north-easterly incident wave direction for this reporting period and over the three years of operation.

Table 47 Abbot Point – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (m)
1	13/04/2014 14:30	3.8	13/04/2014 14:30	6.5
2	24/01/2013 16:00	3.0	24/01/2013 19:00	5.5
3	21/03/2012 03:00	1.9	12/04/2013 00:00	3.6
4	12/04/2013 00:00	1.8	13/06/2016 10:30	3.6
5	02/02/2012 07:00	1.7	20/03/2012 23:00	3.4
6	12/04/2012 15:00	1.6	15/01/2014 10:30	3.4
7	03/10/2015 15:00	1.6	11/07/2012 04:00	3.3
8	09/03/2014 15:00	1.6	12/04/2012 15:00	3.3
9	11/07/2012 03:00	1.5	01/12/2013 22:30	3.2
10	30/12/2015 02:30	1.5	02/02/2012 07:00	3.2

Table 48 Abbot Point – Significant meteorological events with threshold Hsig of 2.5 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
No significant events reported				

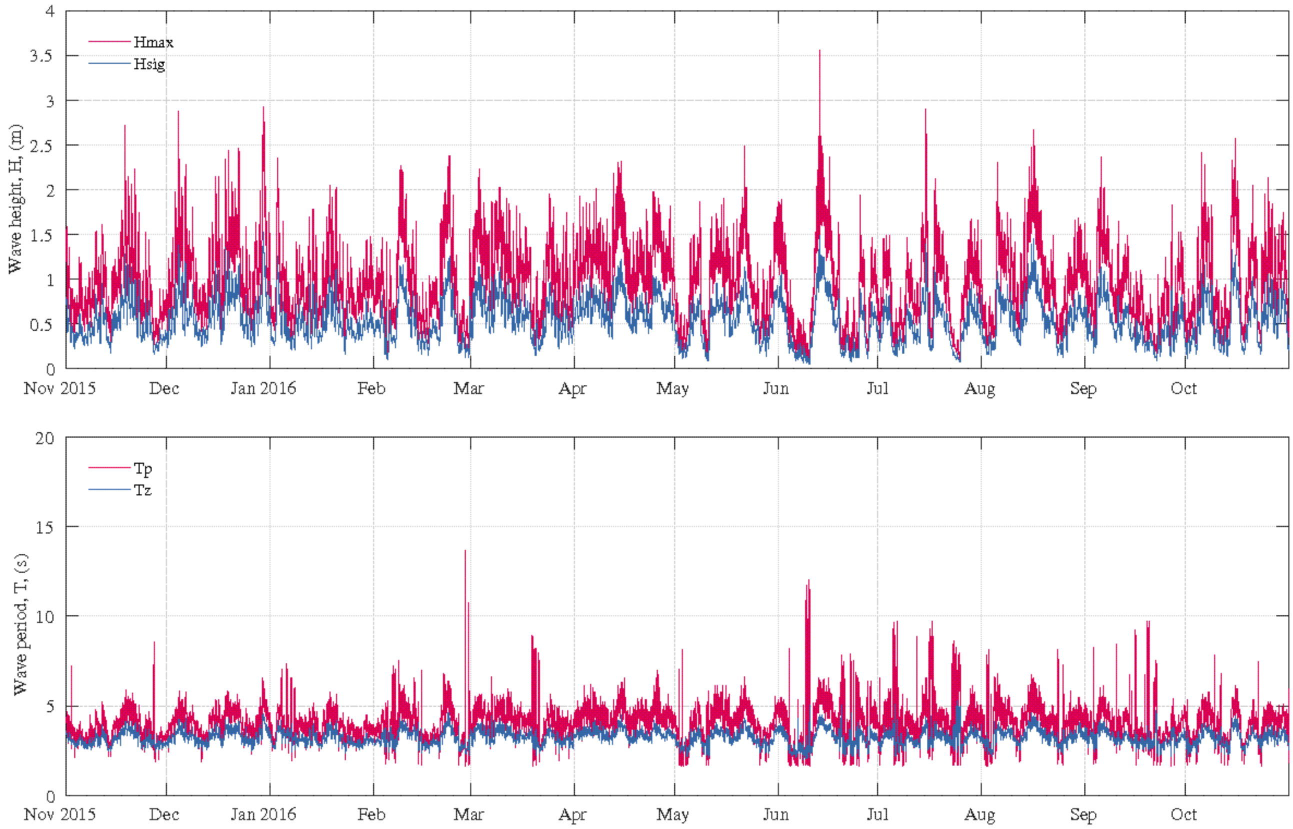


Figure 95 Abbot Point – Daily wave recordings

Figure 96 Abbot Point – Sea surface temperature and peak wave directions

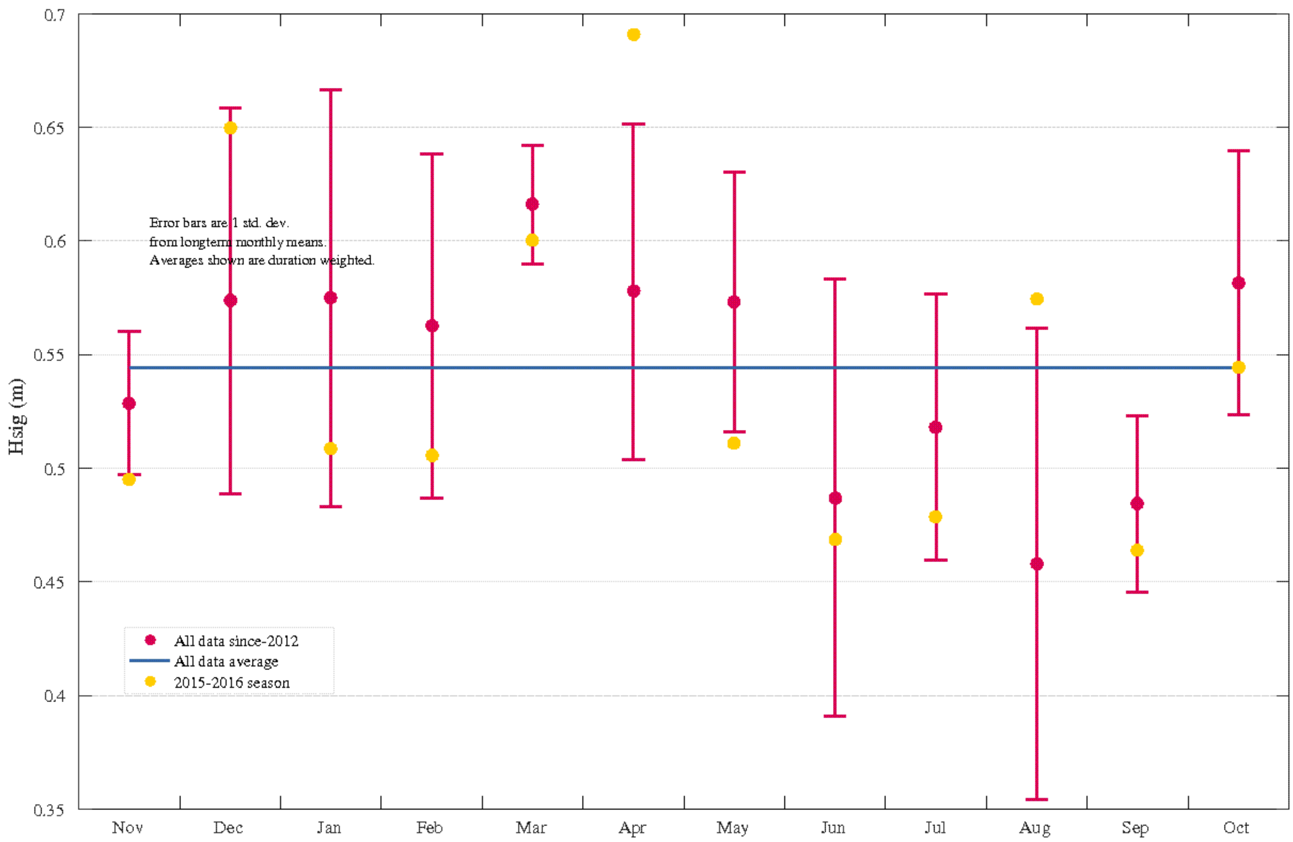


Figure 97 Abbot Point – Monthly average wave height (Hsig) for seasonal year and for all data

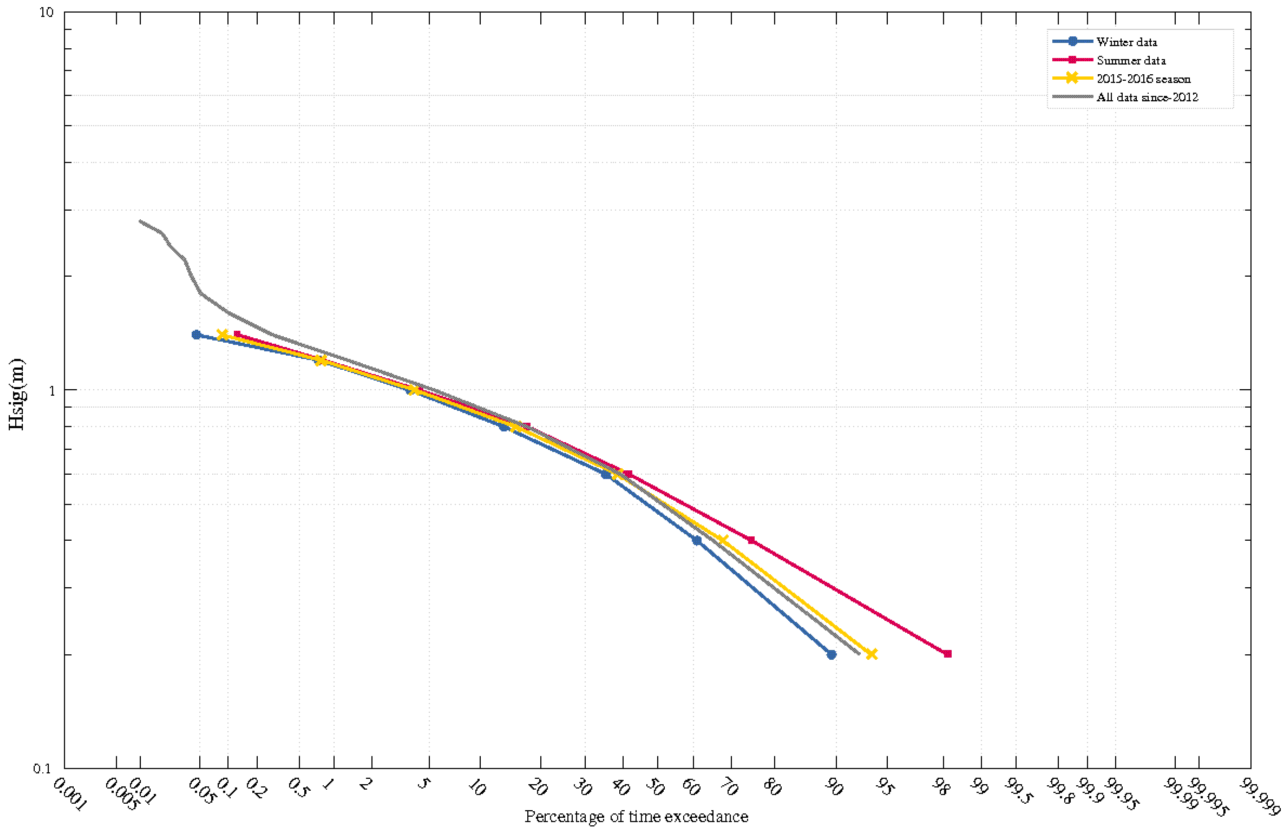


Figure 98 Abbot Point – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

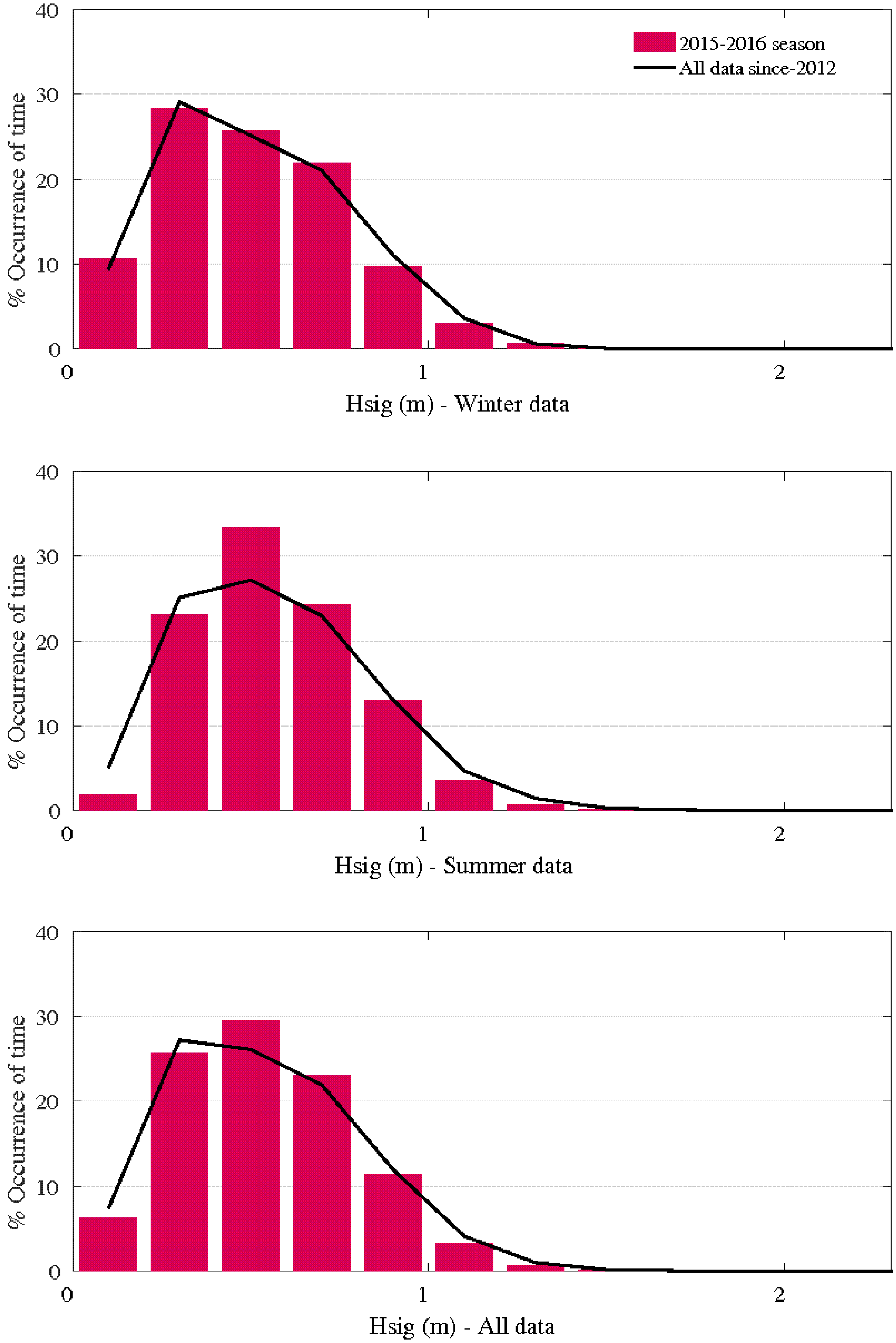


Figure 99 Abbot Point – Histogram percentage (of time) occurrence of wave heights (Hsig)

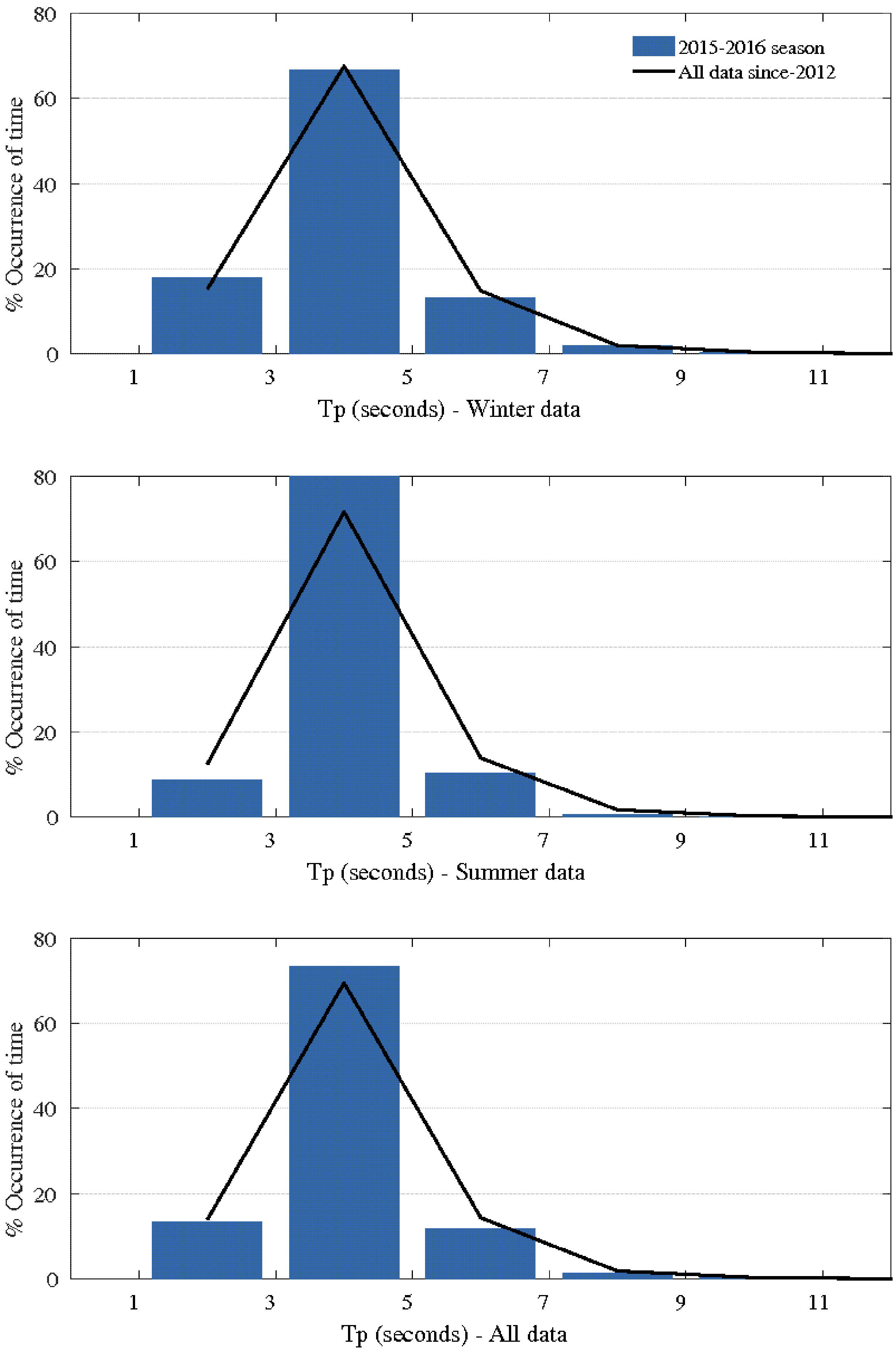


Figure 100 Abbot Point – Histogram percentage (of time) occurrence of wave periods (Tp)

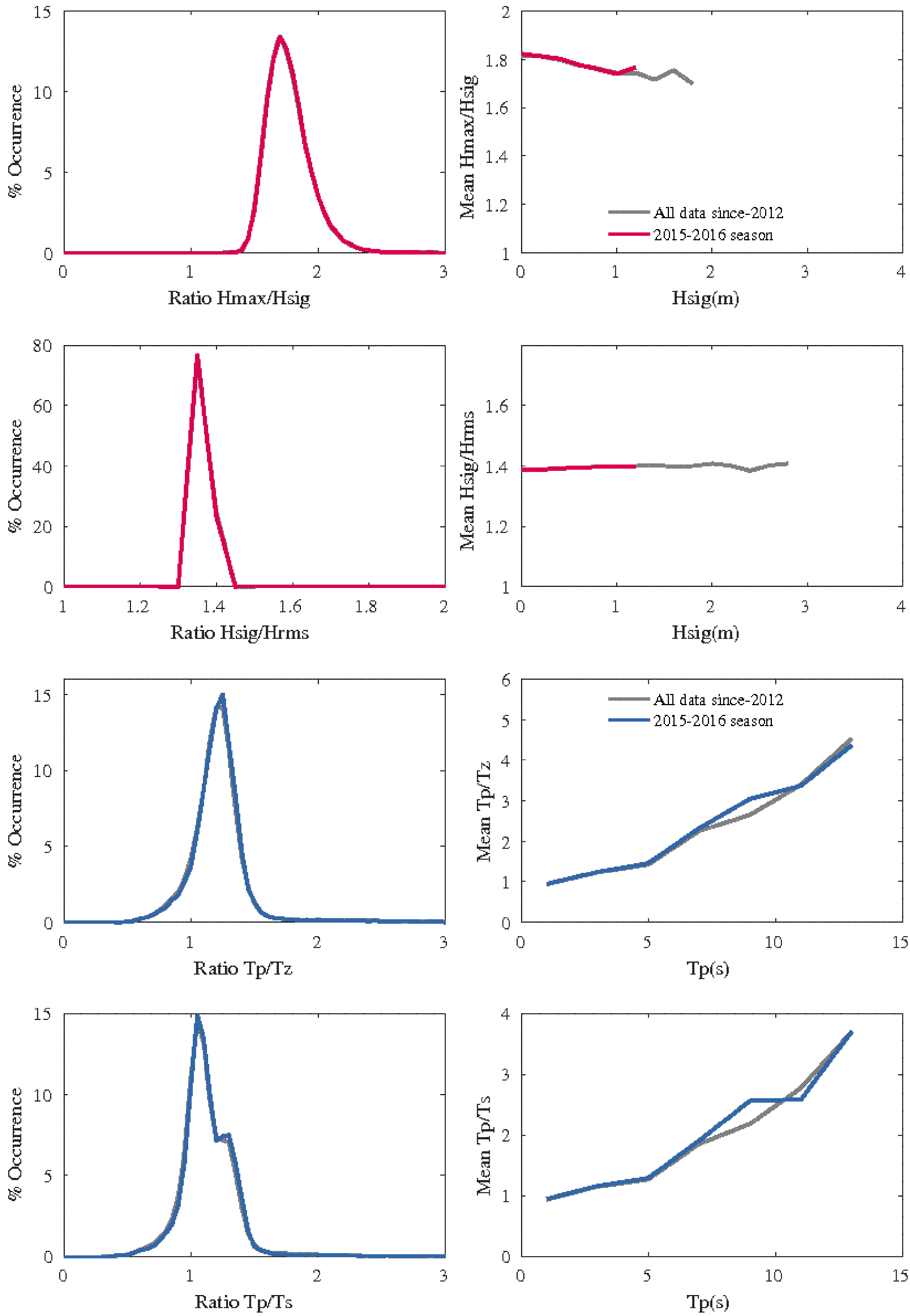
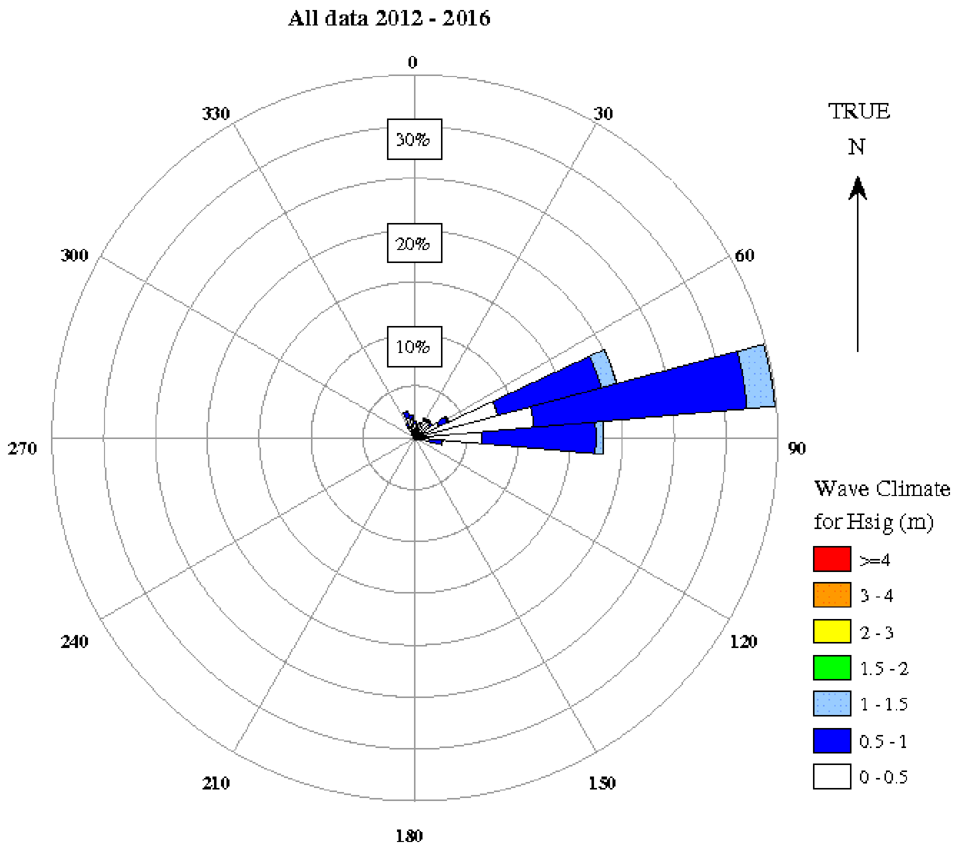


Figure 101 Abbot Point – Wave parameter relationships



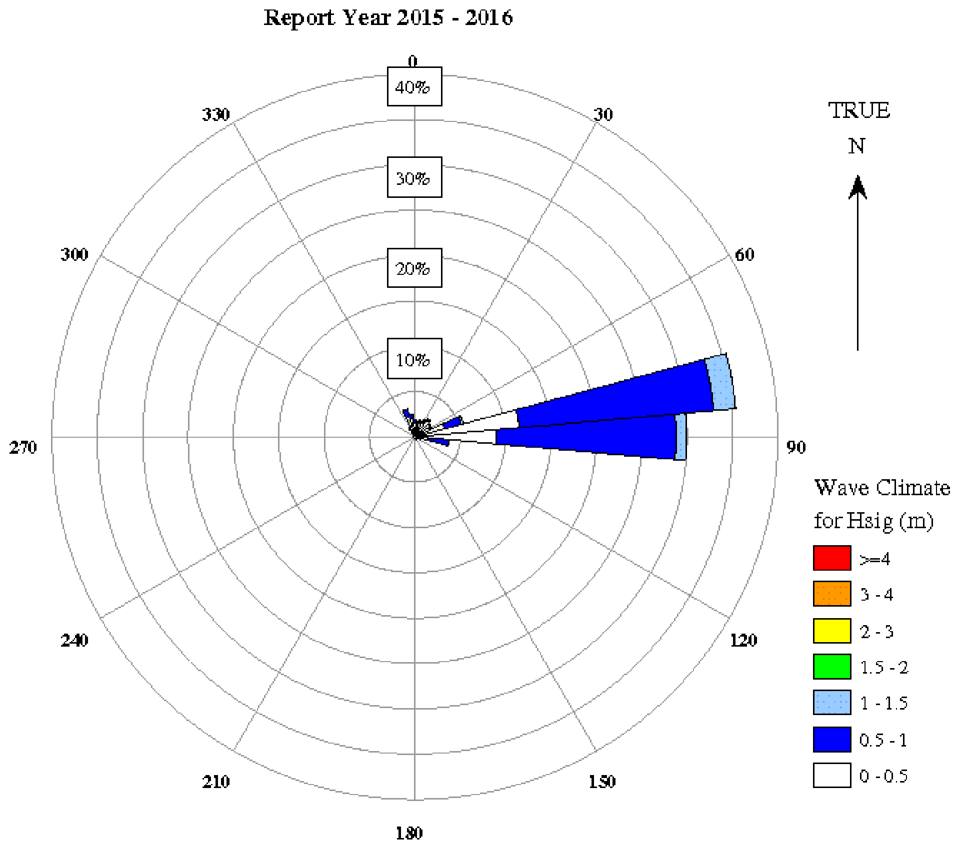


Figure 102 Abbot Point – Directional wave rose

Townsville

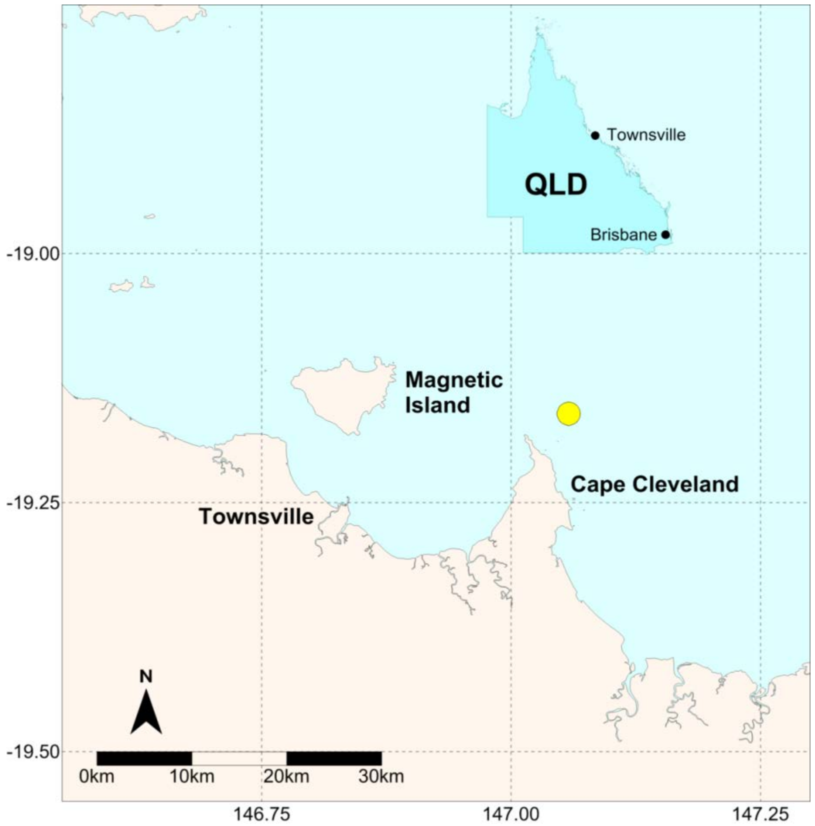


Figure 103 Townsville – Locality plan

Table 49 Townsville – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	20/11/1975	n/a	332,394	40.95
2015–16	01/11/2015	2.15 days	17,464	1

Table 50 Townsville – Buoy deployments during the 2015-16 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
19°09.540' S	147°03.524' E	16	30/12/2015	current

Townsville – seasonal overview

The Townsville wave buoy has been operational for nearly 41 years. During the period from November 2015 to October 2016 there was a total gap of 2.15 days, equivalent to 99.4 per cent data return (Table 49). The buoy was replaced once during the reporting period on 30 December (Table 50).

The largest sustained waves during the reporting period occurred in December, June and July (Table 52). The measured wave heights were lower than the top 10 highest waves (Table 51). Time series of daily wave recordings (Figure 104) show clear increases in wave heights, but not above 4.1 m for Hmax and not above 2.1 m for Hsig.

Peak wave direction (Figure 105) was predominately from the east with an occasional swing to the north-east, north and south. Sea surface temperature (SST) values ranged from 21.5 °C to 32 °C (Figure 105). The SST was high enough for tropical cyclone development November till mid-May and then again from mid-September.

Monthly average Hsig (Figure 106) was within one standard deviation (sd) for almost the entire reporting period, except for February. February experienced wave heights lower than −1 standard deviation.

Wave climate for the reporting period was very similar to the wave climate of the entire record. Percentage exceedance of Hsig (Figure 107) for the reporting period showed the same trend as past data, except for the lowest waves. Histograms for percentage occurrence of Hsig (Figure 108) and peak wave period (Tp) (Figure 109) were also similar between the recent period and the whole record.

The ratios between different wave parameters such as Hmax/Hsigm, Hsig/Hrms and Tp/Tz were consistent between this reporting period and all of the historic data (Figure 110). The ratio Tp/Ts slightly decreased compared to the historic data.

Directional wave rose plots (Figure 111) highlight the dominant easterly direction for the reporting period which was very similar to the entire record.

Table 51 Townsville – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (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
5	30/01/2010 22:30	3	24/01/2013 07:30	5.4
6	23/12/1990 09:27	3	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	11/02/1999 18:30	5.1
10	24/01/2013 06:30	2.7	01/02/1986 20:49	4.9

Table 52 Townsville – Significant meteorological events with threshold Hsig of 1.8 metres.

Date	Hs (m)	Hmax (m)	Tp (s)	Event
30/12/2015 05:30	1.9(2.0)	3.3(3.9)	6.4	Low pressure area off New Zealand
13/06/2016 14:00	1.9(2.1)	3.5(4.1)	7.1	High pressure area situated over southern NSW
18/07/2016 07:30	1.9(2.0)	3.4(4.1)	6.3	Low pressure area north of Cairns and a high around Sydney causing turbulent conditions

Denotes peak Hsig event

Notes: 1. Barometric pressure measured in hectopascals (hPa). The Hsig and Hmax values are the maximums recorded for each event and are not necessarily coincident in time. The Tp and Hsig values are coincident as a single event on the date shown. Due to possible statistical errors arising from finite length records used in calculating wave climate, the above storm peak Hsig and Hmax values are derived from the time series smoothed by a simple three hourly moving average following the recommendation of the literature (Forristall, Heideman, Leggett, Roskam, & Vanderschuren, 1996).

2. Hsig and Hmax values shown in brackets are unsmoothed values as recorded at the site.

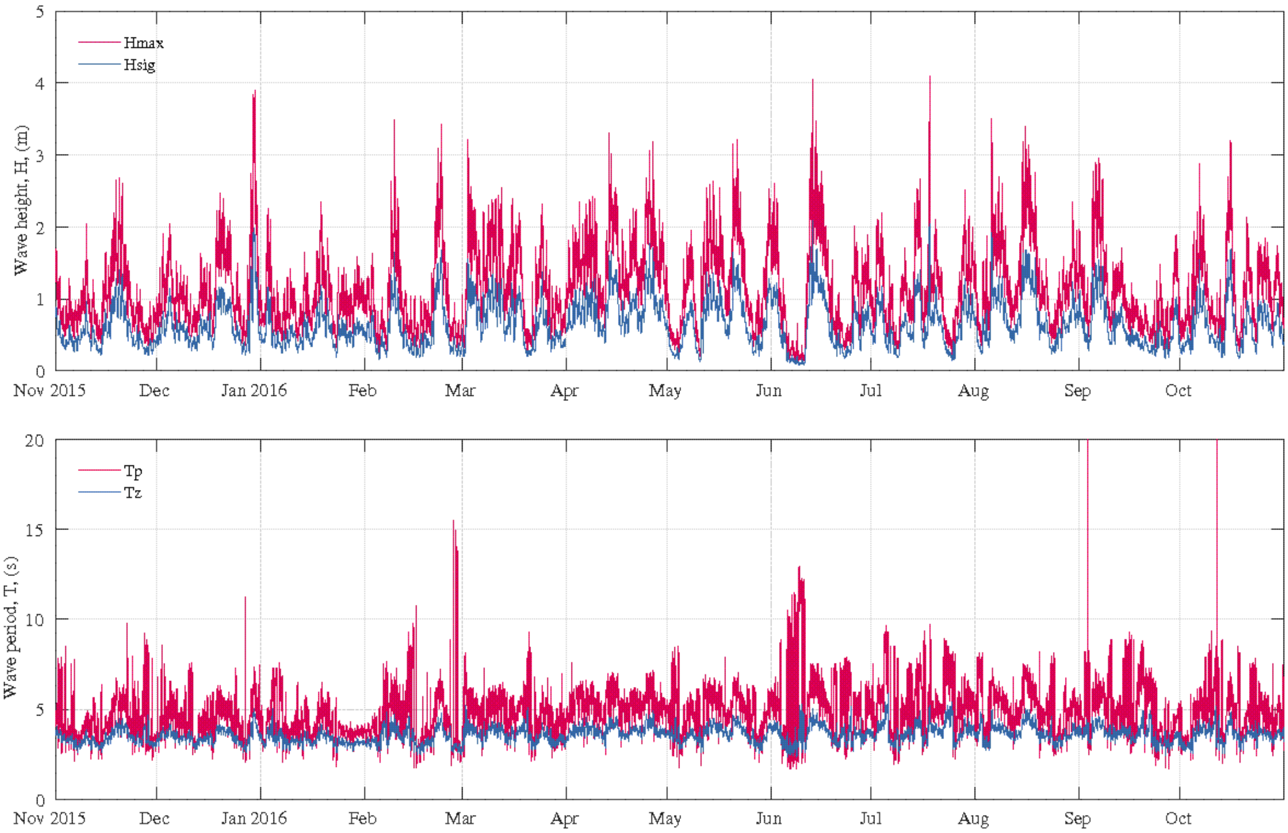


Figure 104 Townsville – Daily wave recordings

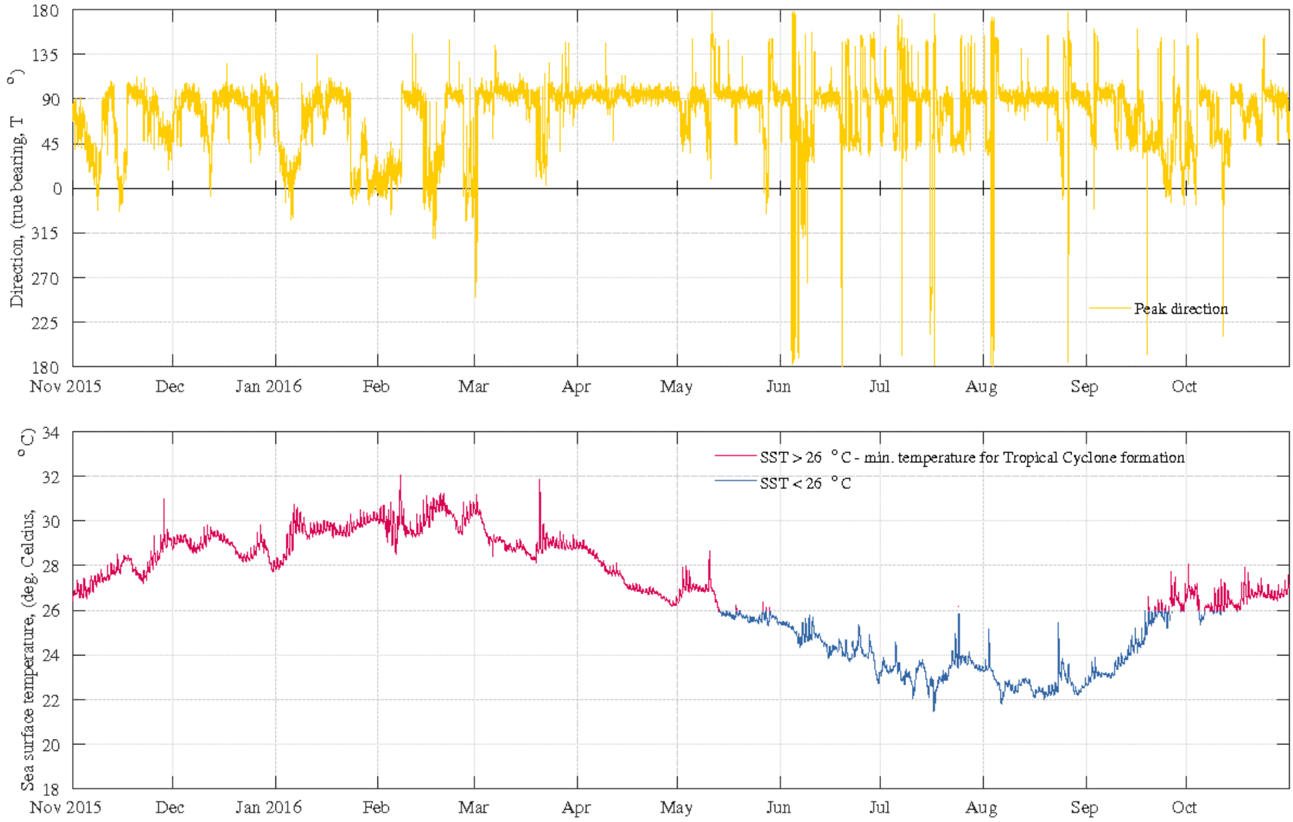


Figure 105 Townsville – Sea surface temperature and peak wave directions

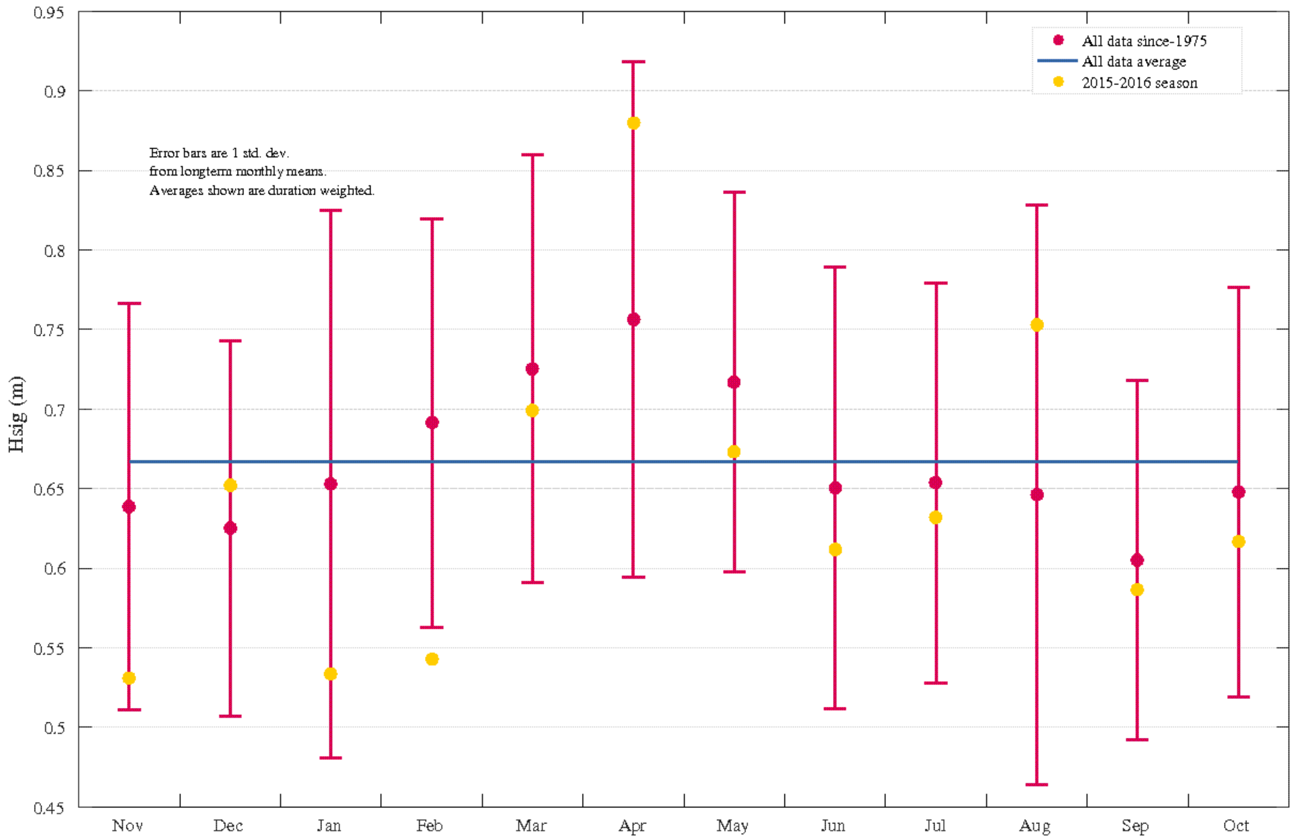


Figure 106 Townsville – Monthly average wave height (Hsig) for seasonal year and for all data

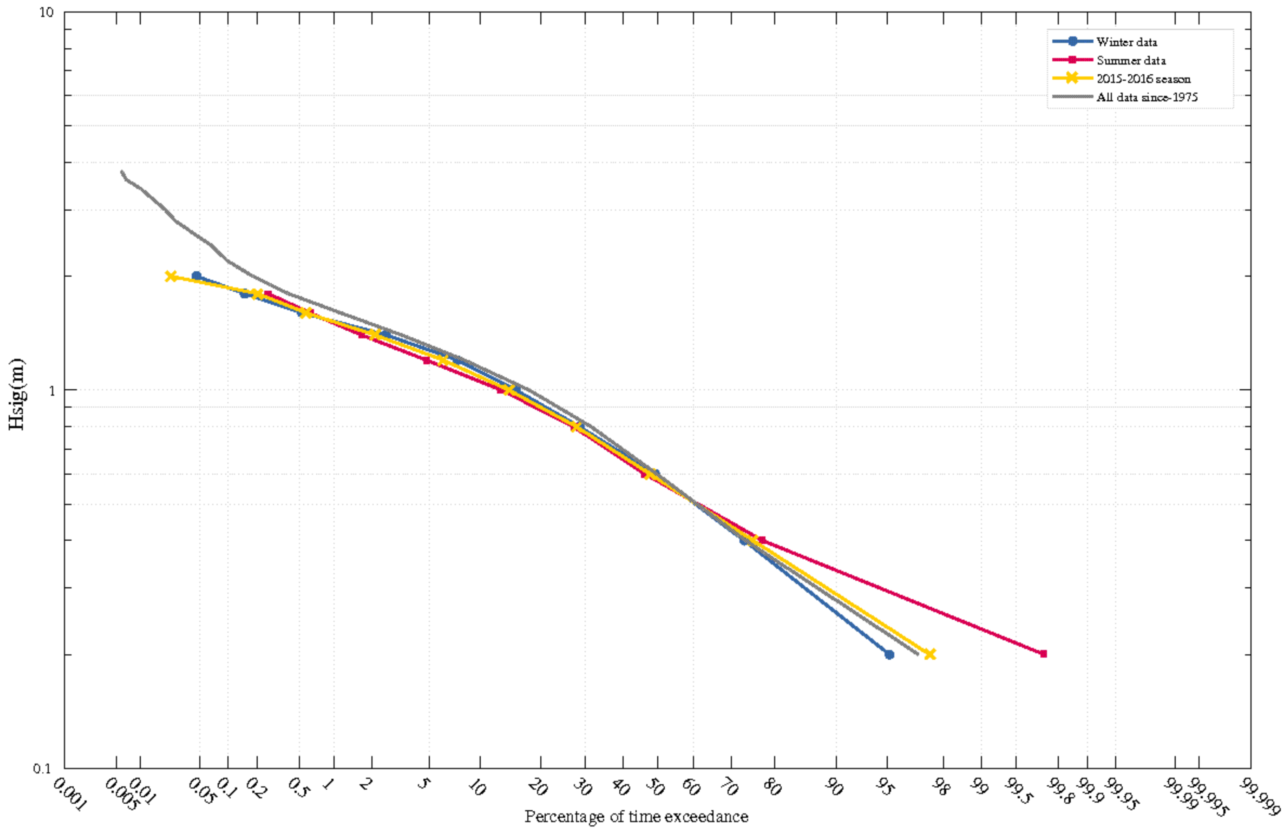


Figure 107 Townsville – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

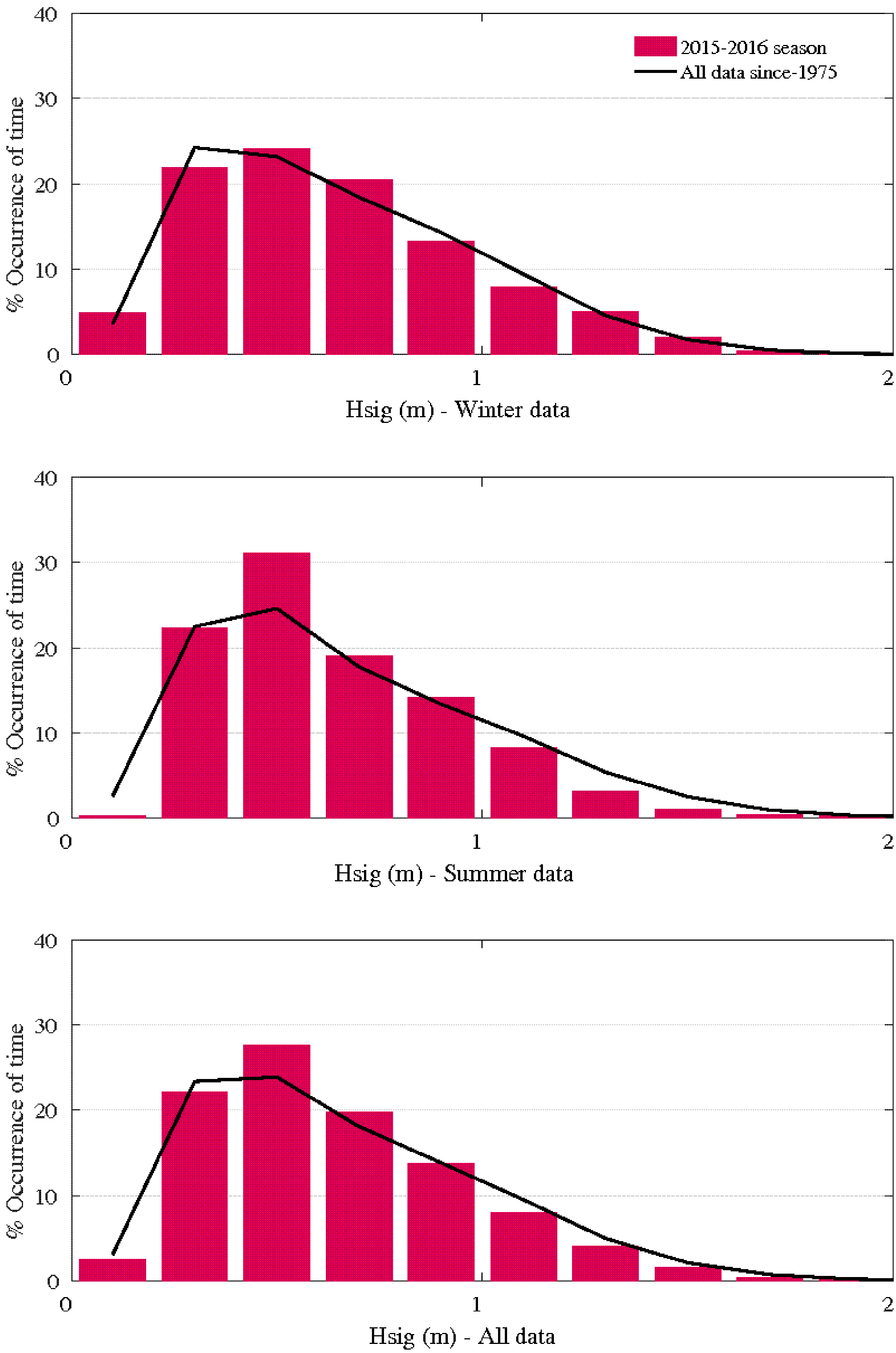


Figure 108 Townsville – Histogram percentage (of time) occurrence of wave heights (Hsig)

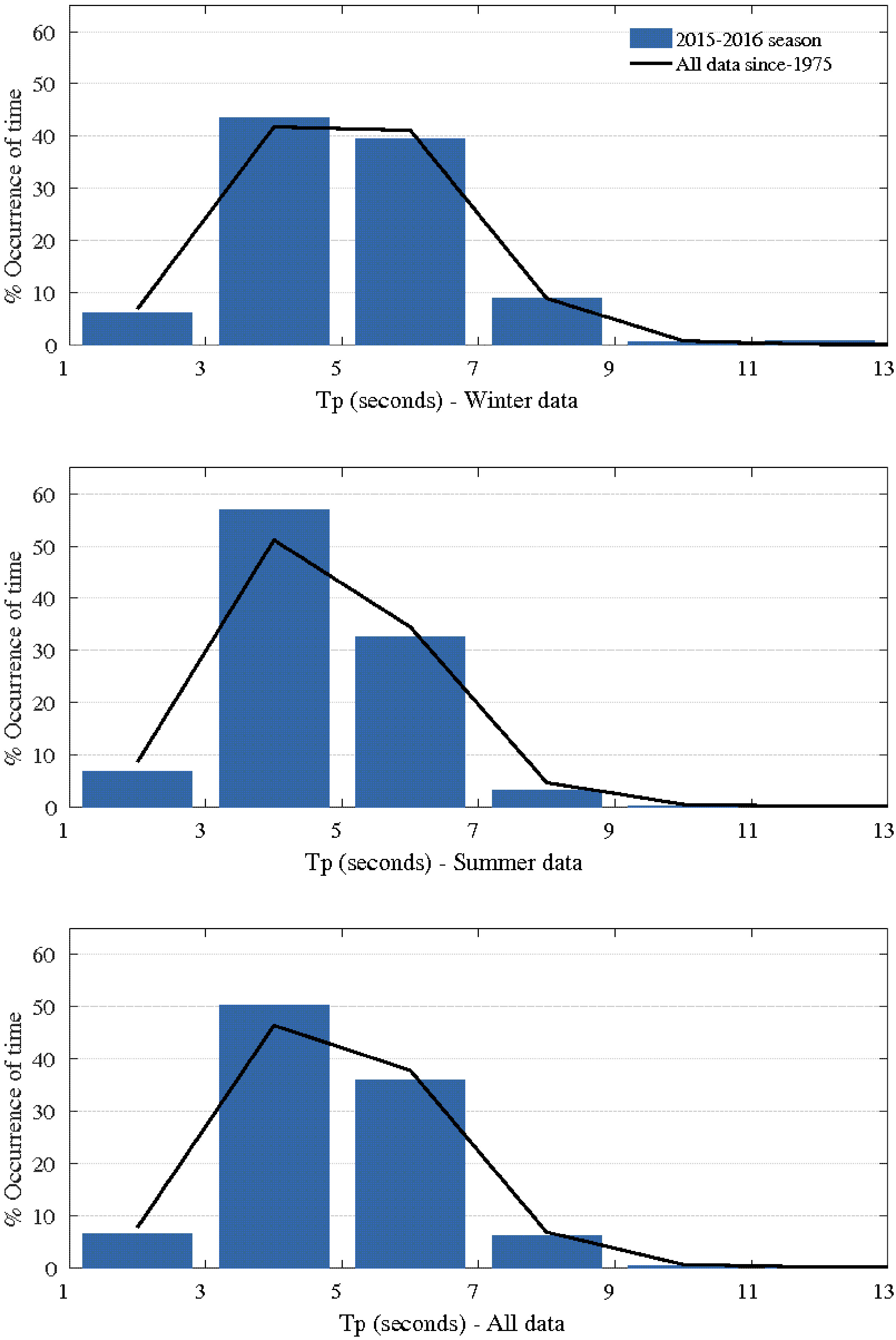


Figure 109 Townsville – Histogram percentage (of time) occurrence of wave periods (Tp)

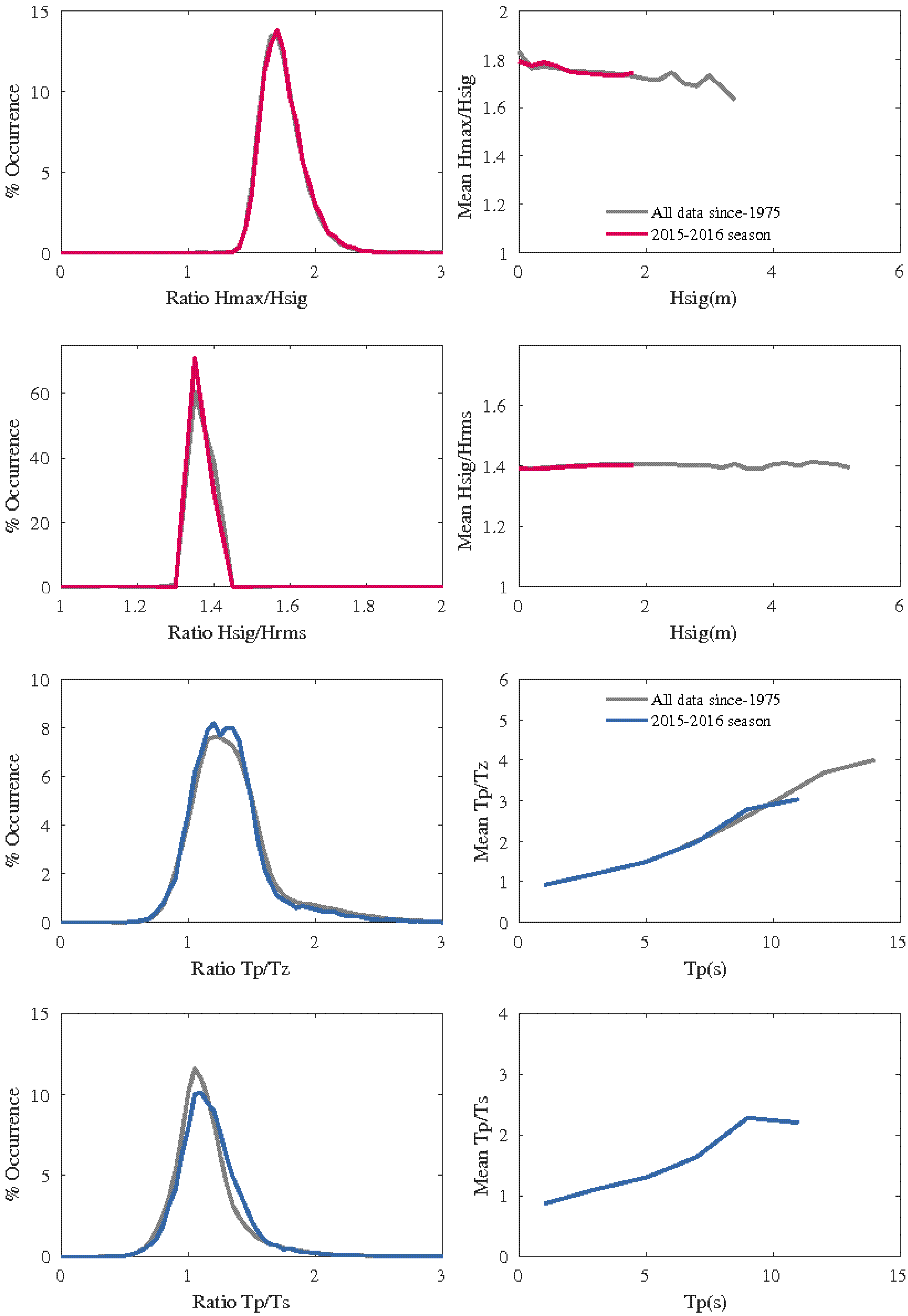
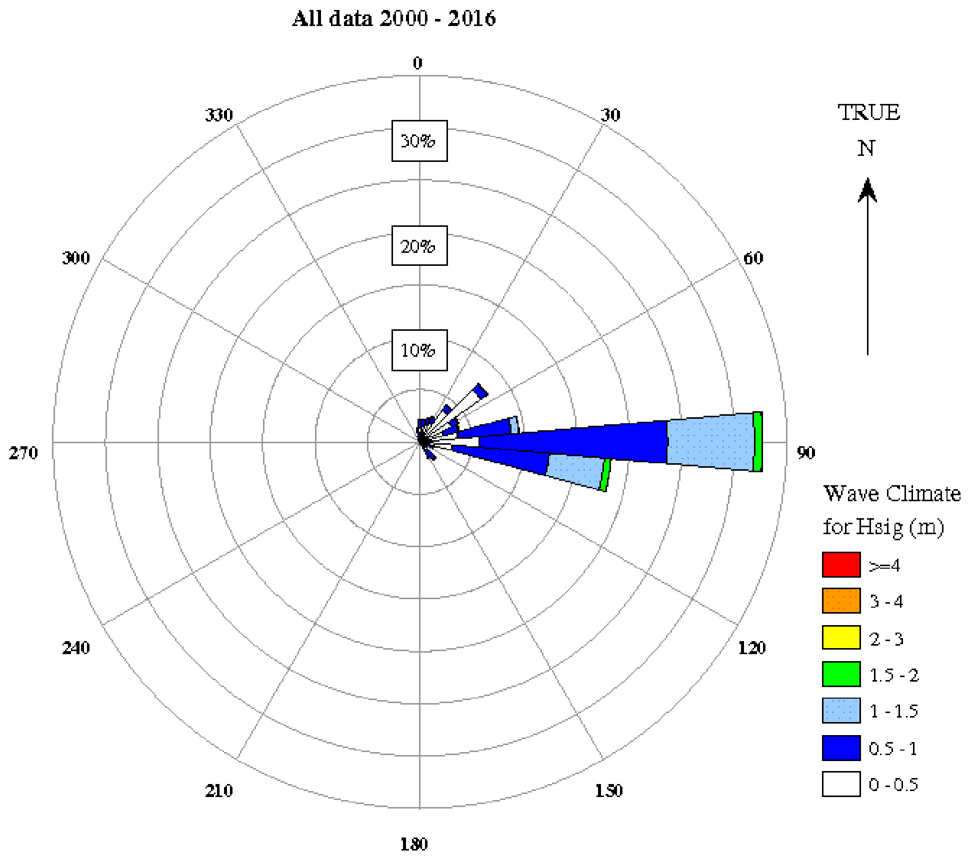


Figure 110 Townsville – Wave parameter relationships



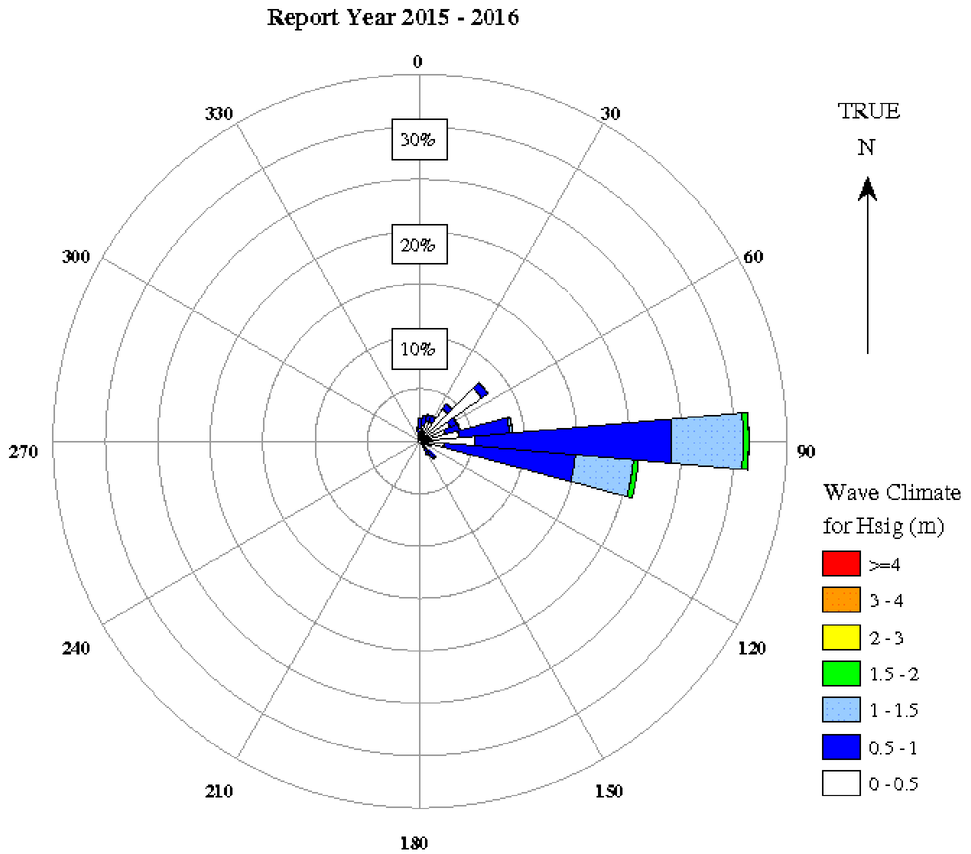


Figure 111 Townsville – Directional wave rose

Cairns

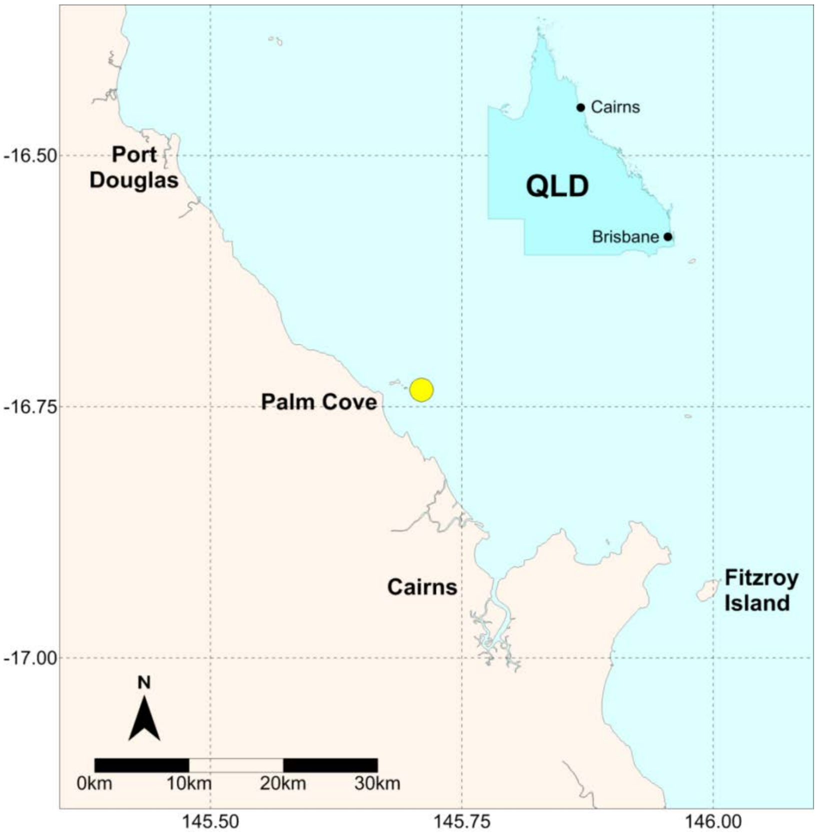


Figure 112 Cairns – Locality plan

Table 53 Cairns – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	04/05/1975	na	342,670	41.5
2015-16	01/11/2015	1.38 days	17,501	1

Table 54 Cairns – Buoy deployments for the 2015–16 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
16°44.013' S	145.42.543' E	12.8	26/02/2016	current

Cairns – seasonal overview

The Cairns wave buoy has been operational for 41.5 years. The data for the period November 2015 to October 2016 only had gaps of 1.38 days, equivalent to 99.6 per cent data return (Table 53). The buoy was replaced once during the reporting period on 26 February 2016 (Table 54).

There were no significant meteorological events during the reporting period (Table 56).

Figure 113 shows the daily wave Height and period. The largest maximum wave height was in June. Recording of sea surface temperature (SST) showed that the SST was high enough for the creating of cyclones from November until the wave buoy was changed on the 26 February. The replacement buoy underestimated SST is out by approximately 6.8 degrees (Figure 114).

The buoy at the start of the recording period was non-directional, until it was replaced with a directional buoy on the 26 February, this change in buoy type is permanent.

The monthly average Hsig (Figure 115) was within one standard deviation (sd) of the historic monthly mean, with the exception of February and March. The average monthly wave height in these months were below the mean −1 sd. The percentage exceedance of Hsig (Figure 116) was lower for all wave heights to the historical data. During winter Hsig below 0.4 m were more frequent than the average historic exceedance

Histograms of percentage occurrence of time for Hsig (Figure 117) and for peak wave period (Tp) (Figure 118) is similar between the reporting period and the entire record.

The ratios between different wave parameters such as Hmax/Hsig were consistent between this reporting period and all of the historic data, these are plotted in Figure 119.

The general wave direction was from the north east through to east with an occasional swing to the south (Figures 114 and 120).

Table 55 Cairns – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (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	19/03/1990 08:42	1.9	12/01/2009 07:00	3.4
8	31/01/1977 09:00	1.9	03/01/1979 03:00	3.3
9	12/01/2009 07:00	1.9	04/03/2008 23:30	3.3
10	03/01/1979 03:00	1.8	31/01/1977 09:00	3.2

Table 56 Cairns – Significant meteorological events with threshold Hsig of 1.5 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
No significant events reported				

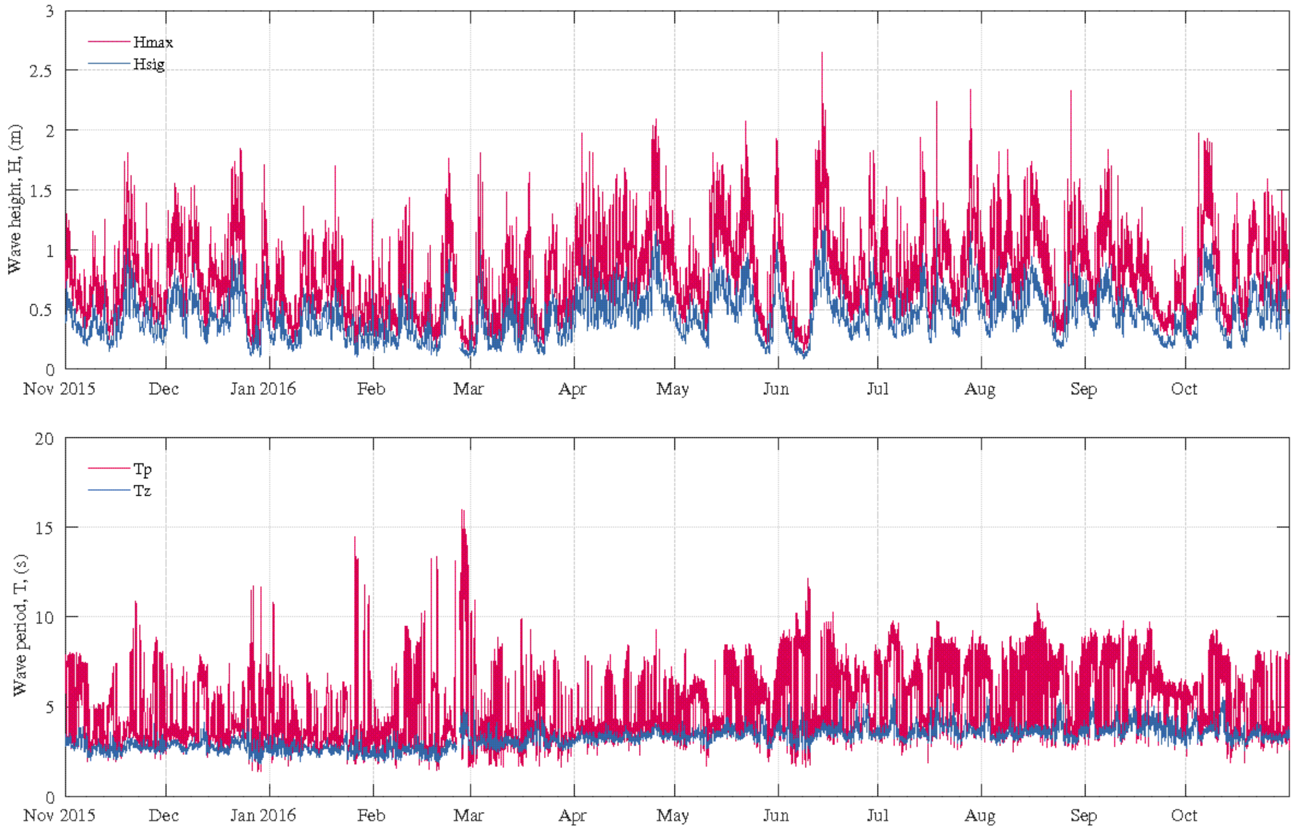


Figure 113 Cairns – Daily wave recordings

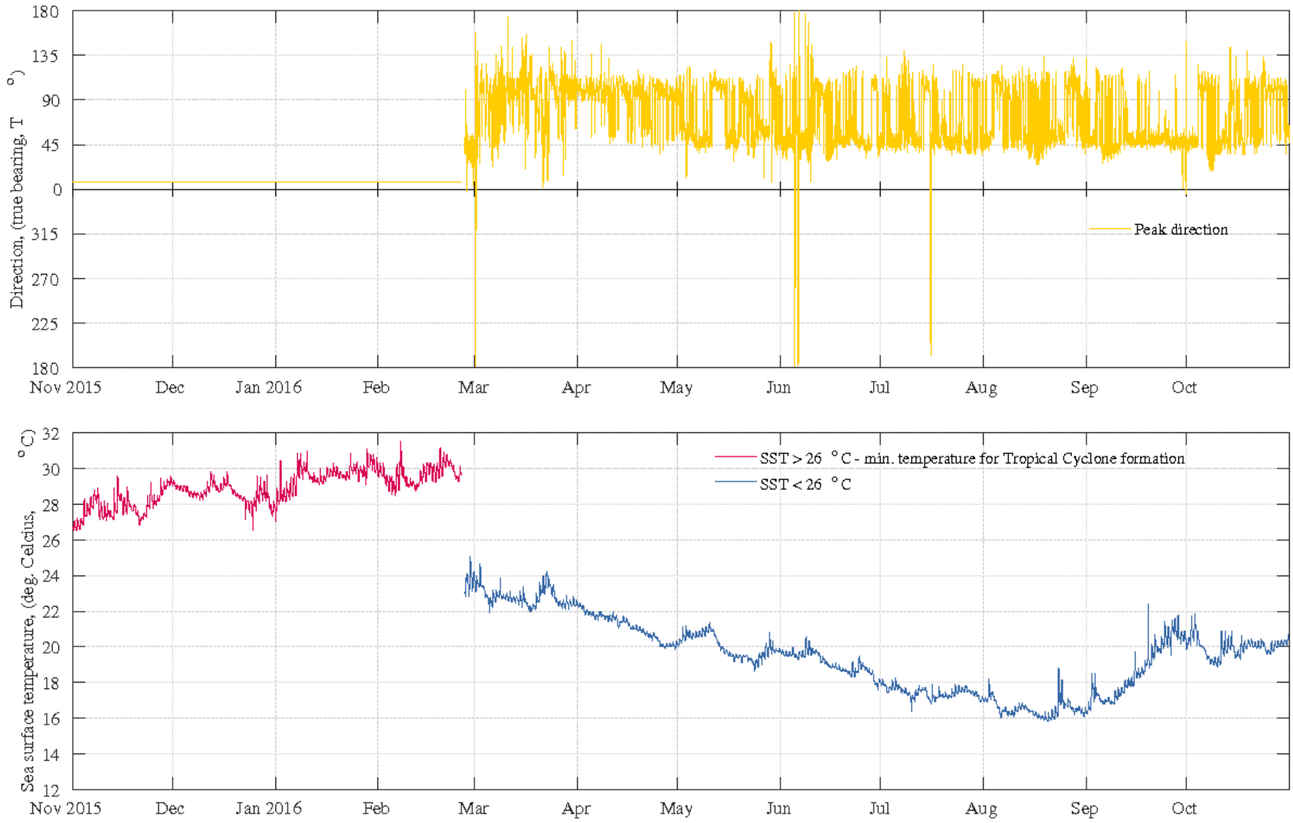


Figure 114 Cairns – Daily Sea surface temperature

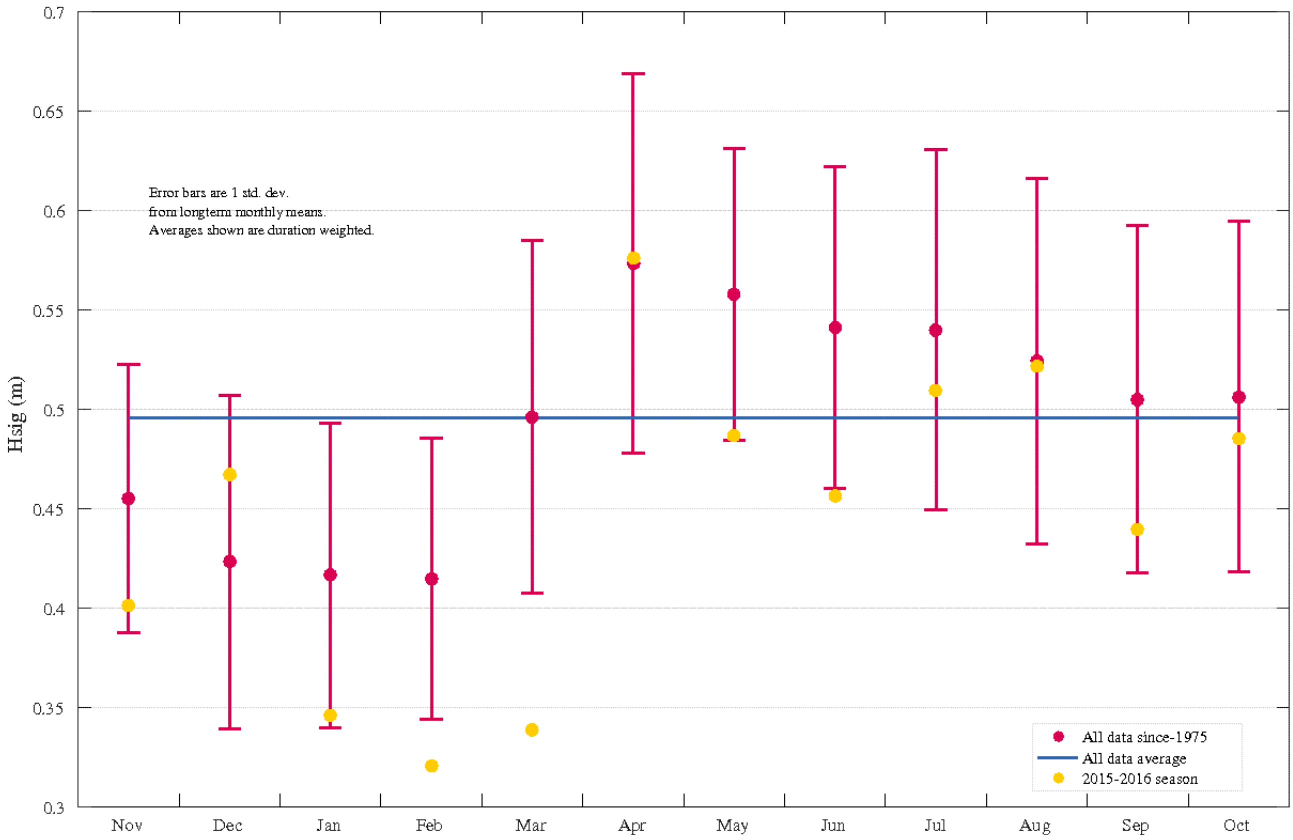


Figure 115 Cairns – Monthly average wave height (Hsig) for seasonal year and for all data

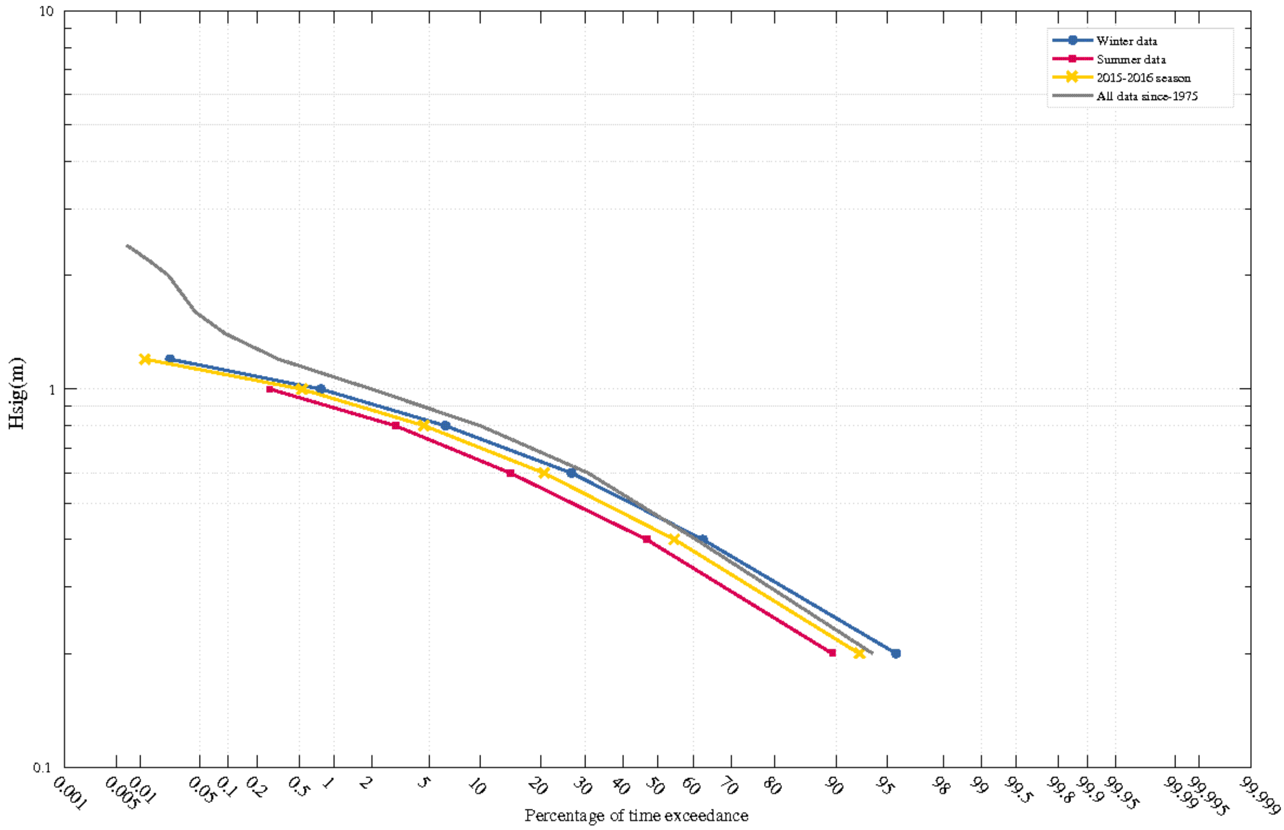


Figure 116 Cairns – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

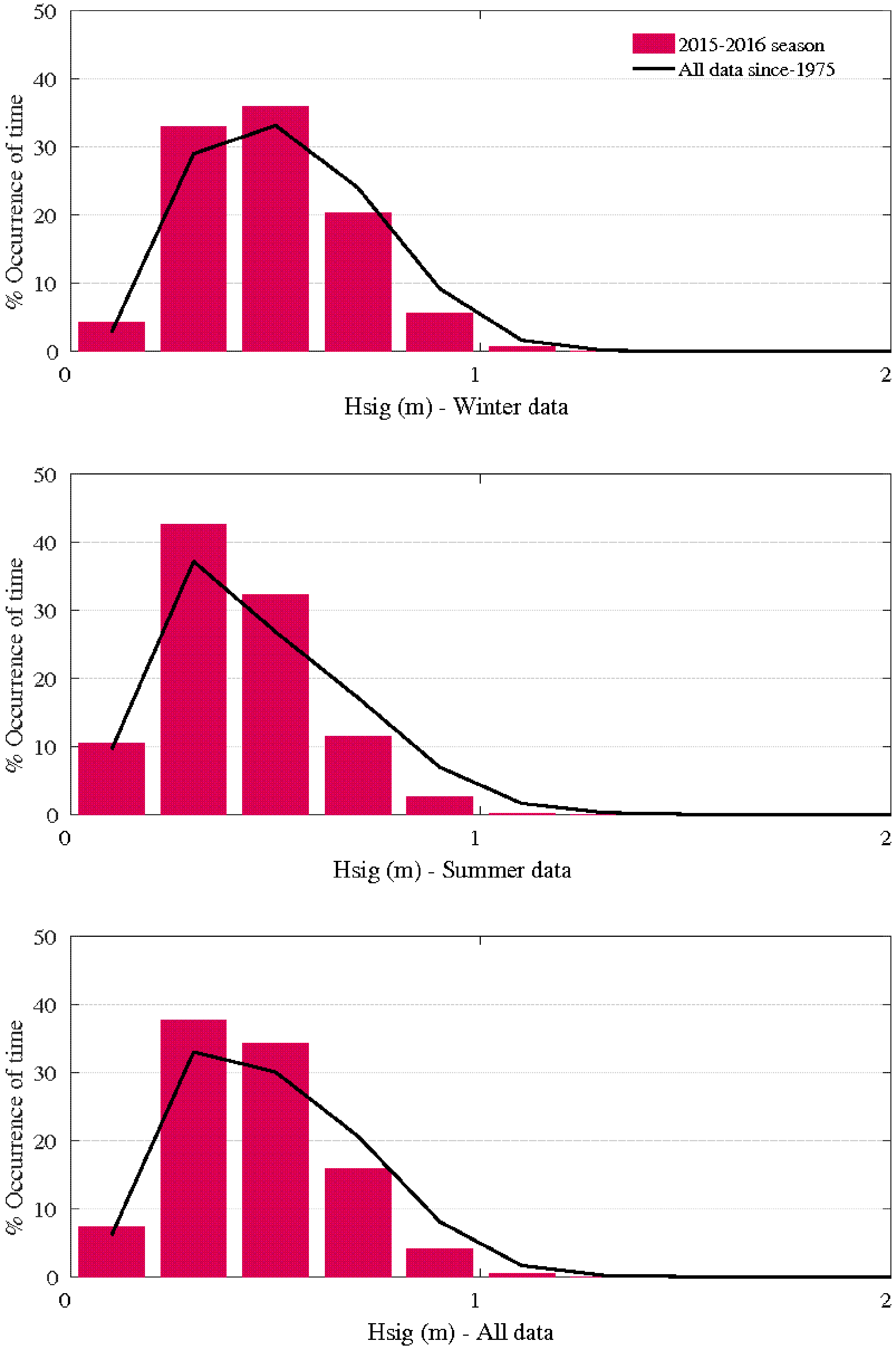


Figure 117 Cairns – Histogram percentage (of time) occurrence of wave heights (Hsig)

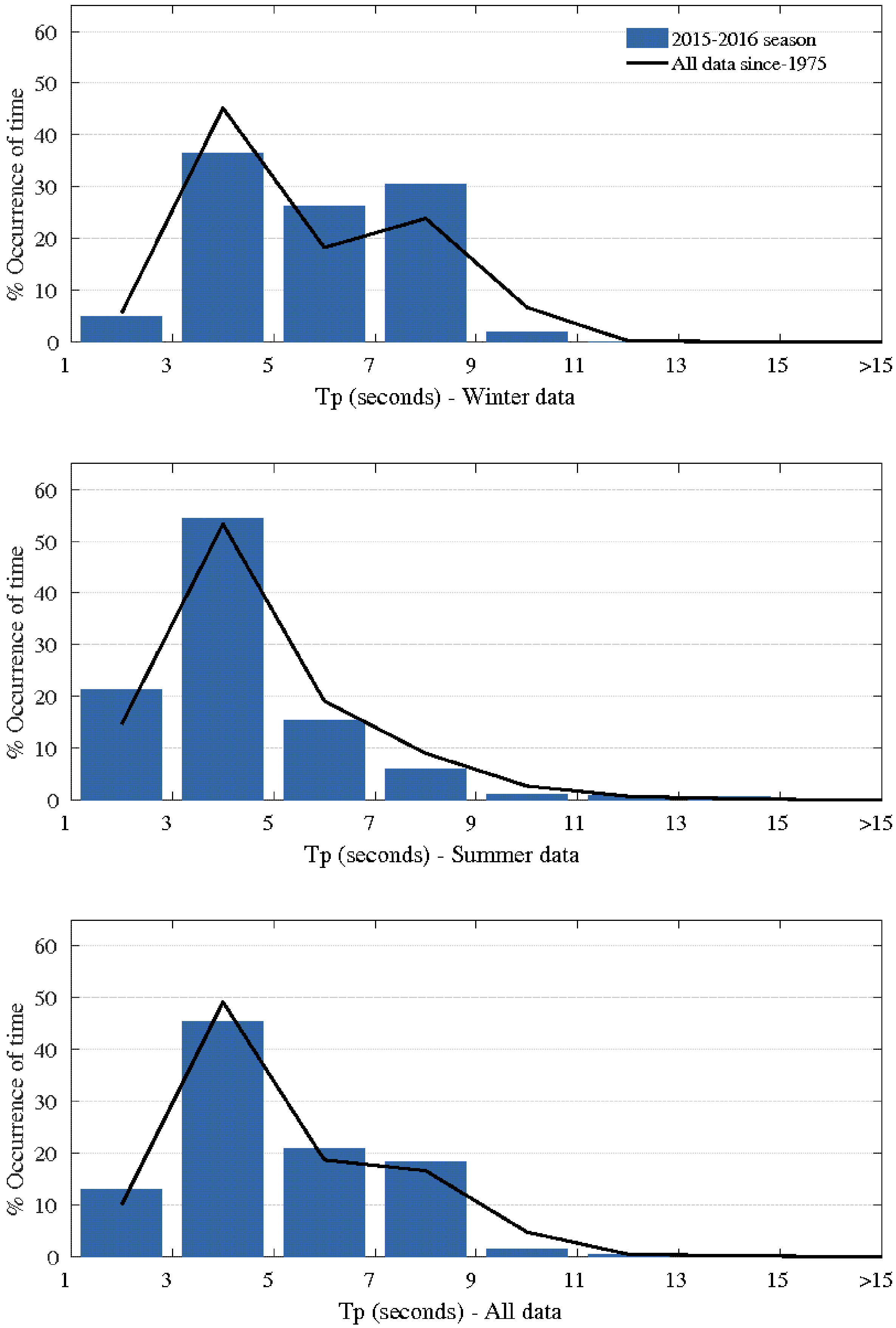


Figure 118 Cairns – Histogram percentage (of time) occurrence of wave periods (Tp)

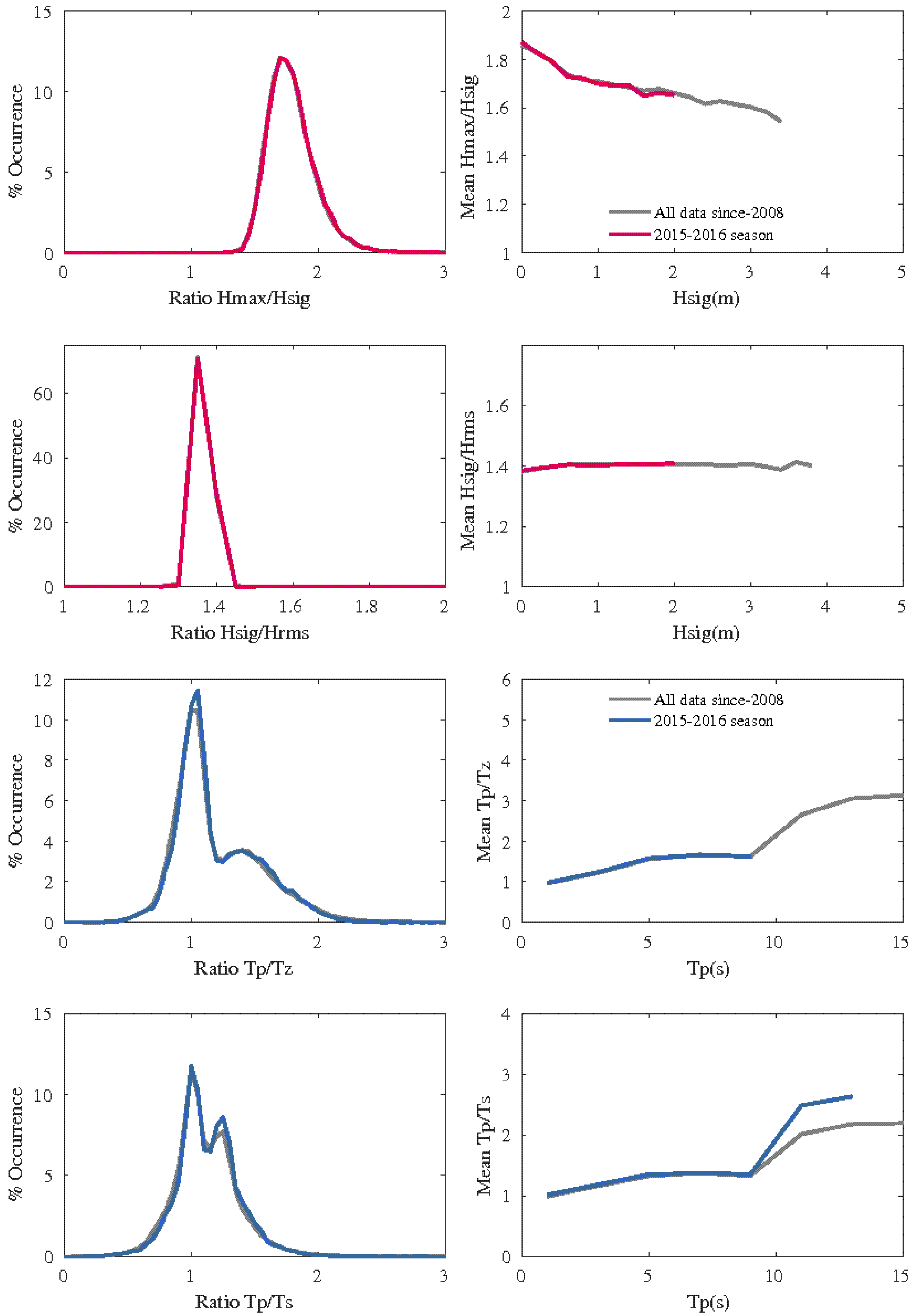


Figure 119 Cairns – Wave parameter relationships

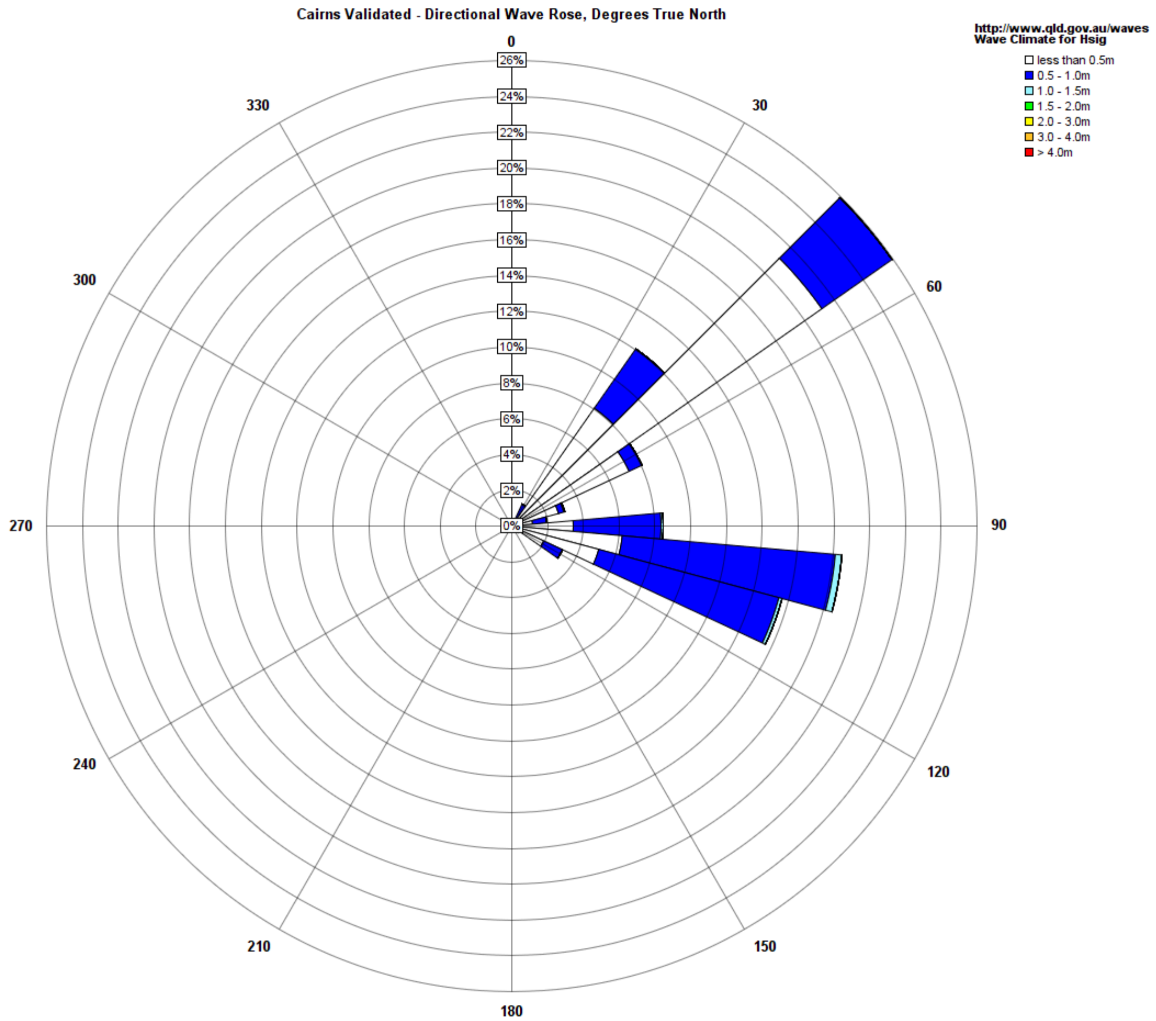


Figure 120 Cairns – Directional wave rose

Albatross Bay

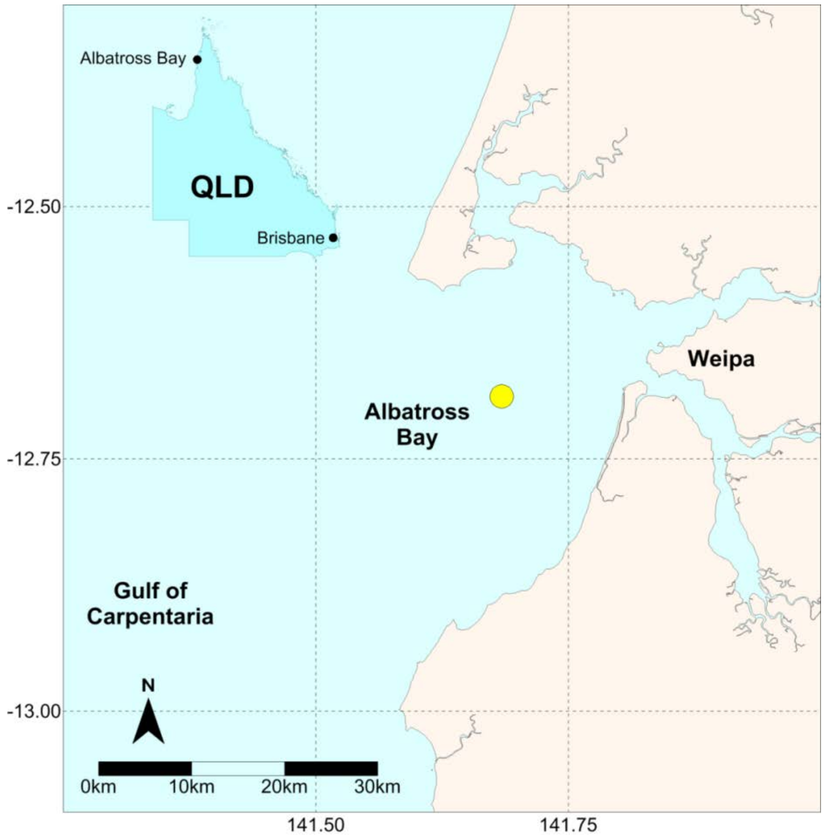


Figure 121 Albatross Bay – Locality plan

Table 57 Albatross Bay – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	21/11/2008	0.29 years	131,966	7.93
2015–16	01/11/2015	3.65 days	17,392	1

Table 58 Albatross Bay – Buoy deployments for the 2015–16 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
12°41.258' S	141°41.008' E	11.8	19/04/2016	current

Albatross Bay – seasonal overview

The Albatross Bay wave buoy has been operational for just under eight years with an overall data return of 96.3 per cent. The data record for the period November 2015 to October 2016 was good, with total gaps of 3.65 days, equivalent to 99 per cent data return (Table 57). The buoy was replaced during the recorded period on 19 April 2016 (Table 58).

Record wave heights were seen during passage of a low pressure system on 29 December. The highest wave heights were, Hmax 4.2 m and Hsig 2.4 m, respectively ranked 9 and 7 (Table 59). Another low pressure system on 16 march, generated maximum wave height of 4.1 which ranked 10th (Table 60). Distinct peaks are shown in Figure 121 during the events in December and March.

The Sea Surface Temperature (SST) measured in the buoy hull shows the recorded values ranged from 25 °C to 34 °C during the reported year. The SST was high enough for tropical cyclone development for most of the year, except for small periods from mid-July to end of September when SST fell below the 26 °C threshold (Figure 122).

Monthly average Hsig showed variance to the long term mean for many months over the recording season. For December and October, average Hsig was greater than one standard deviation (sd) of the historic monthly mean, while January, May and September were below −1 sd (Figure 123). The peak directional wave plot shows varying wave directions from east to west. During the summer months the wave direction is generally southwest.

Overall, wave climate for the reporting period was largely similar to the wave climate during the smaller wave heights (Figure 124). During summer wave heights of 0.5 m and above were more frequent and during winter wave heights lower than 0.4m experienced a lower exceedance.

The histograms of Hsig (Figure 125) show the occurrence of time for the bin 0.2–0.4 m during summer is 5 per cent higher than during winter. Histograms of Tp (Figure 126) were very similar between this season and the whole record, with the 1 to 3 second period being the most predominant.

The ratios between different wave parameters such as Hmax/Hsig were consistent between this reporting period and all of the historic data, these are plotted in Figure 127.

The dominance of the incident wave direction is reflected in the directional wave rose plot (Figure 128) with the most common wave height (Hsig) of less than 0.5 metres from the south western direction.

Table 59 Albatross Bay – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (m)
1	22/01/2013 13:00	4.1	22/01/2013 13:00	6.7
2	12/01/2009 00:00	3.5	11/01/2009 23:30	5.7
3	30/01/2010 03:00	3.3	30/01/2010 05:30	5.5
4	2/02/2012 08:30	2.7	9/01/2015 08:30	5.4
5	19/03/2012 02:30	2.6	3/02/2012 09:00	5.1
6	19/02/2014 06:30	2.6	19/02/2014 07:30	5
7	29/12/2015 08:00	2.4	18/03/2012 19:30	4.3
8	29/12/2011 17:30	2.4	22/01/2011 06:00	4.2
9	22/01/2011 01:00	2.3	29/12/2015 10:30	4.2
10	9/01/2015 09:00	2.2	17/03/2016 17:00	4.1

Table 60 Albatross Bay – Significant meteorological events with threshold Hsig of 1.0 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
29/12/2015 08:00	2.3(2.4)	3.6(4.2)	9.5	Low pressure area (997 hpa) located in the Gulf of Carpentaria
16/03/2016 20:00	1.9 (2.1)	3.5 (4.1)	7.9	Low pressure area (998 hpa) located in the Gulf of Carpentaria

Denotes peak Hsig event

Notes: 1. Barometric pressure measured in hectopascals (hPa). The Hsig and Hmax values are the maximums recorded for each event and are not necessarily coincident in time. The Tp and Hsig values are coincident as a single event on the date shown. Due to possible statistical errors arising from finite length records used in calculating wave climate, the above storm peak Hsig and Hmax values are derived from the time series smoothed by a simple three hourly moving average following the recommendation of the literature (Forristall, Heideman, Leggett, Roskam, & Vanderschuren, 1996).

2. Hsig and Hmax values shown in brackets are unsmoothed values as recorded at the site.

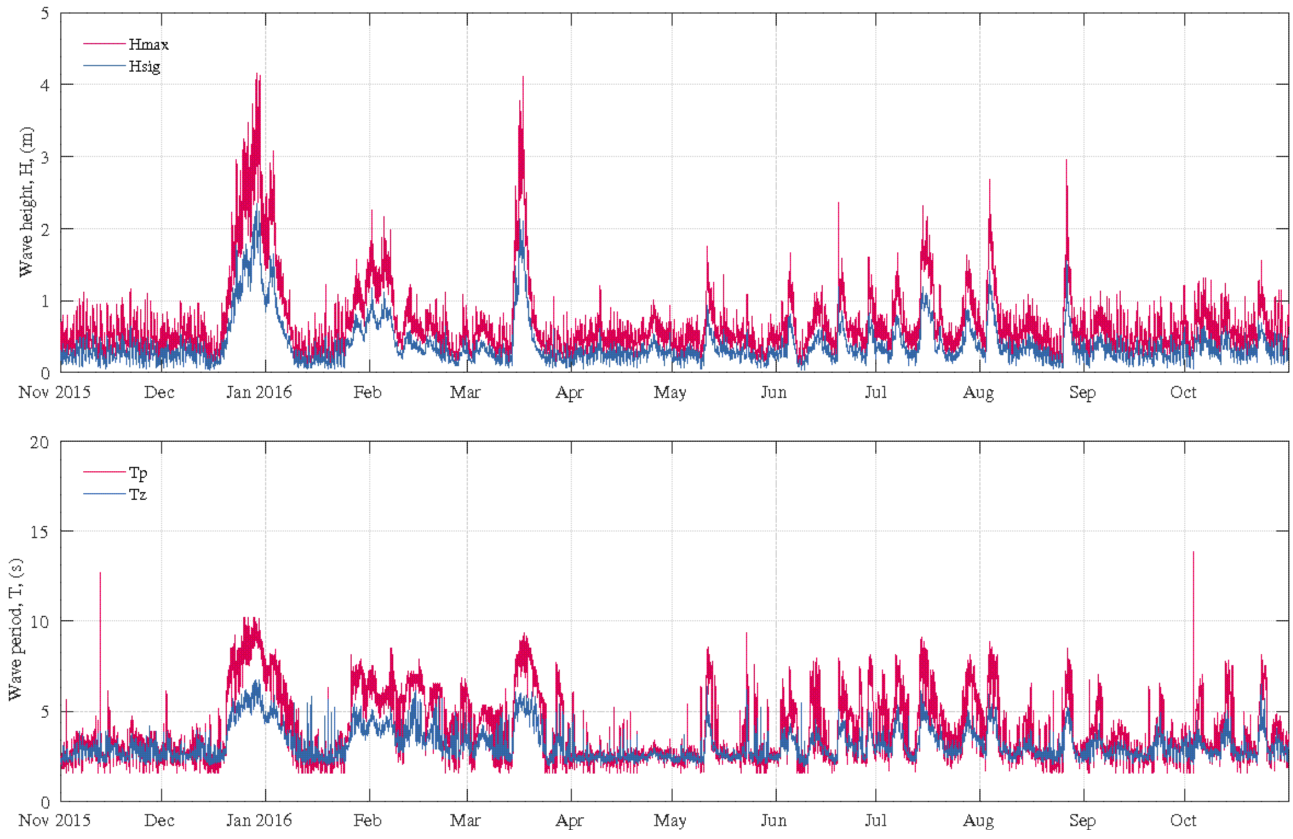


Figure 122 Albatross Bay – Daily wave recordings

Figure 123 Albatross Bay – Sea surface temperature and peak wave directions

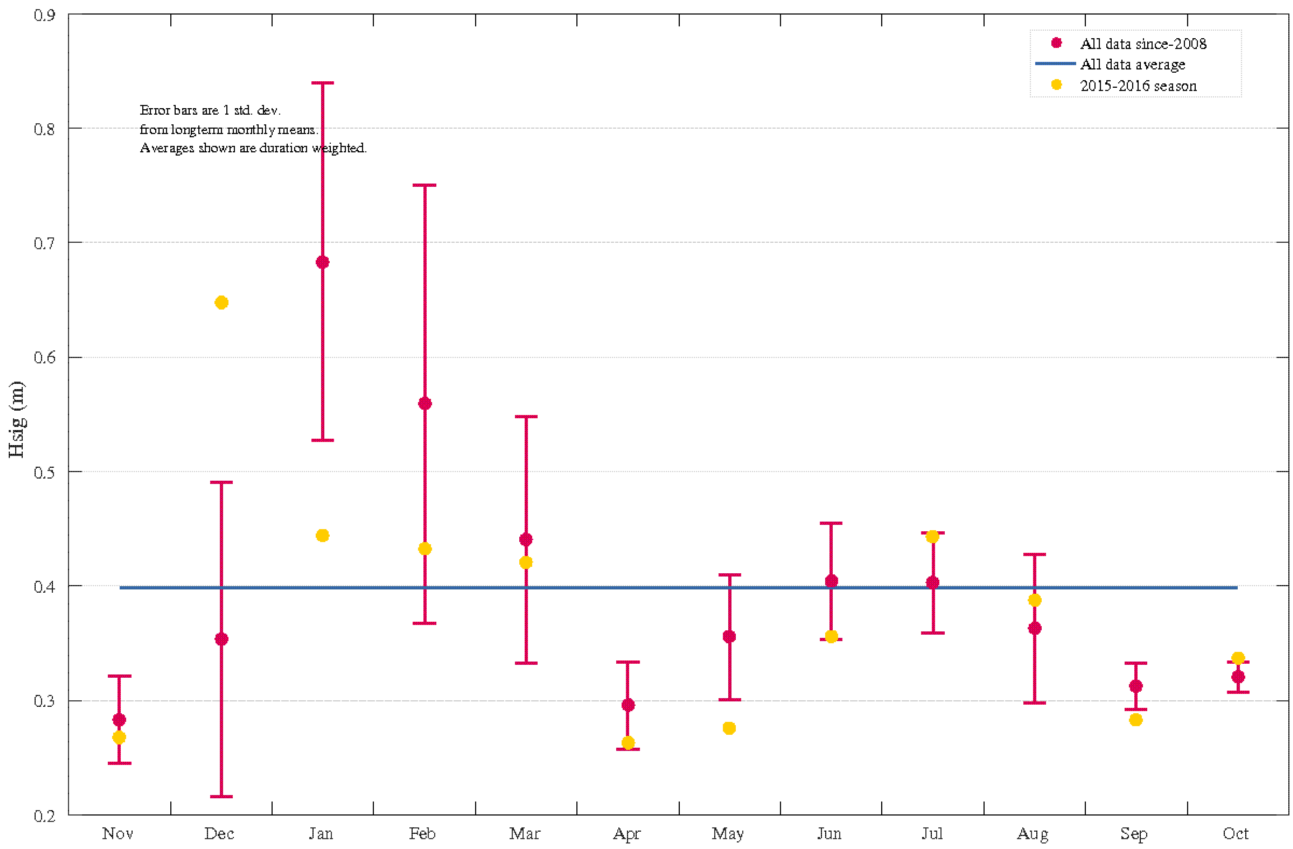


Figure 124 Albatross Bay – Monthly average wave height (Hsig) for seasonal year and for all data

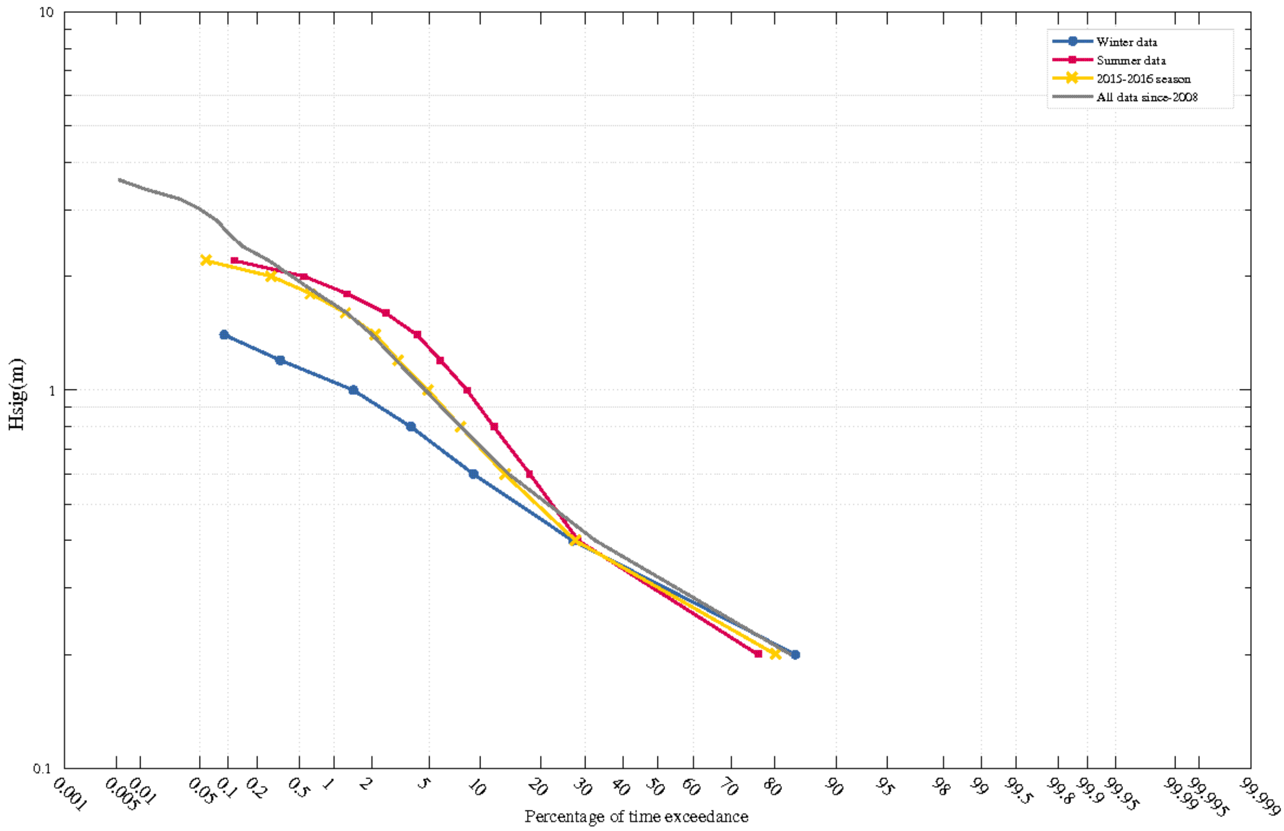


Figure 125 Albatross Bay - Percentage exceedance of wave height (Hsig)

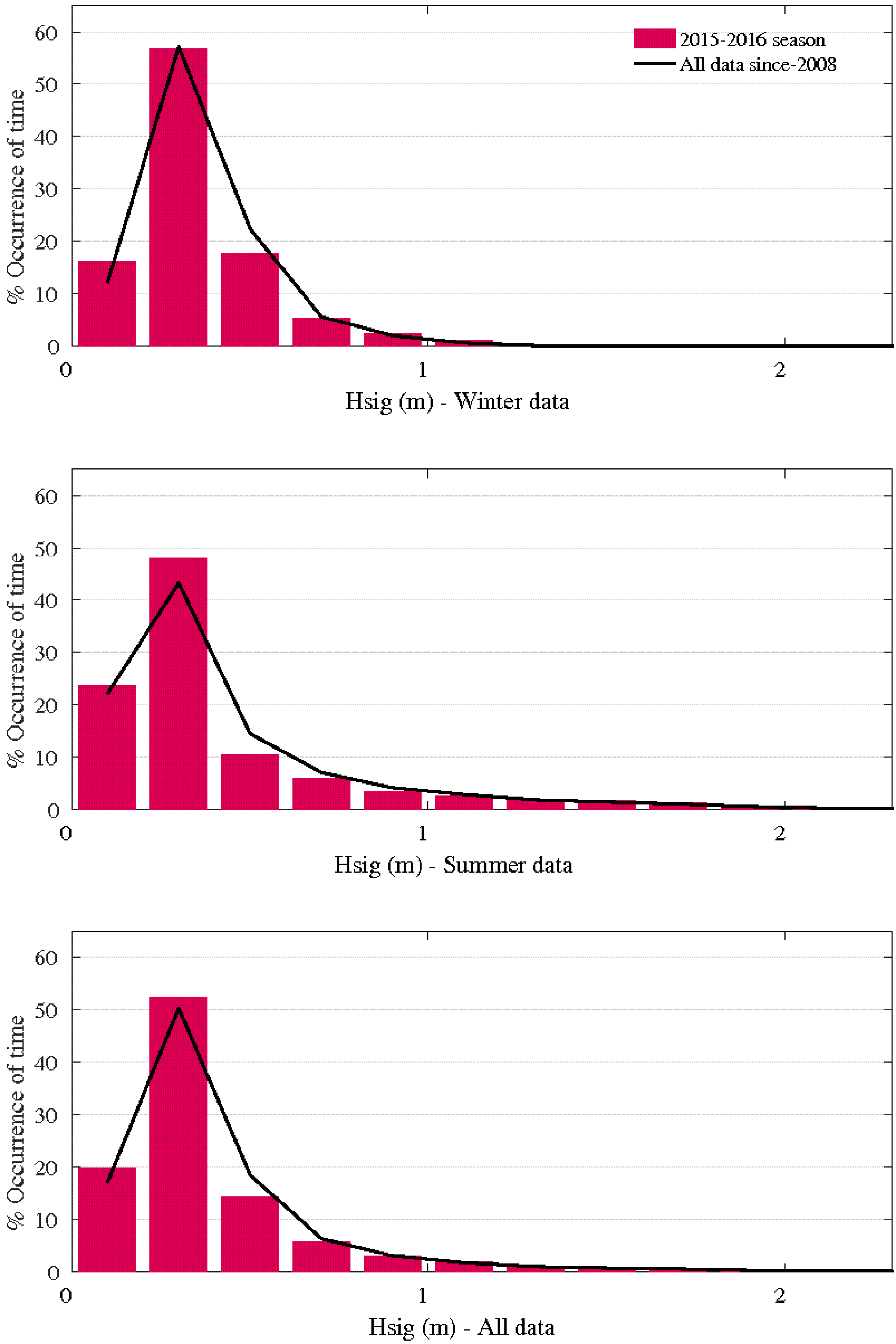


Figure 126 Albatross Bay – Histogram percentage (of time) occurrence of wave heights (Hsig)

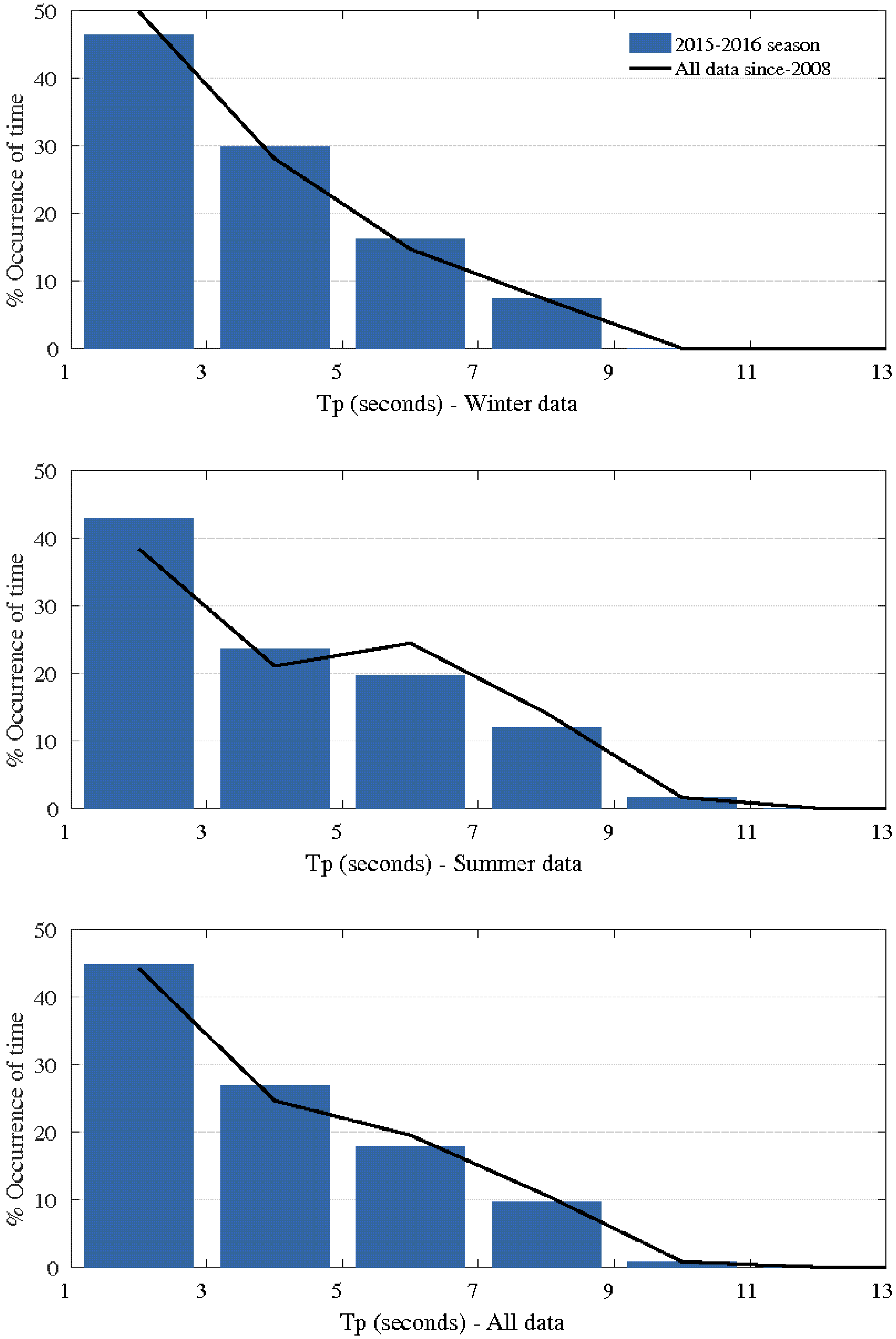


Figure 127 Albatross Bay – Histogram percentage (of time) occurrence of wave periods (Tp)

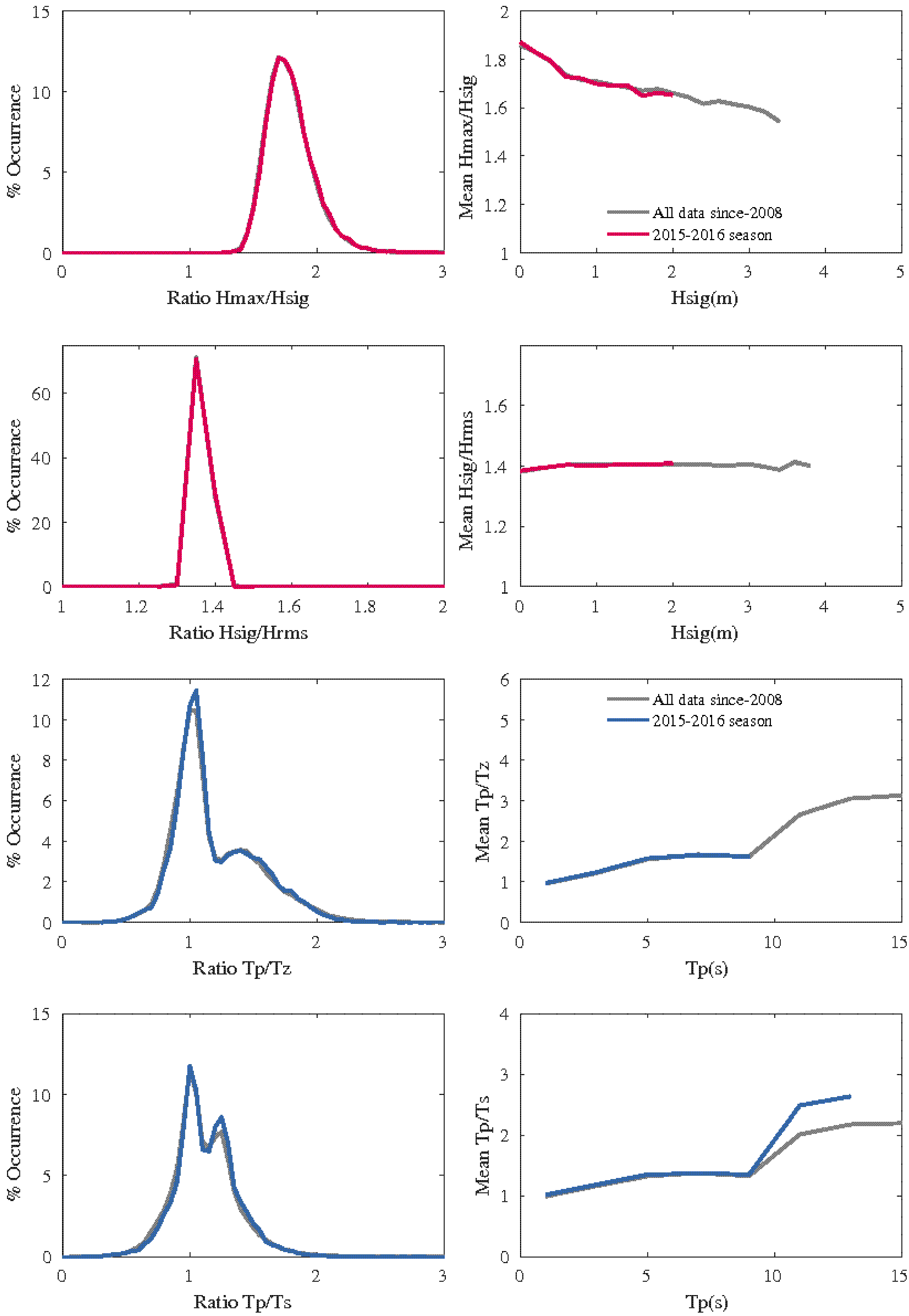
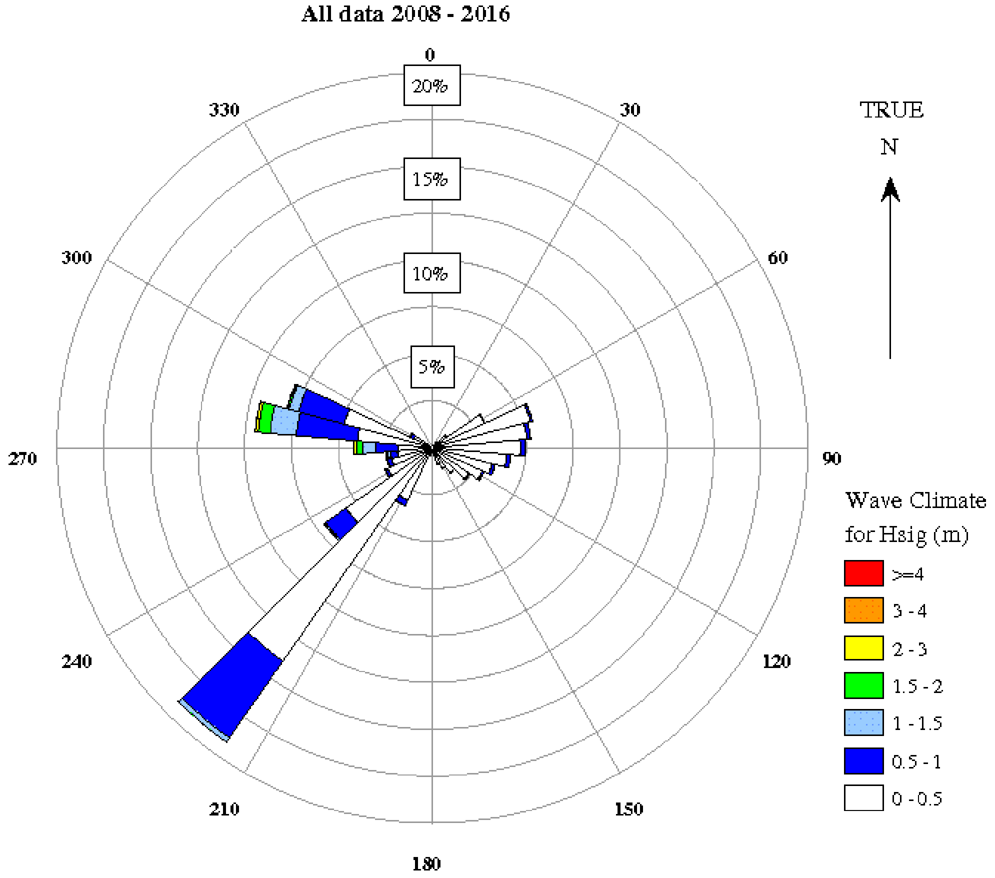


Figure 128 Albatross Bay – Wave parameter relationships



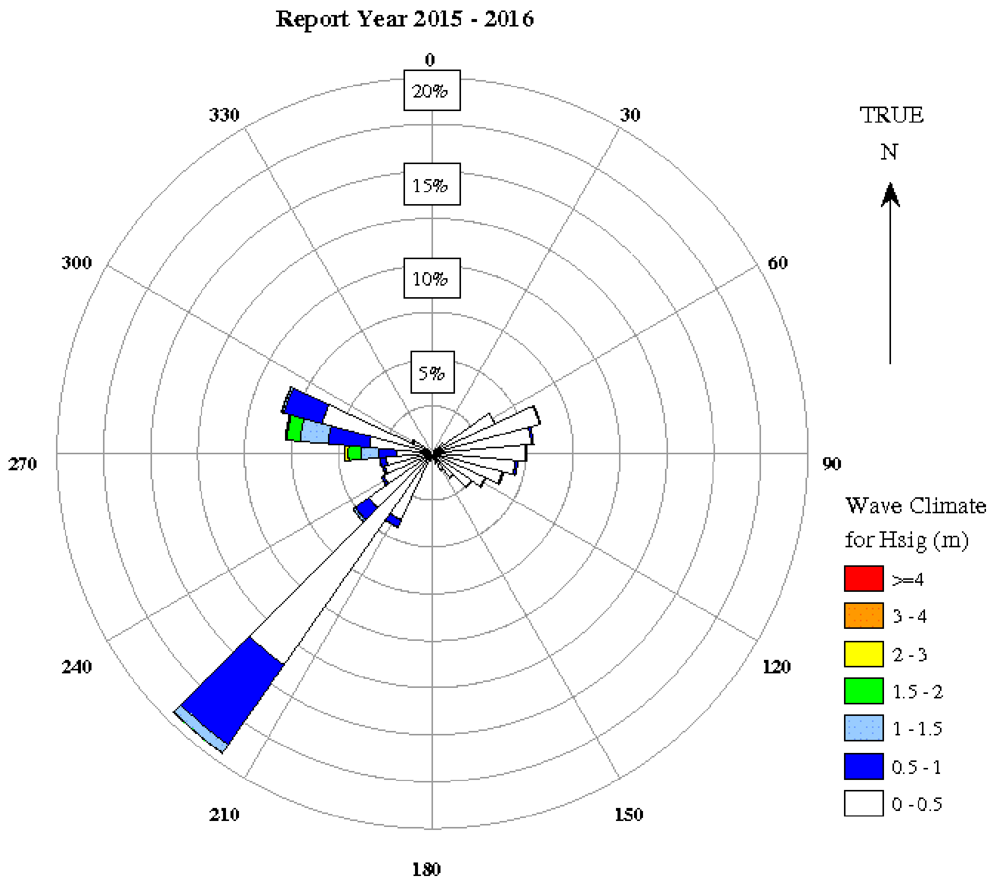


Figure 129 Albatross Bay – Directional wave rose

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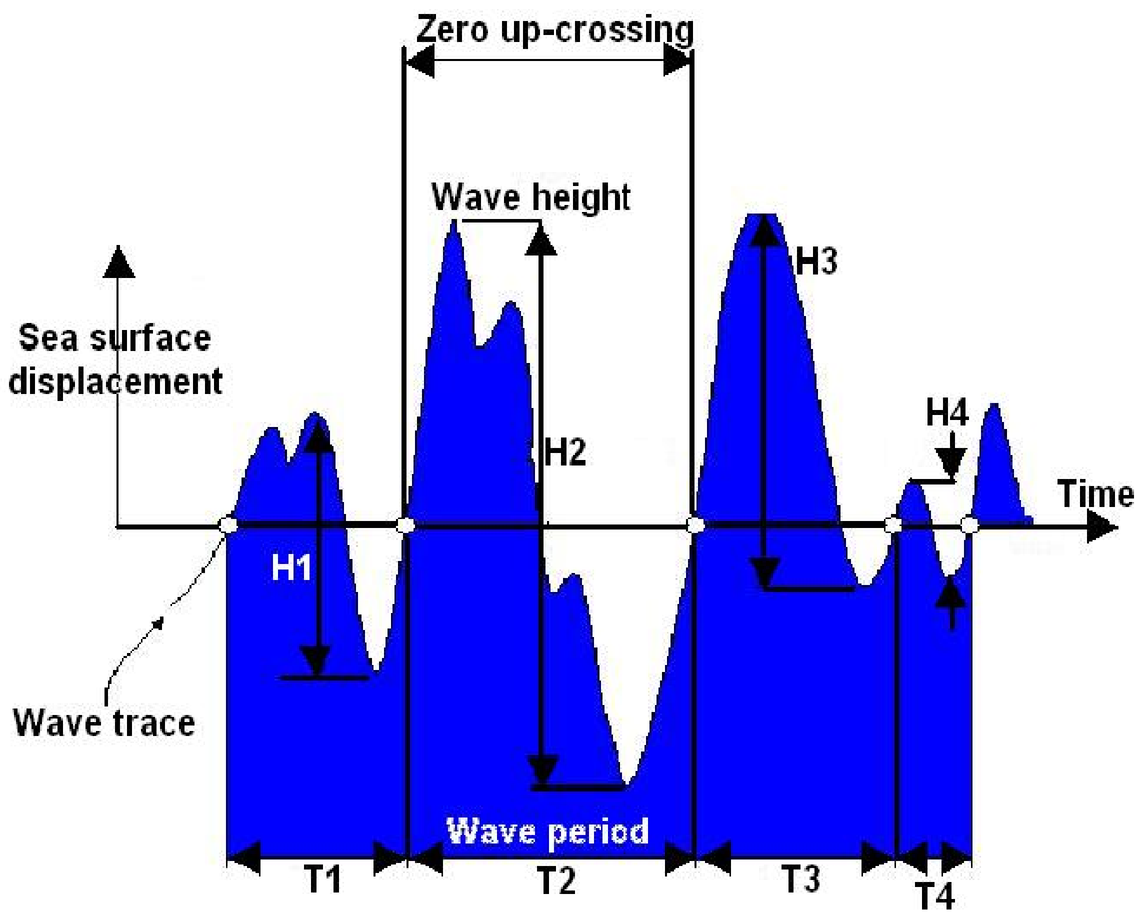
Appendix A Zero up-crossing analysis

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 two 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 Glossary

Parameter	Description
Hs	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.
THsig	The average period of the highest one-third of zero up-crossing wave heights
Hrms	Root mean square wave height from the time domain
Hmax	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.
Tc	The average crest period (in seconds) in a 26.6-minute record.
Tz	The average of the zero up-crossing wave periods (in seconds) in a 26.6-minute record.
H10	Average of the highest 10 percent of all waves in a record
TH10	The period of the H10 waves
THmax	Period of maximum height, zero up-crossing
Tzmax	The maximum zero crossing in a record
Hm0	Estimate of the significant wave height from frequency domain $4\sqrt{m_0}$
T02	Average period from spectral moments zero and two, defined by $\sqrt{m_0/m_2}$
Tp	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.